DID MANUAL

GOVERNMENT OF MALAYSIA
DEPARTMENT OF IRRIGATION AND DRAINAGE

Volume 2 – River Management





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2

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The use of this Manual requires professional interpretation and judgment. Appropriate design procedures and assessment must be applied, to suit the particular circumstances under consideration.

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Foreword

The first edition of the Manual was published in 1960 and was actually based on the experiences and knowledge of DID engineers in planning, design, construction, operations and maintenance of large volume water management systems for irrigation, drainage, floods and river conservancy. The manual became invaluable references for both practising as well as officers newly posted to an unfamiliar engineering environment.

Over these years the role and experience of the DID has expanded beyond an agriculture-based environment to cover urbanisation needs but the principle role of being the country's leading expert in large volume water management remains. The challenges are also wider covering issues of environment and its sustainability. Recognising this, the Department decided that it is timely for the DID Manual be reviewed and updated. Continuing the spirit of our predecessors, this Manual is not only about the fundamentals of related engineering knowledge but also based on the concept of sharing experience and knowledge of practising engineers. This new version now includes the latest standards and practices, technologies, best engineering practices that are applicable and useful for the country.

This Manual consists of eleven separate volumes covering Flood Management; River Management; Coastal Management; Hydrology and Water Resources; Irrigation and Agricultural Drainage; Geotechnical, Site Investigation and Engineering Survey; Engineering Modelling; Mechanical and Electrical Services; Dam Safety, Inspections and Monitoring; Contract Administration; and Construction Management. Within each Volume is a wide range of related topics including topics on future concerns that should put on record our care for the future generations.

This DID Manual is developed through contributions from nearly 200 professionals from the Government as well as private sectors who are very experienced and experts in their respective fields. It has not been an easy exercise and the success in publishing this is the results of hard work and tenacity of all those involved. The Manual has been written to serve as a source of information and to provide guidance and reference pertaining to the latest information, knowledge and best practices for DID engineers and personnel. The Manual would enable new DID engineers and personnel to have a jump-start in carrying out their duties. This is one of the many initiatives undertaken by DID to improve its delivery system and to achieve the mission of the Department in providing an efficient and effective service. This Manual will also be useful reference for non-DID Engineers, other non-engineering professionals, Contractors, Consultants, the Academia, Developers and students involved and interested in water-related development and management. Just as it was before, this DID Manual is, in a way, a record of the history of engineering knowledge and development in the water and water resources engineering applications in Malaysia.

There are just too many to name and congratulate individually, all those involved in preparing this Manual. Most of them are my fellow professionals and well-respected within the profession. I wish to record my sincere thanks and appreciation to all of them and I am confident that their contributions will be truly appreciated by the readers for many years to come.

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Term	Definition
<u>A</u>	
Abrasion	Removal of streambank material due to entrained sediment, or debris rubbing against the bank.
Absorbed	Nutrient that is bound to mineral or organic sediment and therefore only dissolves into water under particular chemical conditions.
Act	Bill becomes an Act would include that the Bill be signed by the Yang Dipertuan Agong and that it be published in the Official Gazette, so that people know the law exists and generally releases it in the public domain.
Adaptive Management	An approach to management that addresses changing site and project conditions, as well as taking into account new knowledge; a management approach that incorporates monitoring of project outcomes and uses the monitoring results to make revisions and refinements to ongoing management and operational actions.
Afflux	The increase in water surface elevation above an obstruction in a stream (a measure of the backwater influence of an obstruction).
Aggradation	A progressive build-up of the channel floor with sediment over several years. Distinguished from the rise and fall of the streambed during a single flood which is called scour and deposition. General and progressive buildup of the longitudinal profile of a channel bed due to sediment deposition.
Algae	'Plant-like' organisms that use various chlorophyll compounds to convert sunlight and instream nutrients into stored energy. This group includes many of the algae that contribute to the thin layer of slime (periphyton) often found on rocks (predominantly diatoms), as well as the macroalgae which grow in long strands.
Alignment	Planform of a channel.
Allowable Shear Stress Design Method	A threshold channel design technique whereby channel dimensions are selected so that the average applied grain bed shear stress is less than the allowable shear stress for the boundary material.
Allowable Velocity	The greatest mean velocity that will not cause the channel boundary to erode.
Allowable Velocity Design Method	A threshold channel design technique whereby channel dimensions are selected so that the applied velocity during design conditions is less than the limiting velocity of the channel boundary.
Alluvial Channel/Stream	Channel fully in alluvium, that have erodible boundaries and are free to adjust dimensions, shape, pattern and gradient in response to change in slope, sediment supply or discharge.
Alluvial Channel Design	A design approach whereby a channel configuration is selected so that it is in balance with the inflowing sediment and water discharges.

Term	Definition
Alluvial Fan	A relatively flat to gently sloping landform shaped like an open fan or a segment of a cone, composed predominantly of coarse-grained soils. The stream deposits these soils wherever it flows from a narrow mountain valley onto a plain or broad valley, or wherever the stream gradient suddenly decreases.
Alluvium	Sedimentary deposits created by streams on river beds, floodplains and as alluvial fans. The term applies to stream deposits of recent time.
Amphidromous Fish	Species that move between fresh and salt water during some part of their life cycle, but not for breeding.
Anadromous Fish	Species that incubate and hatch in freshwater, migrate to saltwater as juveniles to grow, and return to freshwater as adults to spawn.
Angle Of Repose	The maximum angle (as measured from the horizontal) at which gravel or sand particles can stand.
Amplitude	The width of a meander belt.
Anabranch	A secondary channel of a stream that leaves and then rejoins the trunk stream. The two channels are separated by stable, vegetated islands that divide flow at discharges nearly equal to bankfull.
Analogy Design Method	A design approach that is based on the premise that conditions in a reference reach with similar characteristics and watershed conditions can be copied or adapted to the project reach.
Analytical Design Method	The use of bed resistance and sediment transport equations to calculate channel design variables.
Anastomosed Channels	Multiple-thread streams. The multiple channels tend to be narrow and deep because their banks are typically of cohesive sediments; often found on alluvial fans.
Anastomosing	Multiple branching stream channel (strictly, anastomosing is a subset of anabranching streams restricted to fine-grained, low-gradient, organic rich systems).
Annual Flood	The highest peak discharge that can be expected to occur on average in a given year.
Anthroprogenic Constraints	Constraints on a stream or river that are caused by human activities or constructed projects.
Apron	Protective material placed on a streambed to resist scour.
Apron, Launching	An apron designed to settle and protect the side slopes of a scour hole after settlement.
Ari	Average recurrence interval (or return period) is the average length of time between two floods of a given size or larger.
Armouring	Development of a coarse layer of gravel over finer sediments on a stream bed.

Term	**Definition**
Armour Layer	A streambed containing at least some sediment that is too large to be transported by the hydraulic flow conditions, finer particles are selectively removed, leaving a layer of coarser materials.
Armour Layer (Sampling)	Technique used to sample the upper layer of coarse surface layer material.
Articulating Concrete Block (Acb)	A matrix of interconnected concrete block units installed to provide an erosion resistant revetment for streams and rivers.
Artificial Barrier	An unnatural obstacle in a stream (e.g. a dam wall, weir, culvert) that affects (halts or delays) fish migration.
Attenuation	The subsidence or flattening of a floodwave as it moves down the channel.
Ausrivas	An evaluation package which gives an indication of stream condition by comparing the observed aquatic macroinvertebrate taxa at a site to the taxa that were predicted to occur at the site in the absence of environmental stress.
Average Velocity	Velocity at a given cross section determined by dividing discharge by cross sectional area.
Avulsion	A significant and abrupt change in channel alignment resulting in a new channel across the floodplain. Straightening or relocating the channel by constructing dikes or levees is a common causes of channel avulsions
B	
Backfill	The material used to refill a ditch or other excavation, or the process of doing so.
Backwater	Stream water, obstructed by some downstream hydraulic control, that is slowed or stopped from flowing at its normal, open-channel flow condition.
Backwater Bars	Gravel bars that form upstream due to backwater conditions.
Bacteria	Single-celled organisms that are associated with the decay of organic matter.
Bank, Left/Right	The side of a channel as viewed in a downstream direction.
Bank Protection	Treatment of slopes of dikes and banks of streams, lakes and other water bodies by placement of riprap (an engineered layer of graded broken rock pieces) or other forms of protection to prevent erosion by surface runoff, stream flows and/or wave action.
Bank Erosion	The process by which water loosens and wears away soil and rock from the edge of a body of water, usually resulting in an enlargement of the body of water and a corresponding reduction in the size of the land.
Bank Zone	The area above the toe zone, located between the average water level and the bankfull discharge elevation.

Term	Definition
Bankfull	The stage of a channel at junction between the floodplain and the channel. This point is often difficult to define in the field, especially where there are benches in the channel
Bankfull Depth	The distance from the deepest part of the channel to the bankfull elevation line, typically measured across a straight section (riffle) of a channel.
Bankfull Discharge	Used as a surrogate for channel-forming discharge, defined, in part, by the visual identification of morphological bankfull indices.
Bankfull Width	The width of channel at bankfull elevation. In some channels, there is not a floodplain or a bench present to define bankfull width. In those cases, bankfull width is determined by features that do not depend on a floodplain; features similar to those used in the description of an active channel and ordinary high water.
Bar	A local depositional feature within a stream channel. The most common types are mid-channel bars that form within the channel and point-bars that form on the inside of bends of meandering streams.
Barbs	Low-elevation structures projecting from a bank and angled upstream to redirect flow away from a streambank, thereby controlling erosion of the streambank.
Baseflow	Flow in a channel generated by moisture in the soil or groundwater.
Base Level	The lowest point to which a stream runs. These can be local base levels (such as a small lake), or the final base level, the sea.
Basin	It usually refers to a large catchment made up of several catchments that are large in their own right. For example, the Klang River Basin.
Batter	The slope of a bank. Often used to describe changing the bank slope.
Bed Control Structure	A type of grade control structure that is designed to provide a hard point in the streambed that is capable of resisting the erosive forces of the stream.
Bed Erosion	The process by which water loosens and wears away soil and rock from the bottom of a body of water, usually resulting in a deepening of the body of water.
Bed Load Discharge	The quantity of bed load passing a cross section of a stream in (or bed load): a unit of time.
Bed Material	Material found in and on the bed of a stream (May be transported as bed load or in suspension).
Bedrock	The solid rock exposed at the surface of the earth or overlain by soils and unconsolidated material.
Bed Shear	The force per unit area exerted by a fluid flowing past a (tractive force): stationary boundary.
Bed Slope	The inclination of the channel bottom

Term	Definition
Bed Stability	Bed stability is when the average elevation of the stream bed does not change much through time. Aggradation or degradation are the two forms of bed instability.
Bed Zone	The bottom of the channel.
Bedforms	Dunes and other shapes moulded in the bed of the river, usually in sand.
Bedform Scour	Vertical channel bed movement that results from the troughs between crests of the bedforms.
Bedload	The portion of the sediment load that moves along the floor of the channel.
Benches	Flat deposits of sediment that accumulate along streams, above the average water level, but below the bankfull point.
Bend Scour	Bed erosion along the outside of a river or stream bend.
Bendway Weirs	A flow-changing bank stabilization technique used to protect and stabilize stream and river banks. Flows are directed over the weir perpendicular to the angle of the weir.
Benthic	Of or pertaining to animals and plants living on or within the substrate of a water body.
Benthic Drift	The downstream movement of bottom-dwelling plants and invertebrates, accomplished by floating in the current.
Best Management Practices (BMPs)	Practical and economically achievable practices for particular action such as preventing or reducing non-point source pollution.
Bill	Proposed law passed by the Parliament but not yet signed by Agong. It can't be of any force or use.
Billabong	A section of cut-off stream channel (e.g. an oxbow lake) usually on a floodplain. The cut-off channel will progressively fill with sediment over time. Most are connected to the river during floods.
Biodiversity	A word used to describe biological heterogeneity. It covers the number of species of plants and animals present, as well as how different they are from one another.
Bioengineering	Incorporating vegetation into engineering structures (e.g. Grass or shrubs into bank rip-rap).
Biofilm	The mixture of benthic algae, bacteria and fungi which forms a film on submerged surfaces. This layer is the food source for many macro-invertebrates. Also known as periphyton.
Bio-Indicators	Using the health or diversity of organisms in a stream as a measure of the health of the stream (especially in relation to pollution).
Biological Monitoring	The monitoring of organisms.

Term	Definition
Biomass	A measure of the weight of a selected group of organisms (e.g. algal biomass, macroinvertebrate biomass) usually expressed as weight per square metre of streambed.
Biota	The plants and animals of a region.
Blanket	Material covering all or a portion of a streambank to prevent erosion.
Boulder	A rock fragment whose diameter is greater than 250 mm.
Braided Channel	A river channel having multiple sub-channels that meander away from each other and then reunite at intervals.
Bridge Pier Scour	Erosion of a streambed around the piers of bridges.
Brush Layering	A soil bioengineering technique that provides protection against surface erosion and shallow-seated slope failure. It involves the use of alternating layers of live cuttings and soil.
Brush Mattress	A mattress-like covering that is placed on top of the soil. The mattress is made of living, woody plant cuttings that are capable of sprouting roots, branches and leaves.
Brush Revetments	A soil bioengineering technique used to stabilize stream-banks. Brush and tree revetments are non-sprouting shrubs or trees installed along the toe of the streambank to provide bank erosion protection and to capture sediments.
Brush Spur	A long, box-like structure of brush that extends from within the bank into the streambed. They function very similarly to stone stream barbs.
Brush Trench	A soil bioengineering technique that is a row of live cuttings that is inserted into a trench along the top of an eroding streambank, parallel to the stream. The live cuttings form a fence that filters runoff and reduces the likelihood of rilling.
Buffer Strip	A vegetated strip of land that functions to absorb sediment and nutrients.
Buffer-Zone	Usually refers to a strip of riparian vegetation that separates a stream from a potentially damaging land use.
Burst Swimming Speed	Refers to the highest swimming speeds of a fish; generally lasts less than 20 seconds and ends in extreme fatigue.
Buttress	A lateral restraint against slope movement.
C	
Carrying Capacity	The maximum rate of resource consumption and waste discharge that can be sustained indefinitely in a defined impact area without progressively impairing bioproductivity and ecological integrity.
Cantilever Failure	Undercutting leaves a block of unsupported material on the bank top which then falls or slides into the stream, a type of mass failure.
Catadromous Fish	Species that hatch in saltwater, migrate to freshwater as juveniles to grow, and return to saltwater to spawn.

Term	Definition
Catchment	The area of land drained by a river and its tributaries.
Catchment Management	Actions to manage the human impact on a catchment with the intention of protecting the natural values of the catchment, whilst protecting its productive potential.
Celerity	The speed that a floodwave moves down the channel.
Channel	A natural or artificial waterway that periodically or continuously contains moving water. It has a distinct bed and banks that confine the water flowing in the channel.
Channel Alignment Design	Techniques used to establish a stable channel planform.
Channel Bed Slope	A channel's vertical change in bed levels over distance (the gradient).
Channel Bed Width	The width of the bankfull channel.
Channel Evolution	Systematic changes of a stream channel to a perturbation.
Channel Evolution Model (CEM)	A model that illustrates the stages through which a stream progresses when subjected to destabilizing influences.
Channel-Forming Discharge	Concept based on the idea that for a given alluvial stream, there exists a single discharge that, given enough time, would produce the width, depth, and slope equivalent to those produced by the natural flow in the stream. This discharge, therefore, dominates channel form and process.
Channel Storage	Water that is temporarily stored in a natural or constructed channel while en route to an outlet.
Channel Top Width	The horizontal distance along a transect line from top of bank to top of bank, measured at right angles to the direction of flow.
Channelisation	Engineering actions designed to increase the capacity of a channel to carry flood waters (typically include desnagging, straightening, and deepening).
Check Dam	A small dam constructed to slow stream velocity and/or prevent degradation.
Chute Cutoff	A new channel formed by the truncating of a meander bend across the floodplain. The channel flow bypasses the meander bend by cutting straight through it.
Classification	The categorization of a stream reach into a specific class based on factors and measurements such as dominant mode of sediment transport, entrenchment ratio, and sinuosity. Streams can also be classified by their biota, habitat conditions, baseflow levels, and direct measures of water quality.
Clear Water Scour	Occurs when there is insignificant transport of bed-material sediment from the upstream into the contracted section.

Term	Definition
Clear-Water Release	Release of a flow, usually from a reservoir, that carries less sediment than the water is capable of transporting. This usually leads to bed and bank erosion.
Clear-Water Scour	The stream channel erosion that is produced by a clear-water release.
Cobbles	Gravels larger than about 60 mm in diameter (about the size of a fist).
Coffer Dam	An impermeable structure placed in a stream channel that allows water on one side of the structure to be pumped out so that construction can occur in dry conditions.
Cohesive Soil	Soils that have natural resistance to being pulled apart.
Coir	Coconut fibre used in a variety of ways to protect stream-banks from erosion.
Coir Logs	Cylindrical objects constructed from coconut fibre (coir) and bound by mesh.
Collectors	Animals that collect detrital material for consumption.
Community	An ecological term which collectively describes all the species occurring at a location.
Community Coefficient Index	A coefficient that indicates the degree of similarity of two communities based on the number of species that they have in common. CC=2c/(a+b), where a = number of taxa in community 1, b = number of taxa in community 2, and c = number of taxa both communities have in common. Its value ranges from 0 to 1.0, indicating no similarity to complete similarity.
Conceptual Framework (For Waterway Protection)	A systematic and comprehensive approach to protecting waterway ecology and geomorphology, which can be used to guide decisions on development and management (being developed as part of this project).
Condition	The quality or state of a waterway, floodplain or catchment, expressed in terms of the integrity of natural features.
Confidence Limits	Provide a measure of the uncertainty or spread in an estimate. In hydrologic gauge analysis, they are a measure of the uncertainty of the discharge at a selected exceedance probability.
Conservation	All the processes and actions of looking after a place to retain its natural significance and always includes protection, maintenance and monitoring.
Confinement	The width of the active floodplain of a stream. Narrow floodplains can be confined by terraces or rock walls.
Connectivity	The physical connection between places. In a stream, refers to connection along a stream's length (longitudinal connectivity), and between the stream and its floodplain (lateral connectivity).
Constructed Channel	A ditch or reconstructed natural channel.

Term	Definition
Contraction Scour	Erosion of a streambed that occurs when the flow cross section is reduced by natural features, such as stone outcrops, or debris accumulations, or by constructed features such as bridge abutments.
Control (For Evaluation)	This is a sampling site or reach which is the same as the rehabilitation site in every way, except that it is not rehabilitated. The control site is compared with the rehabilitation site as a way of checking that any changes are a result of the rehabilitation, rather than some other unconnected event affecting the whole stream.
Control (Hydraulic)	The point in a stream (such as a constriction or weir) that controls the upstream water level.
Conveyance	The amount of discharge that a stream can carry.
Cover	Referring to vegetation density: the spread over the ground surface within the streamside zone when viewed from above. Also to do with in-stream cover. For biologists, cover can also mean cover for fish and other animals in a stream.
Crib Wall	A soil bioengineering technique used to stabilize stream-banks. The crib is a hollow, box-like structure of interlocking logs or timbers. The structure is filled with rock, soil, and live cuttings or rooted plants. Crib-walls are sometimes used to protect stream-banks from the erosive effects of channel flow.
Critical Shear Stress	The shear stress at the initiation of particle motion.
Cross Vane Structure	A structure that provides grade control and a pool for fish habitat.
Cumulative Impact Assessment	The assessment of the impact on the environment resulting from the incremental impact of an action when added to other past, present or reasonably foreseeable actions, regardless of what agency or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place simultaneously or over time.
Critical Flow	Flow with a Froude number of 1.
Cutoffs (Meander Cutoffs)	Where the stream cuts through the neck of a meander bend.
<u>D</u>	
D_{50}, / D_{100}	The particle size for which 50 and 100 percent of the sample is finer.
Debris	Material distributed along and within a channel or its floodplain either by natural processes or human influences. Includes gravel, cobble, rubble and boulder-sized sediments, as well as trees and other organic detritus.
Decomposers	Organisms such as bacteria and fungi which break down organic matter chemically.
Deflector	A structure that forms a physical barrier to protect the bank, and forces the flow to change direction either by direct impact or deflection.

Term	Definition
Degradation	Degradation has a broad meaning of reduction in quality, and a specific meaning in geomorphology of general lowering of a stream-bed, usually over a period of years, by erosion processes.
Deposition	The settlement of material onto the channel bed.
Design Flows	Stream rehabilitation design should consider a variety of flow conditions. These flows should be considered from both an ecological, as well as a physical, perspective.
Design Flood	The maximum discharge for which a flood control project will offer protection.
Design Storm	A prescribed precipitation distribution and associated recurrence interval.
Desnagging	Removing large woody debris from the bed of streams to increase conveyance.
Detritus	Organic debris from decomposing organisms and their products. A major source of nutrients and energy for some aquatic food webs.
Detritivores	Animals that consume detritus.
Discharge	The rate of flow expressed in volume per unit of time, for example, cubic meter per second. Discharge is the product of the mean velocity and the cross-sectional area of flow.
Dike	An embankment, berm, wall, piling or fill constructed to control flooding of land.
Disturbances	Changes to the physical or ecologic condition that are outside of the normal range of natural variations. Disturbances can be natural or anthropogenic.
Dominant Channel Processes	Dominant channel processes are the forces at work in the watershed, which cause and limit channel change.
Dominant Discharge	The discharge responsible for the largest volume of sediment transport over a long period of record. It is typically a one- to two-year event.
Dormant Post Planting	A soil bioengineering technique involving the use of large dormant stems, branches, or trunks of live woody plant material, that are planted for bank erosion control and creation of riparian vegetation.
Dispersal	The movement of animals or plants from their established range into new areas. The main types of dispersal in streams are drift, aerial dispersal and migration.
Dissolved Oxygen	Oxygen that is dissolved in water and is therefore available for use by aquatic plants and animals.
Disturbance	A process that pushes a stream or its elements away from an equilibrium state. This can be a short-lived push (a pulse disturbance) or a more permanent push (a press disturbance).

Term	Definition
Diversity	A measure of how varied something is. An ecological community with greater diversity will have a large range of species within it.
Drag	The fluid force component acting on a sediment particle, which is parallel to the mean flow.
Drift	A mechanism which allows the downstream migration of organisms. They simply let go of the substrate and drift with the flow.
Dune	A bedform formed in sand in the bed of a stream, usually in the order of tens of centimetres in length and height.
Drop Structure	Any in-channel structure that creates a distinct drop in water-surface elevation in a downstream direction.
Drop / Weir Scour	Scour resulting from an increase in flow velocity through a weir or due to hydraulic forces associated with a drop in water-surface elevation.
Dynamic Equilibrium	Oscillations around a gradually changing mean state in a system (e.g. a change in the composition of macro-invertebrate communities as shading reduces water temperature).
E	
Ecology	The study of organisms and how they interact with each other and their physical surroundings.
Ecological Integrity	The ecological values, including biodiversity, geodiversity, essential ecological processes and life support systems (of a waterway and floodplain).
Ecological Sustainability	The ability of ecosystems to maintain their structural and functional integrity in response to perturbations.
Ecological Value	The natural significance of ecosystem structures and functions, expressed in terms of their quality, rarity and diversity. Significance can arise from individual biological, physical or chemical features or a combination of features.
Ecosystem	The sum of everything pertaining to ecology at a location. This includes physical habitats and organisms.
Ecosystem Structures	The site-specific characteristics of an ecosystem (e.g. species composition, soil, hydrology), synonymous with ‘features’ or ‘patterns’.
Ecosystem Functions	The biological, chemical and physical processes that take place within an ecosystem (e.g. carbon cycling, nutrient assimilation).
Ecosystem Services	The beneficial outcomes that result from ecosystem functions (e.g. cleaner water); the outcomes may accrue to other ecosystems or to humans.
Effective Discharge	The mean of the arithmetic discharge increment that transports the largest fraction of the annual sediment load over a period of years; often used as a surrogate for channel-forming discharge.

Term	**Definition**
Effluent	The point at which flow leaves one channel to flow in to another channel.
Electro-fishing	A method of fishing which uses electric currents to stun fish.
Emergent Macrophytes	Aquatic plants, such as rushes and cumbungi, that are rooted below the water but also extend above the water.
Embankment Bench	A technique used to stabilize steep banks with little or no disturbance at the top of the slope and minimal disturbance to the streambed. For example, a gravel bench is constructed along the toe and protected with riprap.
Engineered Log Jam	Constructed collections of large woody debris that redirect stream flow.
Entrainment	The incidental trapping of fish and other aquatic organisms in waters being diverted for other purposes. Sediment entrainment refers to sediment transported by flows.
Entrained Sediment	Sediment that has been incorporated into a flow by rain drop and flow processes.
Entrenchment	The extent of vertical containment of a channel relative to its adjacent flood plain.
Entrenchment Ratio	The flood-prone width divided by the bankfull width.
Environmental Assessment	Generic term for the process of assessing the environmental effects of projects, plans, programs and policies. Generally involves scooping, analysis/assessment and evaluation.
Environmental Flow Regime	A pattern of flows released from a dam or other regulating structure that are designed to enhance the environmental condition of a stream given other demands placed on water from the stream.
Ephemeral Stream	A stream or reach of a stream that flows only in direct response to precipitation, and whose channel is above the water table at all times. The term may be arbitrarily restricted to a stream that does not flow continuously during periods of as much as a month.
Ephemeroptera, Plecoptera, And Trichoptera Index (EPT)	A biologic assessment technique that is used to assess land use and water quality within a watershed. It uses benthic macro-invertebrates, such as stoneflies, mayflies, and caddis flies as indicators.
Equilibrium	The condition of a stream (whether physical or biological) is stable in relation to the inputs into the system.
Equilibrium Slope	The slope of a channel at which the sediment transport capacity of the reach is in balance with the sediment transported into it.
Estuary	The portion of the mouth of a river that is affected by tides (and hence also salinity).
Eutrophication	A process which involves the overgrowth of algae and macrophytes in a water body due to excessive nutrient loads.

Term	Definition
Evaluation	An assessment of the effectiveness of a strategy in stream rehabilitation. Usually based on monitoring of some sort, but different from monitoring in that evaluation involves an assessment of success or failure, not just its description.
Evolution Of Habitat	Progressive changes in habitat in a natural stream (e.g. progressive filling of a cut -off meander bend).
Erosion	A process or group of processes whereby surface soil and rock is loosened, dissolved or worn away and moved from one place to another by natural processes. Erosion usually involves relatively small amounts of material at a time; but, over a long period of time, it can involve very large volumes of material.
Erosion Control Blankets (ECB)	A temporary protective blanket laid on top of bare soil vulnerable to erosion; commonly made of mulch, wood fibre, or synthetics.
Evapotranspiration	The combination of evaporation from the soil surface and transpiration from vegetation.
Excavated Bench	A technique used to stabilize steep banks with little or no disturbance at the top of the slope and minimal disturbance to the streambed. It involves shaping the upper half or more of the high bank to allow the formation of a bench to stabilize the toe of the slope.
Exotic Plants And Animals	Species of plants or animals that are not naturally found in an area (i.e. not indigenous to the area). Carp and tilapia are examples of exotic fish species, and Mimosa is an example of an exotic plant.
<u>F</u>	
Facet	A distinct morphological segment of a longitudinal profile; riffle, pool, run, or glide (tail-out).
Failure Plane	The surface around which mass-failure occurs on a stream bank (often identified by a tension crack).
Fascine	A soil bioengineering technique used to provide stabilization to the toe of stream-banks. A long bundle of live cuttings bound together into a rope or sausage-like bundles.
Feasibility	An assessment of whether a strategy can really be carried out.
Filamentous Algae	Algae that grow in long thin strands.
Filter Feeders	A form of collector, which uses net-like structures to extract passing detrital material from the stream.
Filter Layer	A layer that prevents the smaller grained particles from being lost through the interstitial spaces of the riprap material, while allowing seepage from the banks to pass. This layer typically consists of a geosynthetic layer or sand, gravel, or quarry spalls.
First-Order Stream	An unbranched tributary.
Fish Ladders	The broad category of techniques used to provide migrating fish with upstream passage around or through fish passage barriers.

Term	Definition
Fish Passage	The movement of fish around an obstacle.
Flood	A flow in a stream that exceeds the normal channel capacity and goes over the banks onto the floodplain.
Flood Frequency	How often the stream goes over its banks. Usually expressed as the probability that the flow will exceed some size in a single year. Thus the 1-in-100 year flood would have a 1 % probability of being equalled in anyone year. See also ARI and return period.
Flood Hazard	The potential for inundation that involves risk to life, health, property, and natural floodplain values.
Floodplain	Land that is adjacent to a waterway (and includes the riparian zone) is subject to flooding (typically at an average recurrence interval of 100 years) and is intricately linked to the waterway.
Floodplain Management	A decision-making process whose goal is to achieve appropriate use of the nation's floodplains.
Flood-proofing	The modification of individual structures and facilities, their sites, and their contents to protect against structural failure, to keep water out, or to reduce the damaging effects of water entry.
Floodway	The channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation by more than designated height.
Flow-Changing Devices	A broad category of structures which can be used to divert flows away from eroding banks.
Flow-Control Structure	A structure either within or outside a channel that acts as a countermeasure by controlling the direction, depth, or velocity of flowing water.
Flow Duration	The percentage of time that a flow level is equalled or exceeded in a stream or river, typically represented with a flow-duration curve.
Flow Hazard	Flow characteristics (discharge, stage, velocity, or duration) that are associated with a hydraulic problem or that can reasonably be considered of sufficient magnitude to cause a hydraulic problem or to test the effectiveness of a countermeasure.
Flow-Frequency Analysis	A consistent, statistical method for denoting the probability of occurrence of flows at a specific point in a stream system.
Flow Regime	The typical, predictable pattern of flows experienced by a stream over many seasons and years. The set of flows considered to be responsible for the character of the stream system.
Flow Regulation	Changes to the timing and volume of flow brought about by dams, diversions or other interference in a river.
Flow Slide	Saturated soil materials which behave more like a liquid than a solid. A flow slide on a channel bank can result in a bank failure.

Term	Definition
Fluvial	Pertaining to water flow and rivers.
Fluvial Fish	Species that live in the flowing waters of rivers or streams but migrate between rivers and tributaries for breeding, feeding, or sheltering.
Fluvial Geomorphology	The study of the origin and evolution of landforms shaped by river processes.
Fluvial System	The natural river system consisting of (1) the drainage basin, watershed, or sediment source area, (2) tributary and mainstream river channels or sediment transfer zone, and (3) alluvial fans, valley fills and deltas, or the sediment deposition zone.
Food Web	The structure used by ecologists to represent the links between organisms within the stream. It is based upon the order in which various organisms consume one another.
Freeboard	The vertical distance above a design stage that is allowed for waves, surges, drift, and other contingencies.
Froude Number	A dimensionless number that represents the ratio of inertial to gravitational forces in open channel flow.
<u>G</u>	
Gabions	Baskets compartmented rectangular container made of wire mesh. When filled with cobbles or other rock of suitable size, the gabion becomes a flexible and permeable unit with which flow- and erosion-control structures can be built.
General Scour	Streambed erosion affecting the entire channel cross section. General scour is a lowering of the streambed across the stream or waterway at the bridge. This lowering may be uniform across the bed or non-uniform. That is, the depth of scour may be deeper in some parts of the cross section. General scour may result from contraction of the flow or other general scour conditions such as flow around a bend.
Geocell	A product composed of polyethylene strips, connected by a series of offset, full-depth welds to form a three-dimensional honeycomb system.
Geodiversity	The physical (geomorphological) diversity of waterway systems at a range of scales from channel to landscape.
Geographical Information System (GIS)	A computer program that manages spatial data in layers.
Geogrid	A geosynthetic formed by a regular network of integrally connected elements with apertures greater than a quarter inch to allow interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as reinforcement.
Geomorphic Equilibrium	The "sediment-transport continuity" of a stream, wherein the quantity and size of sediment transported into the reach is approximately the same as the quantity and size of sediment transported out of the reach. If a stream is in geomorphic equilibrium, the processes of bank erosion and channel migration will be stable or occur only gradually.

Term	Definition
Geomorphic Goals	Goals or objectives based on concepts of landscape position, landforms, and ongoing processes that change them.
Geomorphology	Geomorphology is the study of the Earth's landforms including their origin and structure. Fluvial geomorphology is the subset that deals with streams.
Geomorphology (Fluvial)	The physical structures, processes and patterns associated with waterway systems - including landforms, soils, geology and the factors that influence them.
Geosynthetic	A planar product manufactured from polymeric material used with soil, rock, earth or other geotechnical engineering related material as part of a manmade structure, or system.
Geotechnical Analysis	The evaluation of the forces involved in bank instability problems including gravity acting on the soils in the slope, the internal resistance of soils in the slope and the seepage forces in the soils in the bank.
Geotextile	A permeable geosynthetic comprised solely of textiles.
Grade Control	See Grade stabilization techniques.
Grade Control Structure	A structure built in the bed of a stream to limit erosion of the bed. Can be built of rock, concrete or wood. Operates by reducing velocity, by encouraging vegetation, and by introducing a hard point in the bed.
Grade Stabilization Techniques	Techniques used to stop channel degradation, typically accomplished by the construction of in-channel structures.
Graded Stream	A geomorphic term used for streams that have apparently achieved a state of equilibrium between the rate of sediment transport and the rate of sediment supply throughout long reaches.
Gravel	A rock fragment whose diameter ranges from 2 to 64 mm.
Groundwater	Water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations
Groynes	Solid deflection structures in a stream (partial-width structures) that extend to close to the bank top. Many names are given to these structures, the most common being "spur," "spur dike," "transverse dike," "jetty," etc. Groynes may be permeable, semi-permeable, or impermeable.
Guide Bank	A dike extending upstream from the approach embankment at either or both sides of the bridge opening to direct the flow through the opening. Some guidebanks extend downstream from the bridge (also spur dike).
Guild	A group of plants, which have a similar habit of growth and nutrition or exploit the same class of environmental resources in a similar way.
Gully/Gullies	Entrenched channels extending into areas with previously undefined or weakly defined channel conditions.

Term	Definition
<u>H</u>	
Habitat	A specific environment in which a particular plant or animal lives.
Hardpoint	A streambank protection structure whereby "soft" or erodible materials are removed from a bank and replaced by stone or compacted clay. Some hard points protrude a short distance into the channel to direct erosive currents away from the bank. Hard points also occur naturally along stream-banks as passing currents remove erodible materials leaving nonerodible materials exposed.
Headcut Or Knickpoint	A very steep section of stream bed that migrates upstream if not held by a bed control. Downstream of a head cut is normally incised and unstable.
Headwaters	The most upstream, steepest, portions of a catchment that deliver most water to a stream system.
Herbaceous Cover	A bank-stabilization technique that consists of planted or installed, non-woody vegetation, such as grass and grass-like wetland plants, rushes, sedges, ferns, legumes, and wildflowers.
Heavy Metals	Metals with an atomic number greater than 20 (e.g. mercury and copper). As pollutants, they are persistent and can be harmful to a range of aquatic organisms.
Helical Flow	Three-dimensional movement of water particles along a spiral path in the general direction of flow. These secondary-type currents are of most significance as flow passes through a bend; their net effect is to remove soil particles from the cut bank and deposit this material on a point bar.
Herbaceous Weed	Any weed that does not develop a woody stem.
Hilsenhoff Biotic Index (HBI)	This index was originally developed in 1977 by Dr. William Hilsenhoff of the University of Wisconsin - Madison, to assess low dissolved oxygen caused by organic loading in streams. He developed a range of BI values (0-10) for water quality classifications and degree of organic pollution that are used by the Wisconsin Department of Natural Resources (WIDNR) in their water quality assessment and monitoring programs Water quality classifications for the Hilsenhoff Biotic Index (BI) (*http://www.uwsp.edu/cnr/research/gshepard/History/History.htm*):

BI Value	Water Quality	Degree of Organic Pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very Good	Slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.00	Very Poor	Severe organic pollution

Holding Areas	Areas in a stream that are protected from the current, where fish can rest while migrating, usually upstream.

Term	Definition
Hydraulic Control Structure	A type of grade control structure designed to reduce the energy slope along the degradation zone to the degree that the stream can no longer scour the bed.
Hydraulic Geometry Design Method	Design approach based on the concept that a river system tends to develop in a predictable way, producing an approximate equilibrium between the channel and the inflowing water and sediment.
Hydraulic Radius	The cross-sectional area of a stream divided by its wetted perimeter.
Hydro-Physiographic Area	A drainage basin where the combination of the mean annual precipitation, lithology, and land use produces similar discharge for a given drainage basin.
Hydrograph	The graph of stage or discharge against time.
Hydrology	The science concerned with the occurrence, distribution, and circulation of water on the earth.
Hydro-seeding	A planting process which typically consists of applying a mixture of wood fibre, seed, fertilizer, and stabilizing emulsion with hydro-mulch equipment, which temporarily protects exposed soils from erosion by water and wind for easy plant establishment.
Hyporheic Zone	The zone of saturated sediment adjacent to and underneath the stream. It is directly connected to the stream, and stream water continually exchanges into and out of the hyporheic zone.
I	
Impeded Recovery	Recovery of a stream or its components that is constrained by one or a few press or pulse disturbances (e.g. point-source pollution).
Incision	The change in channel cross section resulting from the process of degradation.
Incised Stream/Channel	A stream or channel that has eroded its bed and banks such that it has a very low flood frequency. In other words, the channel cross-sectional area is obviously too large for its catchment area.
Index Of Biotic Integrity (IBI)	A biological assessment technique that uses fish surveys to assess human effects on a stream and its watershed.
Indicator	Physical, chemical, biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue.
Infiltration	The downward movement of water into the surface of soil.
Inflection Point	The point in a stream bend where one bend ends and the next one begins (often occurs at a riffle).
Integrated River Basin Management (IRBM)	A process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary restoring freshwater ecosystems.

Term	Definition
Integrated Water Resources Management (IWRM)	A process which promotes the coordinated development and management of water, land, and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
Integrity	The condition of a system relative to its original condition.
Intermittent Stream	A stream that flows only at certain times of the year when it receives water from springs or from some surface sources.
Interstitial Spaces	The gaps between the particles that make up the stream bed. These spaces are important habitat for many macro-invertebrates.
Invert	The lowest point in the channel cross-section or at flow control devices such as weirs, culverts or dams.
Invertebrates	An invertebrate is an animal lacking a vertebral column. The group includes 97% of all animal species - all animals except those in the Chordate subphylum Vertebrata (fish, reptiles, amphibians, birds and mammals)
Invertebrate community index (ICI)	It measures the health of the macroinvertebrate community is a tool for biological measuring of aquatic environments. This index is comprised of 10 metrics where sampled sites are compared to relatively undisturbed sites with similar geographical features. The variables measured are Total Number of Taxa, Total Number of Mayfly Taxa, Total Number of Caddissfly Taxa, Total Number of Dipteran Taxa, Percent of Mayflies, Percent of Caddisflies, Percent of Tribe Tanutarsini Midges, Percent of Other Dipterans and Non-insects, Percent of Tolerant Organisms and Total Number of EPT Taxa.
J	
J-Hook	A rock structure used to provide bank stabilization.
Jet Scour	Scour resulting as a jet of flow enters the stream (similar to flow ejecting from the nozzle of a hose).
Junction	The point at which two streams join.
K	
Key	Structural material (e.g., rock and/or wood) buried into the streambank or into the channel bed to prevent flanking of a bank-protection structure due to erosion in the near-bank region.
Knickpoint	Oversteepened point of erosion in a stream bed. May be a small waterfall. Also called a headcut.
L	
Land Treatment Measures	Measures used to reduce runoff of water to streams or other areas.
Lane's Relationship	A qualitative conceptual model, also known as a stream balance used as an aid to visually assess stream responses to changes in flow, slope, and sediment load.
Large Growth	Tree species which potentially have a diameter exceeding 0.3 m and/or height exceeding 5 to 6 metres.

Term	Definition
Large Woody Debris (LWD)	A dead tree, or portion of a tree, that has fallen into a stream. Usually considered to be greater than 0.1 m in diameter, and over a metre long. Also called snags.
Larva	A stage in the life cycle of some aquatic invertebrates. Larvae generally do not resemble the adult form and undergo a pupal stage before becoming an adult.
Larval Fish	Fish that have just hatched. They are often very different in form to their parents.
Lateral Barriers	A barrier restricting water and material flow between a stream and its floodplain (artificial levees would be an example).
Levee	A high-point next to a stream bank that is higher than the average height of the surrounding floodplain. May be formed naturally or artificially.
Life Cycle	A cycle which links the various forms of an organism from egg to adult.
Lift	The fluid force component on sediment particles perpendicular to the mean flow direction.
Limiting Problems/Variables/ Requirements	This is a resource that is required by an organism to survive, but that is most lacking from the stream. The limiting requirement limits the ability of a population to recover from disturbance.
Lithology	The description of rocks or earth materials on the basis of colour, composition and grain size.
Live Bed Conditions	May be assumed at a site if the mean velocity upstream exceeds the critical velocity for the beginning of motion for the median size of bed material available for transport.
Live-Bed Scour	Scour at a pier or abutment (or contraction scour) when the bed material in the channel upstream of the bridge is moving at the flow causing bridge scour.
Local Plan	A district development plan that translates the state policies at local level.
Local Scour	Discrete, tight scallops along the bank-line or as depressions in the streambed resulting from erosion. It is generated by flow patterns that form around an obstruction in a stream and spill off to either side of the obstruction, forming a horseshoe-shaped scour pattern in the streambed.
Log-Pearson Type III Distribution	A commonly used frequency distribution for peak flows. It applies to nearly all series of natural floods; commonly used for stream gage analysis.
Log Toe	A structure installed at the base of a bank slope constructed of log materials to protect the base of the bank from erosive forces.
Longitudinal Barriers	Barriers along a stream's length that disrupt the movement of water and material (e.g. carbon) along the stream.

Term	**Definition**
Longitudinal Continuity	A measure of the continuity of the movement of water and material along a stream. Continuity may be reduced by natural or artificial barriers (e.g. log jams, concrete dams, diversion channels, pumps).
Longitudinal Profile	The profile of a stream or channel drawn along the length of its centreline. In drawing the profile, elevations of the water surface or the thalweg are plotted against distance as measured from the mouth or from an arbitrary initial point.
Lower Bank	That portion of a streambank having an elevation less than the mean water level of the stream.
Lowland Reaches	Lowlands are broad alluvial or coastal floodplains.
Low Flow	A general term that refers to the average low flows in a stream. It is typically due to soil moisture and ground water. Critical habitat conditions often occur during low flows.
Low-Flow Channel	A portion of a channel that conveys low or base-flows.
Lunkers	A technique providing both streambank stability and edge cover in aquatic habitat.
<u>M</u>	
Macro-crustaceans	Crustaceans such as shrimp and crayfish which are large enough to be seen without a hand lens.
Macro-invertebrate	An invertebrate (animal without a backbone) that is visible to the naked eye.
Macrophyte	A vascular water plant. It may be either floating or rooted.
Maintenance	Actions taken to ensure that the stream restoration project performs as designed and attaining project objectives.
Manning's *n*	An empirical factor in Manning's equation, which accounts for frictional resistance of the flow boundary.
Mannings Equation	An empirical equation (i.e. based on experiments rather than theory) used to estimate the velocity, and hence discharge, of a flow.
Mass Failure	The sudden breaking away and downward movement of a cohesive portion (block) of the land surface, as opposed to the gradual erosion of soil.
Mass Wasting	Gravity failure of a slope (including a stream bank) as a single block (same as mass failure).
Mathematical Model	A numerical representation of a flow situation using
Mattress	A blanket or revetment of materials interwoven or otherwise lashed together and placed to cover an area subject to scour.
Mean Annual Discharge / Mean Annual Flow	The averaging of the daily mean discharge over a period of years.

Term	Definition
Mean High Flow	The mean of the highest flows over a period of time.
Meander	Deviation of the stream direction from the shortest possible path down a stream valley. More specifically, a stream reach is said to be meandering if its length is 1.5 times (or more) the length of the valley through which it passes. Any reach that exceeds the length of the valley can be taken as evidence of meandering, but 1.5 is the standard minimum used to confirm meandering activity.
Meander Amplitude	The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between centre lines of channels.
Meander Belt	The distance between lines drawn tangent to the extreme limits of successive fully developed meanders.
Meander Geometry	The five parameters commonly used in the description of meander patterns, including wavelength, radius of curvature, arc length, amplitude, and beltwidth.
Meander Length	The product of the meander wavelength and the valley slope divided by the channel slope.
Meander Loop	An individual loop of a meandering or sinuous stream lying between inflection points with adjoining loops.
Meander Pattern	A series of sinuous curves or loops in the course of a stream that are produced as a stream swings from one side of its floodplain to the other. (Also see Meander geometry).
Meander Ratio	The length of the stream divided by the length of the valley.
Meander Radius	The radius of a circle inscribed on the centreline of a meander of curvature: loop.
Meander Scrolls	Low, concentric ridges and swales on a floodplain, marking the successive positions of former meander loops.
Meander Width	The amplitude of a fully developed meander measured from midstream to midstream.
Meandering Stream	A stream having a sinuosity greater than some arbitrary value. The term also implies a moderate degree of pattern symmetry, imparted by regularity of size and repetition of meander loops. The channel generally exhibits a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders.
Measure	A specific determinant for an indicator.
Mechanism Of Failure	The physical process of erosion. Examples of mechanisms of failure include scour and avulsion.
Median Diameter	The particle diameter of the 50th percentile point on a size distribution curve such that half of the particles (by weight, number, or volume) are larger and half are smaller (D50.)

Term	Definition
Mid-Channel Bar	A bar lacking permanent vegetal cover that divides the flow in a channel at normal stage.
Middle Bank	The portion of a streambank having an elevation approximately the same as that of the mean water level of the stream.
Migration (Of Animals)	Recurring long distance travel by an organism. Many fish species migrate up and down rivers to complete different parts of their life cycle.
Migration (Of Meander Bends)	Erosion of the outside (concave) bank of a river such that the river progressively moves across or down the valley.
Mitigation (Ecology)	Actions taken to avoid or compensate for impacts to habitat resulting from man's activities.
Monitoring	The process of measuring or assessing specific physical, chemical, and/or biological parameters of a project.
Montgomery And Buffington Classification	A classification system based on defining channel processes. It is a geomorphic process-based system.
Morphology	The field of science dealing with changes of river planform.
<u>N</u>	
Natural Channel	A river, stream, creek, or swale that has existed long enough and without significant alteration to establish a dynamically stable route.
Natural Levee	A low ridge that slopes gently away from the channel banks that is formed along stream-banks during floods by deposition
Natural Riverbank	The bank of the river, formed naturally and not part of the dike fill; located below the dike height on the river side.
Neck Cutoff	The loss of a meander resulting from the intersection of meander bends.
Nominal Diameter	Equivalent spherical diameter of a hypothetical sphere of the same volume as a given sediment particle.
Nonalluvial Channel	A channel whose boundary is in bedrock or non-erodible material. Normal stage: The water stage prevailing during the greater part of the year.
Overbank Flow	Water movement that overtops the bank either due to stream stage or to overland surface water runoff.
Non-Point Source (Or Diffuse Source)	Pollution that is contributed from numerous small sources as opposed to a single point-source.
Non-structural Measures	A term originally devised to distinguish techniques that modify susceptibility to flooding from the more traditional structural methods used to control flooding.
Nutrients	Chemicals (usually refers to nitrogen and phosphorus) that are essential for plant and animal growth.

Term	**Definition**
Nymphs	A stage in the life cycle of some aquatic insects. Nymphs have a similar form to the adult insect, but lack wings.
<u>O</u>	
Off-Channel Watering	Stock watering point provided away from the stream banks, water may be pumped to troughs in a paddock.
Ordinary High Water Mark	Generally, the lowest point at which perennial vegetation grows on the streambank. The ordinary high water mark can usually be identified by physical scarring along the bank or shore, or by other distinctive signs. This scarring is the mark along the bank where the action of water (through erosion and deposition of debris) is so common as to leave a natural line impressed on the bank.
Organic Matter	Carbon-based matter of organic origin. This includes vegetable matter as well as the bodies of dead animals.
Organisms	Plants, animals, fungi and bacteria. Things that live.
Outliers	Data points that depart significantly from the trend of the remaining data.
Oversteepened Bank	A streambank that has been steepened beyond the angle of repose or beyond the point to which soil cohesion supports the bank.
Overburden	A term used to describe all soil and ancillary material lies above the area of interest or bedrock horizon in a given area.
Overbank	The area of land between the waterside toe of a setback dike and the top of the streambank.
Overbank Flow	Water movement that overtops the bank either due to stream stage or to overland surface water runoff.
Overstorey	Woody plants greater than 5 m tall, usually with a single stem (e.g. eucalypts, acacias etc.).
Oxbow	The abandoned former meander loop that remains after a stream cuts a new, shorter channel across the narrow neck of a meander. Often bow-shaped or horseshoe-shaped.
<u>P</u>	
Pattern	Plan view of a stream reach.
Pavement	Streambank surface covering, usually impermeable, designed to serve as protection against erosion. Common pavements used on stream-banks are concrete, compacted asphalt, and soil-cement.
Pebble Count	Technique used to sample the surface layer of sediments in gravel-bed streams.
Perennial Stream	A stream that flows continuously. Streams flowing continuously throughout the year and are generally lower than the water table in the region adjoining the stream.

Term	Definition
Perched Floodplain	A floodplain surface that, because the streambed has degraded, becomes high enough above the channel that it is no longer inundated by the current hydrologic regime.
Perching (At Culverts)	A small waterfall formed by a man-made obstruction that forms a barrier to fish passage.
Perennial Flow	Flowing all year round.
Periphyton	A thin layer of algae, bacteria and fungi, which grows on stream substrates (such as rocks and logs) or on the surfaces of macrophytes.
Permanent Stream	A stream that flows for all of most years.
Ph	A measure of the concentration of the acidity or alkalinity of the water (hydrogen ions in water).
Phragmites Reeds	Also known as 'common reeds' (Phragmites australis). Occur in slow moving water.
Pile Dike	A type of permeable structure for the protection of banks against caving; consists of a cluster of piles driven into the stream, braced and lashed together.
Piping	Removal of soil material through subsurface flow of seepage water that develops channels or "pipes" within the soil bank.
Planform	The characteristics of a river as viewed from above (in an aerial photo, on a map, etc.), which are generally expressed in terms of pattern, sinuosity (channel length/valley length) and individual meander attributes such as amplitude, wavelength and radius of curvature.
Planktonic Algae	Algae that float free in the water.
Point Bar	A depositional area formed on the inside bank of a meander that sometimes remains bare of vegetation due to the frequent recurrence of the bankfull discharge.
Point Source	A pollution source that can be pinpointed.
Poised Stream	A stream which, as a whole, maintains its slope, depths, and channel dimensions without any noticeable raising or lowering of its bed (stable stream).
Pool	The deepest point of a stream bed. Pools usually occur at the outside of stream bends and may be separated by shallower areas called riffles.
Press Disturbance	A long-term disturbance.
Problem	In the stream rehabilitation, a 'problem' is defined strictly as any process or attribute that threatens a natural asset or causes it to be damaged, or to no longer be in its natural condition.
Producers	Organisms that can use nutrients to generate energy. This includes plants, algae and bacteria.

Term	Definition
Primary Production	a. The total organic material synthesized in a given time by autotrophs of an ecosystem. b. Rate at which light energy is converted to organic compounds via photosynthesis.
Principle	A fundamental tenet that provides the basis for waterway planning and management.
Pulse Disturbance	A short-lived disturbance.
<u>Q</u>	
Quiescent Zone	A calm zone of water in a stream; opposite of turbulent.
<u>R</u>	
Rapid Drawdown	Lowering the water against a bank more quickly than the bank can drain without becoming unstable.
Rating	A non-dimensional number for an indicator that is evaluated by converting raw data (e.g. total phosphorus concentrations or observations on site) using a rating table.
Reach	a) Any specified length of stream; b) A relatively homogeneous section of a stream having a repetitious sequence of physical and biological characteristics; c) A regime of hydraulic units whose overall profile is different from another reach.
Recurrence Interval	The reciprocal of the annual probability of exceedance of a hydrologic event. Also called “return period.”
Reclamation	A series of activities intended to change the biophysical capacity of an ecosystem. The resulting ecosystem is different from the ecosystem existing prior to recovery or rehabilitation.
Recolonisation	The return of a species or community to an area after some form of disturbance.
Recovery	Return of a stream system to some state that is considered desirable (usually the natural state) following disturbance.
Recovery Pathway	The stages through which a system passes as it gradually recovers.
Redirective Structure	A flow-changing bank stabilization technique. Designed to be placed in the stream, minimize direct impact, and rely more on the characteristics of fluid mechanics to modify the stream-flow direction.
Reference Reach Design Method	An alluvial channel design approach whereby channel dimensions are selected from a similar stable channel.
Regeneration	Vegetation that has grown from natural sources of seed or from vegetative growth, without being artificially planted.
Regime Change	A change in channel characteristics resulting from such things as changes in imposed flows, sediment loads, or slope.
Regime Channel	“Regime” is the condition of a stream with regard to stability. A stream channel that is 'in regime' neither degrades or aggrades over time.

Term	Definition
Regime Design Method	An alluvial channel design approach whereby channel dimensions are selected with the aid of empirically derived equations.
Region	A loose term relating to a tract of country with broadly similar characteristics.
Regional Conservation Value	An asset that is rare within a region (as opposed to an asset that is rare within a catchment but not within a region-which would be classified as having local conservation value).
Regression (As In Channel-Regression Equations)	Equations that define the mathematical relationship among channel attributes and other variables.
Regression Equations (Gauge Analysis)	Used to transfer flood characteristics from gauged to ungauged sites through use of watershed and climatic characteristics as predictor variables.
Regulated Stream Systems	Streams or rivers that are cleared of wood, dammed, channelised, leveed or constrained by other types of hard structures.
Regulated Stream	Stream flows controlled by releases from a dam, or by some other artificial control.
Rehabilitation	The return of as much as possible of the original, undisturbed characteristics of a stream, including the physical structure and stability, water quality, flow regime, and the suite of organisms in the stream. The organisms present in the stream are a good measure, in most cases, of the health of the stream, and thus whether it is being rehabilitated. Ideally, improvements introduced to the stream should be self-sustaining.
Reinforced-Earth	A retaining structure consisting of vertical panels and bulkhead: attached to reinforcing elements embedded in compacted backfill for supporting a streambank.
Reinforced Revetment	A streambank protection method consisting of a continuous stone toe-fill along the base of a bank slope with intermittent fillets of stone placed perpendicular to the toe and extending back into the natural bank.
Relief Bridge	An opening in an embankment on a floodplain to permit passage of overbank flow.
Remediation	Attempts to improve the condition of a stream may produce a stream that is very different from the natural stream, but nonetheless improved. Remediation is often an appropriate goal in urban stream rehabilitation.
Replication	(Evaluation) This is repeat sampling to identify the inherent variability in the system. You can have replicates on many scales-replicate rivers to see if the results can be applied to different streams; replicate study sites within a river to see if all reaches react in the same way; replicate samples over time, to measure the temporal variability; and replicate sub-samples within a sample, to measure spatial variability.
Representativeness	Serving as a typical or characteristic example.

Term	Definition
Resilience	The ability of a community or system to return to equilibrium after a disturbance.
Restoration	The reestablishment of the structure and function of ecosystems. Ecological restoration is the process of returning an ecosystem as closely as possible to pre-disturbed conditions and functions.
Retard	A flow-changing bank stabilization technique. A retard structure increases flow resistance by increasing drag, thereby slowing the velocity in the vicinity of the structure. These structures are more porous with a high percentage of open area.
Return Period (Of Floods)	(More correctly 'average recurrence interval' or ARI) The average time in years between two floods of a given size or larger.
Revetment	Bank protection accomplished by armouring the bank with erosion-resistant material.
Reynolds Number	A dimensionless ratio, relating the effect of viscosity to inertia, used to determine (index) whether fluid flow is laminar or turbulent.
Riffle	The high point in the bed of the stream between two pools (it is often covered in gravel or coarser material and experiences rapid, turbulent low flows).
Riffle	A reach of stream in which the water flow is shallower and more rapid than the reaches above and below; natural streams often consist of a succession of pools and riffles.
Riffle Pool Spacing	The distance between the riffles and the pools in a channel.
Rill	One of a set of well-defined, sub-parallel channels that vary in size according to the erodibility of the soil; generally these channels are only a few inches wide and deep.
Riparian	The area adjacent to flowing water (e.g. rivers, perennial or intermittent streams, seeps or springs) that contains elements of both aquatic and terrestrial ecosystems, which mutually influence each other.
Riparian Buffer	A swath of riparian vegetation along a channel bank that provides some measure of protection from the erosive forces of water along the channel margins.
Riparian Vegetation	The vegetation immediately in contact with water body or sufficiently close to have direct influence on aquatic habitat values.
Riparian Zone	Any land which adjoins, directly influences, or is influenced by a body of water
Ripples	Bedforms that are smaller than dunes (usually centimetres in height).
Riprap	Large, durable materials (usually rocks, sometimes broken concrete, etc.) used to protect a streambank or lake shore from erosion; also refers to the materials used for this purpose.

Term	Definition
River	A large natural waterway confined within a bed and banks. In the context of this manual, the term stream is often used interchangeably with river.
River Corridor	The minimum area that is able to serve the function of containing a major flood and pass water safely to the sea. The width is defined by the lateral extent of the river meanders when the equilibrium channel slope is achieved. Providing space for sediment deposition, floodplain and meander development, and slope reduction serves to maximize channel stability and minimize fluvial erosion hazards. The corridor can be expanded to account for the influence of the watercourse into the surrounding landscape. The current trend is for the river corridor to also cater for the needs of flora & fauna and recreation consideration.
River Reserve	Land being reserved for the purpose of river & flood management (public purpose) in accordance with the provisions of Section 62 of the National Land Code.
River Training	Engineering works with or without the construction of embankment, built along a stream or reach of stream to direct or to lead the flow into a prescribed channel. Also, any structure configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.
Riverine Area	Area on or near the banks of a river.
Rock Toe	A structure composed of rock materials, installed at the base of a bank slope to protect the base of the bank from the erosive forces of stream flow.
Root Wads	The root mass of trees placed in streams. Usually done by driving the trunk into the bank.
Rootwad Revetments	Use of locally available logs and root fans to add physical habitat to streams in the form of coarse woody debris and deep scour pockets.
Rosgen Classification	A stream classification system based on measurements of existing morphology.
Run	The steepest section and shortest longitudinally, starting at the downstream end of a riffle as the channel enters the next pool.
Roughness Coefficient	Numerical measure of the frictional resistance to flow in a channel, as in the Manning's or Chezy's formulas.
Rubble	Rough, irregular fragments of materials of random size used to retard erosion. The fragments may consist of broken concrete slabs, masonry, or other suitable refuse.
Runoff	That part of precipitation which appears in surface streams of either perennial or intermittent form.
<u>S</u>	
Sack Revetment	Sacks (e.g., burlap, paper, or nylon) filled with mortar, concrete, sand, stone or other available material used as protection against erosion.

Term	Definition
Sample	(Evaluation) A measurement of some sort. It could be anything from the average depth of erosion at a site, as measured by erosion pins, to a measure of water quality, or a survey of the invertebrate population present at a site.
Scaling	A template reach may be found in a different part of the catchment than the target reach. The dimensions of the template reach that are related to the position of the reach in the catchment (e.g. sediment size, slope, channel size) need to be adjusted to reflect the dimensions that would be expected in the target reach, given the position and different condition of the target reach in the catchment (e.g. you will probably need to design a larger channel in a cleared catchment than in a forested one).
Scalp	To remove a layer of sand and gravel from a gravel bar.
Scarp	A sharp break in slope, resulting from either mass failure or erosion.
Scooping	A process for determining the scope of issues to be addressed in the environmental impact assessment process and for identifying the significant issues related to a proposal.
Scour	The process of removing material from the bed or banks of a channel through the erosive action of flowing water.
Scour Chains	Chains inserted vertically into the sand or gravel of a stream bed in order to measure the amount of scour and fill taking place during a flood.
Scrapers	Animals which consume the periphyton which grows on the surface of rocks, plants and coarser organic matter.
Seasonality (Of Flows)	A difference in flows between seasons of the year.
Secondary Circulation	A flow velocity across the channel that leads to spiralling currents along the channel. The circulation is associated with channel bends and is responsible for erosion of meander bends.
Sediment	Any mineral or organic matter of any size in a stream channel.
Sediment Budget Analysis	A quantitative sediment impact assessment of channel stability using the magnitude and frequency of all sediment-transporting flows done by comparing the mean annual sediment load for the project channel with that of the supply reach.
Sediment Continuity Analysis	The volume of sediment deposited in or eroded from a reach during a given period of time is computed as the difference between the volumes of sediment entering and leaving the reach.
Sediment Impact Assessment	An evaluation of a designed channel's ability to transport the inflowing water and sediment load, without excessive sediment deposition or scouring on the channel bed.
Sediment Load	The sum total of sediment available for movement in a stream, whether in suspension (suspended load) or at the bottom (bedload).

Term	Definition
Sediment Rating Curve	Correlates sediment flow to discharge for a stream reach or section.
Sediment Rating Curve Analysis	Sediment impact assessment technique used to assess the sediment transport characteristics of an existing or proposed stream project. This approach uses sediment rating curves to compare the sediment transport capacity of the supply reach to the existing and proposed project reach conditions.
Sediment Sampling	Technique used to quantify sediment in streams and rivers.
Sediment Slug	A wave of sand or gravel that moves down a stream channel (usually introduced into the stream in a pulse by mining, gullying, major floods or other extreme events).
Sediment Trap	A structure across a stream that creates a backwater in order to trap sediment.
Sediment Yield	The total sediment outflow from a watershed or a drainage area at a point of reference and in a specified time period. This outflow is equal to the sediment discharge from the drainage area.
Sedimentation	The act or process of depositing sediment.
Seepage	The slow movement of water through small cracks and pores of the bank material.
Segment	A long portion of stream (consisting of several reaches) that is defined by the general geological character of the catchment (e.g. changes in bedrock, faults, long reaches with similar slope etc.).
Shear Strength	The characteristic of soil, rock and root structure that resists the sliding of one material against another.
Shear Stress	A measure of the erosive force acting on and parallel to the channel boundary. It is expressed as force per unit area (N/m^2). In a channel, shear stress is created by water flowing parallel to the boundaries of the channel; bank shear is a combined function of the flow magnitude and duration, as well as the shape of the bend and channel cross section.
Sheet Pile	Flat panels of steel, concrete, vinyl, synthetic fibre, reinforced polymer, or wood. Typical applications include toe walls, flanking and undermining protection, grade stabilization structures, slope stabilization, and earth retaining walls.
Shields Diagram	Classic method for determining critical shear stress.
Shredders	Animals that reduce coarse organic matter to smaller particles while feeding upon it.
SIGNAL Index	An indicator in the Aquatic Life Sub-index that measures effect of pollution on aquatic biota. SIGNAL is an acronym for Stream Invertebrate Grade Number-Average Level.
Silt	Particles bigger than clay (say 4 microns) and smaller than sand (about 0.06 mm).

Term	Definition
Sinuosity	The ratio of stream-channel length, measured in the thalweg from the top of the valley to the bottom of the valley, or ratio of the valley slope to the channel slope. When measured accurately from aerial photos, channel sinuosity may also be used to estimate channel slope (valley slope/sinuosity).
Soil Anchor	Technique used to anchor woody material to the streambed or bank to resist fluvial forces.
Soil Bioengineering	The use of live and dead plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment.
Slope Protection	Any measure such as riprap, paving, vegetation, revetment, brush or other material intended to protect a slope from erosion, slipping or caving, or to withstand external hydraulic pressure.
Sloughing	Sliding or collapse of overlying material. Same ultimate effect as caving, but usually occurs when a bank or an underlying stratum is saturated.
Slope-Area Method	A method of estimating unmeasured flood discharges in a uniform channel reach using observed high-water levels.
Slug	See sediment slug.
Slump	A sudden slip or collapse of a bank, generally in the vertical direction and confined to a short distance, probably due to the substratum being washed out or having become unable to bear the weight above it.
Snags	Large woody debris, but generally referring to the larger logs in a stream.
Spawning	Depositing or releasing eggs/sperm (usually in large numbers). A process employed by animals with external fertilisation such as frogs and fish.
Species Richness	Species richness is simply the number of species present in a sample, community, or taxonomic group. Species richness is one component of the concept of species diversity, which also incorporates evenness, that is, the relative abundance of species.
Specific Energy	The energy per unit weight of water at a given cross section with respect to the channel bottom.
Specific Force	The horizontal force of flowing water per unit weight of water.
Spill-Through	A bridge abutment having a fill slope on the streamward side. Abutment. The term originally referred to the "spill-through" of fill at an open abutment but is now applied to any abutment having such a slope.
Spread Footing	A pier or abutment footing that transfers load directly to the earth.
Spur	A permeable or impermeable linear structure that projects into a channel from the bank to alter flow direction, induce deposition, or reduce flow velocity along the bank.
Spur Dikes	Short dikes that extend out perpendicular from the bank into the channel along a reach of eroded bank.

Term	Definition
Stability	A channel is considered stable (or in dynamic equilibrium) when the prevailing flow and sediment regimes do not lead to long-term aggradation or degradation.
Stage	The elevation of the water surface relative to a datum.
Stage-Discharge Relationship	Discharge plotted against corresponding stage (water surface elevation).
Stakeholders	Individuals or groups who fund a project or are affected by the project.
State Authority	The Ruler-in-Council or the Governor-in-Council of the State
Stewardship	Personal responsibility for taking care of another's property.
Stream	A small natural waterway with a detectable current. Defined within a bed or banks. In the context of this manual, the term stream is often used interchangeably with river.
Stream Barbs	A flow-changing bank stabilization technique that are low dikes or sill-like structures that extend from the bank towards the stream in an upstream direction. As flow passes over the sill of the stream barb, it discharges normal to the face of the weir.
Stream Order	Classification of streams according to their position in the channel network, for example, a first order stream has no tributaries. Streams become larger as their order rises and an increasing number of segments contribute to the flow.
Streambank	The sides of a stream or river.
Streambank Failure	Sudden collapse of a bank due to an unstable condition such as removal of material at the toe of the bank by scour. streambank Any technique used to prevent erosion or failure of a protection.
Streambed	The bottom of a stream or river
Stream Classification	See Classification.
Stream Corridor	Includes the stream and extends in cross section from the channel's bankfull level towards the upland (perpendicular to the direction of stream-flow) to a point on the landscape where channel-related surface and/or soil moisture no longer influence the plant community.
Stream Corridor Rehabilitation	One or more conservation practices used to overcome resource impairments and reach identified purposes.
Stream Order Classification	A stream classification system based upon the degree of channel branching. An nth order stream is formed by the intersection of two or more (n-1) order streams.
Stream Management	Managing all human interaction with a stream (a subset of catchment management).
Stream Power	The product of shear stress and mean velocity. A measure of the available energy a stream has for moving sediment, rock, woody, or other debris.

Term	Definition
Stress	Disturbance pressure which is placed upon a biological population, or ecological community, and results in a shift from an established equilibrium.
Stone Sizing	Technique used to determine the minimum size stone to resist stream velocity.
Structural Measures	Measures such as dams, reservoirs, dikes, levees, floodwalls, channel alterations, high-flow diversions, spillways, and land-treatment measures designed to modify floods.
Structure Plan	A broad master plan that sets out the policies and proposals for the development and use of the land in a state.
Substrate	In biology refers to any surface that organisms use. In geomorphology refers more specifically to the sediment on the bed of the stream (sub-bed material).
Subcritical	Open channel flow conditions with Froude Number less than supercritical flow and greater than unity, respectively.
Succession	The ecological process in which several communities replace one another as the physical conditions change.
Surcharge	A weight on a slope that exerts a down-slope (destabilizing) stress and a perpendicular stress component, the combination of which tends to increase resistance to sliding.
Swale	A marshy depression in a stretch of land.
Supercritical Flow	Flow with a Froude number greater than 1.
Survival	In stream rehabilitation, refers to whether a stream rehabilitation action has survived for a defined period.
Suspended Load	Sediment that is carried suspended in the water column.
Suspended Sediment Concentration	The amount of sediment carried suspended in the water column, usually measured in mg/L.
Sustainable/Sustainability	Management decisions or rehabilitation works result in sustainable ecological communities if the community does not degrade and maintains its equilibrium without further intervention.
Target Reach	The reach that you want to rehabilitate.
Target Species	The species of animal or plant that you want to return to the stream.
Taxa	Plural of Taxon.
Taxon	A taxonomic category or group, such as a phylum, order, family, genus, or species.
Terrestrial Organisms	Animals and plants that live on the land.
Thalweg	The longitudinal line of deepest water within a stream.

Term	Definition
Tetrahedron	Component of river-training works made of six steel or concrete struts fabricated in the shape of a pyramid.
Tetrapod	Bank protection component of precast concrete consisting of four legs joined at a central joint, with each leg making an angle of 109.5^o with the other three.
Threat	A process that through time could lead to deterioration of condition.
Threshold	The point at which a sudden, large change occurs, resulting from gradual changes that produced little change.
Threshold Channel	A channel in which channel boundary material has no significant movement during the design flow. The term threshold is used because the channel geometry is designed so that applied forces from the flow are below the threshold for movement of the boundary material.
Threshold Channel Design	A design approach whereby a channel configuration is selected so that the stress applied during design conditions is below the allowable stress for the channel boundary.
Tieback	Structure placed between revetment and bank to prevent flanking.
Timber Or Brush Mattress	A revetment made of brush, poles, logs, or lumber interwoven or otherwise lashed together. The completed mattress is then placed on the bank of a stream and weighted with ballast.
Toe	Bottom of the bank.
Toe Protection	Loose stones laid or dumped at the toe of an embankment, groin, etc., or masonry or concrete wall built at the junction of the bank and the bed in channels or at extremities of hydraulic structures to counteract erosion.
Toe Zone	The portion of the bank between the average water level and the upper edge of the bottom of the channel.
Top Width	The width of a channel cross section at the water surface.
Total Phosphorus	The sum of the concentrations of soluble and insoluble phosphorus.
Total Scour	The sum of long-term degradation, general (contraction) scour, and local scour.
Total Sediment Load	The sum of suspended load and bed load or the sum of bed material load and wash load of a stream (total load).
Toxicants	The vast array of organic and inorganic chemicals that find their way into streams where they can potentially cause considerable problems.
Tractive Force	The drag or shear on a streambed or bank caused by passing water, which tends to move soil particles along with the stream-flow.
Tractive Power Design Method	A threshold channel design technique used in the assessment of channels in cemented and partially lithified (hardened) soils.
Trajectory	The path of condition that a stream follows after a disturbance. The stream may deteriorate or improve over time.

Term	Definition
Transect	A predetermined line along which vegetation occurrence or other characteristics such as canopy density are counted for monitoring purposes. A channel cross section.
Transition Channel	A stream or river which may behave as an alluvial channel in one flow condition and as a threshold channel in another flow condition.
Trap Efficiency	The proportion of sediment trapped in a particular storage zone (e.g. a dam or stream reach).
Treatment Or Intervention	(Evaluation) This is the thing that you do to the stream (in this case, some stream rehabilitation activity).
Treatment Site Or Reach	In evaluation, the reach or site in which the changes take place, as opposed to the control reach in which no change is made.
Trench-Fill Revetment	Stone, concrete, or masonry material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench armours the bank and thus retards further erosion.
Tributary	A smaller stream that joins a larger one.
Tubestock	Plants grown in tubes that are then individually planted as a revegetation technique.
Turbidity	The cloudiness of water caused by reduction in the transmission of light. Often caused by suspended sediment and other material. Turbidity is usually measured in Nephelometric Turbidity Units.
Turbulence	Motion of fluids in which local velocities and pressures fluctuate irregularly in a random manner as opposed to laminar flow where all particles of the fluid move in distinct and separate lines.
Turf Reinforcement Mats (TRM)	Used to provide permanent erosion protection.
U	
Ultimate Scour	The maximum depth of scour attained for a given flow condition. May require multiple flow events and in cemented or cohesive soils may be achieved over a long time period
Uniform Flow	Occurs when the gravitational forces that are pushing the flow along the channel are in balance with the frictional forces exerted by the wetted perimeter that are retarding the flow.
Unit Discharge	Discharge per unit width (may be average over a cross section, or local at a point).
Unit Shear Force	The force or drag developed at the channel bed by flowing (shear stress) water. For uniform flow, this force is equal to a component of the gravity force acting in a direction parallel to the channel bed on a unit wetted area. Usually in units of stress, Pa (N/m2) or (lb/ft2).
Unsteady Flow	Flow of variable discharge and velocity through a cross section with respect to time.

Term	Definition
Upland Reaches	Stream reaches characterised by narrow terraces and floodplains, usually occurring in the headwaters of a catchment.
<u>V</u>	
Valley Slope	The maximum possible slope for the channel invert and is determined by the local topography, and a channel with a slope equal to the valley slope would be straight.
Value	There are different types of values including environmental, heritage, and recreational values. Generally, the more natural the condition of a stream, the higher its environmental value.
Vanes	Flow-changing structures constructed in the stream designed to redirect flow by changing the rotational eddies normally associated with stream-flow. They are used extensively as part of natural stream restoration efforts to improve in-stream habitat.
Vegetated Gabion	A vegetated gabion incorporates topsoil into the void spaces of the gabion. Woody plantings and/or grass are planted into or through the structure.
Vegetated Reinforced Soil Slope (VRSS)	A soil bioengineering technique that is made up of layers of soil wrapped in synthetic geogrid or geotextile, with live cuttings or rooted plants installed between the wrapped soil layers.
Vegetated Rock Wall	A mixed-construction soil bioengineering streambank stabilization technique. The structural-mechanical and the vegetative elements work together to prevent surface erosion and shallow mass movement by stabilizing and protecting the toe of steep slopes.
Vegetated Stone	Combining rock with soil bioengineering treatments can achieve benefits from both techniques.
Vortex	Turbulent eddy in the flow generally caused by an obstruction such as a bridge pier or abutment (e.g., horseshoe vortex). wandering channel: A channel exhibiting a more or less non-systematic process of channel shifting, erosion and deposition, with no definite meanders or braided pattern.
<u>W</u>	
Wash Load	Suspended material of very small size (generally clays and colloids) originating primarily from erosion on the land slopes of the drainage area and present to a negligible degree in the bed itself.
Water Quality Index (WQI).	Index used for assessing the quality of surface water and is calculated based on the monitoring of 6 chemical pollutants, viz., pH, ammoniacal nitrogen, suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and dissolved oxygen
Waterfall	Usually a geological formation resulting from water, often in the form of a stream, flowing over an erosion-resistant rock formation that forms a sudden break in elevation or nickpoint. Most waterfalls form in mountain environments where the erosive water force is high and stream courses may be subject to sudden and catastrophic change.

Term	Definition
Watershed	A topographically bounded area of land that captures precipitation, filters and stores water, and regulates its release through a channel network into a lake, another watershed, or an estuary and the ocean.
Waterway	A river, creek or stream in which water flows permanently or intermittently; includes bed and banks and any other element of a river, creek or stream that confines or contains water.
Wattle	A soil bioengineering technique made up of rows of live stakes or poles with live plant materials woven in a basket-like fashion. A wattle fence can be used to deter erosion in ditches or in small dry channel beds to resist the formation of rills and gullies.
Wetlands	Defined as areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.
Width Of Stream	The average distance from one bank of the stream to the other at the bankfull point (i.e. the point at which the flow goes onto the floodplain).
Width-To-Depth Ratio	The bankfull width divided by the mean bankfull depth (dimensionless).
Wolman Pebble Count	See Pebble count.
Wolman Walk	See Pebble count.
Woody Debris	See Large woody debris (LWD).
Woody Plants	Vegetation with a distinct trunk and branch structure, ranging from trees to small shrubs.

CHAPTER 1

RIVER MANAGEMENT IN MALAYSIA

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1 RIVER MANAGEMENT IN MALAYSIA

1.1 GENERAL

1.1.1 Introduction

Rivers are valuable natural resources for human life, environment and national development. Basing on the "Kajian Register Lembangan Sungai Kebangsaan (Fasa 2) [1], there are 189 main river basins (Appendix A) in the country, 89 in Peninsular Malaysia, 22 in Sarawak and 78 in Sabah; branching into 1,800 rivers with a total length of over 57,300 km. This list of major river basins in Malaysia is currently being reviewed by the River Management Division of DID Malaysia. Rivers in Malaysia have been playing important roles to the overall development of the Country. They provide water for domestic, agriculture and industrial consumption, power generation and serve as means of transportation and communication as well as food source for the people. Most major towns and cities of Malaysia began as settlements along rivers. Malaysia's rivers generally flow in abundance, a result of the high rainfall and relatively undisturbed catchments.

1.1.2 Definition of River

A river is defined as any natural stream of water that flows in a channel with defined banks (Encyclopaedia Britannica). The source of a river may be a lake, a spring, or a collection of small streams, known as headwaters. From their source, all rivers flow downhill, typically terminating in the sea/ocean as sketched in Figure 1.1. In some cases a river flows into the ground or dries up completely before reaching another body of water. A river is a component of the water cycle. A river's water is normally confined to a channel, made up of a streambed between banks. Most rainfall on land passes through a river on its way to the ocean. Smaller side streams that join a river are tributaries. Usually larger streams are called rivers while smaller streams are called creeks, brooks, rivulets, rills, and many other terms, but there is no general rule that defines what can be called a river. Locally, besides *sungai*, there are also many other terms referring to river; including *alor* (Kelantan), *carok* (Kedah), *parit* (Johor), *batang* (Sarawak) and *terusan*.

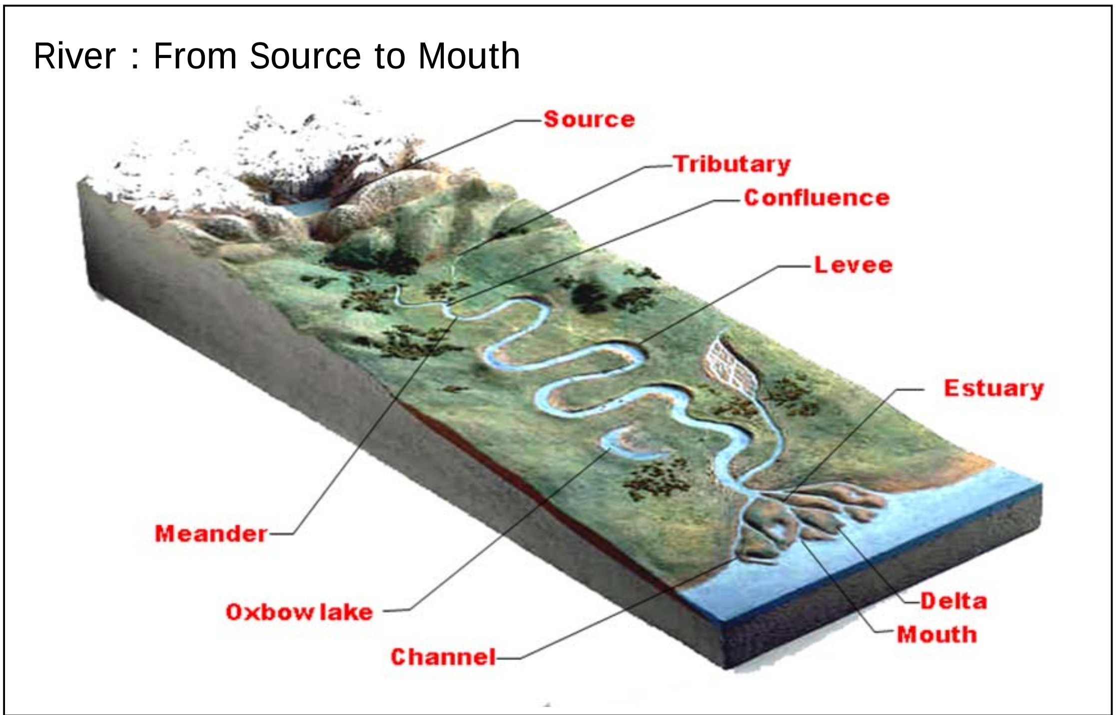

Figure 1.1 Typical River System

In Malaysia, the water within a river generally originates from precipitation through surface runoff, groundwater recharge (as seen at baseflow conditions / during periods of lack of precipitation) and release of stored water in natural or man-made reservoirs, such as wetlands, ponds or lakes. A river conveys water by constantly flowing perpendicular to the elevation contours, thereby converting the potential energy of the water into kinetic energy. Where a river flows over relatively flat areas, the river will meander, start to form loops and snake through the plain by eroding the riverbanks. Sometimes the river will cut off a loop, shortening the channel and forming an oxbow lake from the cut off section. Rivers that carry large amounts of sediment develop complex deltas at their mouths, with saline tidal waters forming estuaries.

Generally rivers can be categorized into 4 main types:

- *Youthful* river - a river with a steep gradient which has very few tributaries and flows quickly. Its channels erode deeper rather than wider.
- *Mature* river - a river with a gradient that is less steep than those of youthful rivers and flows more slowly than youthful rivers. A mature river is fed by many tributaries and has more discharge than a youthful river. Its channels erode wider rather than deeper.
- *Old* river - a river with a low gradient and low erosive energy. Old rivers are characterized by flood plains.
- *Rejuvenated* river - a river with a gradient that has been raised by tectonic activities.

Where a river descends quickly over sloped topography, rapids with whitewater or even waterfalls occur. Rapids are often used for recreational purposes (*Whitewater rafting and kayaking*), While waterfalls are sometimes used as sources of energy, via watermills and hydroelectric plants. Rivers begin at their source on higher ground, either rising from a spring or flowing from a body of water such as a lake, or from damp, boggy places where the soil is waterlogged. They end at their base level where they flow into a larger body of water, the sea, a lake, or as a tributary to another (usually larger) river. The area drained by a river and its tributaries is called its watershed or catchment basin (Watershed is also used however to mean a boundary between catchment basins).

In the Malaysian legal context*, "river"* is defined as follows:

- Section 2 (Interpretation) of the Water Act 1920 (Revised 1989) (Applicable to the States of Negeri Sembilan, Pahang, Perak, Malacca, Penang and the Federal Territory) or similar Water Enactments (for other Peninsular States):
  "*River*" includes (a) a tributary of a river and any other stream or natural water course; and (b) any canal declared by the State Authority of the State in which such canal is situated by notification in the Gazette to be subject to this Act. In some cases, [e.g. Section 7A(2)], "river" is deemed to further include any inland waters, any subterranean water resources or any water in an estuary or sea adjacent to the coast.
- Section 5 (Interpretation) of the National Land code**:**
  "*River*" means any river, stream, creek or other natural watercourse, and any tributary, distributary or artificial deviation thereof.
- For states with their individual water resources / river enactments, the definitions are also fairly similar to that of the Water Act 1920. These include Selangor (Selangor Waters Management Authority Enactment 1999), Sabah (Sabah Water Resources Enactment 1998) and Sarawak (Sarawak Rivers Ordinance 1993).

Rivers assume a special significance ecologically, economically, socially and culturally in Malaysia. Currently there is increasing competition for use of surface waters, within and between consumptive and environmental uses. At the same time, there is also abundant evidence that many Malaysian rivers are in poor condition, and their condition continues to deteriorate.

1.1.3 Uses of Rivers

Rivers have been used as a source of water, for food, for transport, as a defensive barrier and as a source of power to drive machinery. For thousands of years rivers have been used for navigation.

Riverine navigation provides the cheapest means of transport and is still used extensively in Sarawak and Sabah. In the forest logging areas, timber loggers use the river to float felled trees downstream to lumber camps for further processing, saving much effort and cost by transporting the huge heavy logs by natural means. Rivers have been a source of food since pre-history. Apart from being a rich source of fish, prawns, shells and crabs, rivers indirectly aid cultivation by supplying water for crops. Rivers sustain their own food chain. They are a major source of fresh water; hence, it is no surprise to find most of the major towns and cities situated on the banks of rivers. Unfortunately. rivers readily provide an easy means of waste disposal and a source of gravel and sand generated and moved by rivers and used for construction. Rivers should be enjoyed not for their capacity for waste disposal, but rather for the beauty of rivers and their surroundings, which contributes to recreation as well as tourist income.

1.1.4 History

From being gateways to early settlement and having first served as the main means of communication and transport, rivers in Malaysia have gradually taken on other important roles. Many rivers have been agents of rich tin deposits found in flood plains and valleys. This had given rise to the development of the tin industry since the late 1800's, making Malaysia, until the 1980's, the world's largest tin producer.

The early settlers along rivers certainly had ready water supply from the rivers and efficient river transportation system. In the early 1800's, rivers began to support systematic water supply development when water treatment plants were built in all the major towns. Today, about 97% of the total water supply comes from rivers. In the early 1900's, rivers started to provide irrigation water for large-scale rice cultivation. The introduction of double cropping in a number of granary areas in the 1960's, further raised the importance of rivers in the rice cultivation industry. In 1930, the first major hydropower station was constructed at Chenderoh on the Perak River. Since then, rivers have continued to support the nation's energy needs as more dams are built.

Apart from the above, Malaysian rivers and their surroundings have continued to play important roles in the everyday life of riverine residents, being a source of sustenance and featuring strongly in their cultures and religious practices. The dimension of rivers as an asset for environmental enhancement and recreations is growing. The natural beauty of rivers, uniqueness of each, together with the attractions of waterfalls, rapids, lakes, swamps and even caves along the rivers, are making rivers a popular destination for nature lovers and the adventurous. The open spaces and waterfronts afforded by rivers are making rivers a place choice of leisure activities, and even economic development, adding value to properties.

In the 18th century, plantation activities started with land clearing for the cultivation of coffee and sugarcane. Since the first half of the 19th century until 1970s, large-scale land clearing was carried out for rubber plantation, making the country the largest producer of natural rubber then. More lands were cleared for oil palm plantations since the 1970's. The development of tin mining, rubber and oil palm plantations as well as urban development had triggered river erosion and sedimentation. With the advancement of land and air transportation, river transportation quickly declined, while the condition of rivers deteriorated rapidly due to large increase in surface runoff and river sedimentation. As a result, floods become more frequent.

Until the 19th century, floods were mainly caused by heavy downpour during the northeast monsoon season in the east coast states of Peninsular Malaysia. One example of such flooding, a massive one was reported to have occurred in 1886 in the Kelantan and Besut river basins. After the 20th century, the frequency of flood occurrences and extend of flood damages had increased. Seeing an urgent need for river conservancy (river training) to tackle the problem, the Government established the Hydraulic Branch of the Federal Public Works Department in 1921.

In 1926, Malaysia experienced the biggest flood (affecting almost all the States in Peninsular Malaysia) in modern history. This natural disaster became the turning point, where the Hydraulic Branch was strengthened and large budgets were allocated. During the 1927 to 1932 period, the Hydraulic Branch had launched flood control projects in 5 major cities/towns of Kuala Lumpur, Ipoh, Seremban, Tanjong Malim and Bentong. Rivers were realigned, deepened, straightened and widened and sedimentation and flood storage dams were constructed.

Following the slump in the tin and rubber industries and the worsening rice situation in the country in the late 1920's, the then British High Commissioner had on the 1st January 1932 established the Drainage and Irrigation Department (changed to Department of Irrigation and Drainage in 1993), which also absorbed the Hydraulics Branch of the Public Works Department. Besides carryout out the construction, operation and maintenance of irrigation and drainage works for rice cultivation, the new Department was also tasked with hydrological and river conservancy works.

The disastrous national flood in 1970/71 shown in Figure 1.2 awakened the nation and brought about a wider and broader focus and attention in the field of water resources (river) management. Thus, immediately in 1972, flood mitigation became an additional task for the Department (authorized through the "Ministerial Functions Act). The Permanent Flood Commission (refer to Flood Mitigation Manual) was also established in the same year. Figure 1.3 shows the extend of flooding experienced in Kuala Kangsar, the royal town of Perak State, in 1967.

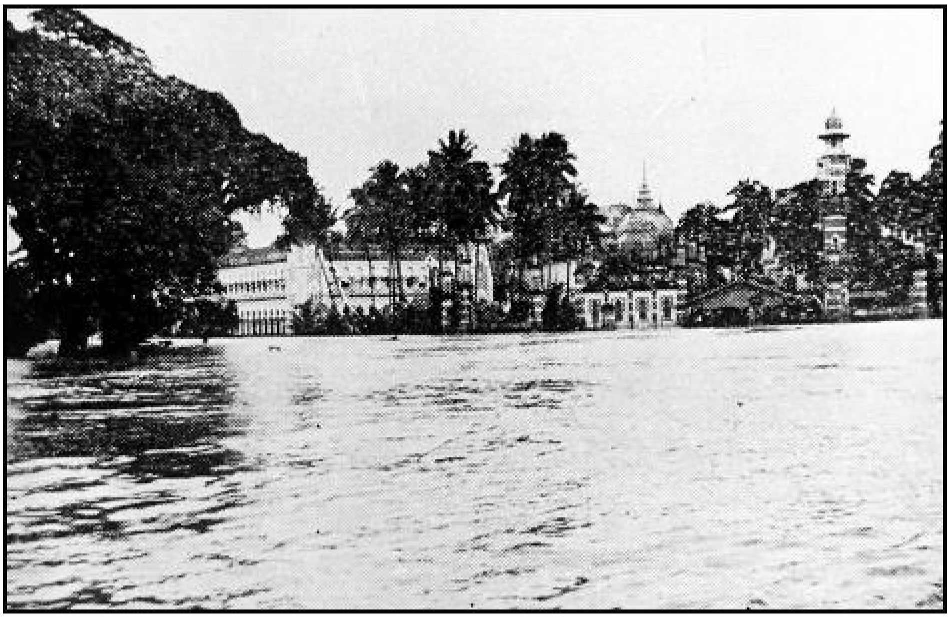

Figure 1.2 1971 Flooding at Masjid Jamek, Kuala Lumpur

In line with the international trend and national need, DID started to move towards Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) with the establishment of the River Management Unit under the River Engineering Branch in 1990. The vision then was well illustrated by a paper entitled "The River Towards 2020". Various new river management programs and activities were introduced and implemented. These include IWRM/IRBM studies, public awareness programs (Kempen Cintailah Sungai Kita), river corridor/riparian development, establishment of river basin information system and guidelines, rivers rehabilitation programs, etc. This Unit subsequently develops into the River Management Division today.

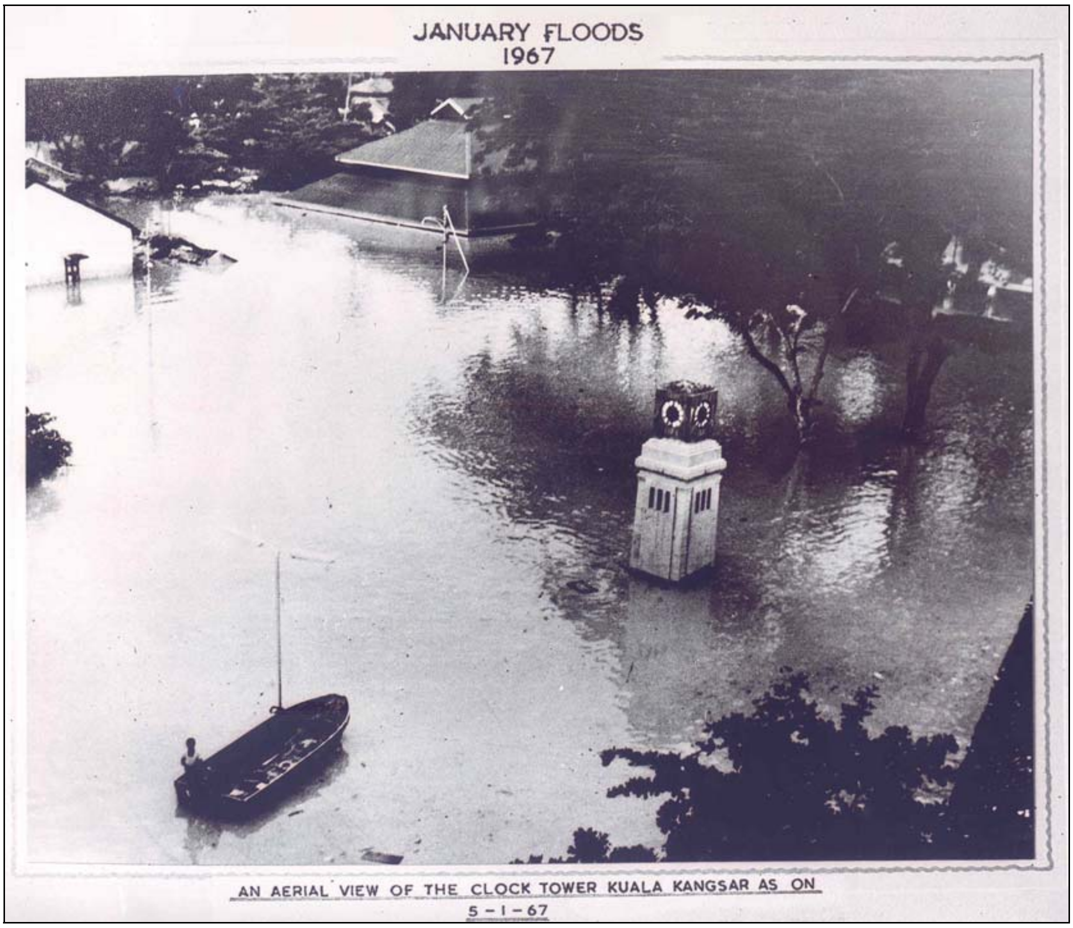

Figure 1.3 1967 Flooding at Clock Tower, Kuala Kangsar

The nationwide drought of 1997 resulted in the establishment of the National Water Resources Council. Though established administratively, the Council is the highest coordinating body on water resources management in the country (For more details, refer to Section 1.3.2.6).

The government's commitment towards IWRM was further strengthened in March 2004 with the re-organisation of former agencies related to water resources into four (4) main ministries, namely, the Ministry of Natural Resources and Environment (NRE), the Ministry of Energy, Water and Communications (MEWC), the Ministry of Agriculture and Agro-based Industry (MOAAI) and the Ministry of Housing and Local Government (MOHLG). With this new set-up, there is:

- Separation of utility (MEWC and MOAAI) and regulatory (NRE and MOHLG) roles of the water resources sector;
- Facilitation of private sector involvement in the water utility sector;
- Bringing together of major natural resource-based agencies (land, water and forest) and environmental agencies under one ministry to facilitate and ensure that all natural resources are managed holistically.

Since its establishment, the River Management Unit under the River Engineering Division has evolved into the River Management Division of today. Its vision is "Clean, Living and Vibrant Rivers" while the main missions include:

- Integrated River Basin Management base on "one river basin – one planning – one management"; and
- Effective river conservancy and rehabilitation works, of world class standard, to ensure river functions as water conveyance and storage, protection against riverbank erosion, scour, sedimentation, and pollution

The States also started to take the relevant steps towards IWRM by enacting integrated river management legislations and establishing relevant agencies. These include:

- Sarawak Rivers Board 1993
- Sabah Water Resources Enactment 1998
- Selangor Waters Management Authority Enactment 1999
- Malacca River and Coastal Development Corporation Enactment 2005
- Water Resources Enactment 2007 (Pahang)

1.2 PROBLEMS AND ISSUES IN RIVER MANAGEMENT

A nation-wide need assessment on IWRM carried out (2005) during the Study on "Effective Implementation of Integrated Water Resources Management in Malaysia" [2] indicated that, across the board, respondents ranked water-related issue as the highest amongst nine issues that were listed, in terms of urgency to be solved. The ranking of the issues listed is presented in Figure 1.4. Although the ranking were fairly evenly distributed, overall, *water related issu*es appeared to be in the top-rank.

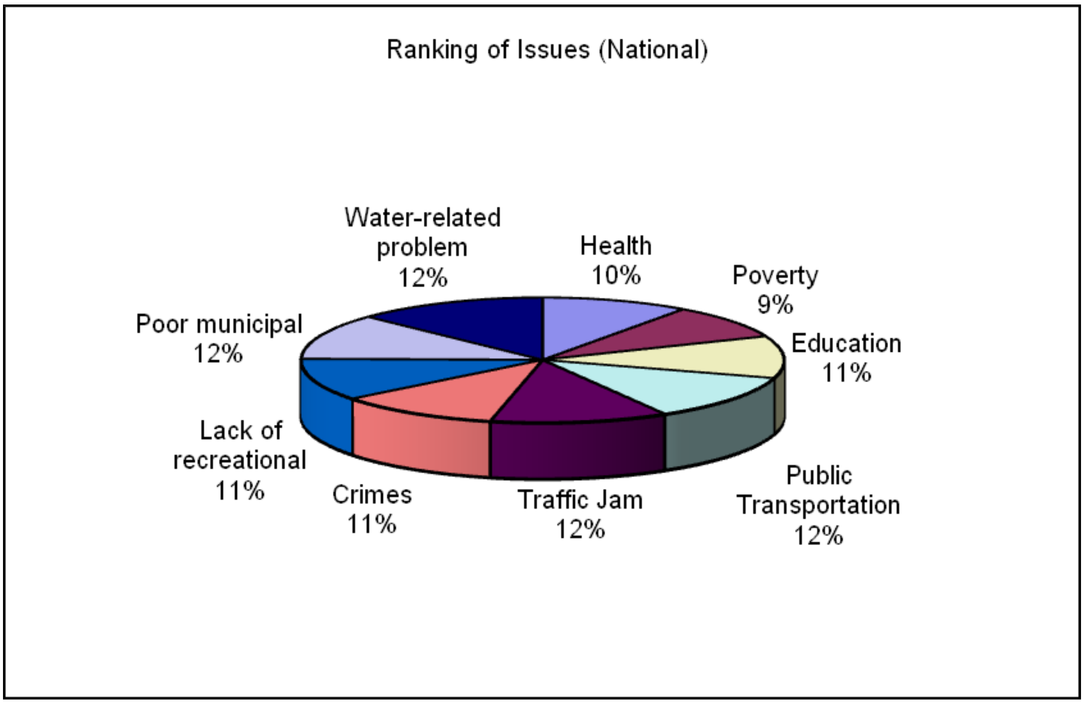

Figure 1.4 Ranking of National Issues (2007)

As to whether the various water sectors have played sufficient roles, the respondents' perception is as indicated in Figure 1.5.

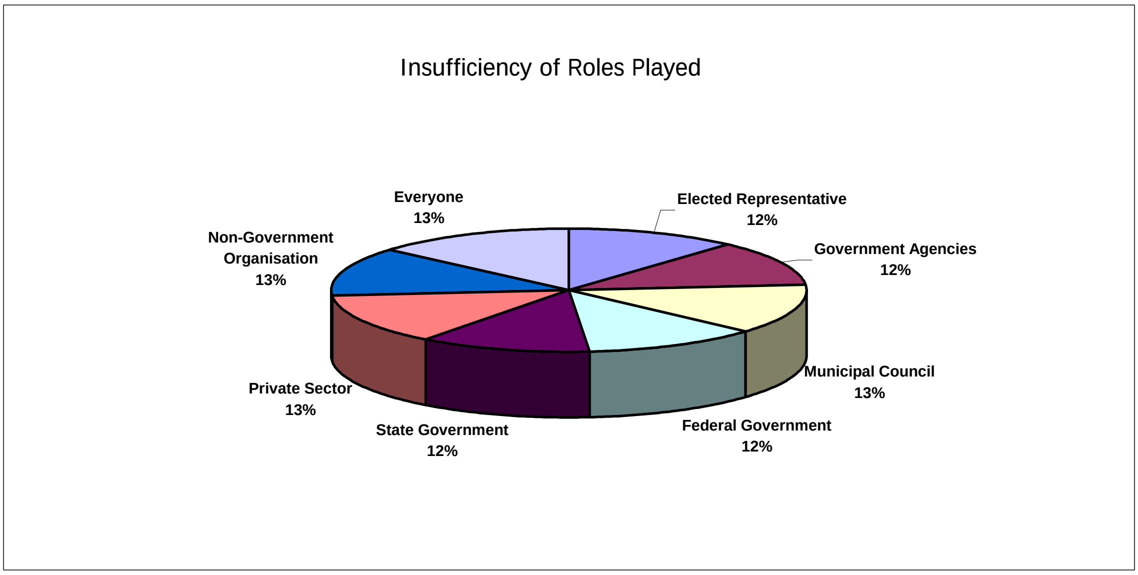

Figure 1.5 Insufficiency of Roles Played (2007)

When questioned about which aspect of the water-related issues is most urgently in need of addressing, the priority as ranked by the respondents is shown in the Table 1.1 below:

Table 1.1 Water-Related Issues

Ranking	Water-Related Issues
1	River Water Quality
2	Catchment/ Landuse Management
3	Flooding
4	Potable Water Supply
5	Institutional Arrangement
6	Segmented Management
7	River Corridor Management
8	Wetlands Management
9	Water Borne Diseases
10	Biodiversity
11	Drought
12	Environmental Flow

1.3 LEGISLATIONS AND INSTITUTIONS

Tables 1.2 and 1.3 present Water Resources/ River Management Legislations for Malaysia.

1.3.1 Relevant Legislations

The following sub-sections outline the various river management issues and the relevant legislation associated with them.

Table 1.2 Water Resources / River Management Legislations Matrix

No.	Relevant Legislative	A Federal / State Function	B River Conservancy & Property Protection	C Water Quality Management	D River Corridor & Reserve	E River Water Use and Abstraction	F River Space Occupation	G Urban Drainage
1	Federal Constitution, 1957 (Revised 1963)	✓						
2	Water Act, 1920 (Revised 1989)		✓	✓	✓	✓		
3	Ministerial Functions Act 1969		✓					
4	Environmental Quality Act 1974 (Revised 1984)			✓				
5	National Forestry Act 1984 (Revised)			✓				
6	Land Conservation Act 1960			✓				
7	Protection of Wildlife Act 1972			✓				
8	National Parks Act 1980			✓				
9	Land Acquisition Act 1960				✓			
10	Fishery Act 1963 (Revised 1985)			✓		✓		
11	National Land Code 1965 (Revised)		✓		✓			
12	Town & Country Planning Act 1976 (Revised)				✓			
13	Pig Rearing Control Enactments			✓				
14	Suruhanjaya Perkhidmatan Air Negara Act 2006					✓		
15	Water Services Industry Act 2006			✓		✓		
16	Irrigation Area Ordinance 1953 (Revised 1989)			✓		✓		
17	Drainage Works Ordinance 1954 (Revised 1989)					✓		
18	Mining Enactment			✓		✓		
19	Merchant Shipping Ordinance 1952 (Revised 1984)						✓	
20	Road Traffic Act 1987						✓	
21	Federal Road Act 1959 (Revised 1989)						✓	
22	Railway Act 1991						✓	
23	Local Government Act 1976			✓				✓
24	Street, Drainage and Building Act 1974			✓				✓
25	Earthwork Bylaw			✓		✓		
26	Mineral Development Act 1994			✓		✓		
27	Electricity Supply Act 1990			✓		✓		
28	Sabah Water Resources Enactment 1998	✓	✓	✓	✓	✓	✓	
29	Sarawak Rivers Ordinance 1993	✓	✓	✓	✓	✓	✓	
30	Selangor Waters Management Authority Enactment 1999	✓	✓	✓	✓	✓	✓	
31	Malacca River and Coastal Development Corporation Enactment 2005	✓	✓		✓			
32	Water Resources Enactment 2007 (Pahang)	✓	✓	✓	✓	✓	✓	

Table 1.3 Water Resources / River Management Agencies / Authorities

No.	Relevant Legislations	A	B	C
		Federal / State	Authority / Agencies	Remarks
1	Federal Constitution 1957	F		
2	Water Act 1920	S	State Authority – District Office, DID provide technical advice	N.Sembilan, Pahang, Perak, Melaka, Penang & F.Territory
3	Ministerial Functions Act 1969	F		
4	Environmental Quality Act 1974	F	Dept. of Environment	Except Sarawak & Sabah
5	National Forestry Act 1984	S	Dept. of Forestry	
6	Land Conservation Act 1960	S	State Authority – Land Administrator	
7	Protection of Wildlife Act 1972	F	Dept. of Wildlife & National Park	Concurrent List
8	National Parks Act 1980	F	Dept. of Wildlife & National Park	Concurrent List
9	Land Acquisition Act 1960	S	State Authority – Land Administrator	
10	Fishery Act 1985	F	Dept. of Fishery	Maritime & Estuary
11	National Land Code, 1965 (Revised)	S	State Authority – Land Administrator, Land Office	
12	Town & Country Planning Act 1976	S	State Authority – Dept. of Town & Country Planning & Local Authority	Concurrent List
13	Pig Rearing Control Enactments	S	Dept. of Veterinary Services / Local Authorities	
14	Suruhanjaya Perkhidmatan Air Negara Act 2006	F	Suruhanjaya Perkhidmatan Air	Peninsular & FT
15	Water Services Industry Act 2006	F	Suruhanjaya Perkhidmatan Air - KTAT	Peninsular & FT
16	Irrigation Area Ordinance 1953	C	State Authority – DID State & Districts	Concurrent List
17	Drainage Works Ordinance 1954	C	State Authority – DID State & Districts	Concurrent List
18	Mining Enactment	S	State Authority – Land & Mines Dept.	
19	Merchant Shipping Ordinance 1952	F	Ministry of Transport – Marine Department	
20	Road Traffic Act 1987	F	Ministry of Transport – Road Transport Department	
21	Federal Road Act 1959	F	Ministry of Works – Department of Public Works	
22	Railway Act 1991	F	Ministry of Transport – Department of Railway	
23	Local Government Act 1976	S	State Authority – Local Authority	Peninsular Malaysia
24	Street, Drainage and Building Act 1974	S	State Authority – Local Authority	Peninsular Malaysia
25	Earthwork Bylaw	S	Local Authority	
26	Mineral Development Act 1994	S	State Authority – Land & Mines Department	
27	Electricity Supply Act 1990	F	Director General of Electricity Supply, Ministry of Energy, Water & Communication	Whole Country
28	Sabah Water Resources Enactment 1998	S	Sabah Water Resources Director (DID)	Current Arrangement
29	Sarawak Rivers Ordinance 1993	S	Sarawak River Board	Single Authority
30	Selangor Waters Management Authority Enactment 1999	S	Lembaga Urus Air Selangor	Single Authority
31	Malacca River and Coastal Development Corporation Enactment 2005	S	Malacca River and Coastal Development Corporation	Coordination Body
32	Water Resources Enactment 2007 (Pahang)	S	Badan Kawal Selia Air (Pahang)	Single Authority

Note : S = State F = Federal C = Concurrent

1.3.1.1 Federal and State Functions

a) Federal Constitution 1957 (Revised 1963)

- *9Th Schedule, Item 6 of State List*: (State works and water) (c) Subject to the Federal List, water (including rivers and canals but excluding water supplies and services); control of silt, riparian rights. [This means State Authority has absolute ownership and power of rivers (wholly within one State) and canals.]
- *9th Schedule, Item 11 of Federal List*: (Federal Works and power, including) (b) Water supplies, rivers and canals, except those wholly within one State or regulated by an agreement between all the States concerned (This applies to river or rivers shared by more than 1 State.); production, distribution and supply of water power.
- *9th Schedule of the Concurrent List: Item 5* (Town and Country Planning), *Item 8* (drainage and Irrigation), *Item 9* (Rehabilitation of mining land and land which has suffered soil erosion), *Item 9D* (Water supplies and services)

b) Street, Drainage and Building Act 1974

An Act to amend and consolidate the laws relating to street, drainage and building in local authority areas in West Malaysia, and for purposes connected therewith.

- *Part III Drains - Section 50 (Local authority to construct and maintain drains and water courses)* (1) Local authority may cause to be made and constructed and maintained surface and storm water drains, culverts, gutters and water courses.

1.3.1.2 River Conservancy and Property Protection

a) Waters Act, 1920 (Revised 1989)

This Federal Act was adopted and applicable to the States of Negeri Sembilan, Perak, Melaka, Pulau Pinang and the Federal Territory. This is an Act to provide for the control of rivers and streams. The Act is enforceable by the State Authority (District Officer or District Land Office usually with the advice of DID).

- *Section 2 (Interpretation)* requires that "*river*" includes (a) a tributary of a river and any other stream or natural water course; and (b) any canal declared by the State Authority of the State in which such canal is situated by notification in the Gazette to be subject to this Act. (DID can propose and submit request for gazetting)
- *Section 3 (Property in Rivers)* Subject to the terms of any express grant made by or on behalf of the Ruler of a State, the entire property in and control of all rivers in any State is and shall be vested solely in the Ruler of such State; provided that in the case of lands held by the Government under grant or lease or reserved for a public purpose (refer to National Land Code) and maintained by a Government Department, such control may be exercised by the Head of such Department, under the direction of the State Authority.
- *Section 5 (1) (Prohibition of acts affecting rivers)* No person shall, except under license, fell any tree so that it falls into a river; in any manner obstruct or interfere with any river; or build any bridge, jetty or landing stage, over or beside any river at a point where the width of such river exceeds 20 feet (enforceable by District Officer).
- *Section 14 (1) (Restriction on construction of walls and buildings on banks of rivers or within flood channels)* Save as may be expressly authorized under the provisions of any other law no person shall in any State erect or build any wall or construct any revetment along the bank on any river or erect any building or structures within fifty feet of any such bank, or within any flood channel declared under this section, except under and in accordance with the terms and condition of a written permission from the State Authority; any such permission may be subject to such conditions and restrictions imposed by the State Authority.
- *Section 14 (2) (Flood Channel)* Where the State Authority is satisfied that the bed of any such river in such State is insufficient to contain the waters thereof in time of such floods as may be reasonably expected, he may by notification in the Gazette declare any land abutting on such

river and extending to such a distance from either or both banks as may be specified in such notification to be a flood channel for such river.

b) National Land Code (Act 56 of 1965)

This Act is applicable only to the States of Malaya to consolidate the laws relating to land and land tenure, the registration of title to land and of dealings therewith and the collection of revenue therefrom. The Act is enforceable by the State Authority (through the State Director of Land and Mines, Land Administrators and District Land Office)

- *Section 5 (Interpretation)* states that "river" means any river, stream, creek or other natural watercourse, and any tributary, distributary or artificial deviation thereof.
- *Section 13 (Delegation of powers of State Authority to State Directors, etc.)*

(1) The State Authority may by notification in the Gazette delegate to the State Director (of Lands and Mines), or to the Registrar, or to any Land Administrator other officer pointed under Subsection (1) of Section 12, the exercise or performance (subject to such conditions and restrictions as may be prescribed in the notification of any powers or duties conferred or imposed on the State Authority by or under this Act.
(2) Provided that… (ii) this Section shall not apply to any power of the State Authority under this Act to make rules: (a) within 50 metres of any such river (includes a reservoir of water resulting from the damming of a river) as may be declared by the State Authority by notification in the Gazette; (b) within 50 metres of any such lake or spring as may be declared by the State Authority by notification in the Gazette, with the edge of any such lake or spring to be delineated therein.

This means only the State Authority has the power to dispose of any land within 50 m of the bank of any such river or from edge of any such lake or spring as may be declared by the State Authority by notification in the Gazette. Such power could not be delegated down to the State Director of Land and Minds, or the Land Registrar.

c) Ministerial Functions Act 1969

This Act makes provisions for declaring the functions and transfer of functions of Ministers, for declaring the styles and titles of Ministers, and for incidental and connected purposes. DID's roles in river conservation (Pemeliharaan Sungai)/ management, flood mitigation (Tebatan Banjir), hydrology and Coastal Engineering were assigned via this Act.

1.3.1.3 Water Quality Management

a) Water Act, 1920 (Revised 1989)

This is an Act to provide for the control of rivers and streams.

- *Section 7A (Prohibition of pollution to rivers)* (For this purpose, "rivers" shall also include any inland waters, any subterranean water resources and any water in an estuary or sea adjacent to the coast of the State). Save as may be expressly authorized under any written law or the terms of any express grant made by the State Authority, no person unless under license, cause to enter or discharge into the river (a) any poisonous, noxious or polluting matter that will render or likely to render or contribute to rendering such river or part thereof harmful or detrimental or injurious to public health, safety or welfare, or to animal or vegetable life or health or to other beneficial uses of such river; (b) any matter which by virtue of its temperature, chemical or biological content or its effect in discolouring the water makes or contributes to making such river or part thereof a potential danger to public health, safety or welfare or to animal or vegetable life or health or to other beneficial uses of such river; (c) any matter by virtue of its physical nature, or its effect in discolouring waters, makes or contributes to making such water, difficult to treat; or (d) oil of any nature, used, waste or otherwise. License to enter or discharge into a river may be granted by the State Secretary. Every license granted shall set out the purpose for which the same is granted and shall be for such period and such conditions and restrictions as may be laid down in the license.

b) *Environmental Quality Act 1974 (Revised 1984)*

This Act relating to the prevention, abatement, control of pollution and enhancement of the environment, and for purposes connected therewith. This Act is enforceable by the Department of Environment.

- *Section 11 Licences (prescribed activities, premises)*
- *Section 12 Power to attach conditions to licenses*
- *Section 21 Power to specify conditions of emission, discharge, etc*
- *Section 24 Restrictions on pollution of the soil*
- *Section 25 Restrictions on pollution of Inland waters.* "Inland Waters" means any reservoir, pond, lake, river, stream, canal, drain, spring or well, or ant part of the sea above the low water line along the coast, or any other body of natural or artificial surface or subsurface water). (1) No person shall, unless licensed, emit, discharge or deposit any environmentally hazardous substances, pollutants or wastes into any inland waters in contravention of the acceptable conditions specified under section 21. (2) A person shall be deemed to emit, discharge or deposit waste into inland waters if (a) he places ant wastes in or on any waters or in a place where it may gain access to any waters; (b) he places any waste in a position where it falls, descends, drains, evaporates, is washed, is blown or percolates or is likely to fall, descend, drain, evaporate, or be washed, be blown or percolated into any waters, or knowingly or through his negligence, whether directly or indirectly, causes or permits any wastes to be placed in such a position; or (c) he causes the temperature of the receiving waters to be raised or lowered by more than the prescribed limits.
- *Section 34A Report on impact on environment resulting from prescribed activities* (1) The Minister, after consultation with the Council (Environmental Council), may by order prescribe any activity which may have significant environmental impact as prescribed activity.
- *Section 51 Regulations* (1) In addition to and not in derogation of any of the powers contained in any other provision of this Act, the Minister after consultation with the Council (Environmental Quality Council) may make regulations for or with respect to – (b) prescribing standards or criteria for the implementation of any declared environmental policy or classification for the protection of the environment and for protecting beneficial uses; (e) prescribing ambient water quality standards and discharge standards and specifying the maximum permissible loads that may be discharged by any source into inland waters, with reference either generally or specifically to the body of waters concerned; (k) prohibiting or regulating bathing, swimming, boating or other aquatic activity in or around any waters that may be detrimental to health or welfare or for preventing pollution.
- *Environmental Quality (Prescribed Premises)(Crude Palm Oil) Regulations, 1977* This Regulation was enacted under Section 51 of the Environmental Quality Act to set and regulate the allowable quantity and quality of effluent discharges of palm oil factories.
- *Environmental Quality (Prescribed Premises)(Raw Natural Rubber) Regulations, 1978* This Regulation was enacted under Section 51 of the Environmental Quality Act to set and regulate the allowable quantity and quality of effluent discharges of raw natural rubber factories.
- *Environmental Quality (Sewage and Industrial Effluents) Regulations, 1978* This Regulation was enacted under Section 51 of the Environmental Quality Act to set and regulate the allowable quantity and quality of effluent discharges of sewage and industrial effluents (Allowable effluent discharge Standard A and Standard B).
- *Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order, 1987* (Not applicable to Sabah and Sarawak which have their own sets of regulations) This Order was enacted under Section 34A of the Environmental Quality Act to specify prescribed activities requiring to carry out Environmental Impact Assessment.
- *Environmental Quality (Schedules Wastes) Regulations, 1989*
- *Environmental Quality (Prescribed Premises) Order 1989: (Scheduled Wastes Treatment and Disposal Facilities), (Crude Palm Oil), (Raw Natural Rubber)*
- *Environmental Quality (Prohibition on the use of controlled Substance in soap, synthetic detergent and other cleaning Agents) Order 1995*

c) *National Forestry Act 1984 (Revised)*

This Act provides for the administration, management and conservation of forests and forestry development within the States of Malaysia (similar Sabah Forest Enactment 1992 and Sarawak Forest Ordinance 1954). The Act is enforceable by the State Authority (Forestry Department)

- *Section 10 (Classification of Permanent Reserved Forests)* the Director, with the approval of the State Authority, shall by notification in the Gazette, classify every permanent reserved forest under one or more of classifications which shall be descriptive of the purpose or purposes for which the land is being or intended to be used: (b) soil protection forest; (c) soil reclamation forest; (d) flood control forest; and (e) water catchment forest.
- *First Schedule, Item 13* The Licensee shall clear the boundaries of the license area to the satisfaction of the district Forest Officer and at all time keep them clean and free from obstruction and shall immediately remove any obstruction resulting from or … to any road or path made or maintained by the Forestry Department, or to any watercourse in or adjacent to the license area.
- *First Schedule, Item 15* (a) The licensee shall not construct any new extraction road or tramway, nor remove … without the permission in writing of the District Forestry Officer. (b) In order to minimize the danger of erosion, the drainage of all extraction lines constructed by the licensee shall be carried out and maintained in accordance with the instructions of the District Forestry Officer who may at any time close the extraction line until the necessary works have been carried out.

d) Land Conservation Act 1960

An Act relating to the conservation of hill land and the protection of soil from erosion and the inroad of silt. The Act shall not come into operation in any State until it has been adopted by a law made by the State Legislature pursuant to clause (3) of Article 76 of the Constitution. The Act is enforceable by the State Authority (Land Administrator).

Part II (Control of Hill Land)

- *Section 3 (Declaration of Hill Land)* The Ruler in Council or the Yang di-Pertua in Council of a State may, by notification in the Gazette, declare any area or class or description of land in the State to be hill land for the purpose of this Act.
- *Section5 (Prohibition of short-term crops except under permit)* No person shall plant any hill land with short-term crops. Provided that the Land Administrator may issue an annual permit to plant specified short-term crops to any applicant who satisfies him that such cultivation will nor cause appreciable soil erosion, and in such permit may prescribe the area of the land and the terms and conditions under which such cultivation is permitted.
- *Section 6 (Restriction on clearing and cultivation of hill land)* (1) No person shall clear any hill land or interfere with, destroy or remove any trees, plants, undergrowth, weeds, grass or vegetation on or from any hill land, provided that it shall be lawful for the Land Administrator, on the application of the owner or occupier of any hill land, to authorise by permit in writing under his hand, subject to such terms and conditions and to such extend and in such manner as may be specified in such permit – (a) the clearing of such hill land fore the purpose of cultivation; (b) the clearing or weeding of such hill land under lawful cultivation.
- *Section 8 (Acquisition of Hill Land)* Whenever it appears desirable to the Ruler in Council or the Yang di-Pertua Negeri in Council, as the case may be, to acquire any hill land for the purpose of preventing soil erosion it shall be lawful for the Ruler in Council or the Yang di-Pertua Negeri in Council to direct that such hill land be acquired either by private treaty or under the Land Acquisition Act; and for purpose of that Act the land to be acquired shall be deemed to be acquired for a public purpose.

e) Fishery Act 1963 (Revised 1985)

This Act relates to fisheries, including the conservation, management and development of maritime and estuarine fishing and fisheries, in Malaysian fisheries waters, to turtles and riverine fishing in Malaysia and to matters connected therewith or incidental thereto.

- *Section 26 (Fishing with explosives, poisons, etc.)* 1(a) any person who uses or attempts to use any explosive, poison or pollutant, or any apparatus utilizing an electric current, or any prohibited gear, for the purpose of killing, stunning, disabling or catching fish… shall be guilty of an offence under this Act.
- *Section 38 (Power of State Authority and Minister to Make Rules Concerning Inland Fisheries)* The State Authority or, in respect of the FT of Kuala Lumpur and Labuan, the Minister may make rules specifically or generally for the proper conservation, development, management and regulation of turtles and inland fisheries in any State in Malaysia or in FT KL and Labuan, as the case may be, and may, in particular, make rules for all or any of the following purposes: (k) for the purpose of the conservation of fish in riverine waters, to regulate and control the construction of any slides, dams or other constructions, or the removal of sand or gravel or other alteration to the natural environment or habitat of fish.

f) Rearing of Animals Enactments

The control and regulation of animals farming including pig rearing comes under the jurisdiction of the state authority. Most states have their own sets of enactments. The current status is shown in Table 1.4 below:

Table 1.4 Acts Related to Control of Pig Farming

STATES	AGENCY	ACT/ ENACTMENT
Johor	State Dept. of Veterinary Services	Rearing of Pigs Enactment (No. 5) 1975 Control and Licensing of Poultry Farming Enactment 1997
Melaka	State Dept. of Veterinary Services	Rearing of Pigs Enactment (No. 3) 1980
N. Sembilan	State Dept. of Veterinary Services	Pig Rearing Enactment (No. 9) 1980 Control and Licensing of Poultry Farming and Poultry Related Activities Enactment
Selangor	State Dept. of Veterinary Services	Control of Pig Farming Enactment 1991 Control of Cattle Enactment 1971
Perak	State Dept. of Veterinary Services	Control of Pig Farming Enactment, 1992 Cattle Registration Enactment 1981 Poultry Farming Enactment 2005
Kedah	State Dept. of Veterinary Services	Cattle Registration Enactment 1990
Perlis	State Dept. of Veterinary Services	Rearing of Pigs Enactment (No. 7), 1987 Cattle Registration Enactment 1966
Terengganu	State Dept. of Veterinary Services	Rearing of Pigs Enactment, 1976 Registration of Cattle Enactment 1995
Kelantan	State Dept. of Veterinary Services	Cattle Enactment 1968 Poultry Farming enactment 2005
Pulau Pinang	Local Councils: Majlis Perbandaran Pulau Pinang Majlis Perbandaran Seberang Perai	Keeping of Pigs By-Law, 1987 Keeping of Pigs By-Laws (Central) 1965 Piggeris By-Laws (South) 1957 License Fees By-Laws 1980
Pahang		Control of Rearing of Pigs enactment 1998 Control of Cattle Enactment 2001 Poultry Farming Enactment 2005
F. Territory		Nil
Malaysia	Dept. of Environment	Environmental Quality Act 1974 (General)

g) Water Services Industry Act (Akta Industri Perkhidmatan Air) 2006

This Act provides for and regulate water supply services and sewerage services and for matters incidental thereof. The Act is applicable throughout Peninsular Malaysia and the Federal Territories of Putrajaya and Labuan. The Act is to be enforceable by the Suruhanjaya Perkhidmatan Air Negara.

- *Section 121 (Offence of Contamination of Water)* (1) A person who contaminates or causes to contaminate any watercourse (includes rivers, streams and creek including any tributary, distributary or artificial deviation thereof, seas, lakes, ground water, dams, reservoirs, ditches, drains and passages, other than pipes, through which water flows for the supply of water to any premises) or the water supply system or any part of the water course or water supply system with any substance (a) with the intention to cause death, (b) with the knowledge that he is likely to cause death, or (c) which would likely endanger the life of any person.

h) Irrigation Area Acts 1953

This Act relates to the establishment and regulation of irrigation areas in Malaysia.

- *Section 23 (Pollution of water)* any person who bathes or washes articles in or otherwise pollutes or causes to be polluted any irrigation tank, channel or water-course shall be liable to imprisonment for a term not exceeding three months or to a fine not exceeding one hundred and fifty ringgit or both. Provided that the appropriate authority may, by order notified in the Gazette, declare that this section shall not apply in any irrigation area specified in such order.

i) Local Government Act 1976

An Act to revise and consolidate the laws relating to local government. The Act is enforceable by local (state) governments.

PART VIII Pollution of Streams

- *Section 69 (Committing nuisance in streams, etc.)* Any person who commits a nuisance or deposits any filth in or upon the bank of any stream, channel, public drain or other watercourse within the local authority area shall be guilty of an offence.
- *Section 70 (Pollution of streams with trade refuse, etc.)* Any person who, within or without the limits of a local authority area (a) puts or causes to be put or to fall or to flow or to be carried into any stream, so as either singly or in combination with other acts of the same or any other person to interfere with its due flow or to pollute its waters, the solid or liquid refuse of any manufactory, manufacturing process or quarry or any rubbish or cinders or any other waste or any putrid matter' (b) cause to fall or flow or knowingly permits to flow or to be carried into any stream any solid or liquid sewage matter, or (c) uses, for the purpose of carrying on any laundry trade, any stream, channel, public drain or other water course or pool, pond or tank' shall be guilty of an offence.
- *Section 71 (Local authority may recover for work done)* (1) Where any expenses are incurred by the local authority in carrying out any work as a result of the offences mentioned in sections 69 and 70, the local authority shall certify the cost thereof to the defaulting persons and the certificate pf the local authority shall be conclusive of the sum due.

j) Street, Drainage and Building Act 1974

An Act to amend and consolidate the laws relating to street, drainage and building in local authority areas in West Malaysia, and for purposes connected therewith.

- *Section 47 (Depositing dirt on the streets, etc.)* This section provides for the prohibition of any person to place, deposit or throw any rubbish or things in public place (that eventually may end up in the water courses).
- *Section 55 (Penalty for making unauthorized drains into canal or stream)* (1) Any person who without the prior written permission of the local authority (a) makes or causes to be made any

drain or into any canal or stream under the control of the local authority, (b) closes up or stops or deviates any drains.

- *(Water closets and trade effluents not to communicate with river, etc., without approval)* (2) No water closet or privy shall be allowed to communicate with any river, canal, stream, pond, lake, and sea or with any public surface or stormwater drain without the prior written permission of the local authority. (3) No trade effluent shall be discharged into or allowed to communicate with any river, canal, stream, pond, lake, and sea or with any public surface or stormwater drain without the prior written permission of the local authority responsible for such drain.
- *Section 70A (Earthworks)* All earthworks (includes any act of excavation, levelling, filling with any material, piling, construction of foundations, or felling of trees, on any land, or any other act of dealing or disturbing any land) within the local council areas shall not commence without the council's prior approval. (17) The local authority may make by-laws (a) in respect of earthworks (Earthworks Bylaw), (b) to provide for plans and specifications in respect of earthworks, (c) the submission of plans, specifications, particulars, documents and reports relating to earthworks… (For more details, refer to Reference [2]: Urban Stormwater Management Manual for Malaysia - MSMA)

k) Earthwork By-law,

By-law enacted under Section 70A (17) (a) of the Street, Drainage and Building Act 1974 (Refer to item i) above.

l) Sewerage Services Act 1993 (Act 508)

An Act to amend and consolidate the laws relating to sewerage systems and sewerage services throughout Malaysia for the purpose of improving sanitation and the environment and promoting public health; and to provide for matters connected therewith and incidental thereto. The Act is enforceable by the Department of Sewerage Services under the Ministry of Housing and Local Government.

- *Section 9 (d)* The Director General of Sewerage Services has the powers and functions to set standards and specifications and to prescribe codes of practice for the planning, design, construction, installation, commission and maintenance of sewerage systems.

m) Mineral Development Act 1994 (Act 525)

An Act to provide for the inspection and regulation of the exploration and mining of minerals and mineral ores and for other matters connected therewith. The Act is enforceable by the Department of Minerals and Geoscience.

- *Section 13 (Good and safe practices and environmental standards)* states that "Fossicking, panning, exploration, mining and mineral processing shall be carried out in accordance with good and safe practices and such environmental standards as may be prescribed under this Act and any written law relating to environment.
- *Section 18 (Effluent Water)* specifies that: (1) Any holder of a proprietary mining licence or mining lease or manager who uses water in connection with mining shall take such measures as to ensure that the water so used shall, before it leaves the mine or waste detention area in which it has been used, comply with such water quality standards as may be prescribed and where such standards have not been prescribed such water shall be reasonably free of solid matter and from chemicals and other substances deleterious to human, animals or vegetable life.
- *Section 19 (Erosion)* states that (1) Every person who undertakes fossicking, panning, exploration or mining shall take such measures as are reasonable to prevent or minimise the erosion of the land which is the subject of the mineral tenement and the effects thereof.

1.3.1.4 River Corridor and Reserve

a) National Land Code (Act 56 of 1965)

The National Land Code is enforceable by the State Authority (State Department of Land and Mines, District Land Office and Land Administrators).

- *Section 5 (Interpretation)* notes that the bed of any river comes under “State land” unless it has been declared as “river reserve”.
- *Section 49 (Effect of advance and retreat of sea)* states that where the shoreline or the bed of any river advances so as to encroach on any alienated land, the area affected by the encroachment shall thereupon cease to form part of that land, and shall become State land; but the boundaries of alienated land shall not be affected by any retreat of the shoreline or of the bed of any river (District Land Office).
- *Section 62 (Reservation of Land)* provides for “State land” (including river land) to be “reserve land” by notification in the Gazette for any public purpose. Towards this, the Gazette notification shall (a) describe the reserved land (requiring details of the exact alignment, size and extend – usually require surveyed drawings); (b) describe the purpose for which the land is reserved (river management and maintenance, flood operation, etc.); (c) designate the officer (DID State director) for the time being having the control of the reserved land; (d) conclusive evidence that the land so described is reserved for a public purpose. (Agency to apply through District Land Office)
- *Section 63 (Power to lease reserved land)* The State Authority may, on an application made by the Officer for the time being having the control of any reserved land, or by any other person or body who has first obtained the approval of that Officer, from time to time grant leases of the whole or any part thereof for any period not exceeding 21 years. (Through District Land Office).
- *Section 64 (Revocation of Reservation)* The revocation of any reserved land either as whole or parts thereof shall be published in the Gazette together with details of a time and place at which an enquiry will be held by the State Director (land and mines). The State Authority shall not revoke any reservation until it has considered a report by the State Director covering the enquiry.
- *Section 65 (Power to license temporary occupation of State land and reserved land)* The State Authority may permit the temporary occupation under license of State land (including “river land”) or reserved land not for the time being used for the purposes for which it was reserved. In the case of “river land”, the temporary occupation licenses may be issued by the Land Administrator on behalf of the State Administrator. For reserved land, such licenses may be issued by the Officer (DID State Director) if authorized by the State Authority, or by the Land Administrator with the approval of the Officer.

b) Land Acquisition Act 1960

This Act relates to the acquisition of land, the assessment of compensation to be made on account of such acquisition, and other matters incidental thereto.

- *Section 3 (Acquisition of Land)* The State Authority may acquire any land which is needed (a) for any public purpose;

c) Town and Country Planning Act 1976

This is an Act for the proper control and regulation of town and country planning in Peninsular Malaysia and for purposes connected therewith or ancillary thereto.

- *Section 2A (National Physical Planning Council)* The main functions of the Council are: (i) To promote in the town and country planning as an effective and efficient instrument towards achieving sustainable development in the country; (ii) To advice the governments (Federal and State) on matters relating to town and country planning; (iii) to set national policies and provide direction on matters relating to town and country planning.

- *Section 4 (State Planning Committee and Its Functions)* The functions of this State Planning Committee are: (i) To promote (within the framework of national policy) the conservation, use and development of all lands in the State; (ii) To advice the State government on matters relating to the conservation, use and development of all lands in the State; (iii) To provide directions to any local planning authority.
- *Section 5 (Local Planning Authority – Local Authority)* One of the main functions of the Local Planning Authority is to regulate, control, and plan the development and use of all lands and buildings within its area.
- *Section 6A (Regional Planning Committee)* The Council may establish a regional planning committee for a region, which consists of an area situated in 2 or more States. The main functions of this committee include: (a) to advice and assist the State Planning Committees and local planning authorities within the region pertaining to the development plans appropriate for the region; (b) to establish policies and devise a comprehensive development plan to guide the development of the region; (c) to plan and coordinate the provision of infrastructure and facilities for the region; (d) to establish uniform process and procedures; and (e) to monitor the implementation of standards, guidelines and procedures.
- *Part III (Development Plans – Local or Structural Plan)* Very important for DID to ensure that the requirement (alignment, reserve, policy statements, etc.) for river management, flood mitigation and coastal management are incorporated in the local or structure plans.

d) Water Act 1920 (Revised 1989)

This Act provides for the control of rivers and streams.

- *Section 4 (Restoration of River Banks)* Any person who shall in any State interfere with the bank of any river may by order of the State Authority be required to restore the same to the condition in which it was immediately prior to such interference or to remake the same in such manner as may be specified in such order.

1.3.1.5 River Water Use and Abstraction

a) Water Act 1920 (Revised 1989)

This Act provides for the control of rivers and streams.

- *Section 7 (Prohibition of diversion of water from rivers, except under license)* No person shall, unless under license, by means of any ditch, drain, channel, pipe, or otherwise divert water of any river from its natural course. Licenses to divert water from a river for use in power generation may be granted by the State Authority. Licenses to divert water for private or domestic purposes, rice cultivation and industrial and other purposes, may be granted by the District Officer with the approval of the State Authority. All licenses granted shall set out the purposes and periods granted and subject to such conditions and restrictions as may be stated therein.
- *Section 8. (1) (License to divert water may authorize interference with State Land or alienated land)* A license under this Act to divert may extend to authorizing the licensee to erect, cut or construct and maintain upon or through any State lands or alienated lands specified in that behalf in the license any pump, line of pipes, flume, race, drain, dam or reservoir and, subject to such conditions and restrictions as may be specified in then license, to take and use the water

b) Water Services Industrial Act (Akta Industri Perkhidmatan Air) 2006

This Act provides for and regulates water supply services and sewerage services and for matters incidental thereof. The Act is applicable throughout Peninsular Malaysia and the Federal Territories of Putrajaya and Labuan.

- *Section 3 (Federal Government to have executive authority)* (1) The Federal Government shall have executive authority with respect to all matters relating to water supply systems and water supply services throughout Peninsular Malaysia and the Federal Territories of Putrajaya and Labuan. (2) The Government shall continue to have executive authority with respect to all matters relating to sewerage systems and sewerage services throughout Malaysia.

c) Suruhanjaya Perkhidmatan Air Negara Act 2006

This Act provides for the establishment of the Suruhanjaya Perkhidmatan Air Negara with powers to supervise and regulate water supply services and sewerage services and to enforce the water supply and sewerage services laws and for related matters.

d) Irrigation Areas Act 1953 (Revised 1989)

This Act relates to the establishment and regulation of irrigation areas in Malaysia. (Refer to Irrigation Manual).

e) Drainage Works Act 1954 (Revised 1989)

This Act relates to drainage works, applicable to the States of West Malaysia only.

- *Section 3 (Declaration of drainage areas)* The appropriate authority may by notification in the Gazette declare any land within any area, affected by any drainage works sanctioned or carried out, wholly or in part, by the Government of Malaysia or of any State to be a drainage area, and such notification shall specify the boundary of the drainage area thereby created.
- *Section 11 (Interference with drainage works)* Any person who without having authority from the officer in charge of such drainage work (a) blocks up or obstructs any drainage works or causes any drainage works to be blocked up or obstructed, (b) encroaches on to any drainage work, (c) places any fish trap in any drainage work, (d) breaches or cuts through the banks or sides of any drainage work, (e) opens, closes or otherwise tampers with any sluice, water gate, regulator, pipe, bench mark, water gauge or other work forming park of such drainage work, (f) suffers or permits fruits, leaves, tree trunks or other vegetation to grow across or fall into any drainage work or fails to take adequate steps to prevent the same, or (g) leads any animals, or suffers or permits any animal to stray upon, the banks or sides of any drainage work; is committing an offence under this Act.
- *Section 12 (Construction of unauthorized drains)* any person who shall construct any canal, water course, drain, ditch or pond within any drainage area so as to connect with any drainage works without any previously obtained permission in writing for such construction from the officer in charge of such area shall be liable to imprisonment for 6 months or to a fine of five hundred ringgit or to both.
- *Section 13 (Unauthorised use of vehicles and boats)*
- *Section 14 (Officer-in-charge of a drainage area)* Every drainage area shall be in charge of a Drainage and Irrigation Engineer, or other such officer as the appropriate authority may from time to time appoint, and such Drainage and Irrigation Engineer, or such other officer shall be known, and is referred to in this Act, as the officer in charge of the drainage area.

f) Mineral Development Act 1994

This Act provides for the inspection and regulation of the exploration and mining of minerals and mineral ores and for other matters connected therewith.

- *Section 18 (Effluent Water)* (1) Any holder of a proprietary mining license or mining lease or manager who uses water in connection with mining shall take such measures as to ensure that the water so uses shall, before it leaves the mine or the waste detention area in which it has been used, comply with such water quality standard as may be prescribed and where such standards have not been prescribed such water shall be reasonably free from solid matter and from chemicals and other substances deleterious to human, animal or vegetable life.
- *Section 19 (Erosion)* Every person who undertakes fossicking, panning, exploration or mining shall take such measures as are reasonable to prevent or minimize the erosion of the land which is the subject of the mineral tenement and the effects thereof.

- *Section 20 (Mine Abandonment)* (4) Abandonment mines and waste detention areas shall be made safe in such a manner as may be prescribed.

g) Electricity Supply Act 1990

An Act to provide for the appointment and functions of a Director General of Electricity Supply, the supply of electricity at reasonable prices, the licensing of electrical installation, plant and equipment with respect to matters relating to safety of persons and for purposes connected therewith

- *Section 52 Power to declare sources of water*
  1) The State Authority in any State, may, at the request of the Director General on behalf of any licensee, by order declare any lake, river or waterway or any part thereof to be a source of water for purposes of the licensee as stipulated in the terms and conditions of his license and, in making the declaration, the State Authority may impose such conditions and restrictions as it may deems fit.
  2) Notwithstanding anything contained in any written law, no person shall dam up or otherwise interfere with any such source of water without first, serving on the licensee either personally or by registered post a three month's notice, in such form as may be prescribed, specifying the work he proposes to undertake.

h) Fishery Act 1963 (revised 1985)

An Act relating to fisheries, including the conservation, management and development of maritime and estuarine fishing and fisheries, in Malaysian fisheries waters, to turtles and riverine fishing in Malaysia and to matters connected therewith or incidental thereto.

- *Section 37 (Promotion of Development and Management of Inland Fisheries)* The Fishery Department Director General may, in consultation with the State Authority may promote the development and management of inland fisheries.
- *Section 38 (Power of State Authority and Ministers to Make Rules Concerning Inland fisheries)* The State Authority may make rules: (a) to promote and regulate aquaculture in riverine waters and in particular, provide for the leasing and licensing of lakes, swamps, mining pools and other pools for the cultivation of fish, (b) to provide for the licensing, regulation and management of any particular inland fishery, (c) to provide for the licensing of fishing vessels in use in riverine waters, (d) to regulate or prohibit any method of fishing in riverine waters or the use or possession of certain types of traps or nets, and to prescribe minimum mesh sizes for fishing nets, (e) to regulate or prohibit the erection, maintenance, making and operation of fishing stakes in riverine waters, (g) to prescribe closed seasons for fishing in any designated area, fishing for certain species of fish or fishing using certain methods of fishing in riverine waters, (h) to designate prohibited areas for fishing for all or certain types of fish or fishing using certain methods of fishing in riverine waters. (k) for the purpose of the conservation of fish in riverine waters, to regulate and control the construction of any slides, dams or other obstruction, or the removal of sand or gravel or other alteration to the natural environment of habitat of fish;
- *Section 39 (Development of Aquaculture)* The State Authority may promote the development of aquaculture (inland fisheries).

1.3.1.6 River Space Occupation

The use of river space for various public utilities and services are also covered by the following acts:

- Merchant Shipping Ordinance 1952 (Revised 1984),
- Road Traffic Act 1987,
- Federal Road Act 1959 (Revised 1989),
- Railway Act 1991.

1.3.1.7 Urban Drainage

a) Local Government Act 1976

This is an Act to revise and consolidate the laws relating to local government.

b) Street, Drainage Building Act 1974

This is an Act to amend and consolidate the laws relating to street, drainage and building in local authority areas in West Malaysia, and for purposes connected therewith. Act shall come into force on such date as the Minister may, after consultation with the State Authority by a notification in the Gazette.

c) Part III Drains (refer to Urban Stormwater Manual – MSMA [2]).

1.3.2 Water Resources and River Management Institutions

As the ownership of water resources and rivers come under the jurisdiction of the State governments (except for specific cases), the actual management and implementation responsibilities are vested with the State authorities (departments, agencies and local authorities).

1.3.2.1 National Water Resources and River Management Institutions

a) National Water Resources Council

At the national level, the National Water Resources Council is the highest IWRM institution. The Council was established as a result of the nation-wide (especially in the Klang Valley) drought of 1997. Originally the Ministry of Works (Water Supply Division under the Public Works Department) was the secretariat. With the establishment of the new Ministry of Natural Resources and Environment (NRE) in March 2004, the secretariat has now become a joint secretariat shared by NRE and KTAK. The main functions of the Council are to:

- formulate a National Water Policy;
- facilitate harmonious and synergistic cooperation between Federal and State Governments;
- facilitate development, allocation and management of the national water resources;
- ensure that the development of national water resources is sustainable in terms of quantity and quality; and
- ensure that all environmental requirements are adhered to;
- Assist in the allocation of water resources for various users and decide priorities during emergencies;
- advise State governments on conservation, protection and gazetting of water catchments; and
- collect and collate information on national water resources and water demand.

The Council is chaired by the Honorabl Prime Minister and composed of the following members:

- Deputy Prime Minister,
- Federal Government:
  Minister of Finance,
  Minister of Natural Resources and Environment (NRE), } Joint Secretariate
  Minister of Energy, Water and Communications (KTAK),
  Minister of Works,
  Minister of Agriculture and Agro-based Industry,
  Minister of Housing and Local Government,
  Minister of Plantation Industries and Commodities
- State Governments
  Menteri Besars of Perlis, Kedah, Perak, Selangor, Negeri Sembilan, Johor, Pahang, Terengganu and Kelantan, and
  Chief Ministers of Pulau Pinang, Melaka, Sabah and Sarawak.

b) Permanent Flood Control Commission

Please refer to Flood Mitigation Manual for more details.

c) Federal Ministries Related to Water Resources after Establishment of the Ministry of Natural Resources and Environment (NRE) and the Ministry of Energy, Water and Communications (KTAK), March 2004. (Separation of Regulatory and Utility Roles),

The separation of Regulatory and Utility functions in water resources management and development became a reality in Malaysia with the establishment of the Ministry of Natural Resources and Environment (NRE) (Kementerian Sumber Asli dan Alam Sekitar) on 27th March 2004 to undertake the major regulatory role. This new Ministry is a combination of departments from 4 previous ministries, resulting in the expanded responsibilities; namely (i) Natural Resources Management, (ii) Conservation and Management of Environments and Shelters, and (iii) Management of Land Survey and Mapping Administration. Currently, the other ministries involved in the water resources sector include the Ministry of Energy, Water and Communications (Kementerian Tenaga, Air and Komunikasi – KTAK), Ministry of Agriculture and Agro-Based Industry (MOA) (Kementerian Pertanian and Industri Asas Tani), Ministry of Housing and Local Government (MoHLG) (Kementerian Perumahan and Kerajaan Tempatan), Ministry of Health (Kementerian Kesihatan) and Ministry of Science, Technology and Innovation (MOSTI) (Kementerian Sains, Teknologi dan Inovasi).

1.3.2.2 State IWRM Institutions

Several States also took the initiative to enact IWRM or river management legislations and set up the related institutions, among them include:

a) Sarawak Rivers Board

Established under the Sarawak Rivers Ordinance 1993, the Board's mission is "Towards Safe, Clean and Natural Rivers" through sustainable development and quality services for the optimum domestic, commercial and recreational use, and to realize the development of rivers as a State's heritage for present and future generations. Though the main objective of the Ordinance is to regulate navigation in the river channel and foreshore areas in Sarawak State, the act also encompasses the overall management and development of the river systems. For more details, please refer Website: *http://www.riversboard.gov.my*

b) Sabah Water Resource Management Director

Following the enactment of the Sabah Water Resources Enactment (SWRE) in 1998, the State Government of Sabah had appointed the Director of DID Sabah to act as the Director of Water Resources with the responsibility to enforce SWRE. With this, water resources management had become an additional function of DID Sabah. This led to the formation of the Water Resources Section and the dissolution of the Hydrological Section in DID Sabah. The main responsibilities of this Section include *Water Resources Management*. (Manage the State's water resources and coordinate administrative action for water resources management), *Water Resources Development* (identify opportunities for water use and promote and facilitate the beneficial use of water; and plan for the orderly development and use of water resources and take measures to resolve conflict between water users), *Water Quality and Environment Management* (take action to protect the quantity and quality of water resources and the aquatic environment), and *Catchment Management* (develop, implement and monitor catchment plans and other plans related to water resource management including floodplain management plans, surface water management plans, and groundwater management plans).
Website: *http://www.did.sabah.gov.my/eng/waterres-test.asp*

c) Selangor Waters Management Authority (Lembaga Urus Air Selangor – LUAS)

Following Federal Cabinet decision in July 1997, the Selangor State Government enacted the Selangor Waters Management Authority Enactment 1999, leading to the establishment of LUAS in August 2000. The Authority is entrusted with the responsibility of ensuring that the State water resources, river basins, coastal zones and environment are well preserved with improved quality through water resources management in a holistic, integrated and sustainable manner. Please refer Website: *http://www.luas.gov.my* for details.

d) Malacca River and Coastal Development Corporation

The Malacca River and Coastal Development Corporation Enactment 2005 was passed by the Legislative Assembly, Malacca on the 29th and 30th March 2005 and gazetted on 28th April 2005. This led to the formation of the Malacca River and Coastal Development Corporation with the appointment of the Chief Executive Officer. The objective of the Corporation is to administer and manage the development of rivers and coasts (notified in Gazette) situated within the State of Malacca on behalf of the State Government.

e) Badan Kawal Selia Air (Pahang)

Badan Kawal Selia Air (Pahang), currently under the Pahang State Secretary Office, was established after the gazetting of the Water Resources Enactment 2007 (Pahang). This enactment, gazetted on 31st December 2007, is an Enactment relating to the control of water resources and abstraction of raw water in the State of Pahang and for matters incidental thereto. With this Enactment, the Water Supply Enactment and Waters Act 1920 (Pahang) are repealed.
Website: *http://suk.pahang.gov.my/usa/* for more details.

1.4 RESPONSIBILITIES OF FEDERAL, STATE AND LOCAL AUTHORITIES

As outlined in the *9Th Schedule, Item 6 of State List* of the Federal Constitution, the State Authority has absolute ownership and power on rivers and canals (wholly within one State). The *9th Schedule, Item 11 of Federal List* of the Constitution also stipulates that for river or rivers shared by more than 1 State, Federal Government may take over the river or rivers when the States concerned cannot come to an agreement on the management and regulation of the river or rivers. So far, no such precedent has been set.

Before dwelling into the Federal and State roles and responsibilities, it is important to note that river management in Malaysia is very complex and broad. There is no single department or agency entrusted with the role. Not only do the river managers have to look at the technical aspects, but also the complexity and sensitivity of Federal/State relationship, inter-agency roles, coordination and integration as well as local environment.

1.4.1 Federal Government's Role and Responsibilities

As outlined under the Federal Constitutions, the ownership of water resources/river and hence river management (except for river or rivers shared by more than 1 states), comes under the jurisdiction of the State authorities. The roles of the Federal government are basically confined to providing policy direction, guidelines, technical and financial supports as well as coordination and conflict resolution. These roles are basically implemented through the National Water Resources Council, various Federal ministries and Federal agencies under them.

Currently, the roles and responsibilities of DID Malaysia in river management are confined to:

- formulate policy,
- establish guidelines,
- formulate river management programs including projects (5-year and annual plans);
- provide technical support,
- provide financial support,

- provide training and capacity building, and
- inculcate awareness.

Such functions are provided for under the Ministerial Functions Act 1969

1.4.2 State Government's Role and Responsibilities

Legally, the State Government has the overall authority in the management of rivers within its own State. As highlighted in Section 1.3.2 above, some States had enacted their own legislations and established single-agency water resources/ river management institutions, while other States may do this by administrative arrangement through the various State committees. These institutions and committees would generally translate and adopt the national legislations and policies for subsequent management and implementation.

The State (including districts) DID's roles (in river management) basically include:

- advise the State authority on matters pertaining to river management,
- implement river management programs and activities (Federal and State funds),
- responsible for the conservation and rehabilitation of rivers,
- prepare river basin master plan, and
- maintain all relevant river facilities.

1.4.3 Local Authorities' Role and Responsibilities

The roles and responsibilities of local authorities to construct and maintain drains and watercourses are covered basically by the Street, Drainage and Building Act 1974. Such roles and functions are generally referred to man-made waterways for urban stormwater management purposes. However, there tends to be gray areas and areas of overlap with DID. In this context, All DID districts were advised to liase with the local councils to clearly define the list of rivers or watercourses to be maintained and managed by each agency.

REFERENCES

[1] *"Kajian Register Lembangan Sungai Kebangsaan* (Fasa 2), JPS Malaysia

[2] *Urban Stormwater Management Manual for Malaysia* (MSMA), JPS Malaysia

APPENDICES

Appendix A List of River Basins

APPENDIX A

LIST OF MAIN RIVER BASINS IN MALAYSIA

Appendix A List of Main River Basins in Malaysia

No.	State	Name of Rivers
1.	Perils	Sungai Perlis
2.	Kedah	Sungai Langkawi
3.		Sungai Kedah
4.		Sungai Merbok
5.		Sungai Tembus
6.		Sungai Muda
7.	Pulau Pinang	Sungai Juru
8.		Sungai Perai
9.		Sungai Pinang
10.		Sungai Jawi
11.	Perak	Sungai Kerian
12.		Sungai Kurau
13.		Sungai Sepetang
14.		Sungai Temerloh
15.		Sungai Beruas
16.		Sungai Raja Hitam / Manjong
17.		Sungai Deralik / Wangi
18.		Sungai Perak
19.	Selangor	Sungai Bernam
20.		Sungai Tengi
21.		Sungai Selangor
22.		Sungai Buloh
23.		Sungai Klang
24.		Sungai Langat
25.		Sungai Chuau
26.		Sungai Sepang
27.	Negeri Sembilan	Sungai Jimah
28.		Sungai Linggi
29.		Sungai Muar Utara
30.		Sungai Pertang
31.		Sungai Mokek
32.	Melaka	Sungai Bharu
33.		Sungai Melaka
34.		Sungai Duyong
35.		Sungai Kesang
36.		Sungai Merlimau
37.	Johor	Sungai Muar
38.		Sungai Batu Pahat
39.		Sungai Air Baloi
40.		Sungai Benut
41.		Sungai Segget
42.		Sungai Pontain Kecil
43.		Sungai Pontian Besar
44.		Sungai Kempas
45.		Sungai Danga
46.		Sungai Skudai
47.		Sungai Tebrau
48.		Sungai Rambah
49.		Sungai Johor
50.		Sungai Pasir Gudang
51.		Sungai Sedili Besar
52.		Sungai Sedili Kecil
53.		Sungai Paloi

No.	State	Name of Rivers
54.		Sungai Mersing
55.		Sungai Teriang
56.		Sungai Tenglu
57.		Sungai Jemaluang
58.	Pahang	Sungai Endau
59.		Sungai Anak Endau
60.		Sungai Rompin
61.		Sungai Pontian
62.		Sungai Bebar
63.		Sungai Bertam
64.		Sungai Bera
65.		Sungai Lepar
66.		Sungai Mentiga
67.		Sungai Pahang
68.		Sungai Kuantan
69.		Sungai Cherating
70.		Sungai Balok
71.	Terengganu	Sungai Kemaman
72.		Sungai Kertih
73.		Sungai Kemasik
74.		Sungai Chukai
75.		Sungai Paka
76.		Sungai Dungun
77.		Sungai Marang
78.		Sungai Ibai
79.		Sungai Landas
80.		Sungai Terengganu
81.		Sungai Merchang
82.		Sungai Chalok
83.		Sungai Setiu
84.		Sungai Keluang
85.		Sungai Besut
86.	Kelantan	Sungai Semarak
87.		Sungai Kemasin
88.		Sungai Kelantan
89.		Sungai Golok
90.	Sabah	Sungai Mengalong
91.		Sungai Lakutan/Sipitang
92.		Sungai Lingkungan/Bukau
93.		Sungai Padas
94.		Sungai Padas Damit
95.		Sungai Klias
96.		Sungai Membakut/Binsulok
97.		Sungai Bongawan
98.		Sungai Kimanis
99.		Sungai Papar
100.		Sungai Moyog
101.		Sungai Inanam/Menggatal/Mengkabong
102.		Sungai Tuaran
103.		Sungai Sulaman/Lapasan
104.		Sungai Kadamaian/Tempasuk
105.		Sungai Kawang-Kawang
106.		Sungai Sarang
107.		Sungai Laya-Laya
108.		Sungai Indarasam/Pomotodon

No.	State	Name of Rivers
109.		Sungai Loro
110.		Sungai Tegarangan
111.		Sungai Milau
112.		Sungai Tagumamal
113.		Sungai Matunggong
114.		Sungai Tigaman
115.		Sungai Bintasan
116.		Sungai Langkon/Bandau
117.		Sungai Kinarom/Bongon
118.		Sungai Tandek
119.		Sungai Marasimsim/Silimpodon
120.		Sungai Benkoka
121.		Sungai Telaga
122.		Sungai Melabong
123.		Sungai Bongkol
124.		Sungai Kanibongan
125.		Sungai Kaidangan/Tengkarasan
126.		Sungai Paitan
127.		Sungai Mamahat
128.		Sungai Sugut
129.		Sungai Timbang
130.		Sungai Makopako/Pagata/Bogaya
131.		Sungai Labuk
132.		Sungai Kolapis
133.		Sungai Samawang
134.		Sungai Gum Gum/Sibuga
135.		Sungai Segaliud
136.		Sungai Sekong
137.		Sungai Sapagaya
138.		Sungai Munmiang
139.		Sungai Kinabatangan
140.		Sungai Manalunan
141.		Sungai Segama
142.		Sungai Lumeru
143.		Sungai Ganduman
144.		Sungai Tegupi
145.		Sungai Sahabu
146.		Sungai Tungku
147.		Sungai Silabukan
148.		Sungai Seganen
149.		Sungai Sepagaya
150.		Sungai Sabahan
151.		Sungai Tingkayu
152.		Sungai Sapang
153.		Sungai Segarong
154.		Sungai Pegagau
155.		Sungai Mantaritip
156.		Sungai Kalumpang
157.		Sungai Balung
158.		Sungai Apas
159.		Sungai Tawau
160.		Sungai Merotai
161.		Sungai Umas – Umas
162.		Sungai Brantian
163.		Sungai Tatulit

No.	State	Name of Rivers
164.		Sungai Kalabakan
165.		Sungai Sarudong
166.		Sungai Sibuda
167.		Sungai Sapulut
168.	Sarawak	Sungai Kayan
169.		Sungai Sarawak
170.		Sungai Samarahan
171.		Sungai Sadong
172.		Sungai Lupar
173.		Sungai Saribas
174.		Sungai Kerian
175.		Sungai Rajang
176.		Sungai Oya
177.		Sungai Mukah
178.		Sungai Balingian
179.		Sungai Tatau
180.		Sungai Kemena
181.		Sungai Similajau
182.		Sungai Suai
183.		Sungai Miri
184.		Sungai Niah
185.		Sungai Sibuti
186.		Sungai Baram
187.		Sungai Limbang
188.		Sungai Trusan
189.		Sungai Lawa

Source: "Kajian Register Lembangan Sungai Kebangsaan (Fasa 2), JPS Malaysia

CHAPTER 2

RIVER CONSERVATION

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2 RIVER CONSERVATION

2.1 INTRODUCTION

The primary objective of this Chapter is to set out the functions and policy and to explain the works of DID with respect to River Conservation. Towards this, it is Important to have a clear picture of the nature of a river, its characteristics and the various factors which influence its behaviour as well as the ways to manage it. The Chapter is divided into 3 main sub-sections. Sub-section 2.1 "Integrated River Basin Management" covers the soft / management aspects of river conservation. Sub-section 2.2 "River Characteristics and Geomorphology" talks about the study of river corridor surface forms and the related processes. Sub-section 2.3 "River Ecosystems and River Health" outlines the fundamental structures of stream ecology and their assessment.

2.1.1 Definition

River Conservation can be defined as "*a generational stance where vows to preserve an ecological integrity of a river system in the interest of a community must be reviewed over and over again*" (Terry Tempest Williams).

2.2 INTEGRATED RIVER BASIN MANAGEMENT (IRBM)

Traditionally water issues in Malaysia have been addressed by various specialized agencies in a somewhat fragmented manner. This sector-based segmented approach has its advantages. However, as the pace of development increases, it has become increasingly evident that there is an urgent need for a broader and holistic approach. Water-related problems can only be effectively dealt with through a collaborative effort by the many stakeholders and with inputs from many technical disciplines. The extent of crisis in water resources management is well known, but dealing with it is more difficult.

2.2.1 Definition of IWRM & IRBM

When talking about water resources and river management, one common question used to surface, i.e. "What is the difference between Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM)?" To answer this, let us first look at the broader picture and define what IWRM is.

2.2.1.1 Integrated Water Resources Management (IWRM)

If effective and sustainable solutions to water problems are to be found, a new water governance and management paradigm is required. Such a new paradigm is encapsulated in the Integrated Water Resources Management (IWRM) concept, which can be defined as *"a process, which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'* ([1] GWP, 2002). IWRM puts in place specific routine processes that ensure that different water-using sectors work together on water services, water projects and water plans towards achieving sustainable water resources development and management.

IWRM explicitly challenges conventional water development and management systems. It starts with the recognition that traditional top-down, supply led, technically based and sectoral approaches to water management are imposing unsustainably high economic, social and ecological costs on human societies and on the natural environment. Business as usual is neither environmentally sustainable, nor is it sustainable in financial and social terms. As a process of change, which seeks to shift water development and management systems from their currently unsustainable forms, IWRM has no fixed beginnings and will probably never end. The global economy and society are dynamic and the natural environment is also subject to change. IWRM systems will, therefore, need to be responsive to change and be capable of adapting to new economic, social and environmental conditions and to changing human values.

IWRM is not an end in itself but a means of achieving three key strategic objectives:

- Efficiency to make water resources go as far as possible;
- Equity in the allocation of water across different social and economic groups; and
- Environmental sustainability - to protect the water resources and associated eco-systems.

It is important to keep in mind that IWRM is a process of change, a process that can start from small beginnings. There is no such thing as a perfect IWRM system and the search for perfection can lead to action atrophy.

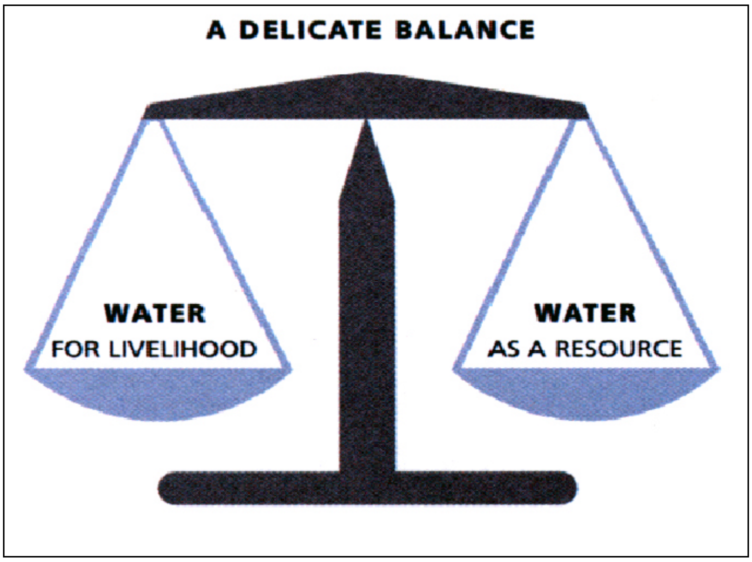


Figure 2.1 IWRM Balancing Act (Effective Implementation of IWRM in Malaysia, 2008)

2.2.1.2 Integrated River Basin Management (IRBM)

On the other hand, Integrated River Basin Management (IRBM) is *the process of coordinating conservation, management and development of water, land and related resources across sectors* within a given river basin*, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems* ([1] GWP, 2002).

Figure 2.2 River Management Vision (JPS 2002)

IRBM is thus a subset of IWRM and is the effective approach or tool to achieve IWRM objectives on the *river basin basis.* In simple terms, it is the management of a river basin as an entity, not as a series of individual, unconnected pieces. It is geared towards integrating and coordinating policies, programmes and practices. It addresses water and water related issues. It requires improved professional capacity and increased financial, legislative, managerial and political capacity.

2.2.2 Best Practice IRBM Principles

Water flows according to natural characteristics and does not respect administrative boundaries - therefore, from pure water resources point of view there might be much logic in managing water according to river basin boundaries. With economic development and population growth, and the consequent pressure on the environment, water resources management becomes even more important and complex and there is an urgent need for a broader and holistic approach. Water-related problems can only be effectively dealt with through a collaborative effort by the many stakeholders and with inputs from many technical disciplines. It is not enough to look at the river; the whole basin or catchment must be considered. To face new challenges in the coming years and looking at global trend in water and river management, the river basin must be planned and managed in a holistic manner. This is crucial as the river basin is a single contiguous physical hydrologic/hydraulic unit, each having its maximum carrying capacity. River basin management is thus widely recognized as the most rational basis to work on: it forms an integrated strategic management approach for water resources management.

The international community, through the 1992 UNCED Earth Summit, had agreed to adopt eight guiding principles for sustainable development that are relevant and are progressively being recognised as "Best Practice" principles. These Principles are:

- River Basin Based Strategies: The best practice in managing rivers and water resources is based on geographical river basins or water catchments.
- Towards Sustainable Development: Overcoming the problems of depleting water resources, droughts, floods sedimentation and pollution, through water conservation and responsible management.
- Integrated and Multi-functional Approach: Integrated and multi-functional approach ensures the availability of resources for all users through co-ordination and co-operation.
- Separation of Regulatory and Service Providers Functions: Separation of functions avoids conflicting interests and allows transparency of actions.
- Economic Value of Water and Cost Recovery: Water, resource management and pollution charges and penalties (polluters pay principle) should reflect the true economic value of the resource. The revenue should generate funds for management, protection and regulation of rivers and water resources.
- Emerging Technologies and New Management Techniques: Effective management of the basin's resources requires leading-edge knowledge, technology and management tools. Information technology and mathematical modelling and risk assessments promote the optimisation of resources development and management.
- Stakeholder Participation: Consumers, service providers and the community at large should be involved in the decision making process and be partners in ensuring the use of best practices in resource and basin management.
- Private Sector Participation: Privatisation may be an effective means of achieving efficiency improvements or funding infrastructure and service improvements.

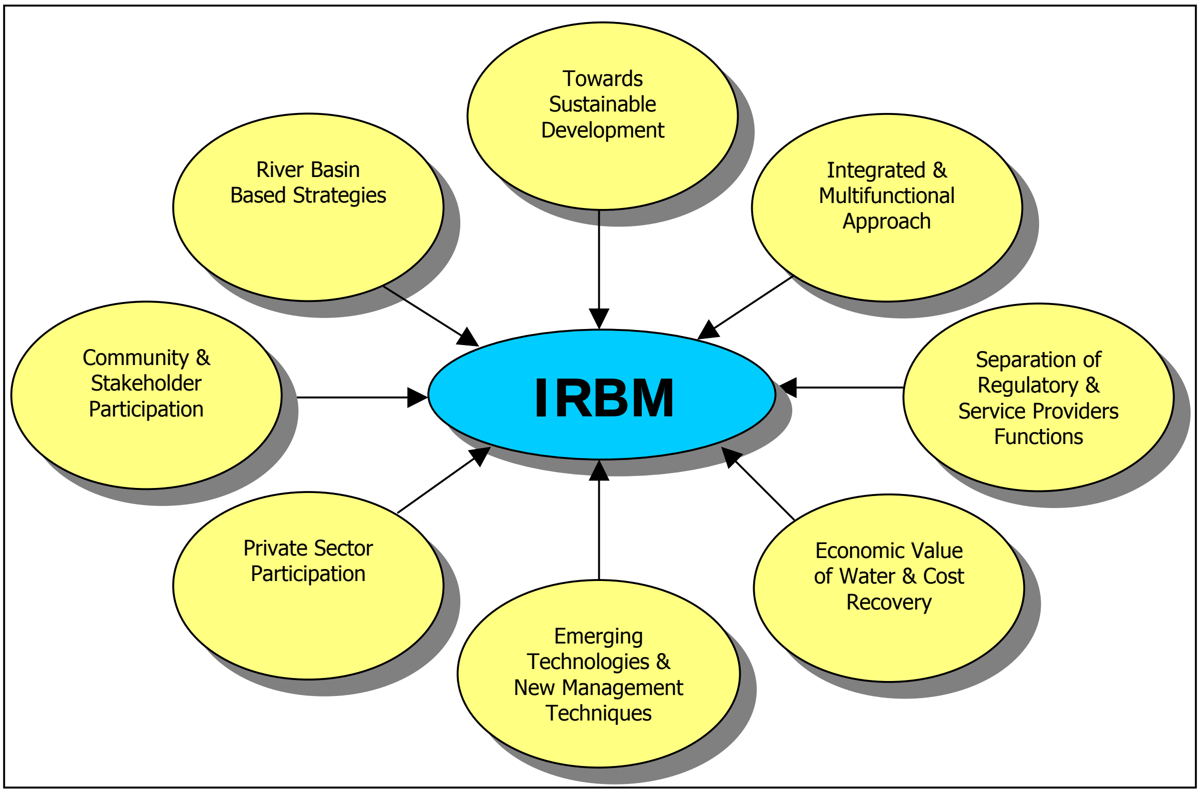


Figure 2.3 IRBM Principles (Klang River Basin Environmental Improvement and Flood Mitigation Project 2003)

a)

2.2.3 Critical Success Factors for Integrated River Basin Management

The critical success factors for managing a river basin can be summarized by Figure 2.4 below:

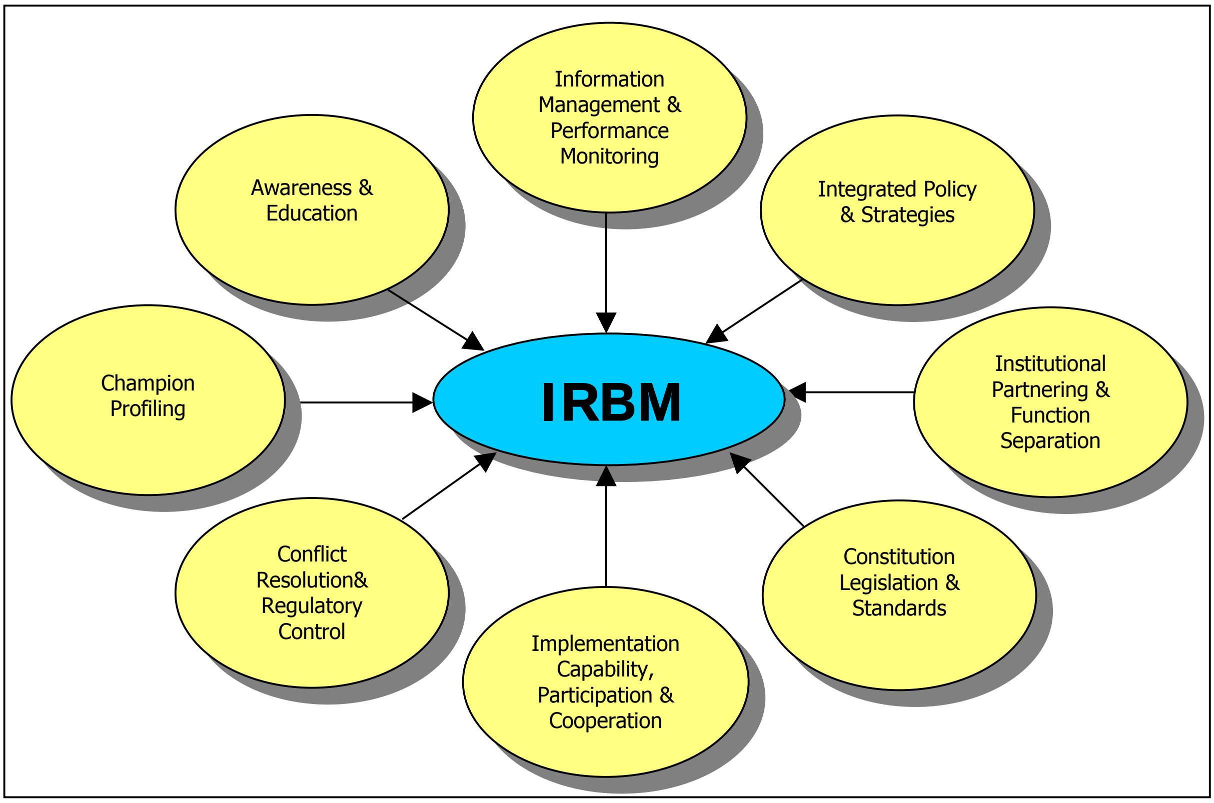


Figure 2.4 IRBM Critical Success Factors (Klang River Basin Environmental Improvement and Flood Mitigation Project)

2.2.3.1 Integrated Policy and Strategies (for the Basin)

For major river basins, especially the shared (interstate) rivers, the IRBM Plan should clearly outlines an overarching policy or institution (developed and agreed upon by relevant parties) that will ensure IRBM is effectively implemented across agencies and administrative boundaries. Whether this is achieved through legislation or co-operation, the co-ordination of agency actions must occur. The river basin policies and outcomes should be set in line with the national policies as established by various national councils, such as National Consultative Council, National Planning Council, National Environment Council, National Forestry Council, National Local Government Council and National Water Resources Council. Other factors to be considered include the river catchment local conditions and characteristics as well as stakeholders' expectations. All these will ensure the concept of integrated water resource/river basin management with planning and other basin activities is embodied in coherent *Government policy and strategies*, at all levels and across all disciplines and jurisdictions.

2.2.3.2 Institutional Partnering and Function Separation

One of the key criteria for effective IRBM implementation is the separation of the regulatory and utility functions. At times there will be conflict of interest or biasness if the agency that is providing the utility services (in water resources) is also carrying out the regulatory functions. The government's commitment towards IRBM was clearly illustrated with the re-organization of former agencies related to water resources into four (4) new ministries, the Ministry of Natural Resources and Environment, the Ministry of Energy, Water and Communication (MEWC), the Ministry of Agriculture and Agro-based Industry and the Ministry of Housing and Local Government (MHLG) on 27th March 2004. With this new setup, there is:

- The separation of utility (MEWC & MOAAI) and regulatory (NRE & MHLG) roles of the water resources sector;
- Facilitate private sector involvement in the water utility fields;
- Bringing together the major natural resource base agencies (land, water and forest) and environment under one ministry to facilitate and ensure that all natural resources are planned and managed holistically.

To ensure effective implementation and close coordination, there is a need to establish effective and transparent *cross-jurisdictional institutional arrangements***.** At the highest level, this comes in the form of the administratively established National Water Resources Council. Institutional partnerships is not only limited to government agencies, but should also include the private sector.

2.2.3.3 Constitution, Legislation and Standards

As discussed under Section 1.3 of Chapter 1 (Legislation and Institution), the country's Federal Constitution has clearly defined the jurisdiction and responsibility (Federal, State and the Concurrent Lists) of river management. Currently, there are adequate legislation, regulations standards and guidelines available to effectively regulate and ensure effective river management. For the states of Selangor, Sabah and Sarawak (Kedah and Pahang are in the process of gazetting their own bills), that have their own integrated enactments or acts, the main issue at hand is having enough resources (financial as well as qualified human resources) and political will to enforce them. For other states that have not yet formulated their own integrated water resources/ river management Enactments/ Acts, the major issue is to get the single-issue authorities to work together and address basin issues in a holistic and integrated manner.

2.2.3.4 Implementation Capacity, Participation and Cooperation

Implementing and maintaining *institutional capability* including skills, advice and training, participation arrangements and the willingness / co-operation by all key stakeholders to achieve a sustainable outcome. Comprehensive capacity building programmes at all levels and at sustained all times. At the same time, stakeholders as well as local community (after all, they are the one most directly affected by what happen in the basin) involvement and participation are paramount for the effective implementation of IRBM. Every effort should be geared towards inculcating and raising the awareness levels as well as advocating the stakeholders' and local community's participation and cooperation.

2.2.3.5 Conflict Resolution and Regulatory Control

IRBM implementation involves many agencies and various stakeholders, each with own focus, concern and jurisdiction. There are bound to be conflicts and clashes. It is important to have an effective mechanism or forum where such conflicts can be resolved amicably ensuring an effective *conflict resolution and regulatory control* processes are established and decisions implemented and non-compliance properly addressed.

2.2.3.6 Champion Profiling

Identifying a champion or champions (politicians or local community or religious leaders) to profile and carry the cause, in this case, integrated IWRM / IRBM is the effective way forward. Advocacy aims to involve and influence these leaders (politicians and other decision-makers) to lead and promote such causes. Advocacy can be quite informal, through lobbying and personal contacts. But advocacy can also be combined with PR techniques to apply public pressure. Advocacy can aim to reach not only politicians and officials but also managers in the private sector and NGOs or local community leaders.

2.2.3.7 Awareness and Education

Awareness in IWRM or IRBM can be defined as the realization or understanding of issues and components associated. It is targeted at influencing *personal attitudes* and *effectiveness* and *social norms* of communities in such a way that behavioural compliance for an efficient, environmental friendly and safe use of water resources is promoted, as well as social pressures towards sound and sustainable policies are stimulated. Establishing the *awareness* of need among the stakeholders and local community for river basin management and the *education* of impacts that development has on the river basin are vital to advocate their participation and involvement.

2.2.3.8 Information Management and Performance Measurement

"Water Resources" is a finite natural resource essential for the well-being of both human society and the natural ecosystems, and in this regard it has to be managed effectively and efficiently to ensure equitable and fair use of water for both human and nature. Within every single major river basin, there are many relevant agencies (public, private, NGOs) and stakeholders, each one has his role to play and owns large volumes of valuable data and information. In this respect, maintaining information management and sharing comprehensive sets of databases are essential for IRBM. There is also a need for *performance monitoring* and periodic reviews and audits of IRBM implementation. Towards this, developing an appropriate information architecture framework to support the effective implementation of IWRM in Malaysia through the sharing and dissemination of information among all stakeholders is essential.

2.2.4 Objectives of IRBM Plan

An IRBM plan for a particular river should be formulated and treated as the overall macro water resources management master plan for the river basin involving all relevant stakeholders (not DID alone). The main objectives of the plan shall incorporate and include the followings:

- Provides clear basin water resources policies, goals, targets and objectives;
- Serves as the overall basin Strategic Plan that will provide the basis and the overall water resources strategic management for the basin; and
- Provides a plan of action for various stakeholders to achieve individual objectives of the various disciplines.

The formulated IRBM Plan should be given the recognition and backing by all concerned for effective compliance. Basing on this formulated and approved IRBM Strategic Plan, all relevant stakeholders and agencies should then proceed to formulate their own individual management and development plans for the river basin. This National Water Resources Council fully recognized this and had at its meeting on 29th July 2003 decided on the "Preparation of River Basin Master Plans".

2.2.5 Concept and Key Components of IRBM Plan

The IRBM plan is an action plan, a tool that describes the framework for the effective management of the water and related land resources in the basin in an integrated manner. The river basin plan is a tool that outlines how the concept of integrated water resources management is going to be implemented at the river basin level. In preparing for the IRBM plan, it is important to note that no two rivers are the same. Their respective best roles and the problems are varied. Typically, the plan should cover / address such aspects as:

- Physical description of the basin;
- Land use inventories;
- Current water availability (Quantity) and demands;
- Pollution (Water Quality) source inventories;
- Aquatic and terrestrial ecosystem needs;
- Vulnerability to floods or extreme meteorological events;
- Identification of stakeholders;
- Implications of changing land use;
- Identification of priority issues (impact issues or user requirement issues);
- Short- and long-term strategies/ goals for the river basin;
- Water related development scenarios, future water demands
- Water allocation and water quality objectives/ targets;
- Strategy, measures and action plan for achievement of goals;
- Financing of water use and management;
- Institutional arrangement to coordinate, monitor, evaluate & review;
- Responsibility and schedule for implementation; and
- Mechanisms for monitoring and updating.

The formulated IRBM Plan should contain clearly defined policies (translated from the National, Federal & State policies) and objectives suitable for the basin and its stakeholders. Inter-sector requirements must be given fair and sufficient attention and consideration. Only then, it can ensure the sustainable development in the basin. It is important not to set too high goals in the basin and generate too high expectations among the stakeholders and partners who may become anxious and disillusion if progress and achievements are slower than expected.

2.2.6 Stakeholders and Public Participation

While the concept is still new in Malaysia, the participatory and bottom up strategy (BUS) and involvement of all stakeholders in the entire project/programme cycle is a key element to ensure success and the long-term sustainability. Strong and smart partnership are essential to create win-win situations, with the community and stakeholders accepting their share of responsibility. Such participatory management mechanisms need time to develop for which appropriate public awareness campaigns and educational programmes would need to be put in place early. Non-governmental organizations (NGOs) can play an important and facilitation role in such programmes.

2.2.7 Awareness and Public Education

By far, the "Love Our River" campaign is the most comprehensive long-term awareness programme on water resources in the country. The former Minister of Agriculture, Datuk Seri Sanusi Junid, launched this public awareness programme on 20th February 1993. The objectives of this programme include:

- Inculcate general awareness on the importance of rivers in every individual's daily life and cultivate the willingness to love and be involved together in managing / preserving our rivers;
- Introduce to the general public measures and practices that can contribute towards sustaining the beauty and protection of our rivers; and
- Enhance and raise the knowledge and techniques in managing rivers and their catchments among relevant agencies to ensure sustainable harmonious and integrated development.

Six (6) main activities were formulated and carried out. These included:

- *River adoption*;
- *River Watch;*
- *River Expeditions;*
- *Education (talks, visits, briefings, etc.);*
- *River Beautification; and*
- *Symposium, Seminars and Workshops*.

"*Love Our Rivers Month*": In order to sustain the awareness programmes and impacts, September had been designated as the national "Love Our Rivers Month" during which a lot of focused awareness activities and publicity programmes are to be held. The month of September was chosen, as it is the end of the "dry period" and near the beginning of the "wet monsoon season" for most parts of the country.

2.2.8 One State One River Programme

One State One River Programme was launched in 2002 with the following objectives:

Dirty, Dead & Abandoned Rivers → Clean, Living, Vibrant, Natural & Life Supporting Rivers

- To achieve clean, lively and valuable river with Class II water quality by 2015;
- To rehabilitate the river and its environment as a natural recreation area;
- To successfully adopt and implement Integrated River Basin Management; and
- To preserve the valuable asset of the river.

The programme required each state to select, with the agreement of state government one polluted river to be rehabilitated. The rehabilitation programme is to be carried out over a 10 to 15 years time frame with several short-term programmes as follows:

- Framework for rehabilitation programmes for upstream, middle and downstream stretch of river.
- Rubbish removal with installation of rubbish trap at source;
- Full enforcement of "Manual Saliran Mesra Alam (MSMA)" by local authorities for all land development;
- Enforcement of treatment system such as 'Food, Oil & Grease' (FOG) and Gross Pollutant Trap (GPT) by local authority for food stalls, market and other activities which contribute to river pollution;
- Resettlement of squatters and relocation of other activities besides river which cause pollution
- River and its reserve to be gazetted and utilized as riparian zone for different habitat depending on the river usage (such as urban, rural and water catchment);
- Promote and encourage private sector to practice Best Management Practices (BMPs) for all type of development such as Erosion and Sediment Control Plan (ESCP) to control erosion and sediment; and
- To tighten approval and enforcement of sand mining rules together with mandatory requirements for silt screen to control suspended sediment materials.

The main implementation strategies are Preventive Measures, Curative Measures and Management, and a few committees involving all stakeholders has been formed to achieve the vision of clean river.

2.2.9 Short Term & Long Term Strategies

River basin-scale objectives cannot be tackled seriously within the scope of three- or five year period. IRBM requires long-term technical and financial action plans and programmes. It also takes time to build sufficient trust and levels of understanding among stakeholders before IRBM implementation activities can begin. Building the capacity of organizations, agencies and civil societies, developing sustainable livelihoods with local people, leveraging resources and implementing sustainable economic measures are critical and require time. Thus, the formulated IRBM Strategic plan should comprise of various action plans with strategies and targets set at various time intervals. Short-term period is set for 1 to 5 years; mid-term target should vary from 5 to 10 years, while the long-term target shall be achievable after 10 years.

2.2.10 Implementation, Monitoring & Coordination

The overall implementation framework for IRBM is as shown in Figure 2.5. At the national level, various policies related to water resources are established by the National Water Resources Council and other councils, including the National Economic Consultative Council, National Physical Planning Council, National Environmental Council, National Forestry Council, National Land Council, and National Local Government Council. These national policies should therefore form the basis for the river basin management. In the development of IRBM plan for a particular basin, these national policies should then be translated into the basin policies and outcomes.

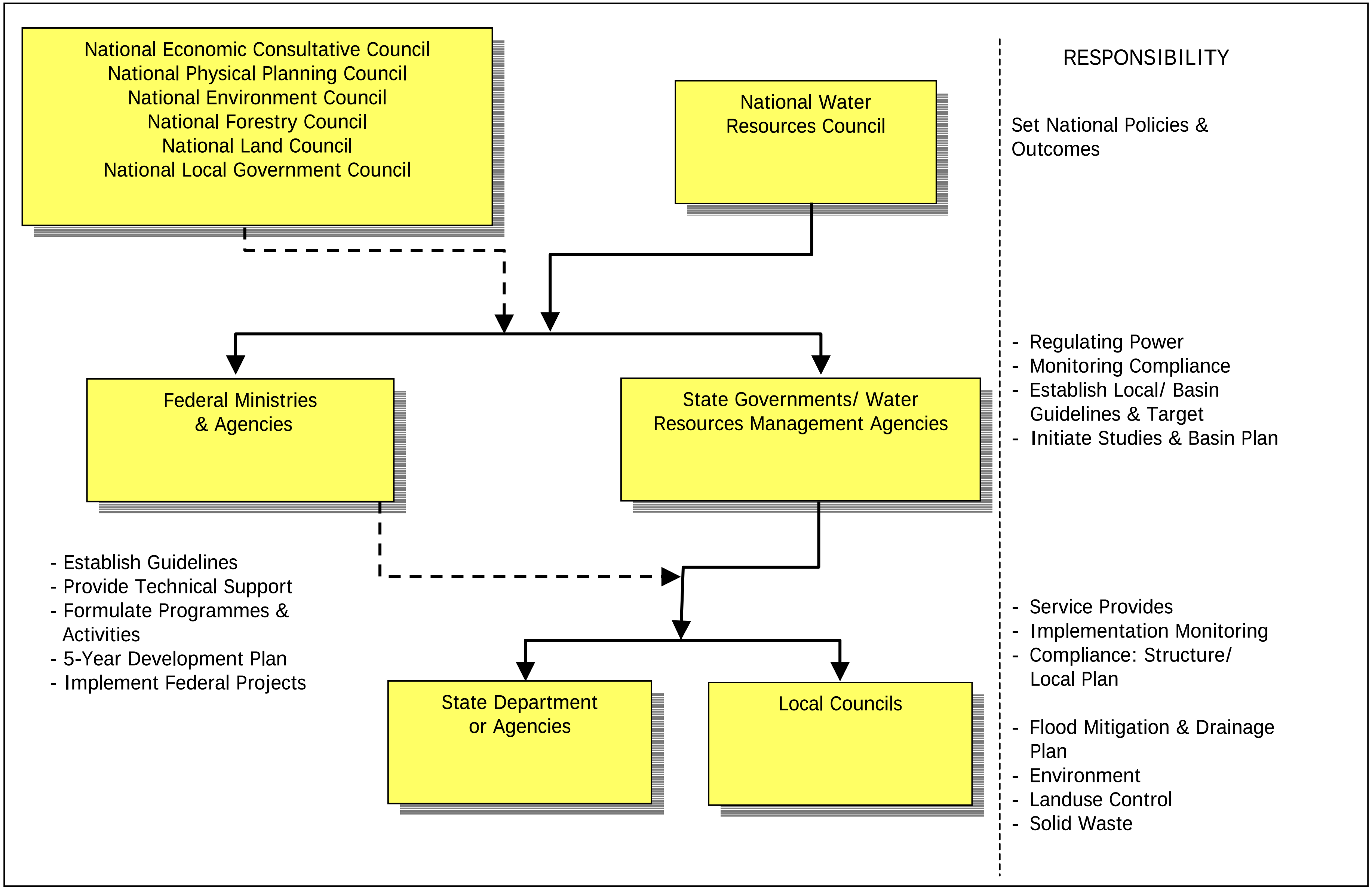


Figure 2.5 Integrated River Basin Management Framework (Klang River Basin Environmental Improvement & Flood Mitigation Project, 2003)

As highlighted earlier, it is essential to get the involvement and participation of the key stakeholders and local communities to ensure the success and sustainability of IRBM. In this respect, it is important to adopt the BUS (Bottom Up Strategy), i.e. getting the input and participation of these stakeholders and local communities from the start of the planning stage (formulation of the IRBM plan) right through until the eventual implementation. This is especially so for projects directly linked to them. Instilling the sense of belonging and willingness to participate are the keys.

In line with the National Water Resources Council decision on 29th July 2003 ("Preparation of River Basin Master Plans"), the formulated IRBM Strategic Plan should be accepted as the overall river basin development strategic Plan by all stakeholders, be it the State Authority, the planners, the regulators, the utility providers, the commercial sector, non-governmental organizations or local communities. For this to materialize, the formulated IRBM Plan must have the highest level of backing. It is thus recommended that the IRBM Plan for all major river basins should be tabled to and endorsed by the National Water Resources Council (Refer to Section 1.3.2.1 a). Depending on the basin's local requirements, the IRBM Strategic Plan may be required to be tabled to and endorsed by other national councils (such as Forestry Council, Physical Planning Council and Environment Council). Basing on this formulated and approved IRBM Strategic Plan, all relevant stakeholders and agencies should then proceed to formulate their own management and development plans for the river basin.

Subsequently, DID will then proceed to formulate the river and river corridor management plan, river basin Flood Mitigation Plan, the water resources supply and demand plan, the basin flood forecasting and management plan, flood emergency response plan and the flood plain management plan.

Effective IRBM implementation requires compliance and integration. Close monitoring and regular on course updating and adjustment are also needed. The mechanism for coordination and integration would vary from state to state depending on the State Authority and the agency entrusted with the responsibility. Figure 2.6 outlines the flow chart for the general IRBM implementation.

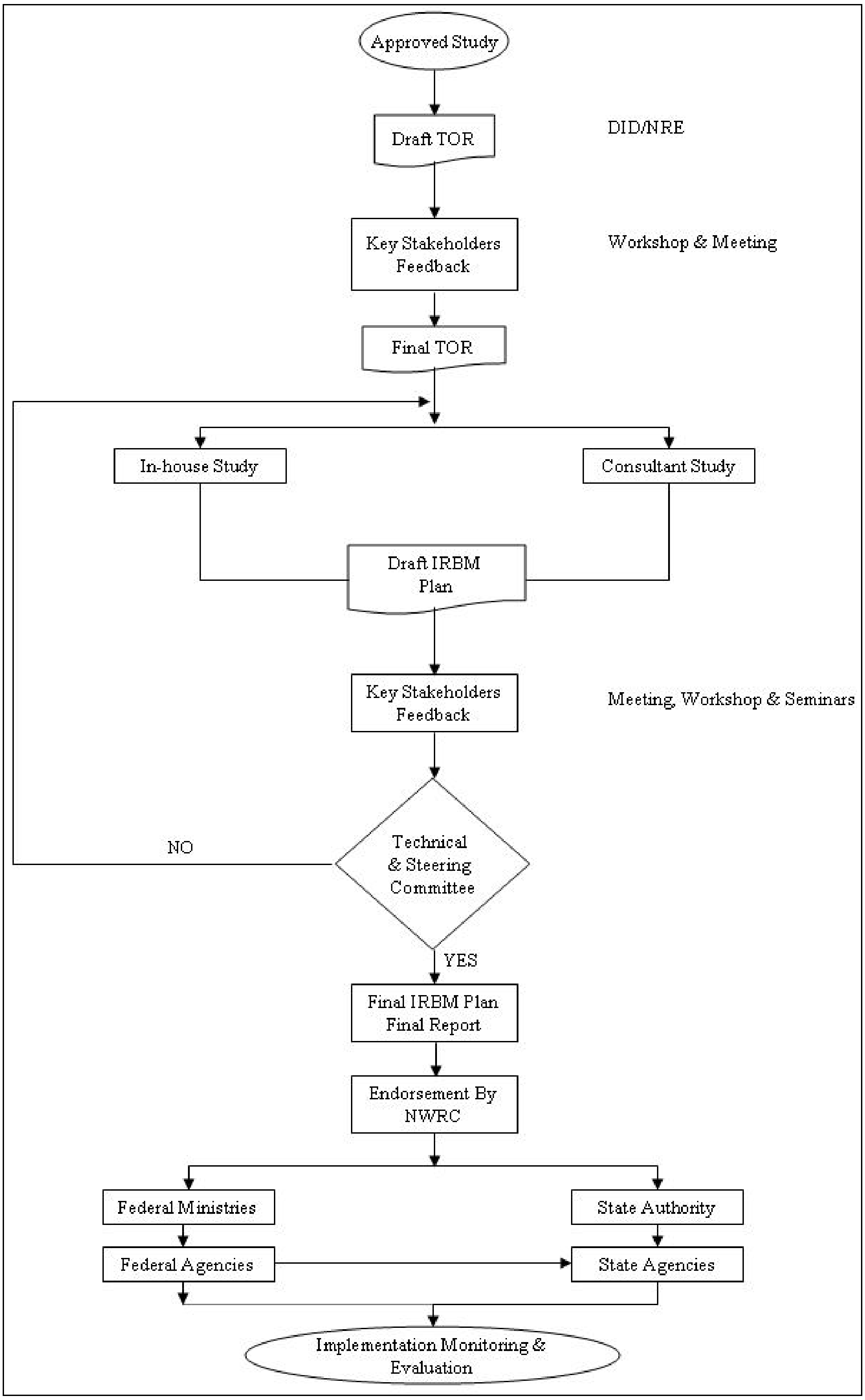


Figure 2.6 IRBM Implementation Flowchart

2.3 RIVER CHARACTERISTICS AND GEOMORPHOLOGY

2.3.1 Introduction

River morphology is the study of river forms and processes pertaining to river development. A thorough understanding of the river characteristics and its geomorphic processes is important especially where habitat restoration, in-stream engineering work, or riverbank stabilization projects are intended will provide quantitative comprehension of the processes that continue to shape the channel over time. In addition, accountability to the public that aquatic habitat and river corridors are being managed competently demands a higher degree of certainty in analysis and design than the use of the norm, which can only be obtained by collection and analysis of physical process data.

2.3.2 Hydrology and Hydraulic Processes

The hydrologic cycle describes the continuum of the transfer of water from precipitation to surface water and groundwater, to storage and runoff, and to the eventual return to the atmosphere by transpiration and evaporation (Figure 2.7).

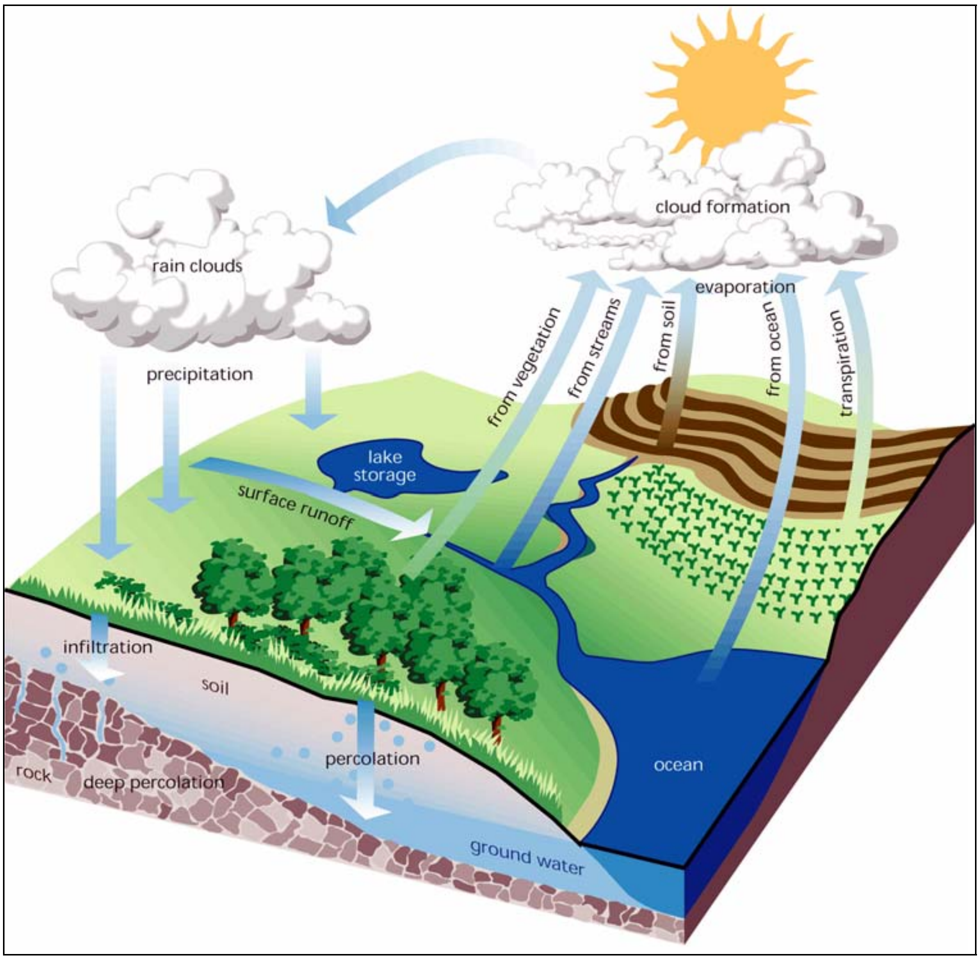


Figure 2.7 The Hydrologic Cycle.

Precipitation returns water to the earth's surface. In Malaysia, most hydrologic processes are described in terms of rainfall events (or storm events), either through monsoonal or off-monsoonal types. The type of precipitation that will occur is generally a factor of humidity and air temperature. Topographic relief and geographic location relative to large water bodies also affect the frequency and type of precipitation. Once precipitation reaches the ground, it can diverge into three general routes. It can return to the atmosphere; move into the soil; or run off the catchment surface into a river system, lake, wetland, or other water bodies. All three routes play a role in determining how water moves into, across, and down the river corridor. In turn, the movement of water in the river corridor forms the river hydraulic processes, which are governed by the channel size, slope, roughness, hydraulic structures along the path, floodplain storage, etc. The hydrology and hydraulic processes are also covered in details in the Hydrology, Modelling and Flood Mitigation Manuals.

2.3.3 Geomorphology Processes

Rivers are complex systems of inputs and responses whose features and forms are rarely constant. Explanation and prediction of their behaviour requires great depth in the understanding of historical conditions and current morphology and processes, at times involving considerable educated speculation, and is always uncertain and prone to risk. In spite of the complexity of predicting or explaining geomorphic responses, there are a number of common generalized channel responses that can be attributed, at least theoretically, to distinct causes. These include aggradation, incision, lateral migration and avulsion, which are most commonly observed in alluvial systems that are free to adjust their channel boundaries.

<u>Aggradation</u> - Aggradation is the progressive accumulation of in-channel sediment resulting in increased channel bed elevation. Aggradation is a response to channel system changes that reduces the channel's capacity to transport the sediment delivered to it. Generally, this occurs as a result of either increased sediment supply (load) or size (gradation), or diminished stream power (transport capacity).

Aggradation associated with increased sediment supply may occur in response to any of the following conditions:

- Increase in sediment size or volume associated with landslides, debris flows, or other geologic disturbances;
- Increase in sediment volume inputs from hill-slope disturbances including vegetation removal, fire, and agricultural and other land use impacts;
- Increase in sediment volume inputs from excessive bank erosion; and
- Increase in sediment volume inputs from excessive bed erosion from channel incision upstream.

Aggradation associated with decreased stream power may occur in response to any of the following conditions:

- Increased channel width resulting in decreased unit stream power;
- Large dams reduce duration of transport discharge;
- Diversions reduce discharge;
- Split flow within a channel reduces discharge in each split channel;
- Reduced channel slope associated with local dams or grade control placed above grade (beaver dams, log jams, culverts, etc.).

Figure 2.8 Channel aggradation

<u>Channel Incision</u> - Channel incision or degradation is the inverse of aggradation and involves the progressive lowering of the channel bed relative to its floodplain elevation. Incised channels (also called entrenched) occur when stream power exceeds the channel bed's resistance, or when sediment output exceeds the sediment input to the reach.

Incision associated with decreased sediment supply may occur in response to any of the following conditions:

- Upstream dams may cause sediment “starvation”;
- Removal of sediment from the channel; and
- Decrease in sediment delivery to the stream system.

Incision associated with increased stream power may occur in response to any of the following conditions:

- Stream channelization and straightening causing a steepening of the channel profile;
- Decreased channel roughness due to channelization, stream clearing and large wood removal;
- Lowering of base level, such as the lowering of a lake, removal of grade control (culvert, bedrock, log controls);
- Increase in peak flows due to land use changes;
- Increase in duration of transport flows associated with vegetation removal, urbanization, or other forms of land development that increase runoff rates and volumes;
- Concentration of high flows within the channel due to encroachment of walls, structures, or levees;
- Channel bed disturbance which disrupts the armour layer (push-up dams or gravel mining), typically resulting in smaller bed substrate and thereby reducing the stream power necessary to mobilize it; and
- Diversion of storm water or sewer discharge into the stream.

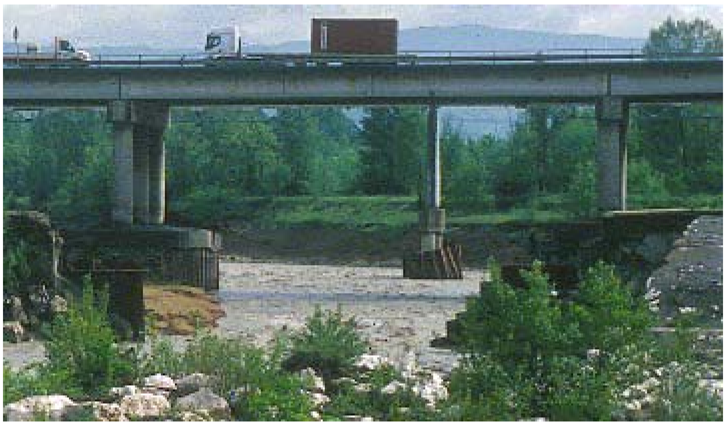


Figure 2.9 Channel Incision or degradation

Lateral Channel Migration and Erosion - Channel migration is the progressive movement of a channel across a valley and involves bank erosion and transport of eroded materials. Lateral channel migration may occur within the context of equilibrium provided that the general form of the channel does not change. In such cases, the width of the channel does not change – as a bank erodes laterally, a point bar develops across the channel, thereby maintaining channel form. However, lateral migration may also occur in response to disturbance or changes in external variables resulting in widening of the channel and other changes in channel form.

Lateral migration may be initiated or exacerbated by the following conditions:

- Hardening of channel banks upstream or across the channel may reduce the channel’s capacity to adjust locally, and may transfer the excess energy to an un-hardened area;
- Channel aggradation;
- Channel incision;
- Riparian and channel bank vegetation removal that reduces bank resistance;
- Excessive saturation of banks during low flow periods due to irrigation; and
- Rapid drawdown and saturation failures related to dam releases.

Channel Avulsion - Channel avulsion is a process whereby a channel shifts its location by cutting across adjacent terrain. Avulsion occurs naturally in meandering streams, most commonly cutting off a mature meander during long-duration or extreme over-bank flows. The occurrence of avulsion can also be brought about by channel manipulation, by armouring channel banks, or as a result of changes in external variables. The mechanism by which avulsion occurs is generally through headcutting and scouring of a new channel through the floodplain. As floodplain slope is usually greater than channel slope, for an equal flow depth, velocity and shear stress can be higher on the floodplain than in the channel. This is particularly an issue for wide shallow channels with active floodplains, because flow depth in the channel and on the floodplain can be very similar. This headcutting and scouring may be initiated during over-bank flows associated with large floods, logjams, beaver dams, or ice jams. Avulsion generally occurs when other channel conditions increase the volume of flow across the floodplain relative to the channel, thereby increasing the erosive forces on the floodplain. Aggradation within the main channel or a blockage of the main channel is the primary conditions under which flow energy increases on the floodplain. The re-entry of floodplain flow to an incised channel also promotes headcutting and channel avulsion. On the floodplain, restrictions that concentrate flow or removal of vegetation that slows flow and provides resistance to erosion may result in energy conditions that lead to avulsion during over-bank flows.

Avulsion occurs in numerous types of channels. Highly sinuous meandering channels may avulse due to insufficient sediment transporting capacity, which results in channel aggradation and further loss of channel capacity. Under equilibrium conditions, this is part of the normal process of meander development. The meander elongates due to erosion of the cut bank and deposition on the point bar; slope, velocity and sediment transport capacity are gradually reduced. During over-bank flows, the differential between the slope of the channel and the slope of the floodplain eventually results in headcutting through the floodplain, causing a meander cutoff (creating a variety of habitat, including backwater habitat, oxbow lakes and wetlands). Multiple-thread channels with high loads of coarse sediment and debris are prone to blockage at the locations where flows split. This causes frequent shifting of the dominant thread, and less frequently, development of new channels across the floodplain as flows are forced over-bank by in-channel aggradation. Finally, all channels are prone to avulsion if they become perched relative to their floodplains. This is common in alluvial-fan environments or along relocated channel segments.

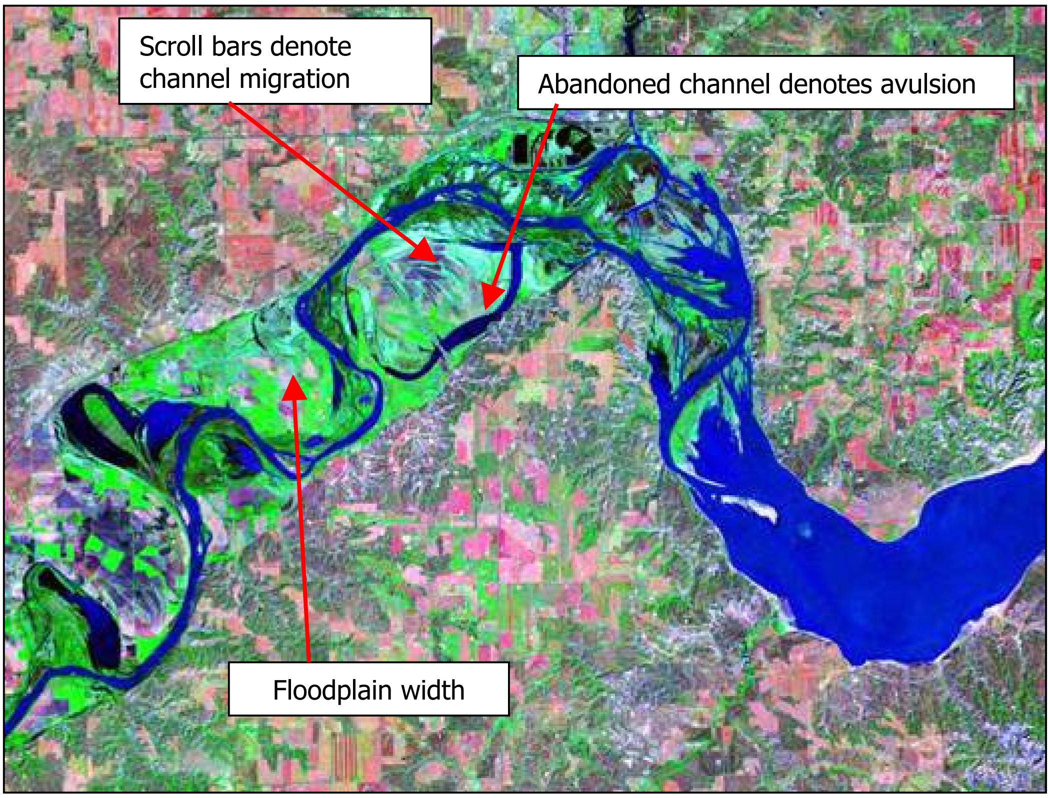


Figure 2.10 Channel migration and avulsion

2.3.4 Sediment Transport and River Geomorphology

The river geomorphology responses as described in the preceding section are mainly results of the sediment transport processes at the particular reach of the river. The source of sediment begins with the erosion of soil and rock in a watershed and transport of that material by surface runoff or by mass wasting. The transport of sediment through a river system consists of multiple erosion and deposition cycles, as well as progressive physical breakdown of the material. Many sediment particles are intermittently stored in alluvial deposits along the channel margin or floodplain, and ultimately re-entrained via bank and bed erosion. Total sediment loads consist of suspended load (the fine-grained fraction transported in the water column) and bed load (the coarse-grained fraction transported along the channel bed). The transport of sediment through the river system depends on the sediment supply (size and quantity) and the ability of the river to transport that sediment supply. Sediment transport and storage are among the major interdependent variables that determine river geomorphology. Many channel features, including deposition bars, riffles, and dunes are manifestations of sediment transport and storage. Table 2.1 lists typical features and associated sediment transport characteristics for the seven basic channel types defined by Montgomery and Buffington [8].

Table 2.1 Channel types, characteristic features and corresponding sediment transport processes based on Montgomery and Buffington[8].

Channel Type	*Characteristic Features*	*Corresponding Sediment Transport Processes*
Cascade	• Disorganized bed material typically consisting of cobbles and boulders • Small, irregularly spaced pools less than a channel width apart	• Large, bed-forming materials typically become mobile only in large flood events (i.e., 50-100yr events) • Gravel in low energy sites are transported by lesser floods • Sediment conditions are probably supply-limited
Step Pool	• Discrete steps formed by large-diameter material separating pools containing finer materials • Poor lengths generally equal to 1-4 channel widths	• Like cascade channels, large, bed-forming materials typically become mobile only in large flood-events • Gravel stored in low energy sites is transported during lesser floods • Sediment conditions are probably supply-limited
Plane Bed	• Characterized by long stretches of featureless bed • Composed of sand to boulder sized materials (typically gravel to cobble)	• Seem to be a transitional state between sediment supply- and sediment transport-limited channel form
Pool Riffle	• Contain alternating topographic depressions (pools) and high points (bars and riffles) typically spaced 5-7 channels widths apart • Generally unconfined, with well-developed floodplains • Generally occur at moderate to low gradients • Substrate varies from sand to cobble (typically gravel)	• Display both sediment supply- and transport-limited characteristics, but the presence of deposition bar forms suggest that they are more transport-limited than plane bed channels
Dune Ripple	• Typically low gradient, sand bed channels containing relatively mobile dunes, bed load sheets, and ripples	• Sediment conditions transport-limited
Bedrock	• Bedrock bed • Often, some alluvial material stored in scour holes and behind obstructions	• Generally reflect a high transport capacity relative to sediment supply or current lack of large roughness elements for sediment retention capacity
Colluvial	• Small headwater streams founded on colluvial fill	• Weak or ephemeral fluvial transport • Long-term sediment flux from these channels appears to be dominated by debris-flows

As seen in Table 2.1, the characteristic features of various channel types are often, to a great degree, the product of a balance between sediment supply and transport. For instance, cascade and step pool channel morphology is maintained by the stability of large, relatively immobile bed materials. Smaller bed material readily moves through these channels during lesser flow events. Such channels are considered to be in a sediment "supply-limited" state, meaning that only a relatively small amount of readily transportable sediment is available. In contrast, dune ripple channel morphology is indicative of a sediment "transport-limited" situation, in which transportable sediment is readily available, and equilibrium between sediment deposition and mobilization is established. Significant bed load transport occurs in dune ripple channels over a broad range of discharges, including relatively low flows. Plane bed and pool riffle morphologies include a mix of transport- and supply-limited characteristics, with the presence of deposition bars in pool riffle systems suggesting a tendency towards transport-limited conditions. Channel bars represent temporary sediment storage in the stream channel, and also represent the incipient floodplain that may become established if additional sediment is deposited on the bar and vegetation takes hold. Bedrock channels tend to be supply-limited, and alluvial materials tend to occur only in "shielded" areas such as scour holes and behind obstructions. However, in contrast to cascaded channels or step-pool channels, bedrock channels may owe their supply-limited character to a current lack of large form-resistant elements such as large wood that would retain alluvial sediment. Colluvial channels are strongly influenced by hill-slope processes, and the majority of long-term sediment flux from these channels appears to be the result of debris flows.

2.3.5 Sediment Transport Analysis

Sediment transport is one of the most important, but least evaluated components of natural stream channel design in bedrock dominated channels, alluvial channels, colluvial channels, and wood-controlled channels alike. As a design component, sediment transport analyses focus on providing for sediment continuity, a factor that is repeatedly cited as a condition for true channel stability. Channel stability in this context implies that there is no net aggradation or degradation of the channel bed, or more simply, that rates of sediment erosion and deposition are in approximate dynamic balance.

Sediment transport analyses pose many challenges. Most sediment transport analyses and design methods focus on channel competence, or the capability of a channel to transport bed material of a given size. Just as important as competence, but less frequently addressed, is consideration of the volume (capacity) of sediment that a channel is capable of transporting. Measurement and prediction of sediment mobility and transport volumes are notoriously difficult and, in most cases, inaccuracies can be in large orders of magnitude. Regression equations based on sufficient sampled data provide the most accurate rating curves of sediment discharge to stream flow. Whenever possible, sediment sampling data should be used to calibrate or aid in selection of transport equations. Model results tend to be more reliable as a comparative tool for "before" and "after" conditions rather than in determining absolute values. For this reason, results of analyses should, in general, be used comparatively rather than absolutely. A number of currently accepted sediment transport analysis approaches and techniques are presented below.

<u>Estimating Sediment Size</u> - Sediment transport evaluations generally begin with a determination of the size fractions of sediment present within a given reach of channel. The measurement of sediment calibre can be performed by several methods including sieve analyses, or settling experiments like the Visual Accumulation Tube (VAT) or the Bottom Withdrawal Tube (BWT). These methods are explained in detail in [3] Julien (1998). Sieve analysis is conducted on bulk samples taken from the field, and consists of sifting sediment through several standard sized sieves. The amount of sediment remaining on each sieve is then weighed to determine the percent of the total weight of a given size fraction. It is best to sample the armour or surface layer separately from the subsurface rather than mixing the two during volumetric sampling, as some transport models require one or the other. Volumetric sampling will always be necessary in cases where the dominant bed material is sand or finer. Other indirect methods include the less accurate pebble count method.

Pebble counts are based on analysis of the relative area covered by given sizes, and essentially consist of measuring the intermediate axis of 100 (or better, up to 400) individual sediment particles collected either at random or within a grid. This sample represents the armour layer, and the resulting particle size distribution will generally be coarser than the average bed material distribution. Hence, pebble counts tend to be biased towards larger particle sizes, and as such are well suited to hydraulic roughness determination, but underestimate the presence of smaller size fractions, which can make up an appreciable portion of the bed load even in gravel-bed streams. This is due to a "hiding factor" effect, whereby small particles lodge in crevices smaller than the fingertip, and a psychological tendency to chose a larger, more palpable particle during the sampling process.

<u>Incipient Motion of Sediment</u> - Sediment transport evaluations generally begin with a determination of the size fractions of sediment present within a given reach of channel as well as the hydraulic

characteristics of the channel. The measurement of sediment calibre can be performed by several methods including pebble counts, sieve analyses, or suspended sediment measurements (Sediment sampling is elaborated in Hydrology, Modelling and Flood Mitigation Manuals). Hence, the assessment of sediment mobility within a channel requires an understanding of the sediment size gradation present, as well as the transport energy available to mobilize that gradation. In many cases, the evaluation of the transport energy available to transport the size fraction present is deemed sufficient for channel design. This is referred to as "incipient mobility", and it addresses mobility purely in terms of sediment size mobilized, rather than sediment volume mobilized. In more complex cases, however, such as those in which the incoming sediment volumes are either excessively large or small, the more difficult calculation of transport volumes may be necessary. Sediment volume is typically a function of stream power, which represents the energy needed to transport sediment in a channel, or, equivalently, a function of hydraulic shear stress, which refers to the force on the streambed. Stream power is a representation of channel capacity, or the quantity of material that the flow is able to transport.

The coarse fraction of a given sediment gradation is generally not in motion under low flow conditions. As flow increases, the energy imparted on sediment increases until at some point, the particle is mobilized. The point at which a sediment particle is just set into motion is referred to as incipient motion, and the shear stress at incipient motion is called the critical shear stress. Particles start to move in steady, uniform flow when the shear stress applied by the flow equals the resistance to movement of the particles. A useful relation can be developed between the flow velocity, depth, and resistance and bed material size by equating the applied shear stress to the resistance at incipient motion. In equation form it is as follows:

$$\tau_o = \tau_c \tag{2.1}$$

Where:

τ_o = average bed shear stress, N/m^2,

τ_C = critical bed shear stress at incipient motion, N/m2,

The average bed shear stress applied by the steady uniform flow, is as follows:

$$\tau_o = \gamma R S_f \tag{2.2}$$

Using flow depth (y) for the hydraulic radius (R) and the Manning's Equation to determine the friction slope (S_f). The average shear stress can be expressed as follows:

$$\tau_o = \rho g y S_f = \frac{\rho g n^2 V^2}{y^{\frac{1}{3}}} \tag{2.3}$$

For non-cohesive bed materials, Shields Relation (Julien 1998) can be used to determine the relation between the critical shear stress and bed material size for the beginning of bed material movement. The relation is as follows:

$$\tau_C = K_s(\rho_s - \rho) g D \tag{2.4}$$

As a first approximation for gravels and cobbles, the critical shear stress varies linearly with grain diameter [3]. A particle diameter of 1 mm will move when the critical shear stress exceeds 1 Pa. At the beginning of sediment movement the applied shear stress is equal to the critical shear stress as given in Eq. 2.1, resulting in the following:

$$\frac{\rho g n^2 V^2}{y^{\frac{1}{3}}} = K_s(\rho_s - \rho) g D_s \tag{2.5}$$

where:

y	= average depth of flow, m
S_f	= slope of the energy grade line, m/m
V	= depth-average velocity, m/s
D_s	= diameter of bed material particle, m
γ	= specific weight of water (9,800 N/m^3)
n	= Manning's roughness coefficient (can be determined by Strickler equation)
K_s	= Shields' coefficient (approximately 0.03-0.047)
S_s	= specific gravity (2.65 for quartz)
ρ	= density of water (999 kg/m^3)
ρ_s	= density of sediment (2,647 kg/m^3 for quartz)
g	= acceleration of gravity (9.81 m/s^2)

Eq. 2.5 gives the fundamental relationship between velocity, depth, resistance to flow (Manning's n), density and a coefficient determined experimentally for the incipient movement of the sediment particles. In Eq. 2.5, reasonable values of Manning's n, specific gravity, and Shield's parameter are substituted to obtain equations for the dependent variables. These values are (1) Shield's parameter $K_s = 0.039$, (2) specific gravity $S_s = 2.65$, and (3) Manning's, $n = 0.041 D_s^{1/6}$. The equation can be solved for the following:

1. Critical velocity for beginning of bed material movement:

$$V_c = 6.19 D_S^{1/6} y^{1/3} \tag{2.6}$$

2. Critical size for the beginning of bed material movement :

$$D_c = \frac{0.042 V^3}{(y^{1/2})} \tag{2.7}$$

3. Depth of flow For no bed material movement as a function of V and D :

$$y = \frac{1.78 \times 10^{-5} V^6}{(D_s^{\,2})} \tag{2.8}$$

This equation is useful to determine clear water-scour at a contraction. This is particularly true if the velocity is converted to discharge using the continuity equation.

The derivations are given in sufficient detail so that engineers can also substitute other values for K_S, S_S and Manning's n to fit their specific data.

The empirical relation between dimensionless shear stress, F_* and Boundary Reynolds Number, Re_* shows the relation between critical shear stress to hydraulic and particle characteristics, which is known as Shield Diagram as presented in Figure 2.11.

Table 2.2 gives the permissible velocities recommended by Fortier and Scobey (1926)[14] for channels at small slope for bed material ranging from fine sand to cobbles. Table 2.3 gives non-scouring velocities for non-cohesive and compact cohesive soils suggested by Keown et al. (1977)[20] for bed material ranging from loess soils to boulders.

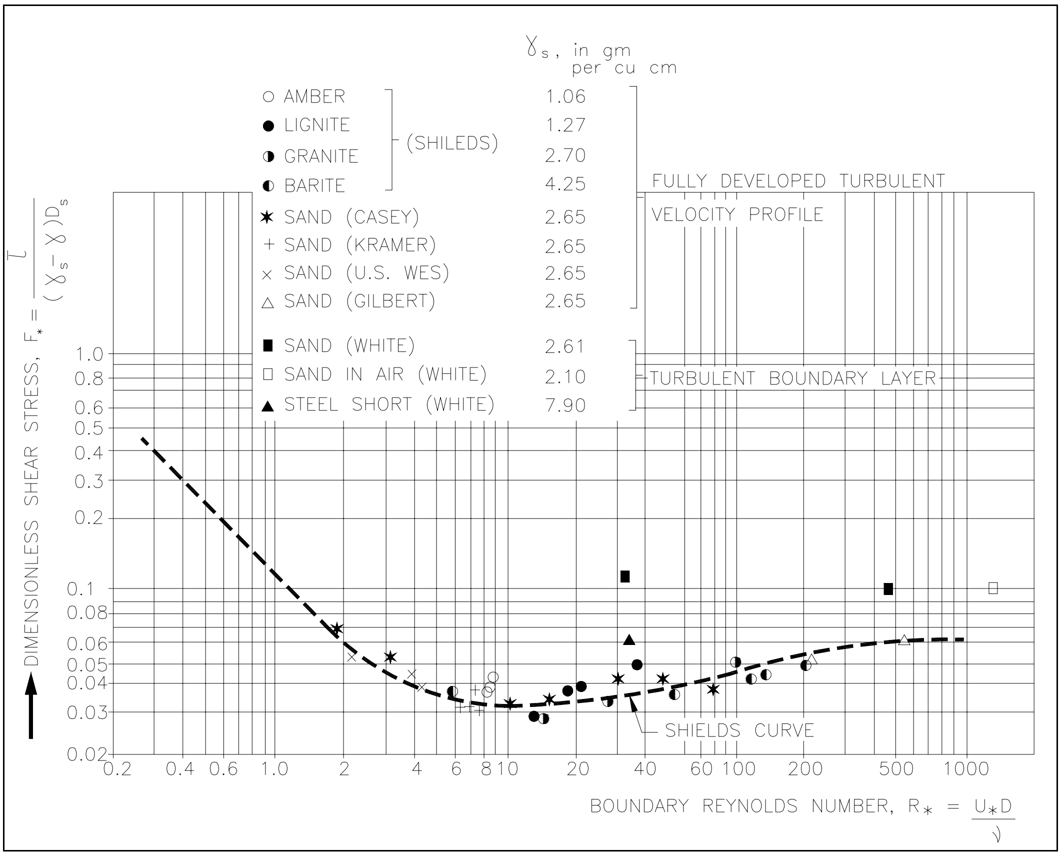


Figure 2.11 Shields Diagram: dimensionless critical shear stress from [16] or [3]

Table 2.2 Maximum Permissible Velocities Proposed by Fortier and Scobey (1926)[14]

		Mean Velocity, after aging of canals [y ≤ 0.9 m (3 ft)]					
Original Material excavated for canals	n	Clear water, no detritus		Water transporting colloidal silt		Water transporting non-colloidal silts, sands, gravels or rock fragments	
		ft/sec	m/sec	ft/sec	m/sec	ft/sec	m/sec
Fine sand (colloidal)	0.02	1.50	0.46	2.50	0.76	1.50	0.46
Sandy loam (non-colloidal)	0.02	1.75	0.53	2.50	0.76	2.00	0.61
Silt loam (non-colloidal)	0.02	2.00	0.61	3.00	0.91	2.00	0.61
Alluvial silt (non-colloidal)	0.02	2.00	0.61	3.50	1.07	2.00	0.61
Ordinary firm loam	0.02	2.50	0.76	3.50	1.07	2.25	0.69
Volcanic ash	0.02	2.50	0.76	3.50	1.07	2.00	0.61
Fine gravel	0.02	2.50	0.76	5.00	1.52	3.75	1.14
Stiff clay	0.025	3.75	1.14	5.00	1.52	3.00	0.91
Graded loam to Cobbles (non-colloidal)	0.03	3.75	1.14	5.00	1.52	5.00	1.52
Alluvial silt (colloidal)	0.025	3.75	1.14	5.00	1.52	3.00	0.91
Graded silt to cobbles (colloidal)	0.03	4.00	1.22	5.50	1.68	5.00	1.52
Coarse gravel (non-colloidal)	0.025	4.00	1.22	6.00	1.83	6.50	1.98
Cobbles and shingles	0.035	5.00	1.52	5.50	1.68	6.50	1.98
Shales and hard pans	0.025	6.00	1.83	6.00	1.83	5.00	1.52

Table 2.3 Non-scouring Velocities for Soils (Modified from a report by Keown et al. 1977[20])

Kind of Soil	Grain Dimensions		Approximate Non-scouring Velocities (meter per second)			
	(mm)	(ft)	Mean Depth (m)			
			0.40 m	1.01 m	2.01 m	2.99 m
For Non-cohesive Soils						
Boulders	>256	>0.840	4.60	5.09	5.79	6.19
Large cobbles	256 - 128	0.840 - 0.420	3.60	4.09	4.70	5.00
Small cobbles	128 - 64	0.420 - 0.210	2.29	2.71	3.11	3.41
Very coarse gravel	64 - 32	0.210 - 0.105	1.59	1.89	2.20	2.50
Coarse gravel	32 - 16	0.105 - 0.0525	1.25	1.43	1.65	1.86
Medium gravel	16 - 8.0	0.0525 - 0.0262	1.01	1.13	1.25	1.40
Fine gravel	8.0 - 4.0	0.0262 - 0.0131	0.79	0.91	1.01	1.16
Very fine gravel	4.0 - 2.0	0.0131 - 0.00656	0.67	0.76	0.85	0.95
Very coarse sand	2.0 - 1.0	0.00656 - 0.00328	0.55	0.64	0.73	0.82
Coarse sand	1.0 - 0.50	0.00328 - 0.00164	0.46	0.55	0.64	0.70
Medium sand	0.50 - 0.25	0.00164 - 0.000820	0.37	0.46	0.55	0.61
Fine sand	0.25 - 0.125	0.000820 - 0.000410	0.30	0.40	0.49	0.55
For Compact Cohesive Soils						
Sandy loam (heavy)			1.01	1.19	1.40	1.49
Sandy loam (light)			0.95	1.19	1.40	1.49
Loess soils in the Conditions of finished Settlement			0.79	1.01	1.19	1.31

<u>Sediment Transport Equation and Modelling</u>

Sediment size and incipient motion particle size are relatively easy to characterize from deposited bed sediments and hydraulic analysis. However, sediment volume is much more difficult to quantify. Sediment volume is typically calculated using sediment transport equations, which are notoriously inaccurate. There are numerous sediment transport equations, each of which developed for specific types of conditions and purposes. As such, they are only applicable to specific types of channels. The applicability of most of these equations is related to the local bed particle size. Whenever possible, the use of measured sediment loads for testing and calibration of the chosen equation(s) is preferred. Actual equations and detailed descriptions are available in standard sediment transport textbooks. Several equations for bed load, suspended load and total load are also presented in Julien (1998) [3].]. In Malaysia, examples of sediment measurement techniques for bed material samples, near-bed sediment transport with Helley Smith samplers and suspended sediment transport with point samplers can be found in REDAC (2006) [43].

In addition to the specific sediment transport equations, there are several sediment transport numerical models available for use in river engineering applications. The most common approach to sediment transport modelling is a steady state, one-dimensional approach. Using channel dimensions, flow conditions and sediment characteristics, the model performs hydraulic calculations, and then calculates sediment loads for each of the channel reaches. Based on the quantity of sediment transported for the given flow, the channel elevation (i.e., slope) is adjusted via a routing scheme. The programme either performs calculations for a given range of flows, or for a given flow. The model continues until there are no more channel adjustments (i.e., equilibrium conditions).

The next level of modelling is the semi two-dimensional modelling approach in which a similar coupled hydraulic and sediment routing scheme is used, but at the end of the routing run, an estimate is made as to whether or not channel width adjustments are appropriate. The third level of modelling is the fully two-dimensional or three-dimensional modelling approaches. These models represent significant improvements in describing fluvial erosion and hydraulic processes, but involve a significant increase in the level of effort needed both in terms of data and analysis requirements beyond current capability. In fact, while utilization of 2-D modelling is beginning to become more widespread for large projects, application of 3-D modelling continues to be impractical due to technological limits such as computer capabilities and high input requirements.

Modelling of sediment transport remains one of the central thrusts of fluvial geomorphic and hydraulic research. It is likely that quantification of sediment volume will eventually become a routine part of channel design once the limitations of sampling and characterization are reduced. Presently, however, the scope of many project design efforts does not include an analysis of sediment transport volume, and quantifying sediment transport remains one of the greatest challenges of, and limitations to, river channel design. The details of the sediment transport classification and equations are given as follows;

i) Sediment Transport Classification

To study sediment transport processes it is possible to classify the transport processes according to origin and mechanisms as in the following scheme (Figure 2.12: Jansen et al., 1979):

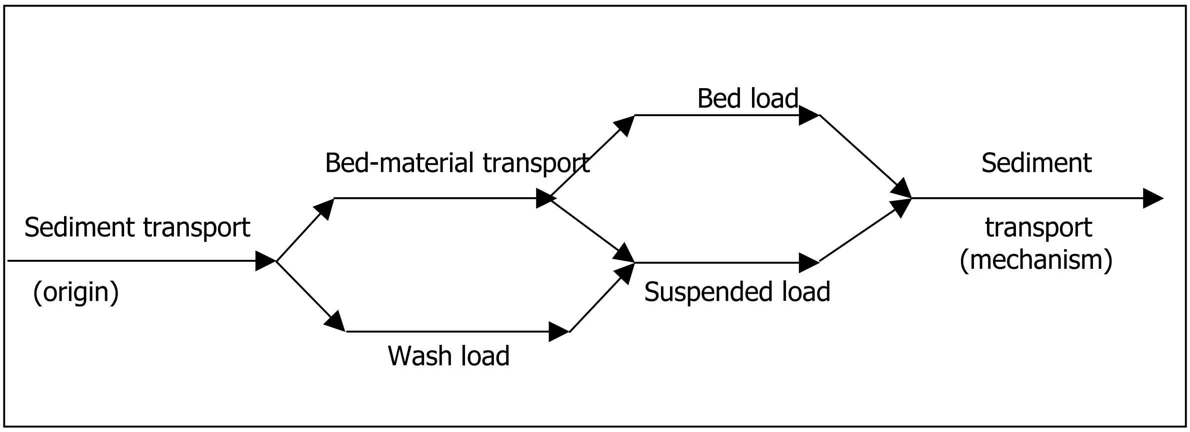


Figure 2.12 Sediment Transport Classifications

ii) Transport formula of Meyer-Peter and Műller (1984)

The empirical formula of Meyer-Peter and Műller (MP-M) for bed-load transport is written as

$$\phi_s = 8(\psi - 0.047)^{3/2} \tag{2.09}$$

With $\mu = \left(C/C_{90} \right)^{3/2}$ (ripple factor) (2.10)

$$\phi_s = \frac{s}{D^{3/2}\sqrt{g\Delta}} \quad \text{(transport parameter)} \tag{2.11}$$

$$\psi = \mu\theta = \frac{\mu hi}{\Delta D} \quad \text{(flow parameter)} \tag{2.12}$$

$$D = \overline{\overline{D}} = \frac{\sum (p_i D_i)}{\sum pi} \tag{2.13}$$

$$C_{90} = 18 \cdot \log(12h/D_{90}) \tag{2.14}$$

Where,

i = energy gradient (bed gradient in case of uniform flow conditions)

s = bed-load transport per unit of width (without pores, otherwise multiply with $1/(1-\varepsilon_p)$ 1.66

D = Characteristic grain size

Re_* = Particle Reynolds number

u_* = Shear velocity = $(\tau/\rho)^{1/2} = u \cdot g^{1/2} / C = \sqrt{ghi}$

Δ = relative density = $(\rho_s - \rho)/\rho \approx 1.65$ for quartz

ν = kinematic viscosity, usually $1.10^{-6}\ m^2/s$

ρ = density of water 1000 kg/m³

ρ_s = density of sediment 1650 kg/m³ for quartz

θ = shield parameter

ε_p = porosity (void volume/total volume) (for sand 0.4 ± 0.05)

It is valid for situations in which $w_s/u_*>1$, $D_m>0.4$ mm, and $\mu\theta<0.2$.

For the MP-M formula an approximate power functions $s = m\ u^n$ can be defined, with n equal to

$$n = \frac{3}{1 - 0.047\psi^{-1}} \tag{2.15}$$

Note: can only be used if C-value is known.

iii) Transport formula of Engelund and Hansen (1967)

The formula of Engelund and Hansen (1967) for total (bed- and suspended bed-material load) Is written as:

$$\phi_s = 0.05\psi^{5/2} \tag{2.16}$$

With

$$\mu = (C^2 / g)^{2/5} \quad \text{(ripple factor)} \tag{2.17}$$

$$\phi_s = \frac{s}{D_{50}^{3/2}\sqrt{g\Delta}} \quad \text{(transport parameter)} \tag{2.18}$$

$$\psi = \mu\theta = \frac{\mu hi}{\Delta D_{50}} \quad \text{(flow parameter)} \tag{2.19}$$

i = energy gradient (bed gradient in case of uniform flow conditions)
s = bed-load transport per unit of width (without pores, otherwise multiply with $1/(1-\varepsilon_p) \approx 1.66$

The formula can also be written as (useful for unsteady flow):

$$\frac{s}{\sqrt{g\Delta D^3}} = 0.05\left(\frac{u_*}{\sqrt{g\Delta D}}\right)^3\left(\frac{u}{\sqrt{g\Delta D}}\right)^2 \tag{2.20}$$

Engelund and Hansen is valid for situations in which $w_s/u_*<1$, $0.19<D_{50}<0.93$ mm, and $0.07<\theta<6$.

iv) Transport formula of van Rijn (1984)

The transport formula of van Rijn (1984) distinguishes between a bed-load part (s_b) and a suspended-load part (s_s):

$$s = s_b + s_s \tag{2.21}$$

A transport stage parameter T is defined as:

$$T = \frac{\tau'_b - \tau_{b\,cr}}{\tau_{b\,cr}} \tag{2.22}$$

with

τ'_b = bed-shear related to grains

$\tau_{b\,cr}$ = critical bed-shear according of the Shields curve

A dimensionless particle parameter D_* is defined as

$$D_* = D_{50}\left(\frac{\Delta g}{\nu^2}\right)^{\frac{1}{3}} \tag{2.23}$$

Bed shear τ'_b is written, with C′ = C_{90} (see Meyer-Peter and Műller) as

$$\tau'_b = \left(\frac{C}{C'}\right)^2 \tau_b \tag{2.24}$$

Bed-load transport then follows from

$$\phi_b = 0.053\frac{T^{2.1}}{D_*^{0.3}} \qquad \text{for } T < 3 \tag{2.25}$$

$$\phi_b = 0.1\frac{T^{1.5}}{D_*^{0.3}} \quad \text{for } T \geq 3 \tag{2.26}$$

With a transport parameter

$$\phi_b = \frac{s_b}{\sqrt{g\Delta D_{50}^3}} \tag{2.27}$$

And s_b is bed-load transport without pores.

Suspended-load transport then follows from

$$s_s = Fuhc_a \tag{2.28}$$

with
u = depth-averaged flow velocity
h = water depth
F = integration factor
C_a = reference concentration at level z_a measured from the bed

The reference concentration (excluding pores) is written as

$$C_a = 0.015\frac{D_{50}}{a}\frac{T^{1.5}}{D_*^{0.3}} \tag{2.29}$$

And the integration factor is written as:

$$F = \frac{\left(\frac{a}{h}\right)^{z'} - \left(\frac{a}{h}\right)^{1.2}}{\left(1 - \frac{a}{h}\right)^{z'} (1.2 - Z')} \qquad (2.30)$$

in which

$$Z' = \frac{w_s}{\left(1 + 2\left(\frac{w_s}{u_*}\right)^2\right) k u_*} + 2.5\left(\frac{w_s}{u_*}\right)^{0.8}\left(\frac{c_a}{1-\varepsilon_p}\right)^{0.4} \quad \text{for } 0.01 \le \frac{w_s}{u_*} \le 1 \qquad (2.31)$$

The fall velocity w_s is computed from the representative grain size of suspended sediment, following from

$$\frac{D_s}{D_{50}} = 1 + 0.011\left(\frac{1}{2}\left(\frac{D_{84}}{D_{50}} + \frac{D_{50}}{D_{16}}\right) - 1\right)(T - 25) \qquad (2.32)$$

v) Transport formula of Ackers and White (1973)

Transport formula of Ackers and White (1973) starts from the definition of D_{gr}:

$$D_{gr} = D_{35}\left[\frac{g\Delta}{v^2}\right]^{1/3} \qquad (2.33)$$

for coarse sediment, which is only considered here if $D_{gr}>60$.

Then can be deduced that

$$G_{gr} = 0.025\left[\frac{F_{gr}}{0.17} - 1\right]^{1.5} \qquad (2.34)$$

With

$$F_{gr} = \frac{1}{\sqrt{g\Delta D_{35}}} \frac{u}{\sqrt{32}\log\frac{10h}{D_{35}}} \qquad (2.35)$$

and

$$X_* = \frac{(\Delta + 1)D_{35}G_{35}}{h}\left\{\frac{C}{\sqrt{g}}\right\} \qquad (2.36)$$

and finally

$$s = \frac{X_* q \rho}{\rho_s (1 - \varepsilon)} \quad \text{with} \quad \varepsilon \approx 0.4 \qquad (2.37)$$

2.3.6 River Classification Systems

In planning a project along a river or stream, awareness of the fundamentals of fluvial geomorphology and channel processes allows the investigator to see the relationship between form and process in the landscape. The detailed study of the fluvial geomorphic processes in a channel system is often referred to as a geomorphic assessment. The geomorphic assessment provides the process-based framework to define past and present watershed dynamics, develop integrated solutions, and assess the consequences of restoration activities. A geomorphic assessment generally includes data collection, field investigations, and channel stability assessments. It forms the foundation for analysis and design and is therefore an essential first step in the design process, whether planning the treatment of a single reach or attempting to develop a comprehensive plan for an entire watershed.

The use of any stream classification system is an attempt to simplify complex relationships between streams and their watersheds. Although classification can be used as a communication tool and as part of the overall restoration planning process, the use of a classification system is not required to assess, analyze, and design stream restoration initiatives. The design of a restoration does, however, require site-specific engineering analyses and biological criteria. More recent attempts to develop a comprehensive stream classification system have focused on morphological forms and processes of channels and valley bottoms, and drainage networks.

Classification systems might be categorized as systems based on sediment transport processes and systems based on channel response to perturbation. Stream classification methods are related to fundamental variables and processes that form streams. Streams are classified as either alluvial or non-alluvial. An alluvial stream is free to adjust its dimensions, such as width, depth, and slope, in response to changes in watershed sediment load. The bed and banks of an alluvial stream are composed of material transported by the river under present flow conditions. Conversely, a non-alluvial river, like a bedrock-controlled channel, is not free to adjust. Other conditions, such as a high mountain stream flowing in very coarse deposited materials or streams which are significantly controlled by fallen timber, would suggest a non-alluvial system.

Advantages of Stream Classification Systems

The following are some advantages of stream classification systems :

- Classification systems promote communication among persons trained in different resource disciplines;
- They also enable extrapolation of inventory data collected on a few channels of each stream class to a much larger number of channels over a broader geographical area;
- Classification helps the restoration practitioner consider the landscape context and determine the expected range of variability for parameters related to channel size, shape, and pattern and composition of bed and bank materials;
- Stream classification also enables the practitioner to interpret the channel forming or dominant processes active at the site, providing a base on which to begin the process of designing restoration;
- Classified reference reaches can be used as the stable or desired form of the restoration; and
- A classification system is also very useful in providing an important cross-check to verify if the selected design values for width/depth ratio, sinuosity, etc., are within a reasonable range for the stream type being restored.

Limitations of Stream Classification Systems

All stream classification systems have limitations that are inherent to their approaches, data requirements, and range of applicability. They should be used very cautiously and only for establishing some of the baseline conditions on which to base initial restoration planning. Standard engineering design techniques should never be replaced by stream classification alone. Some limitations of classification systems are as follows:

- Determination of bankfull or channel forming flow depth may be difficult or inaccurate. Field indicators are often subtle or missing and are not valid if the stream is not stable and alluvial;
- The dynamic condition of the stream is not indicated in most classification systems. The knowledge of whether the stream is stable, aggrading, or degrading or is approaching a critical geomorphic threshold is important for a successful restoration initiative;
- River response to a perturbation or restoration action is normally not determined from the classification system alone;

- Biological health of a stream is cannot be determined through a stream classification system; and
- A classification system alone should not be used for determining the type, location, and purpose of restoration activities.

When the results of stream classification will be used for planning or design, the field data collection should be performed or directed by persons with experience and training in hydrology, hydraulics, terrestrial and aquatic ecology, sediment transport, and river mechanics. Field data collected by personnel with only limited formal training may not be reliable, particularly in the field determination of bankfull indicators and the assessment of channel instability trends.

<u>Stream Classification Systems</u>

Stream Order

Designation of stream order, using the Strahler (1957) method, is dependent on the scale of maps used to identify first-order streams. It is difficult to make direct comparisons of the morphological characteristics of two river basins obtained from topographic maps of different scales. Hence, stream order is of little help to planners and designers looking for clues to restore hydrologic and geomorphic functions to stream corridors.

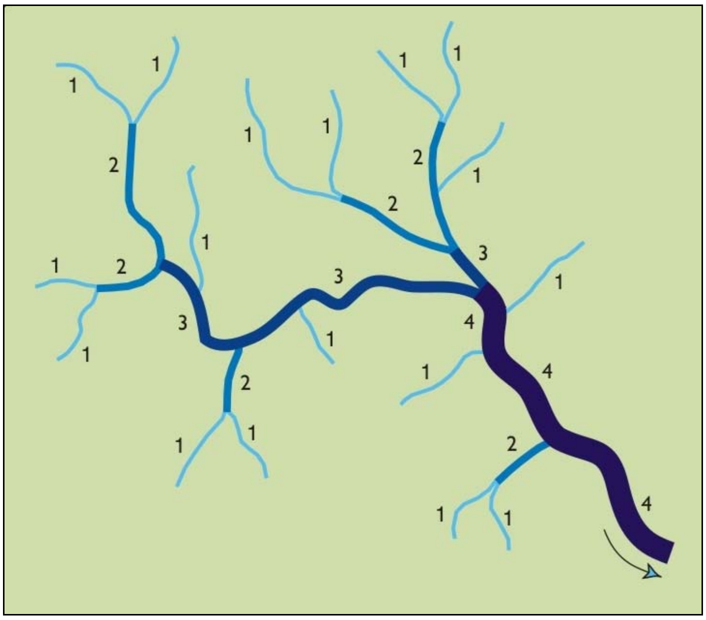


Figure 2.13 Stream ordering in a drainage network

Figure 2.13 shows a method of classifying, or ordering, the hierarchy of natural channels in a watershed or basin from first-order streams down to fourth-order stream.

Schumm

Other classification schemes combine morphological criteria with dominant modes of sediment transport. [9] Schumm (1977) identified straight, meandering, and braided channels and related both channel pattern and stability to modes of sediment transport (Figure 2.14). Schumm recognized relatively stable, straight and meandering channels, with predominantly suspended sediment load and cohesive bank materials. On the other end of the spectrum are relatively unstable, braided streams characterized by predominantly bed-load sediment transport and wide, sandy channels with non-cohesive bank materials. The intermediate condition is generally represented by meandering mixed-load channels.

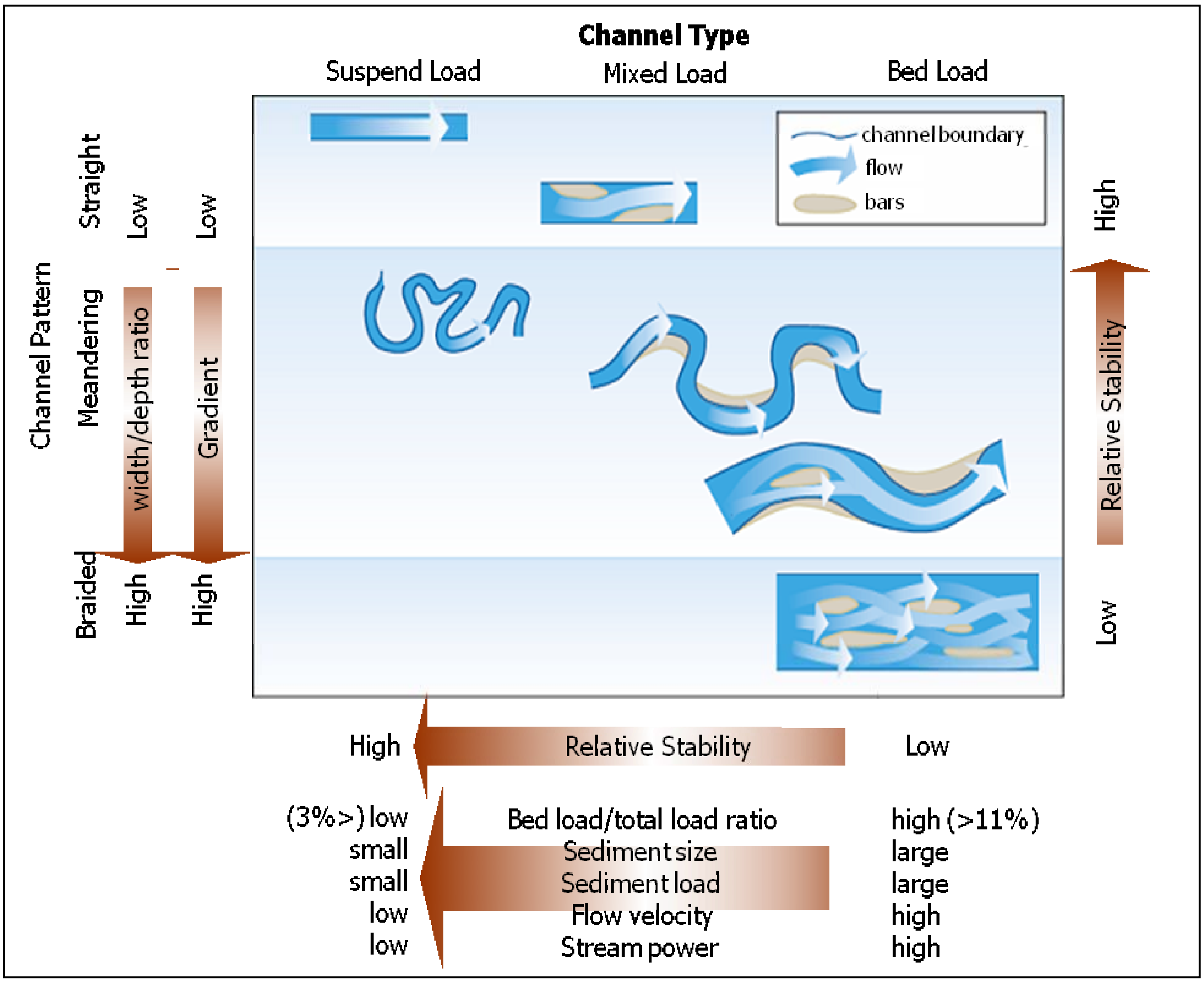
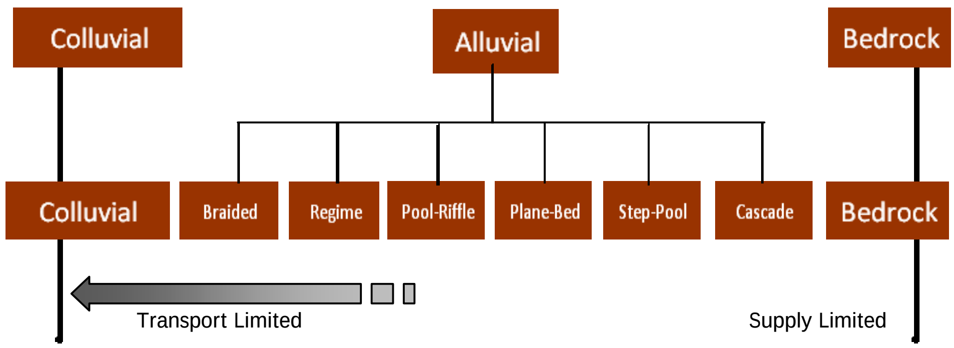


Figure 2.14 Classification of alluvial channels. [9]

Montgomery and Buffington

Schumm's classification system primarily applies to alluvial channels; [8] Montgomery and Buffington (1993) have proposed a similar classification system for alluvial, colluvial, and bedrock streams in the Pacific Northwest that addresses channel response to sediment inputs throughout the drainage network. Montgomery and Buffington recognize six classes of alluvial channels—cascaded, step-pool, plane bed, riffle-pool, regime, and braided included classification for non-alluvial streams (Figure 2.15). The stream types are differentiated on the basis of channel response to sediment inputs, with steeper channels (cascaded and step-pool) maintaining their morphology while transmitting increased sediment loads, and low gradient channels (regime and riffle-pool) responding to increased sediment through morphological adjustments. In general, steep channels act as sediment delivery conduits connecting zones of sediment production with low-gradient response channels.



	Braided	Regime	Pool- Riffle	Plane- Bed	Step- Pool	Cascade	Bedrock	Colluvial
Typical Bed Material	Variable	Sand	Gravel	Gravel, cobble	Cobble, boulder	Boulder	N/A	Variable
Bedform Pattern	Laterally oscillary	Multi-layered	Laterally oscillary	None	Vertically oscillary	None	.	Variable
Reach Type	Respone	Respone	Respone	Respone	Transport	Transport	Transport	Source
Dominant Roughness Elements	Bedforms (bars, pools)	Sinuosity, bedforms (dunes, ripples, bars) banks	Bedforms (bars, pools), grains, LWD, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, LWD, banks	Grains, banks	Boundaries (bed & banks)	Grains, LWD
Dominant Sediment Sources	Fluvial, bank failure, debris flow	Fluvial, bank failure, inactive channel	Fluvial,bank failure, inactive channel, debris flow	Fluvial, bank failure, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Hillslope, debris flow
Sediment Storage Elements	Overbank, bedforms	Overbank, bedforms, inactive channel	Overbank, bedforms, inactive channel	Overbank, inactive channel	Bedforms	Lee & stoss sides of flow obstructions		Bed
Typical Slope (m/m)	S < 0.03	S < 0.001	0.001 < S and S < 0.02	0.01 < S and S < 0.03	0.03 < S and S < 0.08	0.08 < S and s < 0.30	Variable	S > 0.20
Typical Confinement	Unconfined	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Pool Spacing (Channel Widths)	Variable	5 to 7	5 to 7	none	1 to 4	< 1	Variable	Variable

Figure 2.15 Suggested stream classification system for Pacific Northwest. [8]

Rosgen Stream Classification System

One comprehensive stream classification system in common use is based on morphological characteristics described by Rosgen (1996)[12] (Figure 2.16). The Rosgen system uses six morphological measurements for classifying a stream reach - entrenchment, width/depth ratio, sinuosity, number of channels, slope, and bed material particle size. These criteria are used to define eight major stream classes with about 100 individual stream types.

Rosgen uses the bankfull discharge to represent the stream-forming discharge or channel-forming flow. Bankfull discharge is needed to use this classification system because all of the morphological relationships are related to this flow condition; for example width and depth of flow are measured at the bankfull elevation. Except for entrenchment and width/depth ratio (both of which depend on a determination of bankfull depth), the parameters used are relatively straightforward measurements.

The width/depth ratio is taken at bankfull stage and is the ratio of top width to mean depth for the bankfull channel. Sinuosity is the ratio of stream length to valley length or, alternatively, valley slope to stream slope. The bed material particle size used in the classification is the dominant bed surface particle size. Stream slope is measured over a channel reach of at least 20 top widths in length.

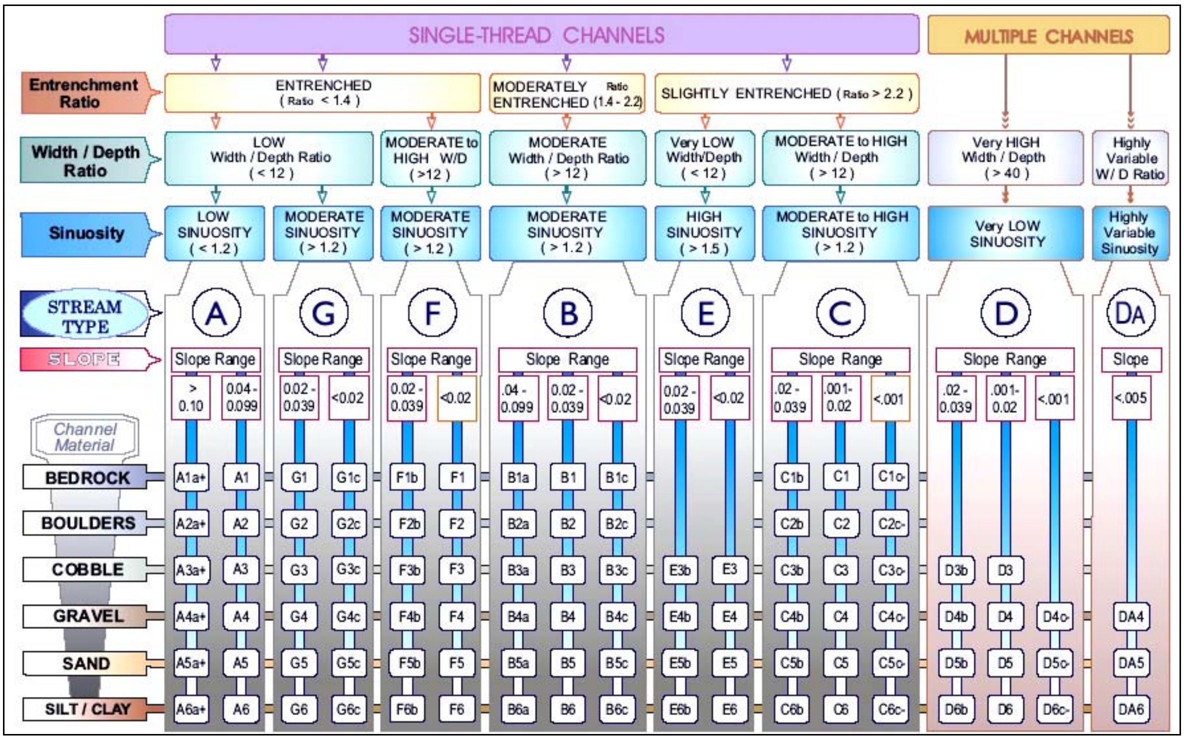


Figure 2.16 Rosgen's stream channel classification system (Level II). [12]

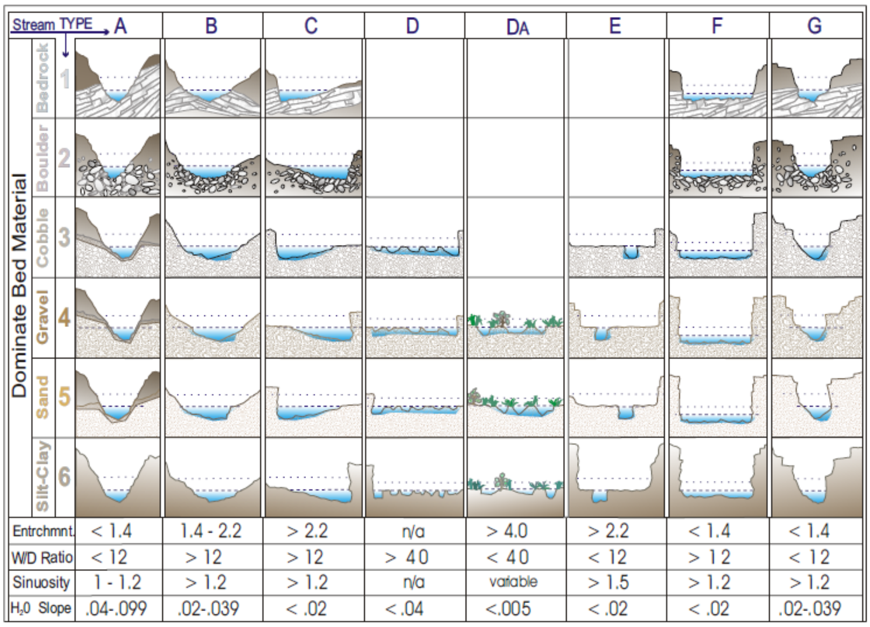


Figure 2.17 Channel Entrenchment

Entrenchment describes the relationship between a stream and its valley and is defined as the vertical containment of the stream and the degree to which it is incised in the valley floor (Figure 2.17). It is, therefore, a measure of how accessible a floodplain is to the stream. The entrenchment ratio used in the Rosgen classification system is the flood-prone width of the valley divided by the bankfull width of the channel.

Flood-prone width is determined by doubling the maximum depth in the bankfull channel and measuring the width of the valley at that elevation. If the flood-prone width is greater than 2.2 times the bankfull width, the stream is considered to be slightly entrenched or confined and the stream has ready access to its floodplain. A stream is classified as entrenched if its flood-prone width is less than 1.4 times the bankfull width. The method of Rosgen has been severely criticized recently and should be used with caution.

Brice and Blodgett

Brice and Blodgett (1978)[13] developed a simple classification scheme oriented primarily towards lateral stability of rivers. The common geomorphic terms for the various types of streams (e.g., meandering, braided) are shown in Figure 2.18. Each term is defined on the small sketches. This classification is also used in HEC-20 (Lagasse et al. 2001)[21] and [22] as a basis for identifying geomorphic factors important to stream stability analyses.

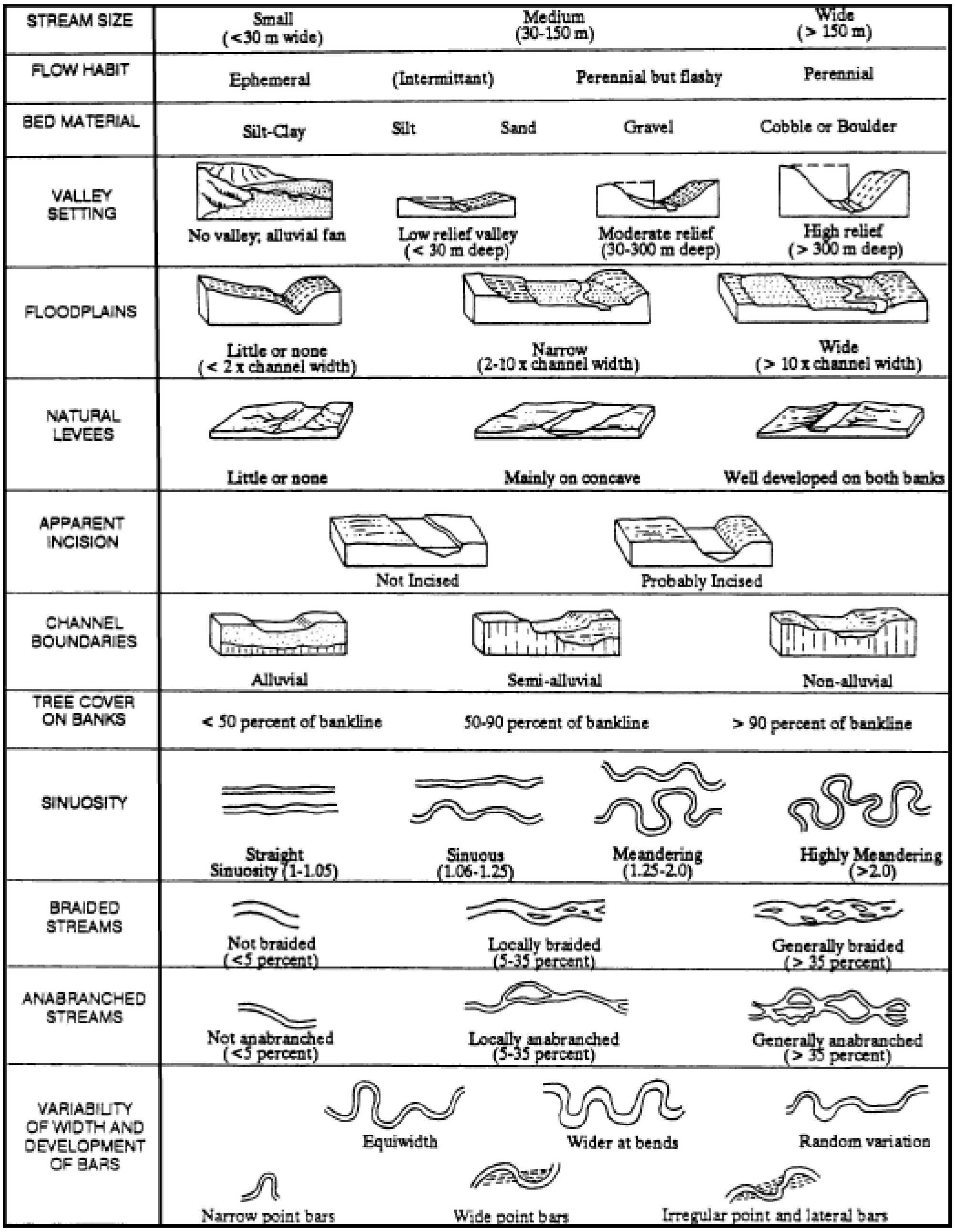


Figure 2.18 Stream properties for classification [13].

Culbertson et al. 1967[24]

Additional information on specific channel features is illustrated in Figure 2.19. Classification based on oxbow lakes is illustrated in Figure 2.19a. In Figure 2.19b, the types of meander scroll formations are shown. By studying scroll formations in terms of age of vegetation, the rate and direction of channel migration can be quantified. The sinuosity index is the ratio of the length of the watercourse to the valley length between the same points. Classification based on natural levees is illustrated in Figure 2.19c. Well-developed levees are associated with older rivers. The floodplain that is broad in relation to the channel width is indicative of an older river. When the river valley is narrow and confined by terraces or valley walls, the river is usually mature. In general, the growth of vegetation (tree cover) is indicative of the presence of silt and clay in the riverbanks and the floodplain. This is particularly true if the floodplain is well drained. With good drainage, the silt and clay are essential to the growth of vegetation because of their water holding capability.

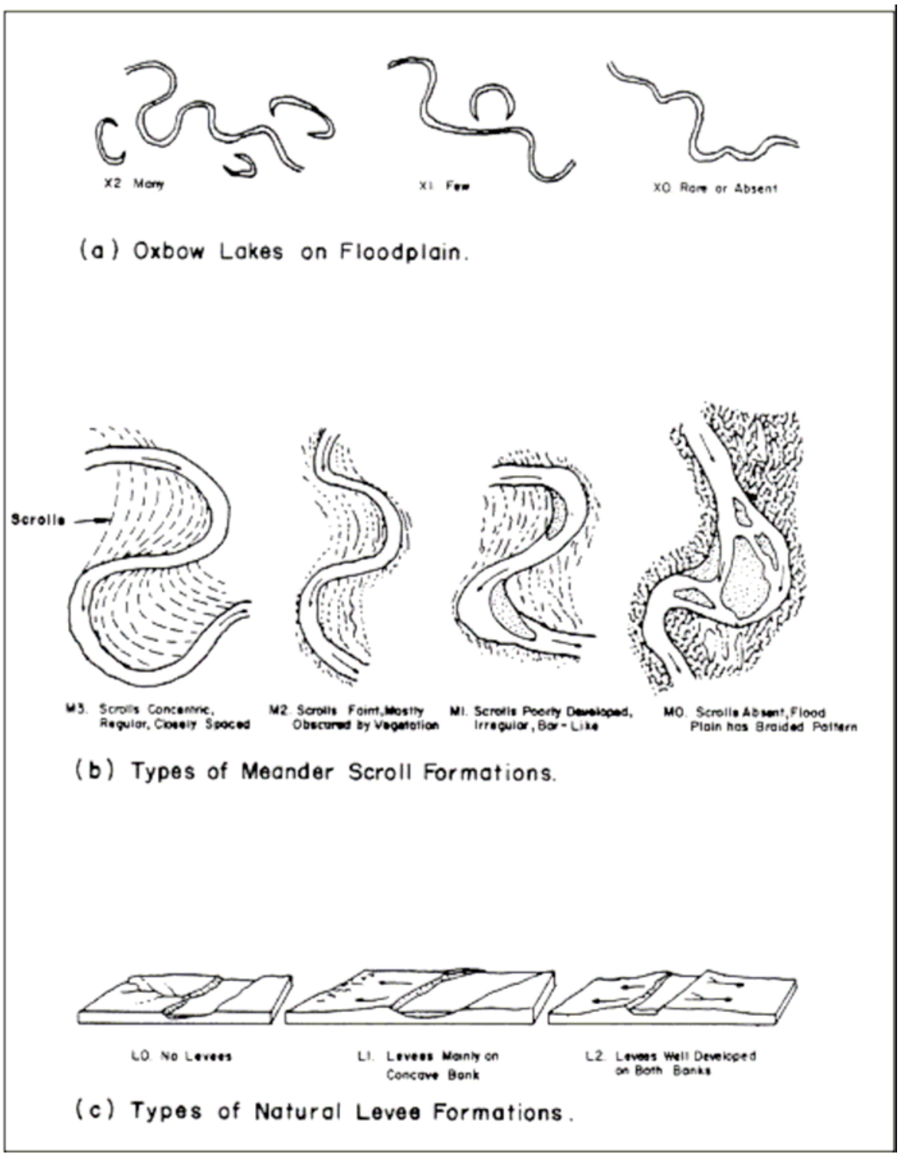


Figure 2.19 Classification of river channels. [24]

Channel Evolution Models

Conceptual models of channel evolution describe the sequence of changes a stream undergoes after certain kinds of disturbances have taken place. The changes can include increases or decreases in the width/depth ratio of the channel and also involve alterations in the floodplain. The sequence of changes is somewhat predictable; so it is important that the current stage of evolution be identified in order that appropriate actions can be planned. [15] Schumm et al. (1984), [18] Harvey and Watson (1986), and [17] Simon (1989) have proposed similar channel evolution models due to bank collapse based on a "space-for-time" substitution, whereby downstream conditions are interpreted as preceding (in time) the immediate location of interest and upstream conditions are interpreted as following (in time) the immediate location of interest. Thus, a reach in the middle of the watershed that previously looked like the channel upstream will evolve to look like the channel downstream. Downs (1995) reviewed a number of classification schemes for interpreting channel processes of lateral and vertical adjustment (i.e., aggradation, degradation, bend migration and bar formation). When these adjustment processes are placed in a specific order of occurrence, a channel evolution model (CEM) is developed.

The models of ([15] Schumm et al. (1984) and [17] Simon (1989 & 1995) have gained wide acceptance as being generally applicable for channels with cohesive banks. Both models begin with a predisturbance condition, in which the channel is well vegetated and has frequent interaction with its floodplain. Following a perturbation in the system (e.g., channelization or change in land use), degradation occurs, usually as a result of excess stream power in the disturbed reach. Channel degradation eventually leads to over steepening of the banks, and when critical bank heights are exceeded, bank failures and mass wasting (the episodic down slope movement of soil and rock) lead to channel widening. As channel widening and mass wasting proceed upstream, an aggradation phase follows in which a new low-flow channel begins to form in the sediment deposits. Upper banks may continue to be unstable at this time. The final stage of evolution is the development of a channel within the alluvium deposit with dimensions and capacity similar to those of the predisturbed channel (Downs 1995). The new channel is usually lower than the predisturbed channel, and the old floodplain now functions primarily as a terrace. Once stream banks build up sufficiently high, either by down cutting or by sediment deposition on the floodplain, they begin to fail due to a combination of erosion at the base of the banks and mass wasting. The channel continues to widen until flow depths are less than the depths required to move the sloughed bank materials. Sloughed materials at the base of the banks may begin to be colonized by vegetation. The added roughness helps increase deposition at the base of the banks, and a new small-capacity channel begins to form between the stabilized sediment deposits. The final stage of channel evolution results in a new bankfull channel and new active floodplain at a lower elevation. The original floodplain has been abandoned due to channel incision or excessive sediment deposition and is now termed a terrace. [15] Schumm et al. (1984) applied the basic concepts of channel evolution to the problem of unstable channelized streams in Mississippi. [17] Simon (1989) built on Schumm's work in a study of channelized streams in Tennessee. Simon's CEM consisted of six stages. A disturbed or unstable stream is in varying stages of disequilibrium along its length or profile. A channel evolution model theoretically may help predict future upstream or downstream changes in habitat and stream morphology (Figure 2.20). Both models use cross sections, longitudinal profile, and geomorphic processes to distinguish stages of evolution. Both models were developed for landscapes dominated by streams with cohesive banks. However, the same physical processes of evolution can occur in streams with non-cohesive banks, though not necessarily in the same well-defined stages outlined in Table 2.4.

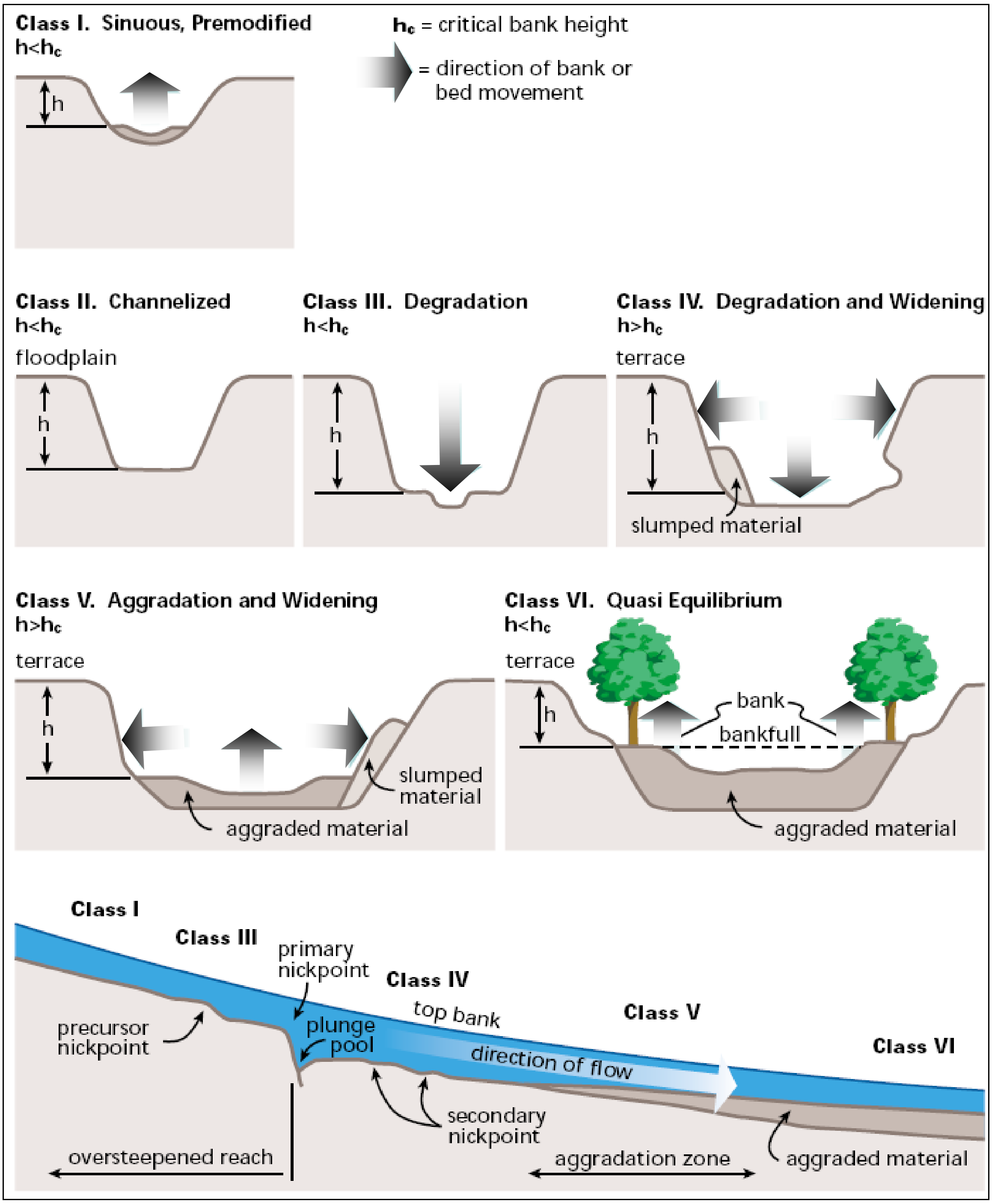


Figure 2.20 Channel evolution model. [17]

Table 2.4 Dominant hill-slope and in stream processes, characteristic cross section shape and bedforms, and condition of vegetation in the various stages of channel evolution. Source: Simon 1989.

Class		Dominant Processes		Characteristics Forms	Geobotanical Evidence
No.	Name	Fluvial	Hillslope		
I	Premodified	Sediment transport- mild aggradation; basal erosion an outside bends; deposition on inside bends		Stable, alternate channel bars; convex top-bank; flow line high relative to top bank; channel straight or meandering.	Vegetated banks to flow line.
II	Constructed			Trapezoidal cross section; linear bank surfaces; flow line lower relative to top bank.	Removal of vegetation
III	Degradation	Degradation; basal erosion on banks.	Pop-out failures	Heightening and steeping of banks; alternate bars eroded; flow line lower relative to top bank.	Riparian vegetation high relative to flow line and may lean toward channel.
IV	Threshold	Degradation; basal erosion on banks.	Slab, rotational and pop-out failures.	Large scallops and bank retreat; vertical face and upper-bank surfaces; failure blocks on upper bank; some reduction in bank angles; flow line very low relative to top bank.	Riparian vegetation high relative to flow line and may lean toward channel.
V	Aggradation	Aggradation; development of meandering thalweg; initial deposition of alternate bars; reworking of failed material on lower banks.	Slab, rotational and pop-out failures; low-angles slides of previously failed material.	Large scallops and bank retreat; vertical face, upper bank, and slough line; flattening of bank angles; flow line low relative to top bank; development of new floodplain.	Tilted and fallen riparian vegetations; re-establishing vegetation on slough line; deposition of material above root collars of slough line vegetation.
VI	Restabilisation	Aggradation; further development of meandering thalweg; further deposition of alternate bars; reworking or failed material; some basal erosion on outside bends deposition of floodplain and bank surfaces.	Low-angle slides; some pop-out failures near flow line.	Stable, alternate channel bars; convex-short vertical face on top bank; flattening of bank angles; development of new floodplain; flow line high relative to top bank.	Re-establishing vegetation extends up slough line and upper bank; deposition of material above root collars of slough-line and upper-bank vegetation some vegetation establishing on bars.

2.3.7 River Channel Pattern

Researchers have variously classified channel patterns as straight, braided, meandering, or anastomosing based on the number of intersecting channel threads and the degree to which the channel meanders (Figure 2.21). Straight channels are rare in nature, as the channel thawed (deepest portion of channel) typically wanders from bank to bank even within a straight channel. Straight channels usually exist only in steep narrow valleys where geologic control prevents meandering and are dominated by sediment transport and colluvial processes. They tend to accumulate or store little alluvial sediment, and the banks and bed are usually dominated by colluvial material that enters the channel via erosion and mass wasting. Meandering channels, by contrast, wander to and fro across a valley and are typically alluvial. Both straight and meandering channels consist of a single thread channel. Braided channels differ in that they exhibit numerous channel threads separated by islands or bars, which are often submerged at high flow. Braided channels are dominated by sediment deposition processes and are alluvial. Multiple thread channels that are relatively narrow and deep, and are separated by well-vegetated, stable islands, are referred to as anastomosing.

Channel patterns can largely be explained in most rivers by the interaction of channel slope, bankfull discharge, bed and bank material, vegetation, and available sediment load. Channel patterns can exhibit similar forms in either equilibrium or disequilibrium conditions. For example, a braided channel may be considered in equilibrium condition across an alluvial fan, but may indicate a degraded condition in a lower gradient alluvial valley. As such, channel patterns can be a key indicator of the degree of degradation where factors leading to their degradation typically occur on a watershed scale. Differentiation of similar channel patterns into equilibrium or degraded conditions is best carried out through reviewing historical channel conditions in response to changes imposed on the channel and its watershed.

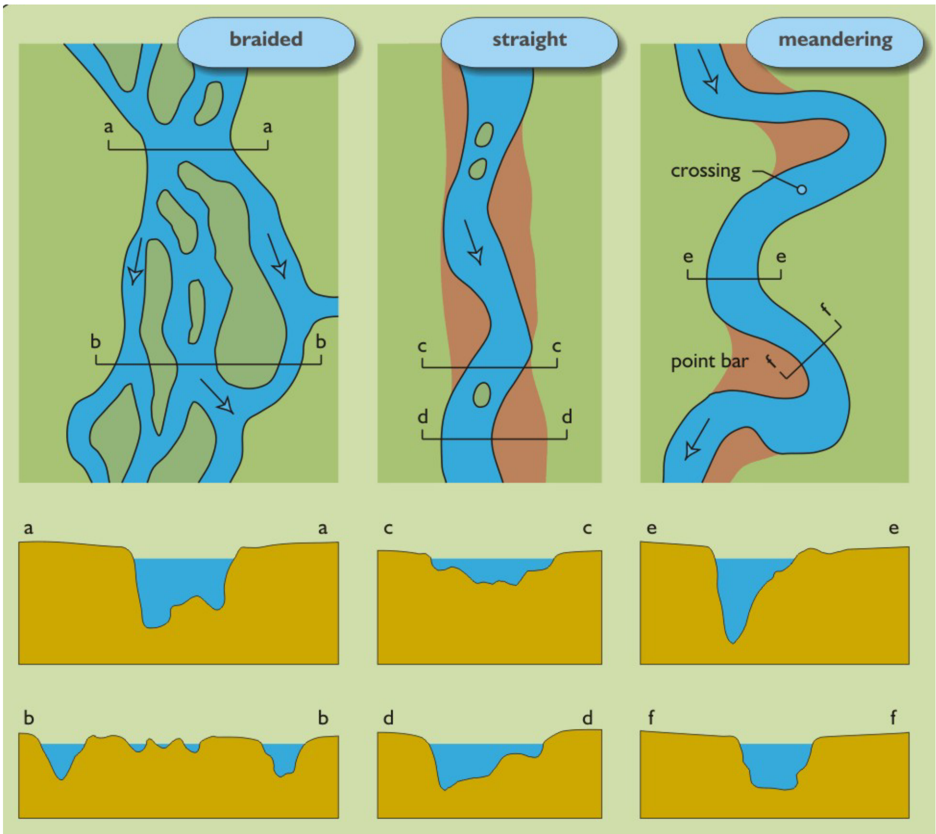


Figure 2.21 Types of channel patterns (after Richardson et al., 1990)

<u>Straight River Channels</u>

There are two types of straight river channels. The first type is formed on a low-gradient valley slope, has a low width-depth ratio channel, and is relatively stable, while the second is established along a steep gradient, high width-depth ratio, high-energy river that has many bars, is braided at low flows. The first type of straight channel may contain alternate bars (Figure 2.22) and results in a sinuous thalweg (flow path connecting deepest points in successive cross sections) within the straight channel. The braided channel, as discussed in detail later, is relatively active and has numerous bars and multiple thalwegs.

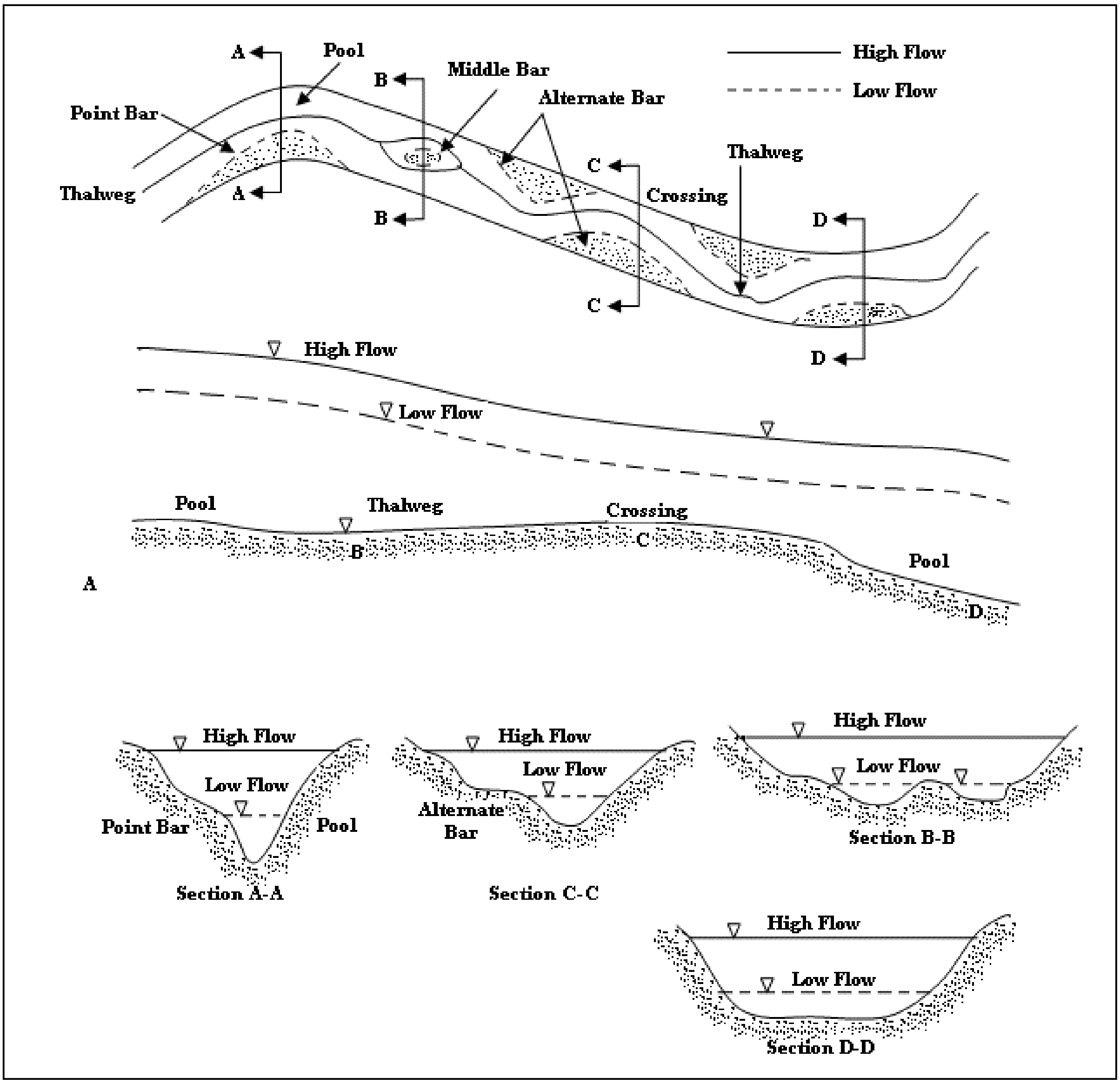


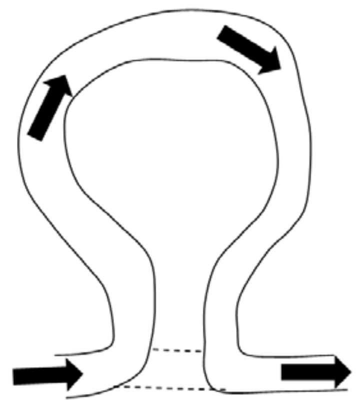
Figure 2.22 Plan view and cross section of a meandering stream (Source [21])

Meandering River Channels

Alluvial channels of all types deviate from a straight alignment. The thalweg oscillates transversely and results in the formation of bends. Thus in general, the river engineer concerned with channel stabilization should not attempt to develop straight channels fully protected with riprap. In a straight channel the alternate bars and the thalweg are continually changing; thus, the current is not uniformly distributed through the cross-section but is deflected towards one bank and then the other. When the current is directed towards a bank, the bank is eroded in the area of impingement; the current is deflected and impinges upon the opposite bank further downstream. The angle of deflection of the thalweg is affected by the curvature formed in the eroding bank and the lateral depth of erosion. The meandering river consists of pools and crossings (Figure 2.22). The thalweg, or main current of the channel, flows from the pool through the crossing to the next pool forming the typical S-curve. In the pools, the channel cross-section is somewhat triangular.

Point bars form on the inside of the bends. In the crossings, the channel cross-section is more rectangular and depths are smaller. At low flows, local slope is steeper and velocities are larger in the crossing than in the pool. At low stages, the thalweg is located very close to the outside of the bends. At higher stages, the thalweg tends to straighten, that is, move away from the outside of the bends and encroach on the point bars to some degree. In the extreme case, the shifting of the current causes chute channels to develop across the point bars at high stages. In Figure 2.22, one can observe the position of the thalweg, the location of the point bars, alternate bars and the location of the pools and crossings. Note that the channel is shallower at crossings than at pools and the banks at crossings may be more subject to erosion. Figure 2.22 illustrates the change in water surface profile from low to high discharges. At low flows the water surface slope is steeper in the crossings and flatter in the pools. The reverse is true at higher discharges. In addition, the thalweg straightens, shortening the path of travel and increasing the local friction slope. In the extreme case, the river slope approaches the valley slope at flood stage. It is during high floods that the flow often cuts across the point bars, developing chute channels; a steeper channel prevails under this condition. In general, bends are formed by the process of erosion and deposition. Erosion without deposition would result only in scalloped banks, and the channel would simply widen until it becomes so large that erosion would terminate. The material eroded from the bank is normally deposited over a period of time on the point bars that are formed downstream. The point bars constrict the bend and enable erosion in the bend to continue, accounting for the lateral and longitudinal migration of the meandering stream. Erosion is greatest across the channel from the point bars. As the point bars build out downstream, the bends gradually migrate down the valley. The point bars formed in the bend ways clearly define the direction of flow. The bars are generally streamlined with their largest portions oriented downstream. If there is rapid caving in the bend ways upstream, the sediment load may be sufficiently large to cause middle bars to form in the crossing.

As a meandering river moves laterally and longitudinally, the meander limbs move at an unequal rate because of the unequal erodibility of the banks. This causes the channel to appear as a bulb form, generally skewed in a downvalley direction. The channel geometry depends upon the local slope, the bank material, and the geometry of the adjacent bends. Over time the local steep slope caused by the cutoff is distributed both upstream and downstream. It may take years before a configuration characteristic of average conditions in the river is attained. When a cutoff occurs, an oxbow lake is formed (Figure 2.23).



Note: Dashed-lines denote channel position after migration take place

Figure 2.23 Neck cutoff

Oxbow lakes may persist for long periods of time before filling. Usually the upstream end of the lake fills quickly to bank height. Overflow during floods carries fine materials into the oxbow lake area. The lower end of the oxbow remains open and the drainage and overland flow entering the system can flow out from the lower end. The oxbow is gradually filled with fine silt and clay. Fine material that ultimately fills the bend way is plastic and cohesive. As the river channel meanders it encounters old bend ways filled with cohesive materials (referred to as clay plugs). These plugs are sufficiently resistant to erosion and serve as semi-permanent geologic controls and can drastically affect river geometry. The variability of bank materials and the presence of features such as clay plugs bring about a wide variety of river forms in a meandering river.

In summary, a meandering river has regular inflections that are sinuous in plan. It consists of a series of bends connected by crossings. In the bends, deep pools are carved adjacent to the concave banks by the relatively high velocities. Because velocities are lower on the inside of the bends, sediments are deposited in these regions, forming point bars. The centrifugal force in a bend causes a transverse water surface slope, and in many cases, helicoidal flow occurs in the bend. Point bar building is enhanced when large transverse velocities occur and sweep the heavier concentrations of bed load towards the convex bank where they are deposited. Some transverse currents have a magnitude of about 15 percent of the average channel velocity.

The bends are connected by crossings (short straight reaches) which are quite shallow compared to the pools in the bendways. Much of the sediment eroded from the outside bank of a bend is deposited in the crossing and on the point bar in the next bend downstream. At low flows, large sandbars form in the crossings if the channel is not well confined. The scour in the bends causes the bends to migrate laterally and sometimes downstream. Lateral movements as large as 760 m (2,500 ft) per year have been observed in alluvial rivers. The meander belt formed by a meandering river is often fifteen to twenty times the channel width. When compared to most braided rivers, meandering rivers have relatively flatter slopes.

The geometry of meandering rivers is measured quantitatively in terms of: (1) meander wavelength λ, (2) meander width W_m, (3) mean radius of curvature r_c, (4) meander amplitude A, and (5) bend deflection angle ϕ. These variables are shown in Figure 2.16. The actual meanders in natural rivers are obviously not as regular as indicated in Figure 2.16. The precise measurement of meander dimensions is therefore difficult in natural channels and tends to be subjective.

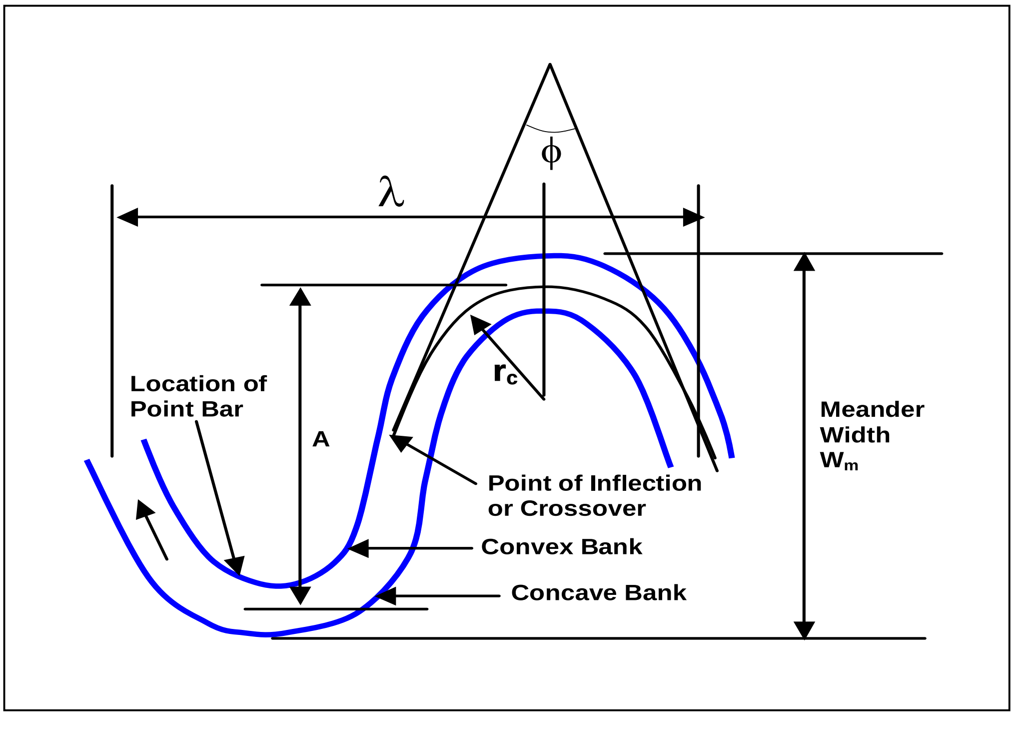


Figure 2.24 Definition sketch for meanders

The empirical relationships between the meander length and the bank-full channel width and the mean radius of curvature respectively, as well as that between the meander amplitude and the bank-full channel width are shown in Figure 2.25 and Table 2.5.

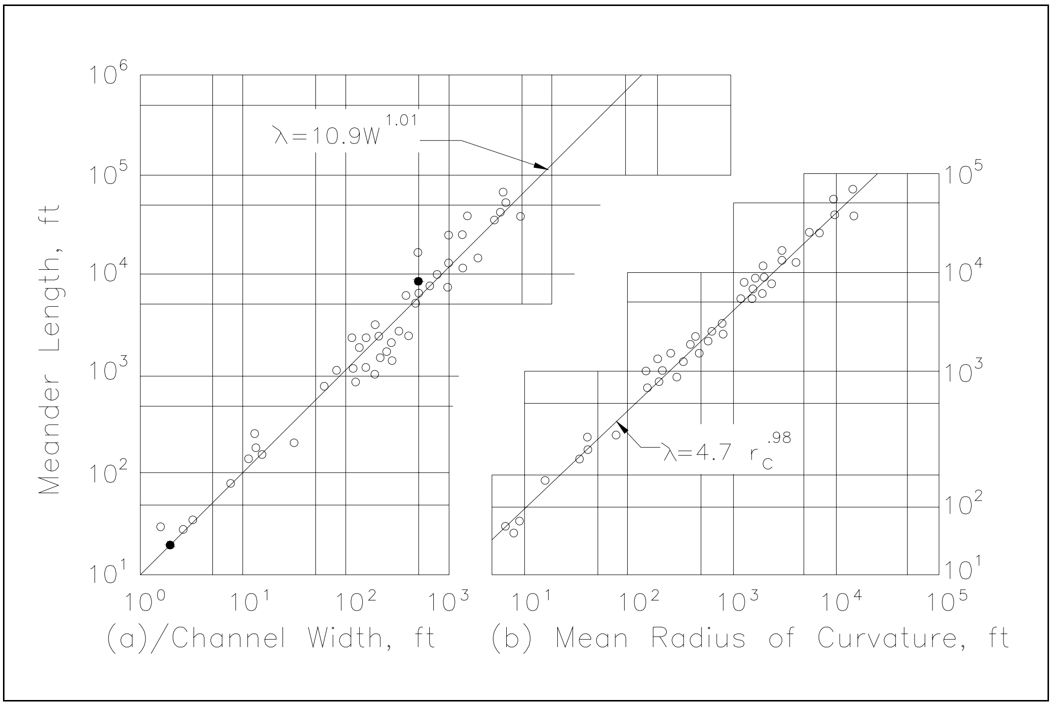


Figure 2.25 Empirical relations for meander characteristics ([10] Leopold et al. 1964).

Table 2.5 Empirical Relations for Meanders in Alluvial Valleys.

Meander Length to Channel Width	Amplitude to Channel Width	Meander Length to Radius of Curvature	Source
$\lambda = 6.6W^{0.99}$	$A = 18.6W^{0.99}$	-	Inglis (1949)
-	$A = 10.9W^{1.04}$	-	Inglis (1949)
$\lambda = 10.9W^{1.01}$	$A = 2.7W^{1.10}$	$\lambda = 4.7{r_c}^{0.98}$	Leopold and Wolman (1960) [26]

Braided River Channels

A braided stream is one that consists of multiple and interlacing channels (Figures 2.18 and 2.21). One cause of braiding is the large quantity of bed load. Generally, the magnitude of the bed load is more important than its size. If the channel is overloaded with sediment, deposition occurs, the bed aggrades, and the slope of the channel increases in an effort to obtain a graded state. As the channel steepens, the velocity increases, and multiple channels develop. These interlaced multiple channels lead to the widening of the overall channel system.

Multiple channels are generally formed as bars of sediment are deposited within the main channel. Another cause of braiding is easily erodible banks. If the banks are easily erodible, the stream widens at high flows and forms bars at low flows; once stabilized, the bars form islands. In general, a braided channel has a relatively steep slope, a large bed-load in comparison to suspended load, and relatively small amounts of silt and clay in the bed and banks. Figure 2.26 defines the various conditions for the formation of multiple channel streams.

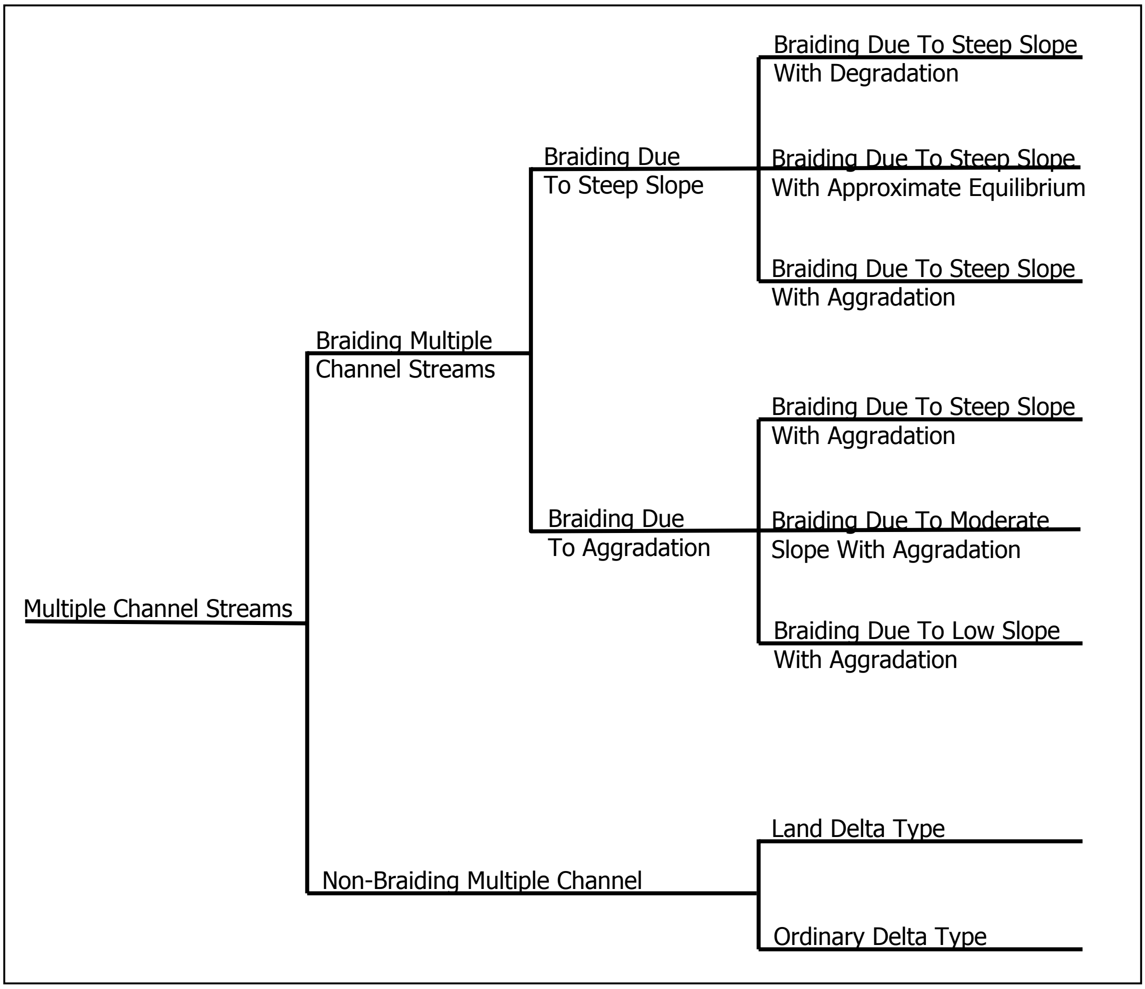


Figure 2.26 Types of multi-channel streams.

The braided stream may present difficulties for highway construction because it is unstable, changes its alignment rapidly, carries large quantities of sediment, is very wide and shallow even during flood flows and is, in general, unpredictable.

River Conditions for Meandering and Braiding

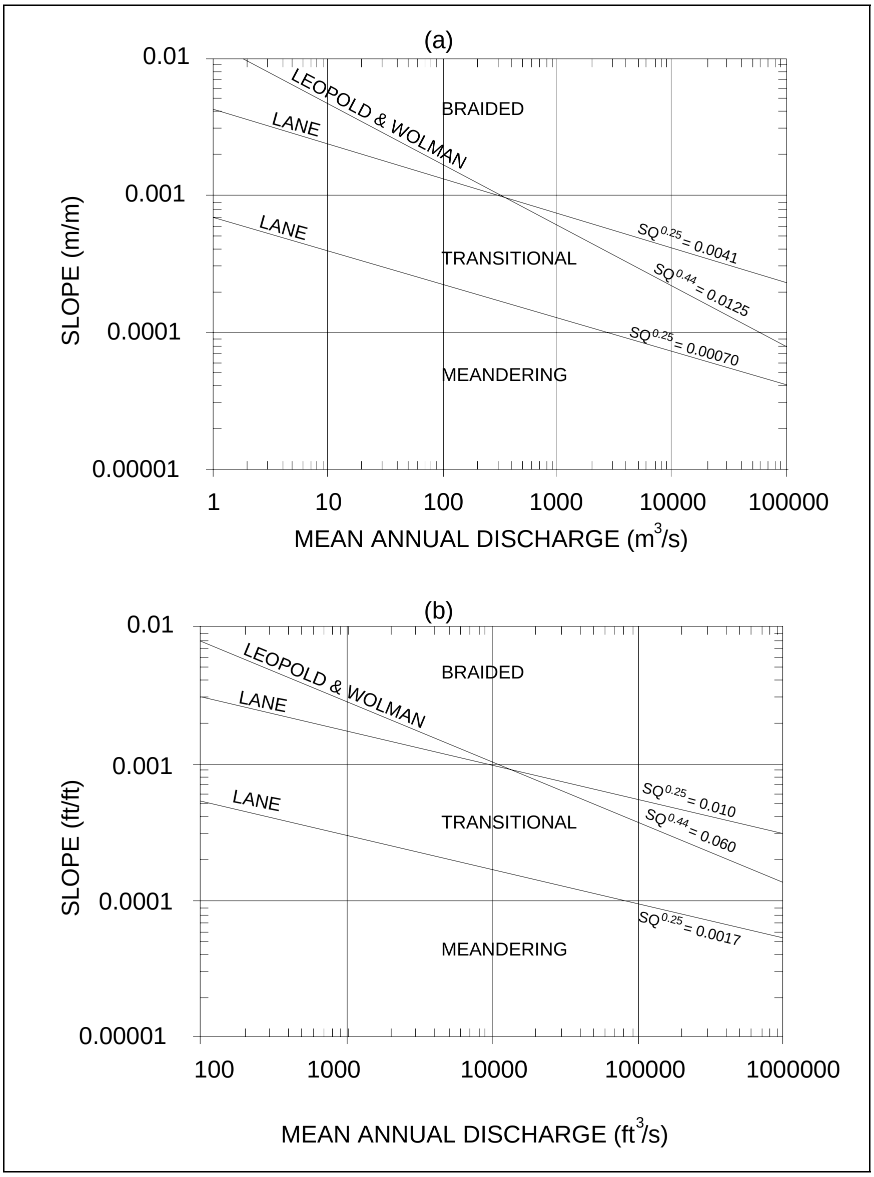
It can be shown that changes in water discharge, sediment discharge or both can cause significant changes in channel slope. The changes in sediment discharge can be in quantity, Q_s, or sediment size, d_{50}, or both. Often, such changes can alter the plan view in addition to the profile of a river. According to Lane (1957), a sand bed channel meanders when:

$$SQ^{0.25} \leq 0.0007 \tag{2.38}$$

Similarly, a sand bed channel is braided when:

$$SQ^{0.25} \geq 0.0041 \tag{2.39}$$

In these equations, S is the channel slope in m/m and Q is the mean discharge in m^3/s. Transitional zone occurs between these values of $S\ Q^{0.25}$. Many U.S. rivers, classified as intermediate sandbed streams, fall in this zone. If a river is meandering but its discharge and slope border on the transitional zone, a relatively small increase in channel slope may cause it to change to a transitional or braided river. Figures 2.27a and 2.27b illustrate the dependence of sand-bed river form on channel slope and discharge. . This diagram should be used with caution because exceptions to the diagram have been observed.



(a = English units b = SI units). Note 1 m3/s = 35.32 ft3/s. [32]

Figure 2.27 (a) & (b) Slope-discharge relationship for braiding or meandering in sandbed stream.

Leopold and Wolman (1960) [26] plotted slope and discharge for a variety of natural streams. They observed that a line could separate meandering from braided streams (Figures 2.27a and b). The equation of this line is:

$$SQ^{0.44} = 0.0125 \qquad (2.40)$$

where:

S = Slope in m/m
Q = Bank-full discharge is m^3/s

Streams classified as meandering by Leopold and Wolman are those whose sinuosity is greater than 1.5. Braided streams are those which have relatively stable alluvial islands and, therefore, two or more channels. Leopold and Wolman note that sediment size is related to slope and channel pattern,

but they do not try to account for the effect of sediment size on the morphology of the streams. They further note that braided and meandering streams can be differentiated based on combinations of slope, discharge, and width/depth ratio, but regard the width as a variable dependent mainly on discharge. This diagram should also be used with caution because it is not always an exact morphological predictor.

2.3.8 Dynamic Equilibrium and Geomorphic Thresholds

One of the fundamental aspects of understanding stream channel behaviour is that stream channels tend towards an equilibrium state in which the input and output of mass and energy to and from a specific reach are equal. The destabilization of streams typically occurs when the balance between sediment input and sediment output from a reach becomes altered. A corollary to this is that overall channel morphology (sinuosity, channel width and slope) remains relatively constant throughout the transfer of mass and energy, assuming inputs to the channel are relatively constant. The term equilibrium in the context of stream channels refers to the relative stability (defined below) of the channel system and its ability to maintain its morphological characteristics over some period of time and range of flow conditions, accommodating minor variations in inputs.

A stream may adjust its character gradually in response to gradual environmental change, such as a slow change in base level (the level below which a stream cannot erode, such as a lake at the channel mouth or a bedrock sill). In this instance, the stream undergoes a complex pattern of erosion, deposition, changes in sediment load and renewed incision as it adjusts to the new base level. The time scale through which equilibrium is exhibited may span hundreds or thousands of years. When in equilibrium, the river is subject to:

- Short term morphological changes due to the seasonal variable discharge (oscillations having frequency of years e.g. 10 years)
- Long term morphological changes due to very slow evolution of the river basin (centuries to thousands of years

At any given point in time during the adjustment, the channel may exhibit equilibrium conditions, though over time the equilibrium changes. This is referred to as dynamic equilibrium. Concept of dynamic equilibrium expressed as a function of sediment yield – the total sediment derived from a watershed per year (See Figure 2.28).

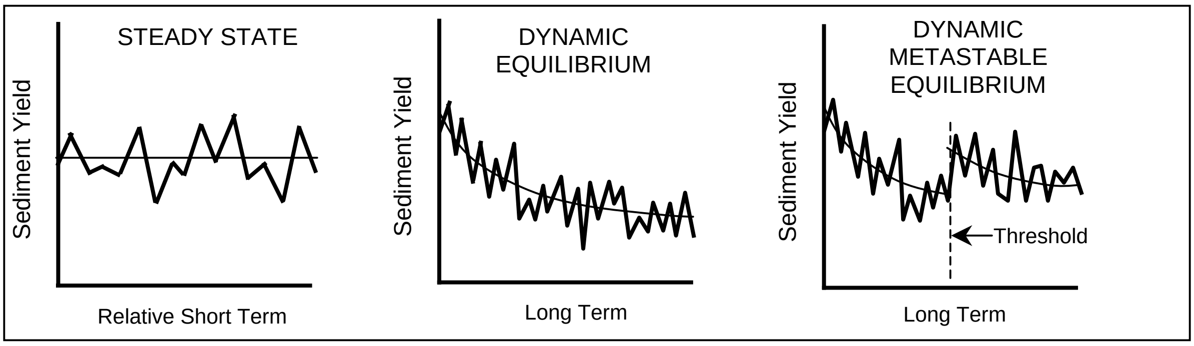


Figure 2.28 Concept of dynamic equilibrium expressed. [15]

Human influences on channels and their inputs can affect rapid destabilization of equilibrium conditions, or force rapid change of equilibrium values. Human influences are varied and complex and can affect all variables influencing channel equilibrium, channel processes and habitat. The most common and drastic human influences are related to urbanization, including changes to the hydrologic regime and constraints imposed on the channel, such as levees, revetments or culverts.

Most 'healthy' stream systems with high quality habitat and other attributes that we value are distinguished by complex energy dissipation mechanisms that include primarily channel roughness elements (e.g. large wood, boulders, complex channel planform and bedform). Vegetation is particularly important to dissipating energy at channel bank margins and in floodplains. Vegetation provides critical stabilizing and roughening functions that make possible the existence of channels with high aquatic habitat value, that is, those with high hydraulic and structural complexity.

Following a disturbance, the system undergoes a period of recovery to pre-disturbance equilibrium conditions. The rate of recovery is generally more rapid at first, slowing asymptotically as equilibrium is approached. For instance, the channel width can resemble a decreasing exponential with respect to time (Richard et al. 2006 [5]). Disturbance is most important to geomorphic form and process when this recovery time is greater than the time between significant disturbances.

2.3.9 Regime Theory and Channel Geometry

The regime theory is based on the tendency of a stream system to attain an equilibrium state under constant environmental conditions (e.g. constant water discharge, as in a canal). It consists of a set of empirical equations relating channel shape to discharge, sediment load and bank resistance. The theory proposes that dominant channel characteristics remain stable for a period of years and that any change in the hydrologic or sediment regime leads to a quantifiable channel response (such as erosion or deposition). Stream reaches that are "in regime" (meaning "in equilibrium") are able to move their sediment load through the system without net erosion or deposition and do not change their average shape and dimensions over a short time period.

Three regime methods for stable alluvial channel design are the Larcey's, Blench's and Simons & Albertson Regime Method. The three basic channel dimensions, i.e., the width, depth, and slope, are calculated as a function of bed-material grain size, channel-forming discharge, bed-material sediment concentration, and bank composition. The regression equations are not dimensionless and must be applied with the units used in their derivation.

i) Regime method of Lacey

Specify d_{50} in mm and obtain angle of repose, ϕ, from chart

Silt factor $f_L = \sqrt{2.5d}$ where d is in mm (2.41)

The three degrees of freedom give the 3 basic equations as

$$U = 0.635 f_L^{1/2} R^{1/2} \tag{2.42}$$

$$P = 4.836\, Q^{1/2} \tag{2.43}$$

$$S = 0.000314 f_L^{5/3} Q^{-1/6} \tag{2.44}$$

The following ancillary equations may also be derived

$$R = 0.473\, f_L^{-1/3} Q^{1/3} \qquad \{= (Q / 9.45 f_L)^{1/3}\} \tag{2.45}$$

$$A = 2.287 f_L^{-1/3} Q^{5/6} \tag{2.46}$$

where:

f_L	silt factor
d	median grain size of bed material (mm)
U	velocity (m/s)
R	hydraulic radius
P	wetted perimeter (m)
Q	discharge (m^3/s)
S	slope
A	area (m^2)

ii) Regime method of Blench

Bed factor $f_B = \{1 + 0.012c\}\sqrt{0.335d}$, (2.47)

where d is in mm, c is in ppm

Side factor $f_S = 0.00929, 0.01858 \& 0.02787$ (2.48)
for banks of slight, medium and high cohesiveness

These two factors are related to the velocity, depth and width by two ancillary definitions:

Bed factor $f_B = U^2 / D$ (2.49)

Side factor $f_S = U^3 / B$ (2.50)

The three degrees of freedom give the 3 basic equations as

$$U = (f_B \ f_S \ Q)^{1/6} \quad (2.51)$$

$$B = (f_B \ Q/f_S)^{1/2} \quad (2.52)$$

$$S = \frac{{f_B}^{2/6} {f_S}^{1/12} \ v^{1/4}}{3.63 g Q^{1/6} \{1 + c / 2330\}} \quad (2.53)$$

The following ancillary equations may also be derived

$$D = (f_S \ Q / {f_B}^2)^{1/3} \quad (2.54)$$

$$A = {f_B}^{-1/3} {f_S}^{-1/6} Q^{5/6} \quad (2.55)$$

where:

f_B	bed factor
C	bed-material sediment concentration (ppm)
D	median grain size of bed material (mm)
f_S	silt factor
U	velocity (m/s)
D	depth (m)
B	channel width (m)
Q	discharge (m^3/s)
S	slope
V	kinematic velocity (m^2/s)
g	acceleration of gravity (m/s^2)
A	area (m^2)

iii) Regime method of Simons and Albertson

a. Classification of channel types
1. Sand bed and sand banks
2. Sand bed and cohesive banks
3. Cohesive bad and cohesive banks
4. Coarse non-cohesive bed material
5. Same as 2, but with heavy wash loads, 2000-8000ppm

b. Formulae

$$P = K_1 Q^{1/2} \quad (2.56)$$

$$B = 0.9P \quad (2.57)$$

$$B_S = 1.09B + 0.66 \quad (2.58)$$

$$R = K_2 Q^{3.6} \tag{2.59}$$

$$D = 1.21R \ \text{ for } R \le 2.1\text{m} \tag{2.60}$$

$$D = 0.93R + 0.61 \ \text{ for } R > 2.1\text{m} \tag{2.61}$$

$$U = K_3 (R^2 S)^m \quad , \quad U = Q/(BD) \tag{2.62}$$

$$\text{or } S = \frac{1}{K_4}\left(\frac{U^2}{gD}\right)\left(\frac{UB}{v}\right)^{-0.37} \tag{2.63}$$

$$\text{i.e.} \frac{C^2}{g} = \frac{8}{f} = \frac{U^2}{gDS} = K_4 \left(\frac{UB}{v}\right)^{0.37}$$

where:

P	wetted perimeter (m)
Q	discharge (m^3/s)
B	mean width (m)
B_S	surface width (m)
R	hydraulic radius
D	mean depth (m)
U	mean velocity (m/s)
S	slope
g	acceleration of gravity (m/s^2)
v	kinematic viscosity (m^2/s)
C	Chezy roughness coefficient
f	Darcy-Weisbach roughness coefficient
K_1, K_2, K_3, K_4, m	coefficients related to the canal type

c. Constants

Coefficient	1	2	3	4	5
K_1	6.34	4.71	3.98	3.17	3.08
K_2	0.572	0.484	0.407	0.253	0.374
K_3	9.28	10.67	-	10.87	9.71
K_4	0.33	0.54	0.87	-	-
m	0.33	0.33	-	0.29	0.29

d. Range of original data

Q	14	-	260 m^3s^{-1}	}	
d	0.03	-	80 mm	}	70 canals in India
c	0	-	8000 ppm	}	43 canals and rivers in USA
S	0.00006	-	0.0097	}	

Hydraulic geometry is a general term applied to alluvial channels to denote relationships between discharge Q and the channel morphology, hydraulics and sediment transport. Channels forming in their own sediments are called alluvial channels. In alluvial channels, the morphologic, hydraulic and sedimentation characteristics of the channel are determined by a large variety of factors. However, alluvial streams do exhibit some quantitative hydraulic geometry relations. In general, these relations apply to channels within a physiographic region and can be obtained from data available on gauged rivers. It is understood that hydraulic geometry relations express the integral effect of all the hydrologic, meteorologic, and geologic variables in a drainage basin for in-bank flows. The hydraulic geometry relations of alluvial streams are useful in river engineering.

Changes in any of these controlling variables may result in a new channel geometry that represents a stable morphology in a new equilibrium state. Hydraulic geometry relations were developed by [25] Leopold and Maddock (1953) for different regions in the United States and for different types of rivers. In general the hydraulic geometry relations are stated as power functions of the discharge:

$$
\begin{aligned}
W &= a\,Q^b \\
Y_o &= c\,Qf \\
V &= k\,Qm \\
Q_T &= p\,Qj \\
S_f &= t\,Qz \\
N &= r\,Qy
\end{aligned} \qquad (2.64)
$$

where:

W = Channel width
y_o = Channel depth
V = Average velocity of flow
Q_T = Total bed sediment load
S_f = Friction slope
n = Manning's roughness coefficient
Q = Discharge as defined in the following paragraphs

The coefficients *a, c, k, p, t, r* and exponents *b, f, m, j, z, y* in these equations are determined from analysis of available data on one or more streams. From the continuity equation ($Q = Wy_oV$), it is seen that

$$a \times c \times k = 1$$

and

$$b + f + m = 1$$

Typical values for these coefficients are :

b = 1/2, f = 1/3, m = 1/6, z = -1/6, j = 2 to 3

Leopold and Maddock (1953) [25] have shown that in a drainage basin, two types of hydraulic geometry relations can be defined: (1) relating W, y_o, V and Q_s to the variation of discharge at-a-station; and (2) relating these variables to the discharges of a given frequency of occurrence at various stations in a drainage basin. Because Q_T is not readily available, they used Q_s, the suspended sediment transport rate. The former are called at-a-station relationships and the latter downstream relationships.

Figures 2.29 and 2.30 illustrate how the hydraulic relations at-a-station and in the downstream direction may be different from one basin to another. For example, the width and depth at-a-station do not change very much in Basin A. The width to depth ratio is almost constant but the velocity increases, as it must, as the discharge increases at-a-station. In Basin B the width to depth ratio decreases with an increase in discharge, i.e., the width changes very little but the depth increases significantly with discharge at-a-station. Note that in both basins, width increases with discharge in the downstream direction, but in Basin B, depth changes very little in the downstream direction. [25] Leopold and Maddock (1953) [25] show that the type of relations illustrated in Figure 2.29 exists in natural rivers.

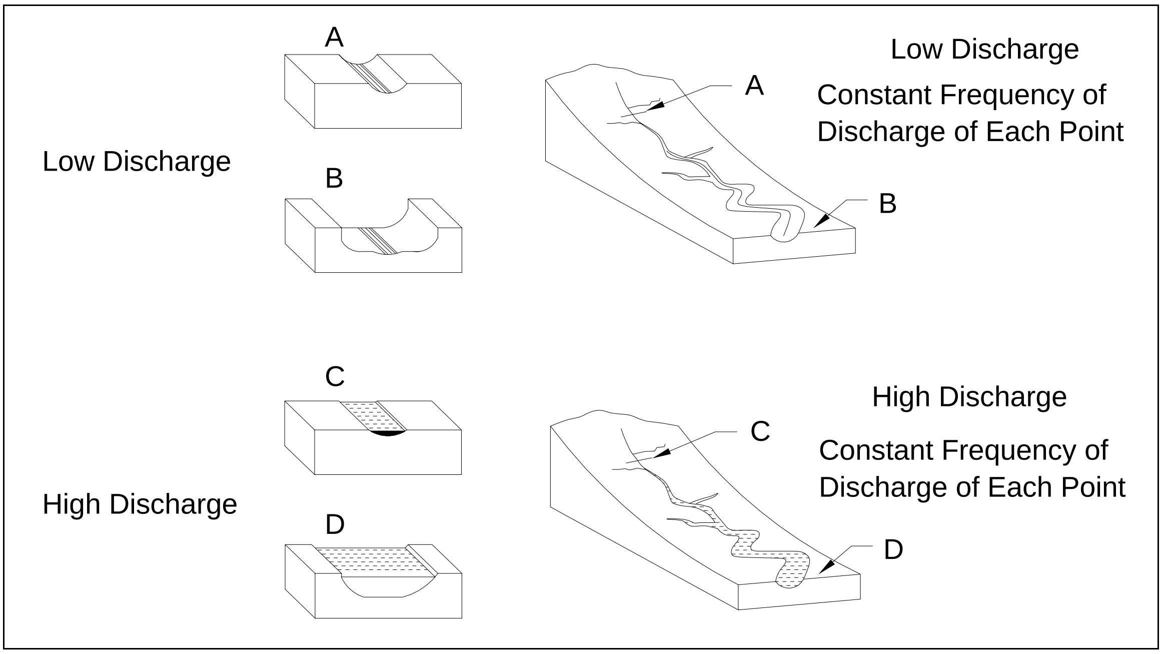


Figure 2.29 Variation of discharge at a given river cross-section and at points downstream. [25]

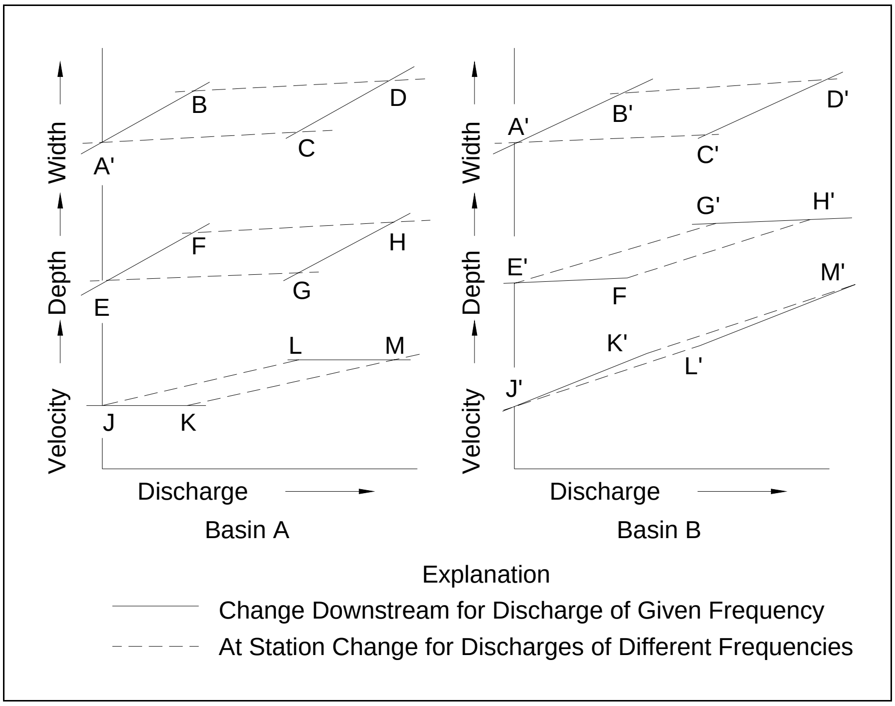


Figure 2.30 Schematic variation of width, depth, and velocity with at-a-station and downstream discharge variation. [25]

The mean values of exponents *b, f, m, j, z,* and *y* as reported by Leopold et al. (1964)[10] are given in Table 2.6. These values are based on an extensive analysis of stream data in the United States and are stream specific.

Table 2.6 At-a-Station and Downstream Hydraulic Geometry Relationships.

Average At-a-Station Relations						
	b	f	m	j	z	y
Average values Midwestern United States	0.26	0.40	0.34	2.5		
Brandywine Creek, PA	0.04	0.41	0.55	2.2	0.05	-0.20
Ephemeral Streams in Semiarid U.S.	0.29	0.36	0.34			
Average of 158 Gauging Stations in U.S.	0.12	0.45	0.43			
Ten Gauging Stations on Rhine River	0.13	0.41	0.43			
Average Downstream Relations (bank-full or mean annual flow)						
	b	f	m	j	*z*	*y*
Average values Midwestern United States	0.50	0.40	0.10	0.8	-0.49	
Brandywine Creek, PA	0.42	0.45	0.05		-1.07	-0.28
Ephemeral Streams in Semiarid U.S.	0.50	0.30	0.20	1.3	-0.95	-0.30
Appalachian Streams	0.55	0.36	0.09			

In Table 2.7, the derived hydraulic geometry relations for conditions at-a-station (variable discharge frequency) and in the downstream direction on the same stream at bankfull discharge (or constant frequency) are given. Note that the term "downstream" implies any other locations along the channel, either upstream or downstream from a selected station. [7] Julien and Simons (1984) determined that bed material size is an important variable in hydraulic geometry relations in alluvial gravel streams. Their relations for non-cohesive gravel-bed rivers in the downstream direction at bankfull discharge (or constant frequency) are also given in Table 2.7.

Table 2.7 Derived At-A-Station and Downstream Geometry Relationships.

At-a-Station	Downstream(1)	Downstream(2)
$y_o = Q^{0.40}$	$y_o = Q_b^{0.46}$	$y_o = Q_b^{0.40}$
$W = Q^{0.26}$	$W = Q^{0.46}$	$W = Q_b^{0.53}\, d_5^{-0.33}$
$V = Q^{0.34}$	$V = Q_b^{0.08}$	$V = Q_b^{0.07}\, d_{50}^{0.33}$
$S_f = Q^{0.00}$	$S_f = Q_b^{-0.46}$	$S_f = Q_b^{-0.4}\, d_{50}^{+1.00}$
(1) Sand Bed (2) Gravel Bed		

[6] Julien and Wargadalam (1995) updated the theory and applications of hydraulic geometry relationships for alluvial channels. In their study, downstream hydraulic geometry of alluvial channels, in terms of bankfull width, average flow depth, mean flow velocity, and friction slope, is examined from a 3-dimensional stability analysis of non-cohesive particles under 2-dimensional flows. Four exponent diagrams illustrate good agreement with several empirical regime equations found in the literature. The analytical formulations were tested with a comprehensive data set consisting of 835 field channels and 45 laboratory channels. The dataset covers a wide range of flow conditions from meandering to braided sand-bed and gravel-bed rivers. The empirically recalibrated equations of Julien and Wargadalam (1995) [6]are:

$$h = 0.2\, Q^{2/(5+6m)}\, d_s^{6m/(5+6m)}\, S^{-1/(5+6m)}$$
$$W = 1.33\, Q^{(2+4m)/(5+6m)}\, d_s^{-4/(5+6m)}\, S^{(-1-2m)/(5+6m)}$$
$$V = 3.76\, Q^{(1+2m)/(5+6m)}\, d_s^{-2m/(5+6m)}\, S^{(2+2m)/(5+6m)}$$
$$\zeta_* = 0.121\, Q^{2/(5+6m)}\, d_s^{-2m/(5+6m)}\, S^{(4+6m)/(5+6m)} \quad (2.65)$$

where

h is the flow depth in m
W is the channel width in m
V is the mean velocity in m/s
Q is the discharge in m^3/s
d_s is the median grain size in m
ζ_* is Shields number
m is $1/\ln(12.2h/d_s)$

For the particular case in which Manning's equation is acceptable, m = 1/6, and the downstream hydraulic geometry relationships are simplified [4] to :

Mean flow depth	$h = 0.2\ Q^{0.33}\ d_s^{0.17}\ S^{-0.17}$
Channel width	$W = 1.33\ Q^{0.44}\ d_s^{-0.11}\ S^{-0.22}$
Mean flow velocity	$V = 3.76\ Q^{0.22}\ d_s^{-0.05}\ S^{0.39}$
Shields parameter	$\tau_* = 0.121\ Q^{0.33}\ d_s^{-0.83}\ S^{0.83}$ (2.66)

2.3.10 The Bankfull Concept

It has been said that "rivers construct their own edifice", that is, the shape of the channel (planform, cross-sectional shape, and profile) is sculpted by the river as it erodes and deposits sediment according to the laws of physics. The end result is a quasi-equilibrium channel, having just the right morphology to move the sediment and water carried by the river. One consistent characteristic of a self-formed alluvial channel is the presence of a floodplain. A floodplain is a relatively flat, deposition surface adjacent to the channel, formed by the river under its present climate and sediment load, and overflowed during moderate peak flow events.

This definition contains several key points. First, the floodplain is a deposition surface, formed by the river, not an erosion surface or a surface formed by other non-fluvial processes that can deposit sediments. Secondly, the floodplain is formed under the current climate and sediment load. Flat surfaces may be present from previous eras of differing climate and/or sediment load, and these surfaces are called terraces. Terraces are generally not "geomorphically active," that is, they are not currently being built by river deposition processes. Finally, the floodplain is overflowed, on the average, several times per year, during moderate peak flow events (such as a 1.5-year or 2-year floods). Terraces may be overtopped, but only by larger, less frequent floods (e.g. 50-year or 100-year events). The term "bankfull" refers to the inner edges of the floodplain, or the points of incipient flooding. The bankfull channel refers to the channel cross-section below the elevation of the floodplain.

In theory, the bankfull channel is sized to convey the dominant discharge. That is, over the long term, most of the sediment load moves at flows bracketing bankfull. Smaller discharges occur much more frequently, but carry little or no sediment due to lack of sufficient shear stress, thus contributing little to the overall sediment budget. Large discharges have the shear stress to move very high sediment loads, but occur rarely, again contributing little to the yearly sediment budget. Thus, it is the moderate flows, centered about bankfull, which move most of the sediment over the long term, and the channel forms itself into a shape to most efficiently convey these flows. The bankfull channel tends to be stable at higher flows as well, since these flows dissipate their potentially high shear stress by spreading out over the floodplain. Overbank flow creates a wide, shallow cross-section, reducing velocities and shear stress to the point where sediment carried in suspension is deposited there, contributing to floodplain construction.

It should be noted here that bankfull is a geomorphic concept. Although bankfull may, on the average, correspond to a certain statistically derived flood (commonly asserted to be the 1.5-year flood), bankfull is defined by the floodplain geomorphic surface in the field. If this surface is not present, then bankfull is not defined.

2.3.11 River Profiles and Bed Material

The slope of a river channel or a river system is usually steepest in the headwater region. The river profile is concave upward and the slope of the river profile can be represented by the equation:

$$S_x = S_o e^{-\alpha x} \tag{2.67}$$

where:

S_x = Slope at any station a distance x downstream of the reference station
S_o = Slope at the reference station
α = Coefficient

Similarly, the bed sediment size is coarser in the upper reaches where the channel slopes are steep and becomes finer downstream. Generally, the size of the bed material decreases with distance according to the relationship

$$d_{50x} = d_{50o} e^{-\beta x} \tag{2.68}$$

where:

d_{50x} = Median size of bed material at distance x downstream of reference station
d_{50o} = Median size of bed material at the reference station
β = Coefficient

The hydraulic geometry relations are applicable to continuous channel behaviour. In some cases, this behaviour (in this case the slope) may become discontinuous as the channel pattern changes from a meandering to a braided one by the formation of cut-offs.

2.3.12 Vegetation and Woody Debris

Vegetation affects the geomorphic process and resultant channel forms by increasing resistance to erosion of channel banks (riparian vegetation) and by interrupting and redirecting channel flow (in-channel wood). Riparian vegetation plays an important role in maintaining a stable channel form by stabilizing streambanks and dissipating energy along the banks in virtually all channel types. The growth of riparian vegetation in or near the channel also facilitates floodplain formation as vegetation increases hydraulic roughness, reduces erosion and promotes sedimentation. Some of the most tortuous meanders occur in streams dominated by sedges in meadow streams. Willows and bamboo plants commonly stabilize newly deposited materials in bars and thereby facilitate the creation of new floodplain area. Upland vegetation also can play a role in channel process by controlling hill-slope erosion, thereby reducing sediment input to stream channels.

Both upland and riparian areas also contribute vegetative debris to the channel. The role of large wood in channels is now recognized as a critical factor affecting geomorphology in forested environments and as a potential component of channel design. Large wood in streams represents large roughness elements that divert flowing water and influence the scour and deposition of sediment in forested streams throughout the world. Large wood in stream channels results from trees that fall from banks or hill slopes. Processes that initiate tree fall include wind throw, bank erosion, channel avulsion, tree mortality, mass wasting and land-use practices such as logging. The introduction of large wood into the channel affects both channel form and process by:

- Creating steps in the longitudinal profile of the streambed (of steep, confined channels), thus dissipating energy, aiding in formation of both pools and riffles, and increasing sediment storage;
- Locally reducing channel gradient (i.e., above the log jam), thereby capturing a finer class of sediment than that would otherwise deposit in the channel;
- Increasing in-channel hydraulic complexity, thereby increasing channel habitat complexity;
- Improving fish habitat by increasing types and sizes of pools (pools associated with wood may be deeper and have more depth variability than free-formed pools);
- Inducing hydraulic head differential to promote hyporheic flow;
- Forming channel bars and inducing sorted gravel deposits important to spawning (this influence has not been extensively studied)

- Promoting sediment deposition along the active channel and floodplain, which provides sites for riparian vegetation colonization, the growth of forested islands in the channel and forest floodplain development;
- Retaining small wood and organic detritus;
- Promoting floodplain connectivity and periods of inundation by increasing channel roughness; and,
- Stabilizing backwater and side-channel areas (chute cut-offs and oxbows).

The geomorphic effects of wood vary with stream size. In low-order, headwater streams (first and second order), large wood often spans the channel, or, if submerged, induces local sediment storage and steps in the water surface profile. In mid-order streams (e.g. third and fourth order), large wood that is large relative to the stream may cause significant channel migration or widening along with sediment storage. In high-order streams (e.g., fourth or fifth order), where large wood is small relative to the channel, wood accumulation may increase channel migration and the development of anastomosing or secondary channels, although islands formed as a result of large woody deposits may actually be quite stable.

2.3.13 Assessment Methodologies

The most important components of geomorphic analysis include:

- Assessment of past channel change;
- Determination of causes of channel change;
- Assessment of current channel conditions, including morphology, stability and departure from conditions expected for the given stream type;
- Assessment of probable future channel evolution; and
- Reduction of uncertainty in key assumptions regarding management, design, processes or conditions, or effects on habitat or critical species.

Habitat restoration, streambank protection and other instream construction projects will likely be unsuccessful if the driving forces of channel adjustments are not recognized and addressed. Consequently, projects designed to mimic or alter natural channel processes require an understanding of the causative agents of change.

<u>Characterizing Existing Channel Conditions</u>

The initial characterization of the project reach should be based on plotted bed and floodplain profiles and maps or aerial photographs that show channel planform. The project reach should be described in terms of channel slope, pattern, sinuosity, and cross-sectional dimensions. Infrastructure controls should be identified and their geomorphic relevance indicated, such as fixed-bed elevations (pipelines, weirs, bridge aprons, etc.) or areas of channel or floodplain encroachment (roads, development, bridges, culverts, levees, etc.).

- Channel Longitudinal Profile - Channel slope is defined as the vertical fall of a stream over a given distance. It is typically reported as a percentage or as feet of drop per mile (ft/mile). Channel profiles (elevation vs. distance plots) depict slope trends on a stream system. The most accurate means of determining the slope of the channel is by surveying the channel thalweg elevation (the deepest thread in the channel bed), the water surface, and the elevation of bankfull (best, if possible) or other high water indicators through a reach (such as "ordinary high water").

  Channel slope is always measured in terms of the channel distance, rather than the valley distance, and can be calculated by the following equation:

$$S=(E_2-E_1)/D \qquad (2.69)$$

Where, S = channel slope, E_2 and E_1 = bankfull elevations (or water surface, in meters) at two similar geomorphic points along the thalweg, and D = channel distance between E_2 and E_1 (in meters).

- Channel Planform - Channel planform is the form of a stream as seen in map (aerial) view. In streams with meandering patterns, planform is quantitatively described in terms of sinuosity by the equations:

$$P=D_c/D_v \quad \text{or} \quad P=S_v/S_c \tag{2.70}$$

Where P = sinuosity, D_c = channel length (meters), D_v = valley length (meters), S_c = channel slope, and S_v= valley slope. Channel length is theoretically best measured along the channel thalweg or, if necessary, the centreline, but can be measured along one bank or the other for small channels.

- Channel Cross-Section - Channel cross-section reflects the two-dimensional view across the channel. A set of surveyed cross-section points should include, at a minimum, terrace elevation, floodplain elevation, top and toe of bank, lower limit of vegetation and thalweg, with enough intermediate points to define the shape of the channel. The ends of the cross-section should extend far enough to define at least some of the important peak flows, although the level of detail can be coarser above bankfull. Generally, the elevation at twice the maximum riffle bankfull depth will encompass the 50-year flood. Typical dimensions measured from a channel cross-section include bankfull width, bank height, bank slope, and channel maximum and average bankfull depth. Conventionally, the right and left banks reflect the sides of the channel as viewed in the downstream direction (Figure 2.31).

In addition to the full cross-sections, width, bank height and thalweg depth should be measured at multiple locations in the reach to characterize the range of variability of pools and riffles. From these locations, a smaller number (minimum: one riffle, one pool, and one pool tail-out zone or other area likely to show response) that are deemed "typical" can be selected.

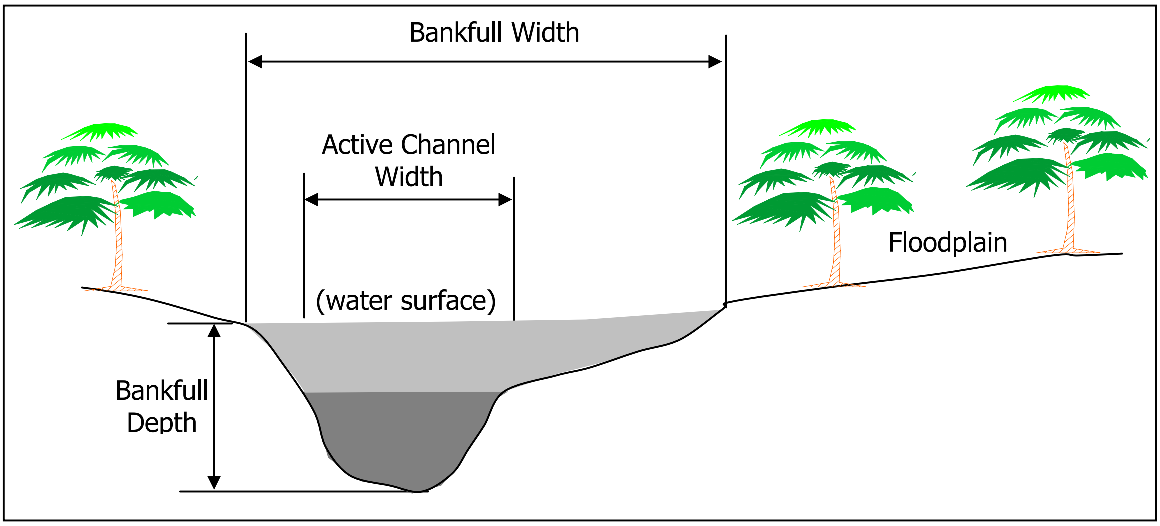


Figure 2.31 Channel cross-section.

- Pools and Riffles - Pools and riffles generally occur at relatively constant spacing in alluvial streams. A pool-riffle sequence is a dynamic response of the channel to a large-scale, non-uniform distribution of three variables: velocity, boundary shear stress and sediment. Riffle spacing is consistently in the order of five to seven times the channel width (Figure 2.32), and can be predicted as:

$$z = 6.31\ W_{bf} \tag{2.71}$$

where z = the distance of riffle spacing (meters), and W_{bf} = bankfull width (meters).

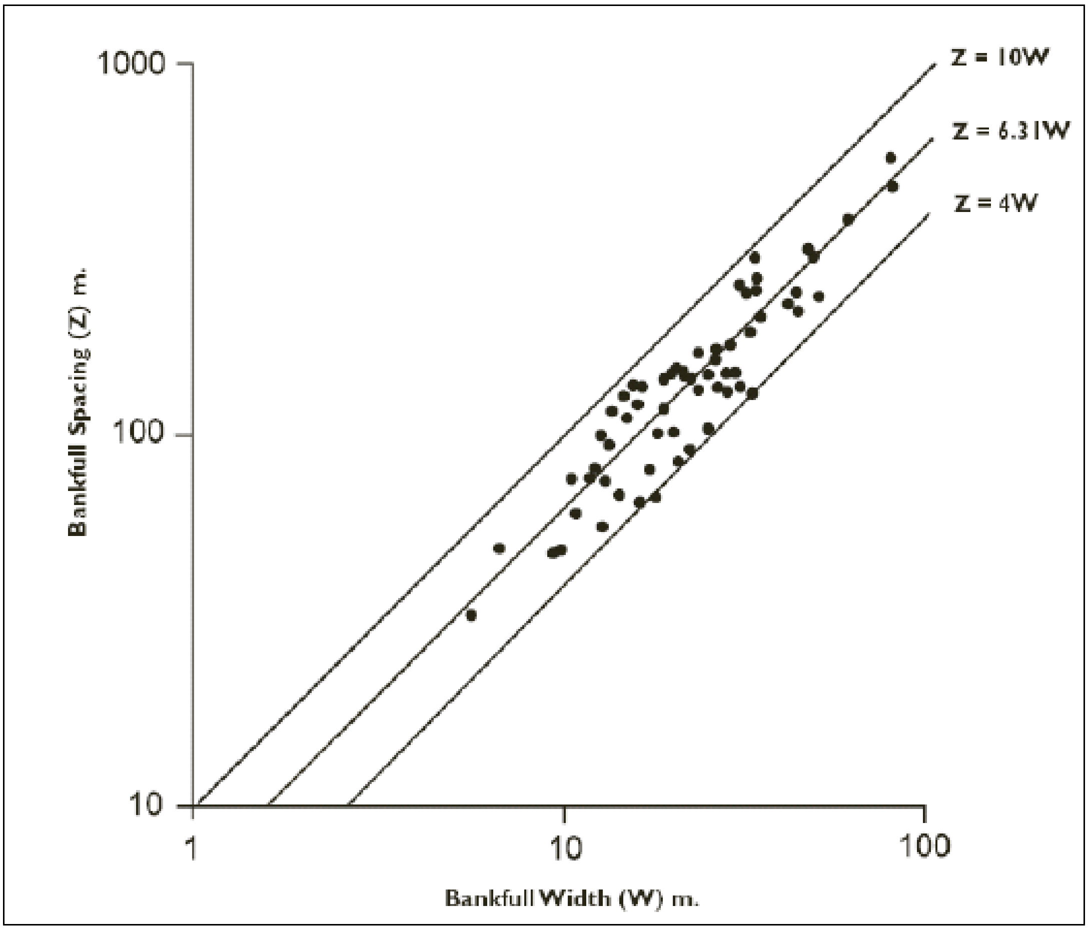


Figure 2.32 Riffle spacing as a function of bankfull width. [10]

- Substrate Analysis and Sediment Transport – The assessment of sediment transport processes requires quantitative information on streambed substrate. This is most accurately carried out with a volumetric sample taken from a location judged to be typical of the active alluvial material. Sometimes, the sample can be obtained from a dry gravel bar, but it often requires instream sampling of an alluvial bedform. The surface layer is gathered and sieved separately from the subsurface layer, yielding a particle size distribution (percentage in each size class) for each stratum. Size distributions are based on the logarithmic Phi (powers of two) scale. That is, 1 - 2 mm, 2 - 4 mm, 4 - 8 mm, etc. The size distributions of the surface and subsurface, and their relationship, provide quantitative information about the average sediment load volume and size, the critical shear stress for bed mobility, fine versus coarse sediment sources, hydraulic roughness, spawning habitat quality, and hyporheic flow potential. From these size distributions, sediment benchmark parameters such as the median size (d_{50}), 84th percentile (d_{84}), percentage of fines and maximum particle size (d_{100}) are determined.

Channel Classification

A classification of stream reaches can aid in visualizing and describing the project site. A detailed review of channel classification is presented in Section 2.3.6.

It is important to note that most classification systems are based on the existing channel morphology of a stream, which may or may not be in equilibrium. In other words, they best describe only existing conditions, not historical conditions or the functional potential of a stream system. A classification system must be used with the understanding that fluvial systems are constantly adjusting and evolving in response to changes in slope, hydrology, land use and sediment supply.

Assessing Historical Channel Changes

- Aerial Photography and Historical Maps - When available, sequential aerial photographs of a stream channel provide a historical record of channel planform changes. Sequential aerial photographs are often available dating back to the 1930s, while other historical photographs can sometimes be found in historical archives dating back to the last century. Historical land survey maps often show details of river location and form as well. This information, coupled with hydrologic data from stream gages, is extremely valuable for understanding how the particular channel responds to floods. An evaluation of historical channel change may reveal previous channel conditions that provided quality habitats or channel stability, which may then be used as the basis for project objectives. However, an aerial photograph provides a snapshot in time and does not necessarily imply channel stability. The stream may have been responding to significant changes in the watershed, or may have been stable under different watershed conditions.
- Ground Reconnaissance - Field observations provide valuable information regarding flood history and channel response. This information is especially valuable when combined with hydrologic data regarding flood- recurrence intervals – for example, the effects of a recent 10-year or 25-year recurrence-interval event might be directly observed in the field. Ground assessment of stream channels may include observable flood impacts, such as abandoned channels, natural channel cut-offs or the accumulation of wood on mid-channel bars. Many geomorphic channel features can be roughly dated according to the age of riparian vegetation that is present. For example, an abandoned side channel with 10-year-old cottonwoods may represent the impacts of a flood documented 10 to 11 years ago. Ground reconnaissance is an essential part of a geomorphic assessment and can provide useful information on the geomorphic effects of large flows in a particular channel reach.

Channel Stability Analysis

Channel stability is assessed by measurements capable of detecting excessive bank erosion, excessive streambed erosion or scour, or excessive deposition. Here "excessive" means outside the expected range of variability for the given stream type and setting. If excessive erosion or deposition is occurring, the channel is in a state of transition from one type to another, i.e. it is changing its basic shape, pattern and/or longitudinal profile. Vertical instability (incision or aggradation) is often coupled with lateral instability (excessive bank erosion and accelerated channel migration or avulsion rates).

Channel incision is commonly indicated by:

- headcuts or knick points, which are steep breaks in channel longitudinal profile. In coarse-bedded streams, headcuts are more subtle (spread out) than in fine-textured systems, and often require a longitudinal profile for definitive identification;
- Over-steepened or vertical banks with evidence of gravitational failure (geotechnical instability, as opposed to surface erosion);
- Previous engineering activities such as extensive channel armouring; and
- Conversion of moist-site vegetation to dry-site vegetation as the floodplain becomes "perched" and the water table falls.

Channel aggradation may be indicated by:

- Pool infilling (often, a mass of finer material may reside over an older, buried coarse pavement layer);
- Excessive overbank deposition, especially, overbank deposits of medium or coarse gravel as opposed to sand and silt;
- Fresh avulsions;
- High width to depth ratio where a lower ratio is expected;
- Excessive mid-channel bar formation, or transverse bars that direct flow into the streambank;
- Excessive locally-derived large wood recruitment; and

- Substrate characteristics indicative of high bedload (poorly developed pavement layer, matrix-supported sub pavement layer, buried pavements, sand dunes or other bedforms in a coarse-bedded stream).

2.4 RIVER ECOSYSTEMS AND RIVER HEALTH

2.4.1 How Stream Ecosystems Work

It is possible to rehabilitate a stream without knowing much about the organisms that live in it. This can be achieved by simply copying the physical structure of the original stream and hoping for the best. However, it can be much more efficient to know something about the group of organisms that are to be promoted and managed.

This section outlines the fundamental structures and processes of stream ecology, so that they can be factored into the design of rehabilitation projects, and their subsequent assessment. What is presented here is a simplistic model of stream ecology that may not do justice to the variability and complexity of ecosystems in the country. However, it does present a good starting point for understanding biological interactions (Rutherfurd et al. 2000[35]).

2.4.1.1 Stream ecology

Stream ecology is the study of communities (stream organisms and the relationships between groups of these organisms), and the way communities and individual species interact with the physical and chemical characteristics of the stream around them. A simple way to look at this complex system is by breaking it up into three parts: the food web, life cycles and resources. This will provide the framework for considering the characteristics of a good community.

a) The Food Web - a Framework for Stream Ecosystems

Figures 2.33 and 2.34 show a simplified food web and ecosystem structure from two sections of a typical stream: an upland stream with varied riffle and pool habitats; and the comparatively less complicated channel of a lowland river. In each of these, the basic ecosystem is very similar, the differences being in the organisms involved (Figure 2.33) and the proportions of processes occurring (Figure 2.34). The food web is a structure in which organisms from higher levels consume those on the levels directly below them. Eventually, all organisms die and return to the bottom of the food web to be broken down into detritus and various forms of nutrient. These are then used by the lower levels of the food web, thus introducing life to the food web once again.

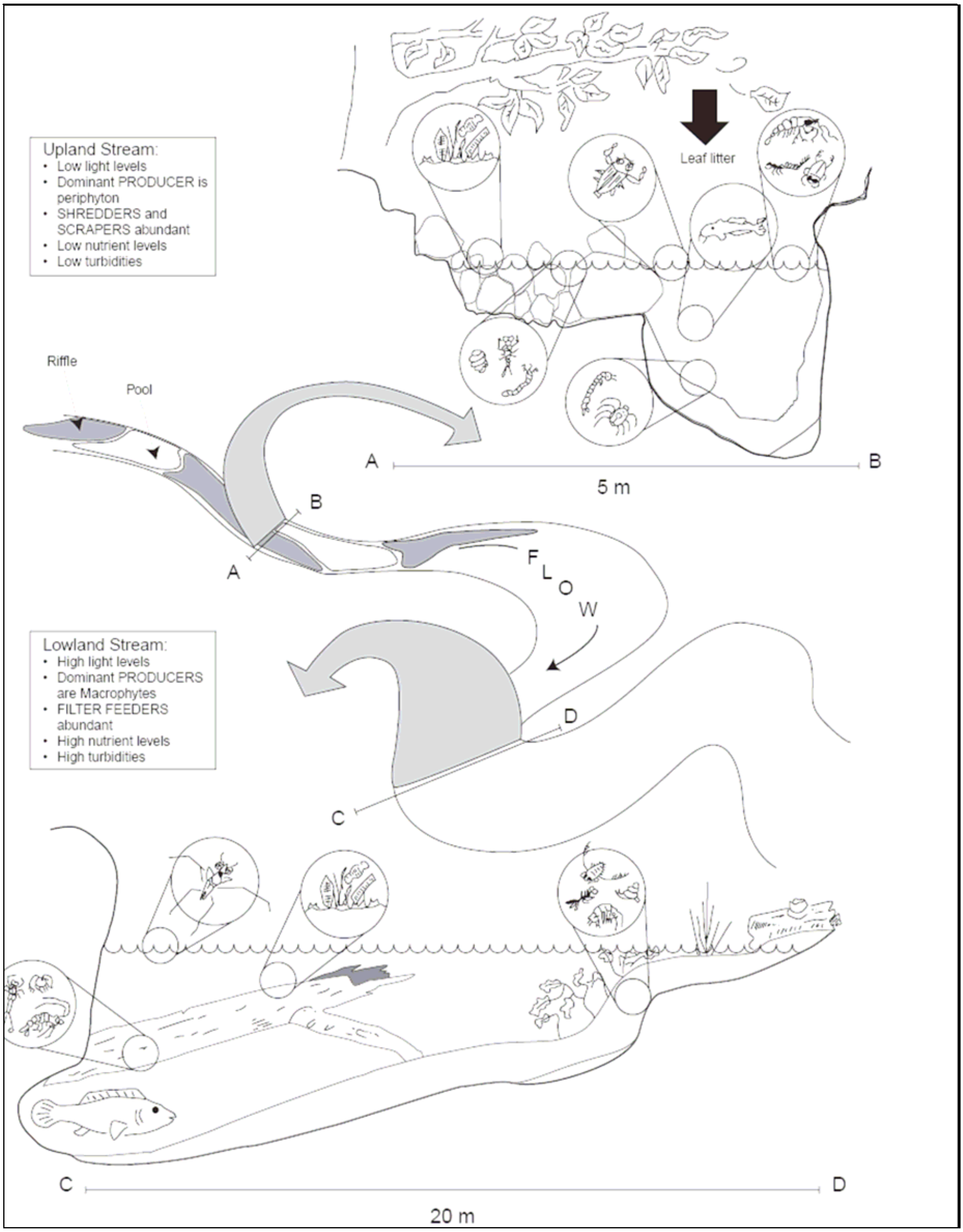


Figure 2.33 This figure contrasts the types of creatures you might find in upland and lowland streams. [35]

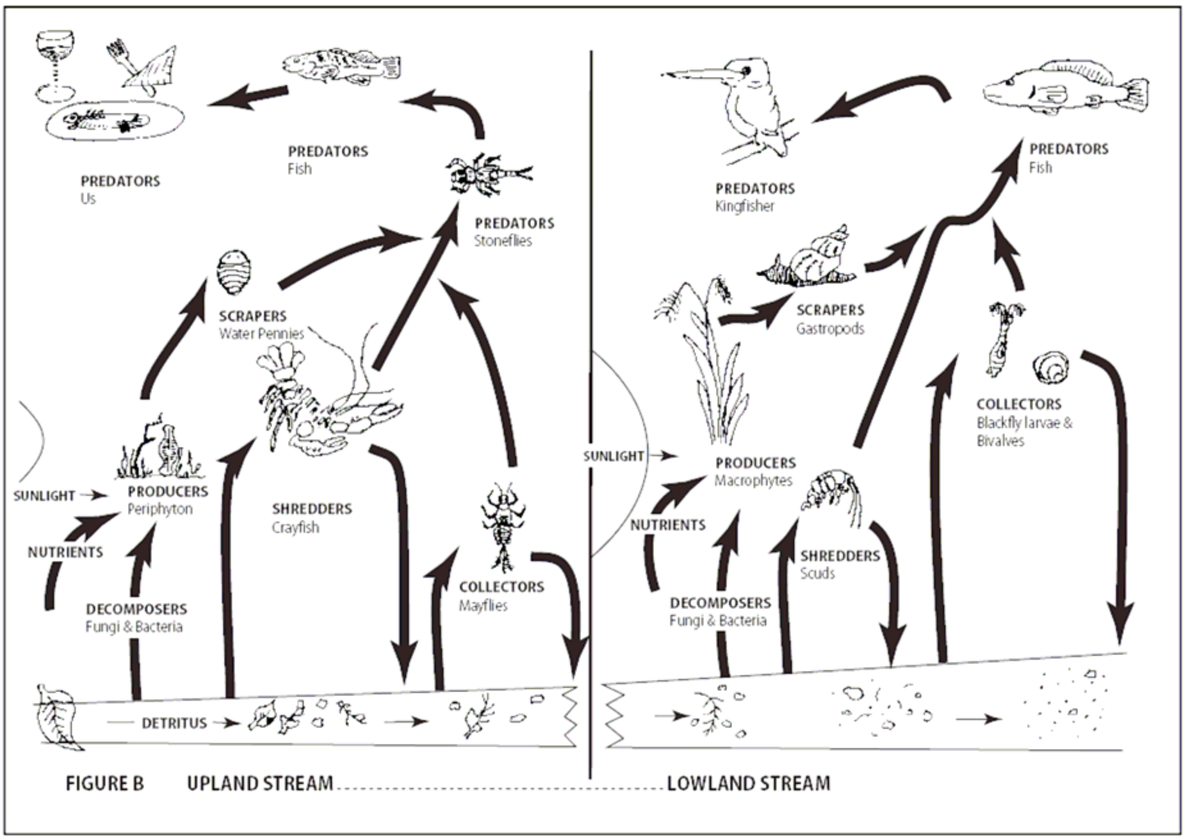


Figure 2.34 The simplified food web describes the interactions between plants and animals in a community-basically, who gets to eat who. [35]

Primary producers

At the bottom of the food web are algae and plants, which create their own energy from sunlight and raw chemicals that are available directly from their surroundings. These are called producers, as they take resources that other organisms cannot readily use, and produce energy in a form that can be readily used by organisms higher up the food web. Unfortunately for them, this usually involves being eaten. In stream environments, the two dominant forms of producers are aquatic plants (macrophytes) (Figure 2.35), and periphyton. The latter refers to the thin layer of algae which coats many of the surfaces in streams. The plants of the riparian zone produce the largest amount of organic matter found in streams and are therefore important producers, despite being out of the watercourse most of the time.

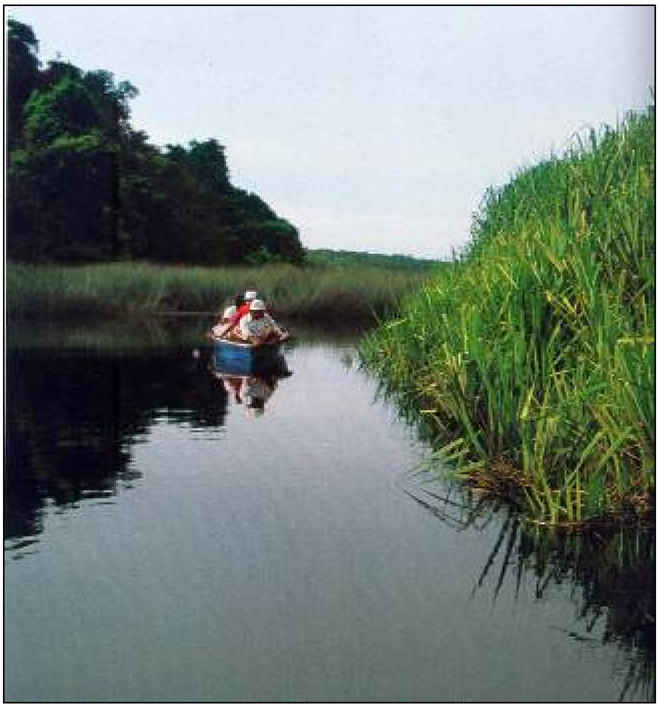


Figure 2.35 Macrophytes growing in the mid course of Bera River, Pahang. [38]

Herbivores

Herbivores occupy the next level up the food web; they consume producers (and decomposers, described below). The two basic types of herbivores present in streams are described by the way they eat. 'Scrapers' graze periphyton, scraping the thin layer of algae, bacteria and fungi from rocks and other hard substrates. This group includes many aquatic snails, together with a variety of other invertebrates equipped with brushes or blades on their mouthparts for removing the firmly attached algal layer. 'Shredders' can eat macrophytes, by chewing through leaves, or boring into the stems of the plants, but most consume old, dead or rotting plant material or detritus.

Predators

All levels of the food web above herbivores involve predators of one sort or another. These are generally larger invertebrates like stoneflies (Plecoptera), and larger animals such as fish, frogs, lizards and birds. Most of the larger stream animals familiar to us are predators, even though they tend to be less numerous than any of the other levels of the food web. The reason there are fewer predators than herbivores is that each predator requires many prey (in a fairly constant supply) to survive.

Detritivores

Detritivores are more numerous than herbivores in streams. This is because of the huge amount of organic matter that finds its way into streams from the catchment area. Leaves, litter, woody debris, and the bodies of dead organisms provide food for detritivores. When organic matter first enters the stream it tends to be large and chunky. The detritivores that first deal with debris are shredders. They break down the debris into smaller pieces, while extracting what nutrients they can from a combination of the old plant matter itself and the bacteria, and fungi that grow on it. Freshwater crayfish (Parastacidae) are a good example of shredding detritivores. In a lot of cases, shredders are relatively inefficient at extracting nutrients, and their fasces are still rich with nutrients. The abrasive effect of downstream movement of organic matter also contributes to its physical breakdown.

As organic matter is chewed, digested and broken into smaller and even smaller pieces, it moves downstream as a cloud of particles. The detritivores that use this form of organic matter are 'collectors' (or filter feeders). Many of them have specialized hairs upon their legs, or around their mouthparts, which strain the fine organics from the water as it flows past them. Blackly larvae (Simuliidae) and net spinning caddis flies (Hydropsychidae) are examples of collectors. Other detritivores collect fine organics in areas of slow flow, where they settle out of suspension and form an easily harvested film on the substrate.

Decomposers

Fungi and bacteria structurally and chemically break down organic matter, releasing the basic components back into the water in the form of nutrients (various states of carbon, nitrogen and phosphorus). These nutrients are then used by producers, completing one of the loops of the food web. Bacteria are found in the water, on most surfaces in the stream, and in the guts of various detritivores.

Implications of ecosystem structure for stream rehabilitation

Animals and plants do not exist in isolation from each other - they require each other for food, shelter, and recycling of waste materials. It is tempting to make some desirable animal a basis for stream rehabilitation. However, the rest of the food web must be supported, particularly when attempting to encourage predators. They will not survive without the food provided by the lower levels of the food web.

b) Life cycles of organisms in streams

Many stream animals have life cycles that involve exploiting a variety of stream habitats during different life stages. For example, fish commonly spawn in one part of their habitat, use a different part as a nursery area, and then disperse into a third area for adult growth. Habitats used by different life stages of the same species may be as different as upland streams and the ocean. However, different habitat use may also occur at smaller scales within the same river system, or even within a single reach. Aquatic insects also move around during their life cycles. For example, leptophlebiid mayflies live on the undersides of stones in moving water as nymphs, then adults leave the stream and live briefly in riparian vegetation before returning to the stream to lay their eggs.

Environmental triggers are a very important part of life cycles. Animals may rely on changes such as water temperature, flow or day length, to indicate that the time has come for a particular part of the life cycle. Many aquatic insects, for example, time their emergence from the water by the water temperature. The warmer the water, the sooner insects will emerge. If water temperatures are raised artificially insects may emerge early and be unable to cope with cold weather.

Though plants are not mobile, they too will have different requirements of their environment at different stages of life. For example, macrophytes may rely on periods of low flow to establish on the stream bank.

Dispersal and migration

Dispersal is often an important part of the life cycle. It is the means by which organisms colonize new areas. Mechanisms of dispersal are often built into the life cycle of a species. The three main types of dispersal are drift, aerial dispersal and migration.

Implications of life cycle complexity for stream rehabilitation

For a life cycle to be successfully completed, the stream must meet the requirements of each life stage, in terms of food and habitat, as well as provide free passage between the habitats and the appropriate environmental triggers for movement between stages. Failure to meet these requirements will result in the local extinction of the animal in question. This can happen quite quickly, within one generation, or by a gradual, insidious decline in population. Fish barriers are a classic example of such a breakdown in life cycles. A dam or weir blocking the upstream passage of young fish will eventually result in the extinction of that species above the obstruction.

c) Resources required by organisms in streams

The physical character of the stream drives the ecology. In fact, the central premise of stream rehabilitation is that the ecology can largely be managed through manipulation of stream resources. These resources can be broken into three groups: the physical habitat available in the stream, the quality and quantity of the water, and the floodplain.

Table 2.8 Some common organisms and some examples of important resources that they require. (Source: Land and Water Resources Research and Development Corporation (2000) [35])

Organism	Examples of important resources
Algae (periphyton)	Light and nutrients
Water milfoil sp.) (Myriophyllum	Light and nutrients, slow moving water
Water skaters (Family: Gerridae)	Pool areas (still water)
Stoneflies (Family: Plecoptera)	High dissolved oxygen, clean coarse substrate, low temperature
Ikan Kelah or Malaysian Red Mahseer (*Tor tambroides* and Tor tambra)	Habitat e.g. Medium to large rivers with rocky, sandy and leafy bottom. Prefers highly oxygenated water and dark environment.

Figure 2.36 Ikan Kelah (or Malaysian Red Mahseer) as Found in Clean Upstream Malaysian Rivers

Habitat

Instream habitat refers to all the physical features of the stream, including the substrate (e.g. rock, sand or mud), the depth and velocity of the water (pool versus riffle), the presence of vegetation in the stream (macrophytes) and around it (riparian vegetation), and any in stream shelter, such as woody debris, undercuts or large rocks. The floodplain is another important component of habitat; inundated vegetation can be important nursery areas for juvenile fish, for example. Streams that offer an array of different habitats are likely to support a greater diversity of organisms. There are several reasons for this.

- The habitat requirements of one species are seldom exactly the same as those of another species. For example, the emergent macrophyte cumbungi (Typha sp .) is found in areas of still or slow-moving water, while ribbonweed (Vallisneria gigantea) can thrive in shallow running water. This is of course rather simplistic—there are obviously many other plants which could thrive in one or both of these environments. However, by having a range of habitats, you create the opportunity for a variety of organisms to utilize those habitats.

- Most organisms with the ability to move need different types of habitat for day-to-day life. For example, a fish may need foraging areas rich in macroinvertebrates, resting areas sheltered from predators, and areas of refuge from floods or drought. Thus, the maintenance of one species requires a variety of habitats.

- The habitat requirements of mobile organisms will probably change during their life cycle. A damselfly, for example, needs good pool environments as a nymph, but as an adult it leaves the water and uses the riparian vegetation as perches and shelter. There are also numerous examples of habitat preference changing with life cycle within the water. To support a single species through its life cycle requires a diversity of habitats.

For these reasons, reaches with more habitat complexity will usually support a larger number of taxa (different types of plants and animals). Substrates that contain a range of particle sizes support larger numbers of taxa than homogenous substrates (Williams 1980 [39]). A reach with pool/riffle/bedrock provide more habitat complexity, and therefore biotic diversity, than another reach of the same length with a simple pool (Brussock et al. 1985 [40]; Statzner and Higler 1986 [41]).

Unfortunately, a widespread impact of post-independent settlement has been the simplification of stream habitats. Riparian vegetation has often been simplified to grasses or a monoculture of shrubs; channels have been straightened; incision has caused a loss of bed complexity; desnagging has removed a lot of instream habitat, and sediment deposition has smothered the stream bed (Figures 2.37). Reduced flow variability downstream of dams may also alter the habitat and thus the fauna in the downstream river course.

Figure 2.37 An extreme example of habitat simplification. On the left is the original urban stream at upper Sg. Kerayong in the Klang valley.

Human impact not only simplifies the structure of streams, reducing the amount of habitat, but also reduces the continual evolution of habitats within a natural stream. For example, consider a meandering stream that periodically cuts-off its meander bends to create billabongs (oxbow lakes), or jumps to new courses on the floodplain (avulsions). Over thousands of years the stream is continually creating billabongs that then progressively fill-in. Different groups of organisms occupy different parts of this succession from open stream to disappearing billabong. In a natural system, at any one time there are always bends in different stages of the succession, providing habitat for all of the communities. By stabilizing the stream and limiting the number of cutoffs, humans are terminating the entire process of succession. Thus, by stabilizing streams and controlling floods, humans reduce the number of habitats as well as their continual renewal.

Water quality and quantity

The flow regime can have a significant impact on stream ecology. Flow has a direct effect on plants and animals through its role as a disturbance of the stream in floods and droughts, as a trigger for migrations, and as a means of connecting with floodplain habitats. Indirectly, flow regime is an important determinant of stream morphology and maintaining instream habitats. Changes in flow are common triggers for spawning migrations in fish. Changes to the flow regime may mean these trigger flows do not occur, or occur at the wrong time. Reducing the number of successful spawning migrations can lead to a decline in the population of the fish species in question.

Water quality can also be very important. Every organism has a range of water quality that it can tolerate. Outside this range, the ability to compete with other organisms for space and food will decline. In this situation, tolerant species will dominate the stream fauna. Unfortunately, it is often exotic species, such as carp, that show the greatest ability to take advantage of such situations. When water quality falls by too much, sensitive organisms will be completely lost from the stream. Water quality is affected by land use (farming, urban areas, construction and industry all have accompanying water quality problems), stock access to streams (increases turbidity and nutrient load), cleared riparian zone (decreased buffering effect, and decreased shading of water), and point sources of pollutant such as drains, sewage effluent and industrial wastewater.

The floodplain

Floodplains are a surprisingly important part of the stream system, providing habitat important to the life cycles of stream animals, and delivering a large quantity of detritus to the stream. During floods, the inundated area is a vast food source and provides habitat for fish spawning and nursery. The floodplain is a comparatively slow-flowing refuge from the destructive forces of the main channel during flood. When the floods recede, they take with them a supply of leaf litter and other detritus which provides food for the detritivores or shredders. Floods also play an important role in the floodplain itself, with some species of plant requiring periods of inundation for regeneration.

In most situations, the stream and the floodplain are so intimately associated that it is sensible to consider them as the same system. In fact, in a natural stream, the boundary between the stream and the floodplain tends to be a vague zone rather than an abrupt border. For example, incision of the stream will lead to a dramatic reduction in flooding that will transform the riparian vegetation communities along the stream, and so change the terrestrial animals that rely on that vegetation. Grazing of riparian zones, on the other hand, can lead to channel erosion that in turn alters the biological communities living in the streams.

Implications of resource requirements for Stream Rehabilitation

The direct relationship between resources and the stream biota is convenient for stream managers. The stream ecology can be managed by manipulating the physical habitat and water quality. However, this is a two-edged sword. If the resources are not in good condition, the ecosystem cannot be expected to recover. It cannot be over-emphasized that for a population of any species to be maintained in a reach, the requirements of all stages of the life cycle must be met. Providing a diversity of habitats will increase the number of species the stream will support, unless some aspect of water quantity or quality is causing a problem. There must be a sufficiently natural flow regime to maintain that habitat complexity, as well as providing appropriate triggers for life cycle changes, and access to flood plain habitat. Managing water quality is another common difficulty, and polluted water can prevent the stream community from improving, even when there is good habitat available.

d) Ecological health

What is a 'good community'? The species that make up a 'good community' is really based on a value judgment that the communities found in pristine streams are ideal. Of course, such communities will vary enormously between different regions (highland versus lowland streams, tropical versus temperate, etc.). However, there are two things good communities have in common: they contain a diversity of species, and a significant proportion of these species are intolerant of 'bad' stream health (such as poor water quality and reduced habitat diversity).

Why is this so? The tolerance of the species present is an indicator of the physical condition of the stream. The presence of a variety of sensitive species suggests that the stream is in good physical condition. However, if only species tolerant of polluted or degraded conditions are present, then this is probably because local conditions are degraded. The organisms present indicate the condition of the stream. Admittedly, this is a very circular argument, but in fact, it is the association with degraded environments that makes many species appear undesirable.

High diversity is considered valuable because a degraded stream will have only plants and animals that are tolerant of the degraded conditions, whereas a healthy site will still have most of those tolerant species, and a variety of sensitive species as well. However, although this is the general rule, it is important to remember that more is not always better. There are some situations where human interference will artificially increase the number of species present in a reach. For example, slight nutrient enrichment in sandy streams can increase the number of macroinvertebrate species present. However, such a change risks losing sensitive species from the stream. Introducing animals or plants not naturally found in the area is another way of artificially raising diversity. This could eventually lead to the decline of local species, and would also reduce diversity between entire streams. For these reasons, natural levels of diversity are the best.

2.4.1.2 Stream ecosystems and rehabilitation: the importance of limiting requirements

Since pre-independent days there have been many far reaching changes to streams in this country. The resulting shift from good to not-so-good communities in our streams is of course the reason for rehabilitation efforts. But changing everything back to pre-independent conditions for the sake of stream ecology is plainly impractical, startlingly expensive, and in most cases impossible. So, when the environment has been so thoroughly altered, and the potential for rehabilitation is limited, how does one know where to start? How does one know which of the changes one can make will have the most effect on improving the stream? This is where the concept of limiting requirements is important.

To explain the concept of 'limiting requirement', it is easiest to consider the needs of a single species. The freshwater blackfish in Australia can be used as an example. The basic needs of this species are good water quality, instream cover in the form of woody debris or rocks, hollow woody debris to spawn in, and a supply of food (benthic macroinvertebrates). Imagine a reach of stream that has fairly good water quality, a moderate food supply, but little woody debris for instream cover and spawning sites. In this case, the woody debris is the limiting requirement (see Figure 2.38).

Any attempt to increase the blackfish population would first need to increase the habitat available. There would be little point in trying to improve other aspects of the stream, such as the water quality or food supply, when more fish would not survive in the reach without more habitat (Figure 2.39). This highlights one of the most important rules for stream rehabilitation: if one's objectives involve altering communities, or increasing populations of certain organisms, one of the first steps must be to identify and treat the limiting requirements. If one treats a non-limiting problem, the success of the project will still be restricted by the influence of the limiting requirement (Figure 2.39). As always, the real situation is almost never as simple as in the blackfish example, for the reasons outlined below.

- In many situations, the changes made to the environment since pre-independent days have had major effects on many aspects of the physical character, water quality and hydrology of our stream systems. Where there are many problems in the stream, all impacting in different ways on stream animals and plants, it can be difficult to judge which is the most important. It is quite possible to have two or more equally limiting aspects of the stream.
- The requirements of many species are not well understood. In the northern hemisphere, much of the stream rehabilitation is focused on trout and salmon. The requirements of these commercially valuable fish are known in great detail, down to the precise grain sizes of bed material for most successful spawning, and the preferred radius of curvature for meander bends.

This level of information is simply not available for Malaysian fish, frogs etc., let alone the less charismatic creatures such as invertebrates.

- Important limiting requirements need not be continually present. The requirements of most species change through their life cycle. For example, many species of fish require a temperature or flow trigger for spawning, special spawning habitat, a different habitat for rearing larvae and juvenile fish, and another one for adults. If one of these is missing at the critical time of year, it could drastically affect the success of reproduction.
- It is more common, and more environmentally sensible, to rehabilitate a stream for a group of animals, or indeed entire communities, rather than a single species. This means juggling the requirements of all the species involved, where they are known.

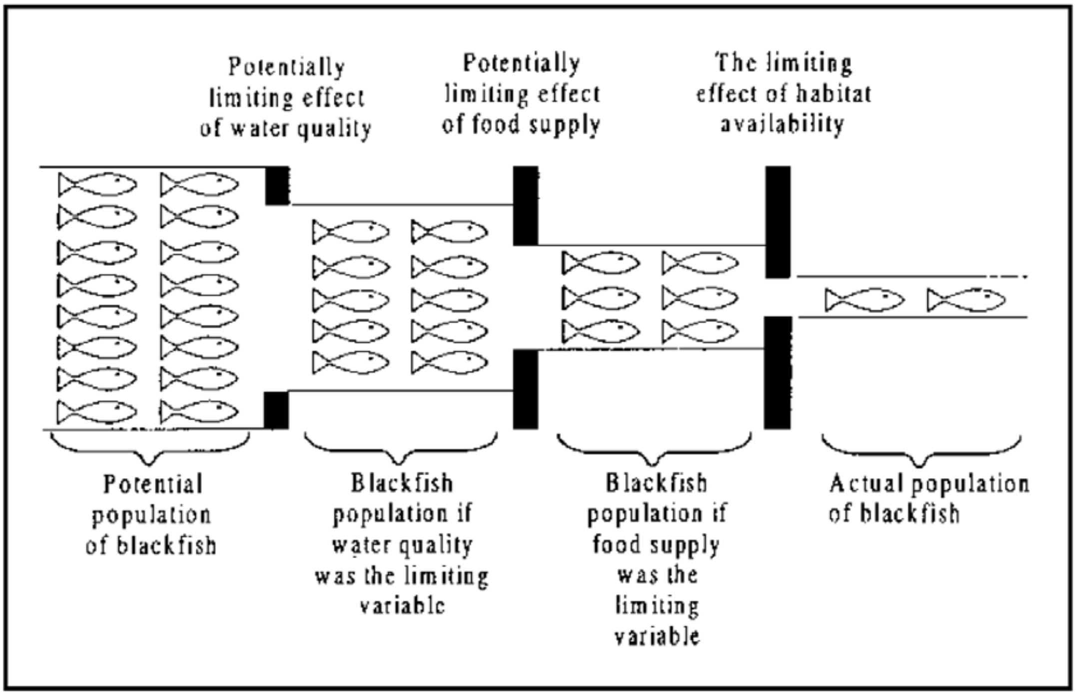


Figure 2.38 The effect of degraded habitat, water quality and food supply on a hypothetical population of blackfish. [35]

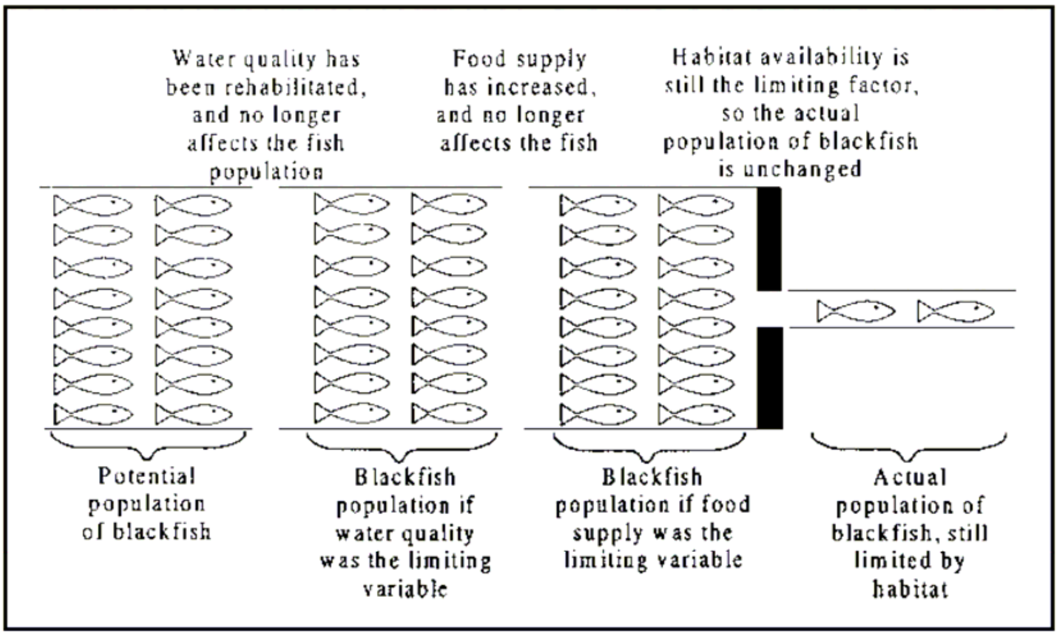


Figure 2.39 The importance of tackling the ‘limiting requirement’ first. [35]

2.4.2 Concept of River Health

The term 'river health' is a useful and widely understood concept. However, it is difficult to describe in precise scientific terms. In this section, river health is taken to mean the degree of similarity to an unimpacted river of the same type, particularly in terms of its biological diversity and ecological functioning. This rather simplistic definition says little of the attributes or behaviors that we might expect of a healthy river but has the advantage of a verifiable, regionally relevant scale against which to measure health. This is analogous to a general assessment of human health (Schofield et al. 1996 [42]).

2.4.2.1 River stresses

In Malaysia, relatively few rivers remain in an unimpacted or pristine state. Most rivers are affected by a number of instream, riparian and catchment modifications or practices. This often results in them being less biologically functional and of lower ecological value than their original states. Important river stresses include nutrient enrichment, increasing salinity, pesticides, sediment loading, water extraction, flow control, loss of riparian vegetation and effluent discharge.

The nature of the ecological impacts caused by modification to river systems varies according to river and modification type. However, in a general sense, human modifications result in a series of physical "river stresses" that have repercussive biological stresses. The five most significant stresses on the biotic components of rivers arise from (Perrow et al. 2002[34]):

- Changes in food for organisms with respect to the quality, quantity and seasonal availability of particular organic matters;
- Decline in water quality with respect to factors such as increases in temperature extremes, turbidity, nutrients, and suspended solids, discharges and the diurnal cycle of dissolved oxygen;
- Deterioration of habitat, including reductions in habitat area, habitat heterogeneity and in-channel shading and greater instability of channel bank and bed sediment;
- Deleterious changes in water quantity ('flow mis-timing') such as altered flow extremes, greater extremes in flow velocities, and reduced diversity of microhabitat velocities; and
- Variation in biotic interactions including increased frequency of diseased fish, disruption of seasonal rhythms, and alterations to decomposition rates and timing to atrophic structure.

The potential ecological consequences of physical human activities in and beside river channels are manifold. However, causes of ecological changes also originate in various locations around the catchment. The same changes brought about by human modifications also cause "human-scale" problems of risk and cost. For instance, channelization schemes have been documented to increase the risk of downstream flooding, to create river system instability that migrates upstream through knickpoint erosion, to be aesthetically undesirable and to require expensive structural solutions and maintenance to keep the scheme operating according to design guidelines. Therefore the ecological dimension generally forms just one of a suite of objectives in undertaking river restoration.

2.4.2.2 Management needs and objectives

To understand why we are interested in measuring river health, it is first necessary to appreciate our changing perceptions of the values and appropriate uses of rivers. In the early days of our country's development, the principal uses of rivers have been navigation, drinking water, irrigation water, effluent disposal and recreation. These uses are of high social and economic value (Schofield et al. 1996 [42]).

More recently, the environmental movement has stimulated the widespread appreciation of the natural and ecological values of rivers through such concepts as "natural rivers", "biodiversity" and "sustainable development". However, inappropriate land use and instream practices have led to a continued decline in the social, economic and environmental values of our rivers.

In the ecological context, rivers in Malaysia have four major management needs:

- protecting and conserving the remaining pristine rivers and pristine river reaches across as many river types as possible;
- protecting endangered riverine species and ecosystems of high conservation value;
- applying ecologically sustainable development (ESD) principles to new developments which might affect rivers; and
- rehabilitating degraded rivers to acceptable levels of river health.

The first steps in achieving these objectives are to:

- provide feedback to river authorities, community groups and the community at large on the current and changing status of river health;
- identify and predict specific impacts and their causes or sources;
- identify reaches of high conservation status requiring protection; and
- demonstrate the effectiveness of management actions aimed at improving the quality of rivers.

2.4.2.3 Assessment methods

Assessment of the condition of rivers in this country until quite recently relies mainly on physio-chemical monitoring and qualitative descriptions. While these approaches have produced some useful results, they have generally failed to provide a consistent and comprehensive assessment of river condition either regionally or nationally, and have said little about the ecological state and environmental quality of rivers.

Moreover, they have been unable to reliably assess the impacts of various instream and catchment practices on river ecosystems or provide reliable answers to management questions in a cost-effective way that can also be understood by the community. The preoccupation with chemical water quality has also largely overlooked structural impacts that have led to alterations to river flow regimes, loss of habitat area, loss of habitat diversity, obstructions to passage through streams and riparian degradation. However, the adoption of a bioassessment method (ASPT) by DID is a good start to address the above shortcomings.

Bioassessment

The need for using bioassessment techniques to measure river health is principally two-fold (Schofield et al. 1996 [42]):

- Assessing ecological values requires direct measurements of the system; and
- Physio-chemical measurements alone are inadequate for assessing river health, as the processes linking changes in physical and chemical conditions in rivers and the ecological state are either poorly understood or too complex. They also do not take into account important changes to river habitat and are frequently instantaneous.

The integration of regionally referenced physical, chemical and biological measures is needed to provide a comprehensive and sensitive assessment of river conditions. The biological measures can involve a wide range of groups including macroinvertebrates, fish, algae, diatoms, microorganisms and macrophytes. Each group reflects environmental stresses in different ways and can be used to assess river health. They have the potential to provide an integrated response to a number of stresses as well as measures over different time-scales. Selective responses to particular stresses at the group, taxon and species levels can help identify specific sources of stress (e.g. a particular type of chemical pollution or change in habitat structure).

The adoption of biological method has been initiated in this country, in particular the ASPT (Average Score Per Taxon) method, with the publication of the guidelines titled "Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai" by DID Malaysia. The reason for the adoption of this index is because it uses qualitative data which can be easily obtained. Tolerance values also need not be given very high priority. Moreover, this index has been used widely in

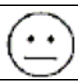
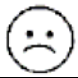
Europe especially in U.K. since 1976. The suitability of this index has been tested in Thailand and therefore it can be used in this country with some minor adjustments. However, continued research should be carried out to further refine the technique for use in this region. The brief guide on the use of macroinvertebrates for classification of river water quality has been adapted from Green World Foundation, Thailand by Danish International Development Assistance (DANIDA), Malaysia with the use of ASPT index.

Owing to the close proximity of Thailand to Malaysia, much information with regards to tolerance values of macroinvertebrate families to organic pollutants used in Thailand have been adopted with some modification made through research done in the Malaysian rivers. Two families, Gerridae and Veliidae, have been omitted from the list of macroinvertebrates due to their mobility i.e. they can escape from any polluted environment easily. Similarly, these two families are also omitted in the Family-level Biotic Index (FBI) in the U.S. for the same reason.

The Biological Monitoring Working Party (BMWP) is a procedure for measuring water quality using species of macroinvertebrates as biological indicators. The method is based on the principle that different aquatic invertebrates have different tolerances to pollutants. The presence of mayflies or stoneflies for instance indicate the cleanest waterways and are given a tolerance score of 10. The lowest scoring invertebrates are worms (Oligochaeta) which score 1. The number of different macroinvertebrates is also an important factor, because a better water quality is assumed to result from a higher diversity of the fauna.

The BMWP score equals the sum of the tolerance scores of all macroinvertebrate families in the sample. A higher BMWP score is considered to reflect a better water quality. From the BMWP scores, the ASPT score is calculated. The ASPT equals the average of the tolerance scores of all macroinvertebrate families found, and ranges from 0 to 10. The main difference between both indices is that ASPT does not depend on the family richness. Based on their tolerances to organic pollution, they are classified into 5 groups as shown in Table 2.9:

Table 2.9 Division of Macroinveterbrates into 5 Groups Basing on their Tolerance to Organic Pollution and the Environment they are Found [44]

Group	Tolerance	Symbol	Present in Environment
1	Very sensitive		Fauna in this group can only be found in pristine river condition.
2	Sensitive		Fauna in this group are usually found in clean or moderately clean rivers.
3	Slightly tolerant		This group resides in clean or moderately clean rivers but not in dirty water.
4	Tolerant		These organisms live in clean, moderately clean as well as dirty water.
5	Very tolerant		This group is found in both clean and dirty water but normally found in abundant in dirty water.

Kick sampling, where a net is placed downstream from the sampler and the river bed is agitated with the foot for a given period of time (the standard is 3 minutes), is employed. Any macroinvertebrates caught in the net are stored and preserved with an alcohol solution, and identified to the family level, this can be done with the live organisms as well.

Table 2.9 provides the organisms used for the tolerance scores with some adjustments made to the Greenworld Organisation lists. For more details on the method and the local species referenced to, please refer to the guidelines "Panduan Penggunaan Makrounvertebrata untuk Penganggaran Kualiti Air Sungai"

Besides the above method, there are also a number of other methods used in the developed countries. Of particular interest are the RIVPACS (or its equivalent, AUSRIVAS, in Australia), HABSCORE (USEPA Rapid Bioassessment Protocols), Habitat Predictive Modelling, and River Habitat Survey (RHS) etc. For the above methods and a few others, reference may be made to "Australian River Assessment System: Review of Physical River Assessment Methods - A Biological Perspective, Monitoring River Heath Initiative Technical Report no 21, Commonwealth of Australia and University of Canberra, Canberra" [36] for more details. These methods are detailed in Appendix 2.B.

The bioassessment methods mentioned above have been developed and applied to wadeable streams and rivers. As these methods become increasingly refined and accepted, effort may then be focused on developing sampling protocols for large rivers. Since this is a relatively new area and there are merits and demerits of using benthic macroinvertebrates, algae or fish as indicators in large rivers, further research effort would be required for their use in the local environment. For details on bioassessment of non--wadeable streams and river, reference may be made to a document from USEPA titled "Concepts and Approaches for the Bioassessment of Non-wadeable Streams and Rivers" (Flotemersch et al. 2006 [37]) which gives a comprehensive account of the different methods available and the merits and demerits of each of the methods.

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APPENDICES

Appendix A – River Characteristics and Geomophorlogy – Examples

Appendix B – River Ecosystems and River Health – Habitat Assessment Methods

APPENDIX A

RIVER CHARACTERISTICS AND GEOMORPHOLOGY - EXAMPLES

APPENDICES

Appendix A River Characteristics and Geomorphology - Examples

Comparison of Regime Equations

1. Observations on three canals yielded the following information:

No	Q m^3s^{-1}	A m^2	So x10^3	R m	P m	D m	B_s m	B m	d mm	C ppm
1	29.19	56.02	0.058	2.04	27.43	2.53	24.38	22.19	0.254	80
2	12.60	21.55	0.063	1.42	15.12	1.83	13.41	11.73	0.094	220
3	4.13	10.03	0.135	0.86	11.58	1.07	10.36	9.33	0.318	227

Assuming that only the discharge, the sediment size and the concentration are given, determine the channel cross section geometry and bed slope for canal 3 by the methods of Lacey, Blench and Simons & Albertson. Assume the bed is sandy in all cases and the bank material highly cohesive.

i) Lacey's method

Silt factor $f_L = \sqrt{(2.5d)} = \sqrt{(2.5 \times 0.318)} = 0.892$

- $U = 0.635\, f_L^{1/2} R^{1/2} = 0.635 \times 0.892^{1/2} \times 0.788^{1/2} = 0.532ms^{-1}$
  {R from below}
- $P = 4.836\, Q^{1/2} = 4.836 \times 4.13^{1/2} = 9.828m$
- $S = 0.000314\, f_L^{5/3} Q^{-1/6} = 0.000314 \times 0.892^{5/3} \times 4.13^{-1/6} = 0.000205$
- $R = 0.473\, f_L^{-1/3} Q^{1/3} = 0.473 \times 0.892^{-1/3} \times 4.13^{1/3} = 0.788$
- $A = 2.287\, f_L^{-1/3} Q^{5/6} = 2.287 \times 0.892^{-1/3} \times 4.13^{5/6} = 7.746m^2$

ii) Blench's method

Bed factor $f_B = \{1 + 0.012c\}\sqrt{(0.335d)} = \{1 + 0.012 \times 227\}\sqrt{(0.335 \times 0.318)}$
$= 1.215$
Side factor $f_S = 0.02787$ (highly cohesive)

- $U = (f_B\, f_S\, Q)^{1/6} = (1.215 \times 0.02787 \times 4.13)^{1/6} = 0.720ms^{-1}$
- $B = (f_B\, Q/ f_S)^{1/2} = (1.215 \times 4.13/0.02787)^{1/2} = 13.418m$
- $S = \dfrac{f_B^{5/6} f_S^{1/12} v^{1/4}}{3.63gQ^{1/6}\{1 + c/2330\}} = \dfrac{0.0276}{49.485} = 0.000558$
- $D = (f_S\, Q/ f_B^2)^{1/3} = (0.02787 \times 4.13/1.215^2)^{1/3} = 0.427$
- $A = f_B^{-1/6}\, f_S^{-1/6}\, Q^{5/6} = 1.215^{-1/6} \times 0.02787^{-1/6} \times 4.13^{5/6}$
  $= 5.732m^2$

iii) Simons & Albertson's method

Assume channel Type 2

- $K_1 = 4.71$, $K_2 = 0.484$, $K_3 = 10.67$, $K_4 = 0.54$ & m=0.33
- $P = K_1\ Q^{1/2} = 4.71 \times 4.13^{1/2} = 9.57$m
- B = 0.9 P = 8.61m
- B_S = 1.09B + 0.66 = 10.05m
- $R = K_2 Q^{0.36} = 0.484 \times 4.13^{0.36} = 0.806$m
  since $R \le 2.1$m,
- D = 1.21R = 0.976m

Hence A = BD = 8.61 x 0.976 = 8.403m^2
A = PR = 9.57 x 0.806 = 7.713m^2 $\therefore$ average A= 8.058m^2

- U = Q/A = 4.13/8.058 = 0.513ms^{-1}
- $0.513 = K_3(R^2 S)^m = 10.67\ (0.806^2 \times S)^{0.33}$
- $\therefore$ S= 0.000156

Or $$S= \frac{1}{K_4}\left(\frac{U^2}{gD}\right)\left(\frac{UB}{v}\right)^{-0.37} = \frac{1}{0.54}\left(\frac{0.513^2}{9.807x0.976}\right)\left(\frac{0.513x8061}{1.0x10^{-6}}\right)^{-0.37}$$
= 0.000177

$\therefore$ average S = 0.000167

iv) Comparison of results

No.	Q $m^3 s^{-1}$	A m^2	U ms^{-1}	So x 10^3	R m	P m	D m	B_S m	B m
Lacey	4.13	7.746	0.532	0.205	0.788	9.828	-	-	-
Blench	4.13	5.732	0.720	0.558	-	-	0.427	-	13.42
Simons & Albertson	4.13	8.058	0.513	0.167	0.806	9.57	0.976	10.05	8.61
Actual	4.13	10.03	0.412	0.135	0.86	11.58	1.07	10.36	9.33

2. Application to stable channel geometry. This method of Julien and Wargadalam (1995) better describes alluvial channels with coarse sands and gravel beds. Calculate the downstream hydraulic geometry for a channel at incipient motion, given Q = 104m^3/s, d_{50} = 0.056 m and τ^*_θ = 0.047 at the beginning of motion.

   Step 1: Roughly estimate the flow depth, e.g., h = 1 m

   Step 2: From the flow depth and grain size calculate m from

$$m = \frac{1}{\ln\left(\frac{12.2h}{d_s}\right)} = 0.186$$

Step 3: Calculate the exponents for flow depth from

$$h = 0.133 Q^{\frac{1}{3m+2}} d_s^{\frac{6m-1}{6m+4}} \tau_*^{\frac{-1}{6m+4}}$$

given $m = 0.186$

$$h = 0.133(104)^{0.39}(0.056)^{0.023}(0.047)^{-0.195} = 1.38\text{m}$$

Step 4: Repeat steps 2 and 3 with the calculated flow depth in step 3 until convergence:

$m = 0.175$, gives $h = 1.49\text{m}$, and $m = 0.172$, gives $h = 1.51\text{m}$

Step 5: Calculate the channel width W, flow velocity V, and slope S by using the last value of m and the exponents of Q, ds, and τ_θ^* in the following equations with m = 0.172:

$$W = 0.512 Q^{\frac{2m+1}{3m+2}} d_s^{\frac{-4m-1}{6m+4}} \tau_*^{\frac{-2m-1}{6m+4}}$$

$$W = 0.512(104)^{0.534}(0.056)^{-0.335}(0.047)^{-0.267} = 36.4\text{m}$$

$$V = 14.7 Q^{\frac{m}{3m+2}} d_s^{\frac{2-2m}{6m+4}} \tau_*^{\frac{2m+2}{6m+4}}$$

$$V = 14.7(104)^{0.068}(0.056)^{0.329}(0.047)^{0.466} = 1.87\text{m/s}$$

$$S = 12.4 Q^{\frac{-1}{3m+2}} d_s^{\frac{5}{6m+4}} \tau_*^{\frac{6m+5}{6m+4}}$$

$$S = 12.4(104)^{-0.397}(0.056)^{0.994}(0.047)^{1.199} = 2.86 \times 10^{-3}$$

Simplified Method of Julien (2002)

From Eq. 2.15 at a slope of S = 0.003

The flow depth is h = 0.2 $(104)^{0.33}$ $(0.056)^{0.17}$ $(0.003)^{-0.17}$ = 1.52 m
The channel width is W = 1.33 $(104)^{0.44}$ $(0.056)^{-0.11}$ $(0.003)^{-0.22}$ = 50.6 m
The mean flow velocity is V = 3.76 $(104)^{0.22}$ $(0.056)^{-0.05}$ $(0.003)^{0.39}$ = 1.25 m/s
The Shields parameter is ζ_* = 0.121 $(104)^{0.33}$ $(0.056)^{-0.83}$ $(0.003)^{0.83}$ = 0.049 which corresponds to incipient motion of the bed material.

3. Beginning of Motion

The incipient motion of be material from the Shields diagram in Figure 2.A.1. Recall that the bed shear stress is $\tau_o = \gamma RS$ and the shear velocity $V^* = \sqrt{\tau_0 / \rho}$

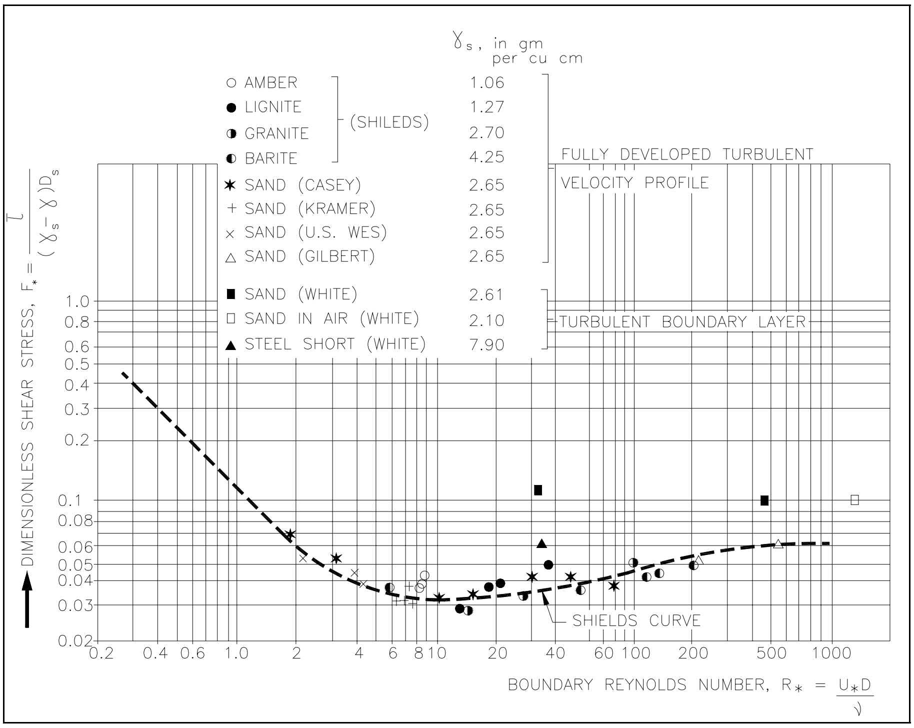

Figure 2.A.1 Shields Diagram: dimensionless critical shear stress from [16] or [3]

(a) For the following conditions determine if the bed material in a sand bed channel is in motion.
R = 1.22 m
S = 0.00038 m/m
D50 = 0.31mm

The shear stress on the bed, at a single vertical in the cross-section, is

9800 N/m^3 x 1.22 m x 0.00038 = 4.5 N/m^2

The shear velocity is V^* = (4.5 / 1000)^{½} = 0.067 m/s

The Shields parameter is $\tau_o/(\gamma_s - \gamma)\, d_s$ = 4.543 / (25970-9800) 0.00031 = 0.91

The grain shear Reynolds number $V^* d_s/\nu$ = (4.543/1000)$^{1/2}$ (0.00031)/1.31 x 10^{-6} = 15.9

This point plots above the incipient motion line in Figure 2.A.1 and indicates the bed material is in motion.

(b) For gravel sized material with the same values of τ_o = 4.5 N/m^2; d_s = 3.1 mm we have:

$\tau_o/(\gamma_s - \gamma)\, d_s$ = 4.54 /(25970-9800) (0.0031) = 0.091

$V^* d_s/\nu$ = (4.54/1000)$^{1/2}$ (0.0031)/1.31 x 10^{-6} = 159

This point plots above the incipient motion line in Shields (Figure 2.A.1) and indicates this channel bed is in motion.

- Critical Velocity for Beginning of Bed Material Movement

a) Sand Size Bed Material

Given depth y is 3.66 m and bed material size d_{50} is 0.31 mm, what is the critical velocity V_c?

$$V_c = 6.19y^{1/6}d^{1/3} = 6.19 \times 3.66^{1/6} \times 0.00031^{1/3} = 0.52m/s$$

b) Gravel Size Bed Material

Given depth *y* is 3.66 m and bed material size d_{50} is 3.1 mm, what is the critical velocity V_c?

$$V_c = 6.19y^{1/6}d^{1/3} = 6.19 \times 3.66^{1/6} \times 0.0031^{1/3} = 1.12m/s$$

c) Cobble size Bed Material

Given depth *y* is 3.66 and bed material size d_{50} is 128 mm, what is the critical velocity V_c?

$$V_c = 6.19y^{1/6}d^{1/3} = 6.19 \times 3.66^{1/6} \times 0.128^{1/3} = 3.88m/s$$

- Critical Size for Beginning of Bed Material Movement

Given depth *y* is 3.66 m and velocity *V* is 0.61 m/s, 1.22 m/s, 2.44 m/s, and 3.66 m/s respectively.

Determine the critical bed material size d_{50}.

V = 0.61 m/s

$$d_c = \frac{0.0042V^3}{y^{1/2}} = \frac{(0.0042)0.61^3}{3.66^{1/2}} = 0.0005m(0.50mm)$$

V = 1.22 m/s

$$d_c = \frac{0.0042V^3}{y^{1/2}} = \frac{(0.0042)1.22^3}{3.66^{1/2}} = 0.00399m(3.99mm)$$

V = 2.44 m/s

$$d_c = \frac{0.0042V^3}{y^{1/2}} = \frac{(0.0042)2.44^3}{3.66^{1/2}} = 0.0319m(31.9mm)$$

V = 3.66 m/s

$$d_c = \frac{0.0042V^3}{y^{1/2}} = \frac{(0.0042)3.66^3}{3.66^{1/2}} = 0.108m(108mm)$$

- Critical Depth at which Bed Material Transport would Stop

(a) Given velocity *V* of 0.61 m/s and bed material size d_{50} of 0.305 mm, determine the critical depth *y* below which there would not be bed material movement.

$$y = \frac{1.78 \times 10^{-5} V^6}{d_{50}{}^2} = \frac{(1.78 \times 10^{-5})0.61^6}{0.000305^2} = 9.86m$$

(b) Given velocity *V* of 0.61, 2.44, and 4.88 m/s and bed material size d_{50} of 152 mm, determine the critical depth *y* when bed material movement would stop.

V = 0.61 m/s

$$y = \frac{1.78 \times 10^{-5} V^6}{d_{50}{}^2} = \frac{(1.78 \times 10^{-5})0.61^6}{0.152^2} = 0.00004m$$

There would not be any bed material movement at this velocity.

V = 2.44 m/s

$$y = \frac{1.78 \times 10^{-5} V^6}{{d_{50}}^2} = \frac{(1.78 \times 10^{-5})2.44^6}{0.152^2} = 0.16\text{m}$$

V = 4.88 m/s

$$y = \frac{1.78 \times 10^{-5} V^6}{{d_{50}}^2} = \frac{(1.78 \times 10^{-5})4.88^6}{0.152^2} = 10.4\text{m}$$

Would this depth occur? No. Why not? The coarser material would armour the bed.

4. Meandering and Braiding

(b) Consider the sinuous point bar stream in Figure 2.A.2 below. Determine the following characteristics: meander wavelength λ; meander width W_m; mean radius of curvature r_c; meander amplitude A; and the bend deflection angle ϕ.

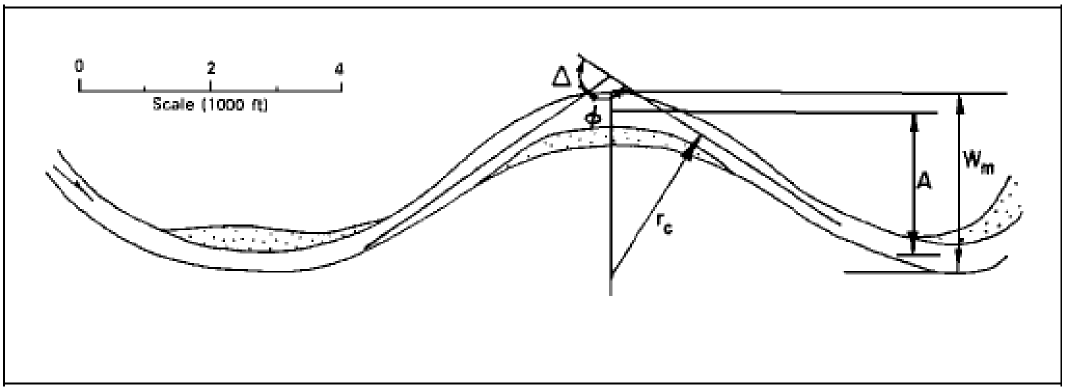

Figure 2.A.2 Sinuous point bar stream

Meander wavelength λ is approximately 11,000 ft (3,353 m)
Radius of curvature r_c is approximately 2,400 ft (732 m)
Channel width W ranges from 250 ft to 850 ft (76 to 260 m) at high stage
Meander amplitude A is 2,200 ft (670 m)
Meander belt width W_m is 2,700 ft (823 m)
Bend deflection angle ϕ is 105°
Sinuosity is 1.2

Table 2.A.1 Change of Variables Induced by Changes in Sediment Discharge, Size of Bed Sediment and Wash Load.

Relationship	Tendency to Braid or Meander
$Q_S^+ D_{50} / C_f \sim S^+ V^+ y_o^- W^+$	B
$Q_S^- D_{50} / C_f \sim S^- V^- y_o^+ W^-$	M
$Q_S D_{50}^+ / C_f \sim S^+ V^+ y_o^- W^+$	B
$Q_S D_{50}^- / C_f \sim S^- V^\pm y_o^\pm W^\pm$	M
$Q_S D_{50} / C_f^+ \sim S^- V^\pm y_o^\pm W^\pm$	M
$Q_S D_{50} / C_f^- \sim S^+ V^+ y_o^- W^+$	B
$Q_S^+ D_{50}^+ / C_f \sim S^+ V^+ y_o^- W^+$	B
$Q_S^- D_{50}^- / C_f \sim S^- V^\pm y_o^\pm W^-$	M
$Q_S^+ D_{50}^+ / C_f^- \sim S^+ V^+ y_o^- W^+$	B
$Q_S^- D_{50}^- / C_f^+ \sim S^- V^\pm y_o^- W^\pm$	M
$Q_S^+ D_{50}^+ / C_f^+ \sim S^+ V^+ y_o^- W^+$	B
Note : An increase in the value of the variable is denoted by a +; and a decrease is denoted by a -. As an example, in the first line, if the value of Q_s increases, the slope, velocity and width will increase, the depth of flow will decrease and the channel may tend towards a braided form.	

(c) Given the sand size d_{50} = 0.5mm, the bankfull discharge Q = 10,000 cfs (283 m^3/s) and the slope S = $2x10^{-4}$, determine the effect of increasing slope, discharge, sediment size and sediment discharge on the planform geometry.

The result of increasing any or several of these variables (Figure 2.19a,b and Table 2.A.1) is to promote braiding of this channel. When locating this stream on Lane's diagram (Figure 2.19a,b) it is shown that with $SQ^{0.25}$ = 0.002 (SI = 0.00082), this river is very close to the line $SQ^{0.25}$ = 0.0017 (0.0007 for SI) for meandering streams. Hence an increase in discharge or slope would likely change the planform to a braided stream.

(d) Determine the effect of increased discharge of bed sediment size, bed sediment load and washload on channel stability, resistance to flow, energy slope and stage of the same river.

The Table 2.A.1 can be used to provide a qualitative response to these changes.

- Increase in discharge results in an increase in stage and a decrease in resistance to flow and channel stability.
- Increase in sediment size results in an increase in stage, resistance to flow and stability. The channel stability might not change if the sediment size is small (e.g. sand or finer).
- Increase in bed sediment load should decrease channel stability and likely trigger a change inplanform geometry from meandering to braided.
- Increasing washload would not affect the planform geometry and stability of the channel because the washload does not deposit in large quantities in the bed.

5 At-a-Station and Downstream Hydraulic Geometry Relationships (SI)

At bankfull discharge conditions Q_1 = 227 m^3/s and the width of a sand-bed stream (d_{50} = 0.6 mm) is W_1 = 76 m, the maximum flow depth is y_{o1} = 2.4 m, the slope is S_{f1} = 2.5 x 10^{-4}, and the maximum velocity is V_1 = 1.5 m/s.

(a) At-a-station Hydraulic Geometry.
Estimate the width, W_2, depth y_{o2}, slope S_{f2} and velocity V_2 at the same station when the discharge Q_2 is 5.7 m^3/s if the cross-sectional geometry is unknown.

The at-a-station hydraulic geometry relationships (Table 2.7) can be used when no specific field data is available.

For width:

$$W_2 = W_1\left(\frac{Q_2}{Q_1}\right)^{0.26} = 76\left(\frac{5.7}{227}\right)^{0.26} = 29.2\text{m}$$

For depth:

$$y_{02} = y_{01}\left(\frac{Q_2}{Q_1}\right)^{0.40} = 2.4\left(\frac{5.7}{227}\right)^{0.40} = 0.55\text{m}$$

Slope is unchanged:

$$S_{f1} = S_{f2} = 2.5\times 10^{-4}$$

For velocity:

$$V_2 = V_1\left(\frac{Q_2}{Q_1}\right)^{0.34} = 1.5\left(\frac{5.7}{227}\right)^{0.34} = 0.43\text{m/s}$$

(b) Downstream Hydraulic Geometry.

Using the same data as for part (a), estimate the width, W_2. depth y_{o2}, slope S_{f2} and velocity V_2 of an upstream section of this stream if the bankfull discharge is 14 m^3/s and the bed material is gravel (d_{50} = 8 mm). How would the hydraulic geometry change if the bed material upstream is sand (d_{50} = 0.6 mm)?

The "downstream" geometry relationships can be used in this case. Two types of relationships are given in Table 2.7. The sand bed relationships are a function of discharge only, whereas the gravel bed relationships are a function of both discharge and sediment size. Both methods are compared in the following.

<u>Flow Depth</u>

Sand bed: $$y_{02} = y_{01}\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.46} = 2.4\left(\frac{14}{227}\right)^{0.46} = 0.66\text{m}$$

Gravel bed: $$y_{02} = y_{01}\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.40} = 2.4\left(\frac{14}{227}\right)^{0.40} = 0.79\text{m}$$

<u>Channel width</u>

Sand bed: $$W_2 = W_1\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.26} = 76\left(\frac{14}{227}\right)^{0.26} = 36.8\text{m}$$

Gravel bed: $$W_2 = W_1\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.53}\left(\frac{d_{S2}}{d_{S1}}\right)^{-0.33} = 76\left(\frac{14}{227}\right)^{0.53}\left(\frac{8}{0.6}\right)^{-0.33} = 7.4\text{m}$$

Friction slope

Sand bed: $S_{f2} = S_f\left(\frac{Q_{b2}}{Q_{b1}}\right)^{-0.45} = 2.5\times10^{-4}\left(\frac{14}{227}\right)^{-0.45} = 9\times10^{-4}$

Gravel bed: $S_{f2} = S_{f1}\left(\frac{Q_{b2}}{Q_{b1}}\right)^{-0.4}\left(\frac{d_{S2}}{d_{S1}}\right)^{1} = 2.5\times10^{-4}\left(\frac{14}{227}\right)^{-0.4}\left(\frac{8}{0.6}\right) = 0.01$

Velocity

Sand bed: $V_2 = V_1\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.09} = 1.5\left(\frac{14}{227}\right)^{0.09} = 1.2\,m/s$

Gravel bed: $V_2 = V_1\left(\frac{Q_{b2}}{Q_{b1}}\right)^{0.07}\left(\frac{d_{S2}}{d_{S1}}\right)^{0.33} = 1.5\left(\frac{14}{227}\right)^{0.07}\left(\frac{8}{0.6}\right)^{0.33} = 2.9\,m/s$

The gravel bed relationships give a steeper, faster flowing and narrower channel as compared to the sand bed relationships. Unless the sediment size is markedly different for two streams, the resulting hydraulic geometry calculated from both sets of equations will be similar.

6 Downstream Sediment Size Distribution

Measurements of sediment size in the Sungai Buloh between Bukit Lagong and Kuala Selangor are given in the following Table 2.A.2

Table 2.A.2 Sediment Size Distribution in the Sungai Buloh .

Distance Downstream of Bukit Lagong		d_{50} (mm)
(km)	(mi)	
0	0	28
24.1	15	0.25
40.2	25	0.018
48.3	30	0.003
56.3	35	0.001

Estimate the mean sediment size d_{50} 10 miles (16.1 km) and 20 miles (32.2 km) downstream of Bukit Lagong.

The gradual decrease in sediment size with downstream distance can be approximated by the following equation:

(SI) $d_{50} = 28\times10^{-0.082x}$

(English Units) $d_{50} = 28\times10^{-0.132x}$

This equation was obtained by regression analysis based on Eq. 2.17. At distances of 10 and 20 miles (16.1 and 32.2 km), the expected mean sediment sizes d_{50} obtained by this relationship are, respectively, 1.34 mm and 0.064 mm.

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APPENDIX B

RIVER ECOSYSTEMS AND RIVER HEALTH - HABITAT ASSESSMENT METHODS

Appendix B River Ecosystems and River Health - Habitat Assessment Methods

This Appendix contains more detailed information on:

1) River Invertebrate Prediction and Classification System (RIVPACS);
2) HABSCORE (USEPA Rapid Bioassessment Protocols);
3) Index of Stream Condition (ISC);
4) Geomorphic River Styles;
5) State of the Rivers Survey;
6) Habitat Predictive Modelling; and
7) River Habitat Survey (RHS).

1) River Invertebrate Prediction and Classification System (RIVPACS)

Scientific Methodology
Monitoring the time trends of individual river parameters or periodic descriptions of river characteristics are not in themselves sufficient to assess and monitor the condition and health of rivers. A methodology is required to measure 'health' against an appropriate, regionally based scale. The only methodology that has attempted, and largely achieved this to date, whether with respect to the physical, chemical or biological conditions, is RIVPACS, the River Invertebrate Prediction and Classification System (Schofield et al. 1996 [42]).

This approach is based on comparing monitored river sites against reference unimpacted, or least impacted sites. It provides a measure of the degree to which an impacted site retains the biological quality it would have had if undisturbed. It also allows prediction of the biotic community anticipated at a site if it was undisturbed. RIVPACS was developed using macroinvertebrate fauna but the same principles can be applied to other faunal groups [42].

History of RIVPACS
In the early 1970s scientists and water managers recognized they needed greater understanding of the ecology of running water sites and their macroinvertebrate communities. Such information was fundamental to the development of a nationwide biological assessment . A four-year project was established to create a biological classification of unpolluted running water sites in Great Britain based on their macroinvertebrate fauna, and to determine whether the macroinvertebrate community at a site could be predicted from physical and chemical features (Parsons et al. 2002).

This led to the development of RIVPACS, a new approach to biological assessment, developed by the River Communities Group at the Centre for Ecology and Hydrology. RIVPACS has since been adopted by other countries and has influenced the European Union Water Framework Directive (WFD) (European Commission, 2000).

The RIVPACS software package is now used to assess biological quality of rivers and streams in the United Kingdom. Equivalent software packages have been developed in other countries (e.g. AusRivAS in Australia) where the generic RIVPACS type approach (also termed a reference condition approach) has been successfully applied. A brief account of the Australian model is given in the following paragraphs.

The AusRivAS (Australian River Assessment System) model
The AusRivAS models predict macroinvertebrate communities that would be expected to occur at test sites in the absence of impact. These predictions are derived from about 250 reference sites, which are assumed to have an undisturbed invertebrate fauna, sampled throughout Western Australia. Various environmental variables (the predictor variables) are used in each model to determine the group of reference sites to which a test site is most similar in terms of river size, landscape setting etc. If the test site is unimpacted, it should support very similar invertebrate families to those at the appropriate group of reference sites. The model compares the invertebrate families predicted to occur at the test site (really the list of families occurring at the equivalent reference sites) with those actually collected at the site. This gives an *O/E* score, which is a measure of the ecological condition of the site. If *O/E* = 1, the test site contains the same families as undisturbed sites with the same

stream characteristics and is assumed to be in good condition. If *O/E* < 1, some families have probably been lost and the site is assumed to be degraded to some extent.

The first step in running a model is to enter the appropriate biological and habitat data from the test site under investigation. The model then performs preliminary analyses to determine whether the test site falls within the experience of that model (i.e. whether the site is in the right region, was sampled at the right time, and can be matched with the reference sites in the model dataset). If the test site passes the validation procedure, the probability of the test site belonging to each reference site group is calculated using the predictor variables. A schematic representation of AusRivAS assessment of site condition is as shown in Figure 2.B.1.

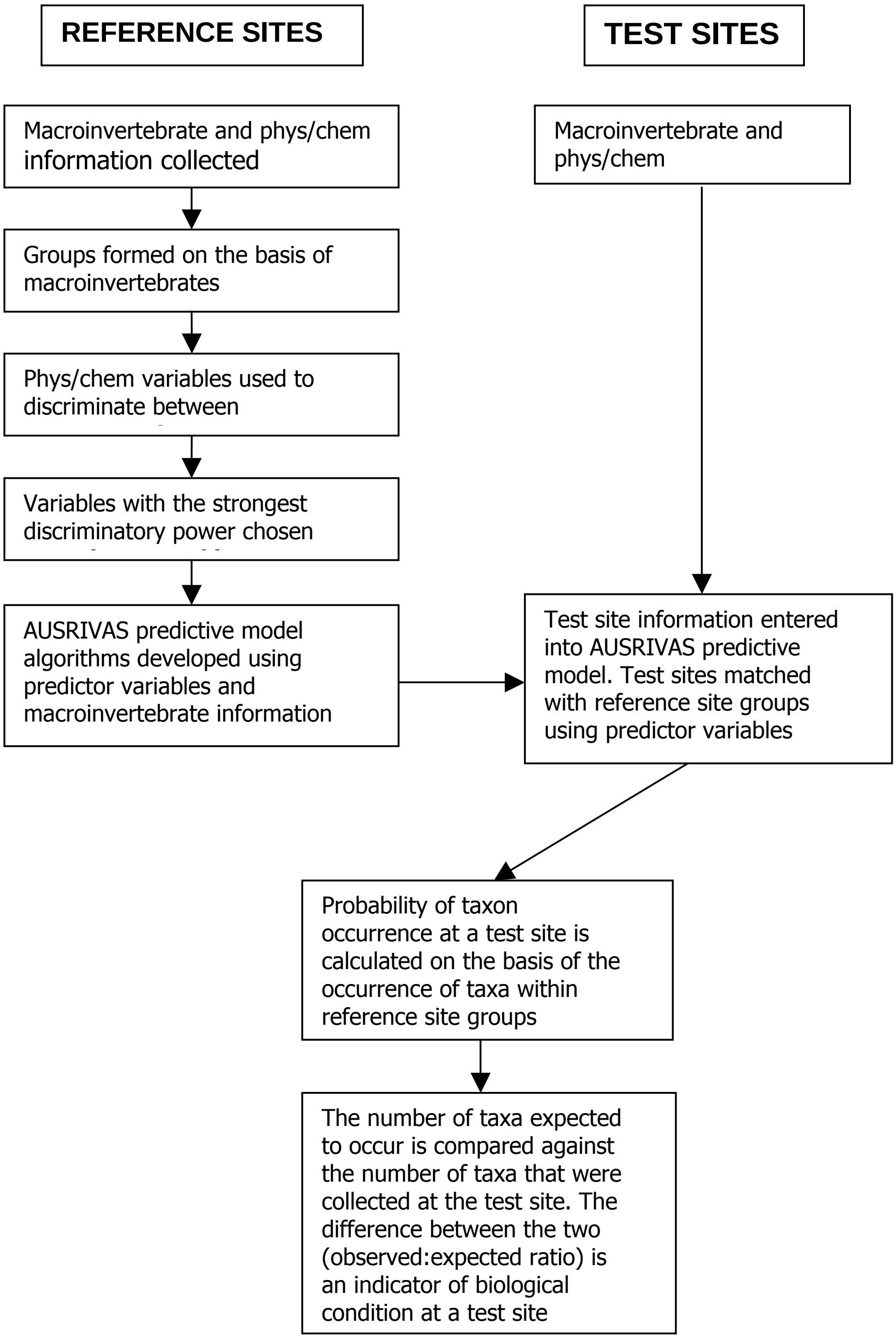

Figure 2.B.1 Schematic representation of AusRivAS assessment of site condition.[36]

The method for calculating the expectation that a family will occur at a test site (i.e. its E value) is given in Table 2.B.1.

Table 2.B.1 Calculation of the probability of a family X occurring at a test site. Combined probability that taxon X will occur at Site Y = 76.5 %.

Reference Site Group	Probability that test site belongs to each Group	Frequency of family X in each Group	Contribution to probability that Family X will occur at the test site
A	0.50	0.90	0.450
B	0.30	0.70	0.210
C	0.15	0.60	0.090
D	0.05	0.30	0.015
Probability that Family X will occur at the test site			0.765

AusRivAS models only consider families with 0.5 probability of occurring at a test site when calculating the overall *O/E* score of a site. If families with less than 0.5 probability of occurrence are used, the list of predicted taxa is larger but the sum of the probabilities of those predicted (i.e. *E*) remains similar because families with low probabilities of occurrence contribute little to the list of expected taxa. However, there is a greater chance of stochastic fluctuations in the number of observed families (i.e.,*O*) because of random events, introducing more error into assessments.

2) HABSCORE (USEPA Rapid Bioassessment Protocols)

The United States Environmental Protection Agency (USEPA) has developed Rapid Bioassessment Protocols (RBP) that use fish, macroinvertebrates or periphyton to assess stream condition. Metrics representing structural, functional and process elements of the biotic community are calculated for each site, and aggregated into an index. This multimetric index represents the biological condition of a site. Physical and chemical data are also measured at each site, and are used to aid the interpretation and calibration of the index, and also to define the reference condition. HABSCORE has utility outside the Rapid Bioassessment Protocols and has been used as a measure of habitat condition in the AusRisAS predictive models and in the Habitat Predictive Modelling approach (Parsons et al. 2002).

HABSCORE is a visually based habitat assessment system that evaluates 'the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community'. It includes factors that characterize stream habitat on a micro-scale (e.g. embeddedness) and a macro-scale (e.g. channel morphology), as well as factors such as riparian and bank structure which influence the micro and macro-scale features. HABSCORE is composed of ten habitat parameters. To reflect the difference in habitat types between upland and lowland streams, separate assessments have been developed for high and low gradient conditions. At each site, individual parameters are assessed and rated according to a continuum of scores that represent optimal, sub-optimal, marginal or poor conditions. A total score is obtained for each site, and is subsequently used to determine the percent comparability to reference conditions. However, the individual parameter scores and the total assessment score also provide an overall assessment of habitat condition at the sampling site. A sample of the HABSCORE Habitat Assessment Field Data Sheets is shown here.

In addition to the HABSCORE assessment of site conditions, a suite of variables that represent factors integrated within HABSCORE are also collected at each site. These factors characterize stream type, watershed features, riparian vegetation, instream features, large woody debris, aquatic vegetation, water quality, inorganic substrate and organic substrate (Table 2.B.3). These factors can be included in the determination of reference conditions, but are mostly used as an interpretative aid to the assessments of stream conditions, made using the multimetric indices (Parsons et al. 2002). These variables are also collected in AusRivAS but are used mainly to aid interpretation of site condition, rather than as predictor variables.

Table 2.B.2 Habitat assessment data sheet for high gradient streams, showing habitat parameters assessed for HABSCORE. Each parameter is scored on a continuum of conditions representing optimal, sub-optimal, marginal and poor conditions. The score is totaled to form the overall assessment of habitat quality (After Barbour et al. 1999) [36]

HABITAT ASSESSMENT FIELD DATA SHEET
HIGH GRADIENT STREAMS

Date: ______________________ Recorders Name: __________________________

Site No.: ___________________ River and Location: ____

Habitat parameter	Condition category			
	Excellent	Good	Fair	Poor
1. Epifaunal (bottom) substrate / available cover	Greater than 70% of substrate favourable for epifaunal colonisation and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonisation potential (i.e. logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonisation potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonisation (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity / depth regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). Slow is <0.3m/s, deep is >0.5m).	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions and bends; moderate deposition in pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel flow status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
6. Channel alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e. dredging (greater than 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

HABITAT ASSESSMENT FIELD DATA SHEET Page 2 of 2

HIGH GRADIENT STREAMS

Date: ____________________ Recorders Name: ____

Site No.: _________________ River and Location: ______________________________________

Habitat parameter	Condition category			
	Excellent	Good	Fair	Poor
7. Frequency of riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; 'raw' areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understorey shrubs, or non woody acrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the treambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimetres or less in average stubble height.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian zone score (score each bank)	Width of riparian zone >18 metres; human activities (i.e. roads, lawns, crops etc.) have not impacted the riparian zone.	Width of riparian zone 12-18 metres; human activities have impacted riparian zone only minimally.	Width of riparian zone 6-12 metres; human activities have impacted zone a great deal.	Width of riparian zone <6 metres; little or no riparian vegetation is present because of human activities.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0

TOTAL HABITAT SCORE _________________

Table 2.B.3 Physical and chemical observations measured alongside the HABSCORE assessment. [36]

Watershed features	Aquatic vegetation
Predominant surrounding landuse	Dominant vegetation type
Local watershed non-point source pollution	Species present
Local watershed erosion	Proportion of the reach with aquatic vegetation
Riparian Vegetation	**Water quality**
Dominant vegetation type	Temperature
Species present	Conductivity
	Dissolved Oxygen
Instream features	pH
Estimated reach length	Turbidity
Estimated stream width	Water odours
Sampling reach area	Water surface oils
Estimated stream depth	Water clarity
Surface velocity	
Canopy cover of river	**Inorganic sediment/substrate**
High water mark	Sediment odours
Proportion of reach represented by riffle, pool and	Sediment deposits
run stream morphology types	Sediment oils
Stream channelization	Presence of black undersides on stones
Presence of dams	Substrate composition
Large woody debris	**Organic substrate**
Cover of large woody debris	Detritus (as CPOM)
	Muck-mud (as FPOM)
	Marl (grey, shell fragments)

As a stand-alone method, HABSCORE provides an ability to assess the quality of instream and riparian habitat at a sampling site. However, a more important function of HABSCORE is that it is used to determine the ability of the habitat to support the optimal biological condition of the region. Assuming that reference sites represent optimal condition, the comparability of the habitat and the biota to this reference state can be plotted to determine the ability of the habitat to support the biological community (Figure 2.B.2). There are three important aspects of Figure 2.B.2:

- the upper right hand corner represents good habitat quality and good biological condition;
- the mid-section of the curve represents a situation where habitat quality decreases and the biological community responds with a concomitant decrease; and,
- the lower left hand corner represents a situation where habitat quality is poor and unable to support the biological community (Barbour, 1991).

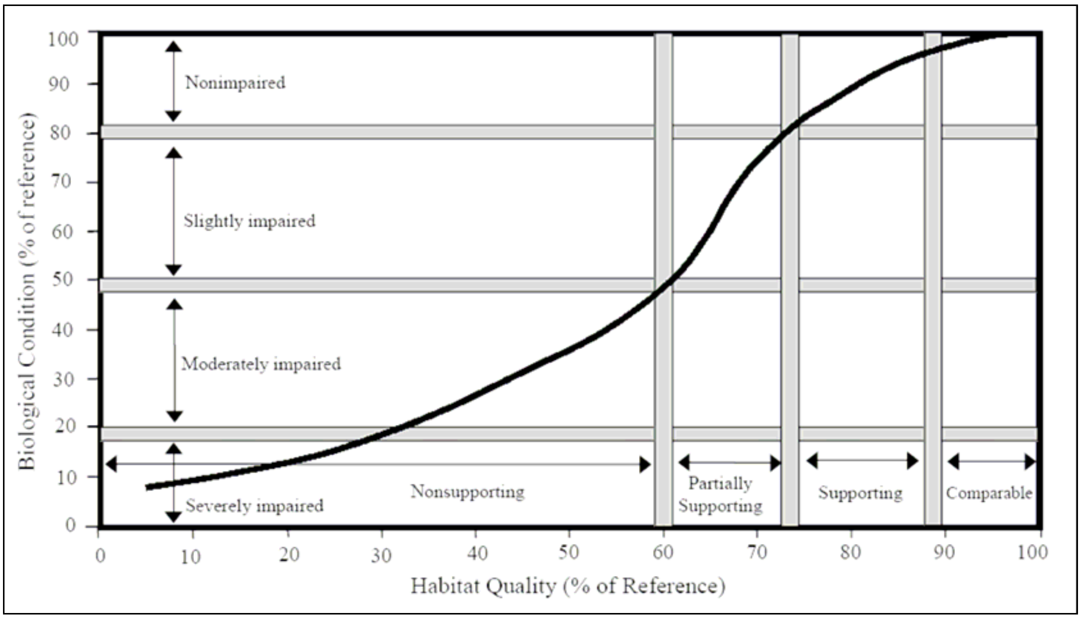

Figure 2.B.2 The relationship between habitat and biological condition. [36]

Apart from the three situations outlined above, a comparison of the condition of the biota with the condition of the habitat can also highlight situations of potential water quality degradation, where habitat quality is high but biological condition is poor (Parsons et al. 2002). Habitat quality is the initial focus of the Rapid Bioassessment Protocols. Habitat quality at the reference sites is compared against habitat quality at the test site, and if equivalent, a direct comparison of the biological condition can be made using the biological metrics. This ensures that assessments of biological condition indicate impairment, rather than inherent natural differences in stream habitat. If habitat quality is lower at a test site than at the reference sites, then the ability of the habitat to support biota is investigated as a first step, before a determination of biological condition is made.

3) Index of Stream Condition (ISC)

The Victorian Index of Stream Condition (ISC) was developed in response to a managerial need to 'use indicators to track aspects of environmental condition and provide managerially or scientifically useful information' in Australia. The ISC evolved in four stages. Stage 1 involved the development of the concept and included a review of stream assessment methods, input from stream scientists and managers, and development of an ISC prototype. The desired attributes considered in the development of the ISC concept were (Parsons et al. 2002):

- the indicators are key components of stream condition;
- the methodology is founded in science;
- the results are accessible to managers;
- data collection methods are objective and repeatable;
- natural variability is considered;
- application is cost effective; and,
- indicators are sensitive to management intervention (Ladson and White, 1999).

Stage 1 is analogous to the aims of the current Physical and Chemical Assessment Module. Stages 2 and 3 involved testing and refining the concept and Stage 4 involved application of the ISC across Victoria.

The ISC measures stream condition within reaches that are between 10 and 30km in length. Reaches are defined as 'contiguous sections of stream chosen so that they are approximately homogeneous in terms of the five components of stream condition'. Reaches are delineated mainly from 1:250000 topographic maps or aerial photographs. Within each reach, measurement sites are selected on the basis of:

- representation of each site to reach characteristics;
- proximity to existing biological, physical and water quality monitoring sites; and,
- accessibility for sampling purposes (DNRE, 1997).

The ISC consists of five sub-indices, which represent key components of stream condition (Table 2.B.4). Each sub-index consists of indicators, which are calculated using data collected in the field or by desk-based methods. Each indicator is then assigned a rating score. Sub-index scores are calculated by summing the component indicator scores, and the overall ISC score is calculated by summing the sub-index scores.

The ISC uses a rating system to assess stream conditions. The use of a rating system is designed to provide as much resolution as possible, within the constraint that there is 'limited knowledge of the relationship between a change in the indicator and environmental effects' (Ladson and White, 1999, p10). Values for each indicator are assigned a rating on the basis of comparison with a reference state (Figure 2.B.3). These ratings are summed to produce an overall score that reflects a continuum of stream conditions from excellent to very poor (Figure 2.B.3). In calculating the overall ISC scores, the scores for each sub-index and for each indicator can be weighted, depending on the perceived importance of each, or the availability of data (Ladson and White, 1999).

1. Calculate ratings for indicators

Indicator Rating	Corresponding reference category	Example values : pH range
4	Very close to reference state	6.5 – 7.5
3	Minor modification from reference state	6.0 - < 6.5 or 7.5 – 8.0
2	Moderate modification form reference state	5.5 - < 6.0 or 8.0 – 8.5
1	Major modification from reference state	4.5 - <5.5 or 8.5 – 9.5
0	Extreme modification from reference state	<4.5 or >9.5

Ratings are summed within each sub-index, then sub-index scores are summed to produce an overall ISC score.

Repeated for each indicator. Reference ranges are derived from existing literature.

2. Calculate ISC score

Overall ISC score	Stream condition
45 – 50	Excellent
35 – 44	Good
25 – 34	Marginal
15 – 24	Poor
< 14	Very poor

Figure 2.B.3 Assessment of stream condition using the Index of Stream Condition. [36]

The ISC is based on the premise that the hydrology, physical form, streamside zone, water quality and aquatic life components indicate the processes and functions that act to influence stream conditions. For example, the hydrology sub-index reflects deviation of the current flow regime from natural conditions, the physical form sub-index reflects channel morphology and the provision of biotic habitat, and the streamside zone sub-index reflects the importance of riparian zone and floodplain processes (Ladson and White, 1999; Ladson et al. 1999). A holistic assessment of stream conditions is achieved by integrating these components into a single ISC score. However, it is recommended that the scores for the component sub-indices are reported alongside the overall ISC score, because the overall score may be composed of sub-indices that vary in condition (Ladson and White, 1999). The ISC was designed to provide an assessment of long term changes in the environmental condition of rural stream reaches 10-30km in length, with surveys conducted at five year intervals (Ladson and White, 1999). As such, the 'level of detail is only sufficient to signal potential problems, suggest their cause and highlight aspects that may need specific investigations' (Ladson et al., 1999, p455). However, the ISC is a tool for determining the success of environmental intervention policies (Parsons et al. 2002) and can be used in a management context to:

- benchmark stream conditions, and for reporting to local, regional, state or federal agencies;
- aid objective setting by, and provide feedback to, natural resource managers; (particularly Catchment Management Authorities) and in particular, to assess trade-offs between utilitarian demands on streams and environmental condition;
- judge the effectiveness of intervention, in the long-term, in managing and rehabilitating stream conditions; and,
- review performance against expected outcomes.

Table 2.B.4 List of indicators used in the Index of Stream Condition [36]

Sub-index	Basis for sub-index value	Indicators within sub-index
Hydrology	Comparison of the current flow regime with the flow regime existing under natural conditions	Amended annual proportional flow deviation. Daily flow variation due to change of catchment permeability. Daily flow variation due to peaking hydroelectricity stations.
Physical Form	Assessment of channel stability and amount of physical habitat.	Bank stability. Bed stability. Impact of artificial barriers on fish migration. Instream physical habitat.
Streamside Zone	Assessment of quality and quantity of streamside vegetation.	Width of streamside zone. Longitudinal continuity. Structural intactness. Cover of exotic vegetation. Regeneration of indigenous woody vegetation. Billabong condition.
Water Quality	Assessment of key water quality parameters.	Total phosphorus. Turbidity. Electrical conductivity. Alkalinity / activity.
Aquatic Life	Presence of macroinvertebrate families	SIGNAL AUSRIVAS

4) Geomorphic River Styles

Geomorphic River Styles is a procedure that provides a baseline survey of river character and behaviour, evaluating the physical controls on river structure at differing positions in catchments. The procedure is set within a nested hierarchical framework and as such, it incorporates assessment of river structure at the catchment, reach and geomorphic unit scales (Parsons et al. 2002).

There are five stages in the assessment of river character and behaviour:

1. Data compilation (description and mapping);
2. Data analysis (explanation of river character and behaviour);
3. Prediction of future likely river structure;
4. Prioritization of catchment management issues; and
5. Identification of suitable river structures for Rivercare planning.

Table 2.B.5 Catchment, reach and geomorphic unit characteristics measured in the Geomorphic River Styles method [36]

CATCHMENT CHARACTERISTICS	GEOMORPHIC UNIT CHARACTERISTICS
Relief measures	Identification
Catchment relief	Within channel units
Catchment relief ratio	Channel marginal units and bank character
Longitudinal profile	Floodplain units
Valley side slope length and angle	Morphology and dimensions of geomorphic units
Areal properties	Shape and size
Catchment area	Channel geometry
Drainage pattern	Channel bed elevation
Elongation ratio	Width to depth ratio
Drainage density	Hydraulic parameters
Linear measurements	Flow character
Stream order	Mannings roughness coefficient (n)
Stream length	Froude number
Other measures	Vegetation character
Geology	Vegetation cover dimensions
Average annual rainfall and monthly averages	Vegetation composition
Landuse	Assemblage and connectivity of geomorphic units throughout the reach
Vegetation distribution and type	Spatial character of geomorphic units
Discharge	Channel – floodplain relationship
REACH CHARACTERISTICS	Lateral stability of the channel
Channel planform	Degree and character of channel obstruction
Planform geometry	Stream power
Radius of channel curvature to mean channel width ratio (rc/w)	Bankfull discharge
	Sediment attributes
Meander wavelength	Grain size and distribution
Type of geomorphic units present	Sorting
Confinement	Rounding
Valley width	Facies / sedimentary structures
Degree and character of channel constriction	Sediment mix and degree of packing
Terrace character	Type of grading
Vegetation character	Sediment relations
Percent coverage	Degree of sediment storage
	Sediment yield or sediment delivery ratio (SDR)

Stage one comprises both pre-field data and field data collection. During the pre-field data collection component, catchment scale characteristics are measured off maps, or by using GIS capabilities (Table 2.B.5). Consideration is also given to historical and archival information about the catchment. The reaches delineated off maps are used as sampling units in the field data collection component. Geomorphic units are identified within each reach and at representative locations and the characteristics of each geomorphic unit are recorded (Table 2.B.5).

In Stage two, data collected in the pre-field and field components are used to interpret river behaviour. This process involves several steps and follows the hierarchical framework. Firstly, the assemblage of geomorphic units is assessed to provide insight into the formative processes within a reach.

The assessment of stream condition using Geomorphic River Styles is achieved using two approaches (Parsons et al. 2002): In the first approach, comparison of contemporary stream conditions with undisturbed conditions allows analysis of changes in both planform (Figure 2.B.4) and cross sectional (Figure 2.B.5) channel structure within different process zones. For example, in the Wolumla Creek Catchment on the South Coast of New South Wales (Figure 2.B.4 and Figure 2.B.5), river channel changes since human settlement of the area can be summarized as follows:

- channel planform and geometry have become better defined;
- the association of geomorphic units is more homogeneous despite a larger range of geomorphic units being present;
- variability in the sedimentary character of geomorphic units has been reduced;
- vegetation associations have decreased in variability and are now more homogeneous;
- longitudinal connectivity has increased throughout the catchment. Lateral channel floodplain connectivity has decreased;
- organic matter and nutrient retention within catchment has greatly decreased; and,
- hydrological implications have been transformed largely as a result of the calibre and volume of materials stored within the channel.

In the second approach, prediction of likely future behaviour is made by extrapolation from contemporary behaviour, sediment storage (Figure 2.B.6) and relationships with theoretical notions of river behaviour (Figure 2.B.7). For example, in the Wolumla Catchment, analysis based on sediment storage identified sites which were most sensitive to future sediment release (Figure 2.B.6). Analysis based on theoretical river behaviour can identify the predictive relationships between variables related to river behaviour and channel geometry (Figure 2.B.7), which in turn, can be used to assist in setting targets for stream restoration programmes. However, in the Wolumla Catchment, the classical notions of river behaviour do not apply. In addition, the ability of variables to predict channel geometry was highly variable among sub-catchments, highlighting the need for analysis of predictive relationships at the scale of sub-catchments (Parsons et al. 2002).

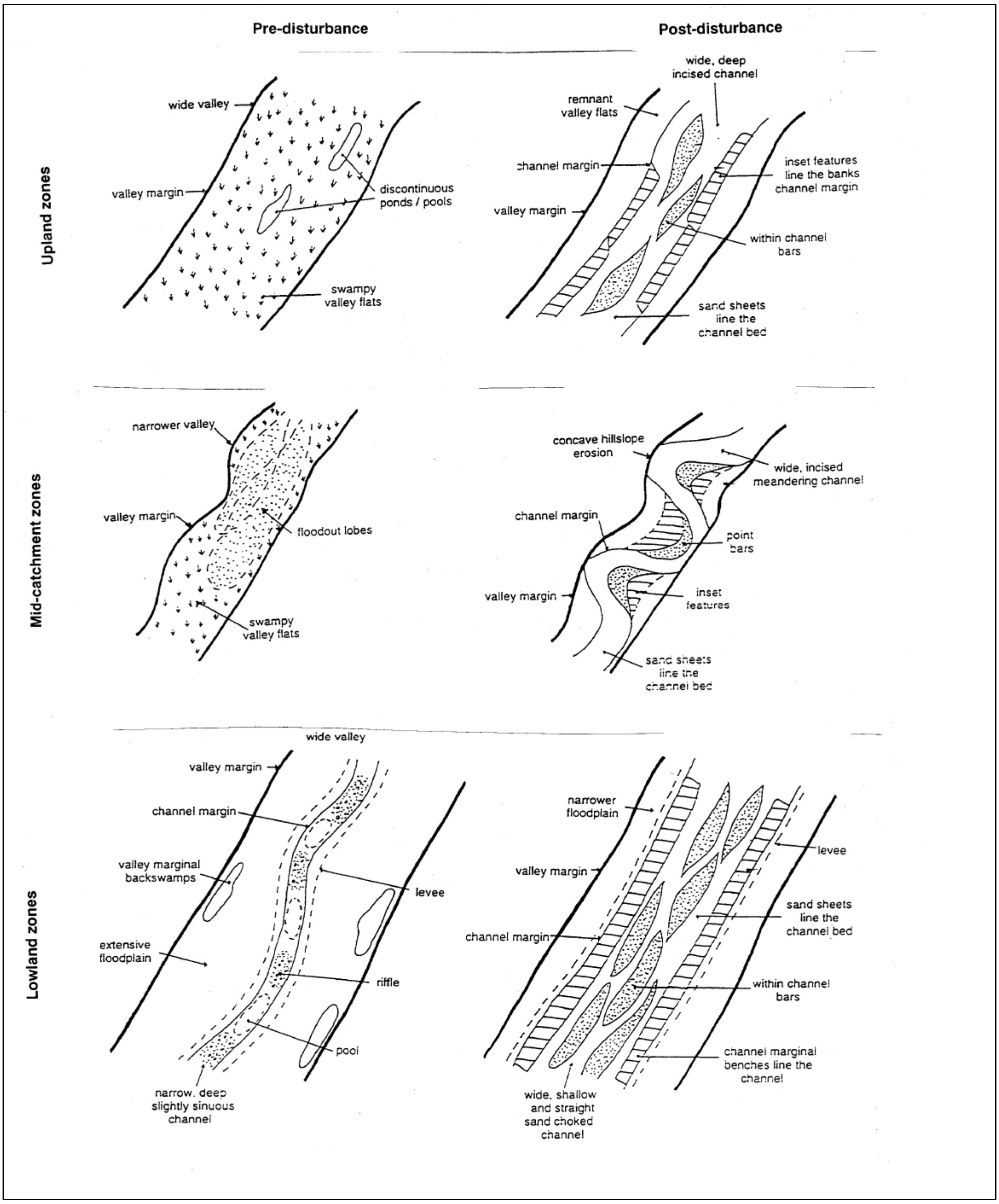

Figure 2.B.4 Planform view of pre-disturbance (left) and post-disturbance (right) channel character within upland, mid-catchment and lowland zones of the Wolumla Creek catchment [36]

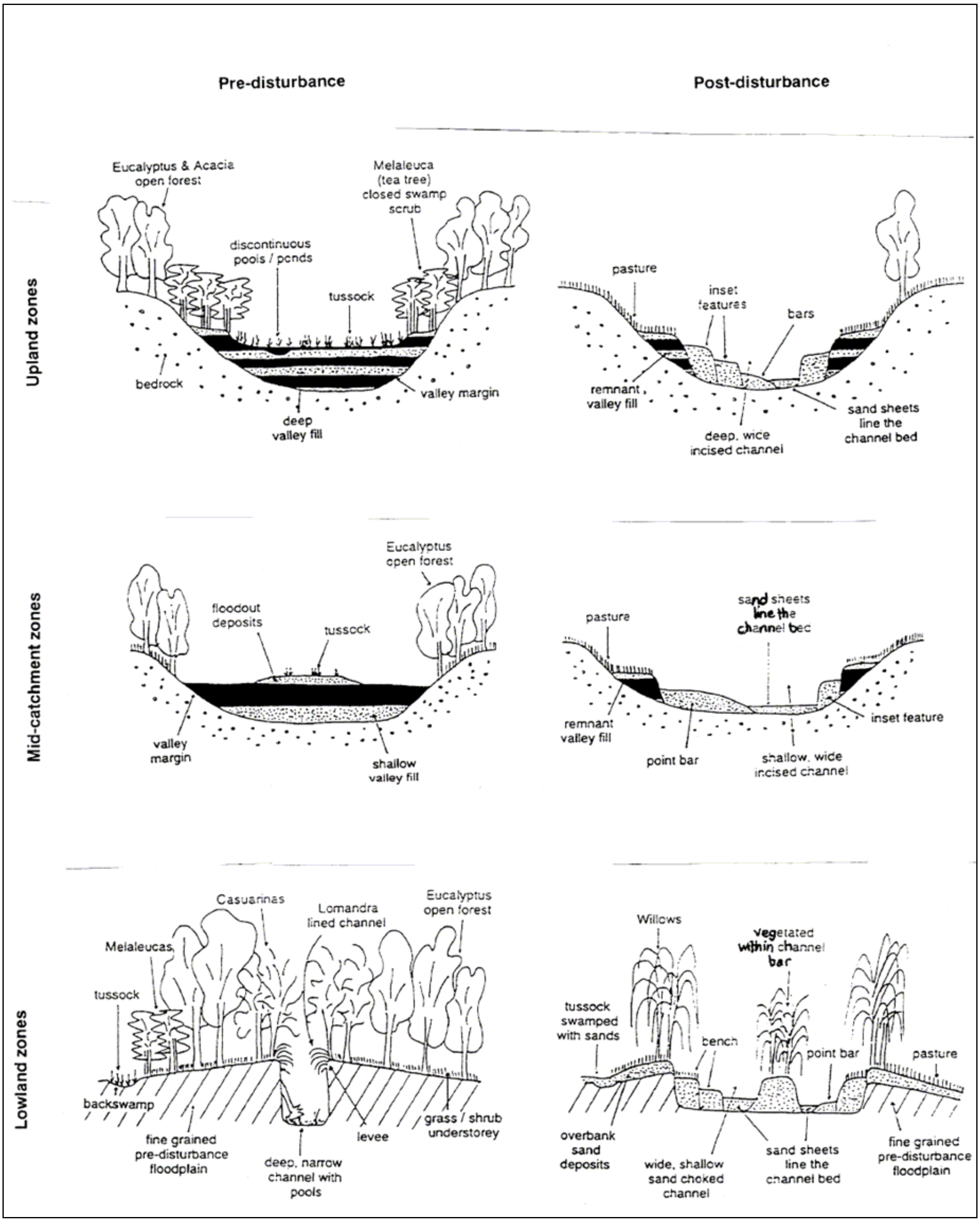

Figure 2.B.5 Cross-sectional view of pre-disturbance (left) and post-disturbance (right) channel character within upland, mid-catchment and lowland zones of the Wolumla Creek catchment. [36]

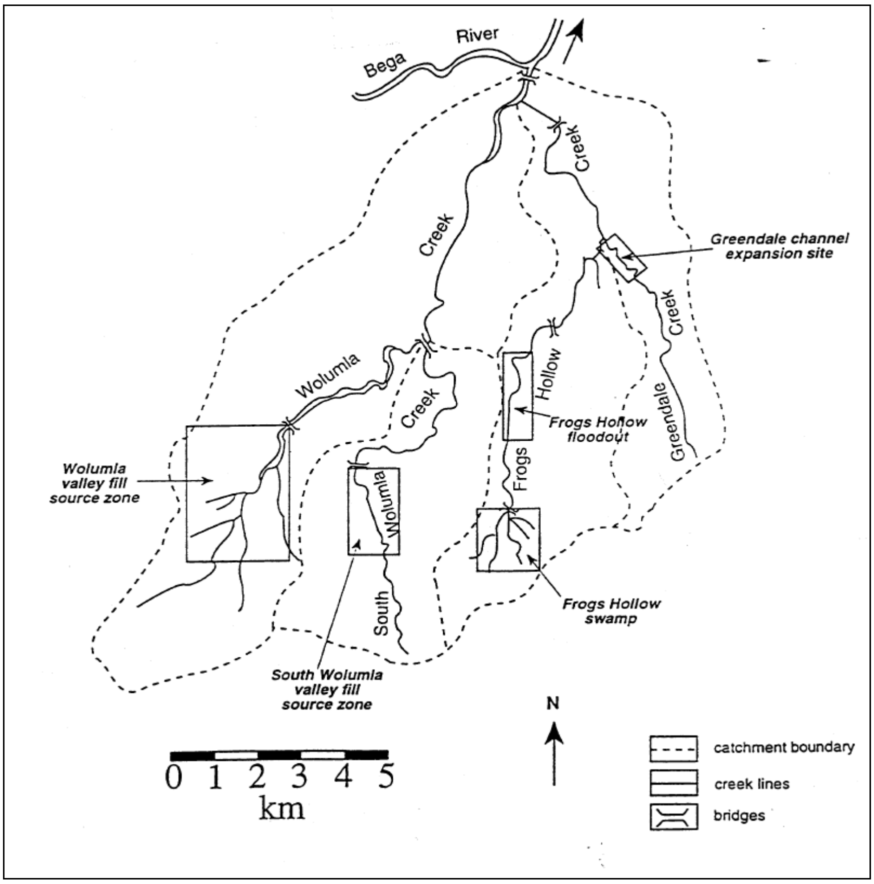

Figure 2.B.6 Identification of sensitive sites in the Wolumla Catchment, based on sediment storage. [36]

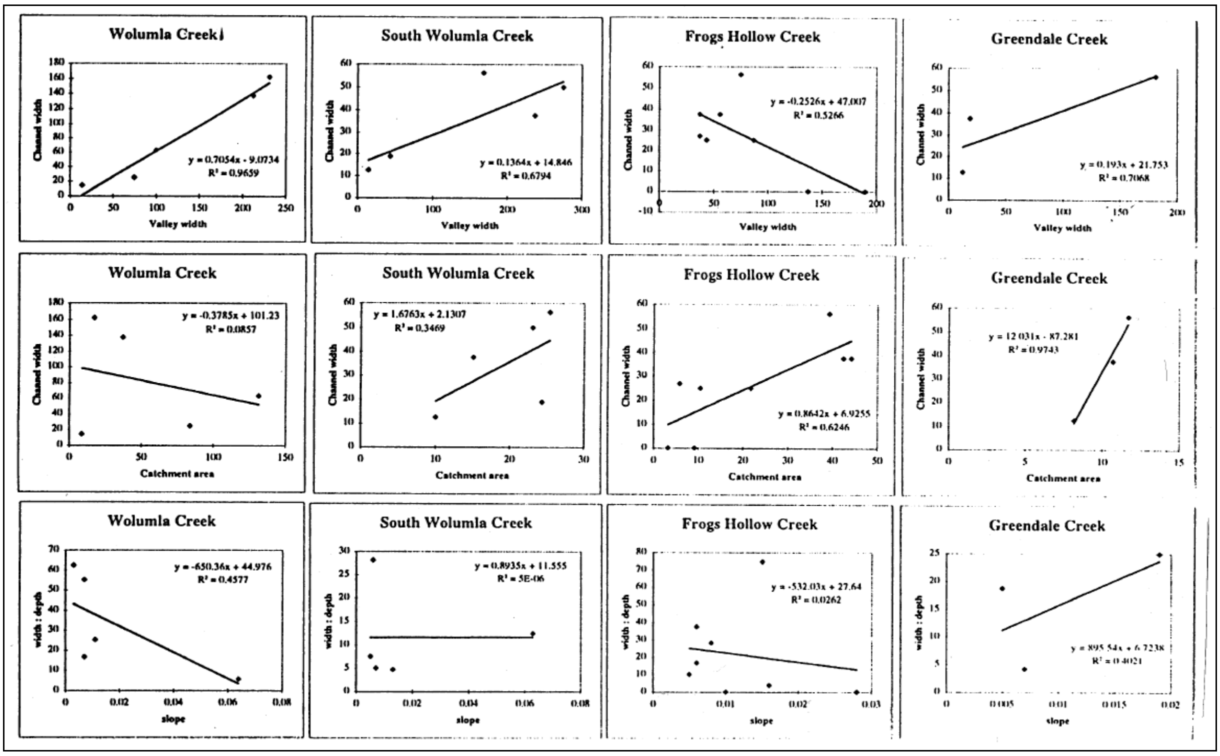

Figure 2.B.7 Predictive relationships between stream characteristics in sub-catchments of the Wolumla Catchment. [36]

5) State of the Rivers Survey

The State of the Rivers Survey was developed in Queensland, in response to a need for detailed information on the physical and environmental conditions of streams and rivers (Anderson, 1993a). This information would then be available to the Queensland Department of Primary Industries (DPI) for use in the Integrated Catchment Management process. The State of the Rivers Survey is not designed to establish the trend or rates of change of stream conditions, but rather, it provides a 'snapshot' of the physical and environmental conditions of streams (Parsons et al. 2002). These data can then be used to:

- provide an objective and comprehensive benchmark against which future trends and rates of change of conditions can be assessed by conducting follow-up surveys;
- provide the fundamental information required to classify rivers and streams; and,
- provide an overview to help identify resource management and utilization practices contributing to the deterioration in physical and ecological conditions of rivers (Anderson, 1993a).

The State of the Rivers Survey was developed in two stages. The first stage involved development and testing of the method. The State of the Rivers Survey has subsequently been applied to assess stream condition in 26 catchments in New South Wales and Queensland (Anderson, 1999).

The State of the Rivers Survey methodology aims to assess the condition of homogenous stream sections within catchments (Anderson, 1993a). The use of homogeneous stream sections facilitates comparison of similar stream types among catchments or sub-catchments, and provides an ability to distinguish inherent natural variability from the effects of human impacts. Division of the catchment into homogeneous stream sections is a hierarchical process that involves the following steps (Parsons et al. 2002):

- a mapping exercise to subdivide streams into homogeneous stream sections on the basis of available data such as geology, soils, sub-catchment structure, stream order, natural and artificial barriers, altitude, catchment slope, stream gradient and vegetation type and cover;
- visual reconnaissance of the catchment to test the initial homogeneity and to further subdivide the rivers and streams at appropriate boundaries;
- further sub-sectioning is made in the course of conducting the instream surveys;
- analysis of the instream site data and testing of homogeneity between sites in the same section may lead to further sub-divisions;
- compilation of relevant catchment data, with further possible revision of sections; and
- final classification of stream sections using different combinations of the attributes for different purposes (Anderson, 1993a; Anderson, 1993b).

Within each stream segment, a representative sampling reach is chosen on the basis of the following criteria:

- the reach should be representative of the types of habitat, morphology and physical and ecological condition of the stream segment;
- to represent habitat diversity, the reach should preferably contain at least two complete pools and riffle/run habitats;
- the whole length of the reach should be visible at one location; and,
- the reach should contain at least one pool, which should be the largest and deepest in the area (Anderson, 1993a).

The number of reaches sampled within each catchment varies according to the size of the catchment and the required resolution of the survey (Anderson, 1993a). In addition to the map-based data that are used to delineate the initial stream sections, the State of the Rivers Survey consists of 11 data components (Table 2.B.6) that are collected at each representative sampling reach. Each data component is composed of different types of variables that represent the physical and environmental aspects of the stream channel (Table 2.B.6). Variables are generally measured using visual estimation, but some variables require physical measurement or interpretive rating of condition.

The basis for assessment of stream conditions in the State of the Rivers Survey is 'the extent to which the values or perceived function of an attribute has declined from a pristine or undisturbed condition' (Anderson, 1999). A series of condition ratings are produced for each data component. Formulas are used to derive condition ratings, using subsets of variables collected within each component (Anderson 1993b). These condition ratings are based on the extent of degradation from a theoretical maximum of 100%, where 100% percent represents the full value, pristine condition or complete function for the component and 0% represents a complete loss of these (Anderson, 1999). Comparisons with representative sites in good condition are also used to scale the ratings (Anderson, 1999).

Table 2.B.6 Data components and types of variables measured in the State of the Rivers Survey.[36]

Sub-section elements[1]
Section boundaries
Sub-catchment centroid
Elevation information

Hydrology[2]
Water flow
Time since last runoff
General local conditions
Instream water quality measurements[3]

Site description
Grid reference
Latitude
Longitude
Catchment area
Altitude
Map details
Site access details
Photograph details

Reach environs – temporal and spatial
Water level at sampling time
Channel pattern
Local land use
Local disturbance
Local vegetation types
Floodplain features
Local and tenure
Overall disturbance rating

Channel habitat
Channel habitat types
Reach length
Sketch of reach

Cross – section[4]
Depth[5]
Water velocity[5]
Bed sediments[5]
Bank dimensions
Bank sediments

Bank condition
Bbank stability[6]
Bank slope[6]
Bank shape[6]
Overall bank condition[6]
Factors affecting stability
Artificial bank protection measures
Levee banks

Bed and bar condition
Bar type and distribution
Bar size
Gravel angularity and shape
Gravel surface characteristics
Bed compaction
Factors affecting stability
Controls stabilising the bed
Passage for fish and other organisms
Overall bed stability rating

Vegetation
Width of riparian zone[6]
Vegetation cover of plant types[6]
Percent exotic species in riparian zone[6]
Local species checklist[6]
Aquatic vegetation – submerged and floating
Emergent aquatic vegetation

Aquatic habitat
Instream debris cover
Canopy cover
Vegetation overhang[6]
Root verhang[6]
Bank overhang[6]
Man-made overhang[6]
Overall site rating for all aquatic life

Scenic, recreational and conservation values
Recreational opportunity type
Recreation types suitable for the area
Scenic value assessment
Initial conservation value assessment

1. This component is usually completed post-survey to characteristic the final hologeneous stream sections
2. This component is desk based and is designed to establish an interface with hydrological and water quality data through HYDSYS
3. Measurement of depth, water temperature, dissolved oxygen, pH, conductivity, salinity, turbidity, secchi depth and water velocity is optional
4. One cross section is measured in each habitat type present within a reach
5. Measured at up to 15 locations within the cross sectional transect
6. Measured for left and right banks

Using the condition ratings for each data component, an assessment of condition is derived for each homogeneous stream section. A final assessment of stream conditions within a catchment is achieved by calculating the number of homogeneous stream sections that correspond to each condition rating, for each data component. The length of stream within each catchment that corresponds to a certain condition can also be calculated. In addition, an overall condition rating can also be calculated for the whole catchment by resetting the condition ratings for all the data components combined (Anderson, 1993c). Thus, stream conditions can be reported on several levels of resolution that can encompass combinations of individual data components or all data components together, as well as individual stream sections or the entire catchment (Figure 2.B.8).

1. Variables representing bed and bar condition are collected in the field

Unstable and Aggrading: high, moderate, low, minimal

Stable

Unstable and Eroding: minimal, low, moderate, high

Bar size as a % of the bed
Bar distribution
Bed stability and process
Bed particle size

Overall stability rating
Controls stabilising the bed
Gravel angularity and shape
Passage restrictions

Bed compaction

2. Selected variables are used to derive the condition ratings for bed and bar condition, using preset formulas

3. Bed and bar condition in stream sections is assessed using the condition ratings

Condition category	Condition rating	Number of sections (%)	Length of major streams (km) (%)
Non-estuarine steam segments			
Very unstable	0 – 20%	16 (9%)	32 (7%)
Unstable	21 – 40%	19 (11%)	42 (10%)
Moderate	41 – 60%	41 (24%)	105 (25%)
Quite stable	61 – 80%	21 (12%)	45 (11%)
Stable	81 – 100%	76 (44%)	200 (47%)
Totals		173	424
Dominant processes			
Eroding		95 (55%)	250 (59%)
Degrading		78 (45%)	174 (41%)

4. Maps can be used to visually depict the condition of each data component, in each stream section

Figure 2.B.8 Steps in assessing stream condition in the State of the Rivers Survey. [36]

6) Habitat Predictive Modelling

Habitat Predictive Modelling is a new, novel method that adds a predictive capacity to the assessment of the physical conditions of rivers (Davies et al. 2000). As with AusRivAS, the major advantage of Habitat Predictive Modelling is that the features expected to occur at a site can be predicted, thus forming a target condition against which to measure habitat impairment. This target condition also has the potential to form the desired state for stream rehabilitation efforts (Davies, 1999). Additionally, in the absence of water quality degradation, physical habitat will have a major influence over biotic assemblages (Davies et al. 2000). As such, Habitat Predictive Modelling complements the AusRivAS biological assessment of stream conditions by providing information on whether biotic impairment at a site is related to poor habitat quality, or to water quality degradation (Parsons et al. 2002).

Habitat Predictive Modelling uses a similar approach to AUSRIVAS, but uses large-scale catchment features to predict local-scale stream physical habitat features (Davies et al. 2000). Local-scale habitat features are measured at reference sites, which are again defined as sites representing least impaired condition (Figure 2.B.9). Classification analysis is then used to form reference sites into groups containing similar habitat features. Large-scale catchment characteristics, usually measured off maps, are then used to discriminate among the local-scale groups and the variables with the strongest discriminatory power are chosen as predictor variables for use in the predictive model algorithm (Figure 2.B.9).

As with AusRivAS, the reference site information forms the template against which test sites are compared to assess habitat conditions (Figure 2.B.9). Local-scale habitat features are measured at the test sites, along with a suite of larger scale catchment characteristics that includes the predictor variables. These predictor variables are used to place test sites into the reference site groups that were formed on the basis of local-scale habitat features. The model then calculates the probability of occurrence of each habitat feature at a test site, based on the occurrence of that feature within the corresponding reference site groups. The habitat features predicted to occur at a test site are compared against the habitat features that were actually observed at the test site, the difference between the two being an indication of habitat condition.

Habitat Predictive Modelling is based on the observation that stream systems are organized hierarchically (de Boer, 1992) and that there is a top down control on the expression of habitat features. For example, Frissell et al. (1986) identified five levels of hierarchical organization: stream systems, segment systems, reach systems, pool/riffle systems and microhabitat subsystems. The characteristics of each level are constrained by physical processes operating at the next highest level. For example, climate and geology act at the larger stream system scale to constrain the expression of bedrock type, longitudinal profile and slope, which are characteristic of the segment scale. In turn, bedrock, longitudinal profile and slope constrain the development of reach systems (Frissell et al. 1986). Although Habitat Predictive Modelling does not aim to capture the same hierarchical levels as Frissell et al. (1986), the prediction of local-scale habitat features from catchment characteristics reflects the constraining relationships between physical processes operating at the large and small levels of the hierarchy. The catchment scale and local-scale variables used in the Habitat Predictive Modelling approach are listed in Table 2.B.7.

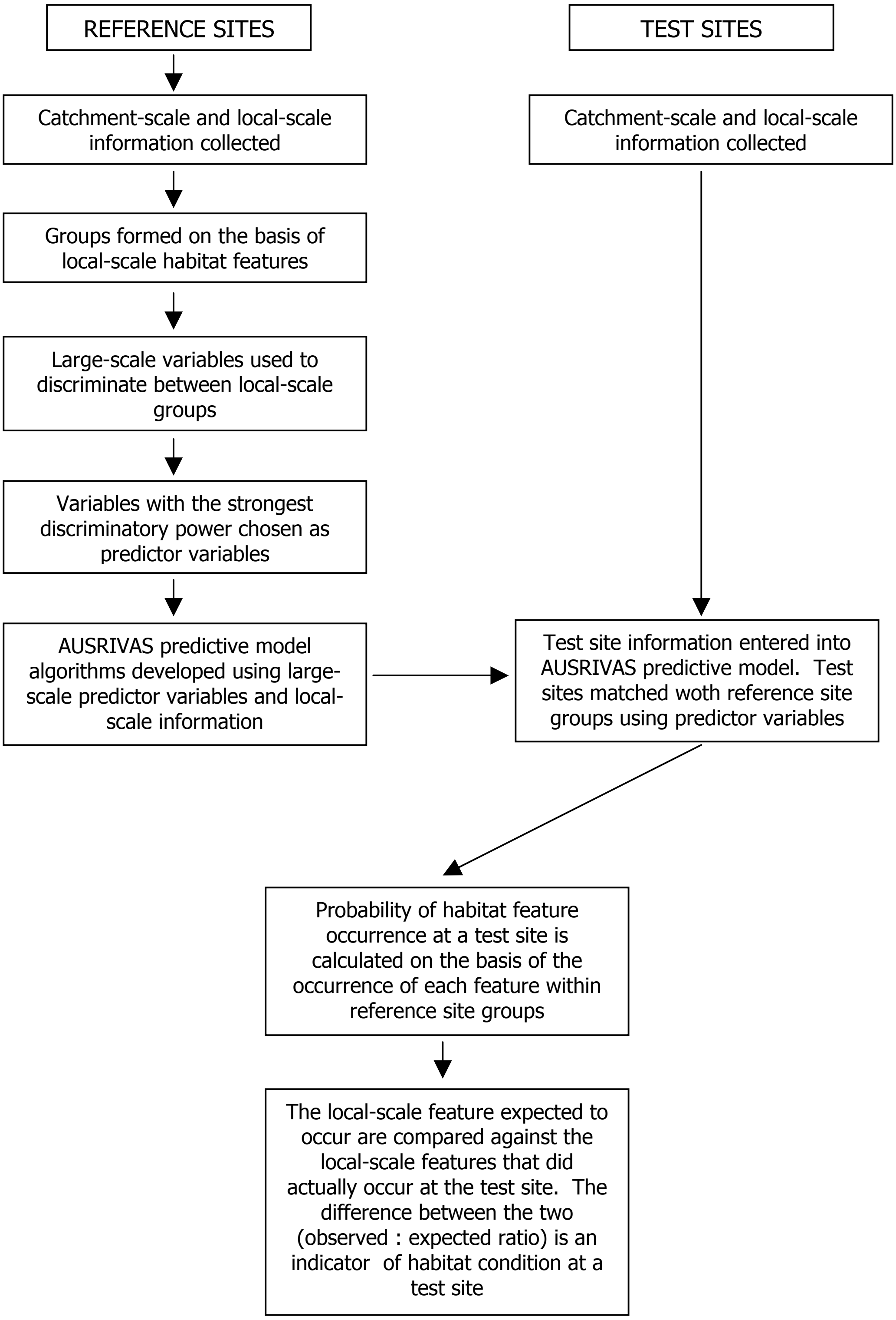

Figure 2.B.9 Schematic representation of Habitat Predictive Modelling and the assessment of habitat condition at a test site. [36]

Table 2.B.7 List of catchment scale and local scale variables used in Habitat Predictive Modelling. [36]

Large scale habitat variables	Local scale habitat variables
Dominant geology in catchment	Riparian width
Percent alluvium in catchment	Percent trees greater than 10m in height
Percent volcanics in catchment	Percent trees less than 10m in height
Percent metasediments in catchment	Percent shrubs and vines
Percent limestone in catchment	Percent grasses, ferns and sedges
Dominant soil type in catchment	Shading of reach
Annual mean rainfall	Stream width
Annual median rainfall	Bank width
Catchment area	Bank height
Maximum catchment length	Percent riffle habitat
Mean catchment slope	Riffle depth
Difference in elevation between source and mouth	Riffle velocity
Relief ratio	Percent edge habitat
Drainage density	Edge depth
Form ratio	Percent boulder in the reach
Elongation ratio	Percent cobble in the reach
Total stream length	Percent pebble in the reach
Valley floor width	Percent gravel in the reach
Valley slope	Percent sand in the reach
Stream order	Percent silt in the reach
Altitude	Percent clay in the reach
Distance from source	Percent bedrock in the riffle
Latitude	Percent boulder in the riffle
Longitude	Percent cobble in the riffle
Alkalinity	Percent pebble in the riffle
Conductivity	Percent gravel in the riffle
pH	Percent sand in the riffle Edge bank vegetation Percent bedrock in the edge Percent boulder in the edge Percent cobble in the edge Percent pebble in the edge Percent gravel in the edge Percent sand in the edge Percent silt in the edge Bottom substrate availability habitat assessment score
	Velocity / depth category habitat assessment score Channel alteration habitat assessment score
	Scouring habitat assessment score Pool / riffle / run / bend habitat assessment score Bank stability habitat assessment score Vegetative stability habitat assessment score Vegetation cover habitat assessment score Total habitat assessment score

Habitat Predictive Modelling assesses stream conditions by comparing the local-scale habitat features predicted to occur at a site in the absence of degradation against the features that were actually observed at a site. The deviation between the two measures (observed/expected ratio) is an indication of habitat quality. This is the same process that is used in AusRivAS to detect biological impairment. However, in adapting a technique designed to detect biological impairment into a method for assessing habitat condition, several limitations have become apparent. Firstly, although AusRivAS predicts the occurrence of macroinvertebrate taxon at a site, there is a need for habitat assessment to predict a more continuous type of data. Currently, the habitat predictive model addresses this by converting each local-scale habitat variable into categories, prior to classification. However, the use of categorical data can result in more than one category being predicted to occur at a site, which may result in a distorted observed : expected ratio (Davies et al. 2000). Secondly, the observed: expected ratio may provide a resolution that is too coarse to accurately reflect habitat condition. For example, one site assessed by Davies et al. (2000) demonstrated an observed: expected ratio of 0.57, which is indicative of impairment. However, examination of the raw data showed that the site actually contained more trees and shrubs than predicted, which indicates that riparian vegetation is not a contributing factor in the habitat impairment observed at this site. Thus, it is suggested that the habitat features predicted to occur should be checked against the observed habitat features to determine if the deviation between them actually represents damage to the stream habitat (Davies et al. 2000). Despite some analytical limitations of Habitat Predictive Modelling, the technique was successful in predicting small-scale habitat features, and represents a promising step forward for habitat assessment.

7) River Habitat Survey (RHS)

The River Habitat Survey (RHS) is a river assessment method used in the United Kingdom. The RHS arose from a need to develop a nationally standardized system to measure, classify and report on the physical structure of rivers (Parsons et al. 2002). In designing the RHS, consideration was given to seven basic requirements:

- capable of producing outputs easily understood and used by river and floodplain managers;
- be a tried-and-tested field method, compatible with existing methods such as river corridor surveys, for use in environmental and post-project appraisal;
- be based on a representative sample of river habitat features;
- have a computer database capable of deriving statistically valid systems for classification;
- can facilitate the description and comparison of physical structure and habitat quality at catchment, regional and national scales;
- be accepted by external organizations, notably the conservation agencies; and,
- with European Directives in mind, have applicability throughout the UK and beyond (Raven et al. 1998b).

Information derived from the RHS is designed to facilitate river management decision making and predict the physical features of a stream that would occur under unmodified conditions (Raven et al. 1997). The RHS was conducted in two phases. The first phase involved the design and testing of survey methods as well as sampling of a reference site database of more than 3000 stream sites across the U.K. (Fox et al. 1998). The second phase is currently under-way and aims to use the RHS in management applications such as catchment management, environmental impact assessments, stream rehabilitation and wildlife conservation (Raven et al. 1998b).

The RHS uses the physical structure of streams to assess the character and quality of rivers (Table 2.B.8). Statistical theory was used to aid the survey design and the selection of sampling sites throughout the U.K. (Jeffers, 1998b, Fox et al. 1998). At each randomly selected site, a 500m length of river is surveyed., 10 spot checks are performed at 50m intervals along this length of river. A range of features is recorded at each spot check (Table 2.B.8). In order to ensure that features and modifications not occurring at the spot checks are included, a sweep up checklist is also completed (Raven et al., 1998b). In addition, cross sectional measurements of water and bankfull width, bank height and water depth (Table 2.B.8) are made at one representative location within the 500m sampling site (Raven et al. 1998b). When used in conjunction with the survey data, these measurements provide information about the geomorphologic processes acting on the site (Raven et al. 1997). Map variables such as altitude, slope, planform and geology (Table 2.B.8) are measured in the laboratory. Data are entered onto an electronic database and photographs of each sampling site are also stored electronically (Raven et al. 1998b).

Table 2.B.8 Variables measured in the River Habitat Survey. (sc) denotes variables collected at spot checks [36]

Background and map derived data	Bank data (left and right recorded separately)
Date of survey	Substrate (sc)
River name	Erosion and deposition features (sc)
Catchment name	Shape
Grid reference	Modifications (sc)
Altitude	Flood embankments
Valley slope	Bank face vegetation structure (sc)
Solid geology code	Extent of bankside trees
Drift geology code	Exposed bankside roots
Distance from source	Number of point bars
Site planform	Extent of side bars
	Banktop land use (sc)
Channel data	**Other site data**
Predominant substrate (sc)	Valley shape
Bedrock	Adjacent land use
Boulders	Broadleaved woodland
Cobbles	Coniferous plantation
Gravel/pebbles	Orchard
Sand	Moorland/heath
Silt	Scrub
Clay	Tall herb/rank vegetation
Artificial	Rough pasture
Not visible	Improved/semi improved grassland
Deposition features (sc)	Tiled land
Braiding/side channels	Wetland
Vegetation types and extent (sc)	Open water
Shading of channel	Suburban/urban development
Tree boughs overhanging channel	Site dimensions
Underwater tree roots	Bank-top height
Fallen trees	Bank-top width
Coarse woody debris	Water Width
Leafy debris	Water depth
Debris dams	Embankment heights
Predominant flow type (sc)	Special floodplain features
Free fall	Artificial open water
Chute	Natural open water
Broken standing water	Water meadow
Chaotic	Fen
Rippled	Bog
Upwelling	Carr
Smooth boundary turbulent	Marsh
No perceptible flow	Flush
No flow (dry)	Notable nuisance species
Extent of waterfalls, cascades, rapids, riffles, runs, boils, glides, pools, marginal deadwater	Giant hogweed
Waterfalls >5m high	Himalayan balsam
Number of riffles	Japanese knotweed
Number of pools	
Modifications (sc)	
Artificial features	
Culverts	
Weirs	
Foot bridges	
Road bridges	
Outfalls	
Fords	

The RHS takes the view that 'in rivers, habitat is the result of predictable physical processes and so conveniently sits between the forces which structure rivers and the biota which inhabit them' (Harper and Everard, 1998 p.395). Thus, the RHS measures variables that represent the character of stream habitats, with the assumption that these variables reflect the geomorphologic processes that are acting to form those habitats (Newson et al. 1998b). While geomorphologic theory underlies many of the variables collected, the RHS is not strictly a geomorphologic survey and specific measurements of geomorphic processes rates are not considered (Newson et al. 1998b). In RHS, the basis for assessing habitat quality, using the information collected at individual 500m sampling sites is:

- quality is based on the presence of channel and river corridor features which are known to be of value to wildlife;
- the two main factors which determine habitat quality are the diversity and 'naturalness' of physical structure; and,
- the system is calibrated, wherever possible, using known top quality sites surveyed specifically for this purpose (Raven et al. 1998b).

Habitat quality assessment can be achieved using four main approaches (Figure 2.B. 10). In the first approach, habitat quality is assessed by identifying sites that have pristine and modification-free channel characteristics and which are located in areas with semi-natural land use. In the second and third approaches, reference site groups that represent similar river types are derived, and rarity of individual features or combinations of features is determined within these reference site groups. In the fourth approach, a habitat quality assessment (HQA) score is calculated from the presence and extent of habitat features recorded in the survey (Raven et al. 1998a). The extent of artificial modification in the channel can also be expressed as a separate habitat modification score (HMS, Raven et al. 1998b).

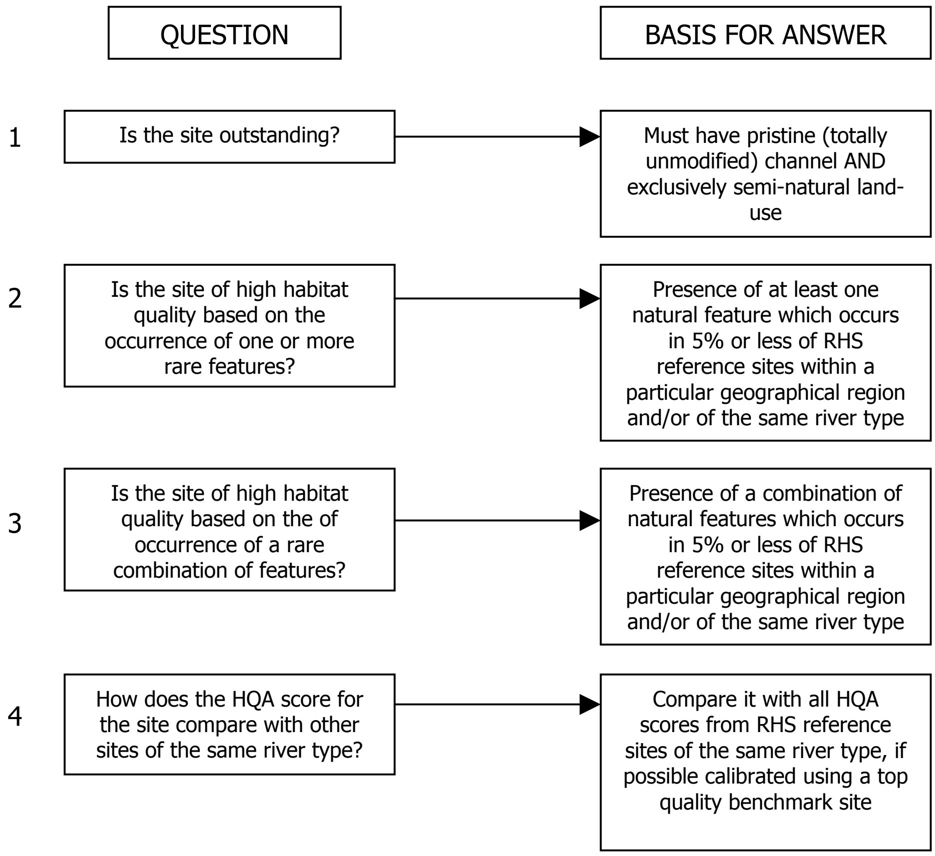

Figure 2.B.10 Four approaches to assessment of habitat quality in the River Habitat Survey. [36]

CHAPTER 3

RIVER REHABILITATION AND RESTORATION

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3 RIVER REHABILITATION AND RESTORATION

3.1 INTRODUCTION

The main objective of this chapter is to present the various river rehabilitation measures with an emphasis on their applications. As river rehabilitation is a relatively new field in this country, there are very limited experiences available locally. Therefore substantial amount of materials incorporated in this chapter are obtained from foreign sources.

This chapter starts with the concepts and principles of rehabilitation, followed by the required hydraulics and engineering measures normally employed for rehabilitation work. A procedure for rehabilitation is provided which covers rehabilitation principles, design and environmental flow management. A topic on recovery of disturbed rivers enlists the various likely disturbances to rivers and the recovery options available. This is followed subsequently with the sections on rehabilitation implementation, monitoring and maintenance of a project.

Throughout this chapter and the rest of this Manual, the terms "stream" and "river" are used interchangeably although the latter normally refer to larger channels.

3.2 STREAM REHABILITATION CONCEPTS AND PRINCIPLES

3.2.1 Concept of River Rehabilitation and Restoration

It is almost always more cost effective and sensible to protect rivers or river reaches that remain in good condition, rather than undertaking expensive rehabilitation works [1]. It is always difficult to procure funds for rivers in good condition as it is felt that they would look after themselves, and that priorities should lie elsewhere, where damage is most visible. However, there is ample evidence that healthy rivers, or healthy river reaches within a larger river system, require active management to ensure they remain in good condition. River scientists and others are now calling for a re-think on the priorities for river management, with a stronger emphasis being placed on the lower-cost option of protecting rivers before they deteriorate. The principle of "*protect first, restore second*" should be the first consideration before undertaking restoration planning. It is sensible to prevent rivers within the catchment, or other river reaches, from becoming degraded to the same extent as those requiring restoration.

It is important to be clear about the goal of stream rehabilitation as espoused in this chapter. One can talk in vague terms about 'environmental values', but the simplest measure of these values is the original (pre-Independent days) condition of the streams. Thus, the target of this chapter is to return, as far as is possible, the vegetation, structure, hydrology, and water quality of the original streams. The assumption is that by providing these physical elements, the original suite of organisms that occupied the stream will also return. At the end, the success of improvements to vegetation, hydrology, hydraulics and stream morphology, should ultimately be judged in relation to the improvements that they bring to the organisms living in, and relying on, the stream. Importantly, the improvements should be self-sustaining, meaning that the stream should not need continual intervention to retain the improved condition. Although this chapter emphasises stream biology as a goal of stream rehabilitation, there are other environmental values that are not related to the organisms in the stream. For example, the intrinsic beauty of a stream is another environmental value, as is the return of riffles to a stream for swimming and fishing. 'Geodiversity' is another reason for rehabilitating streams. This is the notion that the physical structure of a stream itself has intrinsic value, independent of the organisms that live in it. Although it does, but the biological values are equally important and provide a good measure of the general health of a stream system. In any case, restoring streams for ecological reasons usually involves restoring the physical character of the stream as well.

The words river 'restoration', 'rehabilitation' and 'remediation' are often used interchangeably (Rutherfurd et al. 2000) [2]. There are, however, important differences between them:

Restoration

The ideal restoration project will achieve five objectives (often in this order) (modified from National Research Council 1992, Australia):

- Restore the natural range of water quality;
- Restore the natural sediment and flow regime (including the seasonal fluctuations, as well as the annual to decadal pattern of floods);
- Restore a natural channel geometry and stability (if this is not achieved under 2.);
- Restore the natural riparian plant community (if this is not achieved under 2. and 3.); and
- Restore native aquatic plants and animals (if they do not colonise on their own).

Once struck by the exciting idea of restoring streams to their pre-independent era condition, it is important to acknowledge that this will seldom be possible. Firstly, it is often impossible to establish what that condition was. Secondly, such restoration would mean modifying the physical and biological character of the reach (channel form, biological communities) so that they replicate the original state. This would involve changing all of the inputs and outputs (water quality and quantity, sediment, and organisms) from upstream, downstream and the riparian zone, to the pre-independent era state. Because of the connections between the stream and the catchment, in most situations this would only be possible if the entire stream network, and most of the catchment surface, were also restored. Clearly, this will almost never be possible. Even if the attempt was made, the changes that have occurred over the last 100 years may have been great enough to alter many streams irretrievably. More usually the stream manager will aim for 'rehabilitation'.

Rehabilitation

Although restoration may be impossible, this does not leave a degraded stream without hope. By improving the most important aspects of the stream environment, you may create a stream that, although only resembling the pre-independent era condition, is nevertheless an improvement on the degraded stream, and often a valuable environment in its own right. Since restoration is usually impossible, rehabilitation is the more common goal of our work. This is the term used almost exclusively in this Manual.

Remediation

In some cases, even rehabilitation is not possible because of irretrievable changes to the stream. In such a situation, it can be said that the original state is no longer an appropriate aim for the stream, because inputs from the catchment would not support such a condition. In this situation, the suitable treatment is remediation. The aim of remediation is to improve the ecological condition of the stream, but the endpoint of that improvement will not necessarily resemble the original state of the stream. In fact, we may not be able to predict what that endpoint will be like.

In the following sections, the various principles of rehabilitation will be espoused. The term "rehabilitation" would be used throughout this Manual as it is considered to be an approach which is more practical to achieve.

The principles for rehabilitation focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked. The presence or absence of public support for a rehabilitation project can be the difference between positive results and failure. Coordination with the people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the rehabilitated area. In addition, partnership with stakeholders can also add useful resources, ranging from money and technical expertise to volunteer help with implementation and monitoring. The following sections provide the guiding principles for the rehabilitation work (USEPA, 2000)[3].

3.2.2 Preserve and Protect Aquatic Resources

Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems. Thus, rehabilitation does not replace the need to protect aquatic resources in the first place. Rather, rehabilitation is a complementary activity that, when combined with protection and preservation, can help achieve overall improvements in a greater percentage of the nation's rivers. Even with water bodies for which rehabilitation is planned, the first objective should be to prevent further degradation.

3.2.3 Restore Ecological Integrity, Natural Structure, and Function

Rehabilitation should reestablish insofar as possible the ecological integrity of degraded aquatic ecosystems. Ecological integrity refers to the condition of an ecosystem - particularly the structure, composition, and natural processes of its biotic communities and physical environment. An ecosystem with integrity is a resilient and self-sustaining natural system able to accommodate stress and change. Its key ecosystem processes, such as nutrient cycles, succession, water levels and flow patterns, and the dynamics of sediment erosion and deposition, are functioning properly within the natural range of variability. Biologically, its plant and animal communities are good examples of the native communities and diversity found in the region. Structurally, physical features such as the dimensions of its stream channels are dynamically stable. Rehabilitation strives for the greatest progress toward ecological integrity achievable within the current limits of the watershed, by using designs that favor the natural processes and communities that have sustained native ecosystems through time.

Many aquatic resources in need of rehabilitation have problems that originated with harmful alteration of channel form or other physical characteristics, which in turn may have led to problems such as habitat degradation, changes in flow regimes, and siltation. Stream channelization, ditching in wetlands, disconnection from adjacent ecosystems, and shoreline modifications are examples of structural alterations that may need to be addressed in a rehabilitation project. In such cases, restoring the original site morphology and other physical attributes is essential to the success of other aspects of the project, such as improving water quality and bringing back native biota.

Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions. For example, restoring the bottom elevation in a wetland can be critical for reestablishing the hydrological regime, natural disturbance cycles, and nutrient fluxes. In order to maximize the societal and ecological benefits of the rehabilitation project, it is essential to identify what functions should be present and make missing or impaired functions priorities in the rehabilitation. Verifying whether desired functions have been reestablished can be a good way to determine whether the rehabilitation project has succeeded.

3.2.4 Understand Natural Watershed Potential, Watershed Work, and Broader Landscape Concept

A watershed has the capacity to become only what its physical and biological setting - its ecoregion's climate, geology, hydrology, and biological characteristics - will support. Establishing rehabilitation goals for a waterbody requires knowledge of the historical range of conditions that existed on the site prior to degradation and what future conditions might be. This information can then be used in determining appropriate goals for the rehabilitation project. In some cases, the extent and magnitude of changes in the watershed may constrain the ecological potential of the site. Accordingly, rehabilitation planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.

Rehabilitation requires a design based on the entire watershed, not just the part of the waterbody that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. A localized rehabilitation project may not be able to change what goes on in the whole watershed, but it can be designed to better accommodate watershed effects. New and future urban development may, for example, increase runoff volumes, stream downcutting and bank erosion, and pollutant loading. By considering the watershed context in this case, rehabilitation planners may be able to design a project for the desired benefits of rehabilitation, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and nonpoint pollution. For example, in choosing a site for a wetland rehabilitation project, planners should consider how the proposed project may be used to further other related efforts in the watershed, such as increasing riparian habitat continuity, reducing flooding, and/or enhancing downstream water quality. Beyond the watershed, the broader landscape context also influences rehabilitation through factors such as interactions with terrestrial habitats in adjacent watersheds, or the deposition of airborne pollutants from other regions.

Rehabilitation efforts are likely to fail if the sources of degradation persist. Therefore, it is essential to identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible. While degradation can be caused by one direct impact such as the filling of a wetland, much degradation is caused by the cumulative effect of numerous, indirect impacts, such as changes in surface flow caused by gradual increases in the amount of impervious surfaces in the watershed. In identifying the sources of degradation, it is important to look at upstream and up-slope activities as well as at direct impacts on the immediate project site. Further, in some situations, it may also be necessary to consider downstream modifications such as dams and channelization.

3.2.5 Develop Clear, Achievable, and Measurable Goals

Rehabilitation may not succeed without good goals. Goals direct implementation and provide the standards for measuring success. Simple conceptual models are a useful starting point to define the problems, identify the type of solutions needed, and develop a strategy and goals. Rehabilitation teams should evaluate different alternatives to assess which can best accomplish project goals. The chosen goals should be achievable ecologically, given the natural potential of the area, and socioeconomically, given the available resources and the extent of community support for the project. Also, all parties affected by the rehabilitation should understand each project goal clearly to avoid subsequent misunderstandings. Good goals provide focus and increase project efficiency.

3.2.6 Focus on Feasibility

Particularly in the planning stage, it is critical to focus on whether the proposed rehabilitation activity is feasible, taking into account scientific, financial, social and other considerations. Remember that solid community support for a project is needed to ensure its long-term viability. Ecological feasibility is also critical. For example, a wetlands rehabilitation project is not likely to succeed if the hydrological regime that existed prior to degradation cannot be reestablished.

3.2.7 Use of Reference Site

Reference sites are areas that are comparable in structure and function to the proposed rehabilitation site before it was degraded. As such, reference sites may be used as models for rehabilitation projects, as well as a yardstick for measuring the progress of the project. While it is possible to use historic information on sites that have been altered or destroyed, historic conditions may be unknown and it may be most useful to identify an existing, relatively healthy, similar site as a guide for your project. Remember, however, that each rehabilitation project will present a unique set of circumstances, and no two aquatic systems are truly identical. Therefore, it is important to tailor your project to the given situation and account for any differences between the reference site and the area being restored.

3.2.8 Anticipate Future Changes

The environment and our communities are both dynamic. Although it is impossible to plan for the future precisely, many foreseeable ecological and societal changes can and should be factored into rehabilitation design. For example, in repairing a stream channel, it is important to take into account potential changes in runoff resulting from projected increases in upstream impervious surface area due to development. In addition to potential impacts from changes in watershed land use, natural changes such as plant community succession can also influence rehabilitation. For instance, long-term, post-project monitoring should take successional processes such as forest regrowth in a stream corridor into account when evaluating the outcome of the rehabilitation project.

3.2.9 Involvement of Skills and Insights of a Multi-disciplinary Team

Rehabilitation can be a complex undertaking that integrates a wide range of disciplines including ecology, aquatic biology, hydrology and hydraulics, geomorphology, engineering, planning, communications and social science. It is important that, to the extent that resources allow, the planning and implementation of a rehabilitation project involve people with experience in the disciplines needed for the particular project. Universities, government agencies, and private organizations may be able to provide useful information and expertise to help ensure that rehabilitation projects are based on well-balanced and thorough plans. With more complex rehabilitation projects, effective leadership will also be needed to bring the various disciplines, viewpoints, and styles together as a functional team.

3.2.10 Design for Self-sustainability

Perhaps the best way to ensure the long-term viability of a rehabilitated area is to minimize the need for continuous maintenance of the site, such as supplying artificial sources of water, vegetation management, or frequent repairing of damage done by high water events. High maintenance approaches not only add costs to the rehabilitation project, but also make its long-term success dependent upon human and financial resources that may not always be available. In addition to limiting the need for maintenance, designing for self-sustainability also involves favoring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.

3.2.11 Use Passive Rehabilitation when Appropriate

"Time heals all wounds" applies to many rehabilitation sites. Before actively altering a rehabilitation site, determine whether passive rehabilitation (i.e. simply reducing or eliminating the sources of degradation and allowing recovery time) will be enough to allow the site to naturally regenerate. Many times there are reasons for restoring a waterbody as quickly as possible, but there are other situations when immediate results are not critical. For some rivers and streams, passive rehabilitation can reestablish stable channels and floodplains, regrow riparian vegetation, and improve in-stream habitats without a specific rehabilitation project. With wetlands that have been drained or otherwise had their natural hydrology altered, restoring the original hydrological regime may be enough to let time reestablish the native plant community, with its associated habitat value. It is important to note that, while passive rehabilitation relies on natural processes, it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.

3.2.12 Restore Native Species and Avoid Non-native Species

Some natural areas are experiencing significant problems with invasive, non-native (exotic) species, to the great detriment of the native ecosystems and the benefits brought with them. Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls. The temporary disturbance present during rehabilitation projects invites colonization by invasive species which, once established, can undermine rehabilitation efforts and lead to further spread of these harmful species. Invasive, non-native species should not be used in a rehabilitation project, and special attention should be given to avoiding the unintentional introduction of such species at the rehabilitation site when the site is most vulnerable to invasion. In some cases, removal of non-native species may be the primary goal of the rehabilitation project.

3.2.13 Use Natural Fixes and Bioengineering Techniques where Possible

Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants, and provide habitat. Bioengineering techniques can often be successful for erosion control and bank stabilization, flood mitigation, and even water treatment. Specific projects can range from the creation of wetland systems for the treatment of storm water, to the rehabilitation of vegetation on river banks to enhance natural decontamination of runoff before it enters the river.

3.2.14 Monitor and Adapt where Required

Every combination of watershed characteristics, sources of stress, and rehabilitation techniques is unique and, therefore, rehabilitation efforts may not proceed exactly as planned. Adapting a project to at least some change or new information should be considered normal. Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future rehabilitation efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

3.3 HYDRAULICS of RIVER REHABILITATION

3.3.1 Bankfull / Dominant Discharge Verification

The most important stream process in defining channel form is the bankfull discharge, which is essentially the same as the effective or dominant discharge. Bankfull discharge is the flow that transports the majority of a stream's sediment load over time and thereby forms and maintains the channel. Any flow that exceeds the stage of the bankfull flow will move onto the floodplain; therefore bankfull stage is considered the incipient point of flooding. This may or may not be the top of the streambank. If the stream has become incised due to changes in the watershed or streamside vegetation, the bankfull stage may be a small bench or scour line on the streambank. In this case the top of the bank, which was formerly the floodplain, is called a terrace. A stream that has terraces close to the top of the banks is considered an incised or entrenched stream (Figure 3.1a). If the stream is not entrenched, then bankfull is near the top of the bank (Figure 3.1b). The bankfull stage in a typical stream section is as shown in Figure 3.2. Figure 2.23 may be referred to for a pictorial illustration of bankfull width and depth in a stream cross-section. On average, bankfull discharge occurs every 1.5 to 2.0 years. In other words, each year there is about a 67% to 50% chance of a bankfull discharge event.

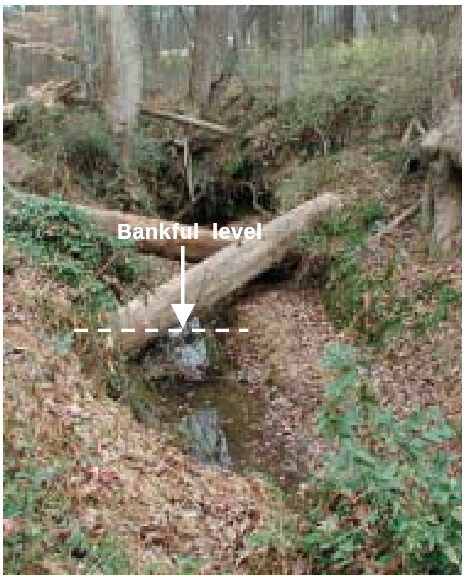


Figure 3.1a Bankfull bench below top of bank in an incised channel

Figure 3.1b Bankfull is at the top of the streambank on this reference reach stream

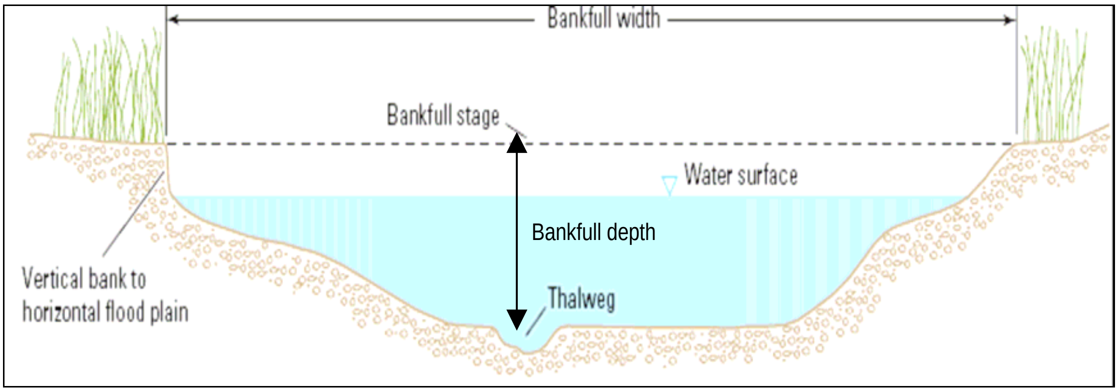


Figure 3.2 Bankfull stage at a typical stream section [158]

Discharge is the volume of water flowing through a stream channel cross section per unit time. If stream flow gauging has been carried out, then the stage-discharge rating curve can be plotted to determine the discharge for the specific elevation of the field-determined bankfull stage. However, most stream reaches are not gauged, so it probably will be necessary to estimate the bankfull discharge and velocity using other methods. Bankfull discharge, Q_{bkf}, can be estimated using Manning's equation Equation 3.1 as follows (Stream Restoration, North Carolina Stream Restoration Institute)[4]:

$$Q_{bkf} = (AR^{2/3} S^{1/2} /n) \qquad (3.1)$$

Where:
Q_{bkf} = Discharge (m^3/s)
A = Cross-sectional area at bankfull stage (m^2)
R = Hydraulic radius at bankfull stage (m)
S = Average channel slope (m/m)
n = Manning's roughness coefficient

The hydraulic radius is determined using Equation 3.2:

$$R = A/P \qquad (3.2)$$

Where:
P = Wetted perimeter of the channel at bankfull stage (m)

The cross-sectional area and wetted perimeter can be calculated using the cross-section survey data. The wetted perimeter, P, can also be approximated using Equation 3.3, which assumes a rectangular channel shape.

$$P = 2D + W \qquad (3.3)$$

Where:
D = Average bankfull depth (m)
W = Bankfull width (m)

Manning's roughness coefficient can be estimated by using Chow's coefficients for various channel substrate and vegetation characteristics (1959). Velocity, V, can then be determined using Equation 3.4:

$$V = Q_{bkf} /A \qquad (3.4)$$

Where:
V = Bankfull velocity (m/s)

3.3.2 Velocity and Shear Stress Estimation

Shear stress is an important parameter in habitat rehabilitation design, because all materials, whether manufactured or natural, used for habitat rehabilitation must be able to withstand the expected shear stress at the design discharge. Thus, in design, all materials and vegetation types are chosen based on the expected shear for a given flow (for example, the 50-year ARI design discharge) at their point of installation. Shear stress is typically measured in units of N/m^2 (Saldi-Caromile et al. 2004)[5].

On any given bank, the material and vegetation types required to resist erosion may vary with location. Lane's diagram, Figure 3.3, shows theoretical distribution of shear stress on streambed and banks on a straight section of trapezoidal channel. Based on Lane's diagram, materials and plants of greater shear resistance are required lower on the bank, while a lighter-duty treatment may be sufficient near the top of the bank. When designing habitat rehabilitation features that include temporary surface protection such as biodegradable fabric, the designer must be sure that the shear resistance of both the temporary protection (e.g. coir fabric) and the long term surface treatment (vegetation) is adequate to withstand hydraulic forces at that location. In addition, when designing using vegetation as the primary erosion protection, factors such as species, site aspect, shade, soil type, moisture conditions, and local climate must all be considered.

Typical permissible shear stresses for various materials for grassed and gravel/riprap lined channel are shown in Table 3.1 including a limited selection of local grasses. Therefore, the information presented may be used as a guide in estimating the shear resistance of similar local grasses that do not appear there. It is also suggested that research be conducted to determine grass species of equivalent shear resistance so that they can be used in the local environment.

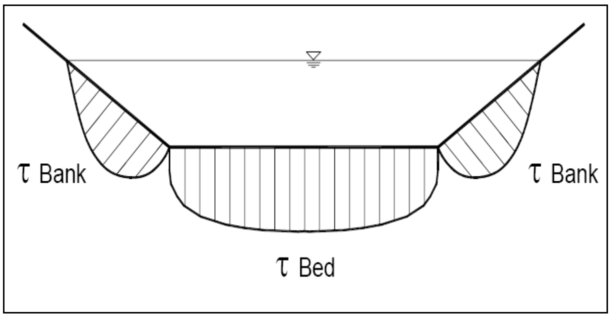


Figure 3.3 Distribution of shear stress on streambed and banks [195]

3.3.2.1 Allowable velocity and shear stress for channel lining materials

Allowable velocity and allowable shear stress values for a number of different "man-made" channel lining materials are presented in Table 3.2. Data in the table were compiled from many sources. Ranges of allowable velocities and shear stresses, therefore, are presented in the table. For manufactured products, the designer should consult the manufacturer's guidelines to determine thresholds for a specific product.

The values in Table 3.2 relate to cross-sectional averaged values. The data typically come from flumes where the flow is uniform and does not exhibit the same level of turbulence as natural channels. The recommended values are empirically derived. The designer should consider modifying tabular values based on site-specific conditions such as duration of flow, soils, temperature, debris in the stream, and plant species, as well as channel shape and planform (Hoag and Fripp 2002)[6]. To account for some of these differences, Fischenich recommends that a factor of safety of between 1.2 and 1.3 be applied to the tabular values.

The allowable limits of velocity and shear stress published by manufacturers for various products are typically developed from studies using short durations. Studies have shown that extended flow duration reduces the erosion resistance of many types of erosion control products as shown in Figure 3.4. Fischenich recommends using a safety factor when flow duration exceeds a couple hours.

Table 3.1 Permissible shear stresses of various grass and gravel/riprap materials

Material	Permissible shear stress (N/m^2)
Class A vegetation Vertiver grass/Rumput wangi (*Vetiveria zizaniodes)*: excellent stand, average height 600mm *Weeping lovegrass*: excellent stand, average height 750mm *Yellow Bluestem Ischaemum*: excellent stand, average height 900mm	175
Class B vegetation Bermuda grass *(Cynodon dactylon)*: good stand, average height 300mm *Weeping lovegrass*: good stand, average height 330mm *Lespedeza sericea*: good stand, not woody, average height 480mm *Alfalfa*: good stand, uncut, average height 280mm	100
Class C vegetation Bermuda grass: good stand, mowed, average height 150mm *Common lespedeza*: good stand, uncut, average height 280mm Grass-legume mix: good stand, uncut (75 – 200mm) Centipedegrass *(Eremochloa ophiuroides*): very dense cover, average height 150mm	45
Class D vegetation Bermuda grass: good stand, cut to 60mm height *Common lespedeza*: excellent stand, uncut (average height 115mm) Cow grass (*Paspalum conjugatum*) or St. Augustine grass (*Stenotaphrum secundatum*): good stand, uncut (75 – 150mm) Grass-legume mix: good stand, uncut (100 – 125mm) *Lespedeza sericea*: very good stand cut to 50mm height	30
Class E vegetation Bermuda grass: good stand, cut to 40mm height Bermuda grass: burned stubble	20
25mm gravel	15
50mm gravel	35
150mm rock riprap	95
300mm rock riprap	190
400mm rock riprap	255
500mm rock riprap	320
600mm rock riprap	385

Note:
1. Permissible shear stresses are equivalent values as obtained from "Integrated Stream Protection Guidelines 2003, Washington State Aquatic Habitat Guidelines Program" [6] except for Item 2 below and Vertiver grass (able to withstand flow up to 3.5m/s).
2. For riprap sizes ranged from 400mm-600mm, the critical shear velocities are derived using $V_c = 0.18d_{max}^{0.487}$ (Costa, 1983) where d_{max} = mean intermediate axis diameter (in mm) of the five largest gravel sizes of a sample and then converted to shear stresses.
3. Grasses in italic are not normally found locally and equivalent grass species need to be identified to withstand the same shear stresses.

Table 3.2 Allowable velocity and shear stress for selected lining materials1/

Boundary category	Boundary type	Allowable velocity (m/s)	Allowable shear stress (N/m^2)
Temporary degradable reinforced erosion control products (RECP)	Jute net Straw with net Coconut fiber with net Fiberglass roving	0.3-0.8 0.3-0.9 0.9–1.2 0.8–2.1	21 72–79 107 96
Non-degradable RECP	Unvegetated Partially established Fully vegetated	1.5–2.1 2.3–4.6 2.4–6.4	144 192–287 383
Hard surface	Gabions Concrete	0.3–5.8 >5.5	479 598

1/ Ranges of values generally reflect multiple sources of data or different testing conditions (Goff 1999), (Gray and Sotir 1996), (Julien 1995), (Kouwen, Li, and Simons 1980), (Norman 1975) (TXDOT 1999)

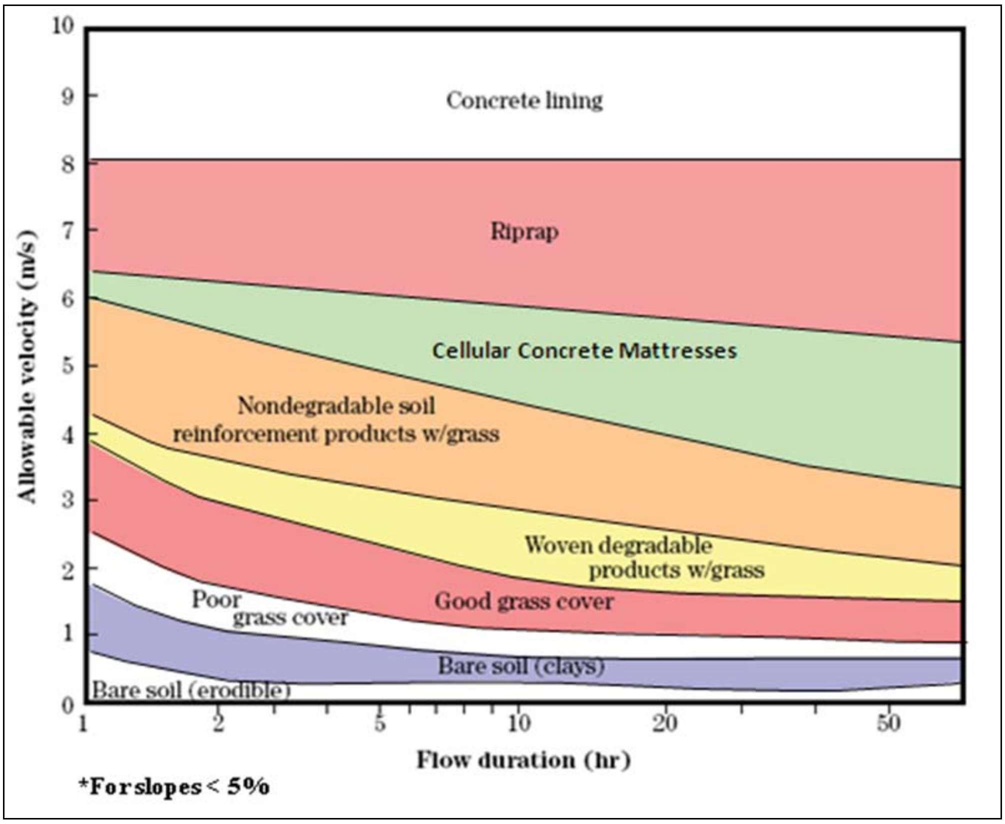


Figure 3.4 Effect of flow duration on allowable velocities for various channel linings [72]

3.3.2.2 Estimating shear stress

Shear equations presented in this Manual allow the designer to estimate bed and bank shear in straight stream reaches and bends. In addition, a means of estimating shear as a function of height in the water column is presented. It is assumed that persons utilizing the equations presented are well versed in hydraulic analysis and familiar with the concepts of shear and scour.

Bed Shear Stress in a Straight Reach

Shear stress on the bed is:

$$\tau_{bed} = \gamma RS \qquad (3.5)$$

Where: τ_{bed} = maximum bed shear stress (N/m^2)
γ= the specific weight of water (N/m^3)
R = hydraulic radius in m
S = energy slope in m/m

The slope of the energy grade line S is usually similar to the hydraulic grade line (water surface) and bed slope (gradient). By definition, the slopes are equal for steady, uniform flow. A standard and appropriate way to calculate channel slope from a surveyed profile is to base the elevation change on the elevations of the thalweg at "zero flow" points. Zero flow points are the points in the bed that would control the pools upstream of major riffles if there were no water flowing in the channel. They are the low points at the head of riffles. In a braided channel, or channels without defined riffles, the mean bed elevation should be used. The mean bed elevation should be determined from several closely spaced cross-sections.

The hydraulic radius R is the cross-sectional area of the wetted channel (A) divided by the wetted perimeter (P), at the design discharge. This value is occasionally replaced by depth of flow y but this should only be done when the width of the channel far exceeds the depth of the channel.

A common application of the equation for maximum bed shear stress is:
Maximum bed shear stress in a straight reach:

$$\tau_{bed} = \gamma\, R\, S = \gamma\, (A/P)\, S \qquad (3.6)$$

$$\tau_{bed} = 9{,}806\, R\, S \qquad (3.7)$$

where: τ_{bed} = maximum bed shear stress (N/m^2)
A = flow cross-sectional area (m^2)
P = wetted perimeter (m)
S = energy slope in (m/m)

This calculation gives a quantitative measure of the erosive force acting on the bed of the channel.

Bank Shear Stress in a Straight Reach

By approximating the channel cross-section as a trapezoid or rectangle, the maximum bed shear stress can be used to estimate the maximum bank shear stress. This stress acts approximately one-third of the distance up the bank (from the bed) and can be approximated by multiplying the maximum bed shear stress by a factor (see Lane's Diagram, Figure 3.3). This factor, K_1, varies based on channel side slope and the ratio of bottom width to depth as shown in Figure 3.5. This approximation applies only to a relatively straight channel reach.

The maximum bank shear stress in a straight reach:

$$\tau_{bank} = K_1\, \tau_{bed} \qquad (3.8)$$

where: τ_{bed} = maximum bed shear stress in N/m^2
K_1 = ratio from Figure 3.5.

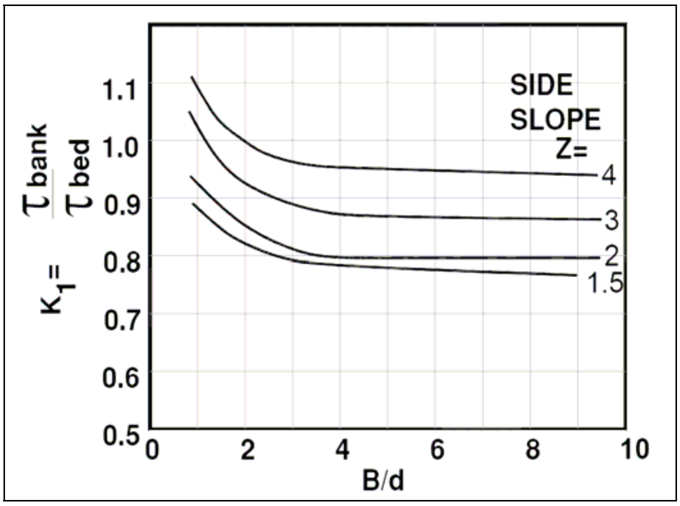


Figure 3.5 Coefficient K1 vs side slope z, and width/depth B/d ratio [7]

The shear stress on the upper bank can be estimated using Lane's Diagram shown in Figure 3.5. Based on this diagram, side shear vs depth can be estimated using the following equation:

$$\tau_x = C\,\tau_{bed} \tag{3.9}$$

where: τ_x = bank shear at distance X from stream bottom (N/m^2)
τ_{bed} = maximum bed shear stress (N/m^2)
C = coefficient from Table 3.3
y = channel depth (m)

Table 3.3 Coefficient "C" vs. depth

Distance X (Distance from stream bottom)	C (From Lane)	C (Recommend for design)
Y	0.0	0.0
0.9 y	0.14	0.14
0.8 y	0.27	0.27
0.67 y	0.41	0.41
0.6 y	0.54	0.54
0.5 y	0.68	0.68
0.4 y	0.79	0.79
0.33 y	0.8	0.8
0.2 y	0.7	0.8
0.1 y	0.5	0.8
0.0 y	0.0	0.8

(Note: Although Lane's shear diagram indicates zero shear at the base of the bank, the design value should be the maximum bank shear in the entire lower 1/3 of the bank height.)

Shear Stress in Bends

Flow around bends creates secondary currents that exert higher shear forces on the channel bed and banks than those found in straight sections. Several techniques are available for estimating shear stress in bends. A relatively simple and widely used method estimates maximum shear stress on channel banks and bed in bends (this equation does not differentiate between bank and bed shear stress). The maximum bed/bank shear stress in a bend is:

$$\tau_{bend} = K_b \, \tau_{bed} \qquad (3.10)$$

where: τ_{bend} = maximum shear stress on bank and bed in a bend (N/m^2)
τ_{bend} = maximum bed shear stress in adjacent straight reach (N/m^2)
K_b = bend coefficient (dimensionless)
and: $K_b = 2.4\, e^{-0.0852(Rc/B)}$
(alternatively, K_b can be determined from Figure 3.7)
where: R_c = radius of curvature of bend (m)
B = bottom width of channel at bend (m)

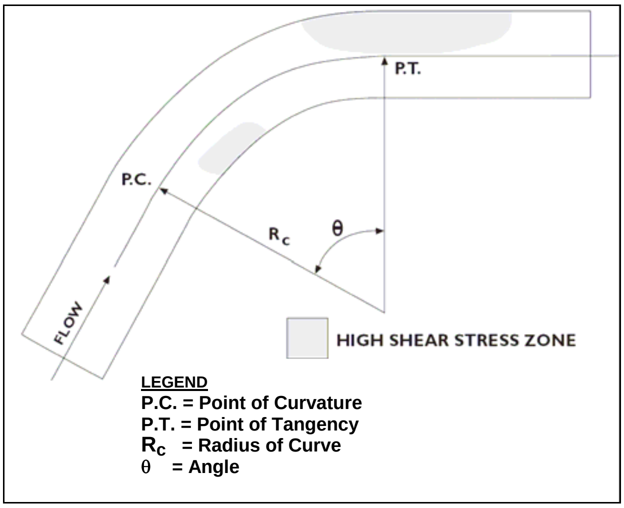


Figure 3.6 Shear stress distribution in a channel bend [7]

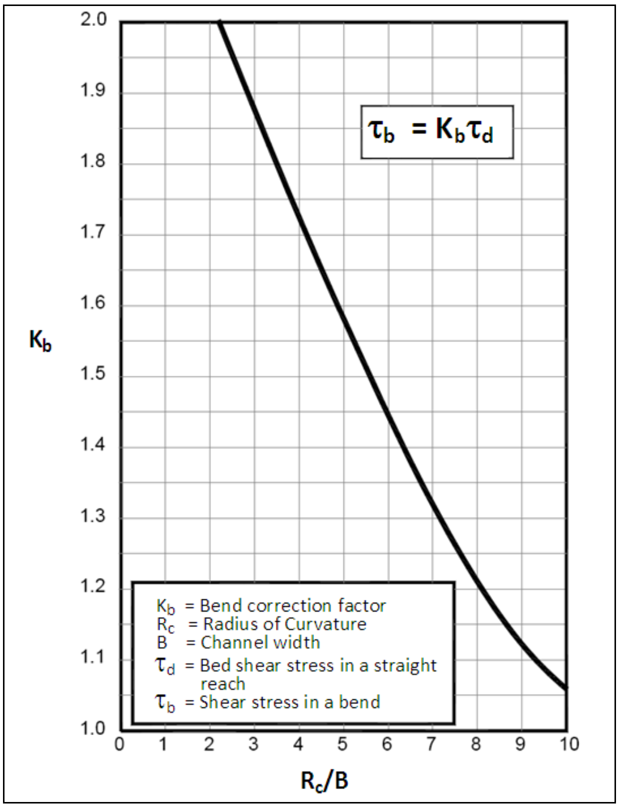


Figure 3.7 Bend scour correction factor Kb vs ratio Rc/B [7]

The maximum bed/bank shear stress is primarily focused on the bank and bed on the outside portion of the bend (Figure 3.6).

The analysis of the vertical distribution of shear stress on banks in bends is not well defined. Secondary currents found in bends complicate shear analysis in these regions. Equation 3.8 can be used as a rough estimate of shear distribution on banks in bends, but it does not account for secondary currents. It is recommended that vertical shear distribution in bends be estimated by using Equation 3.8, judgment based on the severity of the bend and the degree of expected super-elevation of the water surface around the bend. Super-elevation of the water surface around a bend can be estimated as described in the following paragraph.

The water surface elevation increases around the outside of bends as the channel banks exert centrifugal forces on the flow. This super-elevation can be estimated using the following equation:

$$\Delta y = V2\ W / (g\ Rc) \qquad (3.11)$$

where:
Δy = super-elevation of water surface (m)
V = average velocity of flow (m/s)
W = channel top width (m)
g = acceleration due to gravity (9.81m/s^2)
R_c = radius of curvature of bend (m)

3.3.3 Scour Estimation

Scour is an essential contributor to the creation of fish habitat and its maintenance. Many fish-enhancement projects promote scour. It is not the extent or magnitude of the scour that promotes the best habitat, but the frequency of the scour activity. Sites absent of scour tend to provide less habitat complexity than areas subject to moderately frequent scour events, given that intermediate-level disturbances promote aquatic diversity. Sites that are subject to very frequent scour have less habitat value than areas subject to moderately frequent scour events.

Most of the scour equations presented here were developed to predict hydraulic characteristics around man-made structures, such as bridges, located within relatively large, often sand-bed, streams. In general, equations predicting scour in streambeds consisting of gravel and coarser bed material are not considered as reliable, although the scour depth is likely to be less than the scour calculated from the more widely used equations based on homogeneous fine-grained sand substrate.

3.3.3.1 Calculating Potential Depth of Scour

Anticipating the maximum scour depth at a site is critical to the design of a bank treatments and structures by defining the type and depth of foundation needed. Scour depth is also useful when designing anchoring systems or estimating the depths of scour pools adjacent to in-channel structures. Determining the maximum depth of scour is accomplished by:

- Applying calculations based on information derived from a complete hydrologic and hydraulic evaluation of the stream.
- Identifying the type(s) of scour expected.
- Calculating the depth for each type of scour.
- Accounting for the cumulative effects of each type of scour (If more than one type of scour is present, the effects of the scour types are additive.)
- Reviewing the calculated scour depth for accuracy based on: experience from similar streams; conditions noted during the field visit; and an understanding of the calculations.

Types of Scour

Five types of scour are defined below: toe scour, bend scour, contraction scour, drop/weir scour, and jet scour [7].

Toe Scour – Local toe scour appears as discrete and tight scallops along the bank line, or as depressions in the streambed. It is generated by flow patterns that form around an obstruction in a stream and spill off to either side of the obstruction, forming a horseshoe-shaped scour pattern in the streambed. When flow in the stream encounters an obstruction, for example a bridge pier or rock outcrop; the flow direction changes. Instead of moving downstream, it dives in front of the obstruction and creates a roller (a secondary flow pattern) that spills off to either side of the obstruction. The resulting flow acceleration and vortices around the base of the obstruction result in higher erosive forces around it, which move more bed sediment, thereby creating a scour hole. The location around the obstruction is scoured because the bed is eroded deeper at the obstruction than the bed of the stream adjacent to it (Figure 3.8).

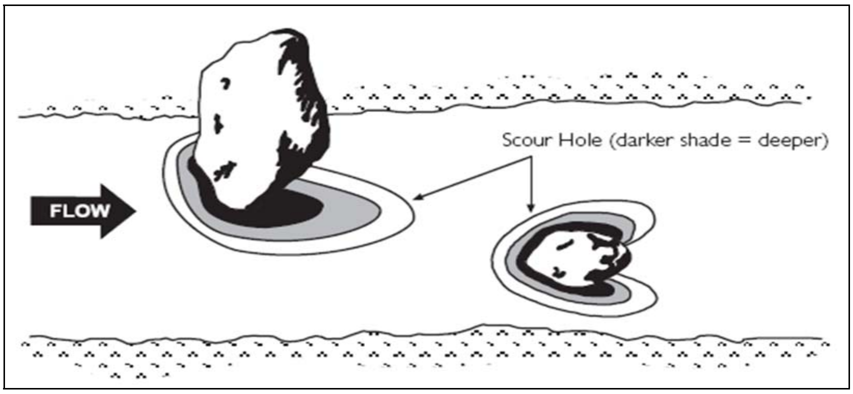


Figure 3.8 Toe scour around a boulder obstruction [7]

Bend Scour – When flow moves along a bend, the thalweg (the deepest part of the streambed) shifts to the outer corner of the channel and pronounced bend scour occurs near the outer edge of the channel. Bend scour results from accelerating and spiraling flow patterns found in the meander bend of a stream. Sharper meander bends (e.g. Figure 3.9) generate deeper scour than gentle bends. The maximum shear stress acting on a bend can be two or more times as high as the shear stress acting on the bed.

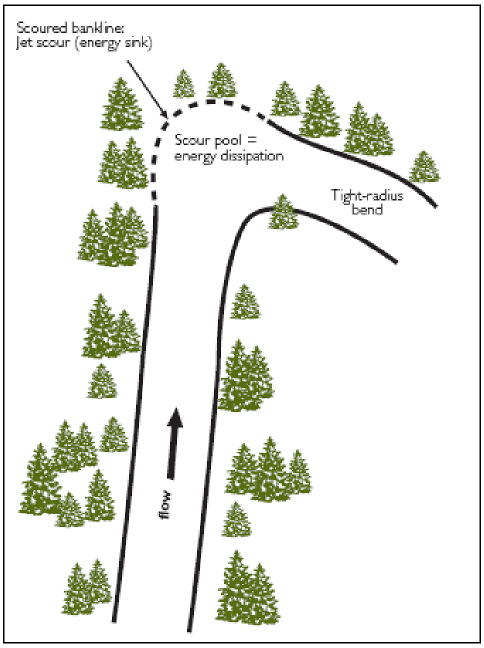


Figure 3.9 Local scour in a sharp river bend [7]

Contraction Scour – Contraction scour occurs when features along the streambank create a narrower channel than would normally form. Often the constricting feature is "harder" than the upstream or downstream bank and can resist the higher erosive forces generated by the constriction. Bedrock outcrops often form natural contractions. The average velocity across the width of the channel increases, resulting in erosion across the entire bed of the channel at the constriction. If the bed material is erodible, the channel bed at the contracted section may be scoured deeper than the channel bed upstream or downstream. Large wood jams or bridge abutments are common examples of features that cause contraction scour. Bank features such as rocky points, overly narrow, man-made channel widths (e.g., with groins), or well-established tree roots on a streambank in smaller channels can cause contraction scour. (Figure 3.10)

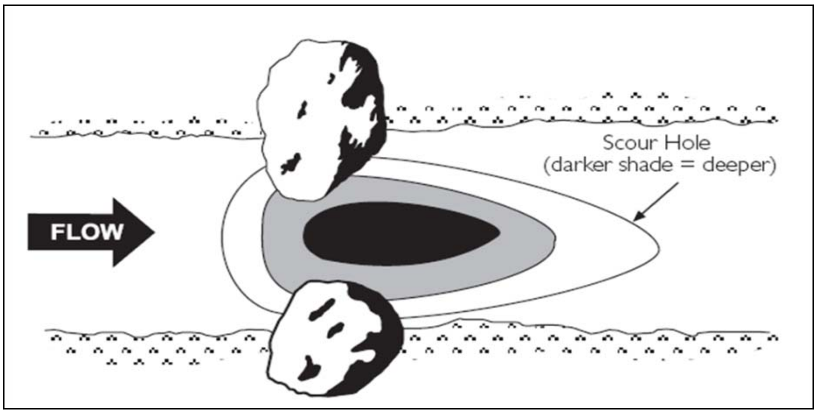


Figure 3.10 Contraction scour [7]

Drop/weir Scour – Drop/weir scour is the result of plunging vertical flow as water pours over a raised ledge or a drop into a pool, creating a secondary flow pattern known as a roller. The roller scours out the bed below the drop. Energy-dissipation pools may result from drop scour. Pools below perched culverts, spillways, or natural drops (such as those found in high gradient mountain streams), are all causes of drop scour (Figure 3.11).

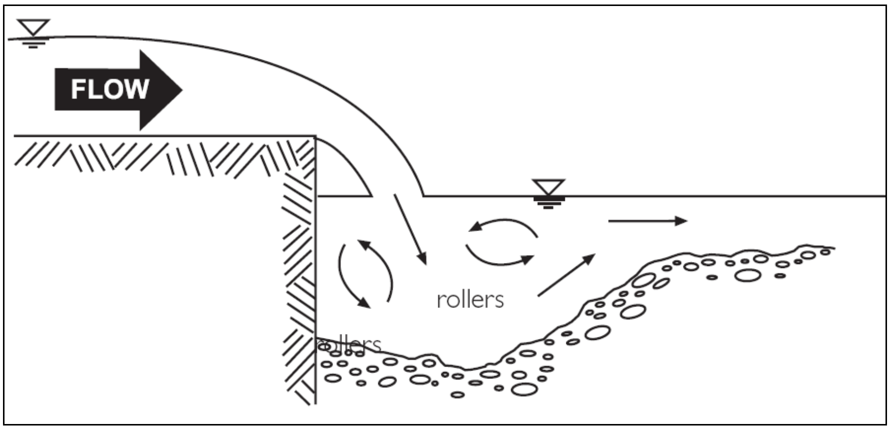


Figure 3.11 Typical drop or weir scour [7]

Deflection Scour – Deflection scour occurs when flow enters the stream in the same manner as flow ejecting from the nozzle of a hose. The entering flow could be submerged, or could impact the water surface from above. The impact force from the flow results in local scour on the streambed and/or bank. Lateral bars, sub-channels in a braided or side channel or tributary, or an abrupt channel bend can also create deflection scour (Figure 3.12 to 3.13).

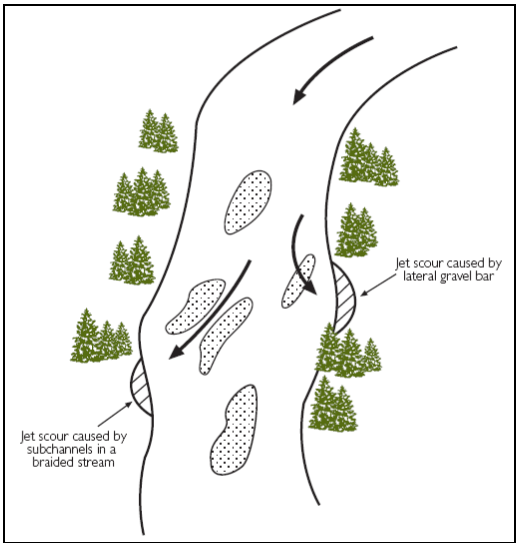


Figure 3.12 Deflection scour caused by lateral gravel bars and braided channels [7]

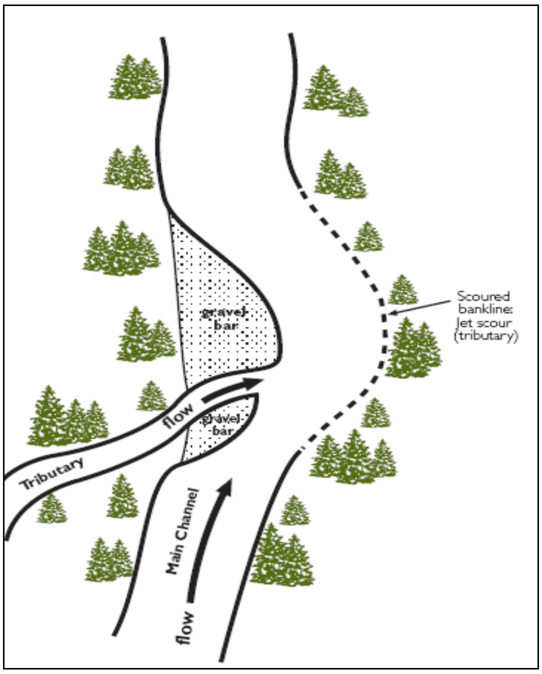


Figure 3.13 Deflection scour at a tributary confluence [7]

All of the scour equations presented are empirical. Empirical equations are based on repetitious experiments or measurements in the field, and therefore, can be biased towards a specific type of stream from which the measurements were made. In general, however, empirical equations are developed with the intention to error on the conservative side if applied correctly.

3.3.3.2 Bridge Scour

A method to organize such an analysis is to use a three level fluvial system approach. This method provides three levels of detail in an analysis: (1) a qualitative determination based on general geomorphic and river mechanics relationships; (2) engineering geomorphic analysis using established qualitative and semi-quantitative relationships and trends to establish the probable behavior of the stream system to various scenarios of future conditions; and (3) detailed quantitative analyses of bed elevation changes using mathematical models such as HEC-6, (U.S. Army Corps of Engineers 1993)[11], BRI-STARS (Molinas 2000)[10], MIKE 11 (DHI) etc. Methods to be used in the three levels of analysis are briefing described in the following sections and in FHWA's HEC-18 (Richardson and Davis 2001)[9].

Scour at bridge crossings is a sediment transport process. Long-term degradation, general scour, and local scour at piers and abutments result from the fact that more sediment is removed from these areas than is transported into them (Richardson and Davis 2001)[9].

Total scour at a bridge crossing is composed of the following components:

(1) Long-Term Aggradation or Degradation

The change in river bed elevation (aggradation or degradation) over long lengths and time due to changes in controls, such as dams, changes in sediment discharge, head cuts, daily tidal flow, and changes in river geomorphology, such as changing from a meandering to a braided stream. These processes may be natural or human induced.

(2) General Scour

The scour that results from the acceleration of the flow due to either a natural or bridge contraction or both (contraction scour). General scour may also result from the location of the bridge on the stream. For example, its location with respect to a stream bend or its location upstream from the confluence with another stream. In this latter case, the elevation of the downstream water surface will affect the backwater on the bridge, hence, the velocity and scour. General scour may occur during the passage of a flood and the stream may fill in on the falling stage. This type of scour involves the removal of material from the bed and banks across all or most of the width of a channel. An illustration of general channel scour is as shown in Figure 3.14a.

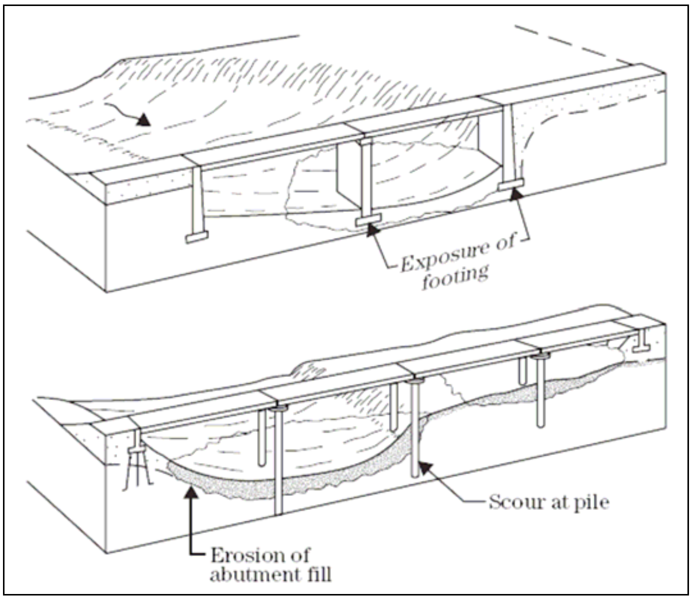


Figure 3.14a General scour of channel [72]

(3) Local Scour

The scour that occurs at a pier or abutment as the result of the pier or abutment obstructing the flow. These obstructions accelerate the flow and create vortices that remove the material around them. Generally, scour depths from local scour are much larger than long-term degradation or general scour, often by a factor of ten. But, if there are major changes in the stream conditions, such as a large dam built upstream or downstream of the bridge or severe straightening of the stream, long-term bed elevation changes can be the larger element in the total scour. Also, scour depths from severe contraction of the flow, (often causing ponding upstream of the bridge) can be larger than local scour. An illustration of local scour at a spur dike and bridge site is as shown in Figure 3.14b.

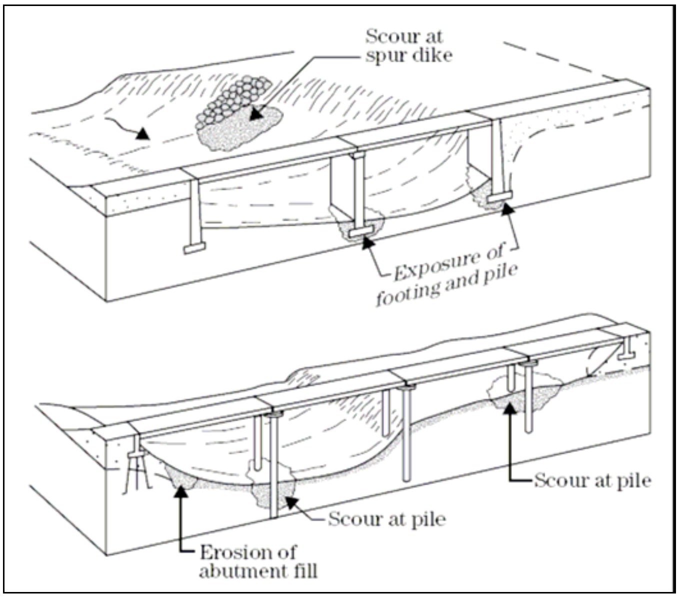


Figure 3.14b Local scour at spur dike and bridge site [72]

(4) Lateral Shifting of the Stream

In addition to the above, lateral shifting of the stream may also erode the approach roadway to the bridge and change the flow angle through the bridge crossing and change both total and local scour.

Long-term Bed Elevation Changes

Long-term bed elevation changes (aggradation or degradation) may be the natural trend of the stream or may be the result of some modification to the stream or watershed condition. In scour analyses, only long-term degradation is considered. Aggradation, if it occurs, is not used to decrease total scour estimate.

The streambed may be aggrading, degrading or not changing (equilibrium) in the bridge crossing reach. When the bed of the stream is neither aggrading or degrading, it is in equilibrium with the sediment discharge supplied to the bridge reach and the elevation of the bed does not change. In this section, we consider long-term trends, not the cutting and filling of the bed of the stream that might occur during a runoff event. A stream may cut and fill during a runoff event and also have a long-term trend of an increase or decrease in bed elevation. The problem for the engineer is to determine what the long-term bed elevation changes will be during the lifetime of the structure. What is the current rate of change in the stream bed elevation? Is the stream bed elevation in equilibrium? Is the streambed degrading? Is it aggrading? Is there a head cut or nickpoint moving upstream? What is the future trend in the stream bed elevation?

Long-term changes are the result of modifications of the state of the stream or watershed and may change with time. Such changes may be the result of natural processes or the result of human activities. The engineer must assess the present state of the stream and watershed and determine future changes in the river system, and from this assessment determine the long-term stream bed elevation. Factors that affect long-term bed elevation changes are: dams and reservoirs (up or downstream of the bridge), changes in watershed land use (urbanization, deforestation, etc.), channelization, cutoff of a meander bend (natural or human induced), changes in the downstream base level (control) of the bridge reach, gravel/sand mining from the stream bed, diversion of water into or out of the stream, natural lowering of the total system, movement of a bend, bridge location in reference to stream planform, and stream movement in relation to the crossing.

Analysis of long-term streambed elevation changes must be made using the principles of river mechanics in the context of a fluvial system analysis. Such analysis of a fluvial system requires the consideration of all influences upon the bridge crossing, i.e., runoff from the watershed to the channel (hydrology), the sediment delivery to the channel (erosion), the sediment transport capacity of the channel (hydraulics) and the response of the channel to these factors (geomorphology and river mechanics). Many of the largest impacts are from human activities, either in the past, the present or the future. The analysis requires a study of the past history of the river and human activities on it; a study of present water and land use and stream control activities; and, finally, contacting all agencies involved with the river to determine future changes in the river.

Clear-water and Live-bed Scour

The two conditions of general and local scour are: (1) clear-water scour; and (2) live-bed scour. Clear-water scour occurs when there is no movement of the bed material in the main channel of the stream upstream of the crossing, or the sediment transport in the upstream reach or floodplain is transported through the bridge opening or local scour holes in suspension. The increase in velocity by contraction of the flow by the bridge or the acceleration of the flow and vortices created by the piers or abutments causes the bed material in the bridge opening or at their base to move.

Live-bed scour occurs when the bed material upstream of the crossing is moving as contact sediment discharge in the contracted bridge opening and/or into the local scour holes.

Typical clear-water scour situations include: (1) coarse bed material streams; (2) flat gradient streams during low flow; (3) local deposits of larger bed materials that are larger than the biggest fraction being transported by the flow (rock riprap is a special case of this situation); (4) armored stream beds where the only locations that tractive forces are adequate to penetrate the armor layer are at piers and/or abutments; (5) vegetated channels where, again, the only locations that the cover is penetrated is at piers and/or abutments; and (6) streams with fine bed material and large velocity or shear stress whereby the bed material in transport washes through a contraction or local scour hole.

Clear-water scour reaches its maximum over a longer period of time than live-bed scour (Figure 3.15). This is because clear-water scour occurs mainly on coarse bed material streams. In fact, clear-water scour may not reach its maximum until after several floods. Also, maximum clear-water scour is about 10 percent greater than the equilibrium live-bed scour. Bridges over coarse bed material streams often have clear-water scour at the lower part of a hydrograph, live-bed scour at the higher discharges, and then clear-water scour on the falling stages.

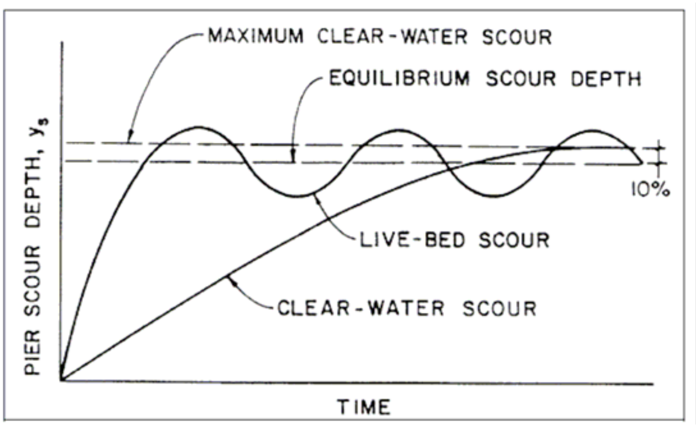


Figure 3.15 Local scour depth at a pier as a function of time [8]

Live-bed scour in sand bed streams with a dune bed configuration fluctuates about an equilibrium scour depth (Figure 3.15). The reason for this is the fluctuating nature of the sediment transport of the bed material in the approaching flow when the bed configuration of the stream is dunes. In this case (dune bed configuration in the channel upstream of the bridge), the maximum depth of scour is about 30 percent larger than the equilibrium scour depth.

The maximum depth of scour is the same as the equilibrium depth of scour for live-bed scour with a plane bed configuration. With antidunes occurring upstream and in the bridge crossing; the maximum depth of scour is from 10 to 20 percent greater than the equilibrium depth of scour. In general, with sand bed streams with dune bed may change to plane bed or antidune during floods.

Contraction Scour

Contraction scour equations are based on the principle of conservation of sediment transport (continuity). In the case of live-bed scour, the fully developed scour in the bridge cross section reaches equilibrium when sediment transported into the contracted section equals sediment transported out. As scour develops, the shear stress in the contracted section decreases as a result of a larger flow area and decreasing average velocity. For live-bed scour, maximum scour occurs when the shear stress reaches the point that bed-material transported in equals the bed-material transported out and the conditions for sediment continuity are in balance. For clear-water scour, the bed-material transported into the contracted section is essentially zero and maximum scour occurs when the shear stress or velocity reaches the critical shear stress or critical velocity of the bed material in the section.

Clear-water contraction scour

Clear-water scour occurs in a long contraction when: (1) there is no bed material transport from the upstream reach into the downstream reach; or (2) the material being transported in the upstream reach is transported through the downstream reach mostly in suspension and at less than capacity of the flow. With clear-water contraction scour, the area of the contracted section increases until, in the limit, the velocity V of the flow or the shear stress τ_o on the bed is equal to the critical velocity V_c or the critical shear stress τ_c of a certain particle size d_s in the bed material. Normally, the width W of the contracted section is constrained and the depth y increases until the limiting conditions are reached.

Live-bed scour

Live-bed scour depths may be limited if there are appreciable amounts of large-sized particles in the bed material. It is appropriate, then, to use the clear-water scour equation in addition to the live-bed scour equation and use the smaller of the two depths. Also, it is appropriate to use the clear-water scour equation if the transport of bed material from upstream of the contraction is small in quantity or composed of fine material that washes through the contraction in suspension.

There are different conditions (cases) of contraction scour at bridge sites depending on the type of contraction, and whether there is overbank flow or relief bridges. Regardless of the case, contraction scour can be evaluated using two basic equations: (1) live-bed scour; and (2) clear-water scour. For any case or condition, it is only necessary to determine if the flow in the main channel or overbank area upstream of the bridge is transporting bed material (live-bed) or is not (clear-water), and then apply the appropriate equation with the variables defined according to the location of contraction scour (channel or overbank).

Critical Velocity

To determine if the flow upstream of the bridge is transporting bed material, calculate the critical velocity for beginning of motion V_c of the d_{50} size of the bed material and compare it with the mean velocity V of the flow in the main channel or overbank area upstream of the bridge opening (Refer to Appendix A for equation for calculation of grain size d_{50}). If the critical velocity of the bed material is larger than the mean velocity ($V_c > V$), then clear-water contraction scour will exist. If the critical velocity is less than the mean velocity ($V_c < V$), then live-bed contraction scour will exist. To calculate the critical velocity, the following equation may be used:

$$V_c = K_u\, y^{1/6}\, d^{1/3} \tag{3.12}$$

where:

V_c = critical velocity above which bed material of size D and smaller will be transported, m/s
y = depth of flow, m
d = particle size for V_c, m
d_{50} = particle size in a mixture of which 50 percent are smaller, m
K_u = 6.19

Live-Bed Contraction Scour

A modified version of Laursen's 1960 equation for live-bed scour at a long contraction is recommended to predict the depth of scour in a contracted section. The modification is to eliminate the ratio of Manning's n:

$$\frac{y_2}{y_1} = \left[\frac{Q_2}{Q_1}\right]^{6/7}\left[\frac{W_1}{W_2}\right]^{k1} \tag{3.13}$$

$$y_s = y_2 - y_o = \text{average scour depth} \tag{3.14}$$

where:

y_1 = average depth in the upstream main channel, m
y_2 = average depth in the contracted section, m
y_o = existing depth in the contracted section before scour, m (see Note below)
Q_1 = flow in the upstream channel transporting sediment, m^3/s
Q_2 = flow in the contracted channel, m^3/s
W_1 = bottom width of the upstream main channel, m
W_2 = bottom width of the main channel in the contracted section less pier width(s), m
k_1 = exponent determined below

V^*/ω	k1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

$V^* = (\tau_o/\rho)^{1/2} = (g y_1 S_1)^{1/2}$, shear velocity in the upstream section, m/s
ω = fall velocity of bed material based on the d_{50}, m/s (Figure 3.16)
For fall velocity in S.I. units (m/s) divide fall velocity in fps by 3.28
g = acceleration of gravity (9.81 m/s^2)
S_1 = slope of energy grade line of main channel, m/m
τ_o = shear stress on the bed, Pa (N/m^2)
ρ = density of water (1000 kg/m^3)

Note: In sand channel streams where the contraction scour hole is filled in on the falling stage, the y_0 depth may be approximated by y_1. Sketches or surveys through the bridge can help in determining the existing bed elevation.

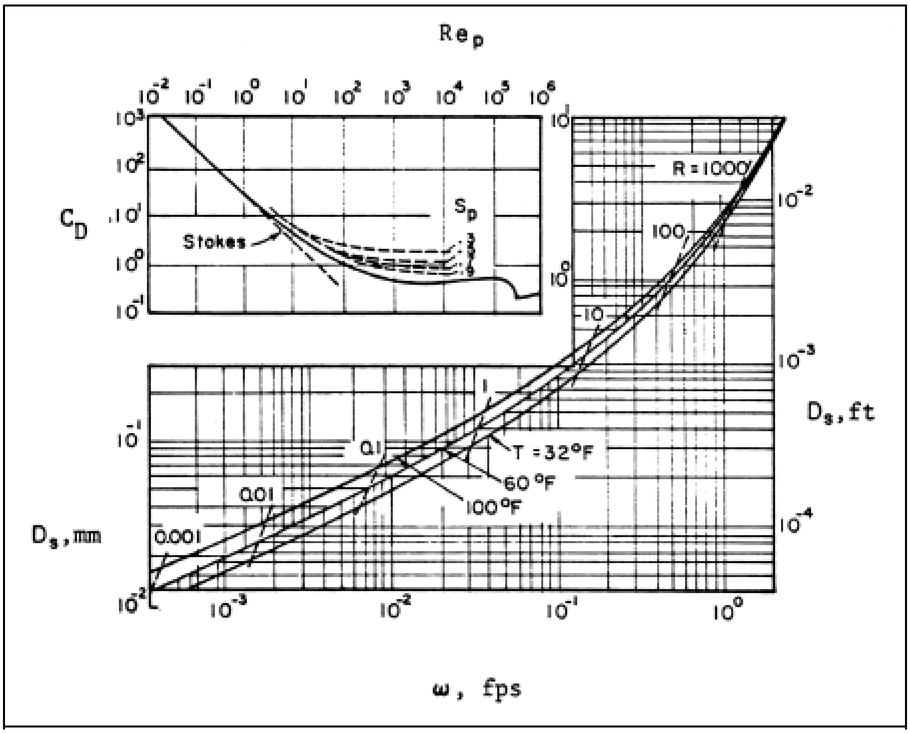


Figure 3.16 Drag coefficient C_D vs particle Reynolds number Re_p for spheres and natural sediments with shape factors S_p and sediment diameter Ds vs fall velocity ω (fps) and temperature T [22]

Clear-water Contraction Scour

The recommended clear-water contraction scour equation is based on a development suggested by Laursen (1963). The equation is:

$$y_2 = \left[\frac{k_u Q^2}{D_m^{2/3} Q^2}\right]^{3/7} \tag{3.15}$$

$$y_s = y_2 - y_o = (\text{average scour depth, m}) \tag{3.16}$$

where:

y_2 = average depth in the contracted section after contraction scour, m
Q = discharge through the bridge or on the set-back overbank area at the bridge associated with the width W, m^3/s
D_m = diameter of the smallest non-transportable particle in the bed material (1.25 d_{50}) in the contracted section, m
d_{50} = median diameter of bed material, m
W = bottom width of the contracted section less pier widths, m
y_o = existing depth in the contracted section before scour, m
K_u = 0.025

Local Scour at Piers

Local scour at piers is a function of bed material size, flow characteristics, fluid properties and the geometry of the pier. The subject has been studied extensively in the laboratory since Laursen in the late 1940s and 1950s. As a result, there are many equations. In general, the equations are for live-bed scour in cohesionless sand bed streams, and they give widely varying results.

In this section, an equation for determining the ultimate local pier scour and another equation to determine the top width of a local pier scour hole will be given. These equations (Richardson and Davis 2001)[9] are as follows:

- FHWA's HEC-18 equation
- Top width equation

FHWA HEC-18 Equation

The FHWA HEC-18 equation (Richardson and Davis 2001)[9] to predict local scour depths at a pier, based on the Colorado State University (CSU) equation, is recommended for both live-bed and clear-water scour.

The equation predicts maximum pier scour depths. The equation is:

$$\frac{y_2}{y_1} = 2.0K_1K_2K_3K_4K_5\left[\frac{a}{y_1}\right]^{0.65} Fr_1^{043} \qquad (3.17)$$

where:
y_s = scour depth, m
y_1 = flow depth just upstream of the pier, m
K_1 = correction for pier shape from Table 3.4 and Figure 3.17
K_2 = correction for flow angle of attack of flow from Table 3.5 and Equation 3.18
K_3 = correction factor for bed condition from Table 3.6
K_4 = correction factor for armoring by bed material size from Equation 3.19
K_5 = correction factor for pier width from Equation 3.23 or 3.24
L = length of pier, m
a = pier width, m
Fr_1= Froude Number directly upstream of the pier = $V_1/(gy_1)^{1/2}$
V_1 = mean velocity of flow directly upstream of the pier, m/s
g = acceleration of gravity (9.81 m/s^2)

For round nose piers aligned with the flow the depth of scour has the following limits:

$y_s \leq 2.4$ times the pier width (a) for $Fr \leq 0.8$
$y_s \leq 3.0$ times the pier width (a) for $Fr > 0.8$

The correction factor for angle of attack of the flow K_2 given in Table 3.5 can be calculated using the following equation:

$$K_2 = \left(\cos\theta + \frac{L}{a}\sin\theta\right)^{0.65} \qquad (3.18)$$

(If L/a is larger than 12, use L/a = 12 as a maximum in Equation 3.18 and Table 3.5)

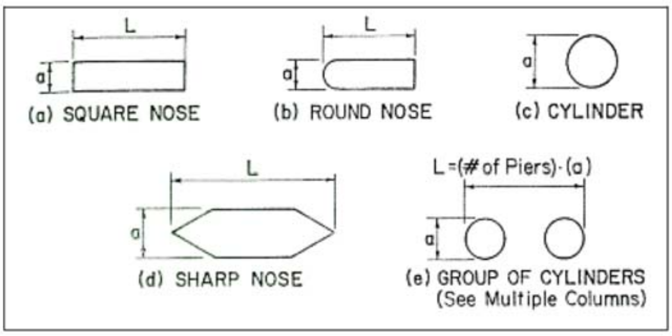


Figure 3.17 Common pier shapes [8]

Table 3.4 Correction factor, K_1 for Pier Nose Shape [8]

Shape of Pier Nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Group of cylinders	1.0
(e) Sharp nose	0.9

Table 3.5 Correction Factor, K2, for Angle of Attack, θ, of the Flow [8]

Angle	L/a=4	L/a=8	L/a=12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0

Angle θ = angle between the flow direction and the pier alignment
L = length of pier, m

Table 3.6 Increase in Equilibrium Pier Scour Depths, K3, for Bed Condition [8]

Bed Condition	Dune Height H in m	K_3
Clear-Water Scour	N/A	1.1
Plane bed and Antidune flow	N/A	1.1
Small Dunes	3> H > 0.6	1.1
Medium Dunes	9> H > 3	1.1 to 1.2
Large Dunes	H > 9	1.3

The correction factor K_1 for pier nose shape should be determined using Table 3.4 for angles of attack up to 5 degrees. For greater angles, K_2 dominates and K_1 should be considered as 1.0. If L/a is larger than 12, use the values for L/a = 12 as a maximum in Table 3.5 and Equation 3.18.

The values of the correction factor K_2 should be applied only when the field conditions are such that the entire length of the pier is subjected to the angle of attack of the flow. Use of this factor will result in a significant over-prediction of scour if (1) a portion of the pier is shielded from the direct impingement of the flow by an abutment or another pier; or (2) an abutment or another pier redirects the flow in a direction parallel to the pier. For such cases, judgment must be exercised to reduce the value of the K_2 factor by selecting the effective length of the pier actually subjected to the angle of attack of the flow.

The correction factor K_3 results from the fact that for plane-bed conditions, which is typical of most bridge sites for the flood frequencies employed in scour design, the maximum scour may be 10 percent greater than computed with CSU equation (Table 3.6). In the unusual situation where a dune bed configuration, with large dunes, exists at a site during flood flow, the maximum pier scour may be 30 percent greater than the predicted equation value. This may occur on very large rivers. For smaller streams that have a dune bed configuration at flood flow, the dunes will be smaller and the maximum scour may be only 10 to 20 percent larger.

The correction factor K_4 decreases scour depths for armoring of the scour hole for bed materials that have a D_{50} equal to or larger than 2.0 mm and D_{95} equal to or larger than 20 mm. Mueller and Jones (1999) [17] developed a K_4 correction coefficient as follows (Equation 3.19):

if D_{50} > = 2 mm and D_{95} > = 20 mm then

$$K_4 = 0.4(V_R)^{0.15} \qquad (3.19)$$

where:

$$V_R = \frac{V_1 - V_{icD_{50}}}{V_{cD_{50}} - V_{icD_{95}}} > 0 \tag{3.20}$$

and

V_{icDx} = Approach velocity corresponding to critical velocity (m/s) for incipient scour in the accelerated flow region at the pier for the grain size Dx (m)

$$V_{icD_x} = 0.645\left(\frac{D_x}{a}\right)^{0.053} V_{cD_x} \tag{3.21}$$

V_{cDx} = Critical velocity (m/s) for incipient motion for the grain size Dx (m)

$$V_{cD_x} = K_u y_1^{1/6} D_x^{1/3} \tag{3.22}$$

y_1 = depth of flow just upstream of the pier, excluding local scour, m
V_1 = velocity of the approach flow just upstream of the pier, m/s
D_x = grain size for which x percent of the bed material is finer, m
K_u = 11.25

Although this K_4 provides a good fit with the field data, the velocity ratio terms are so formed that if D_{50} is held constant and D_{95} increases, the value of K_4 increases rather than decreases. For field data an increase in D_{95} was always accompanied with an increase in D_{50}.

The minimum value of K_4 is 0.4 and V_R must be greater than 0. The bed material size must have D_{50} > 2.0 mm and D_{95} > 20.0 mm.

Flume studies on scour depths at wide piers in shallow flows and field observations of scour depths at wide piers in shallow flows indicate that existing equations, including the CSU equation, overestimate scour depths. Johnson and Torrico (1994)[16] suggest the following equations for a K factor to be used to correct Equation 3.17 for wide piers in shallow flow.

The correction factor to be applied when the ratio of depth of flow (y) to pier width (a) is less than 0.8 (y/a < 0.8); the ratio of pier width (a) to the median diameter of the bed material (D_{50}) is greater than 50 (a/D_{50} > 50); and the Froude Number of the flow is subcritical.

$$K_5 = 2.58\left(\frac{y}{a}\right)^{0.34} F^{0.65} \quad \text{for } V/V_c<1 \tag{3.23}$$

$$K_5 = 1.0\left(\frac{y}{a}\right)^{0.13} F^{0.25} \quad \text{for } V/V_c>1 \tag{3.24}$$

Engineering judgment should be used in applying K_5 because it is based on limited data from flume experiments. Engineering judgment should take into consideration the volume of traffic, the importance of the bridge, cost of a failure (potential loss of lives and dollars) and the change in cost that would occur if the K_5 factor is used.

Topwidth of Scour Holes

The topwidth of a scour hole in cohesionless bed material from one side of a pier or footing can be estimated from the following equation (Richardson and Abed, 1999)[12].

$$W = y_s(K + \cot \phi) \quad (3.25)$$

where:
W = topwidth of the scour hole from each side of the pier or footing, m
y_s = scour depth, m
K = bottom width of the scour hole as a fraction of scour depth
ϕ = angle of repose of the bed material ranging from about 30° to 44°

The angle of repose of cohesiveness material in air ranges from about 30° to 44°. Therefore, if the bottom width of the scour hole is equal to the depth of scour y_s (K = 1), the topwidth in cohesionless sand would vary from 2.07 y_s to 2.80 y_s. At the other extreme, if K = 0, the topwidth would vary from 1.07 y_s to 1.8 y_s. Thus, the topwidth could range from 1.0 y_s to 2.8 y_s and will depend on the bottom width of the scour hole and composition of the bed material.

In general, the deeper the scour hole, the smaller the bottom width. In water, the angle of repose of cohesionless material is less than the values given for air; therefore, a topwidth of 2.0y_s is suggested for practical applications (Figure 3.18).

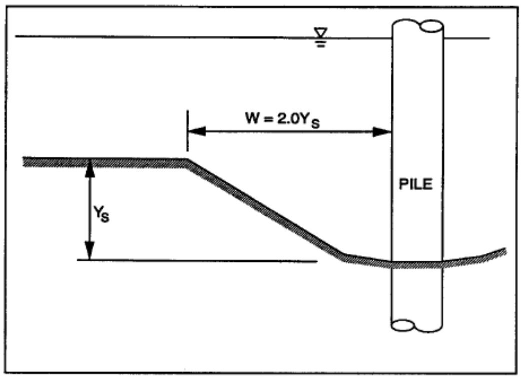


Figure 3.18 Topwidth of Scour Hole [9]

Local Scour at Abutments

The two causes of scour when the flow is obstructed by the abutment and approach highway embankment are: (1) a horizontal vortex starting at the upstream end of the abutment and running along the toe of the abutment; and (2) a vertical wake vortex at the downstream end of the abutment (Figure 3.19).

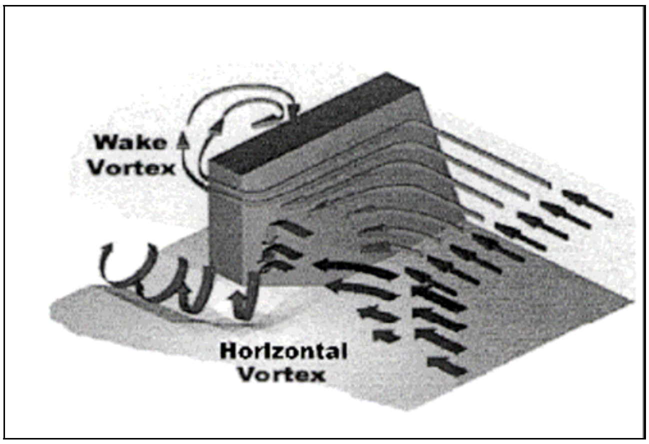


Figure 3.19 Schematic representation of abutment scour [8]

The horizontal vortex at the toe of the abutment is very similar to the horseshoe vortex that forms at piers, and the vertical vortex that forms at the downstream end is similar to the wake vortex that forms downstream of a pier, or that forms downstream of any flow separation.

The wake vortex at the downstream end of the abutment also causes abutment failures. Sometimes the abutment does not fail but only the approach embankment is eroded. Research and the development of methods to determine the erosion from the wake vortex has not been conducted. Methods to protect abutments and the embankments against wake vortex erosion are given in HEC-23 (Lagasse et al. 2001b)[13].

Abutments can be set back from the natural stream bank, placed at the bankline or, in some cases, actually set into the channel itself. Common designs include stub abutments placed on spill through slopes, and vertical wall abutments, with or without wingwalls. Scour at abutments can be live-bed or clear-water scour. The bridge and approach road can cross the stream and floodplain at a skew angle and this will have an effect on flow conditions at the abutment. Finally, there can be varying amounts of overbank flow intercepted by the approaches to the bridge and returned to the stream at the abutment. More severe abutment scour will occur when the majority of overbank flow returns to the bridge opening directly upstream of the bridge crossing. Less severe abutment scour will occur when overbank flows gradually return to the main channel upstream of the bridge crossing.

The three general shapes for abutments are: (1) spill-through abutments; (2) vertical walls without wing walls; and (3) vertical-wall abutments with wing walls (Figure 3.20). These shapes can all have varying angles to the flow. As shown in Table 3.7, depth of scour is approximately double for vertical-wall abutments as compared with spill-through abutments for very short sections of the abutment and approach road. As the length of the abutment and approach road in the floodplain increase, the effect of the spill-through slope is decreased. Scour for vertical wall abutments with wingwalls on short abutment sections is reduced to 82 percent of the scour of vertical wall abutments without wingwalls. As the length of the abutment and approach road in the floodplain increase, the effect of the wingwall is decreased. For long approach road sections in the floodplain, this coefficient will approach a value of 1.0.

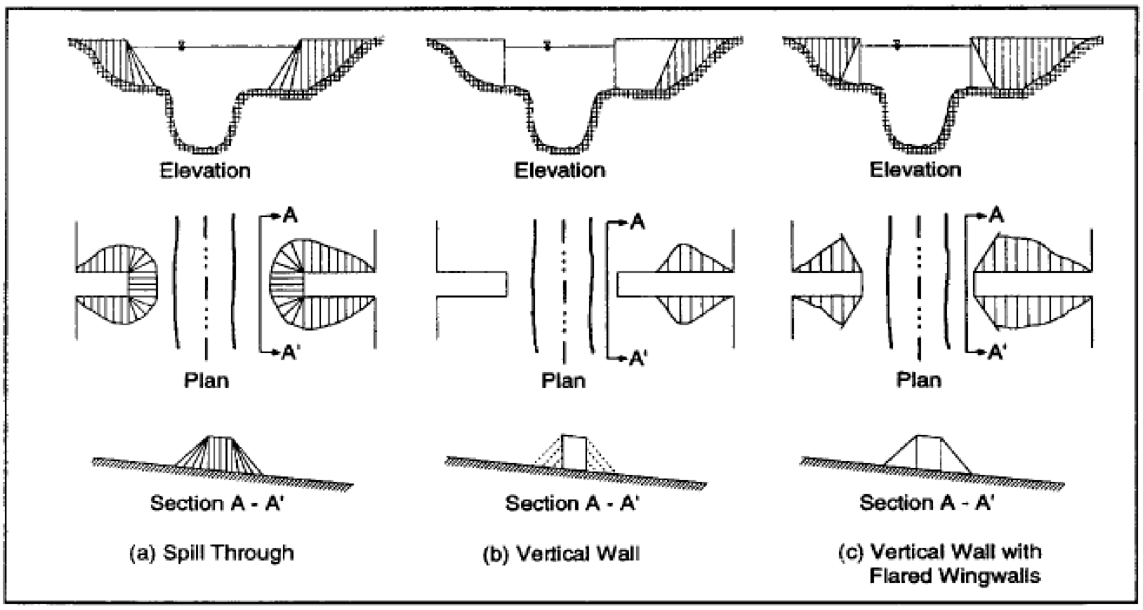


Figure 3.20 Abutment shape [8]

The skew angle for an abutment (embankment) is depicted in Figure 3.21. For an abutment angled downstream, the scour depth is decreased whereas the scour depth is increased for an abutment angled upstream. An equation for adjusting abutment scour depth for skewed embankment is given below (Froehlich's, 1989)[15].

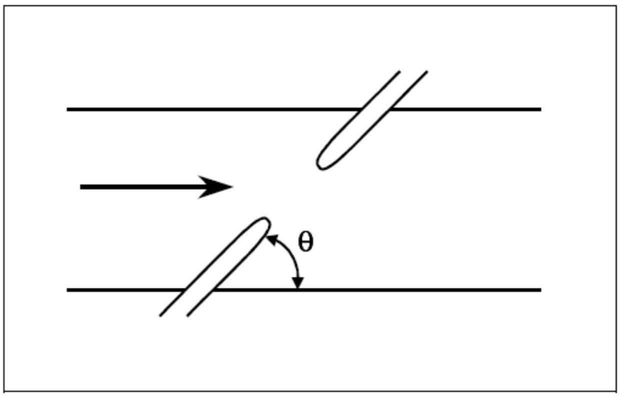


Figure 3.21 Orientation of embankment angle θ to the flow [8]

Froehlich's Live-Bed Scour Equation

To determine the potential depth of scour at existing bridges and to aid in the design of foundations and placement of rock riprap or guide banks at new bridges, [15] live-bed scour equation can be used and as shown below:

$$\frac{y_s}{y_a} = 2.27 K_1 K_2 \left[\frac{L'}{y_a}\right]^{0.43} Fr^{0.61} + 1 \qquad (3.26)$$

where:

K_1 = Coefficient for abutment shape (Table 3.7)
K_2 = coefficient for angle of embankment to flow = $(\theta/90)^{0.13}$ (refer to Figure 3.20 for definition of θ)
$\theta < 90°$ if embankment points downstream
$\theta > 90°$ if embankment points upstream
L´ = length of abutment projected normal to flow, m
A_e = flow area of the approach cross section obstructed by the embankment, m^2,
Fr = Froude Number of approach flow upstream of the abutment = $V_e/(gy_a)^{1/2}$ $V_e = Q_e/A_e$, m/s,
Q_e = flow obstructed by the abutment and approach embankment, m^3/s
y_a = average depth of flow on the floodplain, m
y_s = scour depth, m

Note: That as L´ tends to 0, y_s also tends to 0. In a regression equation, 50 percent of the data are above or below the regression line. The 1 was added to the equation so as to encompass 98 percent of the data.

Table 3.7 Abutment Shape Coefficients for Short Abutment Section [8]

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

3.4 RIVER ENGINEERING

3.4.1 Stream Stabilization Techniques

Techniques to control the riverbed, stabilize channel alignment, protect stream banks and rebuild habitat are outlined in this section. Practical techniques that integrate channel stabilization and ecological restoration are provided. Rivers can be stabilized and habitat restored through techniques such as rebuilding meanders and pool-riffle sequences and managing large woody debris.

Engineering techniques are sometimes required to assist river rehabilitation by protecting waterways from erosion so that vegetation can successfully establish (Water & River Commission, 2001)[18].

3.4.1.1 Alignment Stabilization Guidelines and Techniques

The construction of pool-riffle sequences may need to be combined with other stabilization and channel realignment techniques. There are a number of engineering options available to stabilize banks that are too steep for revegetation. However, the alignment and slope of the channel should first be stabilized. Channel realignment, or "river training", techniques involve installing structures to realign the river by selectively creating sediment depositional zones. Structures are installed to increase the resistance to flow, reduce the flow velocity and trap sediment. The sediment is usually stabilized through vegetation establishment to provide long-term bank protection. Groynes, vane dykes and retards can be used to realign waterways. The structures can be applied to control channel width and form, protect eroding banks and control shifting meanders. Expert design and construction is required as river-training structures can have a major impact on the river reach. Earthworks can be carried out to change the alignment and form of a river channel. Techniques to improve stability include the selective removal or redistribution of sediment in a river channel or introducing meander patterns (Water & River Commission, 2001)[18].

Rebuilding Meanders

Analysis of river behavior has found that stable channels generally follow a similar meander pattern. Where channels have been straightened, such as in a drainage channel, over time the flow can often be observed to rebuild the meander pattern. Sediment is deposited in the low velocity zone in the inner meander and eroded from the opposite bank as flow accelerates around the outer bend. Many rivers also follow a naturally undulating profile as shown in Figure 3.22. This is formed by high flows scouring pools and causing the buildup of coarse bed material forming a riffle. A riffle is like a small 'rapid' and forms an obstruction during low flow conditions. The stream forms a shallow pool upstream of the riffle and a scour hole or splash pool at the downstream base as flows accelerate over the crest and down the slope of the riffle (Water & River Commission, 2001)[18].

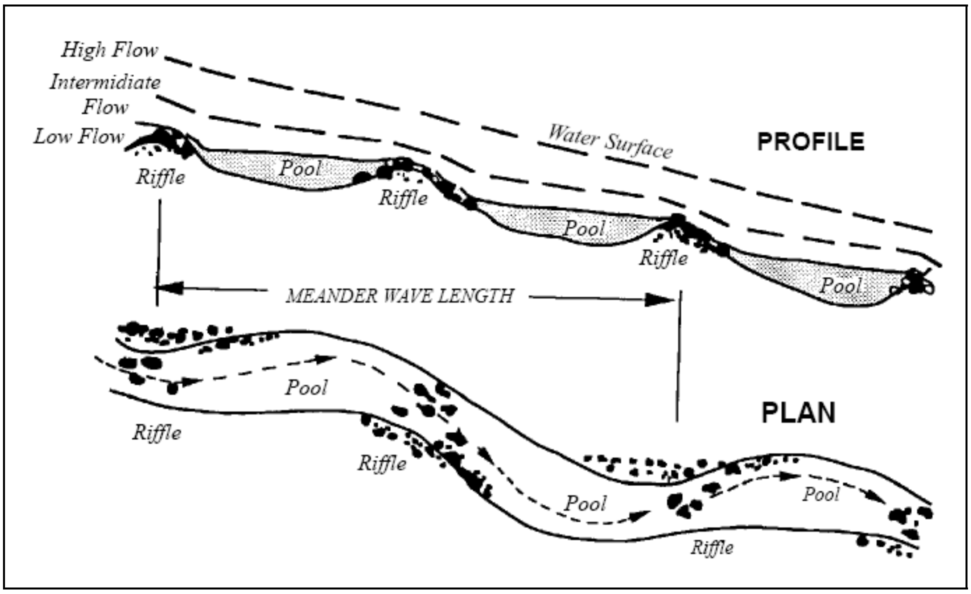


Figure 3.22 Schematic channel pattern and profile [18]

The key to defining a stable stream form is to determine a suitable channel width for the dominant discharge called the "bankfull" discharge. The bankfull width is the width of the channel at water level during an average 1.5 to 2.0 year peak flow event. The bankfull discharge is the dominant channel forming discharge. Channel alignment is related to the bankfull width. Several formulas have been developed to characterise the meander shape. The pattern of river behaviour observed by Leopold, Wolman and Miller (1962) is summarized below and shown in Figure 3.23.

- A full meander wavelength (the distance between two similar points along the channel between which the waveform is complete) is found to occur between 7 and 15 times the bankfull width.
- The average distance between the ends of riffles is half the meander wavelength.
- Generally the river forms a series of regular sinusoidal curves with an average radius range of 2.3 to 2.7 times the bankfull width.

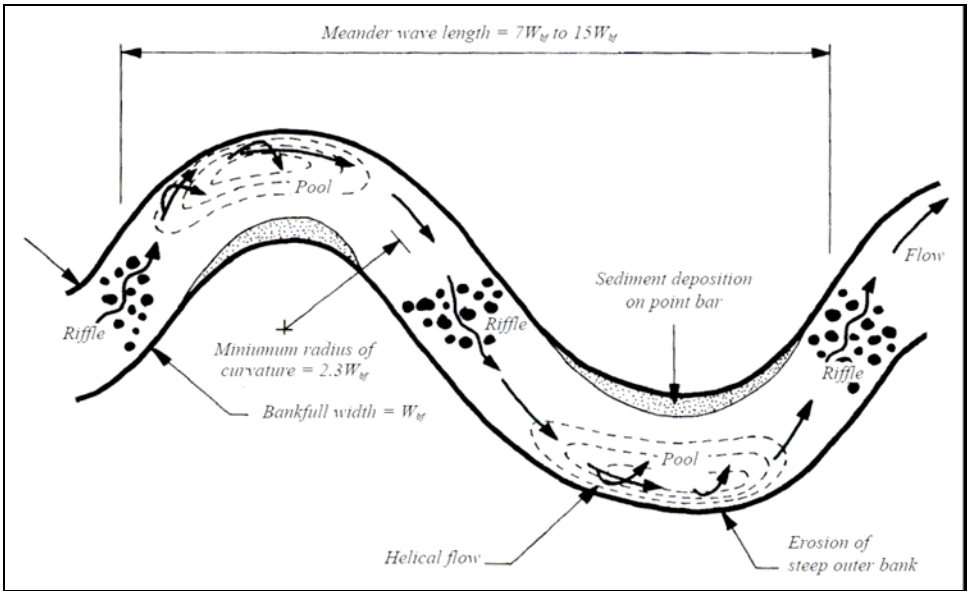


Figure 3.23 Schematic meandering channel pattern [18]

These calculations can be used as a guide to rebuilding meanders and selecting sites to install bed control structures on artificially designed channels or degraded rivers. This analysis can also be used in rehabilitation planning to prioritise works that address problem areas.

Channel stability on straight streams can be restored by rebuilding the meanders as shown in Figure 3.24. The proportions of channel dimensions outlined above can be used as a guide to excavation of a stable channel alignment. A survey will be required to assess the reach and determine a stable slope and channel geometry. The channel alignment should be determined on the basis of bankfull width and then pegged out at the site. The channel will be exposed to erosion following the earthworks, especially in steep or rapidly flowing waterways. Additional stabilization works will be required to control the bed and banks. The banks of the channel should be battered to a maximum slope of 1:4. Brushing or matting can be installed to stabilize the banks until vegetation establishes. Riffle structures could be installed at the site to stabilize the bed level and enhance the stream habitat. Riffles should be constructed at the cross-over point in the middle of a meander. Rebuilding channel meanders can be used to create a more aesthetic landscape, with higher environmental value. However, this technique may not be feasible where space for the stream and floodway are limited, particularly in urban areas.

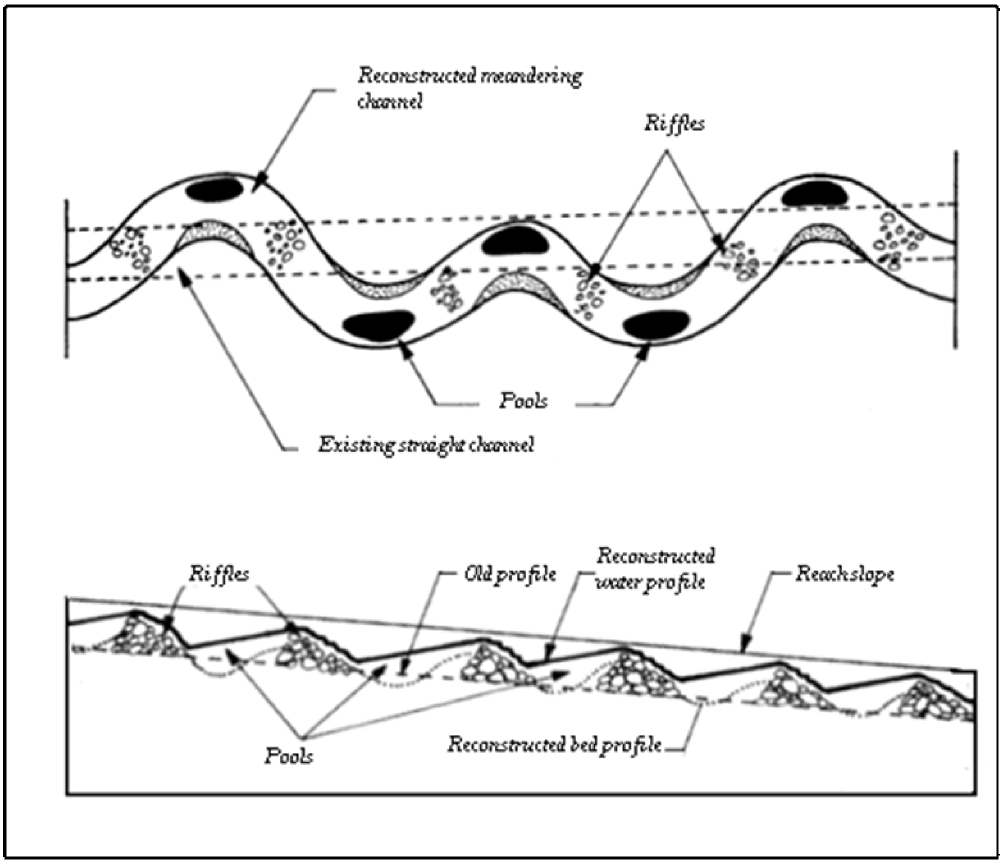


Figure 3.24 Rebuilding meanders [18]

Sediment Management

Channel realignment works may include excavating sediment deposited on the inside of bends. Point bars can build up on the inner meander and restrict the channel width as shown in 3.25. The flow is forced against the outer bank and can cause erosion. Vegetation that becomes established on point bars may need to be cleared so that the river can erode the bar. If the flow does not have enough power to move the sediment, then it may need to be excavated to convey the flow in a smooth alignment. The bankfull width should be determined and sediment removed to re-establish the required channel width.

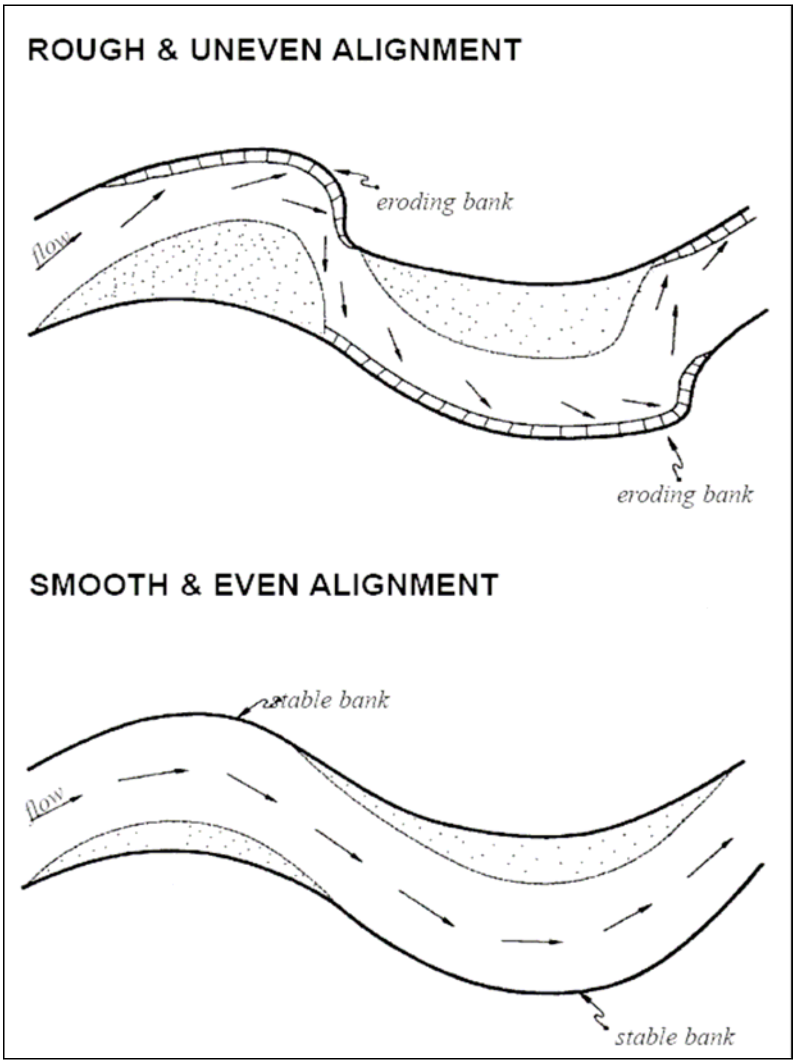


Figure 3.25 Channel point bars causing erosion [18]

Determining an appropriate flow capacity for the channel is essential in designing stabilization works. Channel erosion resulting from increased flow conveyance may require the capacity (usually cross-sectional area) of the channel to be increased or techniques implemented to improve water retention in the upper catchment. Strategies to increase channel capacity can be used to reduce channel and floodway erosion, control meander alignment and manage sedimentation, waterlogging and flooding. However these techniques can have major impacts on a waterway due to possible changes to the slope of the channel, increase in the power of flows and mobilization of sediment. The increased amount of flow being conveyed by the channel may cause further erosion of the banks or bed. Increasing the capacity of the channel can also increase the risk of flooding or sedimentation downstream. The preferred management strategy is to relocate sediment within the channel. The point bar sediment can be pushed against the outer bank to provide additional protection and create areas for planting. The sediment will need to be stabilized using a geotextile. Earthworks may be required where the channel capacity needs to be increased to accommodate increased flows.

Techniques employed in drain management to increase channel capacity include excavating to deepen and/or widen the channel, raising embankments to reduce overtopping of the channel and straightening the channel alignment to increase flow velocity. An alternative technique to cutting a new channel is to create a floodway channel to relieve pressure on the main channel only during high flows. The entry level of the floodway channel will be higher than the level of the main channel bed. The floodway channel will need to be stabilized and entry and exit points will need to be protected, for example by rock paving (riprapping) the banks. The floodway should be maintained with almost complete groundcover to prevent erosion.

Re-orientating Large Woody Debris

Trees falling across the channel can cause debris and leaf litter to accumulate and can dam the waterway. This can exacerbate flooding or cause channel avulsions. Woody debris angled across the flow path can direct flow towards the banks and cause erosion. Obstructions also act to restrict the channel, causing accelerated flow that can have sufficient power to erode the bank.
Selective removal or relocation of logs and other woody debris obstructing the channel may be required to increase flow capacity. Heavy material may need to be removed by winch or excavator. Rather than removing material from the channel, the debris can be relocated against the bank to provide habitat and erosion protection.

Channel realignment may require the installation or repositioning of instream logs and debris. Woody debris should not be removed from waterways unless it represents a significant risk to flooding or is contributing to erosion. The preferred management approach is to modify or relocate and reorientate, rather than remove large woody debris from river channels. This approach is also often cheaper than full-scale removal of woody debris.

Large woody debris can be installed to stabilize channel alignment by directing flows away from the toe of the riverbank. Stream flow should be smoothly directed around the meander and to the centre of the channel. The logs should typically be installed against the outer bank, pointing downstream at an angle of approximately 30°, as shown in Figure 3.26. The butt of the log should be buried approximately one metre into the bank and the logs pegged or anchored into position. The end of the log can be sharpened to reduce disturbance to the bank when being installed. When installing or reorientating woody debris, it should not block more than 10% of the cross-sectional area of the channel in order to minimise the impact on water levels. Alternatively, more than 10% of the cross-sectional area can be blocked to increase wetland habitat across the floodplain, where this is a desirable outcome. Woody debris spaced further apart will affect water levels more than pieces that are closely aligned (about 2 to 4 m apart). Branches that protrude above the water level and trap large amounts of debris moving downstream, should be trimmed. However, remember that protruding timber can help to oxygenate the water column. Also, timber projecting into the flow will increase habitat for microbial life and invertebrate fauna.

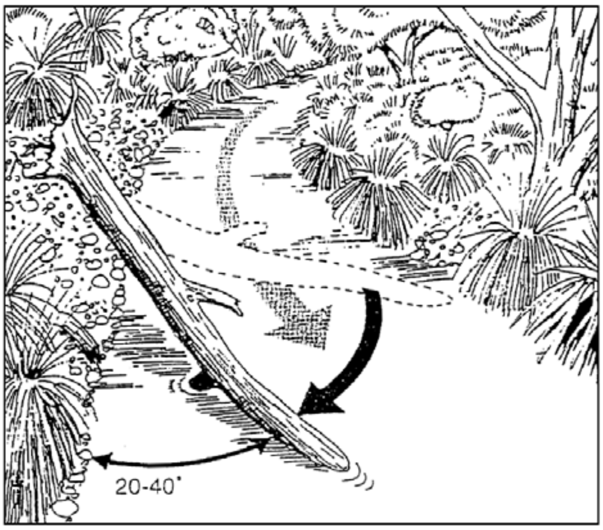


Figure 3.26 Large woody debris bank protection [18]

Nearby undisturbed river reaches of similar size can be used as a reference to determine the amount and type of large woody debris that should naturally be present in the waterway. The original quantity of woody debris does not need to be reinstated to restore habitat. Using the results of channel surveys, woody debris can be strategically placed to create pools and enhance stream habitat.

Wood from tree species that are native to the area should be used. Logs of different sizes and shape and with rough surfaces and hollows should be used in order to increase habitat diversity. Wood that has been treated with chemicals that may be harmful to the environment should not be installed, for example, timber treated for white ants.

Flow Retards and Groynes

Flow retards and groynes (also called stream barbs if submerged) can be installed in waterways to stabilize channel alignment and meanders, protect the toe of an eroding bank and control channel width and form. Retards and groynes are flow obstructions protruding from the bank, angled downstream into the channel of the waterway. Groynes are usually timber fences or concrete blocks or rock structures. Retards are generally lower and longer than groyne structures, however they work in a similar way. Retards only extend up to one metre above bed level, whereas groynes are usually as high as the top of the bank. A series of groynes or retards are constructed along an eroding bank to direct flow away from the bank and to the centre of the channel (Figure 3.27a). The alignment of the waterway can be controlled by the placement of the structures to reduce flow velocity near the bank. Sediment deposits at the base of the eroding bank and can be revegetated. An effectively silted up series of groynes at a river bend is shown in Figure 3.27b and 3.27c.

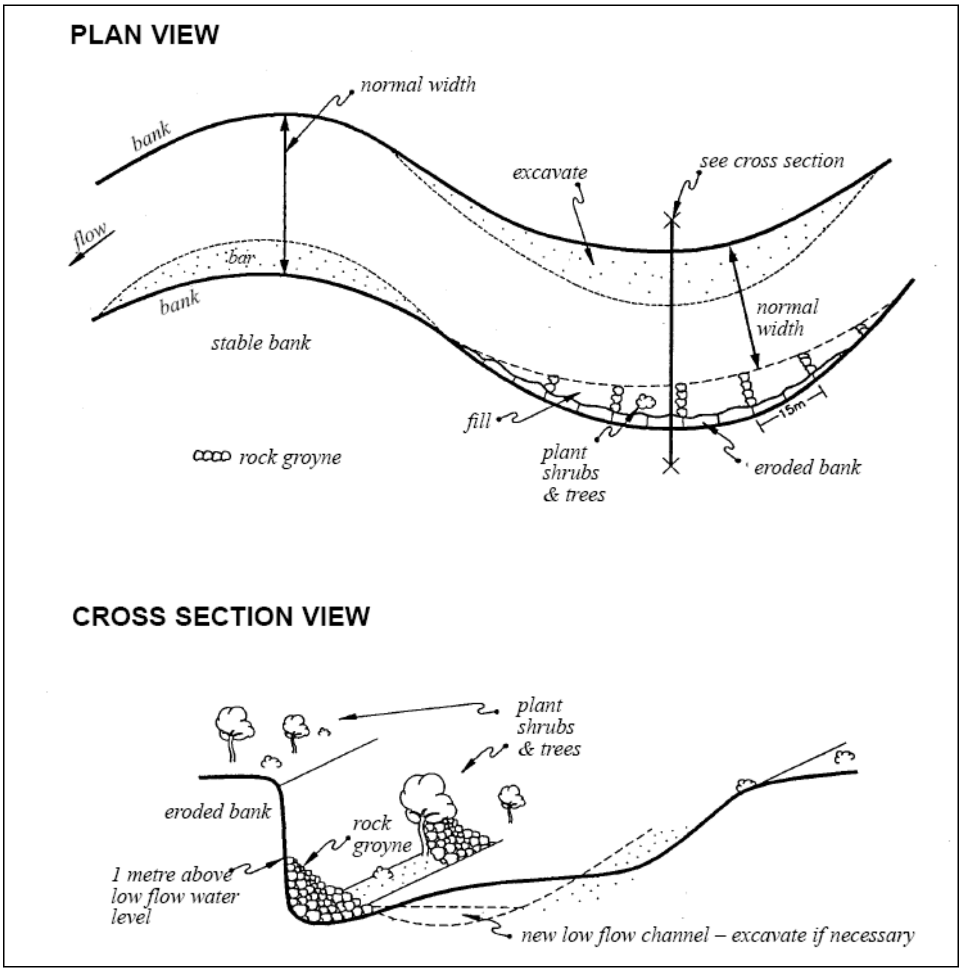


Figure 3.27a Series of rock groynes reinforcing channel alignment [18]

Figure 3.27b Effect of rock groynes at river bend

Figure 3.27c River groynes at eroding river bend of Sg. Pahang at Pekan town

A variety of materials including timber, rock, brushing or wire mesh fencing can be used to construct retards. The structures are secured to piles driven into the riverbed and anchored to the bank to prevent erosion of the abutments. Scour at the downstream end of the structure may occur due to back eddying. A rock apron or 'tail' structure at the end of the retard or groyne can limit this effect. The tail is built by extending the end of the groyne at an angle parallel to the direction of flow. Generally groynes and retards allow through-flow to reduce the pressure on the structure. Impermeable structures are more prone to scour and undermining. Maintenance will be required to clear debris accumulation that may cause unwanted effects.

In the local context, river training work as a form of flow retard has been practiced since pre-independent days. A longitudinal fence, consisting of poles (either of Bakau or bamboo) driven at intervals of 250mm to 400mm is constructed along the proposed bank line. Similar cross fences are constructed at right angles to the longitudinal fence, at intervals of say 5m to 20m. The velocity of flow in the area fenced in is lower than in the river, and deposition of sediment will occur during flood, when the river is heavily charged. In the first instance, the fences should stand only a short length (say 100mm to 200mm) above the level of dry weather flow depending on the size of the river. If they are too high they will be less effective. A reason which has been suggested for this is that tall poles project into zones of high velocity in the following water, and turbulence is set up which extends to the bed, retarding deposition. Also, tall poles are vulnerable to floating logs and debris. As deposition takes place behind and between the low fences which should be erected in the first instance, so new fencing should be erected at progressively higher levels, until the berm is sufficiently high. In due course, the fencing will decay, and unless a good growth of vegetative cover has been induced by then, the berm, having been formed of relatively cohesionless materials, is likely to erode away again. It is essential therefore to encourage vegetative cover early on. Such cover will itself assist in the process of berm formation, as it will induce deposition of the finer sediments, which are generally more favourable to further plant growth, and which will increase the cohesion of the deposits. Vegetative cover also traps floating vegetable matter, which goes to increase the humus content of the deposits, which in turn improves the conditions for growth. The arrangement and alignment of the river training fence for a straight and a meandering river are as shown in Figure 3.28A & 3.28C respectively while Figure 3.28B shows the incorrect alignment arrangement to be avoided.

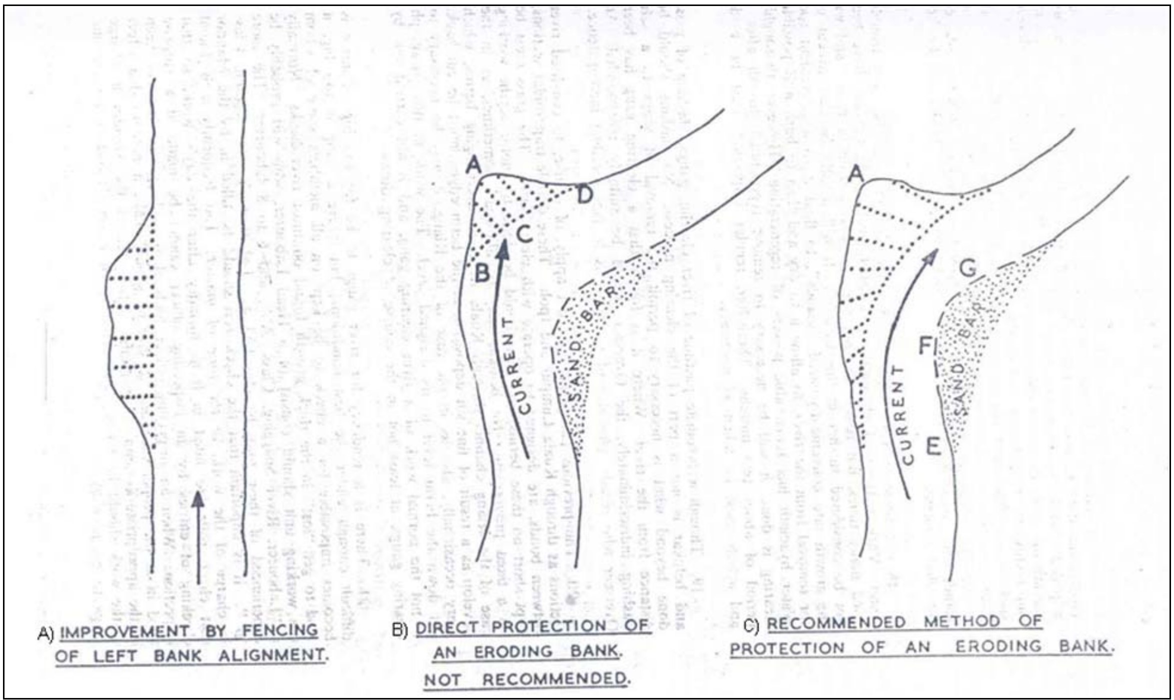


Figure 3.28 River training work using driven poles (DID Malaysia)[19]

Where conditions are severe, for example at Bentong in 1957, double fences were used throughout, both for longitudinal fences and for cross fences. Each double fence consists of two single fences, spaced one 300mm apart. Posts in each fence were whole bamboo and split bamboo alternately, and cross rails of whole bamboo were attached to the post, about 150mm from their tops. These cross rails were placed on the upstream sides of cross fences and on the landward sides of the longitudinal fences. They are attached to the posts by one turn of 14 SWG galvanized wire. Cross fences are 5m apart. The general arrangement is shown in Figure 3.29 (DID Manual 1973)[19]. However, the above practices are seldom used in recent years as they are considered temporary measures.

It is important to maintain the bankfull channel width. Groynes and retards can be installed if the channel is over-widened, but should not extend more than to the stable channel width. The point bar may need to be removed to create a stable width and alignment. In some carefully planned circumstances, groynes and retards can be projected into the bankfull channel to deflect the main flow into the point bar and thus excavate a portion of the bar.

Groynes and retards will not work in systems with a very limited sediment source. Sediment deposition is required and the site made suitable for vegetation establishment to successfully restore and protect the bank in the long term. The technique can be used in deep channels, however the structures may fail in fast flowing waterways. Groynes and retards also enhance habitat diversity by introducing a range of flow conditions in the waterway. See Appendix B for guidelines and a design example of stream barb.

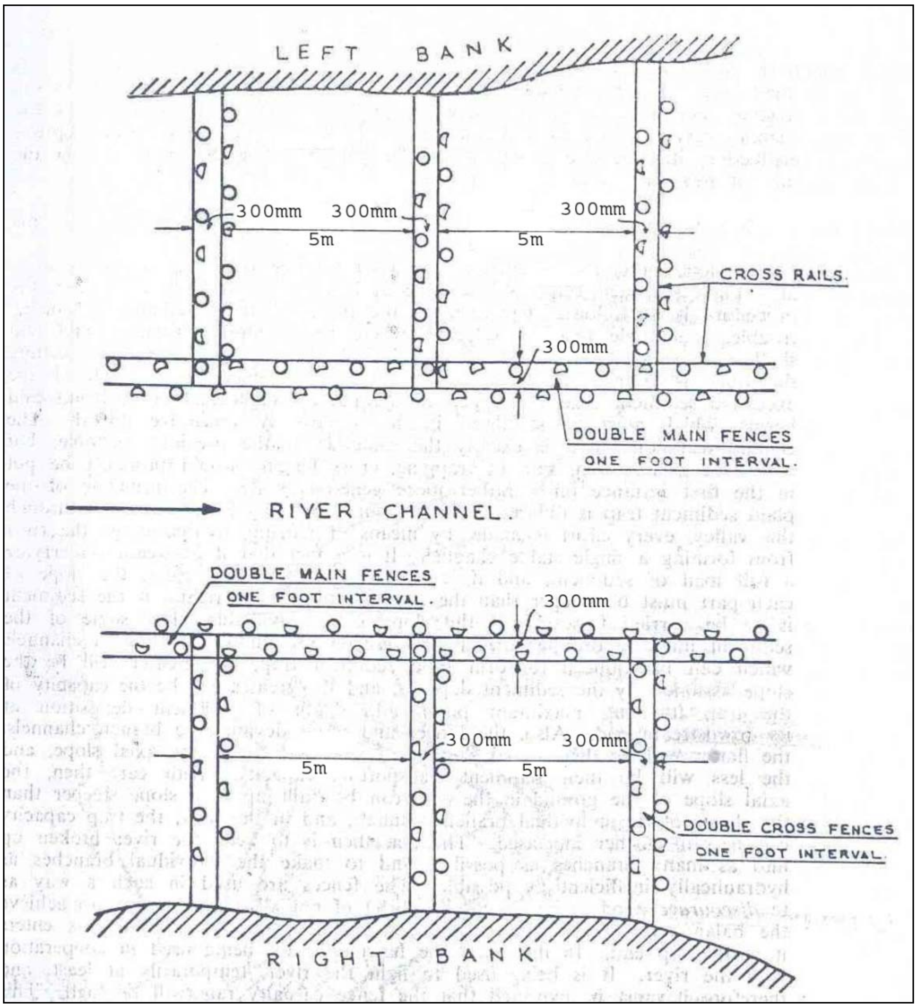


Figure 3.29 Bentong River training and sediment retention (1957)- General arrangement of fences [19]

Vane Dykes

Vane dykes are used on meandering waterways to reduce bank erosion on outer bends and control channel alignment. A series of short vane structures are positioned mid-stream along an eroding bank to encourage sediment deposition (Figure 3.30). The shape and alignment of the vanes interrupt secondary currents that can cause bank erosion. An advantage of the technique is that the bank and bed of the river remain relatively undisturbed during installation as the structures do not require anchoring. Vanes can be used in deep water. The technique will not be as effective in straight or irregularly aligned rivers (Water & River Commission, 2001)[18]. See Appendix C for more details.

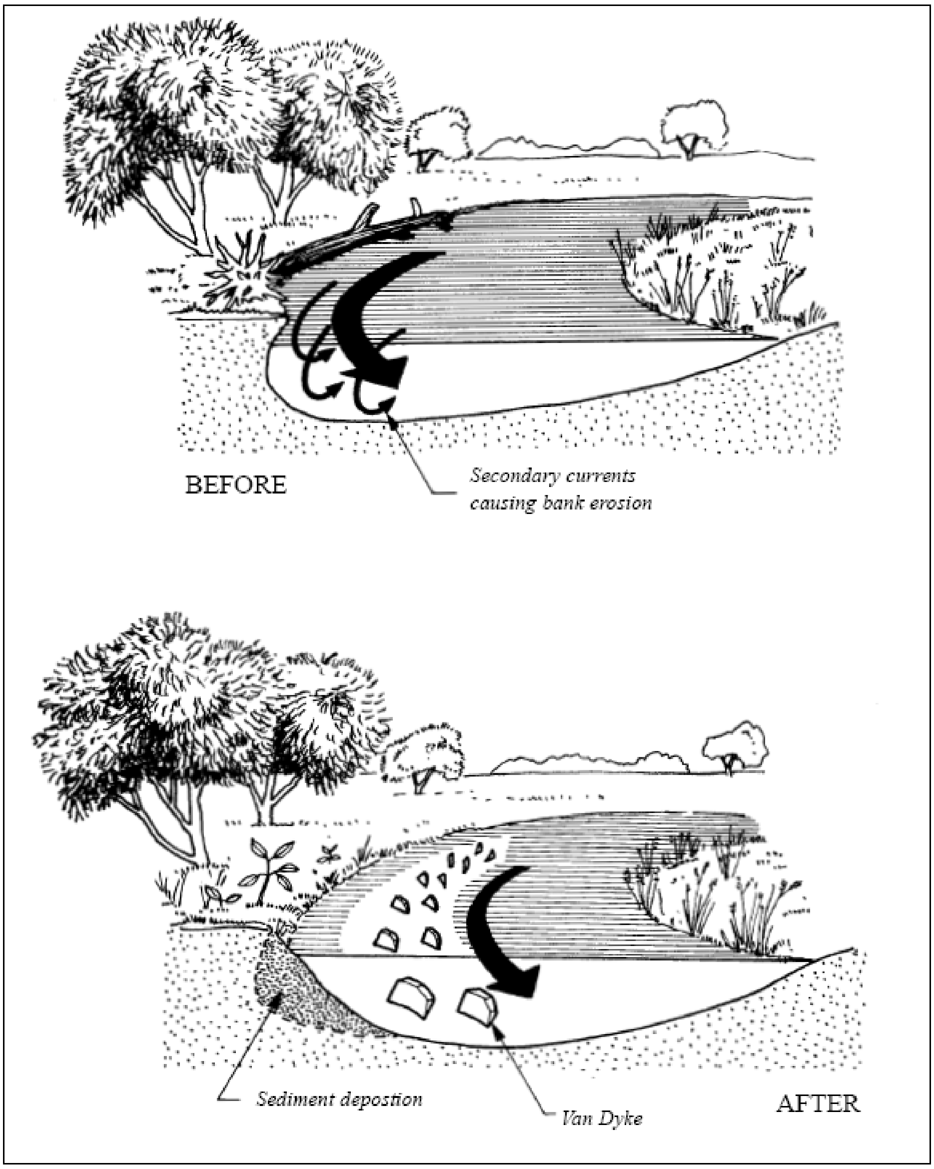


Figure 3.30 Vane dykes applied to reduce bank erosion [18]

3.4.1.2 Grade / bed Control Structures Guidelines and Techniques

Bed control and slope reduction structures can be used to halt the advance of an unstable zone that can progressively cause further upstream erosion. These structures include rock or grass chutes, riffles and drop structures. Rocks, vegetation and woody debris placed in the channel also increase the stability of bed material by dissipating flow energy and increasing the bed resistance to erosion (Water & River Commission, 2001)[18].

Pool and Riffle Design and Installation

A technique used to enhance and restore degraded rivers consists of re-building the pool-riffle sequence. The technique is used where channel deepening, or incision, is the main cause of instability. Channel deepening can be controlled by using riffles to increase the bed level and adjust the slope of the reach so that it is stable within the overall slope of the stream system across the catchment.

Stream flow is controlled over an unstable reach by creating a series of step pools. Figure 3.31a shows the river prior to rehabilitation works (Spencers Brook at Avon River, USA). The channel bed had incised by over 1.5 metres and the head-cut was advancing upstream. The banks of the channel were also collapsing and causing considerable bank widening.

A series of riffles were installed along the river. Figure 3.31b shows the lower riffle on the river bed following two winter flows since construction. The riffle was constructed at the location of the head-cut shown in Figure 3.31a. The site plan (only partially for a larger view) of the rehabilitation works is shown in Figure 3.31c. The stream is considerably straighter than the theoretical meander pattern described in section on "Channel patterns" above. The riffle sequence was constructed to cater to the existing meanders of the stream, rather than conforming to the 'text book' riffle spacing determined by bankfull width. The series of riffles have been successful in controlling the severe bed erosion that was occurring. Sediment has been deposited along the river channel, raising the bed level and filling the head-cut. Note that the rocks of the riffle were rearranged during flooding and there was some scouring about one corner, requiring some maintenance work until the riffle became fully stable.

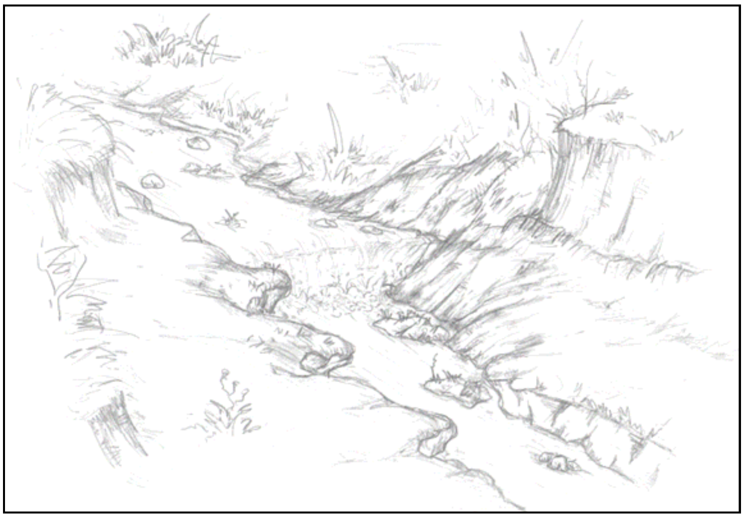


Figure 3.31a Head-cut in Spencers Brook [18]

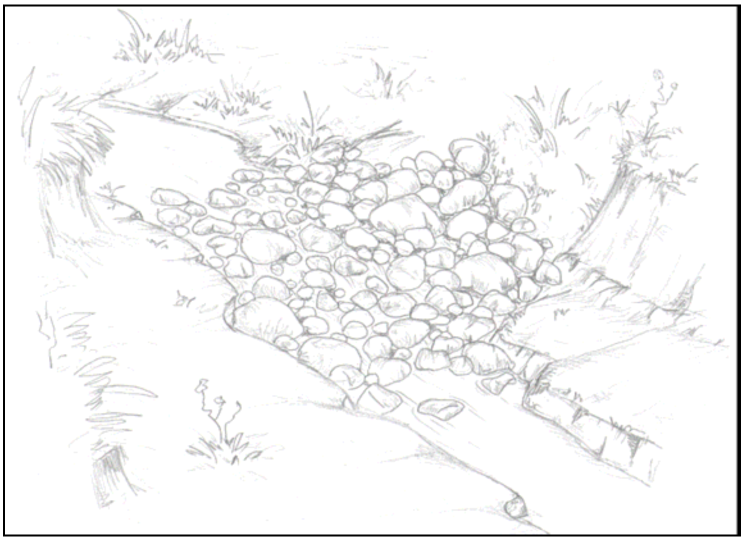


Figure 3.31b Stone Riffle built at Spencers Brook [18]

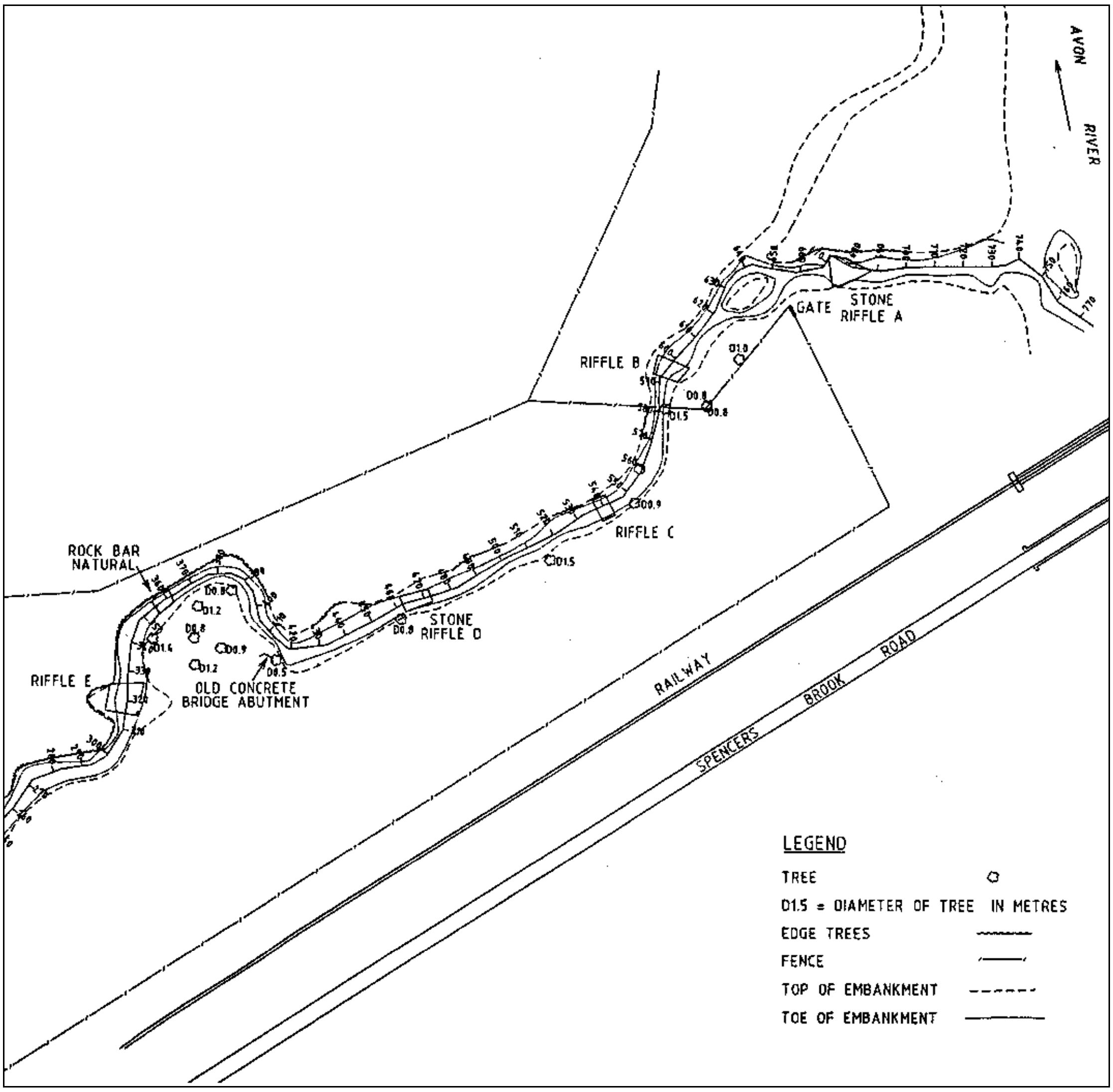


Figure 3.31c Plan View of Riffle Sequence (Spencers Brook at Avon River, USA) [18]

Benefits of Pools and Riffles:

Riffles, snags and other channel controls are important to the stability and ecology of stream systems. The pool-riffle sequence provides a variety of riverine habitats that are able to support a greater diversity of species than sections that have uniform characteristics. Riffles and meanders create variable water speeds and depths and maintain river pools that are important in providing warm weather refuges and breeding areas. The pools also provide resting zones for migrating aquatic fauna after tackling higher velocity flows.

Pool-riffle sequences contribute to channel stability by controlling the velocity of flow and reducing the downstream movement of sediments into the river. Stabilized bed material is important for the establishment of instream vegetation and habitat for aquatic fauna. Sediment accumulates behind the riffle and vegetation can be established on the flanks, stabilizing the banks. By locking the sediment and reducing flow velocities, nutrients in the water column can be removed through biological processes or remain bound in the bed material. Water quality is also improved as the riffle creates turbulence that aerates the water, which in turn supports microbial activity that breaks down organic matter and assimilates nutrients. A riffle structure can be designed to provide a livestock watering or crossing point. The pool created by the riffle can be used for livestock watering or to supply, via a pump, an off-stream tank or trough. Formalized crossings protect both livestock and stream habitat from the problems associated of unrestricted access. These include a reduction in the spread of bowel and urinary water borne diseases that afflict stock and overgrazing and trampling of fringing vegetation. An example of a rock crossing constructed on the river is shown in Figure 3.32

(South Dandalup River, Pinjarra, USA). Livestock do not remain in the river channel for prolonged periods, as the cobbled surface of the crossing is very rough and uncomfortable on the feet of livestock. Additionally, riffles are simple to design and construct and can be relatively inexpensive to build where stone is readily available.

Figure 3.32 Riffle/stock crossing on the River (South Dandalup River, Pinjarra, USA) [18]

Riffles generally do not adversely affect the flood capacity of the river channel, which is often oversized due to erosion anyway. An assessment of the channel capacity should be undertaken when designing instream works. The structures will have negligible impact on flood levels if designed to obstruct less than 10% of the cross-sectional area of the channel. The riffles are fully submerged during medium to high flows. See Appendix D for more details and an example of step-pool design.

Rock and Grass Chutes

A rock chute is similar to a riffle structure and can be used to control the advance of a head-cut. Chutes can be used to stabilize sudden streambed drops, typically 1 to 5 metre falls (Figure 3.33a). A series of chutes can be installed to reduce the slope of the river reach (Figure 3.33b). Sediment is deposited upstream of the chute. A chute can be built downstream of a head-cut (Figure 3.33c) to drown out the fall and halt the upstream progression of bed erosion. The chute can be structured as a drop structure with a fixed crest, forming a weir above the riverbed, or can be more flexible in shape. A fixed crest is a solid wall built along the crest, extending through the chute and into the channel bed (Figure 3.33d). Weir type structures are not preferred as they may impede the passage of aquatic fauna.

Detailed design techniques and programs have been developed to construct rock chutes. A section of the riverbed is hardened with graded rock to increase the bed resistance. Rock armouring is extended to above bankfull stage height to avoid outflanking. The streambed may need to be prepared by excavating a smooth surface and filter cloth may be required between the rock and the bed material on highly erosive or dispersive soils to prevent undermining. The rocks do not require concreting into position. Some rock movement may occur during initial high flows until the structure settles and stabilizes. The downstream and upstream ends of the chute can be constructed with 'cutoffs' as shown in Figure 3.33D. Cut-offs are vertical barriers such as a wall, interlocking sheet piles, or geotextile used to prevent sediment movement through the chute. The cut-offs act to reduce the risk of failure of the chute caused by undermining. Cut-offs are required for steep chutes or in streambeds with high permeability or low cohesiveness.

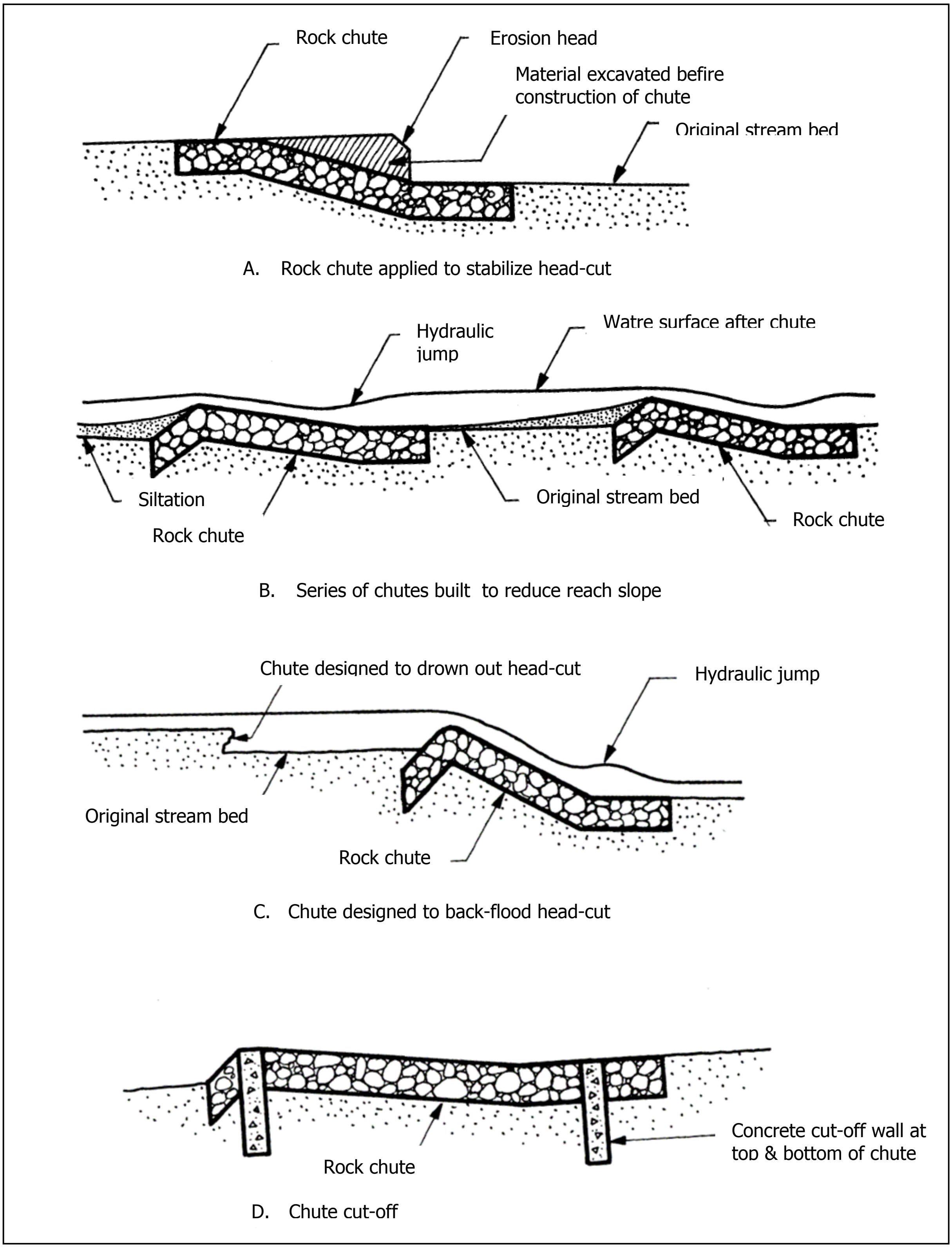


Figure 3.33 Applications of Rock Chutes [18]

Grass chutes can be constructed in waterways to stabilize head-cuts or steep slopes (Figure 3.34). The technique is most applicable on seasonal waterways or where base flows are low. Grass chutes can be used in channels that accommodate occasional bypass or high flows usually located on broad floodplains. A section of the channel is vegetated with dense grass. The grass reduces the velocity of flows, trapping sediment and inhibiting erosion. The species of suitable grass is site specific and will be determined by the climate, soil type and water quality. Grass chutes are not appropriate in channels exposed to heavy livestock grazing or prolonged periods of inundation. Grass chutes are low cost, but require ongoing maintenance. There may also be difficulties in establishing the grass, and it may be necessary to protect the channel during this period.

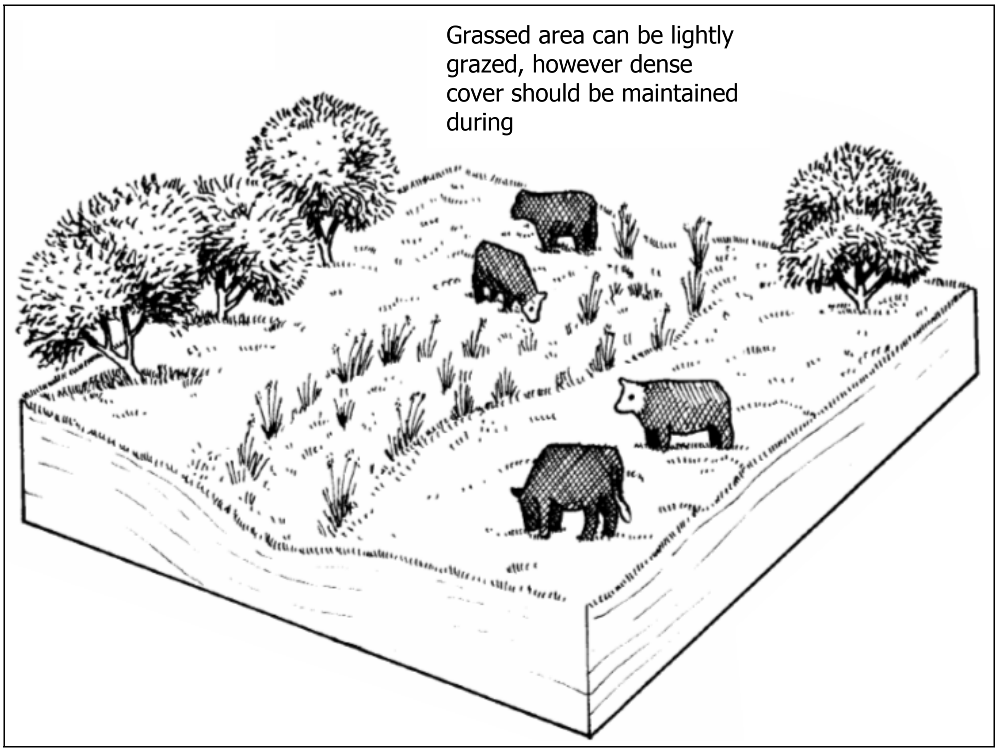


Figure 3.34 Grass chute [18]

Rock and grass chutes should be combined with revegetation to provide long term sediment stabilization. The chutes may be fully submerged during medium to high flows that may have sufficient power to shift sediment. See Appendix E for an example of rock chute design.

Drop Structures

Drop structures consist of a weir and stilling basin or apron as shown in Figure 3.35. Drop structures control the transfer of flow over a large change in height or fall of the streambed. The structures can be used to stabilize steep slopes or control a head-cut. The energy of the streamflow over the vertical drop in bed level is reduced by the formation of a hydraulic jump. Flow energy is dissipated along a sloping rock apron or a stilling basin at the downstream end of the structure to prevent scour in the channel. Headwalls or wingwalls are constructed at the downstream end of the structure to prevent erosion around the outlet caused by back eddying. Reinforced concrete and steel sheet piles are use in construction. Drop structures may be required for large flows, at significant drops or at an outlet of a spillway or pipe structure. Drop structures should be built along a straight section of the channel and aligned perpendicular to the main flow. A stable base is required as bed movement or uneven settlement may cause undermining or cracking of the fixed structure. A series of smaller drop structures can be used rather than one large structure to gradually step the flow down the steep slope and reduce the potential for erosion.

Figure 3.35 Drop structure

Pipes can be used as part of the drop structure to transfer flows over a change in bed level. The technique requires limited earthworks and can be applied to high drops, but is only applicable for low flows.

Outlet structures

Outlet structures are often used where channel instability could occur at a stream confluence with a tributary or drain. The condition of the receiving waterway and the approach angle, level and velocity of the entering flow will determine the potential for erosion and requirement for protection. Protective works or an outlet structure to modify the flow prior to entering the stream may be required to prevent erosion. The bed slope can be reduced or the cross-sectional area of the tributary increased to reduce the velocity of the entry flow. The level of the flow should be the same or slightly less than the water level of the receiving stream. A stilling pond can be constructed at the outlet of a drain or tributary to reduce the flow velocity. Bank protection and bed armouring may be required at the confluence where the depth and width of the receiving stream is insufficient to absorb the energy of the entering flow. Energy dissipaters such as rock scour aprons and gabions or geotextiles and matting can be used to stabilize and protect the stream.

3.4.1.3 Flow Deflection/Concentration Guidelines and Techniques

The purpose of flow deflection/concentration practices is to change the direction of stream flow or to concentrate stream flow. These structures are predominately used to deflect flow away from eroding stream banks, concentrate the flow in the center of the channel, redirect water in and out of meanders, and/or enhance pool and riffle habitats (Stream Restoration Practices Fact Sheet, Stormwater Manager's Resource Center)[20]. Guidelines for their installation are provided in Appendix F for the following structures:

- Wing Deflectors (single)
- Wing Deflectors (double)
- Log, Rock and J-Rock Vanes
- Cut Off Sills
- Linear Deflectors

Wing Deflectors (single)

A single wing deflector is a triangular structure that extends out from the streambank into the stream, with the widest portion along the bank and the point extending into the channel. The purpose is to change or (deflect) the direction of stream flow either to narrow and deepen the baseflow channel or to create sinuosity in the channel.

Wing deflectors can consist of a rock filled log frame or they can be made entirely of rock. In urban stream applications they more often consist entirely of rock. Single wing deflectors are not often used in urban applications as they tend to force water toward the opposite bank, and unless the opposite bank is sufficiently stable or armored, bank erosion can ensue (Figure 3.36).

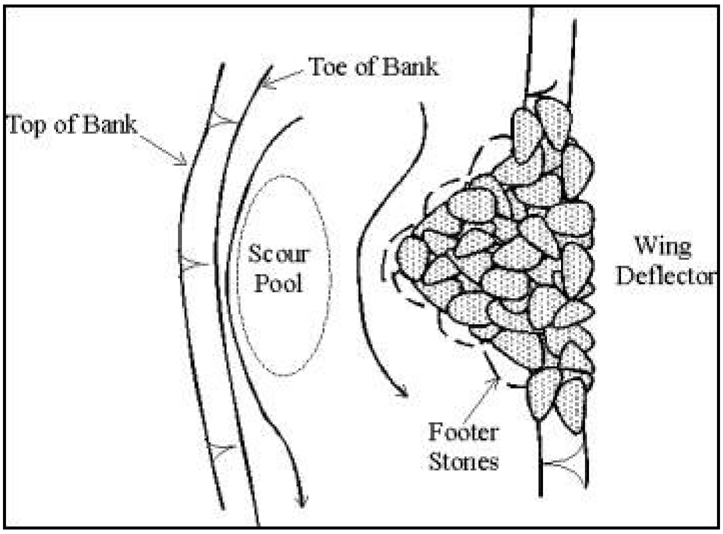


Figure 3.36 Planview of single wing deflector [160]

Wing Deflectors (double)

When two wing deflectors are placed opposite each other they serve to narrow or constrict the flow of water. The double wing deflector is more often used in urban applications as it forces the water toward the center of the channel and deepens the baseflow channel. Double wing deflectors also create an area of increased velocity between them, enhancing riffle habitat between and just upstream of the structure. This increased velocity also creates an area of scour, creating pool habitat downstream of the structure. The construction is the same as a single wing deflector except that in some instances, a rock sill at the stream invert may connect the two structures (Figures 3.37 and 3.38).

Both single and double wing deflectors have significant habitat enhancement potential. These structures enhance habitat through pool formation, the narrowing and deepening of the baseflow channel, and the enhancement of riffle habitat.

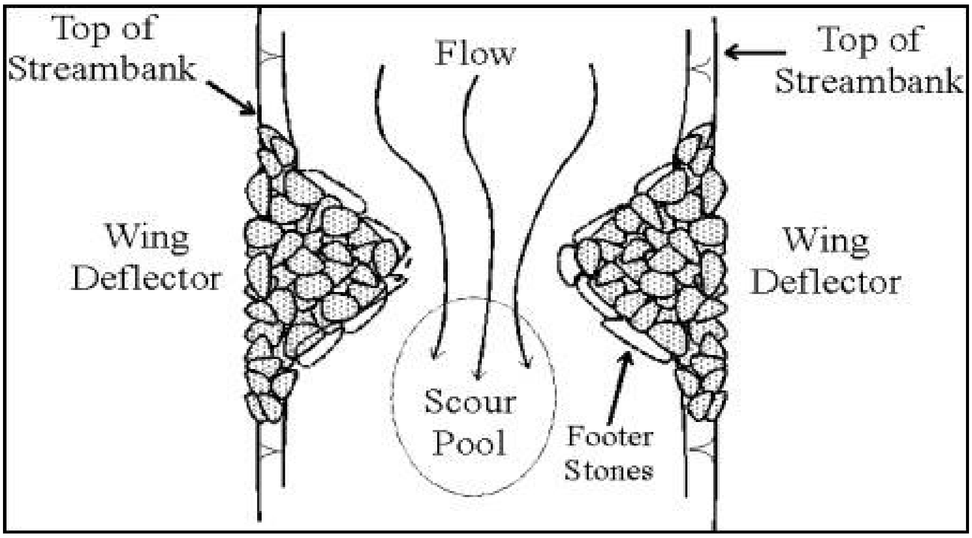


Figure 3.37 Plan View of Double Wing Deflector [160]

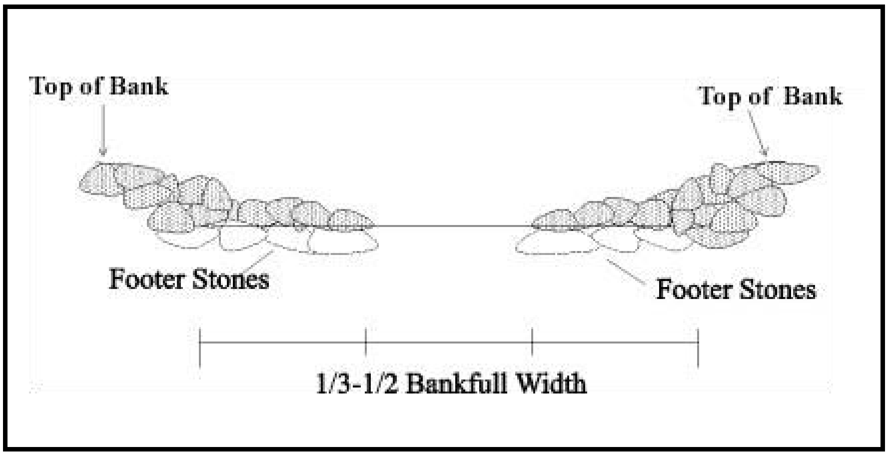


Figure 3.38 Section view of double wing deflector [160]

Log, Rock, and J-Rock Vanes

Vanes are linear structures that extend out from the streambank into the stream channel in an upstream direction. They essentially mimic the effect of a tree partially falling into the stream. They are usually placed along the streambank where erosion is occurring along the toe of the slope. The purpose of vanes is to reduce erosion along the streambank by redirecting the stream flow toward the center of the stream. In addition, they tend to create scour pools on the downstream side. Vanes can be made of rock or log. They grade down from the bankfull elevation at the streambank to the channel invert at their terminus in the stream. Vanes generally extend out from the stream bank 1/3 of the bankfull width and are angled upstream from the bank at a 20 to 30 degree angle. They should be carefully located and installed so as not to produce additional erosion on the upstream side where they meet the bank (eddy scour) or allow flows to outflank them, exacerbating existing bank erosion problems. The only difference between the log vane and the rock vane is the material used. The J - vane is basically the same as a rock vane with the exception that it curls around at the end in the shape of a "J." The curved end portion serves to enhance downstream scour pool formation (Figures 3.39-3.41).

Rock, log and J-vanes have significant habitat enhancement potential through the creation of downstream scour pools, narrowing and deepening of the baseflow channel, and the enhancement of riffle habitat along the upstream side.

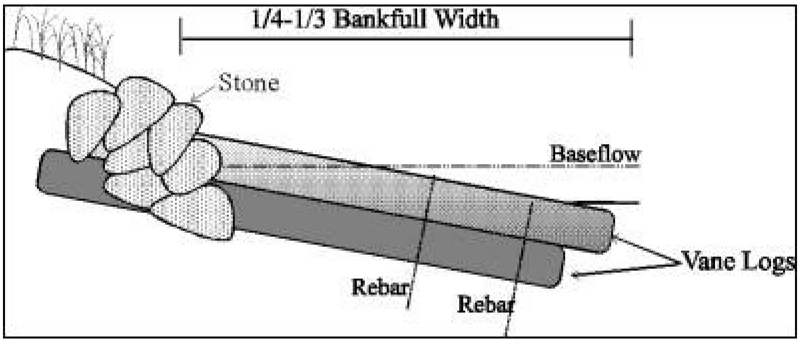


Figure 3.39 Section view of log vane [160]

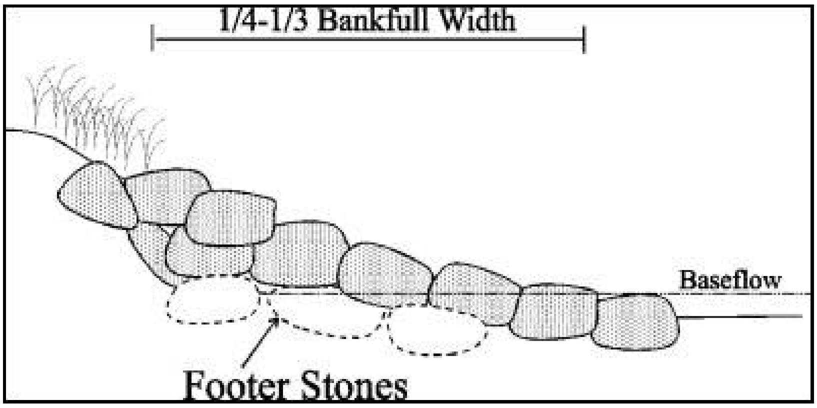


Figure 3.40 Section view of rock vane [160]

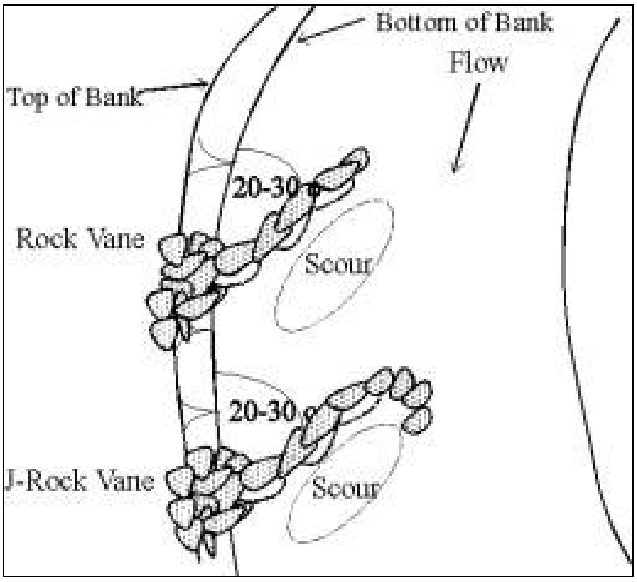


Figure 3.41 Planview of rock vane and J-rock vane [160]

Cut-off Sills

Cut-off sills are low rock sills similar to a linear deflector and often used in conjunction with linear deflectors. They extend out from the streambank into the stream channel at an angle of 20 to 30 degrees from the bank in an upstream direction. They can either intersect with a linear deflector or terminate at the baseflow channel. The purpose of a cut-off sill is to promote deposition and bar formation along the edge of a channel in order to narrow and better define the baseflow channel. They do not extend above bankfull height and are usually much below it. They are also used to stabilize existing bars. In such instances they are installed in the existing bar and extend only slightly above it (Figures 3.42 and 3.43).

Cut-off sills have a modest potential to enhance stream habitat. When utilized in channels with shifting baseflow channels and high bedload movement they can be very effective at stabilizing lateral bars and better defining the baseflow channel.

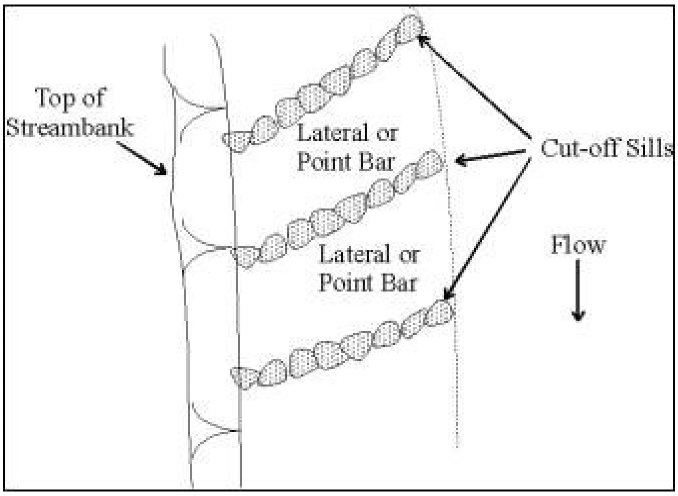


Figure 3.42 Planview of cut-off sill [160]

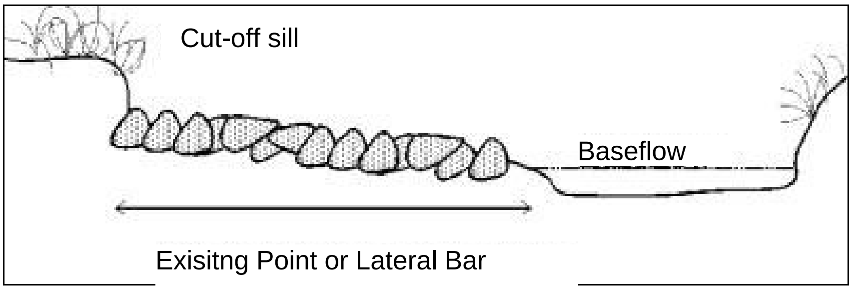


Figure 3.43 Section view of cut-off sill [160]

Linear Deflector

A linear deflector is a line of boulders placed within the stream channel rather than along the bank. The purpose of this structure is to narrow, deepen and better define the base flow channel. The top of the deflector generally does not extend above the bankfull elevation and is usually much below it. The area between the deflector and the stream bank either is back filled with materials excavated during the installation, imported stone/fill, or allowed to naturally sediment in (Figure 3.44).

Placement of a linear deflector must take into consideration the condition of the opposite stream bank. If the opposite bank is potentially unstable, bank stabilization measures may be necessary. If the opposite bank is unstable and left untreated, there is the potential for bank erosion and channel widening. Linear deflectors are most often used in stream channels that are overly wide, have shallow or shifting base flow channels and high bed load sediment movement.

Linear deflectors have a significant potential to enhance stream habitat in streams with shallow, poorly defined baseflow channels. By better defining and deepening the baseflow channel, linear deflectors improve fish passage and expand the total amount of habitat available for fish.

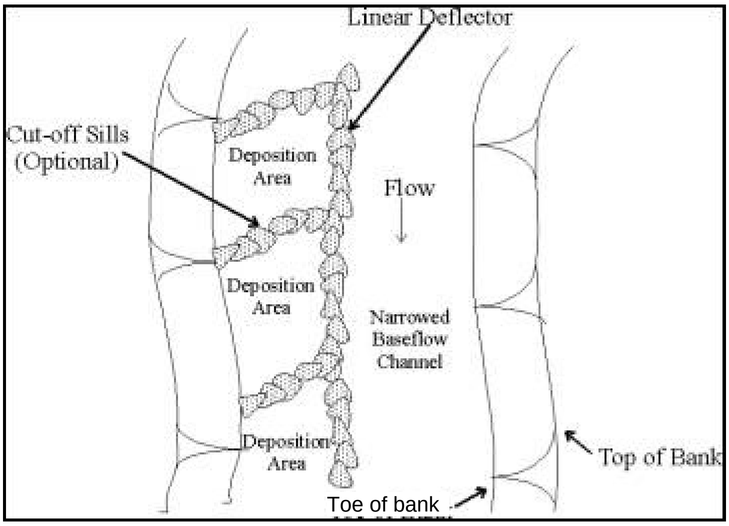


Figure 3.44 Planview of linear deflector [160]

3.4.2 Temporary Flow Diversion Guidelines

Purpose and Applications

A temporary stream diversion is the diverting of the base flow of a perennial stream around a construction site by use of a conduit (pipe) or small diversion ditch (MAINE Erosion and Sediment Control BMP)[21].

Its purpose is:

- To maintain stream flow continuity, quality and habitat and provide a dry working environment for the construction activities.
- To allow the installation of a structure in a perennial stream with minimal impacts on stream turbidity.
- By temporarily diverting the stream's base flow away from the construction areas and into a stable pipe or channel system, clean water is kept out of the active construction area.

This practice applies where flows are low enough and/or the watershed is small enough to allow normal base flows to be handled practically in a conduit (pipe) or small diversion ditch. It is intended for those situations where the temporary stream diversion will only be needed during the drier months of low stream flow, where the time of construction can be minimized, and the site can be stabilized before rainy seasons. For projects involving large streams or rivers that are expected to be under construction for a long period of time, more permanent engineered structures will be needed.

Considerations

Timing: Timing the installation of this measure is critical to coincide with low flow period.

Phasing: To minimize the impact to the stream, phasing the operations must be considered before the stream is diverted. This measure needs to be quickly and carefully installed, well maintained and removed as soon as possible when the construction area is stable.

Constriction of the channel: These practices will increase the velocity of flow due to constriction of the channel and will create a higher potential for erosion and movement of sediments in the stream channel.

Flooding: Any flood flows during the construction period can be expected to damage or destroy this practice. It may contribute to the flooding effects.

Maintenance: This practice is a high maintenance item, and should be considered for use in a cautious manner. The impact of failure on downstream facilities should be carefully considered.

Design Criteria

(Refer to the guidelines and graphics of the Temporary Slope Drain BMP) [21].

The construction of any specific temporary stream diversion shall not cause a significant water level difference between the upstream and downstream water surface elevations (not to exceed 1%) and the velocity should be maintained at a rate similar to existing flow conditions.

Time of Operation: All temporary stream diversions shall be removed within 2 calendar days after the structure is no longer needed. Unless prior written approval is obtained, all structures shall be removed and the area stabilized before expected rainy seasons.

Aggregate: There shall be no earth, sands, silts, clays or organic material used for construction within the waterway channel. Washed coarse aggregate (20mm to 100mm size) shall be the minimum acceptable aggregate size for temporary stream diversions. Larger clean aggregates will be allowed.

Sandbags: Sandbags shall consist of materials, which are resistant to ultra-violet radiation, tearing and puncture, and woven tightly enough to prevent leakage of fill material (i.e., sand, fine gravel, etc.).

Planning Criteria

Select a design method that will least disrupt the existing terrain for the stream reach. Consider the effort that will be required to restore the area after the temporary stream diversion is removed. The following criteria must be considered when selecting a temporary stream diversion method:

Time of year: The time of year may preclude the selection of one or more of the standard methods due to monsoon seasons depending on location.

Site Location: Locate the temporary stream diversion where there will be the least disturbance to the soils of the existing waterway banks.

Removal of the structure: Ease of removal and subsequent damage to the waterway should be primary factors in considering the choice of a design of the stream diversion.

Maintenance: This is a high maintenance item. Weather reports need to be monitored and the structure prepared for anticipated storm events.

Design Criteria

Provisions for temporary stabilization of the inlet, outlet, and return channel shall be included in the design. The materials used in construction must be sound, and capable of withstanding the loads applied. The materials must also be durable and maintain their integrity for the life of the project.

- Excavation of the channel shall begin at the downstream end and proceed upstream. All excavated materials shall be stockpiled outside of the stream sections and temporarily stabilized to prevent re-entry into the stream channel.
- The height of the diversion structure shall be one half the distance from the streambed to stream bank plus one 300mm.
- All dewatering of the construction area shall be pumped to a dewatering basin prior to reentering the stream.
- All excavation materials shall be disposed of in an approved disposal area outside the 100- year floodplain unless otherwise approved.
- The downstream and upstream connection to the natural channel shall be constructed under dry conditions. Sandbags shall contain the stream.

- The process of excavation and stabilization shall be a continuous (uninterrupted) operation. All materials shall be on-site prior to channel construction.
- Periodic inspection and maintenance shall be performed as needed to ensure that the diversion, streambed and streambanks are maintained and not damaged. Maintenance shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of outside of the flood plain and stabilized.

Sandbag-Conduit Diversion: This practice should be limited to streams, which drain less than 2 square km. It should be used only for very short time duration. Because the potential for wash out is high, it must be carefully monitored. It should not be left unattended for any 24-hour period. If a major storm event is expected, the site must be stabilized in preparation for it. The conduit shall be designed to have the hydraulic capacity to handle 2-year storm event or higher depending on its potential damage to adjacent land or properties.

Sandbag-Stone Diversion: This practice should be limited to streams, which drain less than 12 square km. The temporary channel should be able to convey the 5-year storm event or higher depending on its potential damage to adjacent land or properties. The diversion structure shall be installed from upstream to downstream. Sheeting shall be overlapped such that the upstream portion covers the downstream portion with at least a 500mm overlap.

Fabric Based Channel Excavation: This practice should be limited to streams, which drain less than 2 square km. The temporary channel should be sized to convey the 2-year storm event or higher depending on its potential damage to adjacent land or properties. All debris (rocks, sticks, etc.) shall be removed and the channel surfaces made smooth so that the fabric will rest flush with the channel sides and bottom.

Stabilization with Geotextile Fabric:
- The fabric shall have a minimum width such that it is keyed in and anchored at the top of the stream bank.
- The fabric shall be placed so that it rests flush with the channel at all points of contact.
- The fabric shall be placed such that one piece will line the entire channel. If this is not possible, the fabric shall be placed so that it overlaps along the channel's transverse. Longitudinal overlaps shall not be allowed. Upstream sections shall overlap downstream sections. The overlap shall equal 600mm minimum.
- The fabric shall be keyed into 600 x 600mm trenches located at the upstream edge and at 15m intervals (the overlap nearest to each 15m increment). The key-in shall be from top of channel to top of channel. Riprap shall be carefully placed into the trench (without dropping onto the fabric).
- The fabric sections shall be secured with pins (length of 600mm minimum) and washer (diameter 25mm minimum). Overlaps shall be pinned along transverse and longitudinal axes with spacing equal to 900mm maximum.
- The spacing of the pins must follow the manufacturer's specification and is dependent on the anticipated velocities and thickness and type of geotextile fabric.
- The entire bottom of the channel could be riprapped if high velocities were anticipated. When the area is riprapped, it is not required that the geotextile fabric underneath the riprap be pinned.
- An impervious plastic lining can be used in lieu of geotextile fabric. The plastic liner shall be 6 mm or thicker and shall be capable of maintaining strength against the effects of ultraviolet light for a period of at least 60 days.

Removal of the Diversion

- Water shall not be allowed through the natural stream until all construction is completed.
- When the diversion is no longer needed, all structures shall be removed within 2 calendar days.
- After diversion of the stream back to the natural streambed, the temporary diversion channel shall be backfilled and stabilized. Points of tie-in to the natural channel shall be stabilized in accordance with the streambank stabilization BMP.

Maintenance

Inspection: Periodic inspection must be performed to ensure that the structure is maintained and not damaged, that sediment is not entering the stream.

Maintenance: Maintenance shall be performed, as needed, to ensure that the structure complies with the standards and specifications. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of outside of the floodplain and stabilized.

Storm Events: Anticipate major storm events. If a major storm is predicted, emergency measures must be taken to minimize damage.

3.4.3 Bank Protection and Stabilization Guidelines and Techniques

3.4.3.1 Identifying Causes and Predicting Effects of Bank Erosion

To effectively control bank erosion, river bank management must be compatible with the nature of the river system and the composition of its bank. Before restorative methods are applied to eroding banks, it is essential to understand the mechanism of erosion. Otherwise, large investment of time and money may potentially be wasted in projects that fail or require frequent maintenance.

Streambank Zones

Streambanks can be divided into three general zones: toe, bank and overbank zones. These zones are shown in Figure 3.45 and can be described as follows:

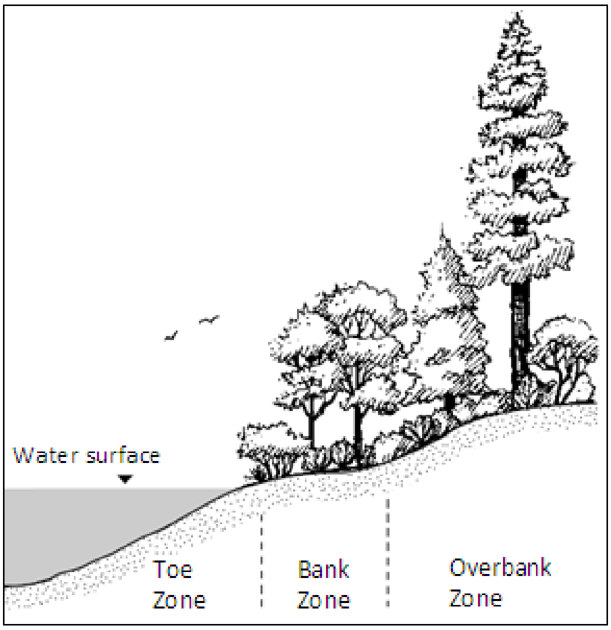


Figure 3.45 Section of streambank zones in natural channels [161]

- *Toe Zone*

The toe zone is that portion of the bank between the Ordinary High Water (OHW) and low water levels. This is the zone most susceptible to erosion as it is exposed to strong currents, debris movements, and wet-dry cycles. This zone is normally inundated throughout much of the year. In areas where stabilization is necessary, non-vegetative structural protection is normally required in this zone because few woody plants can tolerate year-round inundation.

- *Bank Zone.*

The bank zone is that portion of the bank above the OHW Mark (OHWM) that is inundated during periods of moderate flows (i.e. up to bankfull flow). Although above OHWM, these sites are still exposed to periodic erosive currents, debris movement, and traffic by animals and humans. The water table in this zone is frequently close to the soil surface because of its proximity to the river.

- *Overbank Areas.*

The overbank area is that portion of the bank from the bank zone inland that is subjected to inundation or erosive action only during occasional periods of high water (i.e. greater than bankfull flow). This zone is generally subjected to periodic dry periods in which the soil moisture is primarily dependent on characteristic rainfall of the area. When relatively flat and generally underlain by alluvial deposits, this area is also called a floodplain. When it rises steeply and directly from the streambank, this area is called a bluff.

3.4.3.2 Characteristics of Bed and Bank Material

The resistance of natural river banks to erosion is closely related to the characteristics of the bank materials.

- *Bedrock.*

Bedrock outcrops normally are quite stable and subject only to quite gradual erosion and intermittent mass failure. Bedrock outcrops in a bank or bed can prompt erosion of the opposite bank.

- *Cohesionless Banks.*

Streambanks composed of cohesionless soils normally are highly stratified heterogeneous deposits. Cohesionless soils consist of mixture of silts, sands and gravels. These soils have no electrical or chemical bonding between particles and are eroded grain by grain. Erosion of cohesionless soils is controlled by gravitation forces and particle characteristics such as size, grain shape, gradation, moisture content, and relative density. Other factors include the direction and magnitude of flow velocity next to the bank, fluctuations in the shear stress exerted on the banks, seepage force, piping and wave forces.

- *Cohesive Banks.*

Erosion of cohesive streambanks is more complex to analyze than cohesionless banks because of the characteristics of soil particle bonding. Cohesive soils contain large quantities of fine clay particles composed of chemically active minerals that create strong chemical and electrochemical bonds between particles. Other soils characteristics affecting cohesive soil erosion are the type and amount of cations in pore water and the eroding fluid, and composition of the soil including the type and amount of clay minerals. Cohesive material is generally more resistant to surface erosion because its low permeability reduces the effects of seepage, piping, and subsurface flow on the stability of the banks. Because of the low permeability, this material is more susceptible to failure during rapid lowering of water levels. When undercut/or saturated, these bank are more likely to fail due to mass wasting processes such as sliding.

- *Stratified or Interbedded Banks.*

Stratified banks are the most common bank type in natural fluvial systems. The soils in stratified banks consist of layers of materials of various sizes, permeability and cohesion. When cohesionless layers are interbedded with cohesive soils, erosion potential is decided by the erodibility of the component layers and the thickness and position of the cohesionless strata. Where cohesionless soils are not at the toe of the bank, the layers of cohesionless soil are protected by adjacent layers of cohesive soils (the cohesionless soils are still subject to surface erosion). This type of bank is vulnerable to erosion and sliding because of subsurface flows and piping. Where the cohesionless soil occurs at the toe of the bank, it will generally control the retreat rate of an overlaying cohesive unit.

3.4.3.3 Riverbank Failures

All river banks erode to some degree. Because it is a natural ongoing process, it is unrealistic to believe that bank erosion can be or should be totally eliminated. Major floods can always make significant changes in bank lines despite steps taken to prevent it. Thus it is important to understand that the concern is not that erosion occurs, but rather the location and rate at which it occurs.

While bank erosion is occurring naturally over time, it is a process that may be accelerated or decelerated by human activities. Natural erosion can be defined as the processes that occur without significant human activities in the drainage basin or catastrophic natural events such as forest fires. Accelerated erosion can be defined as erosion that is a typically high in magnitude and is different in nature than the erosion experienced at the site or reach in question in the recent past. Both natural events (e.g. high flows) and human activities (e.g. changes in land use) can cause accelerated erosion. Major changes in water quantity, flow direction or debris loads often accelerate bank erosion. These types of changes are often caused by human activities such as urbanization, logging or overgrazing. These activities usually result in increased runoff and sediment yield compared with a basin in a natural condition.

3.4.3.4 Modes of Failure

Bank failures in riverine systems occur through one of three modes:

- hydraulic forces that remove erodible bed or bank material;
- geotechnical instabilities; or
- a combination of hydraulic and geotechnical factors.

They may be explained as follows:

When bed or bank erosion occurs because water flowing in the channel exerts a stress that exceeds the critical shear stress for soil erosion, the mode of failure is hydraulic. Critical shear stress is dependent upon the type and size of the material. It can be exceeded by tangential shear stress caused by the drag of water or by direct impingement of water against a bank. Bed degradation is an example of the first, while local scour induced by debris is an example of the second. Hydraulic failure is usually characterized by a lack of vegetation, high boundary velocities, and no mass soil wasting at the toe of the bank.

The hydraulic mode of bank failure generally occurs in rivers with noncohesive gravelly banks. Rivers with fine-grained bank sediments generally experience the geotechnical mode of failure discussed below. A geotechnical failure occurs when gravitational forces acting on the bank material exceed the strength of the resisting forces, causing downward displacement of the soil mass.

Geotechnical failures that are unrelated to hydraulic erosion are nearly always caused by excess bank moisture problems. Moisture can affect both the stresses and the ability of the bank material to withstand stresses. Failure usually results when the shear strength of the bank material is exceeded. Mass wasting of soil at the toe of the bank is one indication that a geotechnical failure has occurred. The appearance of the failed bank can vary with the material type and the precise cause of the failure.

Bank failures from a combination of hydraulic and geotechnical forces are more common than either force acting alone. Literally hundreds of scenarios can be developed under which a combination of these forces result in bank failures. Examples include: bed degradation that leads to oversteepening the banks and subsequent geotechnical failure: or, when successive slip plane failures occur on a geotechnically unstable bank and hydraulic forces erode mass wasted material at the toe that is resisting further slips.

3.4.3.5 Causes of Failure

The actual causes of bank erosion related to hydraulic and geotechnical modes of failure are complex and varied. They involve stream flow characteristics, streambank properties including groundwater conditions, and the effect of human activities. Successful bank stabilization projects begin by identifying the cause of failure. The causes of erosion can be described as follows:

Erosion from hydraulic forces is generally restricted to circumstances that either affect the velocity or direction of flow. Frequently, human actions are responsible. Examples of actions that can increase mean (and local) velocities include increased flows with land use changes, steeper channel slope from channelization or constriction of the channel for bridge crossings. Changes in flow direction are usually the result of debris in the channel, formation of new islands or bars, or the improper placement of flow deflection structures. Destruction of bank vegetation from land clearing, logging, live stock grazing, or other riparian use can also promote erosion by hydraulic forces.

An example of bank failure caused by hydraulic actions is toe erosion. Toe erosion typically occurs when flow is directed toward a bank at a bend (Figure 3.46). In channel bends, the highest velocity is close to the outer edge of the channel and near the deepest water depth. Forces act on the bank in both the downstream and the vertical directions toward the base of the bank. Centrifugal force causes the water surface elevation to be highest at the outside of the bend (super elevation). As gravity pulls the additional mass of water downward, a rolling, helical spiral is created, with high downward velocities against the bank material. This downward erosive force, coupled with the stream velocity, can undercut the toe of the bank. The downward erosive force on the bank will be greatest in tight bends as opposed to gradual curves. The most severe toe erosion will occur immediately downstream from the point of maximum curvature. At these locations, an increased level of protection will be required.

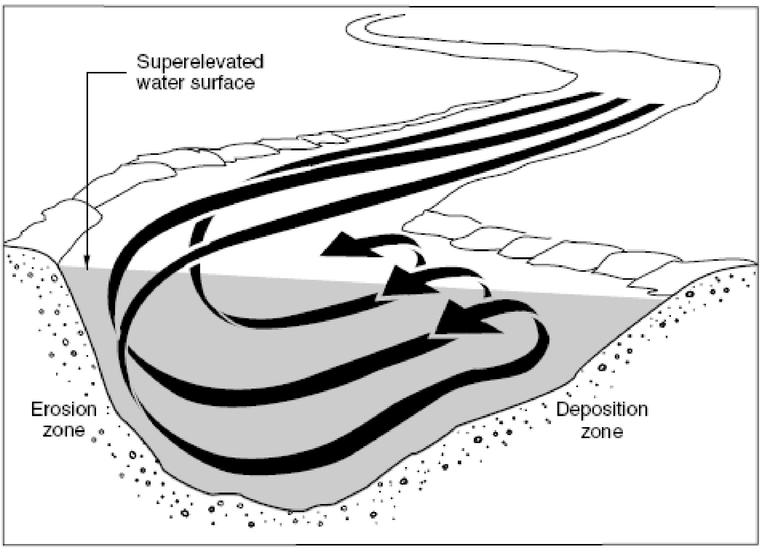


Figure 3.46 Erosion and deposition caused by spiral secondary flow [161]

The process of undercutting is presented in a sequence of illustrations in Figure 3.47 (a), (b), (c), and (d). In the initial position (a), the bank has composite layers consisting of an upper layer of cohesive silt material (commonly reinforced by plant roots) underlain with noncohesive gravels. As water flows along the bend, secondary currents remove the noncohesive material at the toe creating a cantilever overhang of cohesive material (b). At the toe of the bank, where shear stress exceeds critical shear stress, particles are detached from the bank by the flowing water. This oversteepens the bank, causing noncohesive particles higher up on the bank to fall off in thin, vertical slices. When the cohesive silt layer is undercut, the cantilever overhang collapses into the eroded pocket (c). This loose, fallen material is then washed downstream, resulting in a repositioned bank line or bank retreat.

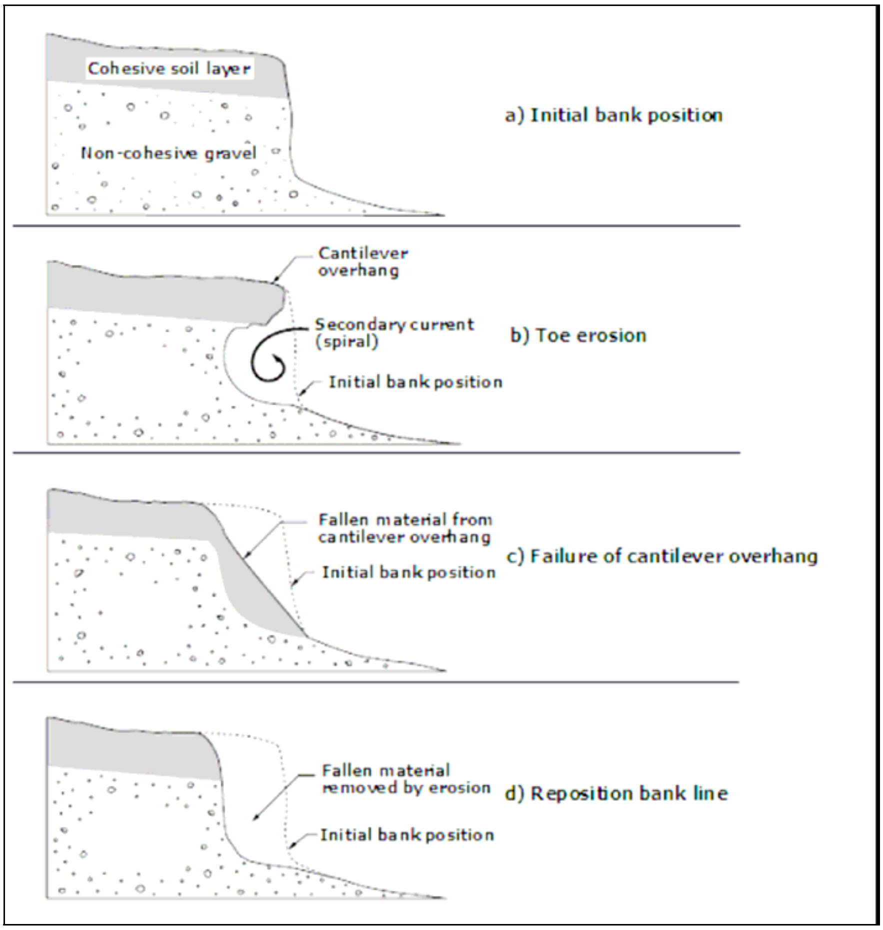


Figure 3.47 Undercutting of a composite bank [161]

Toe erosion or streambed degradation may also lead to geotechnical bank failures by increasing the height of the bank to the point where the sliding forces exceed the resisting forces (shear strength) of the bank materials. Bank failures from only geotechnical forces are normally related to moisture conditions within the bank. As previously mentioned, moisture can affect both the stresses within the bank and the bank material's ability to withstand those forces. Geotechnical failures commonly occur after the flood peak has passed, when banks are saturated and have been oversteepened by undercutting. Common examples of situations that may lead to this type of failure are as follows:

- Failures induced by rapid drawdown occur when the river stage falls following a flood, leaving the banks saturated. The pore water pressure in the bank reduces frictional shear strength of the soil and increases sliding forces by adding weight to the soil mass. This type of failure tends to occur in fine grained soils that do not drain rapidly.
- Banks are destabilized by the piping of soil particles from lenses (thin layers) of cohesionless sands. The piping undermines the overlying bank materials which then collapse.
- Expansion and contraction of soils during wet/dry cycles cause tension cracks that lead to bank failure by collapsing or toppling of blocks of soil.
- Subsurface moisture changes weaken the internal shear strength of the soil mass at the interface of different soil types.
- Capillary action temporarily decreases the angle of repose of the bank material to less than the existing bank slope. The oversteepened slope subsequently fails when the soil dries and capillary forces are no longer present.

3.4.3.6 Additional Causes of Bank Erosion in Natural Environments

In natural streams in undisturbed basins, causes of bank erosion include the following:

- Long term geological process of valley widening, particularly in entrenched streams in narrow valleys. This may involve gradual undercutting of high banks and cliffs, with occasional massive slides and slumps at points of stream impingement, especially during or after severe floods. Widening may be associated with a long term process of valley deepening and slope degradation.
- In streams with floodplains, some bank erosion may be of this type, and some may be of the next category described below.
- Systematic meandering processes in alluvial floodplains. Meander shifting may take various forms including systematic down-valley "sweep" and formation of cutoffs and oxbows. All forms of meander shifting involve erosion on one bank and deposition on the other, the width of channel remaining on average unchanged over a period of years. While the process can be completely natural, it is often accelerated by an increase in sediment load from the basin, or by removal of vegetation from the stream banks and floodplain.
- Extreme floods. Most river channels are adjusted naturally to accommodate without overspill a flood in the range of 2 to 5 years return period. Larger floods have a tendency to widen the channel temporarily, in the case of a 50-year or 100-year flood, extensive bank erosion may result from temporary channel widening, and it may take several years for the channel to shrink and the banks to re-stabilize.
- Debris and vegetation. In some environments, debris piled up by floods can be an important cause of local bank erosion. A debris blockage may cause currents to be deflected and impact directly on an erodible bank, or it may pond up water and bed sediment and thereby cause bed scour and bank collapse downstream of the obstruction. Debris accumulations tend to initiate large-scale turbulence which can be potent in bank erosion. On the other hand, rooted woody bank vegetation appears generally to retard bank erosion, although abruptly projecting large trees and roots may cause local erosion. If the bank is high in relation to depth of rooting, vegetation may be of little benefit.
- Coarse sediment. Rivers undergoing extensive bank erosion often exhibit coarse sediment deposits in the form of channel bars. The sediment is often blamed for erosion on nearby banks and is sometimes removed in order to improve bank stability. But if the erosion and process such as meandering occur, the stream can quickly replace removed deposits. On the other hand, a new source of coarse sediment introduced into the stream for example by a landslide or from a disturbed tributary, may well increase bank erosion.
- Geotechnical instability, as a primary cause of bank erosion, is important mainly in entrenched streams with high steep banks in weak soils and formations. In other cases geotechnical instability tends to come into play after the bank slope has been steepened or heightened by hydraulic scour at the toe. Nevertheless, interpretation and treatment of bank erosion require consideration of both hydraulic and geotechnical factors. Scour at the toe of a marginally stable bank in liquefaction-susceptible fine-grained soils may trigger massive slides in certain circumstances. Water seepage and piping, and sudden drawdown in regulated waterways, may be important causes of failure. Locally, grazing or burrowing animals may be important factors.

3.4.3.7 Additional Causes of Bank Erosion Due to Human Activities

- Basin Development. Where the drainage basin upstream of the stream in question has been altered by developments, such as conversion from forest to farmland or to urban use, flood peaks and sediment often increase dramatically. Increased flood peaks almost inevitably increase potential for bank erosion. Increased sediment loads may foster instability if they contain coarse material that forms channel bars. Surface runoff from cleared fields, concentrated at points along the bank and allowed to run over without culverts or drop pipes, can cause gullying leading to general bank failure.
- Removal of bank vegetation. Removal of trees or bushes from streambanks and adjacent areas often initiates or accelerates bank erosion. Removal usually results from timber harvesting, agricultural intensification, or urban and suburban development. It can often be noticed that banks are receding on a cleared property but not on adjacent properties in a natural state.

- Boat-generated waves from recreational or commercial traffic may be important causes of upper bank erosion in navigated streams and waterways.
- Constriction and obstruction at bridge crossings. Constricted bridge crossings or other encroachments that involve acceleration and concentration of flood flows tend to cause "back eddies" or reverse circulation downstream, which can sometimes erode huge embankments at river banks. Similar phenomena on a smaller scale are common downstream of culverts.
- Local bank protection and river training works, designed to protect against bank erosion at one point or reach of a river, often induce accelerated bank erosion elsewhere. It is now widely recognized that potential third party impacts of local bank protection and river training works should receive careful consideration.
- Sand and gravel mining from stream channels and bars may contribute to bank erosion by causing bed degradation and undercutting of banks.
- Channelizing or straightening has often been resorted to as a cure for a range of stream problems including bank erosion by meandering. Although it tends to arrest meander erosion for a time, channelization often initiates a long sequence of responses including incision or degradation, slope undercutting and a tendency to develop new meanders.

3.4.3.8 Estimation of Future Channel Stability and Behavior

One objective of stability assessment is to anticipate the migration of bends and the development of new bends. The lateral stability of a stream can be measured from records of its position at two or more different times where the available records are usually maps or aerial photographs. Historic surveyed cross-sections are extremely useful. It is recognized that some progress is being made on the numerical prediction of loop deformation and bend migration. At present, however, the best available estimates are based on past rates of lateral migration at a particular reach. However, erosion rates may fluctuate substantially from one period of years to the next (Richardson and Simons 2001)[22].

Measurements of bank erosion on two time-sequential aerial photographs (or maps) require the identification of reference points which are common to both. Useful reference points include roads, buildings, irrigation canals, bridges and fence corners. This analysis of lateral stability is greatly facilitated by a drawing of time changes in bankline position. To prepare such a drawing, aerial photographs are matched in scale and the photographs are superimposed holding the reference points fixed.

Bank erosion rates increase with the stream size as shown in Figure 3.48. Sinuous canaliform streams can then be expected to have the lowest erosion rates and the sinuous braided streams, the highest.

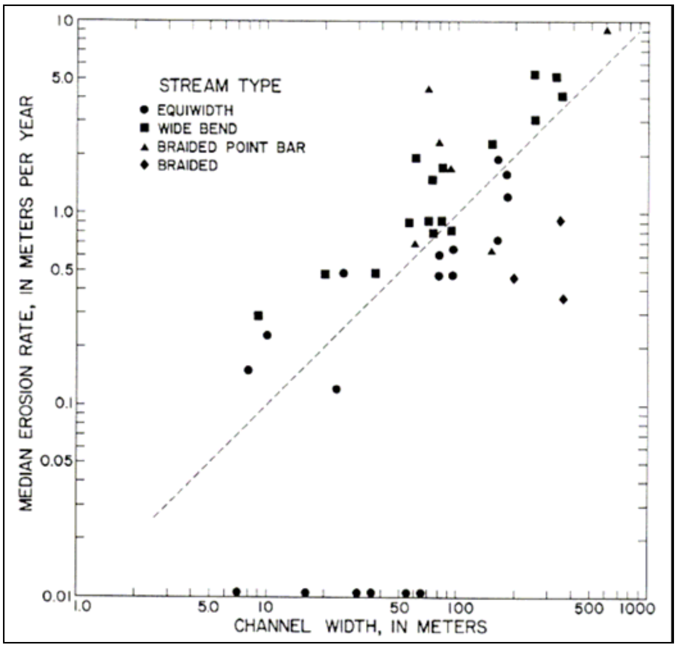


Figure 3.48 Median bank erosion rate in relation to channel width for different types of streams [22]

The lateral stability of different stream reaches can be compared by means of a dimensionless erosion index. The erosion index is the product of its median bank erosion rate expressed in channel widths per year, multiplied by the percent of reach along which erosion occurred, multiplied by 1,000. For example, erosion indexes for 41 streams in the United States are plotted against sinuosity in Figure 3.49. The length of most of these reaches is 25 to 100 times the channel width. The highest erosion index values are for reaches with sinuosity ranging between 1.2 and 2. Erosion indexes are large for sinuous braided and sinuous point bar (wide bend) streams. Equiwidth streams tended to be relatively stable. The erosion index value of 5, in Figure 3.49, is suggested as a boundary between stable and unstable reaches. Brice (1984) considers that reaches having erosion indexes values less than 5 are unlikely to cause lateral erosion problems.

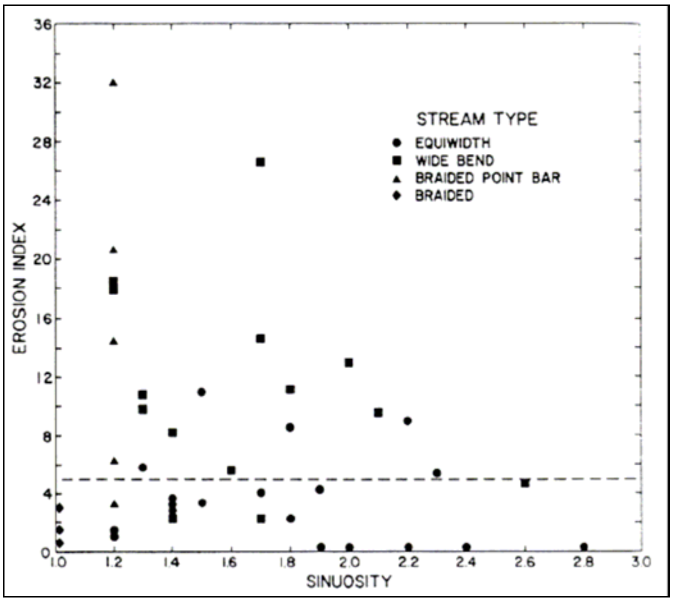


Figure 3.49 Erosion index in relation to sinuosity [22]

A general assessment of bank stability can be made considering the following aspects.

Bank Erosion Rates. It is theoretically possible to determine bank erosion rates from factors such as water velocity and resistance of the banks to erosion. See HEC-18 [9] for a discussion of recent advances in measuring erosion rates. The results in Figure 3.48 provide a first approximation of migration rate of a bend regardless of the hydraulic conditions and sediment characteristics. Past rates of erosion at a particular site provide the best estimate of future rates. In projecting past rates into the future, consideration must be given to the following factors: (1) the past flow history of the site during the period of measurement, in comparison with the probable future flow history (e.g. during the life span of the highway crossing). The duration of floods, or of flows near bankfull stages, is probably more important than the magnitude of floods; and (2) human-induced factors that are likely to affect bank erosion rates. Among the most important of these are urbanization and the clearing of floodplain forests.

Behavior of Meander Loops. If the proposed bridge or roadway is located near a meander loop, it is useful to have some insight into the probable way in which the loop will migrate or develop, as well as its rate of growth. No two meanders will behave in exactly the same way, but the meanders on a particular stream reach tend to conform to one of the several modes of behavior illustrated in Figure 3.50.

Mode A (Figure 3.50) represents the typical development of a loop of low amplitude, which decreases in radius as it extends slightly in a downstream direction. Mode B rarely occurs unless meanders are confined by valley sides on a narrow floodplain, or are confined by artificial levees. Well developed meanders on streams that have moderately unstable banks are likely to follow Mode C. Mode D applies mainly to large loops on meandering or highly meandering streams. The meander has become too large in relation to stream size and flow, and secondary meanders develop along it, converting it to a compound loop. Mode E also applies to meandering or highly meandering streams, usually of the equiwidth point-bar type. The banks have been sufficiently stable for an elongated loop to form (without being cut off), but the neck of the loop is gradually being closed and cutoff will eventually occur at the neck. Modes F and G apply mainly to locally braided sinuous or meandering streams having unstable banks. Loops are cut off by chutes that break diagonally or directly across the neck.

Effects of Meander Cutoff. If cutoffs seem imminent at any meanders, the probable effects of cutoff need to be considered. The local increase in channel slope due to cutoff usually results in an increase in the growth rate of adjoining meanders, and an increase in channel width at the point of cutoff. On a typical wide-bend point-bar stream the effects of cutoff do not extend very far upstream or downstream.

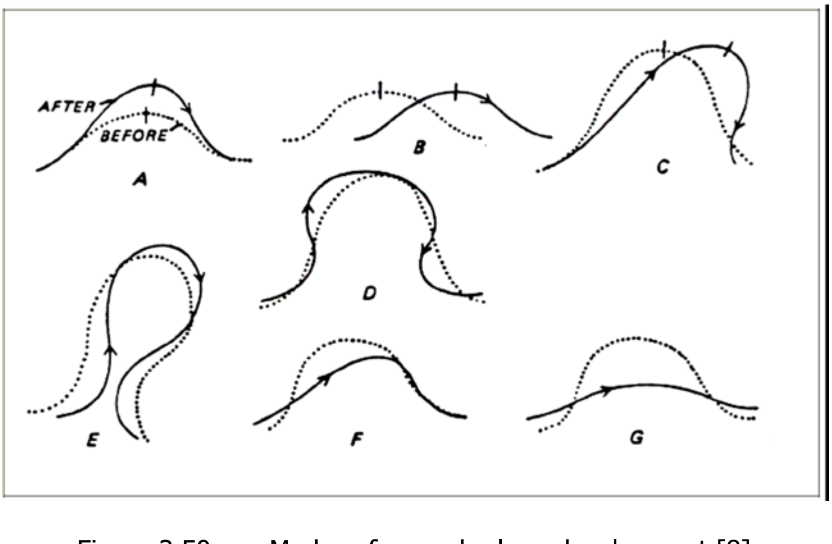


Figure 3.50 Modes of meander loop development [8]

Assessment of Degradation. Field sites having degradation problems are more numerous than sites having aggradation problems. Annual rates of degradation averaged from past records give poor estimates of future rates of degradation. Typical situations exhibit an exponential decay function of the rate of channel degradation. Recent evidence of degradation can be detected from field surveys or by stereo viewing of aerial photographs. Indicators of degradation are: (1) channel scarps, headcuts and nickpoints; (2) gullying of minor side tributaries; (3) high and steep unvegetated banks; (4) measurements of streambed elevation from a referenced datum; (5) changes in stream discharge relationships; and (6) measurements of longitudinal profiles.

Assessment of Scour and Fill. Natural scour and fill refer to fluctuations of streambed elevation about an equilibrium condition. These fluctuations are associated mainly with floods and occur by three different mechanisms operating jointly or independently: (1) bed form migration; (2) convergence and divergence of flow; and (3) lateral shift of thalweg or braids. The maximum scour induced by the migration of a dune is almost one-half the dune height, and dune heights are roughly estimated as one-third of the mean flow depth. In gravel bed streams, most migrating bed forms can be regarded as bars, the height of which is related to flow depth. The migration of a bar through a bridge waterway is mainly of concern because of the deflection and concentration of flow. Bar migration tends to be a random process and its motion can best be tracked from time-sequential aerial photographs.

Gravel bars tend to migrate on braided streams and to remain fixed at riffles on unbraided pool and riffle streams.

Flow convergence in natural streams is associated with scour, whereas divergent currents are associated with deposition. Persistent pools have the strongest convergence of flow and the greatest potential for scour. Such pools are best identified by a continuous bed profile along the thalweg. In braided streams, scour holes are found at the confluence of braids. Field measurement of cross-sectional area and flow velocity at an incised reach near bankfull stage provides a good basis for calculation of scour by extrapolation to the design flood.

Instability of the streambed that results from shift of thalweg is related to stream type and can be assessed from study of aerial photographs. On sinuous streams, the shift of the thalweg during flood is minimal. A greater shift of the thalweg can be expected on sinuous point-bar streams. In straight reaches, alternate bars visible on aerial photographs taken at low stage are commonly present. These alternate bars indicate the potential for thalweg shifting and also for bank erosion when the current is deflected against the bankline. The shift of the thalweg with increase in stage must be considered when determining the location of the point of maximum bed scour and bank erosion.

3.4.4 Geologic and Geomorphic Controls on Bank Erosion

Geologic and geomorphic variables influence river characters and behaviors including, of course, bank erosion. Not only is the geologic and geomorphic history of the river system important but processes such as active tectonics and changing bend configurations can also cause major changes in location and amount of bank erosion.

Historical events such as climate change, and previous channel position determine the geologic controls of alluvial stratigraphy and valley morphology. In addition rock type in and relief of the headwaters influences the type and amount of sediment delivered to a river.

Geomorphic controls on bank stability are channel and valley morphology and the changing position and behaviour of the channel through time. For example, bank erosion varies with changing meander morphology and the stage of adjustment of incised channels. Therefore, geomorphic investigations of channel evolution and morphology will aid in the identification of river reaches that require bank protection as well as those reaches where bank protection will be of little value.

3.4.4.1 Battering and Terracing

Earthworks may be required to reduce steep banks to a stable slope and provide areas for vegetation to establish. This can be achieved by battering or terracing the banks. Earthmoving equipment can be used to reshape the bank to an even slope as shown in Figure 3.51. Banks will need to have a maximum slope of approximately 1:4 (vertical:horizontal) for vegetation to be able to take hold. Terracing involves levelling steps up the bank to create benches for planting, as shown in Figure 3.51. Terraces should be created at a maximum of 300 mm above the low flow level so that plantings have access to soil water moisture. Using earthworks to stabilize stream banks will involve the loss of vegetation already established on the bank and can result in widening the eroding channel. Additional material brought to the site or obtained from within the channel can be used to reshape the banks. Sediment deposited on point bars can be excavated and placed against eroding banks to create a stable slope. The stream bank will be exposed to erosion until vegetation is established to protect the bank. The technique is more applicable to seasonal waterways where there is opportunity to undertake the earthworks and stabilize the area prior to seasonal flows. Continuous flow can cause ongoing erosion. Brushing or matting can be used to stabilize the banks until vegetation establishes. Battering or terracing the banks can be used to prevent bank failure caused by material being washed from the face of the bank or due to overland flow. The technique may not be successful in controlling undercutting or erosion occurring below water level. Additional protection may be required at the base of the bank using hard engineering techniques.

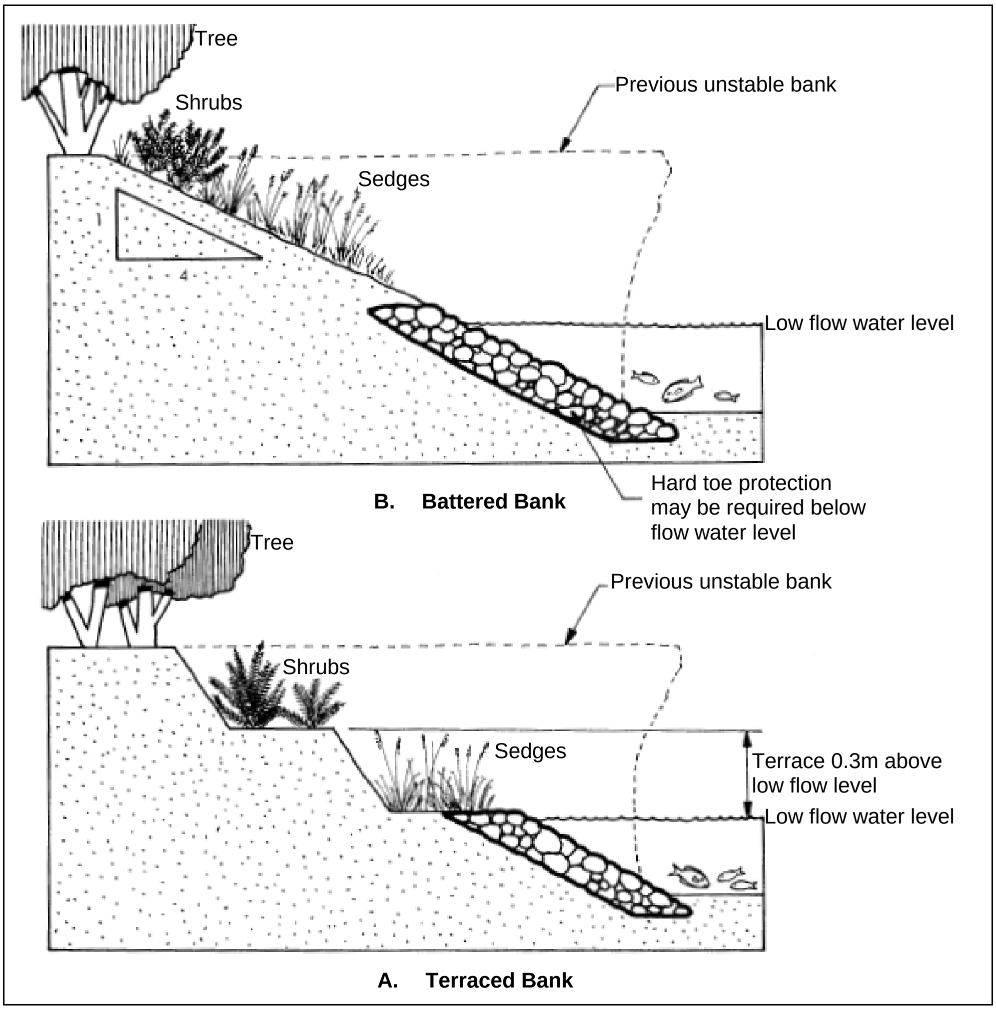


Figure 3.51 Reshaping banks to a stable slope [18]

3.4.4.2 Brushing

Brushing consists of cut trees or branches that can be used to provide superficial bank protection. The technique is most applicable to controlling bank erosion caused by the washing action against the face of the bank. The brush is layered horizontally against the bank, with the butt of the branch facing upstream. Alternatively the branches can be placed with the butts at the top of the bank and the heads facing down the bank, angled downstream. The brushing should be secured into place. It can be tied to anchors on the top of the bank, such as buried logs or posts, and weighted down or pegged into position. Wiring or steel cables can be used to secure the brushing as shown in Figure 3.52. Smaller pieces of brushing can be used to provide bank protection by bundling the material to form mattresses against the bank. The bank may need to be battered prior to placing the material.

Brushing only provides temporary bank protection. The stabilization technique relies on bank revegetation to stabilize the sediment once the brushing has rotted away. The technique is not as stable as harder methods and may not be effective where deep and powerful flows are experienced. Brushing is a low cost bank stabilization technique that provides a variety of additional environmental benefits, such as encouraging regeneration and creating instream habitat and food sources.

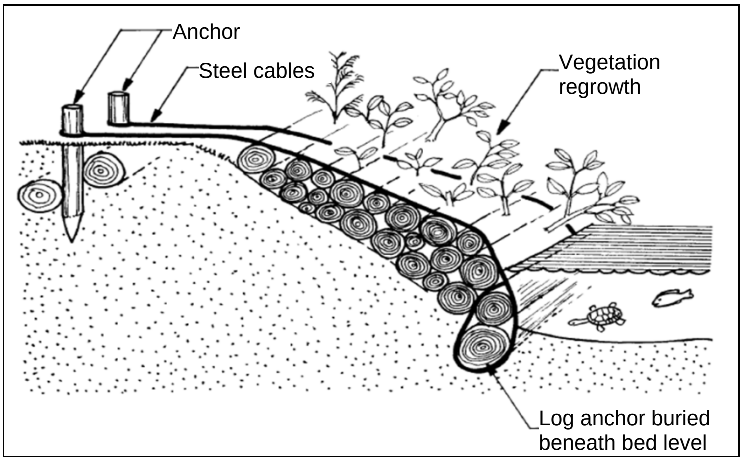


Figure 3.52 Brushing bank protection [18]

3.4.4.3 Organic geotextiles

Organic geotextiles are vegetative mats which can be used to stabilize banks and prevent soil loss caused by overland flow and a lack of vegetative cover. Mats or blankets are manufactured from natural fibres such as wheat straw, jute (hessian) or coconut fibre. Reinforced mats with a natural fibre or plastic woven mesh can be used to provide longer term protection. Mats and blanket rolls come in a variety of sizes and thicknesses. Rolls are available up to 3.66 metres wide by 30 metres long. The densities of the mats vary to allow or block light diffusion. This enables germination and suppresses weed growth. Mats with slits cut for plantings can also be used to control weeds and enable native vegetation growth. Vegetative mats are biodegradable and add organic matter to the soil as they break down. The mats reduce changes in soil temperature, decrease evaporation and improve infiltration and soil water moisture content, resulting in improved plant survival rates. Earthworks may be required to prepare the site. The stream bank may need to be battered to an even slope prior to laying the mat. The surface should be even and free from large rocks or stumps. Topsoil and fertiliser may need to be placed to prepare the bank for seeding. The bank can be hydro-mulched or seeded prior to laying the mat. Hydro-mulching involves spraying the bank surface with a mixture of seed, fertiliser and mulch to bind the soil particles together. Mats should be laid to cover the zone of instability and should extend from below low water level to the top of the bank or above high water mark. The mats should be rolled out onto the bank, down the slope if greater than 35 degrees or perpendicular across the slope if the slope is less than 35 degrees (Figure 3.53). A trench should be dug along the top and bottom of the bank and the edge of the mat buried. Where numerous mats are used along a bank, the edge of the lower mat should be tucked under the edge of the mat above, and the end of the upstream mat should cover the end of the downstream mat.

Mats should overlap by at least 100 mm and be pinned together. The mat will need to be secured into position by burying the side edges and inserting steel "U" shaped pins about every 200-250 mm along the edges of the mat, with 2-4 pins placed centrally per square metre. Steel pins are available from 150 to 600 mm in length. The pin length required to secure the mat will depend on the bank soil structure and site conditions. Mats should be wetted so as to conform to the contour of the bank. Mats protect seed and soil from erosion. The mats have a limited life (about six months to two years) and require the establishment of vegetation to stabilize the bank in the long term. Access by livestock will have to be controlled during this period.

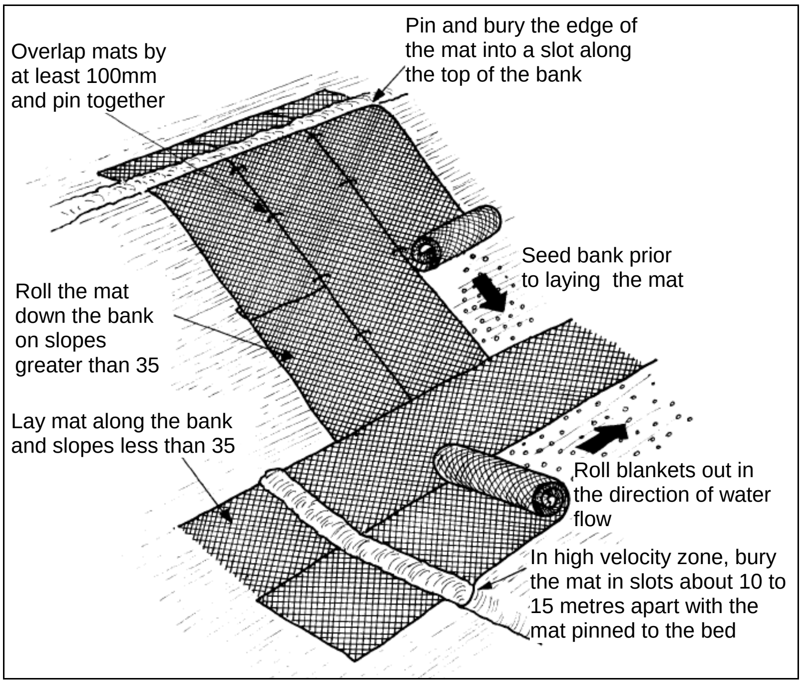


Figure 3.53 Installation of matting to prevent soil loss [18]

3.4.4.4 Log Walling

A log wall can be constructed along the base of an eroding bank to hold the bank material in place. Piles are driven into the streambed with more than half their length buried beneath bed level. Logs are placed horizontally on top of each other behind the support piles and bolted or wired to the posts. Filter cloth is placed behind the logs and the wall backfilled with soil. Local native sedges and rushes, shrubs and trees are planted behind the wall (Figure 3.54). The technique can be applied to provide toe protection from undercutting or treat bank slumping. Log walls cannot be built on hard riverbeds.

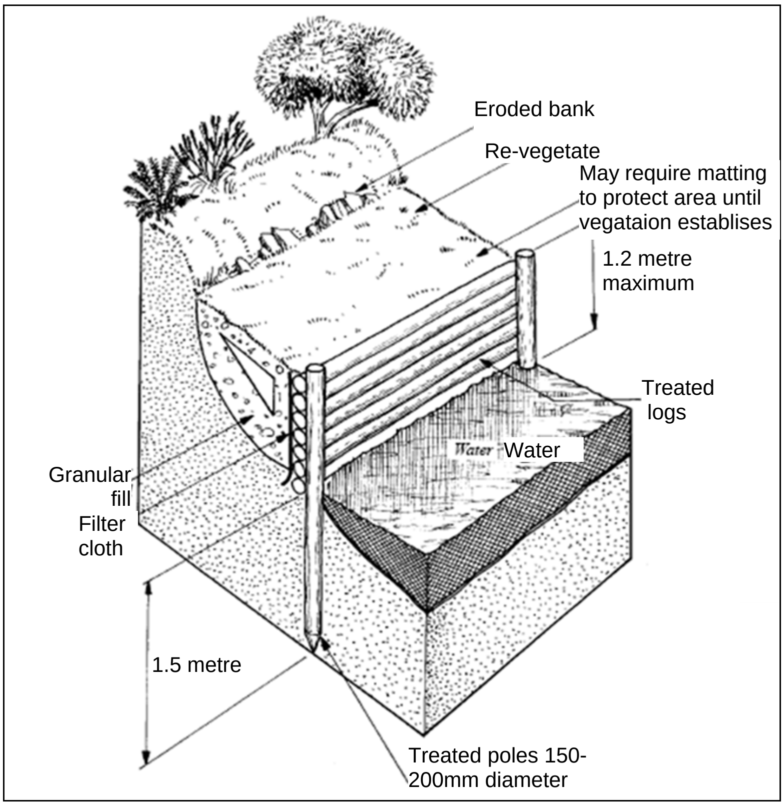


Figure 3.54 Log walling built to stabilize the base of an eroding bank [18]

3.4.4.5 Rock Gabions

Rock gabions are large, rectangular, hexagonal mesh wire cages filled with stone (Figure 3.55a). Gabions can also be extended to large flat rock-filled mattresses. They can be used to build a retaining wall along the base of an eroding bank and can be used for river training. The wall holds the bank material in place and prevents slumping. Empty gabion cages are placed in position at the toe of the bank, filled with stone and wired closed. Filter cloth is placed behind the wall and the bank backfilled with sediment. The bank should be revegetated. Overtime the voids in the gabion trap sediment on which vegetation is able to establish. Minor earthworks may be required to prepare the site. The surface should be level and free from large rocks or stumps prior to installing the gabions. Gabions are flexible and can tolerate movement and settlement in the bed material. Fixed structures, for example, concrete walls are more prone to fracture and failure in a riverine environment due to the movement of sediment caused by water flow or wave action. Gabions are also permeable, allowing bank slopes to drain (Figure 3.55b). The technique does not require expert construction and requires little maintenance. Gabions are available in a range of sizes, usually from 1 to 4 metres long, by 0.5 to 1 metre wide and high. The cages can be further reinforced by installing additional mesh panels to divide the boxes into smaller units. The cages are anchored into position and stretched while filling. Empty cages can be wired together to construct a range of structures. The wire is heavily zinc coated to reduce corrosion. PVC coated wire gabions are also available to provide further protection from corrosion in marine or polluted environments. Hard, durable quarry rock is used to fill the gabions, which is usually carried out by an earthmoving machine. The rock should be tightly packed and the cages slightly overfilled to allow for settlement. Wire bracing is used in the cages to prevent bulging. The rock should be sized slightly larger than the size of the mesh voids (rock sizes 125 mm to 250 mm with less than 7% of smaller material). Gabions can be installed on hard riverbeds, as driving of supporting piles is not required. Gabions are labor intensive and expensive. They are also prone to wire corrosion and abrasion and can be structurally unstable when placed on soft foundations. Finally, they can be prone to vandalism in urban areas.

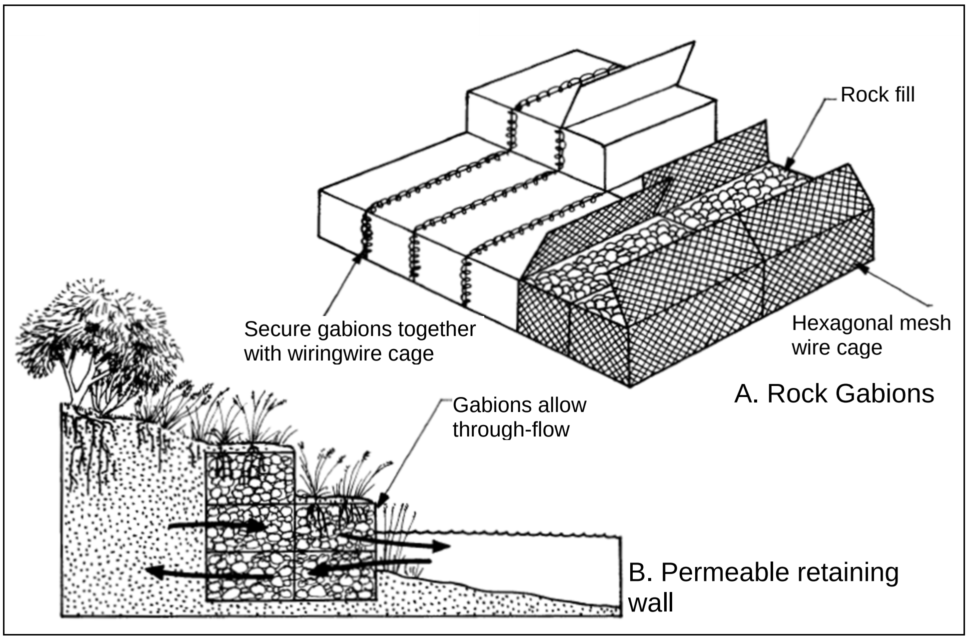


Figure 3.55 Stabilization of steep banks using rock gabions [18]

3.4.4.6 Rock Riprap

Rock riprap is usually the most effective and least expensive method of riverbank protection. It consists of a layer of rock which is placed on a stream bank to protect it from erosion (Figure 3.56). The stream bank is rock paved usually to above high water mark. Reinforcement with riprap of only the toe may be required in some cases to support the bank. The bank may require battering prior to placement of materials. Gravel filters are usually necessary between the rocks and the erodible bank material. Filter cloth can be placed on the bank beneath the rock to provide protection from undermining caused by flows getting above and behind the riprap, washing out sediment and destabilising the works. A trench should be excavated at the toe of the bank and the riprap laid beneath bed level. Alternatively, on hard riverbeds, a rock ledge can be built along the toe of the bank. The technique is applicable to most types of bank erosion and provides long term protection. Sediment accumulation along the riprap can lead to eventual establishment of vegetation. Riprap should not be constructed along banks that are being undermined by bed deepening. The bed level will need to be stabilized prior to undertaking bank stabilization works. Riprap should be constructed of well-graded rock. The tractive forces of high flows will need to be considered in selecting the appropriate size range of materials. The size of the riprap required is determined by the slope of the bank, flow depth, rock density and shape, bed slope and width and radius of curvature of the channel at the site. Detailed design guidelines and programs exist to calculate a design for riprap construction. A brief account on the commonly used equations by Pilarczyk and Maynord to determine the sizes of ripraps is provided in Appendix G. The area to be protected should extend upstream and downstream of the unstable zone for at least a length approximately equal to the channel width. The thickness of the layer of riprap should be a minimum of double the median diameter rock size or at least the maximum rock diameter. An example of riprap design for bank protection using the Pilarczyk's equation is also as shown in Appendix G. The design methods for filters can also be found in Highways in the River Environment [22] or in Julien (2002) [80].

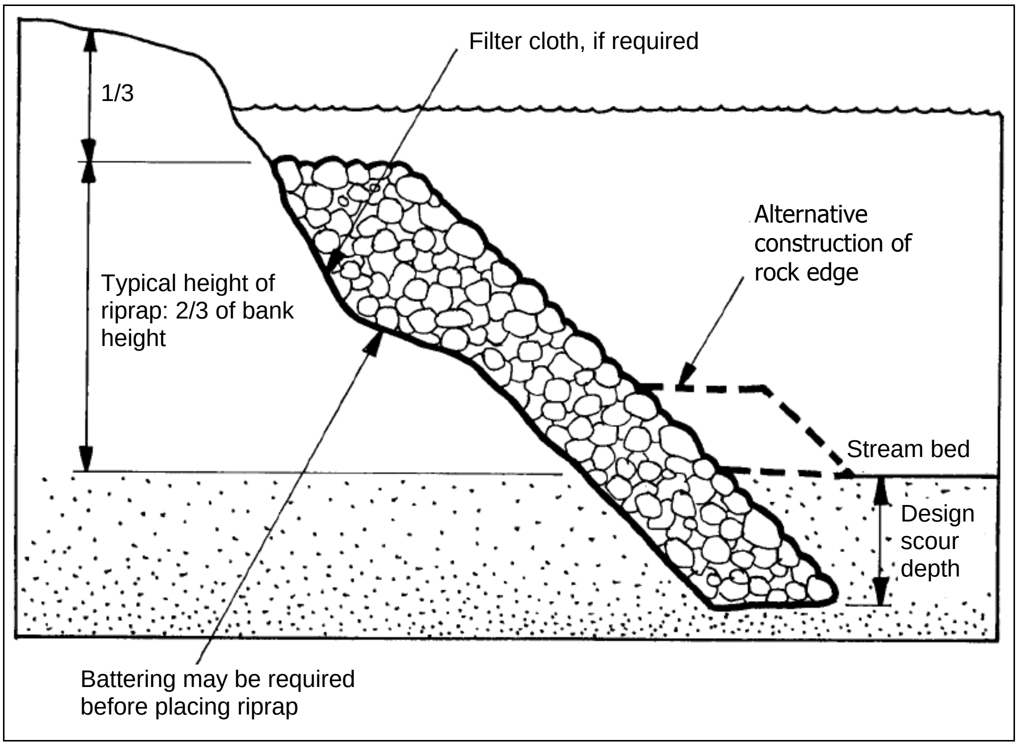


Figure 3.56 Riprap bank protection [18]

3.4.4.7 Geotextiles, mattresses and flexmats

There is a wide range of geotextiles, mattresses and flexmats on the market with applications including slope and bank stabilization and channel lining. Geotextiles are synthetic woven blankets that can be applied to hold sediment in place while allowing water drainage. The fabric acts to support the soil structure and improves the ability of the bed or banks to support and secure a load such as rock or soil placed on top of the material. In highly erosive or dispersive soils, a geotextile is often required beneath structures such as gabions and rock riprap for support and protection against undermining.

Earthworks may be required to prepare an even surface, free from large rocks or stumps. The filter cloth should be rolled on to cover the zone of instability and should extend from below low water level to the top of the bank or above high water mark. Soil, rock or structural works are placed over the cloth. The fabric contours to the bank and is flexible to accommodate further movement. The synthetic fabric has a long life and does not break down under a variety of conditions. Synthetic blankets are available in 100 metre rolls and are about 0.3 to 0.6 mm thick and 1.83 to 5 metres wide.

Geoweb or geocell : Geoweb, geocell or equivalent is a cellular confinement system. It consists of an expandable three-dimensional polyethylene, honeycomb-like structure that can be installed over a layer of geotextile on a prepared slope to be protected. The cells can then be backfilled with sand and gravels and subsequently vegetated as required. The geoweb system stabilizes the selected infill material through confinement of soils in its network of interconnected cells. The perforations provide increased frictional interlock with coarse aggregates and, if vegetated, increase in root lock-up. Integral components include tendons and load-transfer clips for overall system stability (Figure 3.57).

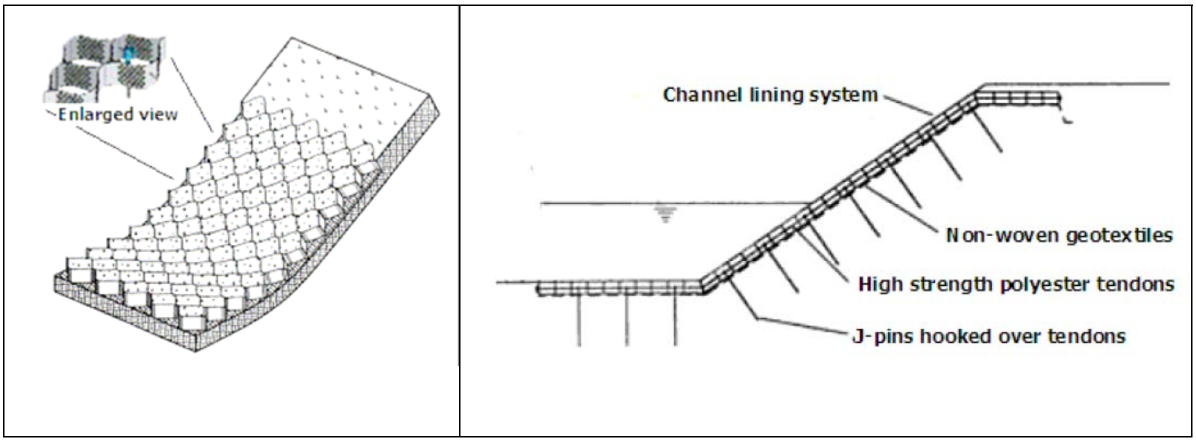


Figure 3.57 Geocell bank protection system (Source: Presto Geoweb system)

Sand-filled mattresses. Sand-filled mattresses consist of two geotextiles attached onto each other, between which sand is interposed. Needled punched onto the top geotextile is a layer of UV stabilized green-coloured fibre which helps to protect it from the sunlight. These mattresses are designed to be laid flat on a prepared slope, joined together, and then filled. They form a large mass of sausage-like sand sections. They should be installed according to the manufacturer's recommendations.

The edges and connections of sand-filled mattresses are vulnerable and must therefore be finished carefully. Mattresses lying next to each other can be sown together and the ends can be secured with, for example, ground anchors. The toe is normally protected either with ripraps or weighted and secured with an enlarged bulb at the end section. As it is very flexible, it can conform to the surface to be protected thus making it suitable for river banks subjected to moderate erosion. However, regular maintenance especially weeding out of very young trees or seedlings is important as damage can be caused by the root systems as the trees grow older. Special care also needs to be exercised in river bank trimming or desilting works as the mattress can be easily damaged by the buckets of excavators (Figure 3.58).

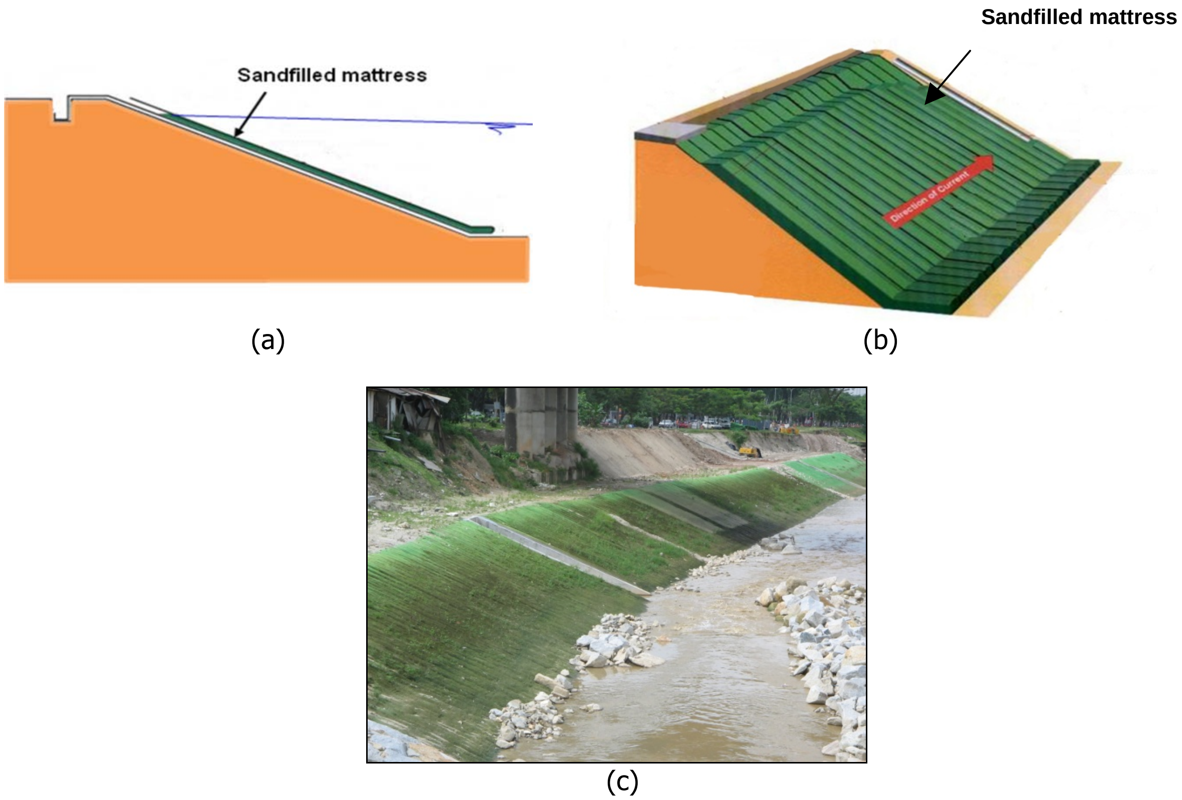


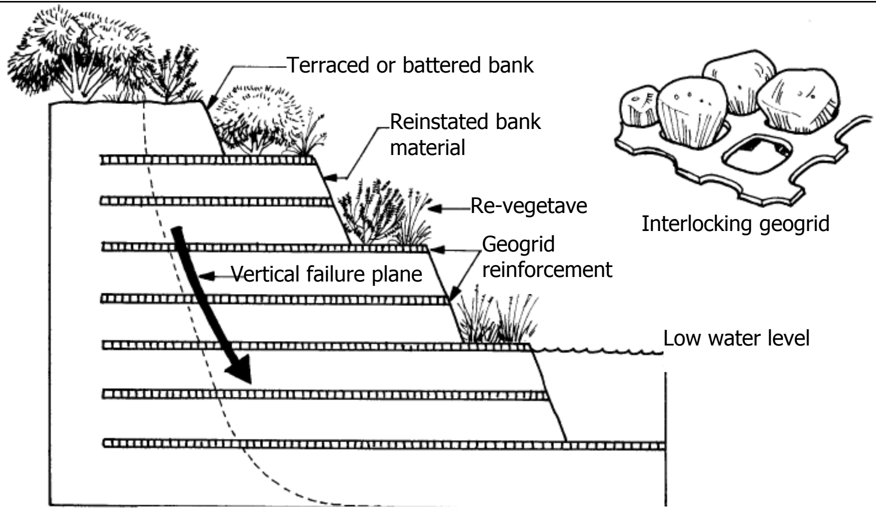
Figure 3.58 Sand-filled mattress for bank erosion protection at Kerayong River, Kuala Lumpur.

Synthetic grids. Synthetic grids can be used to improve the strength of the soil structure. Grids can be installed in horizontal layers through t Anchor einforce the bank against failure along vertical slip planes (Figure 3.59a). Synthetic grids can also be used to line channels and prevent erosion in vegetated channels. Grids can be used in combination with revegetation rather than rock paving or concreting the channel. The grid holds the channel material in place while vegetation takes hold. The root systems lock into the grid, improving the channel resistance to high flows. Reinforced vegetated channels can withstand up to double the flow rates of vegetated channels that are not reinforced. Synthetic or wire mesh can be secured to the bank using "U" shaped pins. The mesh is permeable and allows plantings to provide a more aesthetic finish. The bank can be treated with hydroseeding (spraying a mixture including seeds, fertilizers and binding agents onto the bank). Fine mesh can be used to retain sandy banks and wider mesh sizes for stony or rocky banks.

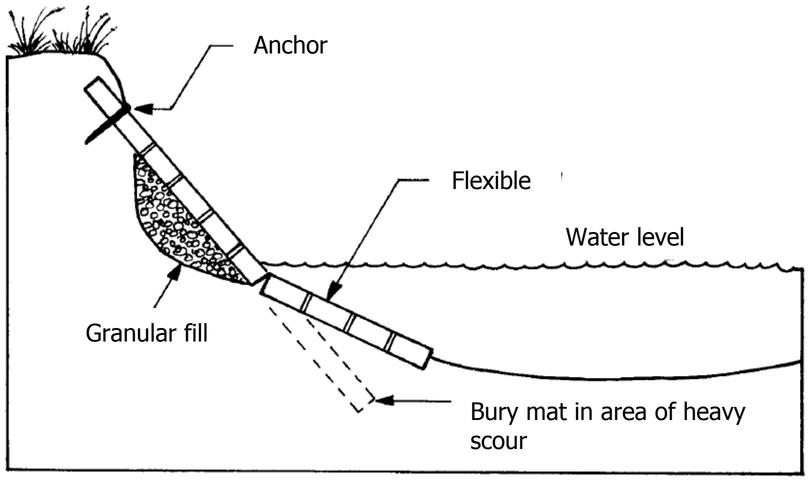
Concrete flexmats. Concrete flexmats can be used to stabilize steep banks and provide harder bank protection (Figure 3.59b). Empty mats that contour to the bank are laid and pumped full of concrete. Concrete bank protection does not allow through-flow of groundwater or the easy establishment of vegetation. The concrete mats may be prone to undermining and failure due to water and sediment movement.

Rock mattresses. Bank stabilization can be achieved by placing rock mattresses along the bank slopes (Figure 3.59c). The empty wire mesh mattresses are laid into position, wired together and filled with rock. Mattresses filled will small stone are more environmentally beneficial than flexmats. The rock mattresses create a rough surface with voids and has similar properties to natural channel conditions, allowing free drainage and greater opportunity for biological activity. Over a period of time, the stabilized banks will become covered with silt and sand and will be able to support vegetation. Alternatively, topsoil may be brought to the site and laid on top of the works, followed by revegetation. The vegetation binds the structural works to the adjacent embankment.

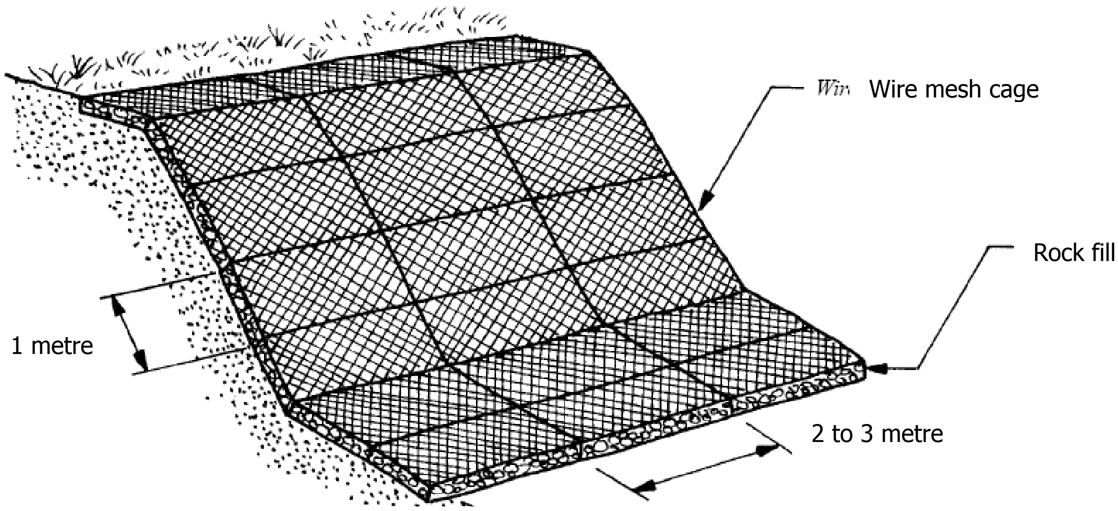
The wire cages that form the mattresses are similar in structure and installation procedure to the gabions, but are thinner and larger in area. They are usually a maximum of 6 metres by 2 metres in area and 0.17 to 0.5 metres thick. Rock sizes should be slightly larger than the mesh void size, but should not exceed two-thirds the mattress thickness. The cages should be slightly overfilled to allow for settling. The bottom compartments should be filled first. The rock material may require compaction to a minimum density specification, depending on the site conditions. A continuous mesh panel can be rolled onto the mattresses and wired to seal the structure. The bank may require battering, to an even slope prior to placing the mattresses. Mattresses may need to be temporarily pegged into position during installation on steep banks (slopes greater than 1:1.5). Suitable local sources of fill material should be investigated when assessing the feasibility of the technique.



a) Bank reinforced with synthetic



b) Concrete flexmat used for bank



c) Bank stabilisation using rock

Figure 3.59 Bank stabilizers [18]

3.4.4.8 Conventional Retaining Walls and Keystone Wall

Retaining walls, especially those constructed from materials such as reinforced concrete, steel, vinyl etc., are less environmentally friendly and should only be used when more environmentally friendly options cannot be implemented due to site restrictions. This point need to be emphasized as the main objective of stream rehabilitation is to restore the stream banks to their natural conditions and such hard structures are counterproductive to that effort.

A retaining wall is a structure that holds back soil or rock from a building, structure, stream or area. Retaining walls prevent downslope movement or erosion and provide support for vertical or near-vertical grade changes. Cofferdams and bulkheads, structures that hold back water, are sometimes also considered retaining walls. Retaining walls are generally made of masonry, stone, brick, concrete, vinyl, steel or timber. Segmental retaining walls have gained favor over poured-in-place concrete walls or treated-timber walls. They are more economical, easier to install and more environmentally sound.

The most important consideration in proper design and installation of retaining walls is that the retained material is attempting to move forward and downslope due to gravity. This creates a lateral earth pressure behind the wall which depends on the angle of internal friction ϕ and the cohesive strength c of the retained material, as well as the direction and magnitude of movement the retaining structure undergoes. Lateral earth pressures are typically smallest at the top of the wall and increase toward the bottom. Earth pressures will push the wall forward or overturn it if not properly addressed. Also, any groundwater behind the wall that is not dissipated by a drainage system causes an additional horizontal hydraulic pressure on the wall. The common types of retaining walls are shown in Figure 3.60 and briefing described in the following sections.

Gravity Walls. Gravity walls depend on the weight of their mass (stone, concrete or other heavy material) to resist pressures from behind and will often have a slight 'batter' setback, to improve stability by leaning back into the retained soil. For short landscaping walls, they are often made from dry-stacked (mortarless) stone or segmental concrete units. Dry-stacked gravity walls are somewhat flexible and do not require a rigid footing.

In the early days, taller retaining walls were often gravity walls made from large masses of concrete or stone. Today, taller retaining walls are increasingly built as composite gravity walls such as: geosynthetic or with precast facing; gabions (stacked steel wire baskets filled with rocks), crib walls (cells built up log cabin style from precast concrete or timber and filled with soil) or soil-nailed walls (soil reinforced in place with steel and concrete rods).

Sheet piling. Sheet pile walls are often used in soft soils and tight spaces. Sheet pile walls are made out of steel, vinyl, fiberglass or plastic sheet piles or wood planks driven into the ground. Structural design methods for this type of wall exist but these methods are more complex than for a gravity wall. As a rule of thumb; 1/3 third above ground, 2/3 below ground. Taller sheet pile walls usually require a tie-back anchor "dead-man" placed in the soil some distance behind the wall face i.e. tied to the wall face, usually by a cable or a rod. Anchors must be placed behind the potential failure plane in the soil.

Proper drainage behind the wall is critical to the performance of retaining walls. Drainage materials will reduce or eliminate the hydrostatic pressure and increase the stability of the fill material behind the wall.

Cantilevered. Prior to the introduction of modern reinforced-soil gravity walls, cantilevered walls were the most common type of taller retaining wall. Cantilevered walls are made from a relatively thin stem of steel-reinforced, cast-in-place concrete or mortared masonry (often in the shape of an inverted T). These walls cantilever loads (like a beam) to a large, structural footing; converting horizontal pressures from behind the wall to vertical pressures on the ground below. Sometimes cantilevered walls are buttressed on the front, or include a counterfort on the back, to improve their stability against high loads. Buttresses are short wing walls at right angles to the main trend of the wall. These walls require rigid concrete footings below seasonal moisture change depth. This type of wall uses much less material than a traditional gravity wall.

Anchored. This version of wall uses cables or other stays anchored in the rock or soil behind it. Usually driven into the material with boring, anchors are then expanded at the end of the cable, either by mechanical means or often by injecting pressurized concrete, which expands to form a bulb in the soil. Technically complex, this method is very useful where high loads are expected, or where the wall itself has to be slender and would otherwise be too weak.

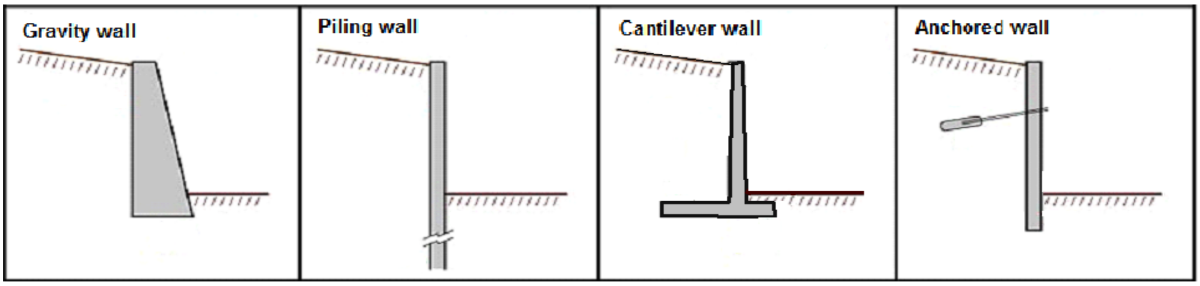


Figure 3.60 Types of conventional retaining walls

Keystone Walls. The keystone retaining wall system is a proprietary retaining wall system and is more aesthetically pleasing than other conventional retaining wall systems. It consists of modular concrete units (Figure 3.61a) for the construction of conventional gravity (Figure 3.61b) or geogrid-reinforced-soil (Figure 3.61c) retaining walls. These concrete units will be capped with corresponding cap units having either a straight or 3 plane split face. They also have holes for installation of 2 fibreglass connection pins which would also help in alignment of the units during placement. Unit core drainage fill consists of 13mm to 18mm of clean, crushed stone material and is placed between and behind the units. The unit core fill also provides additional weight to the completed wall section for stability, local drainage at the face of the wall, and acts as a filter zone to keep the backfill soil from filtering out through the space face between units (Keystone Retaining Wall System ESR 2113 2007)[23]

In the case of geogrid-reinforced-soil keystone wall, the geogrid materials used are proprietary materials used to increase the height of the Keystone Wall system above the height at which the wall is stable under its self-weight as a gravity system. Geogrids are materials specifically designed for use as soil reinforcement.

The gravity wall system relies on the weight and geometry of the keystone units to resist lateral earth pressures. Gravity wall design is based on standard engineering principles for modular concrete retaining walls. Typical deign heights are 2.5 to 3 times the depth of the unit being used. The geogrid reinforced soli system relies on the weight and geometry of the Keystone units and the reinforced soil mass to act as a coherent gravity mass to resist lateral earth pressures. The design of a reinforced soli structure is specific to the Keystone unit selected, soil reinforcement strength and soil interaction, soil strength properties, and structural geometry. The maximum practical height above the wall base is about 15m.

During installation, the wall system units are assembled in a running bond pattern. The units are assembled without mortar or grout, utilizing high-strength fiberglass pins for shear connections, mechanical connections of reinforcing geogrid, and unit alignment. The system may include horizontal layers of structural geogrid reinforcement in the backfill soil mass. The Keystone Design Manual and Manufacturer's Installation Instructions may be consulted for further details.

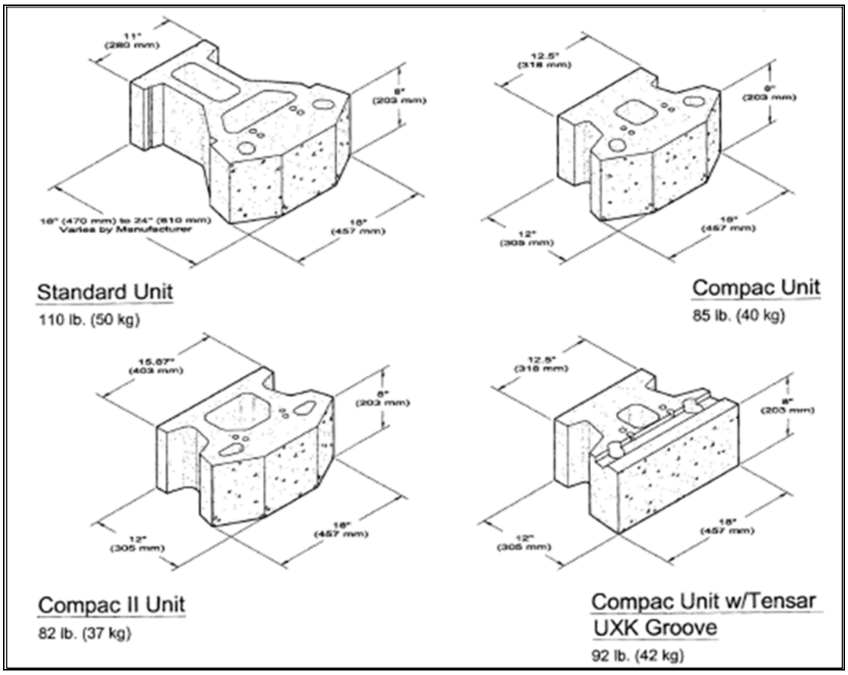


Figure 3.61a Keytone modular concrete unit [23]

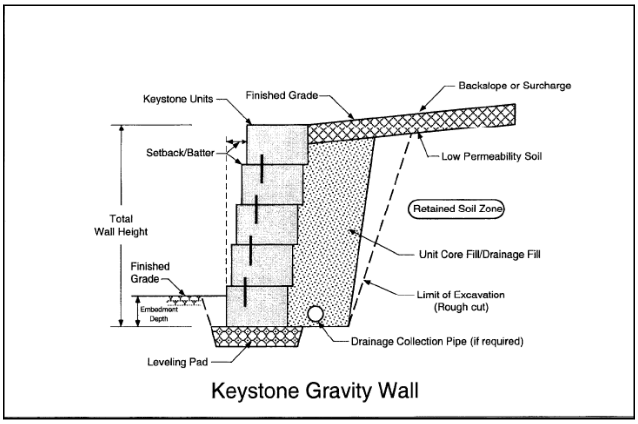


Figure 3.61b Keystone gravity wall [23]

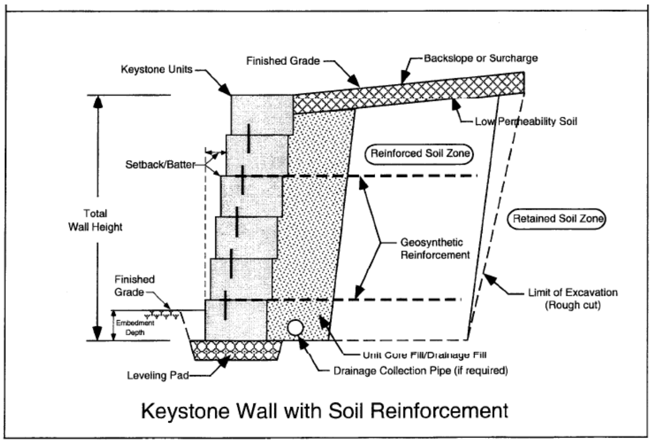


Figure 3.61c Keystone geogrid-reinforced-soil wall [23]

3.5 RIVER REHABILITATION PROCEDURES

3.5.1 River Rehabilitation Plan

A rehabilitation plan should emphasize the maintenance and rehabilitation of the ecological integrity and the dynamic stability of the stream corridor by focusing on multiple scales, functions, and values. A well-conceived and developed stream corridor rehabilitation plan is critical to establishing a framework for documenting the processes, forms, and functions operating within the corridor; identifying disturbances that disrupt or eliminate those functions, and planning and implementing rehabilitation activities. It serves as the cornerstone of the rehabilitation effort by achieving several key functions (Stream Corridor Rehabilitation 2001)[24].

3.5.1.1 Getting Organized

The key components of organizing and initiating the development of a stream corridor rehabilitation plan and establishing a planning and management framework to facilitate communication among all involved will be presented. Ensuring the involvement of all partners and beginning to secure their commitment to the project is a vital aspect of organizing and undertaking a rehabilitation initiative. It is often helpful to identify a common motivation for taking action and also to develop a rough outline of rehabilitation goals. In addition, defining the scale of the corridor rehabilitation initiative is important. Often the issues to be addressed require that rehabilitation be considered on a watershed or whole reach basis, rather than by an individual jurisdiction or one or two landholders.

Setting Boundaries

When boundaries are selected, the area should reflect relevant ecological processes. The boundaries may also reflect the various levels or scales (landscape, stream corridor and reach) at which ecological processes influence stream corridors. In setting boundaries, two other factors are equally important. One is the nature of human-induced disturbance, including the magnitude of its impact on stream corridors. The other factor is the social organization of people, including where opportunities for action are distributed across the landscape. To establish useful boundaries, one effective way of starting this process is through the identification of a stream reach or aquatic resource area that is particularly valued by the community concerned.

Establishing a Technical Team

Planning and implementing rehabilitation work requires a high level of knowledge, skill, and ability, as well as professional judgment. Often, it is found necessary to establish a special technical team to provide more information on a particular issue or subject.

In general, the interdisciplinary technical team should be organized to draw upon the knowledge and skills of different agencies, organizations, and individuals. To be successful, the expertise of the multidisciplinary team is essential. A team with a broad technical background is needed and should include expertise in both engineering and biological disciplines, particularly in aquatic and terrestrial ecology, hydrology, hydraulics, geomorphology, and sediment transport.

Team members should represent interagency, public, and private interests and include major partners, especially if they are sharing costs or work on the rehabilitation initiative. Team makeup is based on the type of task the team is assembled to undertake.

Identifying Funding Sources

Identifying funding sources is often an early and vital step toward an effective stream rehabilitation initiative. The funding needed may be minimal or substantial, and it may come from a variety of sources. Funding may come from State or Federal sources that have recognized the need for rehabilitation due to the efforts of local citizens' groups or the government departments themselves. Funding may come from philanthropic organizations, non-governmental organizations (NGOs), and contributions from private corporations etc. Regardless of the source of funds, the funding agent (sponsor) will almost certainly influence rehabilitation decisions or act as the leader and decision maker in the rehabilitation effort.

Facilitating Involvement and Information Sharing among Participants

Although a variety of outreach tools can be used to inform participants and solicit input, attention should be paid to selecting the best tool at the most appropriate time. In making this selection, it is helpful to consider the stage of the rehabilitation process as well as the outreach objectives. As the rehabilitation initiative involves many parties, the following techniques may be used to facilitate participant involvement and information sharing:

- Regular newsletters or information sheets apprising people of plans and progress.
- Regularly scheduled meetings of landowner and citizen groups.
- Public hearings.
- Field trips and workdays on project sites for volunteers and interested parties.

In addition, the innovative communication possibilities afforded by the Internet and the World Wide Web should be fully utilized.

Documenting the process

Documentation of the various activities being undertaken as part of the stream corridor rehabilitation effort is important. Although the rehabilitation plan, when completed, will ultimately document the results of the rehabilitation process, it is also important to keep track of activities as they occur.

An effective way to identify important rehabilitation issues and activities as well as keep track of those activities is through the use of a "Rehabilitation Checklist" as shown in Appendix H (National Research Council, 1992). The checklist can be maintained by the main implementing agency to engage project stakeholders and to inform them of the progress of rehabilitation efforts. The checklist can serve as an effective guide through the remaining components of rehabilitation plan development and project implementation.

3.5.1.2 Identifying Problems and Opportunities

The development of stream rehabilitation objectives is preceded by an analysis of resource conditions in the corridor. It is also preceded by the formulation of a problem/opportunity statement that identifies conditions to be improved through and benefit from rehabilitation activities. This section focuses on the six steps of the problem/opportunity identification process that are critical to any stream corridor rehabilitation initiative (Stream Corridor Rehabilitation 2001)[24].

Step 1: Data Collection and Analysis

Data collection and analysis are important to all aspects of decision making and are conducted throughout the duration of the rehabilitation process. The same data and analytic techniques are often applied to, and are important components of, problem/opportunity identification; goal formulation; alternative selection; and design, implementation, and monitoring.

Data collection should begin with identifying potential data needs based on technical and institutional requirements. The perspective of the public should then be solicited from participants or through public input forums. Data targeted for collection should generally provide information on both the historical and baseline conditions of stream corridor structure and functions, as well as the social, cultural, and economic conditions of the corridor and the larger watershed. Data are collected with the help of a variety of techniques, including remote sensing, historical maps and photographs, and actual resource inventory using standardized on-site field techniques, evaluation models, and other recognized and widely accepted methodologies. A detailed land survey of the existing cross-sections and planform of the reach of stream concerned would aid in the planning and subsequent design of the rehabilitation works.

Baseline data consist of the existing structure and functions of the stream corridor and surrounding ecosystems across levels or scales (landscape, stream corridor and reach), as well as the associated disturbance factors. These data, when compared to a desired reference condition (derived from either existing conditions elsewhere in the corridor or historical conditions), are important in determining cumulative effects on the stream corridor's structure and functions (i.e., hydrologic, geomorphic, habitat, etc.).

In terms of gathering historical data, emphasis should be placed on understanding changes in land use, channel planform, cover type, and other physical conditions. Historical data, such as maps and photographs, should be reviewed and long-time residents interviewed to determine changes to the stream corridor and associated ecosystems. Major human-induced or natural disturbances, such as land clearing, floods, and channelization, should also be considered. These data will be critical in understanding present conditions, identifying a reference condition, and determining future trends.

It is also important to gather data on the social, cultural, and economic conditions in the area. These data more often than not will drive the overall rehabilitation effort, delimit its scale, determine its citizen and landowner acceptance, determine ability to coordinate and communicate, and generally decide overall stability and capability to maintain and manage.

Data analysis, like data collection, plays an important role in all elements of problem identification as well as other aspects of the rehabilitation process. Data analysis techniques range from qualitative evaluations using professional judgment to elaborate computer models. The scope and complexity of the rehabilitation effort, along with the budget, will influence the type of analytical techniques selected.

Step 2: Existing Stream Corridor Structure, Functions, and Disturbances

The second step is to determine which stream corridor conditions best characterize the existing situation. Corridor structure, functions, and associated disturbances used to describe the existing condition of the stream corridor will be determined on a case-by-case basis. The condition of a stream corridor must be indexed by an appropriate suite of measurable attributes. There are no hard-and-fast rules. However, as a starting point, consideration should be given to describing present conditions associated with the following eight components of the corridor:

- Hydrology
- Erosion and sediment yield
- Floodplain/riparian vegetation
- Channel processes
- Connectivity
- Water quality
- Aquatic and riparian species and critical habitats
- Corridor dimension

It is useful to characterize those attributes which either measure or index the eventual attainment of the desired ecological condition. Some measurable attributes that might be useful for describing the above components of a stream corridor are listed in Appendix I - Attributes for Describing Conditions in the Stream Corridor.

Step 3: Existing vs. Desired Structure and Functions: The Reference Condition

This step in is to define the conditions within which the stream corridor problems and opportunities will be defined and rehabilitation objectives established. It is helpful to describe how the present baseline conditions of the stream corridor compare to a *reference condition* that represents, as closely as possible, the desired outcome of rehabilitation (Figure 3.62).

Figure 3.62 Example reference condition Penanggol River, Sabah

In most cases, reference conditions are developed by comparison with *reference reaches* or *sites* believed to be indicative of the natural potential of the stream corridor. The *reference site* might be the pre-disturbance condition of the stream to be rehabilitated, where such conditions are established by examining relic areas (enclosures, preserves), historical photos, survey notes, and/or other descriptive accounts. Similarly, reference conditions may be developed from nearby stream corridors in similar physiographic settings if those streams are minimally impacted by natural and human-caused disturbances.

Step 4: Causes of Altered or Impaired Conditions

A thorough analysis of the cause or causes of degraded stream channel conditions and habitat is fundamental to identifying management opportunities and constraints and to defining realistic and attainable rehabilitation objectives.

For every stream corridor structural attribute and function that is altered or impaired, there may be a causal chain of events responsible for the impairment. As a result, when conducting a problem analysis, it is useful to consider factors that affect stream corridor ecological condition at different levels or scales, such as landscape, stream corridor and reach.

When analyzing landscape-scale factors that contribute to existing stream corridor conditions, disturbances that result in changes in water and sediment delivery to the stream and in sources of contamination should be considered. The analysis of watershed effects on channels is aided by the use of standard hydrologic, hydraulic, and sediment transport tools.

The effects of altered land use on sediment delivery to streams may be assessed using various analytical and empirical tools. The stream channel itself might provide some clues as to whether it is experiencing an increase or decrease in sediment delivery from the watershed relative to sediment-transport capacity.

In general, stream corridor structural attributes and functions are greatly affected by several important categories of activities such as the following:

- Activities that alter or remove streambank and riparian vegetation (e.g., grazing, agriculture, logging, and urbanization).
- Activities that physically alter the morphology of channels, banks, and riparian zones (e.g. channelization, levee construction, sand/gravel mining, and access trails).
- Instream modifications that alter channel shape and dimensions, flow hydraulics, sediment-transport characteristics, aquatic habitat, and water quality (e.g. dams and grade stabilization measures, bank riprap, logs, bridge piers, and habitat "enhancement" measures).

Altered riparian vegetation and physical modification of channels and floodplains are primary causes of impaired stream corridor structure and functions because their effects are both profound and direct. Addressing the causes of these changes might offer the best, most feasible opportunities for rehabilitating stream corridors. Whatever the situation, it is likely that the analysis will require site-specific application of ecological principles aided by a few quantitative tools.

Step 5: Determination of Management Influence on Stream Corridor Conditions

This step is to determine whether the causative factors are a function of and responsive to management. Specific management factors that contribute to impairment might or might not have been identified with the causes of impairment previously identified. For example, if higher sediment yields are a function of improper sand mining management, the problem might be mitigated simply by altering sand mining practices. The ability to identify management influences becomes critical when identifying alternatives for rehabilitation.

Step 6: Problem or Opportunity Statements for Stream Corridor Rehabilitation

This step is development of concise statements to drive the rehabilitation effort. It serves as a general focus for the rehabilitation effort but also become the basis for developing specific rehabilitation objectives. Moreover, they form the basis for determining success or failure of the rehabilitation initiative.

For maximum effectiveness, these statements should usually have the following two characteristics:

- They describe impaired stream corridor conditions that are explicitly stated in measurable units and can be related to specific processes within the stream corridor.
- They describe deviation from the desired reference condition (dynamic equilibrium) or proper functioning condition for each impaired condition.

3.5.1.3 Developing Rehabilitation Goals and Objectives

The goals development process should mark the integration of the results of the assessment of existing and desired stream corridor structure and functions with important social, economic, and cultural values. The fundamental components of the goal and objective development process are explained below.

Defining Desired Future Stream Corridor Conditions

The development of goals and objectives should begin with a rough outline, and with the definition of the *desired future condition* of the stream corridor and surrounding landscape (Figure 3.63). The desired future condition should represent the common vision of all participants.

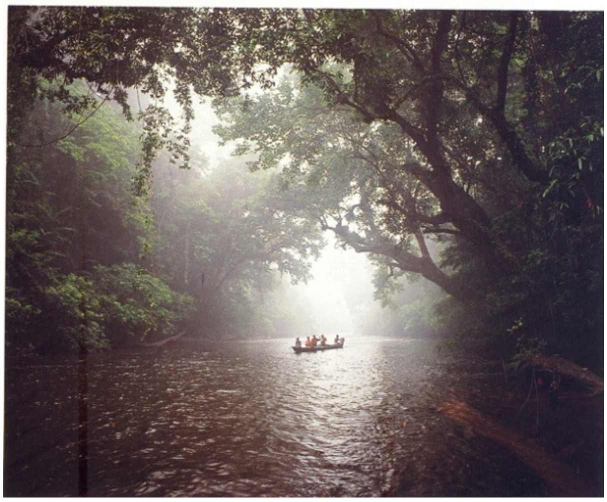


Figure 3.63 Example of future conditions Upper River Reach at Taman Negara

The vision statement should be consistent with the overall ecological goal of rehabilitating stream corridor structure and functions and bringing the system as close to a state of dynamic equilibrium or proper functioning condition as possible.

Identifying Scale Considerations

In developing stream corridor rehabilitation goals and objectives it is important to consider and address the issue of scale. The scale of stream corridor rehabilitation efforts can vary greatly, from working on a short reach to managing a large river basin corridor. As a result, goals and objectives should recognize the stream corridor and its surrounding landscape.

Technical considerations in stream corridor rehabilitation usually encompass the landscape scale as well as the stream corridor scale. These considerations may include social, economic, historical, and/or cultural values; natural resource management concerns; and biodiversity. The following are some important issues relevant to the landscape scale.

The Landscape Scale

Regional Economic and Natural Resource Management Considerations:
Regional economic priorities and natural resource objectives should be identified and evaluated with respect to their likely influence on the rehabilitation effort. It is important that rehabilitation goals and objectives reflect a clear understanding of the concerns of the people living in the region and the immediate area, as well as the priorities of resource agencies responsible for managing lands within the rehabilitation target area and providing support for the initiative (Figure 3.64).

Figure 3.64 Kedah River - landscape scale

Land Use Considerations:

Changes in land use and increases in development are a concern, particularly because they can cause rapid changes in the delivery of storm water to the stream system, thereby changing the basic hydrologic patterns that determine stream configuration and plant community distribution (Figure 3.65). In addition, future development can influence what the stream corridor will be expected to accomplish in terms of processing floodwaters, urban pollutants or nutrients, or with respect to providing wildlife habitat or recreation opportunities. By making an effort to accommodate predictable future land use and development patterns, degradation of stream corridor conditions can be prevented or reduced.

Figure 3.65 Urban stream corridor, Klang River, Kuala Lumpur

Biodiversity Considerations:

Where corridor rehabilitation is intended to result in establishing connectivity on a landscape scale, management objectives and options should reflect natural patterns of plant community distribution and should be built to provide as much biodiversity as possible. In many instances, however, the driving force behind rehabilitation is the protection of certain threatened, endangered game, or other specially targeted species. In these cases a balance must be struck. A portion of the overall rehabilitation plan can be directed toward the life requirements of the targeted species, but on the whole the goal should be a diverse community.

The Stream Corridor Scale

Each stream corridor targeted for rehabilitation is unique. A project goal of rehabilitating multiple ecological functions might encompass the channel systems, the active floodplain, and possibly adjacent hill slopes or other buffer areas that have the potential to directly and indirectly influence the stream or protect it from surrounding land uses. A wide corridor is most likely to include a range of biotic community types and to perform many of the stream functions (floodwater and sediment storage, nutrient processing, fish and wildlife habitat, and others) that the rehabilitation effort is intended to restore. In many cases, however, it will not be possible to reestablish the original corridor width, and rehabilitation will be focused on a narrower strip of land directly adjacent to the channel.

Where narrow corridors are established through urban or agricultural landscapes, certain functions might be restored (e.g., stream shading), while others might not (e.g., wildlife movement). In particular, very narrow corridors may function largely as edge habitat and will favor unique and sometimes opportunistic plant and animal species. In some situations, creating a large amount of edge habitat might be detrimental to species that require large forested habitat or are highly vulnerable to predation or nest parasitism and disturbances.

The Reach Scale

A reach is the fundamental unit for design and management of the stream corridor. In establishing goals and objectives, each reach must be evaluated with regard to its landscape and individual characteristics, as well as their influence on stream corridor function and integrity. For example, steep slopes adjacent to a channel reach must be considered where they contribute potentially significant amounts of runoff, subsurface flow, sediment, woody debris, or other inputs. Another reach might be particularly active with respect to channel migration and might warrant expanding the corridor relative to other reaches to accommodate local stream dynamics.
Defining Rehabilitation Goals

Rehabilitation goals should be defined by the decision maker(s) with input from the interdisciplinary technical team(s) and other participants. As noted earlier, these goals should be an integration of two important groups of factors:

- Desired future condition (ecological reference condition).
- Social, historical, and economic values.

Considering Desired Future Condition

As discussed earlier, the desired ecological future condition of the stream corridor is frequently based on predevelopment conditions or some commonly accepted idea of how the natural stream corridors looked and functioned. Consequently, it represents the ideal situation for rehabilitation, whether or not this reference condition is attainable. This ideal situation has been given the term "potential," and it may be described as the highest ecological status an area can attain, given no political, social, or economic constraints. When applied to the initiative, however, this statement might require modification to provide realistic and more specific goals for rehabilitation.

Factoring in Constraints and Issues

In addition to the desired future ecological condition, definition of rehabilitation goals must also include other considerations. These other factors include the important social, and economic values as well as issues of scale. When these considerations are factored into the analysis, realistic project goals can be identified. The goals provide the overall purpose for the rehabilitation effort and are based on a stream corridor's capability or its ideal ecological condition.

Defining Rehabilitation Goals

The identification of realistic goals is a key ingredient for rehabilitation success since it sets the framework for adaptive management within a realistic set of expectations. Unrealistic rehabilitation goals create unrealistic expectations and potential disenchantment among stake-holders when those expectations are unfulfilled.

The primary goals should follow from the problem/opportunity identification and analysis, incorporating the participants' vision of the desired future condition, and reflecting a recognition of project constraints and issues such as spatial scale, needs found in baseline data collection, practical aspects of budget and human resources requirements, and special requirements for certain target or endangered species. Primary goals are usually the ones that initiated the project, and they may focus on issues such as bank stabilization, sediment management, upland soil and water conservation, flood control, improved aquatic and terrestrial habitat, and aesthetics. There may also be secondary goals which either directly or indirectly support the primary goals of the rehabilitation effort. For example, hiring displaced workers to install conservation practices could serve the secondary goal of resolving the social-economic problems, while also contributing to the primary goal of improving biodiversity in the rehabilitation area.

Defining Rehabilitation Objectives

Objectives give direction to the general approach, design, and implementation of the rehabilitation effort. *Rehabilitation objectives* should support the goals and also flow directly from problem/opportunity identification and analysis.

Rehabilitation objectives should be defined in terms of the same conditions identified in the problem analysis and should specifically state which impaired stream corridor condition(s) will be moved toward which particular reference level or desired condition(s). Rehabilitation objectives expressed in terms of measurable stream corridor conditions provide the basis for monitoring the success of the project in meeting condition objectives for the stream corridor.

It is much more useful to have realistic objectives reflecting stream corridor conditions that are both achievable and measurable than to have vague, idealistic objectives reflecting conditions that are neither.

For example, an overall rehabilitation goal might be to improve fish habitat. Several supporting objectives might include the following:

- Improve water temperature by providing shade plants.
- Construct an instream structure to provide a pool as a sediment trap.
- Work with local landowners to encourage near-stream conservation efforts.

3.5.1.4 Alternative Selection and Design

The selection of technically feasible alternatives and subsequent design are intended to solve the identified problems, realize rehabilitation opportunities, and accomplish rehabilitation goals and objectives. An efficient approach is to conceptualize, evaluate, and select general solutions or overall strategies before developing specific alternatives.

Important Factors to Consider in Designing Rehabilitation Alternatives

The design of rehabilitation alternatives is a challenging process. In developing alternatives, special consideration should be given to managing causes as opposed to treating symptoms, tailoring rehabilitation design to the appropriate scale (landscape/corridor/stream/reach), and other scale-related issues.

Managing Causes vs Treating Symptoms

When developing rehabilitation alternatives, three questions regarding the factors that influence conditions in the stream corridor must be addressed. These are critical questions in determining whether a passive, nonstructural alternative is appropriate or whether a more active rehabilitation alternative is needed:

- What have been the implications of past management activities in the stream corridor (a cause-effects analysis)?
- What are the realistic opportunities for eliminating, modifying, mitigating, or managing these activities?
- What would be the response of impaired conditions in the corridor if these activities could be eliminated, modified, mitigated, or managed?

If the causes of impairment can realistically be eliminated, complete ecosystem rehabilitation to a natural or unaltered condition might be a feasible objective and the focus of the rehabilitation activity will be clear. For instance, if the primary cause of riverbed degradation in a river is due to excessive sand mining, the easiest way to achieve full rehabilitation is by addressing the issue of excessive sand mining. The alternative of building pumping stations to supply water for irrigation at canal intakes and building river estuary barrages to prevent salt-water intrusion may turn out to be an expensive way to treat the symptoms rather than deal directly with the cause of the problem. The rehabilitation of rivers is most effectively achieved by managing the source of the problem rather than treating the symptoms.

If the causes of impairment cannot realistically be eliminated, it is critical to identify what options exist to manage either the causes or symptoms of altered conditions and what effect, if any, those management options might have on the subject conditions. If it is not feasible to manage the cause(s) of impaired conditions, then mitigating the impacts of disturbance(s) is an alternative method of implementing sustainable stream corridor rehabilitation. By choosing mitigation, the focus of the rehabilitation effort might then be on addressing only the symptoms of impaired conditions.

When disturbance cannot be fully eliminated, a logical planning process must be used to develop alternative management options. For example, in analyzing bank erosion, one conclusion might be that accelerated watershed sediment delivery has produced lateral instability in the stream system, but modification of land-use patterns causing the problem is not a feasible management option at this time (Figure 3.66). It might therefore still be possible to develop a channel erosion condition objective and to identify treatments such as engineered or soil-bioengineered bank erosion control structures, but it will not be possible to return the stream corridor to its pre-disturbance condition.

Figure 3.66 Streambank erosion.

Other resource implications of increased watershed sediment delivery will persist (e.g., altered substrate conditions, modified riffle-pool structure, and impaired water quality).

It is important to note that in treating one symptom of impairment, a danger always remains that another unwanted change in stream corridor conditions will be triggered. To continue with the erosion example, bank hardening in one location might interfere with sedimentation processes critical to floodplain and riparian habitats, or it might simply transfer lateral instabilities from one location in a stream reach to some other location.

Landscape/Watershed vs Corridor/Reach

The design and selection of alternatives should address the following relationships:

- Reach to stream
- Stream to corridor
- Corridor to landscape
- Landscape to region

Characterizing those relationships requires a good inventory and analysis of conditions and functions on all levels including stream structure (both vertical and horizontal) and human activities within the watershed.

The rehabilitation design should include innovative solutions to prevent or mitigate, to the extent possible, negative impacts on the stream corridor from upstream land uses. Land use activities within a watershed may vary widely within generalized descriptions of urban, agricultural, recreation, etc. For example, urban residential land use could comprise neighborhoods of manicured lawns, exotic plants, and roof runoff directed to nearby storm drains. Rehabilitation design should address the storm water flows, pollutants, and sediment loadings from these different land uses that could impact the stream corridor.

Since it is usually not possible to remove the human activities that disturb stream corridors, where seemingly detrimental activities like gravel/sand mining, damming, and road crossings are present in the watershed or in the stream corridor itself, rehabilitation design should provide the best possible solutions for maintaining optimum stream corridor functions while meeting economic and social objectives (Figure 3.67).

Figure 3.67 Stream buffers in agricultural areas.

Other Time and Space Considerations

Rehabilitation design flexibility is critical to long-term success and achievement of dynamic equilibrium. Beyond the stream corridor is an entire landscape that functions in much the same way as the corridor. When designing and choosing alternatives, it is important to consider the effect of the rehabilitation on the entire landscape. A wide, connected, and diverse stream corridor will enhance the functions of the landscape as well as those of the corridor. Connectivity and width also increase the resiliency of the stream corridor to landscape perturbations and stress, whether induced naturally or by humans.

Dynamic equilibrium of the stream requires that the rehabilitation design be allowed an opportunity to mold itself to the changing conditions of the corridor over time and to the disturbances that are a part of the natural environment. Alternatives should be weighed against one another by considering how they might react to increasing land pressures, climate changes, and natural perturbations. Structure should be planned to provide necessary functions at each phase of the corridor's development.

Supporting Analyses for Selecting Rehabilitation Alternatives

Once the rehabilitation alternatives have been defined, the next step is to evaluate all the feasible alternatives and management options. In conducting this evaluation it is important to apply several different screening criteria that allow the consideration of a diverse number of factors. In general, the application of the following supporting analytical approaches may be used for the selection of the best alternative or group of alternatives for the rehabilitation initiative:

- Cost-effectiveness and incremental cost analysis
- Evaluation of benefits
- Risk assessment
- Environmental impact analysis (EIA)

For a description of each of the above methods, reference may be made to *Chapter 5: Developing Goals, Objectives, and Rehabilitation Alternatives of "Stream Corridor Rehabilitation-Principles, Processes and Practices".*

3.5.2 Applying Rehabilitation Principles

The application of the rehabilitation principles will be discussed in this section. This section shows how condition analysis and design can lead to rehabilitating corridor structure and the habitat, conduit, filter/barrier; source, and sink functions (Stream Corridor Rehabilitation 2001)[24].

3.5.2.1 Hydrologic Processes

Flow Analysis

Rehabilitation of stream structure and function requires knowledge of flow characteristics. At a minimum, it is helpful to know whether the stream is perennial, intermittent, or ephemeral, and the relative contributions of baseflow and stormflow in the annual runoff. Other desirable information includes the relative frequency and duration of extreme high and low flows for the site and the duration of certain stream flow levels. High and low flow extremes usually are described with a statistical procedure called frequency analysis, and the amount of time that various flow levels are present is usually described with a flow duration curve. Finally, it is often desirable to estimate the channel-forming or dominant discharge for a stream. Channel-forming or dominant discharge is used for design when the rehabilitation includes channel reconstruction. For details on channel-forming or dominant discharge may be obtained from Chapter 2.3 of this volume of the Manual.

Estimates of streamflow characteristics needed for rehabilitation can be obtained from stream gauging data. Procedures for determining flow duration characteristics and the magnitude and frequency of floods and low flows at gauging sites are described in details in Vol. IV "Hydrology and Water Resources" of the DID Manual.

Most stream corridor rehabilitation initiatives are on streams or reaches that lack systematic stream gauging data. Therefore, estimates of flow duration and the frequency of extreme high and low flows must be based on indirect methods such as regional hydrologic analysis. A hydrological procedure for regional hydrologic analysis titled "H.P. 4 - Magnitude and Frequency of Floods in Peninsular Malaysia (1974 Revised and updated 1987)" may be used for streams without gauging data whereas low flows may be estimated using "H.P.12 - Magnitude and Frequency of Low Flows in Peninsular Malaysia (Revised and updated 1985)".

Users are cautioned that statistical analyses using historical streamflow data need to account for watershed changes that might have occurred during the period of record. Many basins in the country have experienced substantial urbanization and development; construction of upstream reservoirs, dams, and stormwater management structures; and construction of levees or channel modifications. These features have a direct impact on the statistical analyses of the data for peak flows, and for low flows and flow duration curves in some instances. Depending on basin modifications and the analyses to be performed, this could require substantial time and effort to obtain realistic analytical results.

3.5.2.2 Geomorphic Processes

In planning a project along a river or stream, awareness of the fundamentals of fluvial geomorphology and channel processes allows the investigator to see the relationship between form and process in the landscape. The detailed study of the fluvial geomorphic processes in a channel system is often referred to as a geomorphic assessment. The geomorphic assessment provides the process-based framework to define past and present watershed dynamics, develop integrated solutions, and assess the consequences of rehabilitation activities. A geomorphic assessment generally includes data collection, field investigations, and channel stability assessments. It forms the foundation for analysis and design and is therefore an essential first step in the design process, whether planning the treatment of a single reach or attempting to develop a comprehensive plan for an entire watershed. For more details on the geomorphic processes including stream classification systems and channel evolution models, please refer to Chapter 2.3 of this volume of the Manual.

Applications of Geomorphic Analysis

Stream classification systems and channel evolution models may be used together in resource inventories and analysis to characterize and group streams. Although many classification systems are based on morphological parameters, and channel evolution models are based on adjustment processes, the two approaches to stream characterization complement each other. Both indicate the present condition of a stream reach under investigation, but characterization of additional reaches upstream and downstream of the investigation area can provide an understanding of the overall trend of the stream.

Stream classification systems and channel evolution models also provide insights as to the type of stability problems occurring within the stream corridor and potential opportunities for rehabilitation. Gullied stream channels are downcutting, so grade stabilization is required before time and money are spent on bank stabilization or floodplain rehabilitation. Similarly, incised channels with lateral instabilities are in the initial stages of widening, a process that often must be accommodated before equilibrium conditions can be attained. Although channel widening is generally accommodated to rehabilitate incised channels, in some cases not allowing the stream to widen might be preferred, depending on the value and priority placed on adjacent land use and structures within the corridor. On the other hand, incised streams that have widened enough for a new inner channel and floodplain to begin forming are excellent candidates for vegetation management since these streams are already tending toward renewed stability and establishing riparian vegetation can accelerate the process.

Both the stream classification and the stage of channel evolution inventories can serve as the foundation for assessing systemwide stability. A channel width/depth ratio F at a mean annual discharge and the percent of silt and clay in the channel boundary M are useful diagnostics for determining systemwide adjustments. Schumm's width/depth ratio is the top width of the bankfull channel and the deepest depth (thalweg) in the bankfull channel cross section. These variables can be plotted on (Schumm's 1960)[26] curve of width/depth ratio vs percent silt-clay ($F = 255M^{-1.08}$) to assess stability (Figure 3.68).

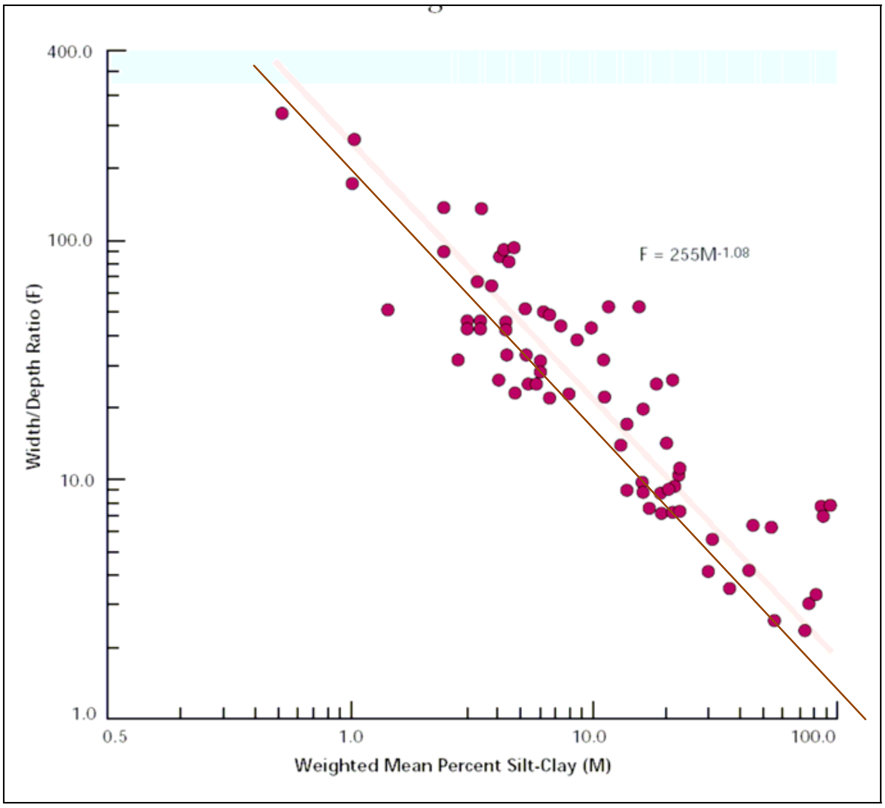


Figure 3.68 Schumm's F versus M relationship [26]

The term "M" is defined by the relationship:

$$M = [(S_c\, W) + (S_b\, 2D)] / (W + 2D) \qquad (3.27)$$

where
S_c = percentage of silt and clay in the bed material
S_b = percentage of silt and clay in the bank material
W = channel width, and
D = channel depth

Data from aggrading streams generally plot above the line of best fit, whereas data for degrading streams plot below the line. Schumm's graph may not always be applicable, but nevertheless provides a guideline in selecting an appropriate width/depth ratio for incised or disturbed channel.

Finally, classification systems and evolution models can help guide the selection of rehabilitation treatments. As mentioned above, there is little opportunity for successfully establishing streambank vegetation in streams with vertical and horizontal instability. The banks of such streams are subject to deep-seated slope failures that are not usually prevented even by mature woody vegetation. Conversely, establishing and managing grasses and woody vegetation is critical to protecting streams that are already functioning properly.

Proper Functioning Condition (PFC)

The U.S. Bureau of Land Management (BLM) has developed guidelines and procedures to rapidly assess whether a stream riparian area is functioning properly in terms of its hydrology, landform/soils, channel characteristics, and vegetation (Prichard et al. 1993, rev. 1995)[25]. This assessment is useful as a baseline analysis of stream condition and physical function, and it can also be useful in watershed analysis. It is essential to do a thorough analysis of the stream corridor and watershed conditions prior to the development of rehabilitation plans and selecting rehabilitation approaches to be used. There are many cases where selection of the wrong approach has led to complete failure of stream rehabilitation efforts and the waste of costs of rehabilitation. In many cases, particularly in virgin land situations, rehabilitation through natural processes and control of land uses is the preferred and most cost-effective method. If hydrologic conditions are rapidly changing in a stream, no rehabilitation might be the wisest course of action until equilibrium is restored.

Proper Functioning Condition (PFC) is a methodology for assessing the physical functioning of a riparian wetland area. It provides information critical to determining the "health" of a riparian ecosystem. PFC considers both abiotic and biotic components as they relate to the physical functioning of riparian areas, but it does not consider the biotic component as it relates to habitat requirements. For habitat analysis, other techniques must be employed. This technique is not a substitute for inventory or monitoring protocols designed to yield detailed information on the habitat or populations of flora or fauna dependent on the riparian-stream ecosystem. The following are definitions of proper function as set forth by BLM:

- *Proper Functioning Condition* – Riparian/wetland areas are functioning properly when adequate vegetation, landform, or large woody debris is present to:
    - Dissipate stream energy associated with high waterflows, thereby reducing erosion and improving water quality.
    - Filter sediment, capture bedload, and aid floodplain development.
    - Improve floodwater retention and ground water storage.
    - Develop root masses that stabilize streambanks against erosive action.
    - Develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses.
    - Support greater biodiversity.
- *Functional-at Risk* – Riparian/wetland areas that are in functional condition, but an existing soil, water, or vegetation attribute makes them susceptible to degradation.
- *Nonfunctional* – Riparian/wetland areas that clearly are not providing adequate vegetation, landform, or large debris to dissipate stream energy associated with high flow and thus are not reducing erosion, improving water quality, or performing other functions as listed above under the definition of proper function.

The absence of certain physical attributes, such as absence of a floodplain where one should be, is an indicator of nonfunctioning conditions.

Assessing functionality with the PFC technique involves procedures for determining a riparian/wetland area's capability and potential, and comparing that potential with current conditions. Although the PFC procedure defines streams without floodplains (when a floodplain would normally be present) as nonfunctional, many streams that lose their floodplains through incision or encroachment still retain ecological functions. The importance of a floodplain needs to be assessed in view of the site-specific aquatic and riparian community.

When using the PFC technique, it is important not to equate "proper function" with "desired condition." Proper function is intended to describe the state in which the stream channel and associated riparian areas are in a relatively stable and self-sustaining condition. Properly functioning streams can be expected to withstand intermediate flood events (e.g. 25- to 30-year flood events) without substantial damage to existing values. However, proper functioning condition will often develop well before riparian succession provides shrub habitat for nesting birds. In other words, proper functioning condition is a prerequisite to a variety of desired riparian conditions.

Although based on sound science, the PFC field technique is not quantitative. An advantage of this approach is that it is less time-consuming than other techniques because measurements are not required. The procedure is performed by an interdisciplinary team and involves completing a checklist by evaluating 17 factors dealing with hydrology, vegetation, and erosional/depositional characteristics (see Appendix J). However, training in the technique is required and with training, the functional determinations resulting from surveys are reproducible to a high degree.

Hydraulic Geometry: Streams in Cross Section

Hydraulic geometry theory is based on the concept that a river system tends to develop in a way that produces an approximate equilibrium between the channel and the in-flowing water and sediment (Leopold and Maddock 1953)[27]. The theory typically relates an independent or driving variable, such as drainage area or discharge, to dependent variables such as width, depth, slope, and velocity. Hydraulic geometry relations are sometimes stratified according to bed material size or other factors. These relationships are empirically derived, and their development requires a relatively large amount of data.

Downstream hydraulic geometry relations define the bankfull width depth velocity and slope of different streams of different bankfull discharges. Figure 3.69 presents downstream hydraulic geometry relations based on the mean annual discharge rather than the bankfull discharge. Similar hydraulic geometry relationships can be determined for a watershed of interest by measuring channel parameters at numerous cross sections and plotting them against a discharge. In Malaysia, downstream hydraulic geometry relationships could be developed from a regional analysis of different rivers in a given State or region. Such plots can be used with care for planning and preliminary design. Nevertheless, the use of hydraulic geometry relationships alone for final design is not recommended.

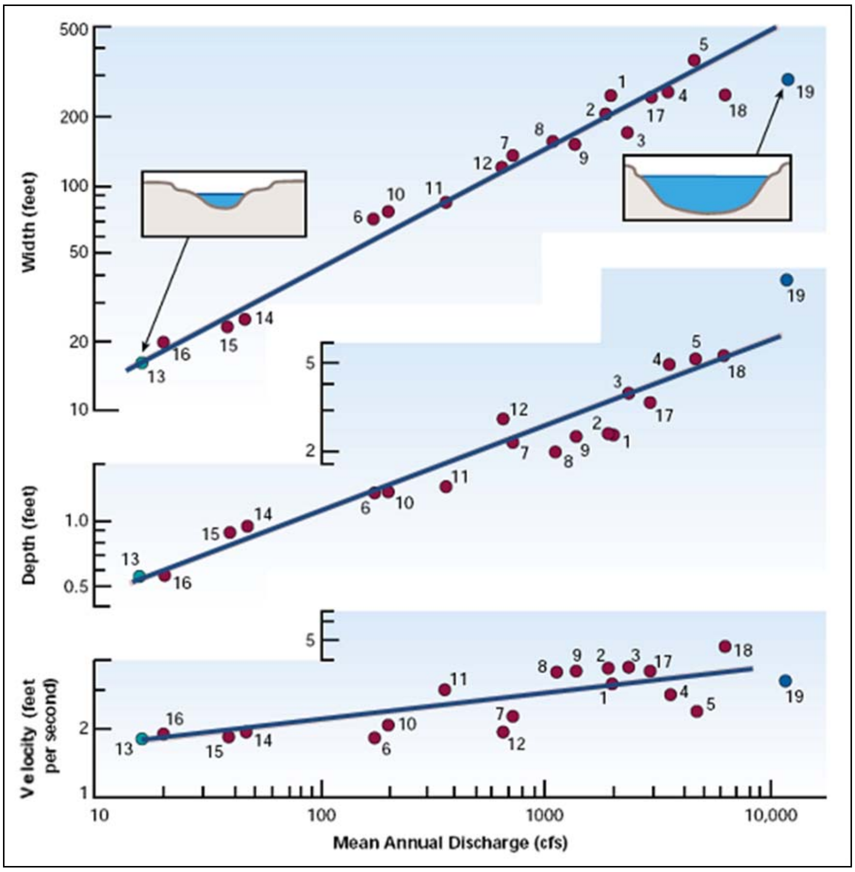


Figure 3.69 Channel morphology related to mean annual discharge for 19 rivers in Wyoming and Montana, USA (1 m = 3.28 ft and 1 m^3/s = 35.32 cfs) [27]

Hydraulic geometry relationships that do not explicitly consider sediment transport are applicable mainly to channels with relatively low bed-material loads. Hydraulic geometry relations can be developed for a specific river, watershed, or for streams with similar physiographic characteristics. Data scatter is expected about the developed curves even in the same river reach. The more dissimilar the stream and watershed characteristics are, the greater the expected data scatter is. It is important to recognize that this scatter represents a valid range of stable channel configurations due to variables such as geology, vegetation, land use, sediment load and gradation, and runoff characteristics.

Sometimes, the bankfull discharge can be replaced with drainage area. This type of analysis may be valid on a regional basis but usually the results of one river cannot be extrapolated to another river system. As an example, Figure 3.70 shows the hydraulic geometry curves developed for the upper Salmon River watershed in Idaho, USA. The scatter of data for stable reaches in the watershed indicates that for a drainage area of about 26 ha. (10 square miles), the bankfull discharge could reasonably range from 2.8 to 7.0 m^3/s (100 to 250 cfs) and the bankfull width could reasonably range from 3 to 10m (10 to 35 feet). These relations were developed for a relatively homogeneous watershed, yet there is still quite a bit of natural variation in the data. This illustrates the importance of viewing the data used to develop any curve (not just the curve itself), along with statistical parameters such as R^2 values and confidence limits in the regression analyses.

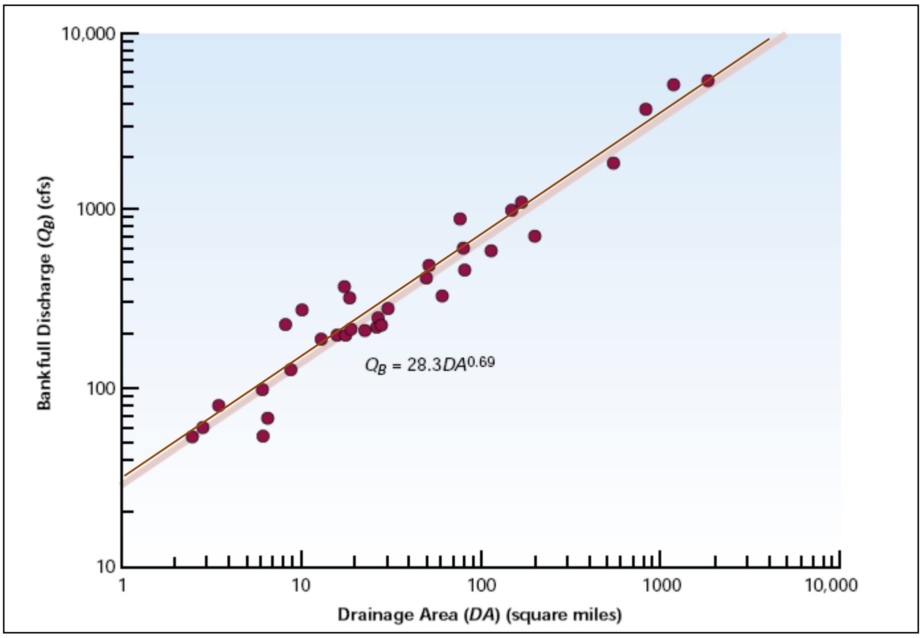


Figure 3.70 Bankfull discharge versus drainage area for Upper Salmon River area, Idaho, USA
(1 m^3/s = 35.32 cfs and 1 mi^2 = 2 6 km^2) [24]

Statistically, the channel-forming discharge is a much more reliable independent variable for hydraulic geometry relations than drainage area. This is because the magnitude of the channel forming discharge is the driving force that creates the observed channel geometry, and drainage area is merely a surrogate for discharge. Typically, channel-forming discharge correlates best with channel width. Correlations with depth are somewhat less reliable. Correlations with slope and velocity are the least reliable.

Hydraulic Geometry and Stability Assessment

The use of hydraulic geometry relations to assess the stability of a given channel reach requires two things. First, the watershed and stream channel characteristics of a reach in question must be the same as (or similar to) the data set used to develop the hydraulic geometry relations. Second, the reasonable scatter of the data in the hydraulic geometry relations must be known. If the data for that specific reach fall outside the reasonable scatter of data for stable reaches in a similar watershed, there is reason to believe that the reach in question may be unstable. This is only an indicator, since variability in other factors (geology, land use, vegetation, etc.) may cause a given reach to plot high or low on a curve.

In summary, the use of downstream hydraulic geometry relations requires that the actual data be plotted and the statistical coefficients known. Downstream hydraulic geometry relations can be used as a preliminary guide to indicate stability or instability in stream reaches, but these indications should be checked using other techniques due to the wide natural variability of the data.

Regional Curves (Dunne and Leopold (1978)[28] looked at similar relationships from numerous watersheds in the U.S. and published *regional curves* relating bankfull channel dimensions to drainage area (Figure 3.71). Using these curves, the width and depth of the bankfull channel can be approximated once the drainage area of a watershed within one of these regions is known. Obviously, more curves such as these are needed for regions that experience different topographic, geologic, and hydrologic regimes; therefore, additional regional relationships should be developed for specific areas of interest. Several hydraulic geometry formulae are presented in Table 3.8. Regional curves should be used only as indicators to help identify the channel geometry at a rehabilitation initiative site because of the large degree of natural variation in most data sets. Channel geometry discharge relationships are more complex for multithread channels.

Exponents and coefficients for hydraulic geometry formulae are usually determined from data sets for a specific stream or watershed. Extremes for the data sets used to generate the hydraulic geometry formulas are given in Table 3.9 (Williams 1986)[34]. The relatively small range of variation of the exponents k2, k5, and k8 is impressive, considering the wide range of situations represented. Because formula coefficients vary, applying a given set of hydraulic geometry relationships should be limited to channels similar to the calibration sites. These graphs should be used with extreme caution in Malaysia. They are merely presented here as examples of regional results that could be obtained for rivers in Malaysia.

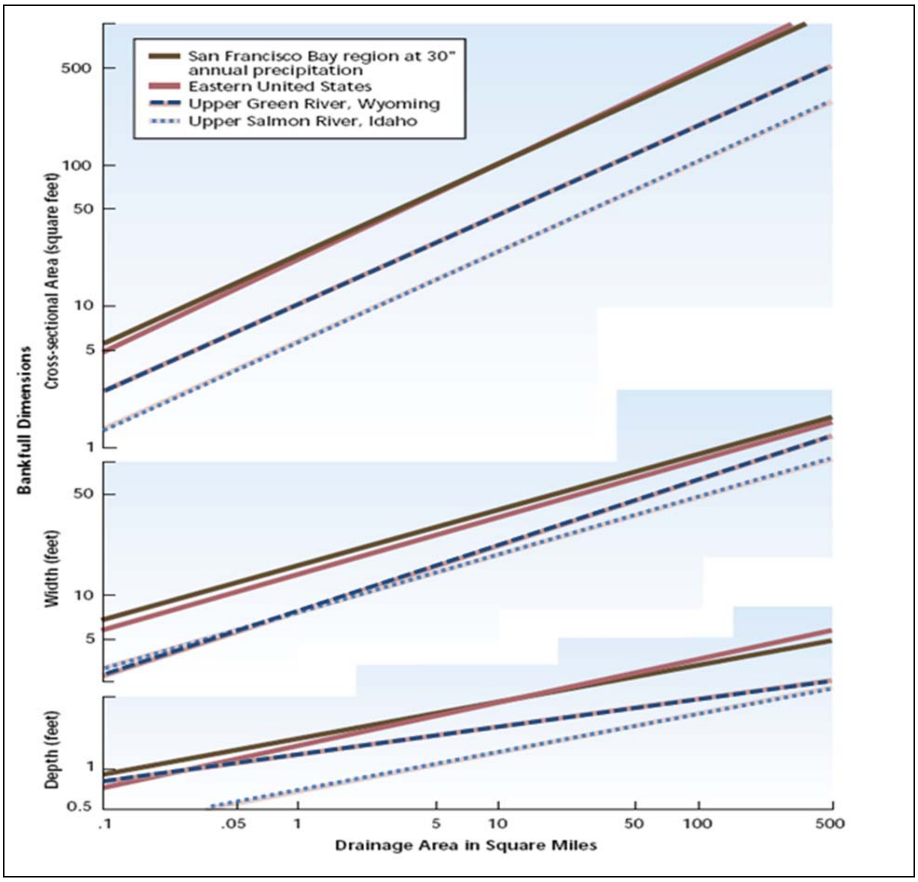


Figure 3.71 Regional curves for bankfull channel dimensions versus drainage area (imperial units) [28]

Table 3.8 Limits of data sets used to derive regime formulae (Imperial units) [24]

Reference	Data Source	Median Bed Material Size (mm)	Banks	Discharge (ft3/s)	Sediment Concentration (ppm)	Slope	Bedforms
Lacey 1958	Indian canals	0.1 to 0.4	Cohesive to slightly cohesive	100 to 10,000	< 500		
Blench 1969	Indian canals	0.1 to 0.6	Cohesive	1 to 100,000	< 301	Not specified	Ripples to dunes
Simons and Albertson 1963	U.S. and Indian canals	0.318 to 0.465	Sand	100 to 400	< 500	0.000135 to 0.000388	Ripples to dunes
		0.06 to 0.46	Cohesive	5 to 88,300	< 500	0.000059 to 0.00034	Ripples to dunes
		Cohesive, 0.029 to 0.36	Cohesive	137 to 510	< 500	0.000063 to 0.000114	Plane
Nixon 1959	U.K. rivers	gravel		700 to 18,050	Not measured		
Kellerhals 1967	U.S., Canadian, and Swiss rivers of low sinuousity, and lab	7 to 265	Noncohesi ve	1.1 to 70,600	Negligible	0.00017 to 0.0131	Plane
Bray 1982	Sinuous Canadian rivers	1.9 to 145		194 to 138,400	"Mobile" bed	0.00022 to 0.015	
Parker 1982	Single channel Canadian rivers		Little cohesion	353 to 211,900			
Hey and Thorne 1986	Meandering U.K. rivers	14 to 176		138 to 14,970	Qs computed to range up to 114	0.0011 to 0.021	

1 Blench (1969) provides adjustment factors for sediment concentrations between 30 and 100 ppm.

Table 3.9 Meander geometry equations [34]

Author	Year	Data	Domain	k1	k2	k3	k4	k5	k6	k7	k8	k9
Nixon	1959	U.K. rivers	Gravel-bed rivers		0.5		0.545	0.33		$1.258n^{2b}$	-0.11	
Leopold et al.	1964	Midwestern U.S.		1.65	0.5			0.4			-0.49	
		Ephemeral streams in semiarid U.S.			0.5			0.3			-0.95	
Kellerhals	1967	Field (U.S., Canada, and Switzerland) and laboratory	Gravel-bed rivers with paved beds and small bed material concentration	1.8	0.5		0.33	0.4	-0.12a	0.00062	-0.4	0.92a
Schumm	1977	U.S. (Great Plains) and Australia(Riverine Plains of New South Wales)	Sand-bed rivers	$37k_1$*	0.38		$0.6k_4$*	0.29	-0.12a	$0.01136k_7$*	-0.32	
Bray	1982	Canadian rivers	Gravel-bed rivers	3.1	0.53	-0.07	0.304	0.33	-0.03	0.00033	-0.33	0.59
Parker	1982	Single-channel Alberta rivers	Gravel-bed rivers, banks with little cohesion	6.06	0.444	-0.11	0.161	0.401	-0.0025	0.00127	-0.394	0.985
Hay and Thorne	1986	U.K. rivers	Gravel-bed rivers with:									
			Grassy banks with no trees or shrubs	2.39	0.5		0.41	0.37	-0.11	$0.00296k_7^{\#}$	-0.43	-0.09
			1-5% tree/ shrub cover	1.84	0.5		0.41	0.37	-0.11	$0.00296k_7^{\#}$	-0.43	-0.09
			Greater than 5-50% tree/ shrub cover	1.51	0.5		0.41	0.37	-0.11	$0.00296k_7^{\#}$	-0.43	-0.09
			Greater than 50% shrub cover or incised flood plain	1.29	0.5		0.41	0.37	-0.11	$0.00296k_7^{\#}$	-0.43	-0.09

[a] Bed material size in Kellerhals' equation is D_{90}.
b_n = Manning n.
$k_1* = M^{-0.39}$, where M is the percent of bank materials finer than 0.074 mm.
$k_4* = M^{0.432}$, where M is the percent of bank materials finer than 0.074 mm.
$k_7* = M^{-0.36}$, where M is the percent of bank materials finer than 0.074 mm.
$k_7^{\#} = D_{54}^{\ 0.84}\ Q_x^{\ 0.10}$, where Q_x = bed material transport rate in kg s^{-1} at water discharge Q, and D_{54} refers to bed material and is in mm.
The discharge used in this equation is mean annual rather than bankfull.

Planform and Meander Geometry: Stream Channel Patterns

The variables in meander geometry are shown in Figure 3.72. Channel planform parameters may be measured in the field or from aerial photographs and may be compared with published relationships. Developing regional relationships or coefficients specific to the site of interest is, however, preferable to using published relationships that may span wide ranges in value and may also be from a different geographical region. As an example, Figure 3.73 shows some planform geometry relations by Leopold (1994) [33]. Meander geometries that do not fall within the range of predicted relationships may indicate stream instability and deserve attention in rehabilitation design. These relationships between the meander width, channel width and radius of curvature are more generally applicable.

They will likely prove to be very good predictors of meandering channel geometry anywhere around the world once the channel width is properly defined from field measurements.

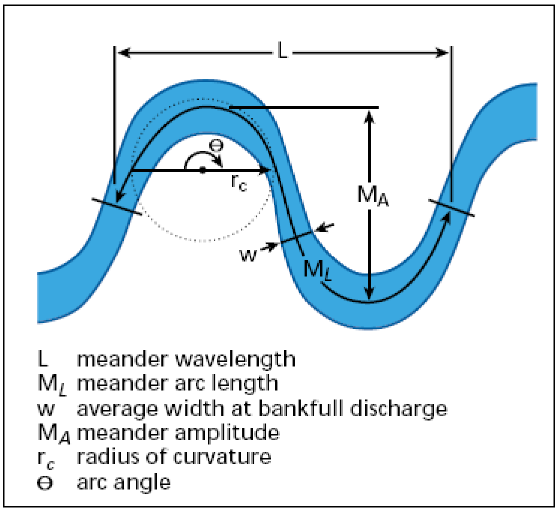


Figure 3.72 Meander geometry variables (Adapted from Williams 1986 [34])

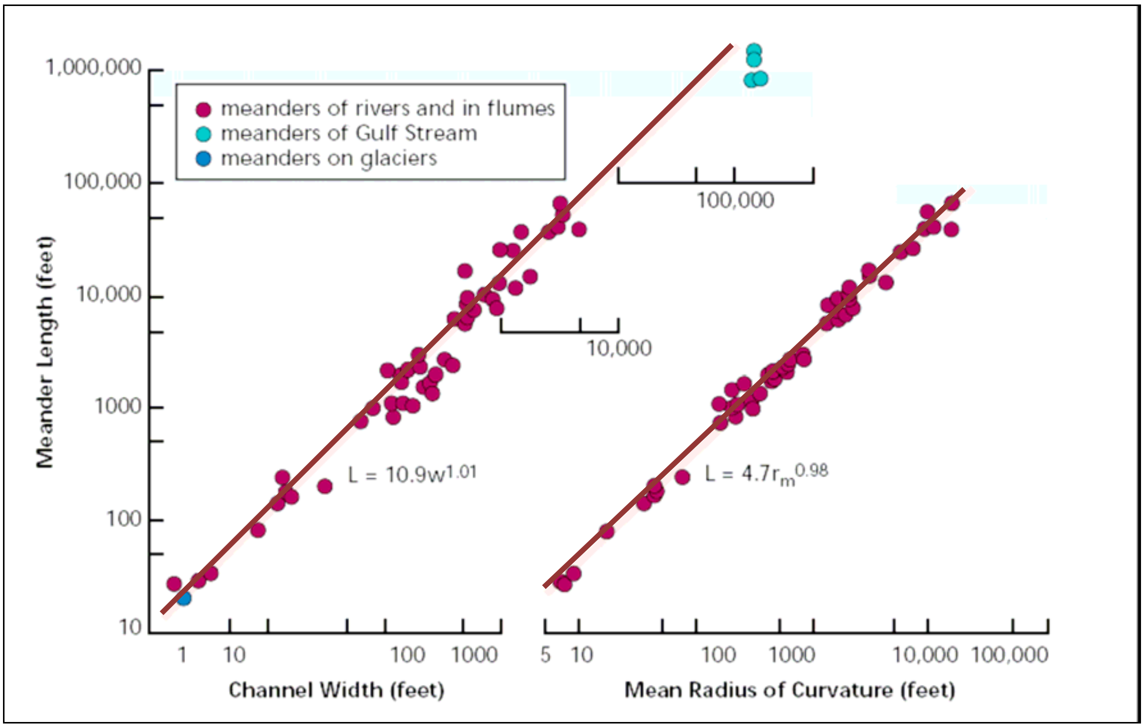


Figure 3.73 Planform geometry relationships (imperial units) [33]

Stream System Dynamics

Stream management and rehabilitation require knowledge of the complex interactions between watershed and stream processes, boundary sediments, and bank and floodplain vegetation. Identifying the causes of channel instability or potential instability and having knowledge of the magnitude and distribution of channel adjustment processes are important for estimating future channel changes, developing appropriate mitigation measures and protecting the stream corridor.
Adjustment processes that affect entire fluvial systems often include channel incision, aggradation, planform geometry changes, channel widening or narrowing, and changes in the magnitude and type of sediment loads. These processes differ from localized processes, such as scour and fill, which can

be limited in magnitude and extent. In contrast, the processes of channel incision and aggradation can affect long reaches of a stream or whole stream systems. Long-term adjustment processes, such as incision, aggradation, and channel widening, can exacerbate local scour problems. Whether streambed erosion occurs due to local scour or channel incision, sufficient bed level lowering can lead to bank instability and to changes in channel planform. It is often difficult to differentiate between local and systemwide processes without extending the investigation upstream and downstream of the site in question. This is because channels migrate over time and space and so may affect previously undisturbed reaches.

Determining Stream Instability

The stage of channel evolution is the primary diagnostic variable for differentiating between local and systemwide channel stability problems in a disturbed stream or constructed channel. Rehabilitation measures often fail, not as the result of inadequate structural design, but rather because of the failure of the designers to incorporate the existing and future channel morphology into the design. For this reason, it is important for the designer to have some general understanding of stream processes to ensure that the selected rehabilitation measures will work in harmony with the existing and future river conditions. This will allow the designer to assess whether the conditions at a particular site are due to local instability processes or are the result of some systemwide instability that may be affecting the entire watershed (Figure 3.74).

Figure 3.74 Bank instability - Determining if instability is localized orsystemwide to establish a correct path of action.

Systemwide Instability

The equilibrium of a stream system can be disrupted by various factors. Once this occurs, the stream will attempt to regain equilibrium by making adjustments in the dependent variables. These adjustments in the context of physical processes are generally reflected in aggradation, degradation, or changes in planform characteristics (meander wavelength, sinuosity, etc.). Depending on the magnitude of the change and the basin characteristics (bed and bank materials, hydrology, geologic or man-made controls, sediment sources, etc.), these adjustments can propagate throughout the entire watershed. For this reason, this type of disruption of the equilibrium condition is referred to as system instability. If system instability is occurring or expected to occur, it is imperative that the rehabilitation initiative addresses these problems before any bank stabilization or instream habitat development is considered.

Local Instability

Local instability refers to erosion and deposition processes that are not symptomatic of a disequilibrium condition in the watershed (i.e., system instability). Perhaps the most common form of local instability is bank erosion along the concave bank in a meander bend that is occurring as part of the natural meander process. Local instability can also occur in isolated locations as the result of channel constriction, flow obstructions (debris, structures, etc.), or geotechnical instability. The channel instabilities often can be attributed to redirection of flow caused by debris, structures, or the approach angle from upstream. During moderate and high flows, obstructions often result in vortices and secondary-flow cells that accelerate impacts on channel boundaries, causing local bed scour, erosion of bank toes, and ultimately bank failures. A general constriction of the channel cross section from debris accumulation or a bridge causes a backwater condition upstream, with acceleration of the flow and scour through the constriction.

Local instability problems are amenable to local bank protection. Local instability can also exist in channels where severe system instability exists. In these situations, the local instability problems will probably be accelerated due to the system instability, and a more comprehensive treatment plan will be necessary. If the upstream reach is stable and the downstream reach is unstable, a systemwide problem may again be indicated. The instability may continue moving upstream unless the root cause of the instability at the watershed level is removed or channel stabilization at and downstream of the site is implemented.

Bed Stability

In unstable channels, the relationship between bed elevation and time (years) can be described by nonlinear functions, where change in response to a disturbance occurs rapidly at first and then slows and becomes asymptotic with time. An example of plotting of channel bed elevation over time for the South Fork Obion River, USA is shown in Figure 3.75. Plotting bed elevations against time permits evaluating bed-level adjustment and indicates whether a major phase of channel incision has passed or is ongoing. Various mathematical forms of this function have been used to characterize bed-level adjustment at a site and to predict future bed elevations. This method also can provide valuable information on trends of channel stability at gauging locations where abundant data from discharge measurements are available (see *Regression Functions for Degradation and Aggradation* below).

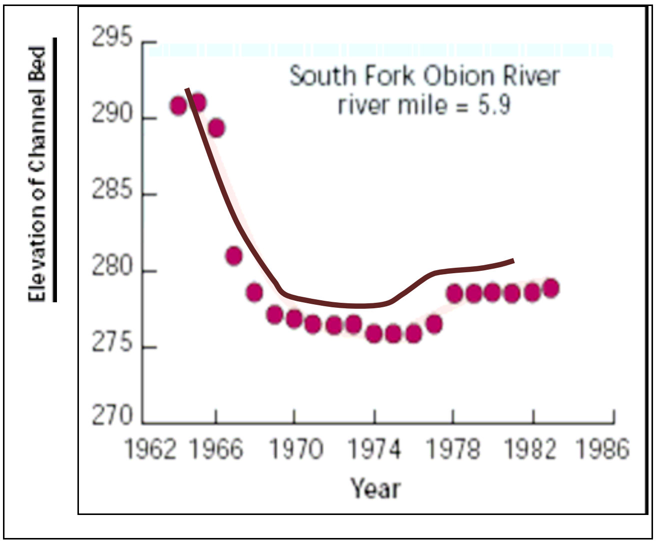


Figure 3.75 Changes in bed elevations over time (Source: The Federal Interagency Stream Restoration Working Group (2001) [24])

Specific Gauging Analysis

In large rivers with bedforms, perhaps one of the most useful tools available to the river engineer or geomorphologist for assessing the historical stability of a river system is the specific gauging record. A specific gauging record is a stage-discharge curve (or rating curve) at a particular stream gauging location plotted against time. A channel is considered to be in equilibrium if the specific gauging record shows no consistent increasing or decreasing trends over time, while an increasing or decreasing trend is indicative of an aggradational or degradational condition, respectively.

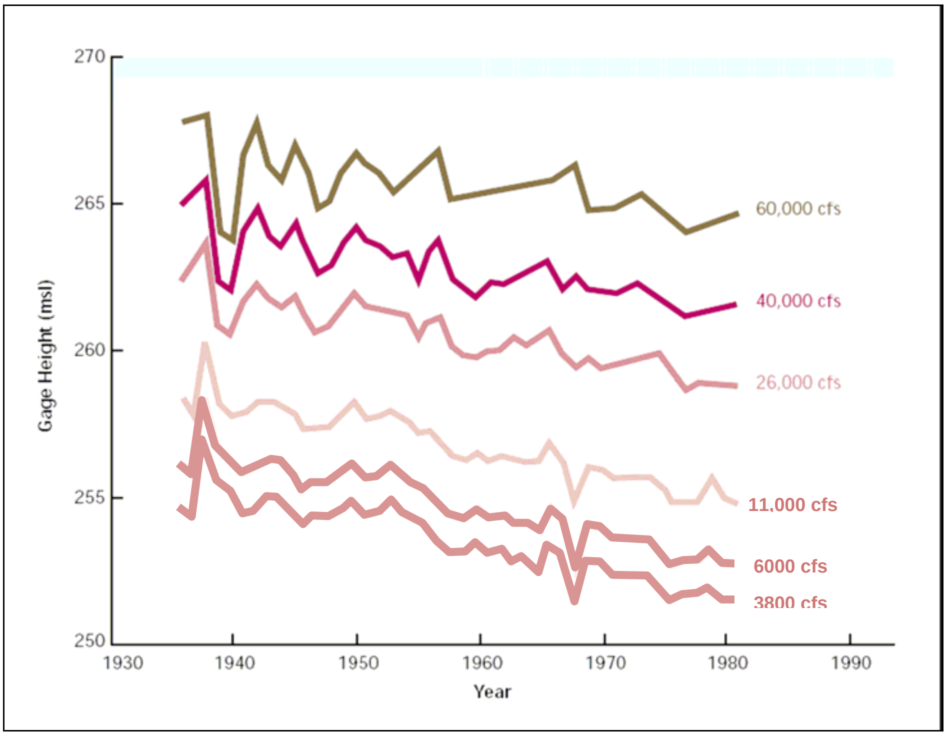


Figure 3.76 Specific gauging plot for Red River at Index, Arkansas [24]

The first step in a specific gauging analysis is to establish the rating curve for each year at the gauge for the period of record being analyzed. A regression curve is then fitted to the data and plotted on the scatter plot. Once the rating curves have been developed, the discharges to be used in the specific gauging record must be selected. This selection depends largely on the objectives of the study. It is usually advisable to select discharges that encompass the entire range of observed flows. A plot is then developed showing the stage for the given flow plotted against time. An example of a specific gauging record is shown in Figure 3.76.

Specific gauging records are a useful tool for assessing the historical stability at a specific location. However, specific gauging records indicate only the conditions in the vicinity of the particular gauging station and do not necessarily reflect river response farther upstream or downstream of the gauge. Therefore, even though the specific gauging record gives changes in water surface elevation, wich is very useful for the determination of levees, or bund, elevations, it does not determine the change in bed elevation. Specifically, the the water surface elevation changes can be induced by changes in bedform configurations, changes in dune height and dune length, as well as changes in water temperature. A final note of caution is that a specific gauge record analysis cannot be performed with fixed stage-discharge relationships. In other words, both the stage and the discharge must be measured separately over a long period of time to establish specific gauge record profiles. Finally, specific gauge records should be coupled with other assessment techniques to assess reach conditions or to make predictions about the ultimate response on a river.

Comparative Surveys and Mapping

One of the best methods for directly assessing channel changes is to compare channel surveys (thalweg and cross section). Thalweg surveys are taken along the channel at the lowest point in the cross section. Comparison of several thalweg surveys taken at different points in time allows the engineer or geomorphologist to chart the change in the bed elevation through time (Figure 3.77).

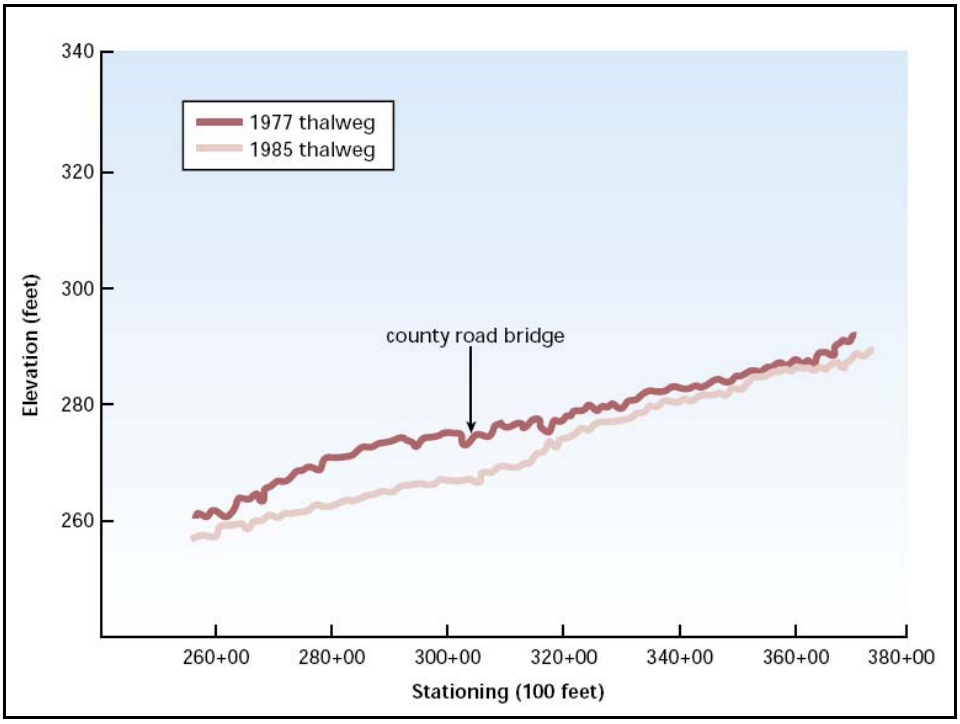


Figure 3.77 Comparative thalweg profiles (1 m = 3.28 ft) [24]

Certain limitations should be considered when comparing surveys on a river system. When comparing thalweg profiles, it is often difficult, especially on larger streams, to determine any distinct trends of aggradation or degradation if there are large scour holes, particularly at bends. The existence of very deep local scour holes may completely obscure temporal variations in the thalweg. This problem can sometimes be overcome by eliminating the pool sections and focusing only on the crossing locations, thereby allowing aggradational or degradational trends to be more easily observed.

Although thalweg profiles are a useful tool, it must be recognized that they reflect only the behavior of the channel bed and do not provide information about the channel as a whole. For this reason it is usually advisable to study changes in the cross-sectional geometry. Cross-sectional geometry refers to width, depth, area, wetted perimeter, hydraulic radius, and channel conveyance at a specific cross section.

If channel cross sections are surveyed at permanent monumented range locations, the cross-sectional geometry at different times can be compared directly. The cross section plots for each range at the various times can be overlaid and compared. It is seldom the case, however, that the cross sections are located in the exact same place year after year. Because of these problems, it is often advisable to compare reach-average values of the cross-sectional geometry parameters. This requires the study area to be divided into distinct reaches based on geomorphic characteristics. Next, the cross-sectional parameters are calculated at each cross section and then averaged for the entire reach. Then the reach-average values can be compared for each survey. Cross-sectional variability between bends (pools) and crossings (riffles) can obscure temporal trends, so it is often preferable to use only cross sections from crossing reaches when analyzing long-term trends of channel change.

Comparison of time-sequential maps can provide insight into the planform instability of the channel. Rates and magnitude of channel migration (bank caving), locations of natural and man-made cutoffs, and spatial and temporal changes in channel width and planform geometry can be determined from maps. With these types of data, channel response to imposed conditions can be documented and used to substantiate predictions of future channel response to a proposed alteration. Planform data can be obtained from aerial photos, maps, or field investigations.

Regression Functions for Degradation and Aggradation

Two mathematical functions have been used to describe bed level adjustments with time. Both may be used to predict channel response to a disturbance, subject to the caution statements below.

The first is a power function (Simon 1989a)[35]:

$$E = a\, t^{b} \qquad (3.28)$$

where
E = elevation of the channel bed, (m);
a = coefficient, determined by regression, representing the pre-modified elevation of the channel bed, (m);
t = time since beginning of adjustment process, in years, where t_0 = 1.0 (year prior to onset of the adjustment process); and
b = dimensionless exponent, determined by regression and indicative of the nonlinear rate of channel bed change (negative for degradation and positive for aggradation).

The second function is a dimensionless form of an exponential equation (Simon 1992)[36]:

$$z / z_0 = a + b\, e^{(-k\,t)} \qquad (3.29)$$

where

z = the elevation of the channel bed (at time t);
z_0 = the elevation of the channel bed at t_0;
a = the dimensionless coefficient, determined by regression and equal to the dimensionless elevation (z/z_0) when the equation becomes asymptotic, a>1 means aggradation, a<1 means degradation
b = the dimensionless coefficient, determined by regression and equal to the total change in the dimensionless elevation (z/z_0) when the equation becomes asymptotic ;
k = the coefficient determined by regression, indicative of the rate of change on the channel bed per unit time;
t = the time since the year prior to the onset of the adjustment process, in years (t_0=0).

Future elevations of the channel bed can, therefore, be estimated by fitting the equations to bed elevations and by solving for the period of interest. Either equation provides acceptable results, depending on the statistical significance of the fitted relation. The main difference between the two equations is that the power formulation implies that the stream will always continue to aggrade or degrade while the exponential formulation will reach equilibrium when t becomes sufficiently long. Statistical significance of the fitted curves improves with additional data. It is possible for a stream to be subjected to successive periods of degradation and degradation. Degradation and aggradation curves for the same site can then be fit separately. For degrading sites, the equations will provide projected minimum channel elevations when the value of t becomes large and, by subtracting this result from the floodplain elevation, projected maximum bank heights. A range of bed adjustment trends can be estimated by using different starting dates in the equations when the initial timing of bed level change is unknown. Use of the equations, however, may be limited in some areas because of a lack of survey data.

Regression Functions for Secondary Aggradation

Once the minimum bed elevation has been obtained, that elevation can be used as the starting elevation at a new t_0 for the secondary aggradation phase that occurs during channel widening. Secondary aggradation occurs at a site after degradation reduces channel gradient and stream power to such an extent that sediment loads delivered from degrading reaches upstream can no longer be transported (Simon 1989a)[35]. Coefficient values for Simon's power function for estimating secondary aggradation can be obtained either from interpolating existing data or from estimating their values as about 60 percent less than the corresponding value obtained for the degradation phase.

The variation of the regression coefficients a and b with longitudinal distance along the channel can be used as an empirical model of bed level adjustment providing there are data from enough sites. Examples using both equations are provided for the Obion River system, West Tennessee, USA (Figure 3.78). Estimates of bed-level change with time for unsurveyed sites can be obtained using interpolated coefficient a-values and t_0. For channels downstream from dams without significant tributary sediment inputs, the shape of the a-value curve would be similar but inverted; maximum amounts of degradation (minimum a-values) occur immediately downstream of the dam and attenuate nonlinearly with distance farther downstream.

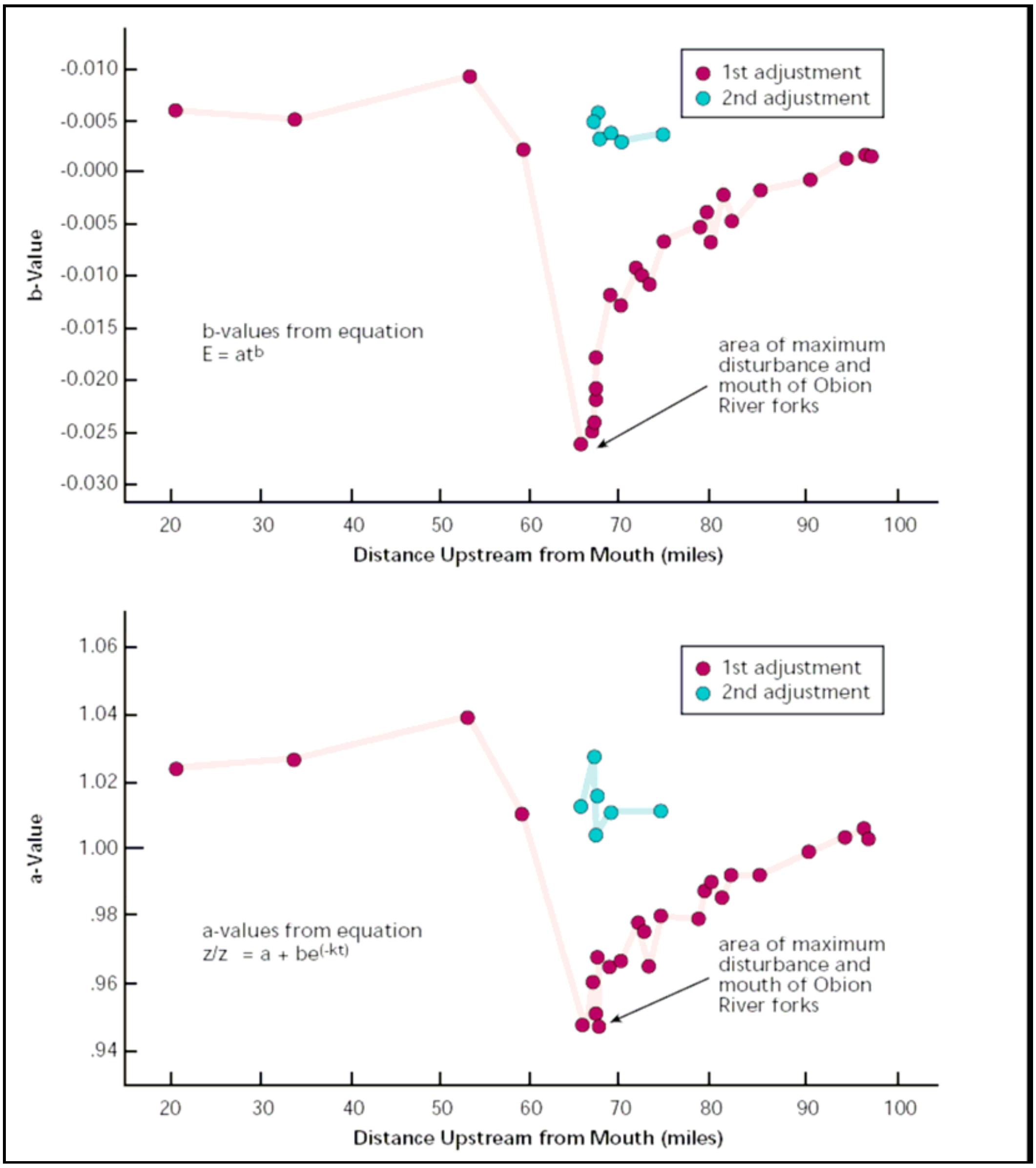


Figure 3.78 Coefficient a and b values for regression functions for estimating bed level adjustment versus longitudinal distance along stream (Imperial units) [36]

If one of the above mathematical functions is used to predict future bed elevations, the assumption is made that no new disturbances have occurred to trigger a new phase of channel change. Downstream channelization, construction of a reservoir, formation of a large woody debris jam that blocks the channel, or even a major flood are examples of disturbances that can trigger a new period of rapid change.

The investigator is cautioned that the use of regression functions to compute aggradation and degradation is an empirical approach that might be appropriate for providing insight into the degradational and aggradational processes during the initial planning phases of a project. However, this procedure does not consider the balance between supply and transport of water and sediment and, therefore, is not acceptable for the detailed design of rehabilitation features. Extrapolations beyond the period of record are also not recommended. For instance a stream that has been aggrading in the past 30 years could eventually degrade in the next 20 years if the site is located just downstream of a recently constructed dam.

Sediment Transport Processes

An account on sediment transport processes is given in Section 2.2.8 Sediment Transport Processes in River Morphology of this volume of the Manual. These processes include erosion, entrainment, transport, deposition, and compaction. Further information may be obtained from standard texts and references including Julien (1998)[38], Simons and Senturk (1997)[30], Chang (1988)[32], Richards (1982)[31], and USACE (1989A)[37] etc.

Numerical Analyses and Models to Predict Aggradation and Degradation

Numerical analyses and models such as HEC-RAS, ISIS-Sediment and MIKE 11 are used to predict aggradation and degradation (incision) in stream channels. The HEC-RAS approach is specifically recommended since the software can be downloaded for free. Numerical analyses and modeling are discussed in "Vol. VII – Engineering Modeling" of the DID Manual.

Bank Stability

Streambanks can be eroded by currents removing soil particles or by collapse. Collapse or mass failure occurs when the strength of bank materials is too low to resist gravity forces. Banks that are collapsing or about to collapse are referred to as being geotechnically unstable (Figure 3.79). The physical properties of bank materials should be described to aid characterization of potential stability problems and identification of dominant mechanisms of bank instability.

Figure 3.79 Bank erosion by removal of toe slope support leading to instability[24]

The extent of geotechnical investigations required varies in planning and design. During planning, enough information must be collected to determine the feasibility of alternatives being considered. For example, qualitative descriptions of bank stratigraphy obtained during planning may be all that is required for identifying dominant modes of failure in a study reach. For a fuller account on the causes of bank instability, reference may be made to Section 3.3.4 "Bank Protection and Stabilization Guidelines and Techniques" of this volume of the Manual.

When rehabilitation design requires more quantitative information on soil properties, additional detailed data need to be collected. Values of cohesion, friction angle, and unit weight of the bank material need to be quantified for stability analysis (Figure 3.80). Because of spatial variability, careful sampling and testing programs are required to minimize the amount of data required to correctly characterize the average physical properties of individual layers or to determine a bulk average statistic for an entire bank. An example calculation of the critical height, H_c, using the equation in Figure 3.80 is given below. It is to be noted that such simplified calculation is meant for general assessment of bank stability only.

Data: Average bank slope, $\beta = 40^\circ$, $c = 12\ \mathrm{N/m^2}$, $\phi = 5^\circ$, $\gamma = 18\ \mathrm{KN/m^3}$

$$H_c = \frac{4c\sin\beta\cos\phi}{\gamma(1-\cos[\beta-\phi])} \tag{3.30}$$

$= 4\mathrm{x}12\sin(40^\circ)\cos(5^\circ)/\{18(1-\cos[40^\circ - 5^\circ])\}$
$= 9.4$ m.

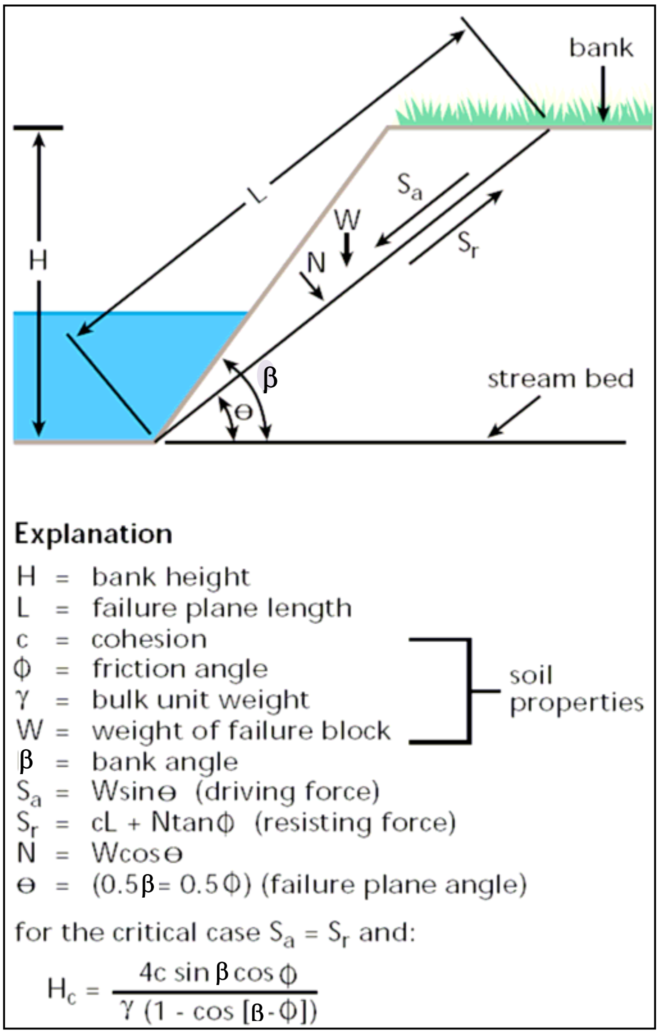


Figure 3.80 An illustration of bank stability analysis (without pore water pressure) relating strength of bank materials to bank height and angles, and to moisture conditions [63]

In applying the above equation, care must be taken to characterize soil properties not only at the time of measurement but also for the "worst case" scenarios at which failure is expected. Unit weight, cohesion, and friction angle vary as a function of moisture content and ground water table. It is usually not possible to directly measure properties of bank materials under worst-case conditions, due to the hazardous nature of unstable sites under such conditions. Besides taking note of the various conditions mentioned in the following paragraphs on bank instability and channel widening, an experienced geotechnical engineer should be engaged to estimate these operational strength parameters for design analyses. For an in-depth quantitative analysis of bank instabilities, reference may be made to the "Vol. VI - Geotechnical Manual, Site Investigation and Engineering Survey" of the DID Manual.

Bank Instability and Channel Widening

Channel widening is often caused by increases in bank height beyond the critical conditions of the bank material. There is a positive correlation between the amount of bed level lowering by degradation and amounts of channel widening. The adjustment of channel width by mass-wasting processes represents an important mechanism of channel adjustment and energy dissipation in alluvial streams, occurring at considerable fast rates in some instances. Present and future bank stability may be analyzed using the following procedure:

- Measure the current channel geometry and shear strength of the channel banks.
- Estimate the future channel geometries and model worst-case pore pressure scenarios and average shear strength characteristics.

For fine-grained soils, cohesion and friction angle data can be obtained from standard laboratory testing (triaxial shear or unconfined compression tests) or by in-situ testing with a borehole vane shear device. For coarse-grained, cohesionless soils, estimates of friction angles can be obtained from reference text. By combining these data with estimates of future bed elevations, relative bank stability can be assessed using bank stability analysis. The use of bank stability chart and bank failure frequency classification is shown in Appendix K.

3.5.2.3 Chemical Characteristics

Assessing water chemistry in a stream rehabilitation initiative can be one of the ways to determine if the rehabilitation was successful. A fundamental understanding of the chemistry of a given system is critical for developing appropriate data collection and analysis methods. Although data collection and analysis are interdependent, each has individual components. It is also critical to have a basic understanding of the hydrologic and water quality processes of interest before data collection and analysis begin.

Data Collection

Constituent Selection

Hundreds of chemical compounds can be used to describe water quality. It is typically too expensive and too time consuming to analyze every possible chemical of interest in a given system. In addition to selecting a particular constituent to sample, the analytical techniques used to determine the constituent also must be considered. Another consideration is the chemistry of the constituent; for example, whether the chemical is typically in the dissolved state or sorbed onto sediment makes a profound difference in the methods used for sampling and analysis, as well as the associated costs. Often it is effective to use parameters that integrate or serve as indicators for a number of other variables. For instance, dissolved oxygen and temperature measurements integrate the net impact of many physical and chemical processes on a stream system, while soluble reactive phosphorus concentration is often taken as a readily available indicator of the potential for growth of attached algae.

Sampling Frequency

The needed frequency of sampling depends on both the constituent of interest and management objectives. For instance, a management goal of reducing average instream nutrient concentrations may require monitoring at regular intervals, whereas a goal of maintaining adequate dissolved oxygen (DO) during low flow and high temperature periods may require only targeted monitoring during critical conditions. In general, water quality constituents that are highly variable in space or time require more frequent monitoring to be adequately characterized. In many cases, the concentration of a constituent depends on the flow condition. For example, concentrations of a hydrophobic pesticide, which sorbs strongly to particulate matter, are likely to be highest during scouring flows or erosion washoff events, whereas concentrations of a dissolved chemical that is loaded to the stream at relatively steady rates will exhibit highest concentrations in extremely low flows. In fact, field sampling and water quality analyses are time-consuming and expensive, and schedule and budget constraints often determine the frequency of data collection. Such constraints make it even more important to design data collection efforts that maximize the value of the information obtained. Statistical tools often are used to help determine the sampling frequency. Statistical techniques, such as simple random sampling, stratified random sampling, two-stage sampling, and systematic sampling, are among the methods of sampling frequency.

Site Selection

The selection of sampling sites is the third critical part of a sampling design. Most samples represent a point in space and provide direct information only on what is happening at that point. A key objective of site selection is to choose a site that gives information that is representative of conditions throughout a particular reach of stream. Because most hydrologic systems are very complex, it is essential to have a fundamental understanding of the area of interest to make this determination. External inputs, such as tributaries or irrigation return flow, as well as output, such as ground water recharge, can drastically change the water quality along the length of a stream. It is because of these processes that the hydrologic system must be understood to interpret the data from a particular site. For example, downstream from a significant lateral source of a load, the dissolved constituent(s) might be distributed uniformly in the stream channel. Particulate matter, however, typically is stratified. Therefore, the distribution of a constituent sorbed onto particulate matter is not evenly distributed. Finally, practical considerations are an important part of sample collection. Firstly sites must be accessible, preferably under a full range of potential flow and weather conditions. Finally, where constituent loads and concentrations are of interest, it is important to align water quality sample sites with locations at which flow can be accurately gauged.

Sampling Techniques

Sampling techniques will not be covered here. The reader can make reference to the "Vol. IV - Hydrological and Water Resources" of the DID Manual for Sediment Sampling. For water sampling, reference may be made to the guidelines from Department of Environment (DOE). However, the required water quality parameters will be briefly described below.

Sediment Analyses

There are a variety of sediment analysis techniques, each designed with inherent assumptions about the behavior of sediments and sediment-bound contaminants. Some of the techniques may help to demonstrate attainment of narrative requirements of some water quality standards. Two of these common analyses are introduced briefly in the following paragraphs.

Bulk sediment analyses provide total concentration of contaminants that are either bound to sediments or present in pore water. Results are reported in milligrams or micrograms per kilogram of sediment material. This type of testing often serves as a screening analysis to classify dredged material. Results of bulk testing tend to overestimate the mass of contaminants that will be available for release or for biological uptake because a portion of the contaminants are not biologically available or likely to dissolve.

Elutriate testing estimates the amount of contaminants likely to be released from sediments when mixed with water. In an elutriate test, sediment is mixed with water and then agitated. The standard elutriate test for dredge material mixes four parts water from the receiving water body with one part sediment (USEPA 1990). After vigorous mixing, the sample is allowed to settle before the supernatant is filtered and analyzed for contaminants. This test was designed to estimate the amount of material likely to enter the dissolved phase during dredging; however, it is also useful as a screening test for determining whether further testing should be performed and as a tool for comparing sediments upstream and downstream of potential pollutant sources.

Analyses of Water Quality Samples

Concentrations of various water quality parameters may be monitored both in the field (*in situ*) and in samples submitted to a laboratory (*ex situ*). Some parameters, such as water temperature, must be obtained in the field. Parameters such as concentrations of specific synthetic organic chemicals require laboratory analysis. Other parameters, such as nutrient concentrations, can be measured by both field and laboratory analytical methods. For chemical constituents, field measurements generally should be only considered as qualitative screening values since rigorous quality control is not possible. Suffice to note that special considerations must be given regarding those parameters typically sampled and analyzed in the field, including pH, temperature, and dissolved oxygen (DO).

In the local context, DOE has been conducting monitoring of rivers since 1978, primarily to establish the status of water quality, detect changes and identify pollution sources. Water quality data are used to determine the water quality status whether in clean, slightly polluted or polluted categories and to classify the rivers in Class I, II, III, IV or V based on Water Quality Index (WQI) and Interim National Water Quality Standards for Malaysia (INWQS) every year. Water Quality Index (WQI) is computed based on 6 main parameters:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Ammoniacal Nitrogen (NH_3N)
- pH
- Dissolved Oxygen (DO)
- Suspended Solids (SS)

Other parameters such as heavy metals and bacteria would be measured according to site requirement. In addition, automatic water quality monitoring stations have been installed to monitor river quality changes on a continuous basis at major rivers in the country. Hence, only parameters other the above need additional sampling as determined according to requirements for those rivers. A checklist is tabulated below as Table 3.10 for ease of reference.

Table 3.10 Checklist for Chemical Characteristics Assessment

No.	Activity
1.	Selection of constituents
	♦ Constituents selected to base on needs and analytical techniques used
	♦ Parameters able to serve as indicators for wider range of variables
2.	Sampling frequency
	♦ At regular interval
	♦ Targeted monitoring during critical condition
3.	Site selection
	♦ Accessible to full range of flows
	♦ Close to gauging station
4.	Sampling techniques
	♦ Sediment sampling (DID Manual)
	♦ Water sampling (DOE Guidelines)
5.	Sediment analyses
	♦ Bulk sediment analysis
	♦ Elutriate testing
	♦ Other specified method ( )
6.	Water quality sampling (based on WQI & INWQS)
	♦ 6 parameters (BOD, COD, NH_3N, pH, DO, and SS)
	♦ Other specified parameters e.g. heavy metal, bacteria etc. ( )

3.5.2.4 Biological Characteristics

Nearly all analytical procedures for assessing the condition of biological resources can be used in stream corridor rehabilitation. Such procedures differ, however, in their scale and focus and in the assumptions, knowledge, and effort required to apply them. These procedures can be grouped into two broad classes - synthetic measures of system condition, and analyses based on how well the system satisfies the life history requirements of target species or species groups.

The most important difference between these classes is the logic of how they are applied in managing or rehabilitating a stream corridor system. This section focuses on metrics of biological conditions and does not describe, for example, actual field methods for counting organisms.

Synthetic Measures of System Condition

Synthetic measures of system condition summarize some aspect of the structural or functional status of a system at a particular point in time. Complete measurement of the state of a stream corridor system, or even a complete census of all of the species present, is not feasible. Thus, good indicators of system condition are efficient in the sense that they summarize the health of the overall system without having to measure everything about the system. Use of indicators of system condition in management or rehabilitation depends completely on comparison to values of the indicator observed in other systems or at other times. Thus, the current value of an indicator for a degraded stream corridor can be compared to a previously measured pre-impact value for the corridor, a desired future value for the corridor, a value observed at an "unimpacted" reference site, a range of values observed in other systems, or a normative value for that class of stream corridors in a stream classification system. However, the indicator itself and the analysis that establishes the value of the indicator provide no direct information about what has caused the system to have a particular value for the indicator.

Deciding what to change in the system to improve the value of the indicator depends on a temporal analysis in which observed changes in the indicator in one system are correlated with various management actions or on a spatial analysis in which values of the indicator in different systems are correlated with different values of likely controlling variables. In both cases, no more than a general empirical correlation between specific causal factors and the indicator variable is attempted. Thus, management or rehabilitation based on synthetic measures of system condition relies heavily on iterative monitoring of the indicator variable and trial and error, or adaptive management, approaches. For example, an index of species composition based on the presence or absence of a set of sensitive species might be generally correlated with water quality, but the index itself provides no information on how water quality should be improved. However, the success of management actions in improving water quality could be tracked and evaluated through iterative measurement of the index.

Synthetic measures of system condition vary along a number of important dimensions that determine their applicability. In certain situations, single species might be good indicators of some aspect of a stream corridor system; in others, community metrics, such as diversity, richness and evenness might be more suitable. Some indicators incorporate physical variables, and others do not. Measurements of processes and rates, such as primary productivity and channel meandering rates, are incorporated into some and not into others. Each of these dimensions must be evaluated relative to the objectives of the rehabilitation effort to determine which, if any, indicator is most appropriate.

Indicator Species

An indicator species may be defined as an organism whose characteristics (e.g. presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest (Landres et al. 1988). Indicators are biological entities whose interactions with the ecosystem make them especially informative about the quality of habitat, communities and ecosystem processes and their purpose is to reflect changes in the ecosystem dynamics at spatial, temporal and organisational scales. The role of an indicator may be played by gene frequencies, populations, species, sets of interacting species, or whole assemblages of communities on a landscape scale.

The Good and Bad of Indicator Species

Indicator species have been used to predict environmental contamination, population trends, and habitat quality; however, their use in evaluating water quality is not covered in this section. The assumptions implicit in using indicators are that if the habitat is suitable for the indicator it is also suitable for other species (usually in a similar ecological guild) and that wildlife populations reflect habitat conditions.

However, because each species has unique life requisites, the relationship between the indicator and its guild may not be completely reliable. It is also difficult to include all the factors that might limit a population when selecting a group of species that an indicator is expected to represent. For example, similarities in breeding habitat between the indicator and its associates might appear to group species when in fact differences in predation rates, disease, or seasonal habitat actually limit populations.

Some management agencies use vertebrate indicators to track changes in habitat condition or to assess the influence of habitat alteration on selected species. Habitat suitability indices and other habitat models are often used for this purpose, though the metric chosen to measure a species' response to its habitat can influence the outcome of the investigation.

Selecting Indicators

If the decision is made to use indicators, then several factors are important to consider in the selection process (Landres et al. 1988):

- *Sensitivity of the species to the environmental attribute being evaluated.* When possible, data that suggest a cause-and-effect relationship are preferred to correlates (to ensure the indicator reflects the variable of interest and not a correlate).

- *Indicator accurately and precisely responds to the measured effect.* High variation statistically limits the ability to detect effects. Generalist species do not reflect change as well as more sensitive endemics. However, because specialist species usually have lower populations, they might not be the best for cost-effective sampling. When the goal of monitoring is to evaluate on-site conditions, using indicators that occur only within the site makes sense. But there are exceptions if the goal of riparian rehabilitation efforts is to provide habitat for migrant species such as neotropical migratory birds.
- *Size of the species home range.* If possible, the home range should be larger than that of other species in the evaluation area. Management agencies often are forced to use threatened and endangered species as indicators. Game species are often poor indicators simply because their populations are highly influenced by hunting mortality, which can mask environmental effects. Species with low populations or restrictions on sampling methods, such as threatened and endangered species, are also poor indicators because they are difficult to sample adequately, often due to budget constraints.
- *Indicator Species Response.* The response of an indicator species to an environmental stressor cannot be expected to be consistent across varying geographic locations or habitats without corroborative research.

Riparian Response Guilds

Vertebrate response guilds as indicators of rehabilitation success in riparian ecosystems may be a valuable monitoring tool but should be used with the same cautions presented above. In the evaluation of the effects of anthropogenic disturbances on small mammals and birds along waterways by Croonquist and Brooks (1991), species were evaluated in five different response guilds, including wetland dependency, trophic level, species status (endangered, recreational, native, exotic), habitat specificity, and seasonality (birds). It was found that community coefficient (CC) indices were better indicators than species richness. The habitat specificity and seasonality response guilds for birds were best able to distinguish those species sensitive to disturbance from those which were not affected or were benefited. Neotropical migrants and species with specific habitat requirements were the best predictors of disturbance.

Edge and exotic species were greater in abundance in the disturbed habitats and might serve as good indicators there. Seasonality analysis showed migrant breeders were more common in undisturbed areas, which indicate the ability of guild analysis to distinguish local impacts. Mammalian response guilds did not exhibit any significant sensitivity to disturbance and were considered unsuitable as indicators.

Aquatic Invertebrates

Aquatic invertebrates have been used as indicators of stream and riparian health for many years. Perhaps more than other taxa, they are closely tied to both aquatic and riparian habitat. Their life cycles usually include periods in and out of the water, with ties to riparian vegetation for feeding, pupation, emergence, mating, and egg laying.

It is often important to look at the entire assemblage of aquatic invertebrates as an indicator group. Impacts to a stream often decrease diversity but might increase the abundance of some species, with the size of the first species to be affected often larger. Therefore, a good indicator species should be low on the food chain to respond quickly, should have a narrow tolerance to change, and should be a native species.

Diversity and Related Indices

Biological diversity refers to the number of species in an area or region and includes a measure of the variety of species in a community that takes into account the relative abundance of each species. When measuring diversity, it is important to clearly define the biological objectives, stating exactly what attributes of the system are of concern and why. Different measures of diversity can be applied at various levels of complexity, to different taxonomic groups, and at distinct spatial scales. Several factors should be considered in using diversity as a measure of system condition for stream corridor rehabilitation.

Levels of Complexity

Diversity can be measured at several levels of complexity - genetic, population/species, community/ecosystem, and landscape. There is no single correct level of complexity to use because different scientific or management issues are focused on different levels. The level of complexity chosen for a specific stream corridor rehabilitation initiative should be determined based on careful consideration of the biological objectives of the project.

Subsets of Concern

Overall diversity within any given level of complexity may be of less concern than diversity of a particular subset of species or habitats. Measures of overall diversity include all of the elements of concern and do not provide information about the occurrence of specific elements. For example, measures of overall species diversity do not provide information about the presence of individual species or species groups of management concern.

Any important subsets of diversity should be described in the process of setting biological objectives. At the community level, subsets of species of interest might include native, endemic, locally rare or threatened, specific guilds (e.g., cavity users), or taxonomic groups (e.g., amphibians, breeding birds, macroinvertebrates). At the terrestrial landscape level, subsets of diversity could include forest types or seral stages. Thus, for a specific stream corridor project, measurement of diversity may be limited to a target group of special concern. In this manner, comparison of diversity levels becomes more meaningful.

Spatial Scale

Diversity can be measured within the bounds of a single community, across community boundaries, or in large areas encompassing many communities. Diversity within a relatively homogeneous community is known as alpha diversity. Diversity between communities, described as the amount of differentiation along habitat gradients, is termed beta diversity. The total diversity across very large landscapes is gamma diversity. Noss and Harris (1986) note that management for alpha diversity may increase local species richness, while the regional landscape (gamma diversity) may become more homogeneous and less diverse overall. They recommend a goal of maintaining the regional species pool in an approximately natural relative abundance pattern. The specific size of the area of concern should be defined when diversity objectives are established.

Measures of Diversity

There are three main categories of diversity measures viz. richness indices, abundance models, and indices based on proportional abundance. Richness indices are measures of the number of species (or other element of diversity) in a specific sampling unit and are the most widely used indices. Abundance models account for the evenness (equitability) of distribution of species and fit various distributions to known models, such as the geometric series, log series, lognormal, or broken stick. Indices based on the proportional abundance of species combine both richness and evenness into a single index. A variety of such indices exist, the most common of which is the Shannon-Weaver diversity index:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \qquad (3.31)$$

where
H' = index of species diversity
S = number of species
p_i = proportion of total sample belonging to the i^{th} species

Results of most studies using diversity indices are relatively insensitive to the particular index used. For example, bird species diversity indices from 267 breeding bird censuses were highly correlated (r = 0.97) with simple counts of bird species richness (Tramer 1969). At the species level, a simple measure of richness is often used in conservation biology studies because many rare species that characterize most systems are generally of greater interest than the common species that dominate in diversity indices and because accurate population density estimates are often not available.

Simple measures of species richness, however, are not sensitive to the actual species composition of an area. Similar richness values in two different areas may represent very different sets of species. The usefulness of these measures can be increased by considering specific subsets of species of most concern, as mentioned above.

Pielou (1993) recommends the use of three indices to adequately assess diversity in terrestrial systems:

- A measure of plant species diversity.
- A measure of habitat diversity.
- A measure of local rarity.

Other indices used to measure various aspects of diversity include vegetation measures, such as foliage height diversity and landscape measures, such as fractal dimension, fragmentation indices, and juxtaposition.

Related Integrity Indices

Karr (1981) developed the Index of Biological Integrity (IBI) to assess the diversity and health of aquatic communities (see Appendix L). This index is designed to assess the present status of the aquatic community using fish community parameters related to species composition, species richness, and ecological factors. Species composition and richness parameters may include the presence of intolerant species, the richness and composition of specific species groups (e.g. oriental darters), or the proportion of specific groups (e.g. hybrid individuals). Ecological parameters may include the proportion of top carnivores, number of individuals, or proportion with disease or other anomalies. Key parameters are developed for the stream system of interest, and each parameter is assigned a rating. The overall rating of a stream is used to evaluate the quality of the aquatic biota.

Rapid Bioassessment

Rapid bioassessment techniques are most appropriate when rehabilitation goals are nonspecific and broad, such as improving the overall aquatic community or establishing a more balanced and diverse community in the stream corridor. Bioassessment often refers to use of biotic indices or composite analyses and Rapid Bioassessment Protocols (RBP) *(Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers).*

The U.S. Environmental Protection Agency (USEPA) evaluates biotic integrity by using an Invertebrate Community Index (ICI) that emphasizes structural attributes of invertebrate communities and compares the sample community with a reference or control community. The ICI is based on 10 metrics that describe different taxonomic and pollution tolerance relationships within the macroinvertebrate community. The RBP established by USEPA were developed to provide states with the technical information necessary for conducting cost-effective biological assessments. Table 3.11 divides RBP's into five sets of protocols (RBP I to V), three for macroinvertebrates and two for fishes.

Table 3.11 Five tiers of the rapid bioassessment protocols [24]

Level or Tier	Organism Group	Relative Level of Effort	Level of Taxonomy/ Where Performed	Level of Expertise Required
I	Benthic invertebrates	Low; 1-2 hr per site (no standardized sampling)	Order, family/field	One highly-trained biologist
II	Benthic invertebrates	Intermediate; 1.5-2.5 hr per site (all taxonomy performed in field)	Family/field	One highly-trained biologist and one technician
III	Benthic invertebrates	Most rigorous; 3-5 hr per site (2-3 hr of total are for lab taxonomy)	Genus or species/laboratory	One highly-trained biologist and one technician
IV	Fish	Low; 1-3 hr per site (no fieldwork involved)	Not applicable	One highly-trained biologist
V	Fish	Most rigorous; 2-7 hr per site (1-2 hr per site are for data analysis)	Species/field	One highly-trained biologist and 1-2 technicians

Algae

Although not included in the above sets of protocols, algal communities are useful for bioassessment as they generally have short life spans and rapid reproduction rates, making them useful for evaluating short-term impacts. Sampling impacts are minimal to resident biota, and collection requires little effort. Primary productivity of algae is affected by physical and chemical impairments. Algal communities are sensitive to some pollutants that might not visibly affect other aquatic communities. Algal communities can be examined for indicator species, diversity indices, taxa richness, community respiration, and colonization rates. A variety of nontaxonomic evaluations, such as biomass and chlorophyll, may be used and are summarized in Weitzel (1979)[57]. Rodgers et al. (1979)[56] describe functional measurements of algal communities, such as primary productivity and community respiration, to evaluate the effects of nutrient enrichment.

Although collecting algae in streams requires little effort, identifying for metrics, such as diversity indices and taxa richness, may require considerable effort. A great deal of effort may be expended to document diurnal and seasonal variations in productivity.

Benthic Macroinvertebrates

The intent of the benthic rapid bioassessment is to evaluate overall biological condition, optimizing the use of the benthic community's capacity to reflect integrated environmental effects over time. Using benthic macroinvertebrates is advantageous for the following reasons:

- They are good indicators of localized conditions.
- They integrate the effects of short-term environmental variables.
- Degraded conditions are easily detected.
- Sampling is relatively easy.
- They provide food for many fish of commercial or recreational importance.
- Macroinvertebrates are generally abundant.
- Many recorded background data.

As indicated above, the RBP are divided into three sets of protocols (RBP I to III) for macroinvertebrates. RBP I is a "screening" or reconnaissance-level analysis used to discriminate obviously impaired and non-impaired sites from potentially affected areas requiring further investigation. RBP II and III use a set of metrics based on taxon tolerance and community structure similar to the ICI. Both are more labor-intensive than RBP I and incorporate field sampling. RBP II uses family-level taxonomy to determine the following set of metrics used in describing the biotic integrity of a stream:

- Taxa richness.
- Hilsenhoff biotic index (Hilsenhoff 1988).
- Ratio of scrapers to filtering collectors.
- Ratio of Ephemeroptera/Plecoptera/ Trichoptera (EPT) and chironomid abundances.
- Percent contribution of dominant taxa.
- EPT index.
- Community similarity index.
- Ratio of shredders to total number of individuals.

RBP III further defines the level of biotic impairment and is essentially an intensified version of RBP II that uses species-level taxonomy. As with ICI, the RBP metrics for a site are compared to metrics from a control or reference site.

Locally an approach close to RBP II level of rapid bioassessment has been made possible with the adoption of the biological method, ASPT (Average Score Per Taxon) by the DID. A brief account of ASPT is given in Section 2.4.2.3 - Assessment Methods and the details are provided in the published guidelines titled "Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai" by DID Malaysia.

Fishes

The most compelling ecological factor for the use of fish as bio-indicators is that structurally and functionally the diverse fish communities directly and indirectly provide evidence of water quality by incorporating all the local environmental perturbations into the stability of the communities themselves (Hocutt 1981). The use of fish as bioindicators has following advantages:

- They are good indicators of long term effects and broad habitat conditions.
- Fish communities represent a variety of trophic levels.
- Fish are at the top of the aquatic food chain and are consumed by humans.
- Fish are relatively easy to collect and identify.
- Water quality standards are often characterized in terms of fisheries.
- Most of the vertebrate species and subspecies are fish.

The disadvantages of using fish as bioindicators are as follows:

- The cost.
- Statistical validity may be hard to attain.
- It is difficult to interpret findings.

Electrofishing is the most commonly used field technique. Each collecting station should be representative of the study reach and similar to other reaches sampled; effort between reaches should be equal. All fish species, not just game species, should be collected for the fish community assessment. Karr et. Al. (1986)[43] used 12 biological metrics to assess biotic integrity using taxonomic and trophic composition and condition and abundance of fish. The Index of Biological Integrity (IBI) developed by Karr was designed for small warm streams (Refer to Appendix L for more details).

Establishing a Standard of Comparison

With stream rehabilitation activities, it is important to select a desired end condition for the proposed management action. A predetermined standard of comparison provides a benchmark against which to measure progress. For example, if the chosen diversity measure is native species richness, the standard of comparison might be the maximum expected native species richness for a defined geographic area and time period.

Historical conditions in the region should be considered when establishing a standard of comparison. If current conditions in a stream corridor are degraded, it may be best to establish the standard at a period in the past that represented more natural or desired conditions. In addition, the geographic location and size of the area should be considered. Patterns of diversity vary with geographic location, and larger areas are typically more diverse than smaller areas.

Evaluating the Chosen Index

For a hypothetical stream rehabilitation initiative, the following biological diversity objective might be developed. For example if a primary concern in the area is conserving native amphibian species and that 30 native species of amphibians have been known to occur historically in the watershed. The objective could be to manage the stream corridor to provide and maintain suitable habitat for the 30 native amphibian species.

Diversity can be measured directly or predicted from other information. Direct measurement requires an actual inventory of the element of diversity, such as counting the amphibian species in the study area. The IBI requires sampling fish populations to determine the number and composition of fish species. Measures of the richness of a particular animal group require counts. Determining the number of species in a community is best accomplished with a long-term effort because there can be much variation over short periods. Variation can arise from observer differences, sampling design, or temporal variation in the presence of species. Direct measures of diversity are most helpful when baseline information is available for comparing different sites. It is not possible, however, to directly measure certain attributes, such as species richness or the population level of various species, for various future conditions. For example, the IBI cannot be directly computed for a predicted stream corridor condition, following management action.

Predictions of diversity for various future conditions, such as with rehabilitation or management, require the use of a predictive model. Assume the diversity objective for a stream corridor rehabilitation effort is to maximize native amphibian species richness. Based on knowledge of the life history of the species, including requirements for habitat, water quality, or landscape configuration, a plan can be developed to restore a stream corridor to meet these needs. The plan could include a set of criteria or a model to describe the specific features that should be included to maximize amphibian richness. Examples of indirect methods to assess diversity include habitat models (Shroeder and Allen 1992)[55], (Adamus 1993)[44] and cumulative impact assessment methods (Gosselink et. Al. 1990)[54], (Brooks et al 1991)[45]. Predicting diversity with a model is generally more rapid than directly measuring diversity. In addition, predictive methods provide a means to analyze alternative future conditions before implementing specific rehabilitation plans. The reliability and accuracy of diversity models should be established before their use.

Classification Systems

Classification is an important component of many of the scientific disciplines relevant to stream corridors - hydrology, geomorphology, limnology, plant and animal ecology. Table 3.12 shows some of the classification systems in USA that might be useful as an example in identifying and planning riverine rehabilitation activities. Without giving an exhaustive review of the classification schemes or any recommended classification system, emphasis is placed on some of the principal distinctions among classification systems and factors to consider in the use of classification systems for rehabilitation planning, particularly in the use of a classification system as a measure of biological condition. It is likely that multiple systems will be useful in most actual riverine rehabilitation programs. The common goal of classification systems is to organize variation. Important dimensions in which riverine classification systems differ include the following:

- *Geographic domain*. The range of sites being classified varies from rivers of the world to local differences in the composition and characteristics of patches within one reach of a single river.
- *Variables considered.* Some classifications are restricted to abiotic variables of hydrology, geomorphology, and aquatic chemistry. Other community classifications are restricted to biotic variables of species composition and abundance of a limited number of taxa. Many classifications include both abiotic and biotic variables. Even purely abiotic classification systems are relevant to biological evaluations because of the important correlations (e.g., the whole concept of physical habitat) between abiotic structure and community composition.

- *Incorporation of temporal relations.* Some classifications focus on describing correlations and similarities across sites at one, perhaps idealized, point in time. Other classifications identify explicit temporal transitions among classes, for example, succession of biotic communities or evolution of geomorphic landforms.
- *Focus on structural variation or functional behavior.* Some classifications emphasize a parsimonious description of observed variation in the classification variables. Others use classification variables to identify types with different behaviors. For example, a vegetation classification can be based primarily on patterns of species co-occurrence, or it can be based on similarities in functional effect of vegetation on habitat value.
- *The extent to which management alternatives or human actions are explicitly considered as classification variables.* To the extent that these variables are part of the classification itself, the classification system can directly predict the result of a management action. For example, a vegetation classification based on grazing intensity would predict a change from one class of vegetation to another class based on a change in grazing management.

Table 3.12 Example of Selected Riverine and Riparian Classification Systems [24]

Classification System	Subject	Geographic Domain	Citation
Riparian vegetation of Yampa, San Miguel/Dolores River Basins	Plant communities	Colorado	Kittel and Lederer (1993)
Riparian and scrubland communities of Arizona and New Mexico	Plant communities	Arizona and New Mexico	Szaro (1989)
Classification of Montana riparian and wetland sites	Plant communities	Montana	Hansen et al. (1995)
Integrated riparian evaluation guide	Hydrology, geomorphology, soils, vegetation	Intermountain	U.S. Forest Service (1992)
Streamflow cluster analysis	Hydrology with correlations to fish and invertebrates	National	Poff and Ward (1989)
River Continuum	Hydrology, stream order, water chemistry, aquatic communities	International, national	Vannote et al. (1980)
World-wide stream classification	Hydrology, water chemistry, substrate, vegetation	International	Pennak (1971)
Hydrogeomorphic wetland classification	Hydrology, geomorphology, vegetation	National	Brinson (1993)

Use of Classification Systems in Restoring Biological Conditions

Rehabilitation efforts may apply several national and regional classification systems to the riverine site or sites of interest because these are efficient ways to summarize basic site description and inventory information and they can facilitate the transference of existing information from other similar systems.

Most classification systems are generally weak at identifying causal mechanisms. To varying degrees, classification systems identify variables that efficiently describe existing conditions. Rarely do they provide unequivocal assurance about how variables actually cause the observed conditions. Planning efficient and effective rehabilitation actions generally requires a much more mechanistic analysis of how changes in controllable variables will cause changes toward desired values of response variables. A second limitation is that application of a classification system does not substitute for goal setting or design. Comparison of the degraded system to an actual unimpacted reference site, to the ideal type in a classification system, or to a range of similar systems can provide a framework for articulating the desired state of the degraded system. However, the desired state of the system is a management objective that ultimately comes from outside the classification of system variability.

Analyses of Species Requirements

Analyses of species requirements involve explicit statements of how variables interact to determine habitat or how well a system provides for the life requisites of fish and wildlife species. A complete specification of relations between all relevant variables and all species in a stream corridor system is not possible. Thus, analyses based on species requirements focus on one or more target species or groups of species. In a simple case, this type of analysis may be based on an explicit statement of the physical factors that distinguish good habitat for a species (places where it is most likely to be found or where it best reproduces) from poor habitat (places where it is unlikely to be found or reproduces poorly). In more complicated cases, such approaches incorporate variables beyond those of purely physical habitat, including other species that provide food or biotic structure, other species as competitors or predators, or spatial or temporal patterns of resource availability.

Analyses based on species requirements differ from synthetic measures of system condition in that they explicitly incorporate relations between "causal" variables and desired biological attributes. Such analyses can be used directly to decide what rehabilitation actions will achieve a desired result and to evaluate the likely consequences of a proposed rehabilitation action. For example, an analysis using the habitat evaluation procedures might identify macroinvertebrate production as a factor limiting fish population. If fish populations are a concern, at least some parts of the stream rehabilitation effort should be directed toward increasing macroinvertebrate production. In practice, this logical power usually requires knowledge of the fish and macroinvertebrate habitat requirements.

The complexity of these methods varies along a number of important dimensions, including prediction of habitat suitability versus population numbers, analysis for a single place and single time versus a temporal sequence of spatially complex requirements, and analysis for a single target species versus a set of target species involving tradeoffs. Each of these dimensions must be carefully considered in selecting an analysis procedure appropriate to the problem at hand.

There are several habitat evaluation/simulation procedures or models which can be used to carry out impact assessment, mitigation and habitat management such as in Habitat Evaluation Procedures (HEP); whereas the Physical Habitat Simulation (PHABSIM) model provides hydraulic and habitat simulations, habitat evaluation, and weighted usable area with stream discharge etc.

Another modeling approach to aquatic habitat restoration is the Riverine Community Habitat Assessment and Restoration (RCHARC) concept. This model is based on the assumption that aquatic habitat in a rehabilitated stream reach will best mimic natural conditions if the bivariate frequency distribution of depth and velocity in the subject channel is similar to a reference reach with good aquatic habitat. Study site and reference site data can be measured or calculated using a computer model. The similarity of the proposed design and reference reach is expressed with three-dimensional graphs and statistics.

Yet another interesting modeling approach is the Vegetation-hydroperiod Model which simulates the gradients of site moisture conditions within the riparian zone. Hydroperiod is defined as the depth, duration, and frequency of inundation and is a powerful determinant of what plants are likely to be found in various positions in the riparian zone with facility for casting forward or backward in time to alternative distributions, and designing new distributions. More detailed descriptions of the above models can be found in the referenced documents.

3.5.3 Rehabilitation Design

The purposes of stream rehabilitation design can range from simply conveying water to restoring self sustaining ecological functions. They may need large-scale reconstruction of entire stream reaches or localized applications (Stream Corridor Restoration : Principles, Processes and Practices 2001) [71]. The success of a stream corridor design depends on how well the restored system sustains itself over time while accommodating identified needs. To achieve success, designers and implementers must understand the stream corridor, watershed, and landscape as a complex of working ecosystems that influence and are influenced by neighboring ecosystems. The design criteria, standards, and specifications should be for a specific physical, climatic, and geographic location. This approach produces multiple benefits, including:

- A healthy, sustainable pattern of land uses across the landscape.
- Improved natural resource quality and quantity.
- Restored and protected stream corridors and associated ecosystems.
- A diversity of native plants and animals.
- A gene pool that promotes hardiness, disease resistance, and adaptability.
- A sense of stewardship for private landowners and the public.

3.5.3.1 Valley Form, Connectivity, and Dimension

Valley form, connectivity, and dimension are characteristics of valley form that influence many functions (Figure 3.81). The broad concept of connectivity, as opposed to fragmentation, involves linkages of habitats, species, communities, and ecological processes across multiple scales. Dimension encompasses width, linearity, and edge effect, which are critical for movement of species, materials, and energy within the stream corridor and to or from ecosystems in the surrounding landscape. Design should therefore address these large-scale characteristics and their effect on functions.

(a)

(b)

Figure 3.81 Stream corridors. (a) Stream valley side slopes and (b) floodplain gradients and stream corridor [24]

Stream Corridor Connectivity and Dimensions

Generally, the widest and most contiguous stream corridor which achieves habitat, conduit, filter, and other functions (see Section 3.2) should be an ecologically derived goal of rehabilitation. Thresholds for each function are likely found at different corridor widths. The appropriate width varies according to soil type, with steep slopes requiring a wider corridor for filter functions. A conservative indicator of effective corridor width is whether a stream corridor can significantly prevent contaminants contained in runoff from reaching the stream. As discussed in Section 3.1, the corridor should extend across the stream, its banks, the floodplain, and the valley slopes. It should also include a portion of upland for the entire stream length to maintain functional integrity.

Figure 3.82 presents an example of these connections. The open areas within the ladder pattern are representative of areas that are unavailable for rehabilitation because of competing land uses. Innovative management practices that serve the functions of the corridor beyond land ownership boundaries can often be prescribed where land owners are supportive of rehabilitation. Altering land cover, reducing chemical inputs, carefully timed mowing, and other management practices can reduce disturbance in the corridor.

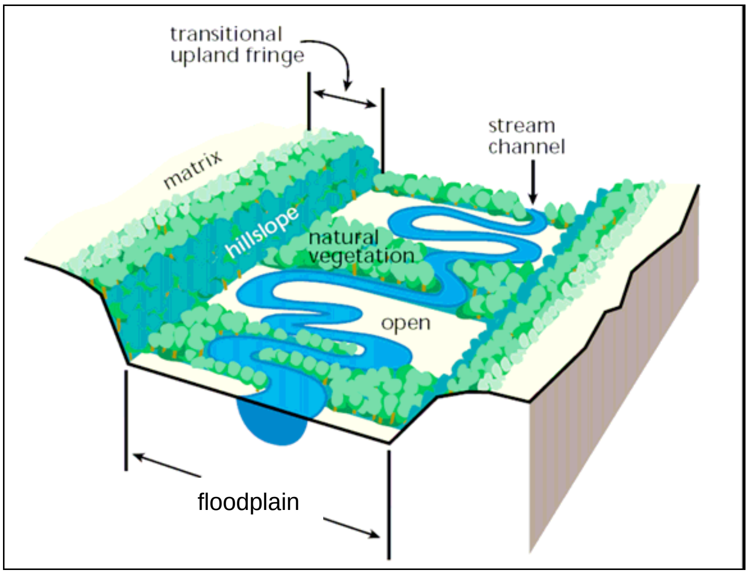


Figure 3.82 Connections across a stream corridor [63]

Restricting rehabilitation to a narrow part of the stream corridor usually does not restore the full horizontal diversity of broad floodplains, nor does it fully accommodate functions that occur during flood events, such as use of the floodplain by aquatic species.

In floodplains where extensive subsurface hydrologic connections exist, limiting restoration to streamside buffer zones is not recommended since significant amounts of energy, nutrient transformation, and invertebrate activities can occur at great distances from the stream channel outside the buffer areas. Similarly, failure to anticipate channel migration might result in a corridor that does not accommodate fundamental dynamic processes.

Rehabilitation of an ecologically effective stream corridor requires consideration of uplands adjacent to the channel and floodplain. Upland slopes might be a source area for water maintaining floodplain wetlands, a sediment source for channels on bedrock, and the principal source of organic debris in high-gradient streams.

Corridor Width Variables

The minimum width of stream corridors is based on ecological criteria (Figure 3.83). Five basic situations in a river system are identified, progressing from seepage to river.

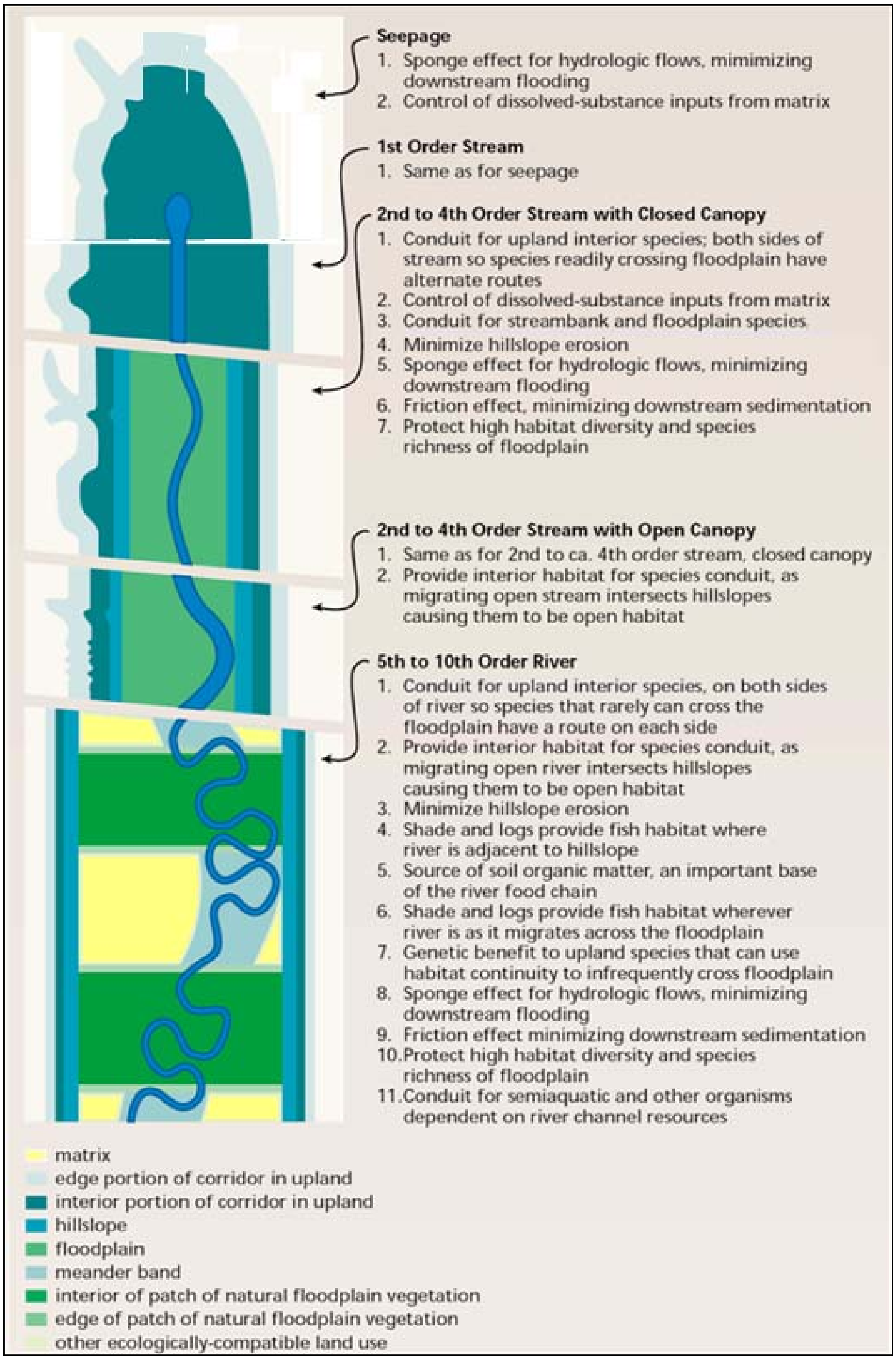


Figure 3.83 Stream corridor width variables [76]

Cognitive Approach : Reference Stream Corridor

If a nearby stream corridor in a similar landscape and land use provides these functions adequately, it can be used to indicate the connectivity and width attributes that should be part of the design.

Analytical Approach: Functional Requirements of a Target Species

The rehabilitation plan objectives can be used to determine dimensions for the stream corridor rehabilitation. The requirements of the most sensitive species typically are used for optimum corridor dimensions. Optimum corridor dimensions can be achieved through collaboration with individuals and organizations who have management authority over adjacent lands. Dimensions include width of edge effect associated with boundaries of the corridor and pattern variations within the corridor, maximum acceptable width of gaps within the corridor, and maximum number of gaps per unit length of corridor.

Designing for Drainage and Topography

The stream corridor is dependent on interactions with the stream to sustain its characters and functions (see Section 3.2). The rehabilitation process should include blockage of artificial drainage systems, removal or setback of artificial levees, and rehabilitation of natural patterns of floodplain topography, unless these actions conflict with other social or environmental objectives such as flooding or habitat. Rehabilitation of micro-relief is particularly important where natural flooding has been reduced or curtailed because a topographically complex floodplain supports a mosaic of plant communities and ecosystem functions as a result of differential ponding of rainfall and interception of ground water. Micro-relief rehabilitation can be accomplished by selective excavation of historic features within the floodplain such as natural wetlands, levees, oxbows, and abandoned channels. Aerial photography and remotely sensed data, as well as observations in reference corridors, provide an indication of the distribution and dimensions of typical floodplain micro-relief features.

3.5.3.2 Soil Properties

Stream corridor functions depend not only on the connectivity and dimensions of the stream corridor, but also on its soils and associated vegetation. The variable nature of soils across and along stream corridors results in diverse plant communities (Figure 3.84).

Figure 3.84 Variable soils result in diverse plant communities [24]

Where native floodplain soils remain in place, soil surveys should be used to determine basic site conditions and fertility and to verify that the proposed plant species to be restored are appropriate. Most sites with fine textured alluvium will not require supplemental fertilization, or fertilizers might be required only for initial establishment. Soil should always be tested before making any fertilizer design recommendations.

The connections and feedback loops between runoff and the structure and functions of streams are described in Section 3.2. The functions of soil and the connection between soil quality, runoff, and water quality are also established in the same section. For all land uses, emphasis needs to be placed on implementing conservation land treatment that promotes soil quality and the ability of the soils to carry out the following four major functions:

- Regulating and partitioning the flow of water (a conduit and filter function).
- Storing and cycling nutrients and other chemicals (a sink and filter function).
- Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials (a filter, sink, and barrier function).
- Supporting biological activity in the landscape (a source and habitat function).

Soil Microfauna

On new or disturbed substrates, or on row-cropped sites, essential soil microorganisms (particularly mycorrhizal fungi) might not exist. These are most effectively replaced by using rooted plant material that is inoculated or naturally infected with appropriate fungi. Stockpiling and reincorporating local topsoils into the substrate prior to planting is also effective. Particular care should be taken to avoid disturbing large trees or stumps since the soils around and under them are likely source areas for reestablishment of a wide variety of microorganisms. Inoculation can be useful in restoring some soil mycorrhizal fungi for particular species when naturally infected plant stock is unavailable.

3.5.3.3 Plant Communities

Vegetation is a fundamental controlling factor in stream corridor function. Habitat, conduit, filter/barrier, source, and sink functions are all critically tied to the vegetative biomass amount, quality, and condition (Figure 3.85). Rehabilitation designs should protect existing native vegetation and restore vegetative structure to result in a contiguous and connected stream corridor.

Figure 3.85 Stream corridor vegetation along Kerayong River

Rehabilitation goals can be general (e.g. returning an area to a reference condition) or specific (e.g. restoring habitats for particular species of interest). Selection of vegetative species may be based on the desire to provide habitat for a particular species of interest. The current trend in rehabilitation, however, is to apply a multispecies or ecosystem approach.

Riparian Buffer Strips

Managers of riparian systems have long recognized the importance of buffer strips for the following reasons (Eightmile River Wild and Scenic Study Committee, April 2005)[73]:

- Provide shade that reduces water temperature.
- Cause deposition of (i.e., filter) sediments and other contaminants.
- Reduce nutrient loads of streams.
- Stabilize streambanks with vegetation.
- Reduce erosion caused by uncontrolled runoff.
- Provide riparian wildlife habitat.
- Protect fish habitat.

- Maintain aquatic food webs.
- Provide a visually appealing greenbelt.
- Provide recreational opportunities.

Although the value of buffer strips is well recognized, criteria for their sizing are variable. In urban stream corridors a wide forest buffer is an essential component of any protection strategy. Its primary value is to provide physical protection for the stream channel from future disturbance or encroachment. A network of buffers acts as the right-of-way for a stream and functions as an integral part of the stream ecosystem.

Existing Vegetation

Existing native vegetation should be retained to the extent feasible, as should woody debris and stumps (Figure 3.86). In addition to providing habitat and erosion and sediment control, these features provide seed sources and harbor a variety of microorganisms, as described above. Old fencerows, vegetated stumps and rock piles in fields, and isolated shade trees in pastures should be retained through rehabilitation design, as long as the dominant plant species are native or are unlikely to be competitors in a matrix of native vegetation (e.g., fruit trees), (Stream Corridor Restoration : Principles, Processes and Practices 2001)[71].

Figure 3.86 Remnant vegetation and woody debris along a stream.

Non-native vegetation can prevent establishment of desirable native species or become an unwanted permanent component of stream corridor vegetation. For example, Silktree Mimosa (Albizia Julibrissin) grows very rapidly and will displace other vegetation such as along the stream bank of the Gombak River and the lower Klang River (Figure 3.87). Similarly, exotic species in the waterways such as water hyacinth (Eichhornia Crassipes) may thrive so vigorously that waterways may be covered up completely within a short period of time (see Appendix N for suggested control methods for these plants). Generally, forest species planted on agricultural land will eventually shade out pasture grasses and weeds, although some initial control (harrowing, mowing, burning) might be required to ensure tree establishment.

Figure 3.87 Thriving Silktree Mimosa (Albizia Julibrissin)

Plant Community Rehabilitation

An objective of stream corridor rehabilitation work might be to restore natural patterns of plant community distribution within the stream corridor. Examination of the reference stream corridor is often the best way to develop information on plant community composition and distribution. Once reference plant communities are defined, design can begin to detail the measures required to restore those communities (Figure 3.88). Rarely is it feasible or desirable to attempt to plant the full complement of appropriate species on a particular site. Rather, the more typical approach is to plant the dominant species or those species unlikely to colonize the site readily.

Figure 3.88 A thriving and diverse plant community within a stream corridor (Sabah).

Large-scale rehabilitation work sometimes includes planting of undergrowth species, particularly if they are required to meet specific objectives such as providing essential components of endangered species habitat. However, it is often difficult to establish under growth species, which are typically not tolerant to full sun, if the rehabilitation area is open. Where particular under growth species are unlikely to establish themselves for many years, they can be introduced in adjacent forested sites, or planted after the initial tree plantings have matured sufficiently to create appropriate under growth conditions.

It has been a common practice in stream corridor planting programs to include non-native species which are selected for their rapid growth rates, soil binding characteristics, ability to produce abundant fruits for wildlife, or other perceived advantages over native species. These actions sometimes have unintended consequences and often prove to be extremely detrimental. Stream corridor rehabilitation designs should emphasize native plant species from local sources. It may be feasible in some cases to focus rehabilitation actions on encouraging the success of local seedfall to ensure that locally adapted populations of stream corridor vegetation are maintained on the site.

Horizontal Diversity

Stream corridor vegetation, as viewed from the air, would appear as a mosaic of diverse plant communities that runs from the upland on one side of the stream corridor, down the valley slope, across the floodplain, and up the opposite slope to the upland. With such broad dimensional range, there is a large potential for variation in vegetation. Some of the variation is a result of hydrology and stream dynamics. Three important structural characteristics of horizontal diversity of vegetation are connectivity, gaps, and boundaries.

Connectivity and Gaps

As discussed earlier, connectivity is an important evaluation parameter of stream corridor functions, facilitating the processes of habitat, conduit, and filter/barrier. Stream corridor rehabilitation design should maximize connections between ecosystem functions.
Habitat and conduit functions can be enhanced by linking critical ecosystems to stream corridors through design that emphasizes orientation and proximity. Designers should consider functional connections to existing or potential features such as vacant or abandoned land, rare habitat, wetlands or meadows, diverse or unique vegetative communities, springs, ecologically innovative residential areas, movement corridors for flora and fauna, or associated stream systems. This allows for movement of materials and energy, thus increasing conduit functions and effectively increasing habitat through geographic proximity. Generally, a long, wide stream corridor with contiguous vegetative cover is favored, though gaps are commonplace.

The most fragile ecological functions determine the acceptable number and size of gaps. Wide gaps can be barriers to migration of smaller terrestrial fauna and indigenous plant species. Aquatic fauna may also be limited by the frequency or dimension of gaps. The width and frequency of gaps should therefore be designed in response to planned stream corridor functions. Bridges have been designed to allow migration of animals, along with physical and chemical connections of river and wetland flow. For example, underpasses can be constructed to benefit particular species at bridges (Figure 3.89). Although not typically equal to the magnitude of an undisturbed stream corridor without gaps, these measures allow for modest functions as habitat and conduit.

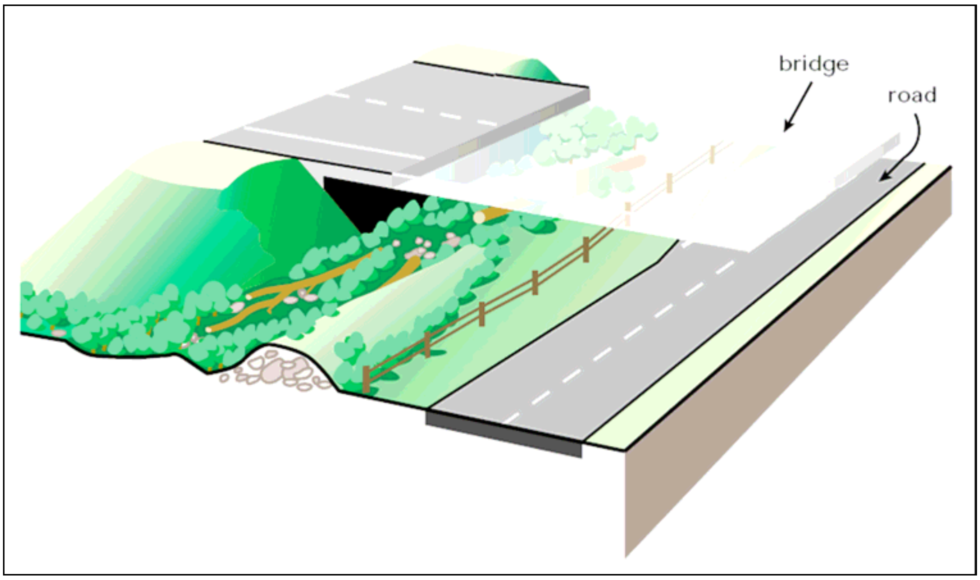


Figure 3.89 Underpass design. Underpasses should be designed to accommodate both vehicular traffic and movement of small fauna [63]

The filtering capacity of stream corridors is affected by connectivity and gaps. For example, nutrient and water discharge flowing overland in sheet flow tends to concentrate and form rills. These rills in turn often form gullies. Gaps in vegetation offer no opportunity to slow overland flow or allow for infiltration. Where reference dimensions are similar and transferable, restored plant communities should be designed to exhibit structural diversity and canopy closure similar to that of the reference stream corridor. The reference stream corridor can provide information regarding plant species and their frequency and distribution. Design should aim to maintain the filtering capacity of the stream corridor by minimizing gaps in the corridor's width and length.

Boundaries

The structure of the edge vegetation between a stream corridor and the adjacent landscape affects the habitat, conduit, and filter functions. Boundaries between stream corridors and adjacent landscapes may be straight or curvilinear. A straight boundary allows relatively unimpeded movement along the edge, thereby decreasing species interaction between the two ecosystems. Conversely, a curvilinear boundary with lobes of the corridor and adjoining areas reaching into one another encourages movement across boundaries, resulting in increased interaction.

Vertical Diversity

Heterogeneity within the stream corridor is an important design consideration. The plants that make up the stream corridor, their form (grasses, shrubs, small trees, large trees), and their diversity affect function, especially at the reach and site scales. Stratification of vegetation affects wind, shading, avian diversity, and plant growth (Forman 1995)[76]. Typically, vegetation at the edge of the stream corridor is very different from the vegetation that occurs within the interior of the corridor. The topography, aspect, soil, and hydrology of the corridor provide several naturally diverse layers and types of vegetation. The difference between edge and interior vegetative structure are important design considerations (Figure 3.90). An edge that gradually changes from the stream corridor into the adjacent ecosystems will soften environmental gradients and encourage more interaction between ecosystems.

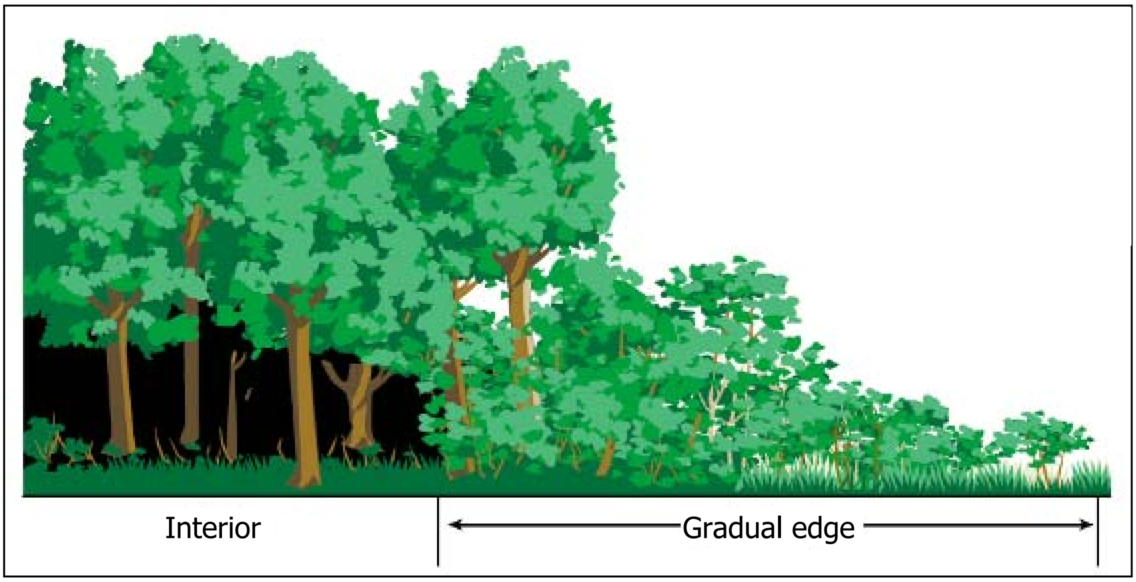


Figure 3.90 Gradual Edge vegetative structure [24]

These transitional zones encourage species diversity and buffer variable nutrient and energy flows. Although human intervention has made edges more abrupt, the conditions of naturally occurring edge vegetation can be restored through design. The plant community and landform of a restored edge should reflect the structural variations found in the reference stream corridor. To maintain a connected and contiguous vegetative cover at the edge of small gaps, taller vegetation should be designed to continue through the gap. If the gap is wider than can be breached by the tallest or widest vegetation, a more gradual edge may be appropriate. Vertical structure of the corridor interior tends to be less diverse than that of the edge. As can be observed at the reference stream corridor, edge vegetation is usually shrubby and difficult to traverse, whereas inner shaded conditions produce a more open forest floor that allows for easier movement. Snags and downed wood may also provide important habitat functions.

3.5.3.4 Habitat Measures

Other measures may be used to provide structure and functions. They may be implemented as separate actions or as an integral part of the rehabilitation plan to improve habitat, in general, or for specific species. Such measures can provide short-term habitat until overall rehabilitation results reach the level of maturity needed to provide the desired habitat. These measures, such as nest structures and food patches, can also provide habitat that is in short supply.

Loss of riparian or terrestrial habitat in stream corridors has resulted in the decline of many species of birds and mammals that use associated trees and tree cavities for nesting or roosting. The most important limiting factor for cavity-nesting birds is usually the availability of nesting substrate, generally in the form of snags or dead limbs in live trees. Snags for nest structures can be created using explosives, girdling, or topping of trees.

Food patch planting is often expensive and not always predictable, but it can be carried out in wetlands or riparian systems mostly for the benefit of waterfowl. Environmental requirements of the food plants native to the area, proper time of year of introduction, management of water levels, and soil types must all be taken into consideration.

Influence of Hydrology and Stream Dynamics

Natural floodplain plant communities derive their characteristic horizontal diversity primarily from the influence of stream migration and flooding. When designing rehabilitation of stream corridor vegetation, nearby reference conditions are used to identify the appropriate plant species and communities. A good understanding of current and projected flooding is necessary for design of appropriately restored plant communities within the floodplain. In undeveloped areas, stream gauge data may be available, or on-site interpretation of landforms and vegetation may be required to determine whether floodplain hydrology has been altered through channel incision or other causes.

Generally, planting efforts will be easier when trying to restore vegetation on sites that have suitable moisture conditions for the desired vegetation, such as in replacing historical vegetation on cleared sites that have unaltered streamflow and inundating discharges.

Some stream corridor plant species have different requirements at different life stages i.e. during establishment and as adult. This can complicate what constitutes suitable moisture conditions and may require separate consideration of establishment requirements, and perhaps consideration of how sites might change over time.

Soil Bioengineering for Floodplains and Uplands

Soil bioengineering is the use of live and dead plant materials, in combination with natural and synthetic support materials, for slope stabilization, erosion reduction, and vegetative establishment. There are many soil bioengineering systems, and selection of the appropriate system or systems is critical to successful rehabilitation. Reference documents should be consulted to ensure that the principles of soil bioengineering are understood and applied. A detailed description of soil bioengineering systems is given in "Volume 17 - Bioengineering Measures" of the Urban Stormwater Management Manual for Malaysia (MSMA) as well as in Chapter 3.3 River Engineering of this Manual.

3.5.3.5 Stream Channel Rehabilitation

Some disturbances to stream channels (e.g. from surface mining activities, extreme weather events, or major highway construction) are so severe that rehabilitation within a desired time frame requires total reconstruction of a new channel. Selecting dimensions (width, depth, cross-sectional shape, pattern, slope, and alignment) for such a reconstructed channel is perhaps the most difficult component of stream rehabilitation design. In the case of stream channel reconstruction, stream corridor rehabilitation design can proceed along one of two broad tracks:

- A single-species rehabilitation that focuses on habitat requirements of certain life stages of species. The existing system is analyzed in light of what is needed to provide a given quantity of acceptable habitat for the target species and life stage, and design proceeds to remedy any deficiencies noted.
- An "ecosystem rehabilitation" or "ecosystem management" approach that focuses design resources on the chemical, hydrologic, and geomorphic functions of the stream corridor. This approach assumes that communities will recover to a sustainable level if the stream corridor structure and functions are adequate. The strength of this approach is that it recognizes the complex interdependence between living things and the totality of their environments.

Channel Design Variables

Traditional channel design methods for fixed-boundary or threshold channels focus on efficient flow conveyance where water surface elevation and velocity are of primary importance. The independent hydraulic design variables are the design discharge and channel roughness. The dependent hydraulic design variables are width, depth, and slope. Channel roughness is a dependent variable if there is a choice of boundary materials. In channel design, these dependent variables are adjusted to achieve the desired hydraulic conditions. Attention is given to the hydraulic losses due to changes in the channel configuration and obstructions such as bridge piers and culverts. Hydraulic design can be accomplished using the energy or momentum equations, in conjunction with a resistance equation such as Manning's equation. The channel boundary is assumed to be immobile at the design discharge, and bed-material sediment inflow is negligible (Stream Rehabilitation Design 2007)[72].

Channel design becomes more complicated in alluvial channels, where the bed is mobile and where bed-material sediment inflow is significant. In addition to water surface elevation, efficient transport of sediment becomes a focus in the hydraulic design of alluvial channels. Alluvial streams have the capability to adjust their channel geometry to efficiently transport sediment. The design process seeks to achieve a state of dynamic equilibrium by computing and selecting appropriate values for channel geometry. A geomorphic relationship from a reference reach or a selected hydraulic geometry relationship is also required. The characteristics of threshold and alluvial channels are summarized in Table 3.13.

Table 3.13 Characteristics of threshold and alluvial channels [72]

Channel boundary	Threshold channel	Alluvial channel
	Immobile at design discharge	Mobile
Bed-material sediment inflow	Usually small or negligible	Significant
Dependent variables	Width Depth Slope Roughness, if there is a choice of boundary materials	Width Depth Slope Planform Bank roughness Roughness due to obstructions or structures
Independent variables	Design discharge Channel roughness	Design hydrograph Channel-forming discharge Bed-material sediment inflow Bed material Streambank characteristics
Design equations	Energy Momentum Resistance	Energy Momentum Resistance Sediment transport Geomorphic relationship
Design goal with respect to channel stability	Pass the design discharge below the top of bank without mobilizing the boundary	Pass the incoming sediment load without significant aggradation or degradation or planform change

Channel Design Methods and Approaches

Channel design approaches can be broadly categorized by their applicability to threshold or alluvial channels. For threshold channels, the recommended design method will provide a stable channel boundary that will not unravel. This is accomplished for a design discharge and a specified channel boundary material. Channel cross-sectional dimensions and channel slope are selected, and velocities and/or shear stresses are calculated iteratively, using the energy or momentum equations and a hydraulic resistance equation, so that calculated values do not exceed acceptable critical values. Hydraulic design methods for threshold channels are well established and available from several sources. Two methods are recommended for the hydraulic design of threshold channels: the allowable velocity method and the allowable shear stress method. In general, the allowable velocity method is most applicable when velocity measurements are available, while the allowable shear stress method is often applied in relatively straight channels when velocity measurements are not available.

For alluvial channels, hydraulic design methods require sediment transport analysis to ensure sediment continuity through the project reach. The recommended design methodology suggests analytical solutions of resistance and sediment transport equations, in combination with application of fluvial geomorphic principles. When possible, alluvial channels are sized for the channel-forming discharge. The recommended design method generates a preliminary channel geometry that can transport the incoming water and sediment load for the selected channel design discharge. Development of this preliminary or initial design geometry is based on a single discharge, the channel-forming discharge. The design philosophy for alluvial channels is to use appropriate fluvial geomorphic principles combined with analytical equations for flow resistance and sediment transport to solve for the dependent design variables of width, depth, slope, and planform.

The long-term stability of the preliminary channel design is evaluated using a flow-duration curve or a long-term hydrograph that includes the full range of discharges. Design adjustments may then be made to the channel design based on issues related to stability, flood effects, and sedimentation.

Characteristics of the hydraulic design philosophies for threshold and alluvial channels are shown in Table 3.14.

Table 3.14 Hydraulic design philosophies [72]

Design discharges	Threshold channels	Alluvial channels
	Maximum design discharge	Channel-forming discharge Flow-duration curve and/or long-term hydrograph
Design criteria	Critical velocity/shear stress	Continuity of sediment
Dependent variables	Width, depth, and slope (roughness if there is a choice of boundary material)	Width, depth, slope, planform, bank roughness, and roughness due to obstructions or structures
Design equations	Energy, momentum, and hydraulic resistance	Energy, momentum, hydraulic resistance, sediment trans- port, and geomorphic relationship

Threshold channels are designed so that the streambed is immobile for the full range of natural discharges, as long as these discharges are below the design flow. In alluvial channels, it is important to determine the discharge at which the streambed begins to move. This can be accomplished using the threshold criteria from the Shields diagram. In gravel-bed streams, the sediment transport capacity dramatically increases when the armor layer is disrupted or destroyed, and the coarse material becomes thoroughly mixed with the substrate material. A mobile streambed is not necessarily unstable, but mobile beds require a higher level of analysis to determine stability, within the limits required of the design. Stability of vegetated or gravel banks can be determined using allowable velocity methods or shear stress methods.

a) Analogy Method

The analogy method is used to select channel dimensions and is based on the premise that conditions in a reference reach with similar characteristics and watershed conditions can be copied to the project reach. The method can be used for both threshold and alluvial channels, but if used for threshold channel design, bed stability in the project channel should be checked using threshold methods. For alluvial channels, the analogy method is used to select one of the primary dependent design variables of width, depth, or slope (preferably width). Planform can also be determined using the analogy method. The reference reach must be stable and alluvial and have the same channel-forming discharge as the project reach. A stable channel is one in which the stream's planform, cross section, and longitudinal profile are sustainable. The bed and banks in the project and reference reaches must be composed of similar material, and there should be no significant hydrologic, hydraulic, or sediment differences in the reaches.

b) Hydraulic Geometry Method

A suitable hydraulic geometry relationship can be used to select a value for one of the dependent variables for the channel-forming discharge. The hydraulic geometry method is similar to the analogy method, but it is more useful because a range of discharges is used. Hydraulic geometry theory is based on the concept that a river system tends to develop in a predictable way, producing an approximate equilibrium between the channel and the inflowing water and sediment (e.g. Section 2.2 of this Manual).

c) Analytical Method

Once one of the dependent design variables (preferably width) is determined using analogy or hydraulic geometry methods, the other two dependent design variables (depth and slope) should be calculated using an analytical, or computational, method. This is accomplished using one of several resistance and sediment transport equations available in the literature. If the resistance and sediment transport equations are solved simultaneously for a specified channel-forming discharge, a family of solutions can be calculated. The analytical solution for depth and slope that matches the analogy or hydraulic geometry solution for width provides the three dependent design variables. Analytical methods can be more easily undertaken using computer programs such as the USACE SAM (Thomas, Copeland, and McComas 2003) or HEC–RAS (U.S. Army Corps of Engineers) etc.

Characteristics of the analogy, hydraulic geometry, and analytical design methods are summarized in Table 3.15. The analogy methods, hydraulic geometry relations, or analytical techniques mentioned in the above procedures are described in more details in the reference text (Chapter 9 – Alluvial Channel, Stream Rehabilitation Design, 2007 [72]).

Table 3.15 Characteristics of analogy, geometry, and analytical hydraulic design methods [72]

Analogy	Basis	Requirements	Recommended for determination of
	Channel dimensions from a reference reach can be transferred to another location	Reference reach must be stable and alluvial Reference reach must have same channel-forming discharge, valley slope, and similar bed and bank characteristics	Top width of channel-forming discharge channel and planform
Hydraulic geometry	Channel dimensions can be determined from regression relationships with independent variables	Regression curves must be developed from stable and alluvial reaches and from physiographically similar watersheds	Top width of channel-forming discharge channel and planform
Analytical	Depth and sediment transport can be calculated from physically based equations	Estimates of bed-material gradation and resistance coefficients must be obtained	Depth and slope

Channel Analysis and Design Techniques

A variety of applicable open channel analysis and design techniques are available to the designer. The specifics and details regarding the use and application of several analysis and design techniques are presented in the reference document "Stream Restoration Design National Engineering Handbook, USDA August 2007". This section provides a framework in which to evaluate these techniques.

Reference Reaches

Use of reference reaches has been a useful means to identify stream rehabilitation potential. The term reference reach has several meanings. As used above, the reference reach is a reach that will be used as a template for the geometry of the rehabilitated channel. The width, depth, slope, and planform characteristics of the reference reach are transferred to the design reach, either exactly or by using analytical or empirical techniques to scale them to fit slightly different characteristics of the project reach (for example, a larger or smaller drainage area).

A second common meaning of the term reference reach is a reach with a desired biological condition, which will be used as a target to strive for when comparing various rehabilitation options. For instance, for a stream in an urbanized area, a stream with a similar drainage area in a nearby unimpacted watershed might be used as a reference reach to show what type of aquatic and riparian community might be possible in the project reach. Although it might not be possible to return the urban stream to predevelopment conditions, the characteristics of the reference reach can be used to indicate what direction to move toward.

Channel Types

The nature of the interaction of the flows and sediments with the channel boundary should be used in the selection of the appropriate design approach. Channels can be divided into two general categories based on the sediment load and the stability of the channel boundary during normal flow.

a) Threshold channels

A threshold channel is defined as a channel in which channel boundary material has no significant movement during the design flow. The term threshold is used because the channel geometry is designed such that applied forces from the flow are below the threshold for movement of the boundary material.

Examples are streambeds formed by high runoff during extreme floods or dam breaks and streams armored due to reduction in the upstream sediment supply and degradation. Examples of threshold channels are shown in Figures 3.91 through 3.93.

Figure 3.91 Riprap-armored threshold channel

Figure 3.92 Grass-lined threshold channel [72]

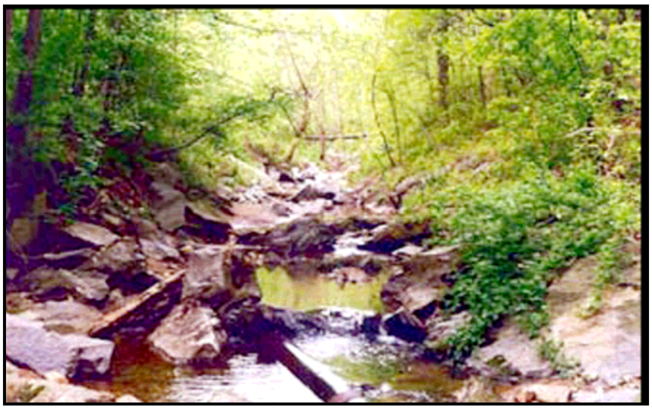


Figure 3.93 Bedrock threshold channel [72]

Fine sediment will pass through coarse bed streams as wash load. Washload is finer than the bed-material and does not deposit on the streambed, except sometimes at very low flow. However, wash load may be an environmental issue as it increases turbidity and can clog fish gills. Threshold channels do not have the ability to quickly adjust their geometry, as do alluvial channels, because the material forming the channel boundary is not erodible within the normal range of flows, and there is no significant exchange between the sediment in transport and the bed.

The design goal of a threshold channel design technique is to produce a channel that has positional or engineering stability. As long as the flows in the channel are below the design discharge, the particles that make up the channel boundary are stable, and the section, plan, and profile of the channel should be essentially static over time. The use of threshold design does not necessarily imply the absence of sediment movement, but rather that the transport capacity is sufficiently large to carry the sediment load through the system without meaningful deposition at boundary stresses less than those required to erode (mobilize) the boundary. For this reason, threshold channels are often designed near the erosion threshold of the boundary during design flows to prevent deposition that would change channel characteristics.

It is to be noted that in some literature, the term threshold channel refers to a channel that is at the threshold of movement or at the initiation of motion, not some point below movement. However, the boundary of a threshold channel in this case is below this point for flows up to the design discharge, not directly at the threshold of motion.

The following step-by-step procedure for design of natural threshold channels is from American Society of Civil Engineers (ASCE) Manual 54 (ASCE 1975, or Julien 2002)[80]. This method is applicable when width, depth, and slope are design variables; for example, slope can be varied and is not dictated by geology or other constraints. Although the procedure is presented as a series of linear steps, the actual design process is iterative, and design variables should be refined as the process proceeds from preliminary to final results. This method provides only the average channel cross-sectional dimensions. Channel variability in width and depth, and riffles and pools may be added later. Threshold methods should be used to determine the stability of the channel in areas where velocity and shear stress are increased, such as constrictions and riffles.

Step 1: Determine design bed-material gradation/ channel boundary - Determine the design bed-material gradation and the design discharge. The design discharge is the maximum flow at which channel stability is required. Channel-forming discharge theory is not generally used as the design flow for threshold channel design because the boundary of the channel will be immobile, and natural fluvial process will not be able to adjust channel dimensions.

Step 2: Determine preliminary width - Use hydraulic geometry or regime formula (described in the Chapter 2.3 of this Manual) with the design discharge to compute a preliminary average flow width. It is appropriate to use hydraulic geometry theory in threshold channels, even though the boundary is immobile. This is because natural flow processes will tend to form helical cells of specific widths; if the channel is too wide, ineffective flow areas will develop in the channel. If wash load is available in the stream, it may become trapped in these ineffective flow areas, and the channel will eventually narrow, even though the boundaries are immobile, and the calculated average velocity is sufficient to move the wash load.

Step 3: Estimate critical shear stress/velocity - Using the design bed-material size gradation, estimate the critical bed stress. This may be determined using a Shields parameter approach with a factor of safety, the Gessler probability approach, or the Lane tractive force approach. If the allowable velocity approach is used, determine the allowable velocity from published tables.

Step 4: Determine flow resistance (Manning n) - Use the bed-material size, estimated channel sinuosity, bank vegetation, and flow depth to estimate a flow resistance coefficient. The Cowan (1956)[86] method is applicable for channels with multiple sources of roughness. If resistance due to bars and bedforms are not important, formulas such as those proposed by Julien (2002)[80] may be used to compute resistance coefficients.

Step 5: Calculate depth and slope - Using the continuity equation and a uniform flow equation, compute the average depth and bed slope needed to pass the design discharge. Sinuosity may be computed by dividing the valley slope by the bed slope. Adjustment of the flow resistance coefficient for sinuosity and reiteration may be required.

Step 6: Determine planform - Planform is a function of the sinuosity and meander wavelength. Although threshold channels are not self forming, it is appropriate to use the same techniques outlined in following section on alluvial channels to determine planform in threshold channels.

Step 7: Assess for failure and sediment impact - After the threshold channel design is complete, an assessment of failure should be made. This involves determination of the discharge at which the allowable velocity or shear stress would be exceeded. Confirmation should be made that the channel boundary will not become active, in which case alluvial design techniques should be examined. In addition, the possible impacts of sediment deposition should be assessed.

b) Alluvial channels

Alluvial streams and channels have bed and banks formed of material transported by the stream under present flow conditions. There is an exchange of material between the inflowing sediment load and the bed and banks of the stream. The sediment transported in an alluvial channel tends to be coarser and of a larger amount than that transported in a threshold channel. Examples of alluvial channels are shown in Figures 3.94 through 3.96. Since natural alluvial channels adjust their width, depth, slope, and planform in response to changes in water or sediment discharge, an alluvial channel will not be as static as a threshold channel.

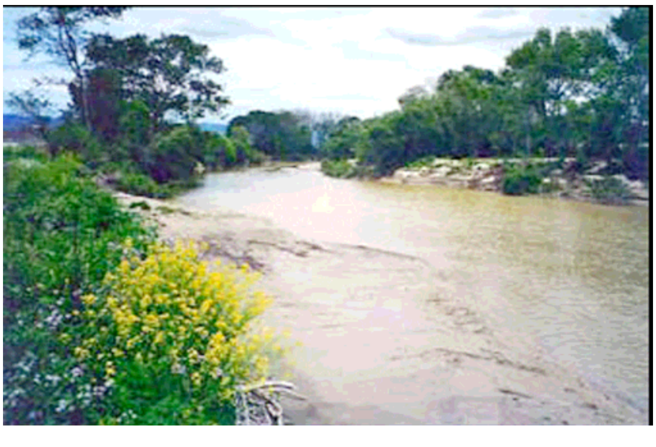


Figure 3.94 Sand-bed alluvial channel [72]

Figure 3.95 Sand and gravel-bed alluvial channel [72]

Figure 3.96 Gravel-bed alluvial channel [72]

Alluvial channel designs require an analysis of channel stability. An alluvial stream is defined as stable when it has the ability to pass the incoming sediment load without significant degradation or aggradation, and when its width, depth, and slope are fairly consistent over time. The design goal of an alluvial channel design technique is often to produce a channel that has dynamic equilibrium or geomorphic stability. Bank erosion and bankline migration are natural processes and may continue in a stable channel. When bankline migration is deemed unacceptable, then engineering solutions must be employed to prevent bank erosion. Bank protection measures are addressed in the Chapter 3.3 "River Engineering" of this volume of the Manual.

The basic steps in alluvial channel design are as follows:

Step 1: Determine the channel-forming discharge - The initial design step is to determine the stable geometry for a single discharge. Use bankfull discharge, effective discharge, or a discharge of specific peak frequency.

Step 2: Determine sediment inflow for the project reach - Calculate a sediment transport rating curve for the upstream supply reach. The sediment discharge may be computed based on a typical upstream cross section at a normal depth with an appropriate sediment transport equation, e.g. Julien (1995).

Step 3: Develop a stability curve - Calculate a family of slope-width-depth solutions that satisfy resistance and sediment transport equations for the channel-forming discharge. This step provides a channel geometry that is capable of transporting the inflowing sediment load through the project reach. The equations are used to calculate the design variables of width, slope, and depth from the independent variables of discharge and sediment inflow.

Step 4: Determine channel width - A channel top width for the channel-forming discharge is selected from the stability curve using geomorphic principles or project constraints. Analogy methods, hydraulic geometry curves, or the geomorphic relations in Section 2.2 that can be used to select width. Depth and slope for the selected width are determined from the stability curve.

Step 5: Conduct an analytical sediment budget analysis - Using the design channel dimensions, calculate a sediment-transport rating curve in the project reach. Using a flow-duration curve that includes some high flood discharges, calculate sediment yield into and out of the project reach.

Step 6: Determine channel planform - Sinuosity is determined from the calculated channel slope and valley slope. Remaining planform design parameters include the meander wavelength, an appropriate channel length for one meander wave length, and the trace of the channel.

Step 7: Natural variability in cross-sectional shape - Variability in channel width and depth can either be allowed to develop naturally or can be part of the project design. Sand-bed streams have the ability to create natural variability in channel form rather quickly because they are characterized by significant bed-material sediment transport. If variability is to be included in the project design, dimensions for cross sections in riffles and pools can be obtained from stable reaches of the existing stream or from reference reaches.

Step 8: Instream structures - Successful stream rehabilitation often includes the use of bank protection, grade control, and habitat features. To rehabilitate a stream with physical habitat features resembling a natural stream, a combined technology approach is required. Sound physical principles and well established engineering formulas are used in the analysis and design of both soft and hard features. Systems composed of living plant materials are often used in association with inert materials, such as wood or rock, and manufactured products. A significant flood event (normally no smaller than the 10-year frequency discharge) is used to size structures and compute scour depths. In addition, the quantity of water and its related hydroperiod largely determines what type of vegetation will grow in an area.

c) Transition channels

A clear distinction between threshold and alluvial channels may not always be apparent. One reach of the stream may be alluvial, while another has the characteristics of a threshold channel. A threshold reach can be changed to an alluvial reach by flattening the slope. A stream may be alluvial at low discharges when there is an adequate sediment supply, and then act like a threshold channel at high discharges. Conversely, a channel may function as a threshold stream at low flows, but during very high discharge become mobile (Figure 3.97). In these situations, it is often appropriate to apply both threshold and alluvial channel design techniques.

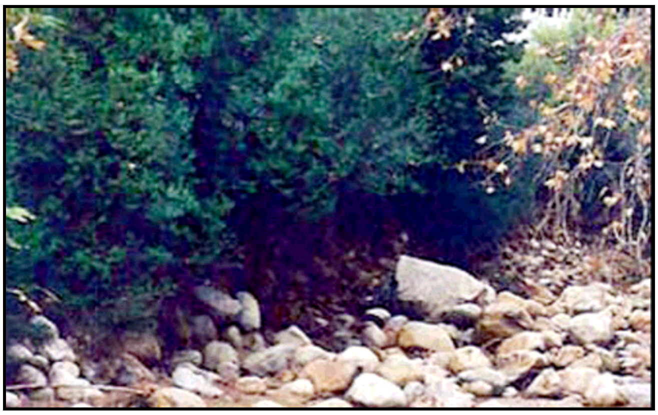


Figure 3.97 Boulder-bed channel that could be a threshold channel or an alluvial channel, depending on the design discharge [72]

If an armor layer is present, a stream may be a threshold channel at low flows and on the rising limb of a flood hydrograph, but behave as an alluvial channel at high flows when the armor layer is mobilized, and on the falling limb of the flood hydrograph, when sediment is being deposited. Therefore, it is important to evaluate channels through their entire flow range to determine how they will react to natural inflow conditions and how their stability status may change as a function of discharge.

The armor layer of a gravel bed stream is shown in Figure 3.98. Note the much finer subsurface bed material exposed when a few cobbles were removed from the armor layer. Armor layer thickness is typically equal to the D_{90} particle size of the subsurface material.

Figure 3.98 Subsurface layer exposed after removal of three cobbles from the armour layer [72]

Use of Channel Models for Design Verification

Any stream corridor rehabilitation design needs careful scrutiny because its long-term impact on the stream system is not easy to predict. Sound engineering often dictates the use of computer models or physical models to check the validity of a proposed design. Since most practitioners do not have easy access to physical modeling facilities, computer models are much more widely used.

Computer models can be run in a qualitative mode with very little data or in a highly precise quantitative mode with a great deal of field data for calibration and verification. Computer models can be used to easily and cheaply test the stability of a rehabilitation design for a range of conditions, or for a variety of alternative channel configurations. A "model" can vary widely in cost and complexity depending on the reach to be modeled. The decision as to what models are appropriate should be made by a hydraulic engineer with a background in sediment transport.

The costs of modeling could be small compared to the cost of redesign or reconstruction due to failure. If the consequences of a project failure would result in a high risk of catastrophic damage or death, and the site-specific conditions result in an unacceptable level of uncertainty when applying computer models, a physical model is the appropriate tool to use for design. A more detailed treatment of this subject is available in "Vol. VII - Engineering Modeling" of the Manual.

Detailed Design

Channel Shape

Natural stream width varies continuously in the longitudinal direction, and depth, bed slope, and bed material size vary continuously along the horizontal plane. These variations give rise to natural heterogeneity and patterns of velocity and bed sediment size distribution that are important to aquatic ecosystems. Widths, depths, and slopes computed during design should be adopted as reach mean values, and rehabilitated channels should be constructed with asymmetric cross sections. Similarly, meander planform should vary from bend to bend about average values of arc length and radius. A reconstructed floodplain should not be perfectly flat (Figure 3.99). For design of channel planform, please refer to Appendix M - Determination of Channel Planform for more details.

Figure 3.99 A stream meander and raised floodplain. Natural floodplains rise slightly between a crossover and an apex of a meander [24]

Channel Longitudinal Profile and Riffle Spacing

In stream channels with significant amounts of gravel (d_{50} > 2 mm) riffles should be associated with steep zones near meander inflection points. Average riffle spacing is often (but not always) half the meander length since riffles tend to occur at meander inflection points or crossovers. In general, riffle spacing varies from 4 to 10 channel widths with the least squares best fit at 6.3 times the channel width. Riffle spacing tends to be closer to 4 times the channel width on steeper gradients and 8 to 9 channel widths on more gradual slopes. See Appendix N – Determination of Channel Variability for more details.

Stability Assessment

The risk of a rehabilitated channel being damaged or destroyed by erosion or deposition is an important consideration for almost all rehabilitation work. Designers of rehabilitated streams are confronted with rather high levels of uncertainty. In some cases, it may be wise for designers to compute risk of failure by calculating the joint probability of design assumptions being false, design equation inaccuracy, and occurrence of extreme hydrologic events during project life.

Bed Stability

Bed stability is generally a prerequisite for bank stability. Aggrading channels are liable to braid or exhibit accelerated lateral migration in response to middle or point bar growth. Degrading channels widen abruptly when bank heights and angles exceed a critical threshold specific to bank soil type. Bed aggradation can be addressed by stabilizing eroding channels upstream, controlling erosion on the watershed, or installing sediment traps, ponds or basins. If bed degradation is occurring or expected to occur, and if modification is planned, the rehabilitation initiative should include flow modification, grade control measures, or other approaches that reduce the energy gradient or the energy of flow. The various types of grade control structures are described in Chapter 3.3 – River Engineering of this Manual.

Bank Stability

Bank stabilization can generally be grouped into one of the following three categories: (1) indirect methods; (2) surface armor; and (3) vegetative methods. An armor is a protective material in direct contact with the streambank. Armor can be categorized as stone, other self-adjusting armor (sacks, blocks, rubble, etc.), rigid armor (concrete, soil cement, grouted riprap, etc.) and flexible mattress (gabions, concrete blocks, etc.). Indirect methods extend into the stream channel and redirect the flow so that hydraulic forces at the channel boundary are reduced to a nonerosive level. Indirect methods can be classified as dikes (permeable and impermeable) and other flow deflectors such as bendway weirs, stream "barbs," and vanes. Vegetative methods can function as either armor or indirect protection and in some applications can function as both simultaneously. A fourth category is composed of techniques to correct problems caused by geotechnical instabilities. Please refer to Chapter 3.3 – River Engineering of this Manual for bank protection techniques.

Allowable Velocity & Stress Check

Perhaps because of its simplicity, the allowable velocity method has been used directly for many rehabilitation applications. Velocity of the design event can be manipulated by adjusting channel length (and thus slope), width, and roughness. Channel roughness was adjusted by adding meanders, planting shrubs, and adding coarse bed material.

Boundary shear stress is more appropriate than velocity as a measure of the forces driving erosion. The average boundary shear stress acting on an open channel conveying a uniform flow of water is given by the product of the unit weight of water (γ = 9,810 N/m^3) times the hydraulic radius (R, m) times the bed slope S:

$$\tau = \gamma R S \tag{3.31}$$

The most famous graphical presentation of allowable shear stress criteria is the Shields diagram, which depicts conditions necessary for initial movement of noncohesive particles on a flat bed straight channel in terms of dimensionless variables. The Shields criterion for channel stability is (Julien 1995)[85]:

$$RS/[(G-1)d_s] \sim 0.06, \text{ for } d_s > 6 \text{ mm} \tag{3.32}$$

where G = 2.65 is the specific gravity of the sediment and d_s is a characteristic bed sediment size, usually taken as the median grain diameter d_{50} for widely graded material. Note that the hydraulic radius R and the characteristic bed sediment size d_s must be in the same units for the Shields constant to be dimensionless. For sand-bed channels, it is considered that the bed will be mobile for design conditions. Reference is made to Chapter 3.2 – Hydraulic for River Rehabilitation of this Manual for more details.

3.5.3.6 Streambank Rehabilitation

Even where streams retain relatively natural patterns of flow and flooding, stream corridor rehabilitation might require that streambanks be temporarily (years to decades) stabilized while floodplain vegetation recovers. The objective in such instances is to arrest the accelerated erosion often associated with unvegetated banks, and to reduce erosion to rates appropriate for the stream system and setting. In other cases, land development or modified flows may dictate the use of hard structures to ensure permanent stream stability, and vegetation is used primarily to address specific ecological deficiencies such as a lack of channel shading. In either case streamflow projections are used to determine the degree to which vegetation must be supplemented with more resistant materials (natural fabrics, wood, rock, etc.) to achieve adequate stabilization.

Integration of woody vegetative cuttings, independently or in combination with other natural materials, in streambank erosion control projects is generally referred to as soil bioengineering. Soil bioengineered bank stabilization systems have not been standardized for general application. Bioengineering techniques are effective on small streams at relatively low slopes. However, they tend to be ineffective in large streams or stream subjected to frequent flash floods from steep watersheds.

Soil bioengineering approaches usually employ plant materials in the form of live woody cuttings or poles of readily sprouting species, which are inserted deep into the bank or anchored in various other ways. This serves the dual purposes of resisting washout of plants during the early establishment period, while providing some immediate erosion protection due to the physical resistance of the stems. Plant materials alone are sufficient on some streams or some bank zones, but as erosive forces increase, they can be combined with other materials such as rocks, logs or brush, and natural fabrics (Figure 3.100).

(a) (b)

Figure 3.100 A stabilized streambank. Plant materials can be combined with other materials such as rocks, logs or brush, and natural fabrics (a) during and (b) after installation [24]

Stabilization Techniques

Many techniques can be designed to adequately solve a specific bank stability problem by resisting erosive forces and geotechnical failure. The challenge is to recognize which technique matches the strength of protection against the strength of attack and therefore performs most efficiently when tested by the strongest process of erosion and most critical mechanism of failure. Environmental and economic factors are integrated into the selection procedure, generally making soil bioengineering methods very attractive. The chosen solution, however, must first fulfill the requirement of being effective as bank stabilization; otherwise, environmental and economic attributes will be irrelevant.

Plants may be established on upper bank and floodplain areas by using traditional techniques for seeding or by planting bare-root and container-grown plants. However, these approaches provide little initial resistance to flows, and plantings may be destroyed if subjected to high water before they are fully established. Cuttings, pole plantings, and live stakes taken from species that sprout readily are more resistant to erosion and can be used lower on the bank (Figure 3.101). In addition, cuttings and pole plantings can provide immediate moderation of flow velocities if planted at high densities. Often, they can be placed deep enough to maintain contact with adequate soil moisture levels, thereby eliminating the need for irrigation. The reliable sprouting properties, rapid growth, and general availability of cuttings of selected pioneer species makes them particularly appropriate for use in bank revegetation projects.

Figure 3.101 Results of live staking along a streambank [24]

Other bank stabilization techniques include brush mattresses, geotextile system usually in combination with seeding and coconut fibres, vegetated plastic geogrids and other non-degradable materials where geotechnical problems require drainage or additional strength, tree revetments made from whole tree trunks laid parallel to the bank and cabled to piles or deadman anchors etc. These and many other artificial bank stabilization measures are given in more details in Chapter 3.3-"River Engineering" in this Manual.

3.5.3.7 Instream Habitat Recovery

This section discusses the design of instream habitat structures for the purpose of enhancing physical aquatic habitat quality and quantity. It should be noted, however, that the best approach to habitat recovery is to restore a fully functional, well-vegetated stream corridor within a well-managed watershed. Over the long term, design should rely on natural fluvial processes interacting with floodplain vegetation and associated woody debris to provide high-quality aquatic habitat.

Instream Habitat Features

The following procedures to restore instream habitat are adapted from Newbury and Gaboury (1993)[87] and Garcia (1995)[88]. Once a reach has been selected, give priority to reaches with habitats and species of special interest and determine whether it is a biological, chemical, or physical problem? The following steps are suggested to detect physical habitat problems.

- *Drainage basin*. Trace watershed lines on topographical and geological maps to identify sample and rehabilitation basins.
- *Profiles*. Sketch main and tributary long profiles to identify discontinuities that might cause abrupt changes in stream characteristics (falls, former base levels, etc.).
- *Flow*. Prepare flow summary for rehabilitation reach using existing or nearby records if available (flood frequency, minimum flows, historical mass curve). Correct for drainage area differences. Compare magnitude and duration of flows during spawning and incubation on a yearly basis to determine minimum and maximum flows required for successful reproduction.
- *Channel geometry survey*. Select and survey sample reaches to establish the relationship between channel geometry, drainage area, and bankfull channel-forming discharge. Quantify hydraulic parameters at design discharge.
- *Rehabilitation reach survey*. Survey rehabilitation reaches in sufficient detail to prepare channel cross section profiles and construction drawings and to establish survey reference markers.
- *Preferred habitat*. Prepare a summary of habitat factors for biologically preferred reaches using regional references and surveys. Identify multiple limiting factors for the species and life stages of greatest concern.
- *Design a habitat improvement plan*. Quantify the desired results in terms of hydraulic changes, habitat improvement, and population increases. Integrate selection and sizing of rehabilitation works with instream flow requirements.
- *Select potential schemes.* Select schemes and structures that will be reinforced by the existing stream dynamics and geometry.
- *Test designs.* Test designs for minimum and maximum flows and set target flows for critical periods derived from the historical mass curve.
- *Periodic Surveys.* Arrange for periodic surveys of the rehabilitated reach and reference reaches, to improve the design, as the channel ages. Arrange for on-site location and elevation surveys and provide advice for finishing details in the stream.
- *Monitor and evaluate results*.

Instream Habitat Structures

Aquatic habitat structures (also called instream structures and stream improvement structures) are widely used in stream corridor rehabilitation. Common types include weirs, dikes, random rocks, bank covers, substrate reinstatement, fish passage structures, and off-channel ponds and coves. In general:

- Structures should never be viewed as a substitute for good riparian and upland management.
- Ecological purpose of structures and site selection are as important as construction technique.

- Scour and deposition are natural stream processes necessary to create fish habitat. Overstabilization therefore limits habitat potential, whereas properly designed and sited structures can speed ecological recovery.
- Use of native materials (stone and wood) is strongly encouraged.
- Periodic maintenance of structures will be necessary and must be incorporated into project planning.

Instream Habitat Structure Design

Design of aquatic habitat structures should proceed following the steps presented below (Shields 1983)[89]. The process should be viewed as iterative, and considerable recycling among steps should be expected.

Plan Layout

The location of each structure should avoid conflicts with bridges, riparian structures, and existing habitat resources (e.g., stands of woody vegetation). Care should be taken to place structures where they will be in the water during baseflow and spaced to avoid large areas of uniform conditions. Structures that create pools should be spaced five to seven channel widths apart. Weirs placed in series should be spaced and sized carefully to avoid placing a weir within the backwater zone of the downstream structure, since this would create a series of pools with no intervening riffles or shallows.

Select Types of Structures

The main types of habitat structures are weirs, dikes (also called barbs, deflectors, spurs, etc.), random rocks (also called boulders), and bank covers (also called lunkers). Substrate reinstatement (artificial riffles), fish passage structures, and off-channel ponds and coves have also been widely employed. Examples of in-stream habitat structures are shown in Figure 3.102.

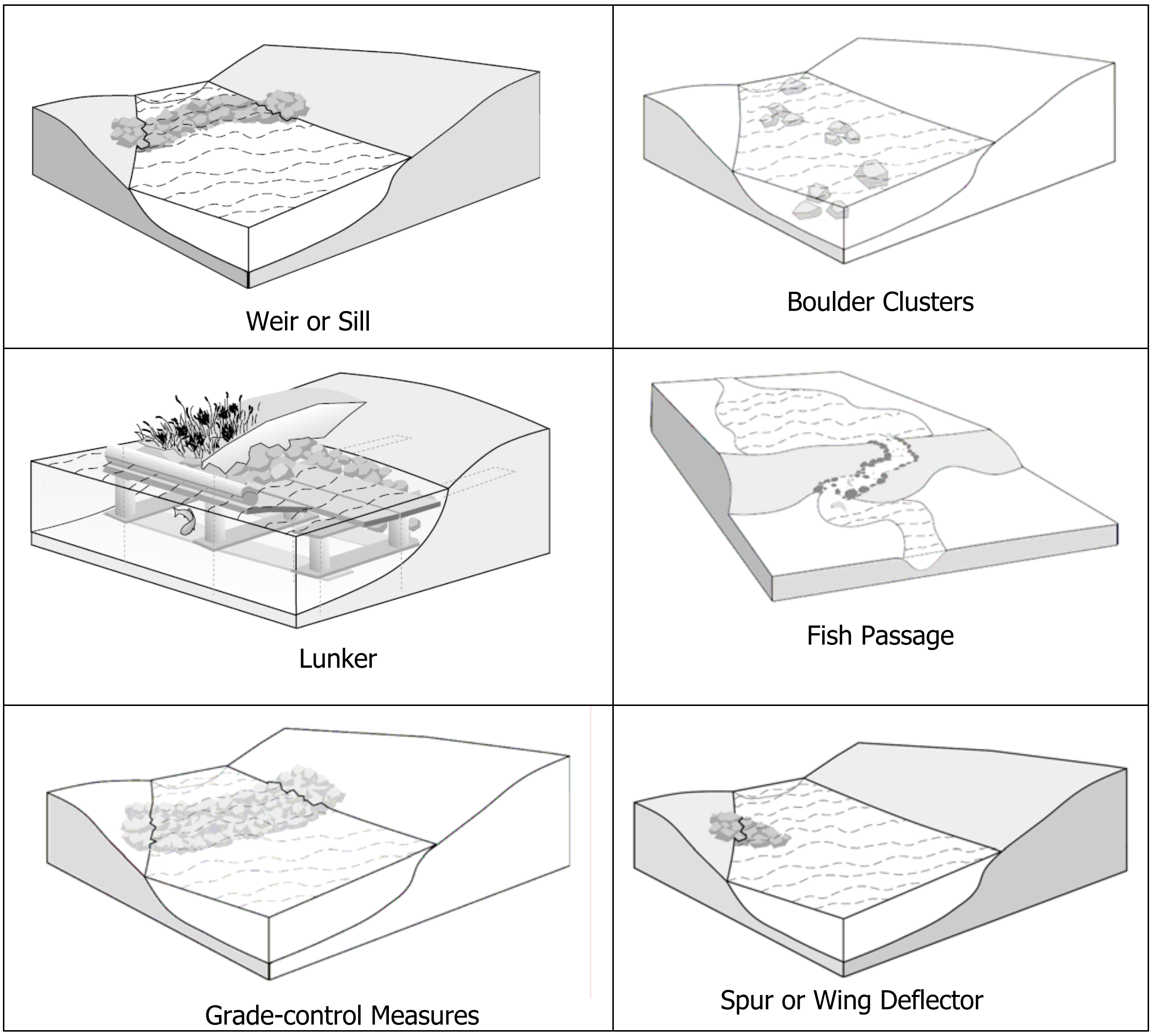


Figure 3.102 Instream Habitat Structures [63]

Size the Structure

Structures should be sized to produce the desired aquatic habitats at the normal range of flows from baseflow to bankfull discharge. A hydrological analysis can provide an estimate of the normal range of flows (e.g., a flow duration curve), as well as an estimate of extreme high and low flows that might be expected at the site. In general, structures should be low enough that their effects on the water surface profile will be slight at bankfull discharge.

Investigate Hydraulic Effects

Hydraulic conditions at the design flow should provide the desired habitat; however, performance should also be evaluated at higher and lower flows. Barriers to movement, such as extremely shallow reaches or vertical drops not submerged at higher flows, should be avoided. If the conveyance of the channel is an issue, the effect of the proposed structures on stages at high flow should be investigated. Structures may be included in a standard backwater calculation model as contractions, low weirs, or increased flow resistance (Manning) coefficients, but the amount of increase is a matter of judgment. Scour holes should be included in the channel geometry downstream of weirs and dike since a major portion of the head loss occurs in the scour hole. Hydraulic analysis should include estimation or computation of velocities or shear stresses to be experienced by the structure. Reference may be made to Vol. IV –" Hydrology and Water Resources" of the DID Manual as well as Chapter 3.2-"Hydraulic for River Rehabilitation" of this volume of the Manual.

Consider Effects on Sediment Transport

If the hydraulic analysis indicates a shift in the stage-discharge relationship, the sediment rating curve of the rehabilitated reach may change also, leading to deposition or erosion. Although modeling analyses are usually not cost effective for a habitat structure design effort, informal analyses based on assumed relationships between velocity and sediment discharge at the bankfull discharge may be helpful in detecting potential problems. An effort should be made to predict the locations and magnitude of local scour and deposition. Areas projected to experience significant scour and deposition should be prime sites for visual monitoring after construction. A more detailed description of sediment transport is provided in Chapter 2.3 – "River Characteristics and Morphology" of this volume of the Manual.

Select Materials

Materials used for aquatic habitat structures include rocks, fencing wire, posts, and fallen trees. Priority should be given to materials that occur on site under natural conditions. In some cases, it may be possible to salvage rock or logs generated from construction of channels or other project features. Logs give long service if continuously submerged. Even logs not continuously wet can give several decades of service if chosen from decay-resistant species. Logs and timbers must be firmly fastened together with bolts or rebar and must be well anchored to banks and bed. Rock size should be selected based on design velocities or shear stress.

3.5.3.8 Land Use Scenarios

As discussed in earlier, most stream corridor degradation is directly attributable to land use practices and/or hydrologic modifications at the watershed level that cause fundamental disruption of ecosystem functions (Figure 3.103). Ironically, land use practices, including hydrologic modifications, can offer the opportunity for rehabilitating these same degraded stream corridors. Where feasible, the objective of the rehabilitation design should be to eliminate or moderate disruptive influences sufficiently to allow recovery of dynamic equilibrium over time.

Figure 3.103 Sediment-laden stream attributed to impacts from surrounding land uses [24]

If chronic land use impacts on the stream or riparian system cannot be controlled or moderated, or if some elements of the stream network (e.g., headwaters) are not included in the rehabilitation design, it must be recognized that the rehabilitation action may have limited effectiveness in the long-term. Rehabilitation measures can be designed to address particular, site-specific deficiencies (an eroding bank, habitat features), but if they do not restore self-maintaining processes and the functions of a stream corridor, they must be regarded as a focused "fix" rather than an ecosystem rehabilitation. In cases where land use practices are the direct cause of stream corridor degradation and there is a continuing downward trend in landscape condition, there is little point in expending resources to address symptoms of the problem rather than the problem itself.

3.5.4 Environmental Flow Management

3.5.4.1 Definition of Environmental Flow

Environmental flow concept means enough water is left in our rivers, which is managed to ensure downstream environmental, social and economic benefits (The World Bank 2003)[96]. The process to establish it may poses great challenges since it requires integration of input from expert teams of various disciplines and negotiations between stakeholders.

Increasing population and development result in higher competition for the use of water. Worldwide, there is growing awareness that modification to river flows need to be balanced with maintenance of essential 'water-dependent ecological services'. The World Bank in Technical Note C.1, Environmental Flows: Concepts and Methods (2003) defines environmental flows as:

"The water that is left in a river ecosystem, or release into it, for the specific purpose of managing the condition of that ecosystem"

The report notes that several terms are used to describe flows for ecological maintenance of rivers but the terminology of environmental flows is a 'comprehensive term that encompasses all components of the river, is dynamic over time, takes cognizance of the need for natural flow variability, and addressed social and economic issues as well as biophysical ones'.

The International Union for Conservation of Nature (IUCN) in a publication (Flow. The Essentials of Environmental Flow - 2003) [97] defines environmental flows as:

"The water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated"

The IUCN made a distinction between the amount of water needed to maintain an ecosystem in a close-to-pristine condition, and that, which might eventually be allocated to it, following a process of environmental, social and economic assessment. It is the latter, which is referred to as the environmental flow. This flow may maintain the ecosystem in a less-than-pristine condition.

A closely related river flow is baseflow, which is to be differentiated from environmental flow although it may be taken as a component of the latter. Baseflow is the portion of stream flow that is not from runoff but comes from groundwater which seeps into a channel slowly over time. It is the primary source of running water in a stream during dry weather.

3.5.4.2 Objectives of Environmental Flow Management

Aquatic ecosystems, such as rivers, wetlands, estuaries and near-coast marine ecosystems provide a great variety of benefits to people. These include 'goods' such as clean drinking water, fish and fibre, and 'services' such as water purification, flood mitigation and recreation opportunities (IUCN 2003)[97].

The objective of environmental flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems.

River ecosystem health deteriorates when natural flows of water, sediments and organic materials through a river system are substantially disrupted or modified by human activities. River damming and associated alteration of natural flow and sediment transport patterns and water temperature are now widely recognized as a leading cause of declines in freshwater biodiversity globally. Previous occurrences of water supply shortages in populated areas and in small river basins, over the last ten years lead to increase awareness of water stress among the population (DID 2007, Draft Final Report

Volume IV)[98]. However, water stress is also faced by environmental systems through human withdrawal of water from surface and groundwater. This leads to problems of:

- Poor water quality due to reduced dilution capacity;
- Reduced flushing ability due to generally reduced flow volumes;
- Increase in percentage of sewer waste water relative to total river flow especially in dry periods;
- Degraded ecosystem due to change in water levels;
- Changes in the food chain structure as the ecosystems adjust to new aquatic environments;
- Increase in salinity intrusion due to reduced river flow within the estuary;
- Changes in the vegetation (especially mangrove) in the estuary as a result of salinity changes;
- Alteration of river hydraulic capacities resulting in increase of sedimentation or erosion.

3.5.4.3 Environmental Flow Management Strategies

Environmental Flow Management Strategies are directed at two main types of management response to the potential and extent of altered flow regimes (Environmental Flow Assessment with Emphasis on Holistic Methodologies)[99]:

- A proactive response, intended to maintain the hydrological regimes of undeveloped rivers as close as possible to the unregulated condition, or at least to offer some level of protection of natural river flows and ecosystem characteristics, and
- A reactive response, intended to restore certain characteristics of the pre-regulation flow regime and ecosystem in developed rivers with modified/regulated flow regimes.

Both of these circumstances can be addressed using the environmental flow assessment methods currently available. No simple figure can be given for the environmental flow requirement of rivers; it is subjected to a number of factors including (Hydrology and Earth System Sciences, 2004)[100]:

- The size of the river;
- Its natural state, 'type' or perceived sensitivity; and
- A combination of the desired state of the river and its future use.

Consequently, before defining the flow requirements, broader objectives or strategies must be determined to indicate the type of river desired.

For some river systems, river flows are set to achieve specific pre-defined ecological, economic or social objectives. This is called objective-based flow setting. The application of an objective-based approach by water managers necessitates, firstly, that the desired status of the river has been agreed upon. And, secondly, that is possible to define non-linear relationships between flow variables and river health, or preferably threshold flow, which triggers some change of state. Whilst there is a wealth of scientific evidence on basic hydro-ecological relationships, the challenge for scientists is to translate this general knowledge into site-specific quantified rules. Thus, although environmental flows setting are a practical river management tools, an element of expert or engineering judgment remains.

3.5.4.4 Methods of Determining Environmental Flow

Currently, there are over 200 approaches for determining environmental flows, which are being proposed or implemented in more than 50 countries worldwide (Santa Fe Watershed Association, June-July 2007)[101]. Many of the methodologies are country specific and no single country has yet developed an all-encompassing method. Several different categorizations of these methods exist, some of which are shown in Table 3.16:

Table 3.16 Summary of Environmental Flow Methods

Organisation	Categorization of Methods	Sub-category	Example
IUCN (Dyson et al. 2003)	Methods		Hydrological (e.g. Q95 Index) Ecological (e.g. Tennant Method)
		Desk-top analyses	Hydrological (e.g. Richter Method) Hydraulic (e.g. Wetted Perimeter Method) Ecological
		Functional Analysis	BBM, Expert Panel Assessment Method, Benchmarking Methodology
		Habitat Modelling	PHABSIM
	Approaches		Expert Team Approach, Stakeholder Approach (expert and non expert)
	Frameworks		IFIM, DRIFT
World Bank (Brown & King, 2003)	Prescriptive approaches	Hydrological Index Methods	Tennant Method
		Hydraulic Rating Methods	Wetted Perimeter Method
		Expert Panels	
		Holistic Approach	BBM
	Interactive approaches		IFIM DRIFT
IWMI (Tarme, 2003)	Hydrological index methods		Tennant Method
	Hydraulic rating methods		Wetted Perimeter Method
	Habitat simulation methodologies		IFIM
	Holistic methodologies		BBM DRIFT Expert Panel Benchmarking Methodology

In general, these methodologies can be grouped into four categories:

- Hydrological Methods;
- Hydraulic Methods;
- Habitat quality methods; and
- Holistic methods

a) Hydrological Methods

Simplest of all, hydrological methods as typically a desktop methodology, are based on the use of the hydrological data, usually in the form of historical monthly or daily flow records. This methodology is considered to be the most appropriate at the planning level of water resource development.

These are the simplest and most widespread Environmental Flows methods. They are often referred to as desktop or look-up methods and they rely primarily on historical flow records. Environmental flow is usually given as percentage of average annual flow or as a percentile from the flow duration curve, on an annual, seasonal or monthly basis. Most methods simply define the minimum flow requirement, however, in recognition of the 'Natural Flow Paradigm'. More sophisticated methods have been developed to take several flow characteristics into account (such as low-flow duration, rate of flood rise/fall, etc).

Hydrological Index Methods provide a relatively rapid, non-resource intensive, but low-resolution estimate of environmental flows. The methods are most appropriate at the planning level of water resources development, or in low controversy situations where they may be used as preliminary estimates.

The most frequently used methods include Tennant Method (Tennant, 1976)[105] and RVA (Range of Variability Approach) (Richter et al, 1997)[106] both developed in the USA.

The Tennant method was originally called the 'Montana Method' by Tennant because it was created using data from the Montana region and was developed through field observations and measurements. Tennant collected detailed cross-section data that characterized different aspects of fish habitat. These include width, depth, velocity, temperature, substrate and side channels, bars and islands, cover, migration, invertebrates, fishing and floating, esthetics and natural beauty. These metrics were related to a qualitative fish habitat quality. This allowed for a determination of discharge to fish habitat through the correlation of physical geometric and biological parameters to discharge. Tennant (1976)[107] then related percentile of the average flow would relate to fish habitat qualities and produced an easy-to-apply standard that can be used with very little data. The technique utilizes only the average annual flow for the stream. It then states that certain flows relate to the qualitative fish habitat rating that is used to define the flow needed to protect fish habitat, i.e. the quality desired.

The Tennant method is considered a standard setting method, meaning that it uses a single, fixed rule as a minimum base flow. This means that it is easily applied to any situation without collecting an abundant data or being expensive.

b) Hydraulic Methods

Hydraulic approaches use changes in simple hydraulic variables, such as wetted perimeter or maximum depth. It is usually measured across single, limiting river cross-sections, as surrogate for habitat factors known or assumed to be limiting to target biota.

The most commonly used hydraulic rating methodology worldwide today is the generic wetted perimeter method. Basic assumption is that river integrity can be directly related to the quantity of wetted perimeter. The wetted perimeter is the length of stream bottom substrate that is wet along a cross section oriented perpendicular to the river. Environmental flows are calculated by plotting the variable of concern against discharge. This produces a curve of the relationship between discharge and wetted perimeter that can be analyzed for the breakpoint or inflection point. Commonly, a breakpoint, interpreted as a threshold below which habitat quality becomes significantly degraded, is identified on the response curve, or the minimum environmental flow is set as the discharge producing a fixed percentage reduction in habitat. There is an ongoing discussion about how the breakpoint should be defined, and this is the main disadvantage of this method.

c) Habitat Simulation Methodologies

The habitat simulation methods attempt to determine environmental flow on the basis of detailed analyses of the quantity and suitability of instream physical habitat are available to target species under different discharge (flow regimes). Typically, the flow-related changes in physical microhabitat are modeled in various hydraulic programs, using data on one or more hydraulic variables collected at multiple cross-sections within the river study reach. The simulated available habitat conditions are linked with information on the range of preferred to unsuitable microhabitat condition for target species, life stages, assemblages and/or activities, often depicted using seasonally defined habitat suitability index curves. The resultant output, usually in the form of habitant-discharge curve for the biota, or extended as habitat time and exceedence series, are used to predict optimum flows as environmental flow.

Physical Habitat Simulation System (PHABSIM) is one of the commonly used instream flow models. PHABSIM uses four hydraulic criteria that are calculated from field measurements and related to fish habitat quality. The hydraulic variables included in the model are water depth, flow velocity, substrate and cover (Gillilan and Brown 1997)[108]. The required field data include cross-section survey. The outputs of PHABSIM are weighted usable area (WUA) curves that relate discharge to a fish habitat index for different life stages of fish species of interest and habitat guild (Waddle 2001)[109].

One of the most complete methods from this group is Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Services. In IFIM, the investigator examines more than a snapshot of the microhabitat characteristics of the stream to determine minimum flow. IFIM also considers micro habitat characteristics like stream temperature and water quality along the stream channel (Gillilan and Brown 1997)[108]. IFIM also tends to be used to determine the effect of an activity on habitat, and in restoration situations once the effect of the activity is better understood (Gordon et al 1992)[110]. Users within the U.S. Fish and Wildlife Service found IFIM to either be too complicated to apply (too expensive, not trained well enough, or took too much time), or too simplistic (models or curves needed improvement).

d) Holistic Methods

Holistic methods are actually frameworks that incorporate hydrological, hydraulic and habitat simulation models. They are the only Environmental Flow methodologies that explicitly adopt a holistic, ecosystem-based approach to environmental flow determinations.

In recent years, holistic approaches have greatly contributed to the field of environmental flow assessment. Doupe and Petitt 2002)[111] believe that in order to determine Environmental Flow it is necessary to find balance between requirements for water in an eco-system and socio-economic environment that leads to holistic and comprehensive approach for water resources management in open watercourses. In holistic methodology, important and/or critical flow events are identified in terms of selected criteria defining flow variability, for some of all major components or attributes of the river ecosystem. The basis of most approaches is the systematic construction of a modified flow regime from scratch (i.e. bottom-up), on a month-by-month (or more frequent) and element-by-element basis, in which each element represent a well defined feature of the flow regime intended to achieve particular ecological, geomorphologic, water quality, social or other objectives in the modified system (King and Tharme, 1994)[112]. In contrast, environmental flows are defined in terms of acceptable degrees of departure from the natural (or other reference) flow regime, rendering them less susceptible to any omission of critical flow characteristic or processes than their bottom-up counterparts (Burn, 1998)[113].

The building block methodology (BBM) is being a holistic methodology that addresses the health (structure and functioning) of all components of the river ecosystem, rather than focusing on selected species. BBM remains one of only two methodologies in the world for which a manual has been written (King et al. 2000 [114]), the other being IFIM (Milhous et al. 1989 [115]). The BBM is presently the most frequently applied holistic methodology in the world.

The advantage of the BBM 'expert team approach' is its flexibility and consensus building amongst experts who come to the best solution based on the data and model results available. The disadvantage is that it is not necessarily replicable and another group of expert might come to different conclusions.

Recently evolving from the BBM and other similar methodologies as an interactive, top-down holistic methodology comprising four modules (biophysical, social, scenario development and economic), the Downstream Response to Imposed Flow Transformation (DRIFT) process (King et al., 2000 [114]) offers innovative advances in environmental flow assessment. It focuses on identification, by a multidisciplinary team, of the consequences of reducing river discharges from natural, through a series of flow bands associated with particular sets of biophysical functions, and of specific hydrological and hydraulic character, in terms of the deterioration in system condition. The DRIFT methodology is an interactive, scenario-based approach, designed for use in negotiations, and contains a strong socio-economic component, important when quantifying subsistence use of river resources by the people living in the riparian zone.

Although DRIFT is usually used to build scenarios, its database can equally be used to set flows for achieving specific objectives. Two other activities outside DRIFT provide additional information to the decision-maker:

- A macro-economic assessment of each scenario, to describe its wider regional implications in terms of industrial and agricultural development, cost of water to urban areas and so on; and
- A public participation process, in which the wider body of stakeholders can voice its level of acceptability of each scenario.

e) Study on Environmental Flows in Malaysia

Although many river basins in Malaysia have yet to reach the 'closed basin' status, but increasing water demand for irrigation, domestic and industrial consumption and hydropower, together with catchment developments as well as encroachment into the riparian land, have lead to decline in the health of the water-dependent ecosystems (DID – 2005 [116]). It would therefore be desirable that minimum environmental flows for each river basin be specified that will allow and facilitate measures to be taken to avoid the decline of the valuable ecosystem. The form of such environmental flow can simply be a specified discharge value (hydrological methods), or the specification of a water depth to provide habitat for fishes (hydraulic methods), or as complex as a description of a completely modified flow regime to maintain a whole river and floodplain ecosystem (Habitat quality and Holistic methods).

As environmental flow is often site specific, the minimum flow requirements are normally determined from its average natural flows for management purposes (hydrological methods) (DID – April 2005 [117]). The National Water Resources Study (2000)[118], for example, used a rule-of-thumb of 10% Average Annual Flow (AAF) as the minimum flow required for planning purposes. Such minimum flow releases have also been used for the previous and similar water resources study in Malaysia. Another example, Study on Integrated River Basin Management for Sungai Langat (2005) [119], proposed a nominal amount equivalent to 20% of the estimated mean daily flow to be maintained in the river as environmental flow base on Tennant Method (Hydrological Index Method). The method states that 40% of the Average Annual Flow (AAF) of a river is an 'outstanding' minimum flow and 20% of the AAF is a 'satisfactory' minimum flow. The analysis carried out in the Study with 22 years of flow data at Kajang gauging station stated that Average Daily Flow at the station is 7.5 m^3/s. As such, the outstanding and satisfactory minimum flow for Sg. Langat at Kajang is 3.0 m^3/s (40%) and 1.5 m^3/s (20%) respectively. The AAF of ungauged catchments in peninsular Malaysia may be estimated from Water Resources Publication No.12 [157].

Kerian and Kurau River Basins Integrated Study (2005) [120] attempted to calculate the minimum environmental flows from low flows and matched against the minimum requirements of selected key aquatic habitat through habitat quality analysis. This method serves to provide an indication of the flows that can maintain sensitive habitats and ecological processes. Unfortunately to date, appropriate references are not available in this country to assess the ecological effects resulting from such changes in flows. In the absence of any ecological indices, the environmental flows were estimated based on percentages of low flows for four key components as suggested in Comprehensive Management Plan of Muda River Basin (JICA, 1995) [121] as listed below:

- *Discharge Necessary to Conserve Natural Low Flows*. Natural low flows are defined as the naturally occurring low flows due to prolonged periods without rain and that the outflow of water is from base flow and subsurface storage in the basins. The 1-day and 7-day low flows are reflective of natural low flow regimes and their return periods indicate water availability in the river system during low flow episodes. The 7-day low flow with a return interval of once in every 25 years is adopted as the minimum discharge assumed necessary to conserve the natural low flow regimes, river aquatic ecosystems and streambank stability. The 50-year return interval flow is not taken into consideration since the effects of such low flows on the aquatic life forms would have been quite drastic, and many aquatic and riparian species may not be able to survive such prolonged droughts and low flows.
- *Discharge Necessary to Maintain an Acceptable Water Quality.* The target is to upgrade or maintain at least the water quality standard of Class II for all rivers. Class II water is good for

recreational use with body contact, and for very sensitive fish species which are intolerable to pollution. Class II water will only necessitate conventional treatment if abstracted for water supplies while Class III waters would require extensive treatment.

- *Discharge Necessary to Conserve River Ecology.* Certain stretches along rivers are active breeding locations for fish and other aquatic life, which are also sensitive to ecological alterations. The survival of these sensitive areas depends on the depth, volume and the quality of water in the river systems. Fish survival in natural rivers depends on certain limits of minimum water depth and velocity for breeding and swimming. There must also be sufficient water available for dilution so that the fish can survive in areas with high BOD loading in the water. The most important consideration is the availability of water for reproduction, where a minimum depth of water is critical for their life cycle and space for comfort swimming. The JICA Report (1995) [122] advocated a minimum depth of 30 cm to 50 cm for fishes in Sg. Muda. In the absence of rating curves to derive the relationship between volumetric flow rates with depth, a minimum discharge for Class II waters could be adopted as the minimum requirements for fish and aquaculture.
- *Discharge Necessary to Maintain River Scenery.* Picturesque and beautiful river scenery has always invoked tranquility and well being to person viewing it. The scenic quality of river depends, amongst other, on water quality, flow characteristics, riparian and stream bank vegetation. Places with waterfalls and cascades with rock boulders and sand banks could be converted to tourist attraction sites. To maintain a scenic quality, a criterion of 50% rather than 20% (of JICA's recommendation) of the mean discharge from the area-discharge curves could be adopted.
- *Discharge Necessary to Prevent Salt-water Intrusion.* Near coastal areas, consideration should be given to maintain the fresh water aquatic habitat and prevent salt-water intrusion at low flows.

Study on Comprehensive Management Plan of Muda River Basin (1995) [121] found that the discharge to maintain the appropriate river water quality is evaluated as the most dominant factor to determine the minimum requirement for Environmental Flow. Based on the above requirements, implementing environmental flow would require an active intervention programme to maintain the flows to its minimum requirements and to meet at least Class II water quality in the medium to long term. Two approaches have been identified. These are an active flow management and a restrictive flow management.

- *Active Flow Management*. Active Flow Management involves actions designed to ensure a minimum environmental flow in the river system for its biota, ecological habitats and morphology. Such actions are taken to provide a minimum percentage of flow depth for ecology, scenic quality or for dilution of pollution to maintain high water quality standard. In the Murray-Darling Basin in Australia for example, a 1 in 5 year flood event in the Barmah-Milewa Forest is enhanced through release from a major storage in the basin and following this, the great egret bred for the first time since 1979, as did nine species of frogs, and native fish (ICUN, 2003) [102]. The following could be proposed:

  Establish Environmental Flow Monitoring and Management Programme (EFMMP). The existing flow regime in many rivers may not be sufficient to cater for the present minimum environmental requirements for natural flow, ecology and scenic quality in sub-basins. It is recommended that an active management and monitoring programme to regulate the flows by sub-basins be instituted to ensure that the minimum flows are maintained. This programme is related to conserve water catchments, water quality control and preventive measures and enforcement. It will provide appropriate methods for the collection of data and protocols for monitoring and management to ensure that assessments are well structured and repeatable. The programme should amongst other include:

  - *Data collection.* Establish a data-collection programme. This should include measurements of hydrology (river flows), hydraulic (water level and river cross-section) and ecology (species present, location found and links with flow) from each of the sub-basins for a wide range of flows. These are deemed important for the development of an Environmental Flow Indices (EFI) for benchmarking;

- *Development of Environmental Flow Indices (EFI) for Benchmarking.* Many studies provide only a range of minimum environmental flows required for various beneficial uses, but it does not provide environmental indices to denote the relationships between habitat conditions and flows. The EFI will provide such a relationship where the conditions of the flows in the rivers based on water chemistry, biota, and morphology can be measured and assessed. Each river system and its sub-basins will have its own environmental flow indices, which reflect the specific relationships between habitat conditions and flows. Environmental flow management will be made easier with the establishment of a set of EFI as guidelines or for benchmarking for main rivers and their sub-basins in the future. Such indices can be obtained through a series of pilot studies;
- *Conduct Pilot Studies.* The development of the Environmental Flow indices (EFI) must be underpinned by pilot studies using a range of methods and available data to compare outcomes and test appropriateness. All indices to be developed have to be further applied and tested under specific flow conditions before definitive assessments can be made, and the indices to be used as benchmarks in the future. An important consideration is to ensure that the methods are compatible, providing reliable results;
- *Monitoring Management Measures.* Monitoring of management measures, when they are instituted should amongst others, include:
  - Comprehensive description of overall environmental conditions and future changes;
  - The environmental condition of the rivers and their sub-basins as summarized in an environmental index value to indicate the direction and change of local condition;
  - Connectivity within the two or more river systems, between the main river system and its tributaries and catchments, and of upland and lowland reaches of the rivers; and
  - Identification of the potentials to aid the recovery of threatened sections of the rivers or of biotic species in the river systems.
- *Maintain Natural Storages for Environmental Flows.* Absence of environmental flows puts the existence of aquatic and riparian ecosystems that benefit the villagers/fisherman whose livelihood are dependent on their product, at risk. As the goal of environmental flow is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the ecosystem.
- *Maintain Environmental Flows in Upper Basins.* The upper parts of many river basins have very little development and therefore their environmental flows are relatively constant in quasi-equilibrium with their morphology. Because of this, maintenance of their depths and velocity are also relatively straightforward if there is no disturbance to the landuse in the areas. If there is no landuse alteration, these upper areas will provide sufficient environmental flow to maintain the spawning grounds for aquatic life forms and for the river system to develop into good aquatic habitats.
- *Restrictive Flow Management.* Restrictive flow management occurs where abstractions or diversion are controlled. Abstractions may be from the river itself or from groundwater within an aquifer supplying the river. In most river basins, there is no restrictive flow specifically for supplying environmental flows. It is recommended that some form of management to ensure a minimum environmental flow such as Restrictive Flow Management in the Paddy Cultivated Areas. This recommendation is mainly for areas within the large paddy cultivation areas. Some measures could be implemented relatively quickly and achieve immediate results in terms of environmental flows.

3.6 RECOVERY OF DISTURBED RIVERS

Stream rehabilitation is about the recovery of stream systems following disturbance [123]. That disturbance could come from human impact (such as clearing, flow regulation, desnagging, salinity, etc.) or from natural disturbances such as floods or droughts. In many situations, human disturbance has made streams more susceptible to natural disturbances such as floods. A stream manager needs to appreciate the following:

- Natural disturbance is an important process in streams.
- Human influence has added new disturbances and has increased the frequency and impact of many natural disturbances.
- Severe disturbance will reduce complexity (which will in turn reduce ecological diversity).

- Understanding recovery path is a powerful tool for stream rehabilitation.
- Once a disturbance has ceased, streams will gradually recover 'equilibrium'. This new equilibrium condition may look quite different from the channel before the disturbance.

When a rehabilitation project is being planned, it is important to consider how recovery will proceed. Working with the natural recovery of a stream can lead to much cheaper and more efficient rehabilitation.

A stable stream has a fixed reach morphology (i.e. set slope, cross-sectional size and shape, bed and bank material, pool-riffle spacing, and planform), and the organisms living in the reach (i.e. populations and diversity) will not see degradation or lateral migration of a stable channel reach. For stream morphology, the inputs are the amount and timing of sediment and water entering the reach (the flow regime). Averaged over time, water and sediment will move through the reach without causing major changes such as aggradation and degradation. For stream ecology, the inputs not only include water and sediment, but also include water quality, energy and food supply. This balance can be disturbed by a change in quantity and timing of the input, or in the stream's ability to process those inputs.

It is important to emphasise that streams in equilibrium are not totally inert. Equilibrium implies constant channel adjustment in response to the fluctuations in water and sediment discharge. Streams in equilibrium also constantly evolve in response to changes in water quality and aquatic habitat. Steady-state equilibrium covers both seasonal variation and year-to-year variation (caused by normal variation in climate). The concept of equilibrium implies a sufficient time to allow the passage of a whole range of flows that form the channel and the stream communities.

Streams do not always follow a simple equilibrium–disturbance–recovery pattern. Thus, some streams can have multiple equilibrium states in response to the same inputs. The notion that stream morphology and biology will return to some form of equilibrium following disturbance underpins most of this part of manual, and is usually an acceptable starting point for stream management.

3.6.1 Disturbances Affecting Rivers

Research over the last few decades has shown that much of the natural morphology and biology of our streams is a product of disturbance as much as equilibrium. It is possible that the frequency of disturbance is critical for the type of biota naturally living in a stream. In every stream there are occasionally disturbances large enough to disturb the steady-state equilibrium, and change the character of the stream. In biological terms the disturbance is classified according to duration and the same principles apply to geomorphic systems.

Two types of disturbance are:

- Pulse events, with a short, discrete duration, such as floods; and
- Press disturbances that may be steadily applied over a long period (e.g. climatic change, catchments clearing, removing riparian vegetation).

3.6.1.1 Pulse Events

An example of a pulse-type disturbance is the sudden avulsion of the stream channel from one position on the floodplain to another. When a major pulse disturbance occurs, the stream will have an immediate response, followed by a gradual recovery phase and finally a return to steady-state equilibrium. For example, a toxic chemical spill will create a pulse of pollution, decimating the fish and invertebrate populations downstream. Once the toxic pulse has passed, animals will recolonise the affected reach, gradually building up populations to something resembling the original levels.

There are two points to make on this disturbance response.

- Firstly, the stream may not return to the original equilibrium condition, but find a new, steady state. For example, the fish population may have been dominated by certain species before the disturbance, and different species can colonize the reach after the pulse event.
- Secondly, quite a small initial disturbance can be sufficient to cause a major response from the stream. This occurs when a disturbance pushes a stream past some intrinsic threshold for major change. It is important to realise that threshold exceedance can happen quite naturally, even without external changes.

3.6.1.2 Press Disturbances

Many press-type disturbances such as increased sediment loads, grazing, salinity, and clearing of catchment vegetation lead to changes in hydrology. If the average inputs to the stream are changed for a long period the stream will adjust to be in equilibrium with those inputs. For example, if the annual flood increases gradually, this will eventually lead to a commensurately larger channel, with all of the morphological variables adjusting as sketched in Figure 3.104.

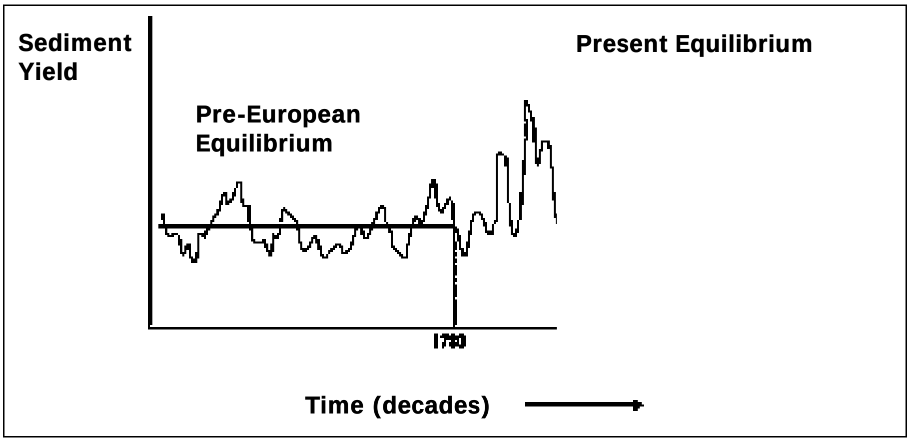


Figure 3.104 New equilibrium state showing greater variability after disturbance [123]

If the press disturbance were removed, there would follow another period of recovery, as the stream adapted to the reversion to the old conditions (Figure 3.105).

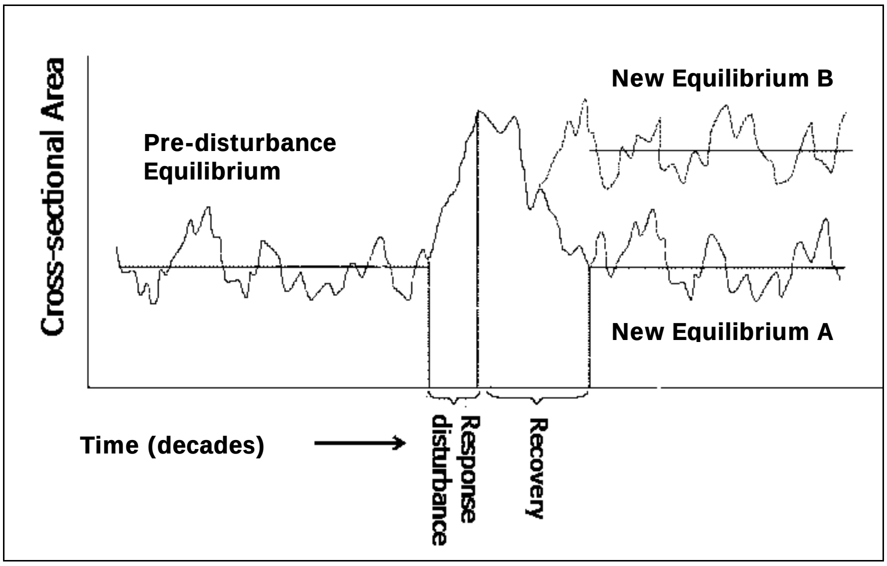


Figure 3.105 Recovery from a pulse disturbance, to an equilibrium resembling pre-disturbance A and a new equilibrium B [123]

3.6.2 Natural Recovery

The Recovery path for a stream refers to the stages that a stream will go through as part of the recovery process. As sketched in Figure 3.106, the incision of small streams provides a good example of a recovery path.

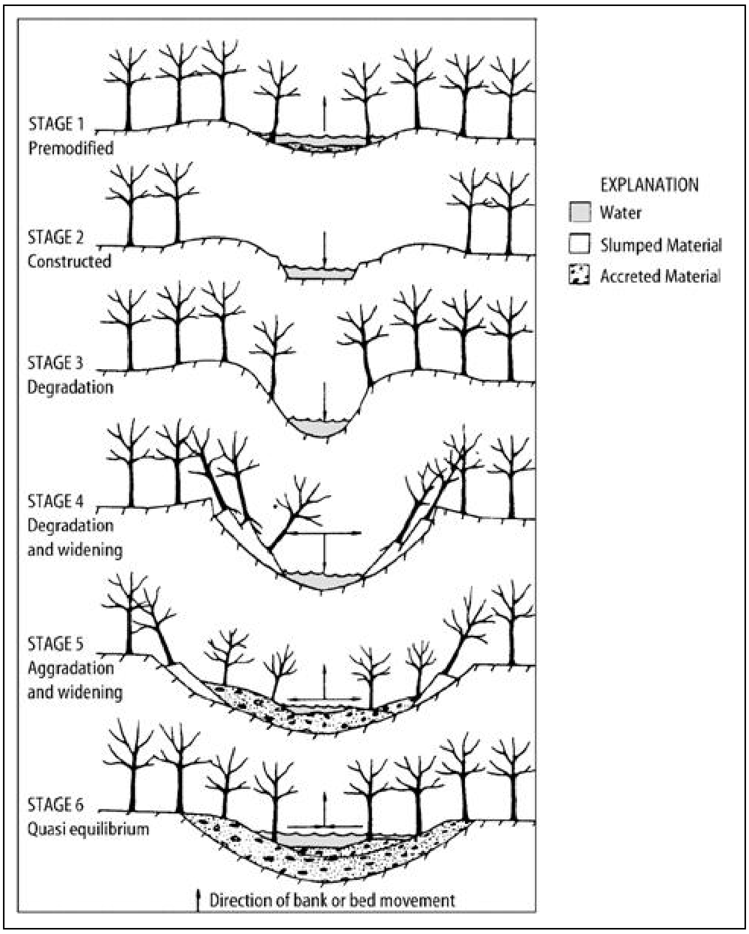


Figure 3.106 Recovery of Incised Stream [123]

The ability to predict the recovery path is a very powerful tool for stream management. It allows the stream manager to speed up natural recovery by pre-empting critical stages. For example, artificially stabilising the bed (say with rock chutes) would mean that the widening phase could begin perhaps decades earlier than otherwise, leading to a faster recovery.

3.6.3 Equilibrium, Disturbance, and Complexity

Although there are recovery of reach morphology and biology in terms of regaining equilibrium, they may not equal to a healthy, restored stream. It is possible for a degraded stream to have a stable channel and biological community. Many rural streams are in this condition. Although such streams are often quite stable, they have been affected by changes to hydrology, clearing and grazing in the riparian zone, often channel incision and bad water quality, and are thus limited in the habitat they offer and the communities they support. However, steady-state equilibrium is a good start, and often a prerequisite for further improvement.

For instance, following incision, the new channel is a bare rectangular trench with very little geomorphic complexity, carrying very flashy flows, and with little biological value. Over time, a new floodplain is gradually formed within the incised trench (Figure 3.107a & b). This may take decades to develop. At this stage, the channel has reached a new state of equilibrium.

Figure 3.107a An incised stream with a stable bed, that is now developing laterally [123]

Figure 3.107b The bed and banks have stabilized, and vegetation has invaded the channel, producing a much improved habitat [123]

3.6.4 Geomorphic Recovery

The path followed by a stream while recovering from disturbance depends on which elements of the stream have been affected. Disturbances are usually reflected in changes to the following elements of the stream:

- Rate of erosion and sedimentation;
- Particle size of sediment carried on the bed and in suspension;
- Size of the channel (erosion or deposition);
- Shape of the cross-section (e.g. may become deeper, or wider and shallower); and
- Planform of the channel (for example, sinuosity).

It is important to note that it often takes much longer for a stream to recover than it does to be disturbed. Gully erosion and major channel changes often occur rapidly in a series of large floods. It will then take decades of lower flows for them to recover their original form, if they ever do. Similarly, it can take only days to artificially remove riparian vegetation or large woody debris. It will take decades or centuries to naturally restore them.

The rate at which stream morphology recovers after disturbance often depends on four related factors: stream power, sediment supply, the frequency of large floods, and riparian vegetation (assuming that other disturbances have been removed).

- *Stream power.* Stream power is a product of channel slope and discharge. It is a measure of the ability of a stream to carry sediment and do work in the channel. Recovery usually involves a balance of deposition and erosion in the right places. If the stream is too powerful, then the sediment required for recovery is transported right through the reach. If the stream has too little power, then there is insufficient transport of sediment, and erosion of bed and banks to facilitate recovery.
- *Sediment availability.* Natural recovery often requires the right sort of sediment in the correct amounts. For example, some highly eroded streams require deposition of point bars and benches for the stream to recover. In other streams, natural riffles will form only from coarse sediment. In yet other streams the deposited substrate is so infertile (e.g. sand and gravel) that it cannot be recolonised by vegetation. The fine suspended fraction of sediment has to be trapped somehow to encourage growth. Thus, the rate of recovery often depends upon the rate at which sediment of a particular size is supplied, and the rate at which it is deposited.
- *Frequency of flows of various sizes.* The rate of recovery of streams depends upon the range of flows that they carry. Often the most important flows are the moderate sized floods. For example, many years of low flows will do little to build bars and benches, or remove sediment slugs, while too many large floods will continue to destabilize the channel. Furthermore, many disturbed streams are more susceptible to channel instability than they were before human impact. This is because banks are not protected by vegetation, the bed is not protected by a

large woody debris, and more water is often contained within deepened channels (i.e. greater stream power). As a result, floods become more 'geomorphologically effective' and do more damage. This means that a single large flood can reverse years of recovery and so recovery is delayed.

- *Recovery of riparian and in-channel vegetation.* Although vegetation recovery is a biological variable, the long-term restoration of streams almost always relies on the recovery of associated vegetation in the channel and in the riparian zone. Vegetation stabilizes sediment in the channel (e.g. bars, benches, and banks).

The importance of these factors will vary along a single stream (with rates of recovery usually fastest in the high-energy upper reaches, and decreasing downstream). Climate is also important, because of its influence on-stream flow and riparian vegetation. In this country, riparian vegetation can grow rapidly to a closed canopy in a few years.

The time frame required for geomorphic recovery of Australian streams as shown in Table 3.17 may provide an indication of the extent of recovery time for geomorphology and riparian zone of our local streams.

Table 3.17 Estimated recovery times of various river elements after press and pulse disturbances [123]

Variable	Recovery time in headwaters	Recovery time in lowland streams
Geomorphology:		
Sinuosity in channelised stream	10 – 50 years	50 – 100 years
Bars, benches	10 – 50 years	10 – 50 years
Sediment slugs (time to move through)	5 – 10 years	50 – 100 years
Step-pool sequence	5 – 20 years	–
Riparian zone:		
Riparian vegetation	10 – 50 years	10 – 50 years
Macrophytes in the channel	–	1 – 5 years
Large woody debris in the channel	50 – 100 years	100 – 200 years

3.6.5 Biological Recovery

The recovery of a population or community of stream animals and plants depends on four factors.

- *The presence of appropriate environmental conditions in the project area.* This includes the physical habitat that your rehabilitation project has set out to create or improve, as well as water quality and the state of the food web. This will determine the carrying capacity of your reach - the potential population it can sustain.
- *A supply of animals or plants to recolonise the area.* This supply may be small populations within the reach, from up or down stream, or it may be from different catchments, depending on the animal or plant in question and whether there is any insurmountable barrier between the source and your reach.
- *The rate of population growth.* This will determine how quickly the recolonising individuals will build up the population to the carrying capacity of the reach. This depends on the rate at which colonizing individuals arrive, and how quickly they reproduce.
- *The nature of the disturbance.* The rate of recovery will also depend on the disturbance that the stream is recovering from, whether it was pulse or press, the intensity of disturbance and the history of disturbance in the area.

Animals and plants can be in refuges in the rehabilitated reach itself, upstream or downstream reaches, or even nearby catchments. The closer this source is to the rehabilitation site the better - individuals are more likely to find the site quickly. There are a variety of possible restrictions to recolonisation. The most commonly recognised are the instream barriers to upstream movement posed by dams, weirs, road crossings, and in fact anything which creates a waterfall or fast flowing shallow area. As can be seen from Table 3.18 biological recovery can be relatively fast, unless it relies on development of physical complexity, which is itself a slow process (see Table 3.18) or colonizing organisms must travel great distances to reach the rehabilitated site.

Table 3.18 The influence of the type of disturbance on recovery times for stream ecosystems [124] & [125]

Type of disturbance	Examples of disturbance	Typical effects of disturbance	Recovery time
Pulse	• Construction in the stream. • Moderate flood.	Reduces species abundance and diversity, but there is still some community present (ie. the food web is more or less intact).	Less than 1 year
Pulse	• Chemical spills affecting a single reach.	Completely destroys communities, but only one reach affected. Up and downstream sources of colonists.	Less than 2 years
Press	• Geomorphic disturbance of one reach, such as limited channelisation.	Ecologically, similar to above, but habitat is degraded and simplified. Habitat must recover before the stream ecosystem can.	Depends on the rate of geomorphic recovery (decades). Ecological recovery will probably be fast in comparison.
Pulse/press	• A very widespread pulse, such as a severe flood through an entire large catchment, poisoning of an entire stream. • Widespread and long-term press, such as occurs in rural areas as a result of changes such as clearing, grazing, decreased water quality, desnagging, etc.	Stream fauna is depauperate through a very large length of stream. No refuges or other sources of colonists within the stream system. This will be the case for many rehabilitation projects which improve a reach in the middle of a widely degraded stream system.	The more mobile species (insects with aerial stages) will return in around 5 years. Less mobile species will return — may take more than 25 years. Some may never return.

An incompletely restored stream can affect recovery. This is because firstly, while your rehabilitation project may have tackled the worst problem present, there will probably still be others, like water quality, or food sources, which will continue to limit the target species and prevent the population from reaching its full potential. Secondly, some limiting factors will affect not only the completeness of recovery, but also the rate. Three "environmental" factors affect biological recovery: (1) supply of animals and plants which will recolonize the reach; (2) relocation of animals and plants from the supply area to the rehabilitated area; and (3) restrictions / barrier for such recolonization.

3.6.6 Recovery Principles for Stream Rehabilitation

A major aim of stream rehabilitation is to establish conditions similar or close-to original conditions. When near-pristine conditions cannot be obtained, the aim is to provide appropriate habitat complexity, stability, and resources for the community of organisms living in the stream. An understanding of disturbance and recovery can aid this quest in several ways. Firstly, major disturbances can occur naturally. Secondly, understanding how the stream is likely to recover from disturbance means we can work with the stream through a better understanding of the following:

- What stages the stream will go through (the recovery path);
- Roughly how long it will take to get through each stage;

- What may be limiting, or slowing down the recovery; and
- What are likely to be the limiting requirements for organisms living in the stream (e.g. where will they come from?).

This knowledge provides a basis for deciding whether to intervene in the system or not. Generally, the following options are available:

Option 1. Allow the stream to recover at its natural rate (management then is to control any new disturbances that could jeopardize that recovery).

Option 2. Accelerate the natural recovery by controlling factors that will limit or impede the natural recovery of the channel.

Option 3. Artificially accelerate the recovery of the stream by predicting the recovered condition, and creating this artificially.

Option 4. Decide that there is little hope of the channel to recover naturally and artificially a better channel can be created.

Option 5. Decide that there is little hope of the channel to recover without a huge rehabilitation effort, so decide to spend your rehabilitation effort on a reach that is expected to be more successful.

3.6.7 River Problems and Solutions

An important thing that one can do to protect river reaches is to identify and eliminate existing and developing problems. Processes for identifying and prioritizing problems are looking at the target river reach i.e. upstream area, downstream area and the riparian zone (Land and Water Resources Research and Development Corporation, 2000)[126].

3.6.7.1 Riparian Vegetation

Riparian vegetation plays an important role in (Managing Natural Resources)[127]:

- Stabilization of river banks. Riparian vegetation can protect banks from scour and collapse. Generally, a bank covered with vegetation will erode at a lower rate than a bare bank.
- Maintenance of water quality. Vegetation is an important filter that helps to reduce the speed of water runoff from surrounding areas, thereby allowing sediments and nutrients to be trapped.
- Provision of habitat for aquatic species. Riparian vegetation is an important source of food for both fish and aquatic insects. The mottled nature of riparian vegetation creates cover for predator and prey, habitat for threatened plants, and habitat and feeding areas for fish.
- Maintenance *of habitat conditions.* The shade provided by riparian vegetation helps to regulate water temperature and light levels, thereby maintaining suitable water quality for aquatic plants and animals. Reducing the temperature leads to higher oxygen levels for aquatic fauna. Limiting the available light reduces weed and algal growth.

Riparian zone is often highly productive making it vulnerable to be overused. Poorly managed streambanks has resulted in colonies of illegal human settlements (or squatter houses) on the streambanks leadimg to erosion, soil compaction and weed invasion as well as a loss of vegetation cover (Figure 3.108). Healthy streambank vegetation and instream habitat, such as woody debris, increases habitat for fauna and improves water quality by reducing runoff. The management of riparian land becomes problematic where there are infestations of weeds such as *lallang* and shrubs such as Silktree Mimosa (Albizia Julibrissin), where the area is devoid of native vegetation or un-kept secondary forest (*belukar*). Catchment areas with remnant native vegetation are a high priority for the protection of biodiversity.

Figure 3.108 Squatter Dwellings along River Bank (Sg Kayu Ara)

Riparian vegetation in poor condition is characterized by:

- Unkept secondary forest (belukar) with shrubs, lallang (Imperata cylindrica) and other tall grass species.
- A high proportion of pasture areas or weeds such as lallang and other tall grass species.
- Illegal human dwellings and live stock damage in the form of stock pathways, bank erosion, soil compaction, animal faeces (unregulated cattle rearing) in and around the water's edge, and sediment in the water.
- Little suitable habitat for native plant and animal species.
- Significant and active erosion, which is not natural.

Riparian vegetation and *belukar* in poor condition commonly occurs in areas used for agriculture, stock access or construction works. It is important that these areas are revegetated and preserved as "green lungs" as soon as possible. If rivers are not revegetated, it is likely that they will become further degraded and water quality for both humans and native fauna will decline. Weed and shrub infestations occur in disturbed environments. They would compete with native species for light and nutrients, often growing faster than their native counterparts and transformed riparian vegetation from native to an introduced flora.

River snags are large woody debris including large limbs, branches and occasionally complete trees. They are significant because they provide habitat for a range of species, including fish, invertebrates and microscopic organisms. Desnagging rivers leads to loss of habitat and increases flow rate which results in channel erosion. If woody debris is causing a problem it can be realigned so that it lies at an angle of 20-40^{o} to the bank to reduce flooding or erosion.

Retaining healthy riparian vegetation is the cheapest way of preventing degradation such as protecting intact riparian vegetation. If there are isolated plants or small patches left, ensure that these are not removed during rehabilitation works, such as weeds and shrubs removal.

Some guidelines for revegetation along rivers are:

- Survey river sections or tributaries that have riparian vegetation in good or excellent condition. Record the different species present and note which ones are dominant. This will be useful when deciding upon a seed or planting mix.
- The species mix should reflect the vegetation types that will typically occur along the river. Preferably a range of species should be used, including trees, shrubs and ground covers. The roots of the trees and shrubs will penetrate deep into the soil profile and help to bind the soil together. The ground cover plants will reduce the amount of bare ground and help to trap sediments and nutrients from the adjacent land.

- It is important to observe where particular species occur in relation to the river. Grasses, small sedges, rushes and reeds inhabit along the edge of the stream and are very important for binding the soil. It is important to try and replicate this pattern when revegetating the banks.
- Squatter houses at the river edges should be relocated and the exposed ground re-vegetated.

Bank stability is greatly increased if the banks are reinforced by good tree root system (MoAF, DID Manual 1973)[128]. Therefore trees should not be cut down unless necessary and the roots should not be removed after the trees are felled. However, semi-aquatic growth such as *mengkuang (Pandanus caricosus)* or *rembia (Metroxylon sagu),* which encroaches on slow flowing waterways to such an extent that flow is seriously impeded, should be removed. Bank grown with the offending *mengkuang* is found at points where the river tends to deposit sediment, and not at points where there is a tendency to erode. Offensive *rembia* if not removed will spread into the river from an adjacent stand, and provided that the whole stand is not removed, the banks will be held by what remains.

In some slow flowing streams including ponds and reservoir, water hyacinth (*kiambang*) can be very troublesome. It will usually be best to cut up the growth into conveniently sized 'islands', to float it to a convenient spot for removal from the river/lake, to allow it to dry and then dispose it. Water hyacinth has remarkable powers of regeneration and may seriously interfere with fishing, boat travel or reservoir operations. Although thoroughly clearing is done, it will be necessary to remove regenerated growth after a period of about two months.

3.6.7.2 Biodiversity

'Biodiversity' is an abbreviation for the term 'biological diversity' (DID 2005, KTA Tenaga)[129]. The understanding of the term is almost always restricted to the notion of species richness. Biodiversity refers to the variety of life considered at all levels – from genetic variation in a species through to the variety of communities which live in particular habitats and the physical conditions under which they live. Biodiversity encompasses all species of plants, animals and microorganisms, and the ecosystem of which they are part. It is usually considered at three different levels, 'genetic diversity', 'species diversity' and 'ecosystem diversity'.

Genetic diversity is the diversity within species, as measured by the variation within genes. Such diversity covers distinct population, or varieties, of the same species, as in rice, for example, or genetic variety within a population, which may be very high or very low. Species diversity refers to the variety of living organisms on earth, estimated at between 13 and 14 million, of which only 1.75 million (about 13 percent) have been scientifically documented (UNEP 1995)[130]. Species richness on earth is the result of hundreds of millions of years of evolutionary history. Ecosystem diversity refers to the variety of the habitats, biotic communities and ecological processes in the biosphere.

While there is no accurate account of the loss of species and this loss may occur even before species are discovered, an estimate places the potential at 15,000 to 50,000 per year from 1990 onwards, due mainly to deforestation in the tropics (Reid and Miller, 1988). The main causes of loss of species have been identified as (i) habitat loss, degradation and fragmentation, (ii) over-exploitation by commercial harvesting, logging, fishing and hunting, (iii) pollution, (iv) introduction of exotic species, and (v) climate change. Habitat loss which has been occurring with alarming rapidity in many river basins, are considered as the most serious of them.

Rivers provide important habitats and serve as feeding and breeding grounds for a wide range of riverine biodiversity that lives in the river as well as in the river-fringing vegetation. Rivers also form a key component of our environment and landscape. They provide the means for delivering water to every corner of the earth and are vital for the healthy functioning of nature itself.

3.6.7.3 Aquatic Life

For aquatic life, the Interim National Quality Standards for Malaysia (INWQS) can be used to categorize types of usage such as aquatic life (DID 2005, KTA Tenaga)[129]. Species such as macroinvertebrates of the EPT type (Ephemeroptera-Plecoptera-Trichoptera) are very sensitive to aquatic environmental perturbation.

They require excellent water parameters such as high BOD, low temperature and low suspended sediment in order to survive. These types of species are suitable as indicator species, not only due to their sensitivity but also to their immobility. They tend to inhabit low order streams (1^o and 2^o). River order classification of Horton and Stahler (Witzel & Lekens, 1979)[132], stated that streams with order 1^o and 2^o found in the hilly and mountainous types are fast-flowing and oligotrophic in nature, as compared to 3^o and 4^o in which the river flows are slower, gentler and more eutrophic. Other mobile species such as fish and dipterans are less susceptible and can be seen in a more degraded environment and can be tolerant to pollution.

Other species such as Ephemeroptera (mayflies), Plecoptera (stonefly) and Trichoptera (caddisflies) are suitable as indicator. Fish can also be a good indicator of environmental pollution. They can be easily caught and identified, tagged and released as compared to macroinvertebrates but they are not as sensitive.

Straightening and widening of river to prevent flooding is environmentally unfriendly for many aquatic organisms. By making the waterway straight, the velocity of water passing through it during heavy downpour is extremely fast resulting in the dislocation of many aquatic organisms. These organisms, including fish, will be washed away downstream resulting in the reduction of biodiversity in the affected section of the river. The widening of the river system, on the other hand, will cause the flow of the water during drought season to be very low or non-existent. The reduction in flow will definitely be fatal to aquatic organisms, particularly the fish.

Wetlands will definitely increase biodiversity of terrestrial animal particularly water birds. The birds referred to under this category are those, which frequent and swim in fresh water, swamps, ponds and rivers. The presence of reeds (Figure 3.109) in a river, swamp, or wetland will be a suitable nesting ground for white-breasted water hen (Figure 3.110) and slaty-breasted rails (Figure 3.111). All local, fairly large birds with very long legs, long neck and long dagger-like bill such as heron, reef egret and cinnamon bittern will be flocking to this wetland to feed on fish, frogs and other creatures living in the water. The created wetland will provide a resting area for wintering, migratory bird as far as from China and Russia. These include common sandpiper, pintail snipe and redshank.

Figure 3.109 Reeds grown at riverine areas

Figure 3.110 White-breasted Waterhen (amaurornis phoenicurus)

Figure 3.111 Slaty-breasted Rail (**Gallirallus striatus)**

The wetland, once it is established, can be a suitable area to rehabilitate the almost extinct otters. The hairy-nosed otter (Figure 3.112), which lives in large rivers, often near their mouth, and even in the sea can be introduced into the wetland. Besides, the widely distributed common otter can also be introduced into the lake to enhance its biodiversity.

Figure 3.112 Hairy-nosed otter (Lutra sumatrana)

The greatest contribution of the wetland would be maintaining the high biodiversity of fishes in the river system. It is noteworthy that many species of fish have become locally extinct from many stretches of rivers. It is speculated that the disappearance of many fishes in the area is due to degradation of their spawning areas. The construction of wetlands with large floodplain area will provide the necessary spawning ground for fishes. During rainy season, most of the floodplain areas will be inundated with water and during which most riverine fishes release their eggs. The area is also suitable as a nursery ground for the juvenile fish before they are ready to occupy the main pond and river. In order to increase the biodiversity of freshwater fishes in any river, initial stocking of the extinct fish must be carried out.

Introduction of exotic species into the riverine environment, either intentionally or accidentally, for fish feed and aquarium trade is a major issue particularly from the perspective of indigenous freshwater species conservation. Once introduced to a suitable aquatic environment, the exotic fauna and flora can potentially breed excessively and cause displacement of the indigenous populations.
Excessive harvesting and the use of destructive and illegal fishing practices and methods, such as derris roots, poisons, explosives, small mesh nets and fish traps, can lead to the reduction of fish population.

3.6.7.4 Erosion and Sedimentation

Rivers constantly adjust the shapes of their channels and erode or silt their bed and banks under natural conditions. Human activities often lead to a dramatic increase in sediment yield to streams. Urban development usually removes forests within a basin that results in soil erosion and sedimentation. The highlands are important water catchments that are major sources of our water supply. Although forests form the largest single land use in our highlands, there is increasing interest towards highland development. Disturbances involving vegetation clearing, especially on the unstable and sensitive steep slopes, will result in soil erosion and sometimes landslides. The types of land use in the highland catchment which impact most significantly on rivers and riverine wetlands are forestry (i.e. timber extraction), agriculture, mining, industry and urbanization.

Substantial erosion is common in urban development sites such as in the Klang River Basin, generating a large volume of sediment that is deposited downstream (DID 2005, DHI, SMEC & Dr. Nik & Associates)[34]. The majority of the sediment generated in the urban basin appears to have eroded off construction sites. The large volume of sediment that currently enters drains, streams and rivers is an economic and environmental cost to the community. The public indirectly bears the cost of regularly cleaning drains and watercourses, whilst the related increase in flood levels can have a direct impact on property and life. The degradation of environmental assets has obvious ecosystem impacts, whilst affecting the quality of life in and around urban areas and downstream.

All developments are required to have an approved Earthworks Plan (regulated under the Earthworks By-law by local councils) prior to construction that sets out erosion and sediment controls. Despite this requirement, it has been reported that all planned measures, although installed, are usually not properly maintained. Visual inspection at sites revealed that extreme erosion hazard at construction sites is primarily due to the exposure of large bare land during long construction periods. Control measures are commonly limited to major sediment basins on the down slope boundary of the site and revegetation.

A coordinated effort is required by agencies to provide the necessary inter-government management structure, technical information and support required to control land development, promote erosion and sediment control, provide training, review Earthworks Plans and install, monitor and enforce site controls. This comprehensive approach has to cover three main areas, namely:

- *Land Use Planning Control.* Stricter land use planning controls related to:
  - The physical limitations of land development
  - The development approval process, and
  - The standard of erosion and sediment controls in Earthworks Plans
- *Awareness.* Knowledge of the practical design, installation and maintenance of on-site development controls by all involved parties
- *Monitoring and Enforcement.* A coordinated and effective monitoring and enforcement system, with agency management responsibilities and authority clearly identified. Municipals Council/Local Authority would be the primary level of authority responsible for the implementation of controls, supported by JPS and DOE.

The direct impacts of erosion and sedimentation to the community and the environment in an urban basin include:

- Flooding caused by reduced river channel/drain capacity
- Drain cleaning and river channel and harbour desilting costs
- Increased construction costs from site landform damage, structure damage (e.g. drains), reduced site accessibility, sediment basin cleaning or off-site sediment removal
- Loss of riverine vegetation
- Damage to riverside developments from sediment deposition
- Declining water quality and increased cost of water treatment; and
- Adverse impacts on aquatic ecosystems, especially benthic organisms and fish breeding habitat

The most comprehensive guidelines that describe erosion and sedimentation processes, set out control principles and measures and describe management responsibilities are:

- Guideline for Prevention and Control of Soil Erosion and Siltation in Malaysia (Jabatan Alam Sekitar/Department of Environment (DOE), Ministry of Science, Technology and Environment, Malaysia, 1996)[134]; and
- Urban Stormwater Management Manual for Malaysia or MSMA (Department of Irrigation and Drainage Malaysia, 2000[135]).

The Urban Stormwater Management Manual for Malaysia (DID, 2000[135]) is a comprehensive manual for urban stormwater design, covering processes, control principles, works design and plan preparation, as well as maintenance requirements. It includes four chapters that primarily deal with erosion and sediment control (Volume 15, Chapter 38-39; Volume 16, Chapter 40-41), two chapters on landscaping and bioengineering measures (Volume 17, Chapter 42) and a section on soil loss estimation (Volume 5, Chapter 15.5.2). The Manual presents the range of control measures recommended for basin sites and should be utilized as the principal guidelines for erosion and sediment control.

Volume 15 and 16 of the Manual cover erosion control, providing guidelines suitable for the design of control by planners, and for use by Council and DID engineers in the provision of advice, review of plans and audit of on-site works. Chapter 38 repeats much of the information contained in the DOE (1996)[134] Guidelines for Preventation and Control of Soil Erosion and Siltation in Malaysia.

a) Erosion

The rate of erosion has increased in many places due to human settlements and developments along the rivers. There are two main reasons for this increment. The first is the larger scale clearing of natural vegetation from catchments for agricultural and other development. The second factor is the removal of native riparian vegetation from along riverbanks. This has weakened the ability of riverbanks to resist the forces of flood flows and resulted in eroding riverbanks. Erosion could be classified as soil (catchment) erosion and river erosion (sediment transport):

- River Basin Erosion

Soil erosion issues need to be tackled at the source in order to ensure minimum impacts of soil erosion, which would subsequently lead to river siltation [35]. For better management of river basin, a soil erosion risk map will have to be produced to identify high-risk areas as well as monitoring of activities from time to time. The factors influencing soil erosion include rainfall intensity, soil erodibility, slope length and steepness at the river corridor and land use management. Steep and deforested areas are most severely prone to soil erosion.

For high erosion risk areas, monitoring via high resolution satellite images (1m to 2m resolution) annually, need to be carried out by the relevant authority to track changes in land use as well as identification of cleared area within the basin. More frequent enforcement by the DOE on the development of high-risk areas would also be required. Rehabilitation and protection against erosion and sedimentation for the river corridor within the basin need to be carried out by the property developers if the land is privately owned or the local authority for non-privately owned land. More attention should also be given to control indiscriminate or illegal clearing of areas with potentially high erosion risk. Where developments in these areas are unavoidable, preventive and mitigation measures should be initiated early and duly enforced.

- River Erosion

Riverbank and bed erosion indicate channel instabilities as shown in Figure 3.113 (REDAC 2006)[137]. During high flows and floods, channel erosion continues, causing the bed and banks under considerably great stress. Erosion is accelerated and the confined power of the currents may rapidly reshape the bed and the banks. Generally, the outer edges of the river bends (concave side) are subjected to scouring, undercutting and erosion which will result in sediments being deposited in the inner bends. Once erosion and sedimentation processes are fully understood, then the appropriate techniques to manage them can be easily applied.

Figure 3.113 Example of riverbank erosion (left) and riverbed erosion (right) on the Muda River

There are four main processes that contribute to bed erosion:

- *Decrease in sediment supply.* This can occur when the natural passage of sediment through the system is interrupted by upstream dams, weirs, catchment erosion control works, or excavation in the river bed.
- *Increase in bed slope.* This can be a result of straightening the river, removing of bed control, weir or crossing, or excavating the bed of the river for other landuses e.g. industries and recreation.
- *Increase in velocity (not associated with an increase in slope).* This can be as a result of a channel constriction such as debris, fill and vegetation on the river bed or bridge abutments.
- *Increase in discharge.* This can be as a result of increase urban runoff, catchment clearing or increase in rainfall. It can also be from regulated water transfers for irrigation and other suppliers.

For a more detailed description of erosion and sedimentation processes in rivers, please refer to Chapter 2.3 - River Morphology of this volume of the Manual.

Effective erosion control on the main river channel and tributaries will require careful planning, design, construction, and maintenance measures. Effective protection may involve special attention to bed degradation, grade control, toe protection, upper bank seepage, and other factors relating to bank instability as well as removal of the bank material by flowing water. There are a wide variety of both natural and man-made materials are currently available to control riverbank erosion. These include vegetative measure (turfing), rock riprap, gabions, concrete blocks in various configurations, sand-filled mattresses, fibre mattresses, and hard-engineering measures such retaining walls (concrete, sheet pile and keystone walls).

Revegetation of the riverbanks is a simple, low-cost and effective means of controlling and restoring unstable sections of the riverbanks. It also provides significant benefits to the ecology and aesthetics of the area, making riverine environment a highly desirable recreational resource. Riverbank vegetation: (1) provide a protective barrier to flow against the riverbank keeping erosive velocities at bay; and (2) the roots bind the soil and gravel in the banks, thus providing direct resistance to the erosive forces acting on the banks

Today, riverbank protection efforts are expected to address issues such as habitat, aesthetics and water quality in addition to flood control and erosion protection. Bioengineering systems utilize vegetation as a principal component and can provide sound riverbank protection while maximizing ecological and water quality benefits. The advantages of this technique are:

- Aesthetically pleasing (provides greater opportunity for incorporating trees, bushes, flowers and grasses along the river corridor);
- Improved wildlife habitat (planting provide shelter, protective cover and homes for birds, turtles and small animals);
- Improved fish habitat (provide shelter and breaks in the stream current, this is important for fish to live and reproduce, overhanging vegetation also provide shelter); and
- Water quality benefits (plantings and buffer areas reduce riverbank erosion and filter overland runoff into the river; vegetation shades the river and reduces water temperature).

There are a number of management measures available to address the problems of channel erosion:

- Dealing with the causes
  - Use planning mechanisms to control catchment activities in certain areas and/or specific activities throughout the basin;
  - Implement and enforce soil protection measures;
  - Repair current land degradation with measures to control soil erosion and the loss of sediment from the site;
  - Include soil conservation measures in agricultural extension services;
  - Create riparian buffer zones to trap sediments from diffuse sources along the river;
  - Sediment traps at sites of soil disturbance and in small tributaries;

  - Installing detention basins to limit flooding and to trap sediments;
  - Control developments along riverbanks through enforcement of river reserves;
  - Control clearing and disturbance along the river reserve; and
  - Re-establishing vegetation along the riverbanks and riparian zones where it has been lost or destroyed.
- Dealing with the signs
  - Erosion control by vegetation;
  - Erosion control by protection works; and
  - Excavation of sand with strict safeguards.
- Restoration of the rivers
  - Channel alignment work to stabilize accumulated sediments and control river channels; and
  - Bedform restoration to recreate pools and riffles using environmentally friendly structures.
- Others
  - Develop the procedures for prevention and correction of riverbank erosion;
  - New design guidelines;
  - Leaflets/pamphlets on riverbank protection for the land owners/public;
  - Procedure for evaluation of riverbank stability;
  - Laboratory investigations of some major hydraulic and geotechnical aspects of riverbank erosion and its control; and
  - A small reduction in speed may produce a significant reduction in boat wakes, one of the main causes of bank erosion.

It is suggested that the future trend of riverbank stabilization methods should be towards the bioengineering solutions and should involve the active participation of all the stakeholders involved. For a more detailed description of the various bank protection methods, please refer to Chapter 3.4-River Engineering of this Manual.

b) Sedimentation

The variability of sediment transport is largely affected by changes in discharge from time to time. The landscape that the river flows through is the other influence. The contribution from severely eroded lands resulting from various human activities, perhaps the most significant, also determines the quantity of sediment movement in the channel. Changes in sediment concentration vary from storm to storm. During periods of low flow, relatively little sediment transport takes places. As flow increases, more sediment is entrained from the streambeds and banks. Sediment particles of various sizes, particularly the fine and coarser ones become suspended depending on the flow velocity. Materials from the stream bank are also eroded largely by the action of bank carving as the waters in the channel continuously undermine the bank, which ultimately results in total collapse. The reduced flow velocities in backwater areas of river system cause suspended sediment to settle and cause sedimentation problems as illustrated in Figure 3.119 near Muda Dam (REDAC 2006).

Figure 3.119 Sediment dredging near Muda Dam [137]

The processes involved in the stream channel eventually increase the load carried by the river in solute, suspended and bed material form. The selective transport of sediment may be explained as follows: firstly, sediment is actively sorted during transport and; secondly, different components of the stream sediment are in equilibrium with different flow condition. Extreme events are also important in shaping a river channel. In fact, the greatest geomorphic process usually occurs during such times. New channels may be scoured alternately with infills of old one coupled with extensive erosion of river banks in most cases. Ultimately, the deposition of sediments within the stream channel is associated with the formation of a variety of sedimentary structures and bedforms.

c) Sand Mining

Sand extraction from a waterway or sand mining can only be viewed favorably in terms of providing construction material, and the potential benefit to flood mitigation of an enlarge waterway. Sand mining should not be allowed when the sand extraction exceeds the upstream sediment supply of a river. Sand mining should only be considered in places where there is an accumulation of sediment or riverbed aggradation. The benefits to flood mitigation, however are questioned given the fact that rivers, e.g. Sg. Muda, have been known to cause excessive flooding despite excessive sand mining (REDAC 2006)[137].

Figure 3.120 Example of in-stream sand mining (left) and riverbed degradation (right) at Sg. Muda [137]

Minimizing the negative impacts of sand abstraction requires a detailed understanding of the response of the channel to sand mining activities. In general, such information on Malaysian rivers is still very scarce. Hence, quantitative prediction of channel changes is difficult. Current DID guidelines for sand extraction are found in "Garis Panduan untuk Memproses dan Menetapkan Syarat-syarat Pengambilan Pasir Sungai". These guidelines enlist the conditions to be complied with by the operators when they carry out sand mining operation in the rivers.

As shown in Figure 3.120, sand mining on the Muda River (REDAC 2006)[137] can cause major problems to rivers, specifically in the cases where extraction exceeds natural replenishment. The deleterious consequences of sand mining include:

- significant river bed degradation that alters the main functions of rivers;
- river bank instability and excessive bank caving;
- major instability problems at river bridge crossings including excessive scour around bridge piers, bridge abutments and irrigation canal intakes;
- the lowering of the water surface requires pumping water stations to supply water to irrigation canals;
- salinity problems and salt-water intrusion at low flows near the river mouth; and
- sand mining also increases the turbidity of the water which has a negative impact on water quality and aquatic habitat.

In-stream sand and gravel mining in rivers should be gradually reduced and eventually stopped. Other sources of sand and gravel should be preferable. For instance, off-stream sand and gravel mining operations on the river flood plains should be far less damaging to the river environment. The sand and gravel borrow areas within the river corridor could eventually be turned into wet detention storage areas that would be beneficial to the attenuation of flood waves during large floods, and also meet the double objective of providing wetlands for aquatic species. Off-stream sand and gravel mining offers an alternative to current practices that could be very welcome in a way that would: (1) decrease water turbidity; (2) enhance fisheries; (3) increase the stability of bridges and other river structures; (4) circumvent the need for estuary barrages to prevent salt-water intrusion; (5) limit the need for pumping stations at irrigation canal intakes; and (6) provide recreational and environmental areas in the broad river corridor.

3.6.7.5 Water Quality and Waste Water

There is a wide variety of water quality problems, which can affect the rivers. Six ecologically important categories of water quality problems are (Land Water Resources Research and Development Corporation (2000)[139]:

- turbidity and fine sediment that will restrict the area where photosynthesis can occur, clog the gills and guts of animals, and smother the stream bed;
- nutrients that under certain environment conditions, will lead to nuisance plant growth, and in extreme cases eutrophication;
- low dissolved oxygen that will cause the suffocation of stream organisms;
- high and low temperature affect dissolved oxygen levels and the metabolism of stream fauna;
- salinity can be toxic to stream organisms and reduces dissolved oxygen concentrations; and
- toxicants, a large group of toxic materials that include heavy metals, oils, pesticides and herbicides, and a large variety of naturally occurring and synthetic chemicals used in fuels, manufacturing, and just about anything else one can think of.

Many river systems in Malaysia are either slightly polluted or heavily polluted due to partially and non-treated disposal of domestic sewage, soil erosion, industrial effluents and solid waste (Land Water Resources Research and Development Corporation (2000)[139]. In order to identify strategies and programs for water quality improvement for any river, a load assessment and water quality modeling study should be carried out. Among the water quality parameters to be assessed are Ammonia-Nitrogen, Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO). The objectives are to achieve a desired water quality standard such as of Class III and IIB of the INWQS with respect to BOD, ammonia and dissolved oxygen.

The main government departments responsible for managing various aspects of river water are the Department of Environment (DOE), the Department of Irrigation and Drainage (DID) and the relevant local authorities. However, currently the DOE plays the major role in water quality management with respect to emission control, licensing, monitoring, etc. Other authorities administer regulations, which influence water quality, include the Town and Country Planning Department. Although there is no obvious overlapping of roles, there could be lack of awareness of effects of poor water quality in rivers basin. To ensure river water quality is maintained and improved, concerted efforts and coordination by all of these organizations is needed. Hence a strong Integrated River Basin Management (IRBM) organization is required to maintain and improve water quality in river basin.

The sources of pollution in river basins may be categorized into 'point' or 'non-point' or diffused sources [38]. Point sources, so named due to its discrete locations, are relatively easy to identify and control. Non-point sources are in less discrete sites such as farms, forests and urban areas where pesticides, herbicides and fertilizers applied to fields, as well as residues from roads, are washed into receiving waters by rain, contributing to the pollution loads in the rivers.

a) Point Source Pollution

Some point sources in river basin area are as follows:

- *Industrial Effluent* – In many cases, even when wastes from these industries are treated, large quantities of organic and inorganic wastes still enter surface waters because of partial or ineffective treatment at site. Industrial effluents from illegal factories and workshops were discharged into the river system without any prior treatment and these had led to the deterioration of water quality in the river systems in river basins.
- *Animal Wastes* - Animal farming such as pig farming poses a serious threat to water quality downstream where the farms are largely located. Their existence has given rise to serious

organic pollution in receiving waters due to inadequate effluent treatment by the farmers. Even with holding ponds for solid waste retention in the farms, the wastes are not treated and therefore pollute the waters downstream. Other animal husbandry activities include cattle and poultry farming which also contributed to the poor water quality of rivers. Untreated effluents from these farms contribute a substantial increase in Ammoniacal Nitrogen (AN), *E.coli*, BOD, COD and SS.

- *Sand Mining Activities* – The increase in total suspended solids in some rivers is due to sand mining activities. Sand mining activities interfere with light penetration in the waters and thus directly affect photosynthesis and the feeding efficiency of aquatic organisms. Sedimentation reduces the complexity of benthic habitat at macro and micro scales and thus affects the aquatic ecosystem of the rivers in the basins.
- *Solid Waste* – Non-liquid and non-gaseous waste generated especially from squatter settlements and markets (e.g. Figure 3.121).
- *Sewerage Discharge* – In some rural areas within the river basins, some villagers still use inefficient sewerage systems such as the traditional pour and flush toilet which discharges raw sewage into the rivers. Sewerage treatment plants serving urbanized areas are another source of sewage pollution when the system fails or becomes inefficient. Again partially treated effluents from these facilities have high concentrations of E.coli, BOD and AN.

Figure 3.121 Squatter communities along Klang River bank

b) Non-Point Source Pollution

Non-Point Source (NPS) pollution comes from many diffused sources. NPS pollution is caused by rainfall, which having passed through the surface of the land or through the soil carries with it the nutrients and leached material as runoff. As the runoff flows, it picks up more natural and human induced pollutants, pesticides and fertilizers, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. Some examples of NPS pollution are:

- *Agricultural Runoff.* Paddy fields, oil palm plantations, rubber plantations and other agricultural and farming activities dominate the landscape of many river basins. Due to the extensive application of agro-chemicals in these plantations, many undesirable chemical residues are washed into inland and coastal waters posing surface and groundwater contamination, which is not easily amenable to conventional treatment.
- *Land Development.* The opening up of lands for agricultural, urban and industrial development has caused a lot of soil erosion in the river basins.
- *Saltwater Intrusion.* Some estuaries experience an extremely high range of salinity fluctuation. During dry periods, salt wedge will penetrate further upstream especially during high tides. Saline intrusion has been identified as one of the threats to paddy plant and water supply intake points near coastal area. The problem has caused relatively low crop yields at paddy plots and interrupted supply of river flow to water supply treatment plant.

Pollutants such as heavy metals, pesticides and herbicides pose health hazards to human beings and aquatic life. Consumption of fish, shrimps, prawns or cockles containing heavy metal may result in disturbed reproduction rates and life span. Pesticide and herbicide contamination may lead to death or chronic long-term illness in humans as well as impairing the fertility and development of both humans and aquatic fauna.

The main control tool in managing point and non-point sources pollution is legislative control. In Malaysia, legislative control of water pollution focuses primarily on point source pollution, notably sewage treatment plant and factories. Local authorities in the various States are directly responsible for the implementation of central government policies and programmes on pollution control and abatement. In order to control sources of pollution, regular inspections by enforcement agencies to check on compliance to the various acts and regulations have to be conducted.

Permits for sewage discharge are given by DOE based on environmental impact assessments (EIA), which include license conditions, such as discharge limits, monitoring and frequency parameters, and reporting. Regular reporting is required by licensed Sewerage Treatment Plants (STP) or Waste Water Treatment Plant (WWTP). Permission is given to discharge effluents of Standard A or Standard B depending on whether the water is taken for portable water supply. No specific evaluation of river capacity to carry pollution is normally taken. The standard is sufficiently restrictive to obtain desired water quality objectives. Through the reporting requirements for issued effluent licenses and DOE's own investigations, DOE may take appropriate action in case of non-compliance. In view of pollution from discharges of poorly treated STPs still prevail as can be seen in the Klang River system, more stringent counter-measures are needed if river water quality is to be improved.

For sites without WWTP, spillage from wastewater and floor washing usually end up in drains (e.g. from repair shops and dry factories). Terraced industrial lots, which are meant for dry operations only, have been found to carry out substantial wastewater wash downs into the drainage system. The wastewater then flows into the river system. Settlement tanks that are not regularly desludged would not properly perform their function as solid removal and consequently influence the river water quality. Regular desludging and proper treatment of the dislodged material needs to be done to address this problem.

Regular Water Quality monitoring is required in the river system to provide valuable information on the changes in environmental condition of the river. Water quality in river systems can be improved through pollution load reduction, institutional and legal strengthening, monitoring and public awareness. Domestic non-point load and existing loads from squatter settlements need to be reduced by ensuring effluent is diverted through septic tanks or other local treatment facilities. This approach will reduce loadings into the river systems until resettlement is fully implemented. Monitoring and enforcement, licensing procedures and management of the pollution load and water quality improvement are required for point-source pollution. Awareness and information campaigns to reduce non-point source pollution in general and especially at night markets, stalls, restaurant areas and workshops are to be coordinated together with the introduction of infrastructure facilitating a proper handling of the discharges, and issuance of fees and fines among the measures.

3.6.7.6 Solid Waste

Waste generation rates continue to increase in Malaysia resulting from increased use in residential, commercial, institutional and industrial activities. In 2005, about 7.34 million tones of solid wastes were generated in Malaysia, and expected to reach 30,000 tons per day in 2020. The rate varies according to the type of waste generators and landuse. On the composition of solid waste, it is estimated that about 45% of the waste is made up of food waste, 24% of plastic, 7% of paper, 6% of iron and glass and others made of the rest. The average per capita generation rate in urban areas is estimated between 0.5 – 0.8 kg/cap/day. Malaysia's solid wastes contain a very high organic component and consequently have high moisture content and a bulk density of about 200kg/cu.m. Current solid waste management practices within the country are unable to provide comprehensive coverage. As a consequence, considerable quantities of solid waste may be disposed illegally and outside designated disposal sites (DID 2005 : DHI, SMEC and Dr. Nik & Associates)[133].

The growing industrialization and urbanization of the country have been accompanied by a rapid increase in solid waste generation, which has to be managed by an appropriate waste collection and disposal system. Many parts of the community including squatter communities, particularly along the river courses, are poorly serviced by rubbish collection services.

Rubbish which is indiscriminately disposed of finally ends up in storm drains and rivers. Another major source of solid waste in rivers appears to be the illegal dumping of industrial, commercial and construction waste. General street litter also constitutes a major portion of this problem as it is washed or blown into open stormwater drains.

The main reason for the large amount of river solid waste can be mainly attributed to the lack of education and awareness in environmental consciousness, inadequate collection services and facilities, insufficient economic incentives and the absence of adequate licensing and enforcement.

Solid waste, which is deposited in the waterways and drains by any mechanism, is defined as River Solid Waste (Figure 3.122). For example in the Klang River Catchment, approximately 80% of the Non-collected solid waste ultimately enters the river system. In addition to this solid waste load, it is estimated that for every 100 tonne of waste collected and disposed of at landfill sites, 5 tonne (5%) of waste is collected and then dumped into the Klang River system illegally every year.

Figure 3.122 River solid waste collected at log-boom (Sg. Klang)

The effects of waste in the river system are wide ranging that include:

- High cost of removing waste from the rivers and tributaries;
- Degradation of water quality through organic and inorganic contaminants such as food scraps, heavy metals, oils and grease, and toxic substances. Introduced bacteria may affect human health and cause unacceptable risks to the environment;
- Diminishing the aesthetic appeal of waterway covering the river beds and displaying waste throughout the waterway;
- Increase flooding risks through increased resistance to flow and reduced cross-section areas through plugging and choking within the waterways;
- Causing damages to structures such as plugging water intakes, culverts and bridges openings;
- Posing physical hazards to flora and fauna, e.g. fish caught in plastic bags, mammal stomachs filled with trash and plastic; and
- Foul smell due to decomposition of waste.

The consequences of the effects outlined above are considered to be significant that include:

- Increased health risk through contamination of water;
- Environmental problems such as loss of bio-diversity and river erosion;
- Loss of income from tourism industry;
- Significant economic cost through increased flood levels; and
- Loss of public amenity by reducing the recreational value of the river system.

Currently river solid waste is trapped by a range of different devices including:

- Trash screens in drains and small tributaries, removing submerged and floating river solid waste; and
- River booms for trapping floating waste.

The most noticeable river solid waste to the human eye is the floating waste which can be trapped using trash-boom. Screening and solid waste trapping could capture a significant portion of the river solid waste. As a large percentage of the solid waste entering the river system will not float or float just below the water surface, capturing this submerged river solid waste soon after it has entered the waterway increases the total removal rate of waste significantly. Removing wastes may minimise the impact on water quality and improves the aesthetics of the river. However, it does not remove non-solids such as oils, greases, chemicals and dissolved pollutants. In the long term, this is considered uneconomical and impractical. Therefore, it is very important therefore to minimise the quantity of solid waste entering the river system at its source rather than removing the waste after it has entered the river system.

3.7 REHABILITATION IMPLEMENTATION MONITORING and MAINTENANCE MANAGEMENT

3.7.1 Rehabilitation Implementation

Implementation is a critical component of the stream corridor rehabilitation process. It includes all the activities necessary to execute the rehabilitation design and achieve rehabilitation goals and objectives. Where the implementation of rehabilitation measures goes beyond just removing disturbance factors and taking other passive approaches that allow the stream corridor to restore itself over time, technical considerations relating to site preparation, site clearing, construction, inspection, and maintenance are required (Stream Corridor Restoration – Principles, Processes, and Practices, 2001)[141].

3.7.1.1 Site Preparation

Site preparation is the first step in the implementation of rehabilitation measures. Preparing the site requires that the following actions be taken (Watson et al. 2005)[142].

Delineating Work Zones

The work zone for rehabilitation is determined most fundamentally by the features of the landscape that must be affected to achieve rehabilitation goals. Boundaries of property ownership, special restrictions imposed, and natural or cultural features that might have special significance can also determine the extent of the work zone. The delineation of those zones in the field should be the first activity conducted on the site. The zones should be marked by visible stakes and more preferably by temporary fencing. Such delineation will provide a clear demarcation of limits of work to all parties involved in the rehabilitation activities and reduce related disputes on site.

Preparing Access and Staging Areas

A site is often accessed from a public road in an upland portion of the stream corridor site. Ideally, for convenience, a staging area for workmen, equipment, and materials can be located near an access road close to the rehabilitation site but out of the stream corridor. The staging area should also be out of view from public thoroughfares, if possible, to increase security. The access road and staging area should be sited away from sensitive wildlife habitat and endangered species besides having proper drainage, wash-troughs for vehicles, and proper maintenance of all existing facilities.

Taking Precautions to Minimize Disturbance

Every effort should be made to minimize and, where possible, avoid site disturbance. Emphasis should be placed on addressing protection of existing vegetation and sensitive habitat, erosion and sediment control, protecting air and water quality, protecting cultural resources, minimizing noise, and providing for solid waste disposal and worksite sanitation.

Protection of Existing Vegetation and Sensitive Habitat

Fencing can be effective to ensure protection of areas within construction sites that are to remain undisturbed (e.g. vegetation designated to be preserved, sensitive terrestrial habitat, or sensitive wetland habitat). As in delineating work zones, fencing should be placed around all protected areas during initial site preparation, even before the access road is fully constructed, if possible, but certainly before wholesale earthmoving begins. Fencing material should be prominent, and areas should be labeled as protection areas. Regular inspection and repair of fencing should be conducted.

Erosion

Many well-established principles of effective erosion and sediment control measures have been readily discussed. When applied to stream corridor rehabilitation, every effort should be made to prevent erosion because prevention is always more effective than the removal of sediment particles in runoff. Erosion and sediment control measures should be installed during initial site preparation. The most basic method of control is to reduce the flow velocity of surface runoffof the areas to remain undisturbed. Properly chosen, installed, and maintained sediment control measures can provide a significant degree of filtration for sediment-bearing runoff. Where undisturbed areas lie downslope of implementation activities, one method of controlling sediment is the use of a silt fence (Figure 3.123), which is normally made of filter fabric. Silt fences can provide a significant degree of filtration for sediment-bearing runoff, but only if correctly chosen, installed, and maintained.

Figure 3.123 Silt fence at a construction site. Properly chosen and installed silt fences can provide a significant degree of upland sediment control [24]

Water Quality

Although sediment is the major source of water quality impairment on construction sites, it is not the only source. Motorized vehicles and equipment or improperly stored containers can leak petroleum products. Vehicles should be steam-cleaned off site on a regular basis and checked for antifreeze leaks and repaired. (Wildlife can be attracted to the sweet taste of most antifreeze and poisoned.) Various other chemicals such as fertilizers and pesticides can be washed off by rain. Most of these problems can be minimized or avoided entirely by thoughtful siting storage areas for chemicals and equipment and staging areas. Gradients should not favor rapid overland flow from these areas into adjacent streams and wetlands. Distances should be as great as possible and the intervening vegetation as dense as site traffic will allow.

Occasionally, implementation activities will require the entry or crossing of heavy equipment into the stream channel (Figure 3.124). Construction site planning and layout should always seek to avoid these intrusions. When these intrusions are absolutely necessary, they should be infrequent. In addition, any equipment used in these activities should be thoroughly steam-cleaned prior to stream entry.

Figure 3.124 Heavy equipment. Avoid heavy equipment in stream channels unless absolutely necessary [24]

Using Appropriate Equipment

Standard earthmoving and planting equipment is appropriate for most rehabilitation work. Small channels or wetland pool areas can be excavated with backhoes or track-mounted excavators. The latter can be more mobile over rough or steep terrain (Figure 3.125). They also have adequate reach and power to work at a distance from the stream channel and are able to maneuver individual rocks and logs with remarkable precision.

Figure 3.125 Track-mounted excavator in operation at a slope protection site (Sg. Kerayong).

Where access is good but the riparian corridor is intact, instream modifications can be made with a telescoping crane. This equipment comes in a variety of sizes. A fairly large, fully mobile unit can extend across a riparian zone 30m wide to deliver construction materials to a waiting crew without disturbing the intervening ground or vegetation. Where operational constraints permit their use, bulldozers and scrapers can be very useful, particularly for earthmoving activities that are absolutely necessary to get the job done. In addition, loaders are excellent tools for transporting rocks, transplanting large plants, and digging and placing sod.

For planting, tractors with mounted disks or harrows are generally suitable for use unless the ground is extremely wet and soft. Under these circumstances, light-tracking equipment with low-pressure tires or rubber tracks might work. Seeds planted on rehabilitation sites are commonly broadcast by hydroseeding, requiring a special tank truck with a pump and nozzle for spraying the mixture of seeds, fertilizer, binder, and water (Figure 3.126). Where access is limited, hand planting might be resorted to.

Figure 3.126 Hydroseeding of a bank slope. Special tank trucks carrying seed, water, and fertilizer can be used in revegetation efforts.

3.7.1.2 Site Clearing

Once the appropriate construction equipment has been acquired and site preparation has been completed, any necessary site clearing can begin. Site clearing involves setting the rehabilitation work limits, removing undesirable plant species, addressing site drainage issues, and protecting and managing desirable existing vegetation.

Rehabilitation Work Limits

Site clearing should not proceed unless the limits of activity have been clearly marked in the field. Where large trees are present, each should be marked with colored and labeled flagging to ensure that the field crew understands what is to be cut and what is to remain and be protected from damage.

Removal of Undesirable Plant Species

Undesirable plant species include non-native and invasive species that might threaten the survival of native species. Undesirable plants are normally removed by mechanical means, but the specific method should be tailored to the species of concern as far as possible. For example, simply cutting the top growth might be adequate management for some plants, but others might resprout rapidly. Where herbicides are selected (and permitted), their use might need to precede clearing of the top growth by up to 2 weeks to allow full absorption of certain chemicals used for this purpose. For initial brush (bushes, shrubs etc.) removal, a variety of track-mounted and towed equipment is available. Hand clearing with portable tools might be the only appropriate method in some sensitive or difficult areas.

Protection and Management of Existing Vegetation

Protecting existing vegetation on a rehabilitation site requires a certain degree of attention and advanced planning. An area on a site plan that is far from all earthmoving activity might appear to the site foreman as the ideal location for parking idle equipment or stockpiling excess soil. Only a careless minute with heavy equipment, however, can reduce a vegetated area to churned earth. Vegetation designed for a protection zone should be clearly marked in the field.

Existing vegetation might also require temporary protection if it occupies a part of the site that will be worked, but only late in the implementation sequence. Before that time, it is best left undisturbed to improve the level of overall erosion control. In this case, clearing should be phased and this requirement must be specified in the contract documents.

3.7.1.3 Installation and Construction

Following site preparation and clearing, rehabilitation installation activities such as earthmoving, diversion of flow, and the installation of plant materials can then proceed.

Earthmoving

Fill Placement and Disposal

How and where fill is placed on a site should be determined by the final placement of rehabilitation measures. Where plants will be the final treatment of a fill slope, the requirements for soil materials and compaction are not as severe. However loose soil on a steep slope is still prone to erosion or landslide. Where fill is to be placed on slopes steeper than about 2:1, a geotechnical engineer should determine whether any special measures are required (Figure 3.127). Even on gentler slopes, surface runoff from above should not be allowed to saturate the new material since the stability of non-compacted fills is generally quite low.

To reduce grading expenses, the cut and fill should be balanced so no material needs to be transported to or from the site. If the volume of material resulting from cuts exceeds that from fills, some of the soil must be disposed of off-site. Disposal sites can be difficult to locate and require additional transportation costs. Earthworks should be planned well in advance to avoid unanticipated delays during implementation. As a general rule, topsoil removed from the site should be properly stockpiled for reuse during the final stages of implementation. Even if undesirable species are present, the topsoil will provide a growth medium suitable for the plant community appropriate to the site. It will also be a source of native species that can reestablish the desired diversity most rapidly.

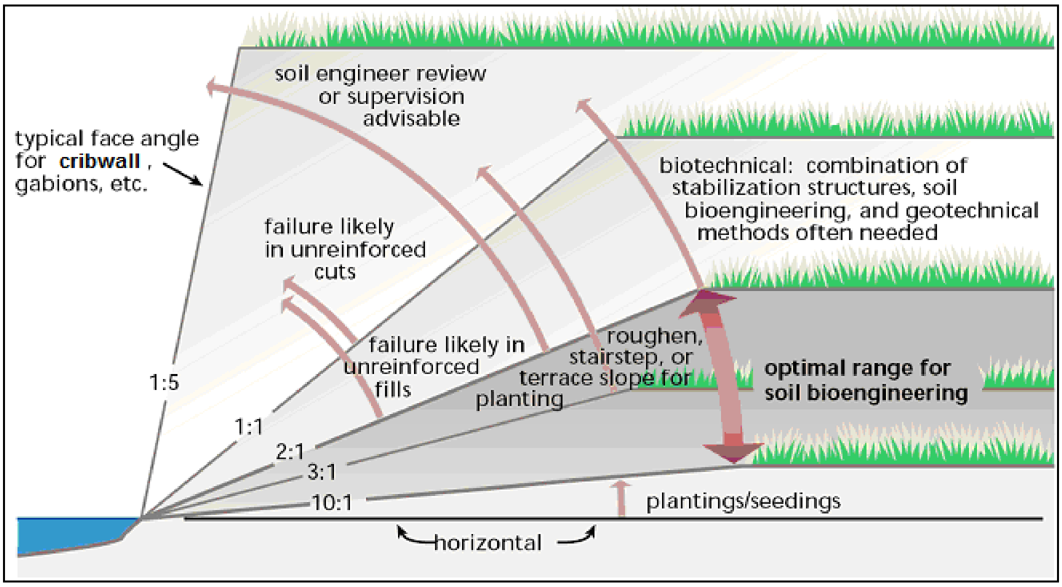


Figure 3.127 Treatment of cuts and fills. Slope gradient is an important factor in determining appropriate rehabilitation measures [24]

Contouring

The overall topography of the graded surface should be designed to minimize the uncontrolled flow of runoff in the graded direction. Channelized flow should be diverted to ditches cut into the soil that more closely follow the level contours of the land. Dispersed sheet flow should be broken up by terraces or benches along the slope that also follow topographic contours.

Final Grading

Earthmoving should result in a slope that is stable, minimizes surface erosion by virtue of length and gradient, and provides a favorable environment for plant growth. Where plans specify a final slope gradient steeper than about 1:1, however, vegetation reestablishment will be very difficult, and a combination of stabilization structures, soil bioengineering, and geotechnical methods will probably be necessary. The shape at the top of the slope should have a rounded edge, forming a gradual transition between upland and slope suitable for plant growth.

Rough-textured slopes, resulting from vehicle tracks or serrated blades, provide a much better environment for seedlings than do smooth-packed surfaces (Figure 3.128). Small terraces should be cut into slopes steeper than about 3:1 to create sites of moisture accumulation and enhanced plant growth. Compaction by excessive reworking from earthmoving equipment can result in a lower rate of rainfall infiltrating the soil and, consequently, a higher rate of erosive surface runoff. The result is a loss of topsoil needed to support plant growth and less moisture available for remaining plants.

Figure 3.128 Track-roughened area. Rough-textured slopes providea much better environment for seedlings than do smooth packed surfaces [24]

Diversion of Flow

Channelized flow (from stream channels, ditches, ravines, or swales) might need to be diverted, impounded, or otherwise controlled during implementation of rehabilitation measures. In some cases, this need might be temporary, until final grading is complete or plantings have become established. In other cases, the diversion is a permanent part of the rehabilitation. Permanent facilities which frequently replace temporary measures at the same location are often constructed of different and more durable materials.

Temporary dikes, lined or grassed waterways, or pipes can be used to divert channelized flow. Runoff can also be impounded in ponds or sediment basins to allow sediment to settle out. Most temporary measures are constructed from materials at hand. Dikes (ridges of soil up to a meter high) are constructed to achieve some stability and are sometimes armored to resist erosion.

Pipes or lined ditches can carry channelized water down a slope that is steep enough to otherwise suffer erosion (Figure 3.129); they can also be used to halt erosion that has already occurred from uncontrolled discharges. Sediment ponds and traps are basins either dug into the soil with a rock-armored overflow or impounded by an embankment with an outlet. A fraction of the sediment carried by the site runoff will settle out in the trap, depending on the ratio of surface area or storage volume to inflow rate.

Figure 3.129 Lined ditch to intercept runoff on slope

Plant Establishment

Plant establishment is an important part of most rehabilitation initiatives that require active rehabilitation. Native species should be used where possible to achieve the rehabilitation goals. Vegetation can be installed by seeding; planting vegetative cuttings; or using nursery-grown barerooted, potted, and burlap-wrapped seedlings. If natural colonization and succession is appropriate, techniques may include controlling exotic species and establishing an initial plant community to hasten succession.

Timing

The optimum conditions for successful plant installations vary from site to site. As a general rule, temperature, moisture, and sunlight must be adequate for germination and establishment. Survival is influenced by species used and how well they are matched to site conditions, available moisture, and time of installation. In the local climate, the growth of roots occurs throughout the year, except during intervening dry spells. In any case, supplemental irrigation is usually needed after planting to ensure successful establishment of vegetation.

Acquisition of Plants

Native plant species are preferable over exotic ones, which might result in unforeseen problems. Some plant materials can be obtained from commercial sources, but many will need to be collected. When attempting to restore native plant communities, it is desirable to use appropriate genotypes. This requires the collection of seeds and plants from local sources. Early contact with selected sources of rooted stock and seed can ensure that appropriate species in adequate quantities will be available when needed.
The site itself might also be a good source of salvageable plants. Live cuttings can be collected from healthy native vegetation at the donor site. Sharp, clean equipment must be used to harvest the plant material. Vegetation is normally cut at a 40 to 50 degree angle using loppers, pruners, or saws. If the whole plant is being used, the cut is made about 250 mm above the ground, which encourages rapid regeneration in most species. Cuttings typically range from 10 to 50 mm in diameter and 0.6 to 2 m long.

Transportation and Storage

The requirements for the transport and storage of plant materials vary, depending on the type of material being used. Depending on species, seeds may require a minimum period of dormancy of several weeks or months. Some seeds may also require scarifying or other special treatment. Nurseries that specialize in native plants are recommended because they should be cognizant of any special requirements.

Although the necessary information for any chosen species should be readily available from local seed sources or agricultural extension offices, the timing for procurement must be recognized and accounted for in planning the planting schedule. Live cuttings present rather severe limitations on holding time. Thus, donor sites must be close to the rehabilitation site, and access and transportation must be well coordinated to coincide with the correct stage of construction.

Rooted stock is also prone to drying, particularly if pots or burlap-wrapped roots are exposed to direct sun. Onsite storage areas should be chosen with ample shade for pots. Bare-rooted or burlap-wrapped stock should be heeled into damp ground or mulch while awaiting final installation.

Planting Principles

The specific types of plants and plant installations are generally specified in the construction plans and therefore will have been determined long before implementation. A project manager or site supervisor should also know the basic installation principles and techniques for the area.

The type of soil used should be determined by the types of plants to be supported. Ideally, the plants have been chosen to match existing site conditions, so stockpiled topsoil can be used to cover the plant material following layout. However, part of the rehabilitation of a severely disturbed site might require the removal of unsuitable topsoil or the import of new topsoil. In these situations, the requirements of the chosen plant species should be determined carefully and the soil procured from suitable field sites that have no residual chemicals and undesirable plant species. When using seeds, planting should be preceded by elimination of competing plants and by preparation of the seedbed. The most common methods of seeding in a rehabilitation setting are hand broadcasting and hydroseeding. Hydroseeding and other methods of mechanical seeding might be limited by vehicular access to the rehabilitation site.

When using either cuttings or rooted stock, the soil and the roots must make good contact. This requires some compaction of the soil, either by foot or by equipment, to avoid air pockets. Another aspect to consider is that quite frequently after seeding, the resulting soil is too rough and loose to support vigorous seed growth. The roughness promotes rapid drying, and the looseness yields poor seed-to-soil contact and also erratic planting depths. As a result, some means of compaction should be employed to return the soil to an acceptable state for planting.

Competing Plants

Although a well-chosen and established plant community should require no human assistance to maintain vigor and function, competition from other plants during establishment might be a problem. Competing plants commonly do not provide the same long-term benefits for stability, erosion control, wildlife habitat, or food supply. The rehabilitation plan therefore must include some means to suppress or eliminate them during the first year or two after planting.

Competing plants may be controlled adequately by mechanical means. Cutting the top growth of competing plants can slow their development long enough for the desired plants to become established. Hand weeding is also very effective, although it is usually feasible only for small sites or those with an ongoing source of volunteer labor.
Unfortunately, some species can survive even the most extreme mechanical treatment. They will continue to reemerge until heavily shaded or crowded out by dense competing stands. In such cases the alternatives are limited. The soil containing the roots of the undesired vegetation can be excavated and screened or removed from the site, relatively mature trees can be planted to achieve near-instantaneous shading.

Irrigation

In any rehabilitation that involves replanting, the need for irrigation should be carefully evaluated. Irrigation might not be needed in wetland and near-stream riparian sites or during rainy seasons. Irrigation may be essential to ensure success on upland sites during the drier months of the year. Initial costs are lowest with a simple overhead spraying system. Spray systems, however, have inefficient water delivery and have heightened potential for vandalism. In some suitable sites, drip-irrigation system may provide as an alternative.

3.7.1.4 Inspection

Frequent, periodic inspection of work, whether done by a landowner, contractor, volunteer group, or government personnel, is mandatory. Defects such as poor planting methods, stressed plant materials, inadequate soil compaction, or sloppy erosion control, may become evident only weeks or months after completion of work unless the activities on the site are regularly reviewed. Some of those activities may require specialized testing, such as the degree of compaction of a fill slope. Most require little more than observations by an inspector familiar with all elements of the design.

In the case of contracted work, it is the responsibility of the construction supervisor to monitor installation activities to ensure that the contractor completes work according to the contract plans and specifications. At key points during construction, the supervisor should consult with clients and design team(s) for assistance. The inspector should create comprehensive documentation of the construction history in anticipation of any future audit or quantity dispute.

On-Site Inspection Following Installation

The final inspection after installation determines the conditions under which the contractor(s) can be paid and the contract finalized. It must occur promptly and should determine whether all elements of the contract have been fulfilled satisfactorily. Before scheduling this final inspection, the project manager and inspector, together with any other necessary members of the rehabilitation team, inspect the work and prepare a list of all items requiring completion by the contractor. This "prefinal" inspection is in fact the most comprehensive review of the work that will occur, so it must be conducted with care and after nearly all of the work has been completed. The final inspection should occur with representatives of both the client and the contractor present after completion of all required work and after site cleanup, but before equipment is removed from the site to facilitate additional work if necessary. A written report should state the complete or provisional acceptance of the work, the basis on which that judgment has been made, and any additional work that is needed prior to final acceptance and payment. For more details on construction supervision, reference may be made to Vol. XI-"Construction Management" of the Manual.

Follow-up Inspections

Planning for successful implementation should always look beyond the period of installation to the much longer interval of plant establishment. Twelve or more additional site visits are advisable over a period of about two years. If they are included in the specifications, they may be the responsibility of the contractor. A sample inspection schedule is shown in Table 3.19.

Table 3.19 Sample inspection schedule

Time since Installation	Inspection Interval
2 Months	2 weeks (4 total)
6 Months	1 month (5 total)
2 Years	6 month (3 total)

Documentation of follow-up inspections can include standard checklists, survey data, cross sections, data sheets, data summaries, and field notes. Sketches, maps, and permanent photo points can be used to document vegetation development. Video recordings can be particularly useful to document the performance of structures during various flows, to illustrate wildlife use and floodplain storage of floodwaters, and otherwise to record the performance and functions of the corridor system.

Problems discovered in the inspection process should be documented in a report that details deficiencies, recommends specific maintenance, and explains the consequences of not addressing the problems. Consequently, the reporting and response loop should be simple and direct so that inspections indicating the need for replanting and emergency structural repairs can be reported and resolved without delay. An example of a fully rehabilitated stream is as shown in Figure 3.130.

Figure 3.130 Rehabilitated Stream

General Inspection

To the extent feasible, the entire stream corridor should be inspected annually to detect areas of rapid bank erosion or debris accumulation. A general inspection can also identify inappropriate land uses, such as encroachments of roads near banks or uncontrolled irrigation water returns, that might jeopardize rehabilitation measures, affect water quality, or otherwise interfere with rehabilitation objectives. The integrity of fences, water access, crossings, and other livestock control measures should be inspected.

Bank and Channel Structures

Special inspections should be conducted following high flows, particularly after the first flood event following installation. Soil bioengineering measures should be assessed during prolonged drought and immediately after high flows during the first few years following installation until the system is well established. Most routine inspections of bank and channel measures should be conducted during low-water conditions to allow viewing of the measure as well as channel bed changes that might threaten its future integrity. This is particularly true of bank stabilization works where the principal mechanism of bank failure is undermining at the toe.

Vegetation

Streambanks that have been stabilized using plantings alone or soil bioengineering techniques require inspections, especially in the first year or two after planting (Figure 3.131). It is important that the planted material be checked frequently to ensure that the material is alive and growing satisfactorily. Any dead material should be replaced and the cause of mortality determined and corrected if possible. Any newly established nonnative populations should be eradicated quickly.

Figure 3.131 Revegetated streambank

The effectiveness of bank protection is based largely on the development of the plants and their ability to bind soils at moderate flow velocities. The bank protection measures should be inspected immediately after high-flow events in the first few years, particularly if the plantings have not fully established. Washouts, slumping of geogrids, and similar problems require detection and correction, since they might become the sites of further deterioration and complete failure if left uncorrected.

Floodplain and other off-channel plantings might be important components of the corridor rehabilitation plan as well. Inspection requirements are similar to those on streambank sites but are less critical to the integrity of the project in terms of preventing additional damage. Nevertheless, several site visits are appropriate during the first growing season to detect any problem that may arise.

3.7.1.5 Maintenance

Maintenance encompasses those repairs to rehabilitation measures which are based on problems noted during inspections, are part of regularly scheduled upkeep, or arise on an emergency basis.

- *Remedial maintenance* is triggered by the results of the scheduled inspections (Figure 3.132). The inspection report should identify and prioritize maintenance needs that are not emergencies, but that are unlikely to be addressed through normal scheduled maintenance.
- *Scheduled maintenance* is performed at intervals that are pre-established during the design phase or based on project-specific needs. Such maintenance activities such as clearing culverts or regrading roads can be anticipated, scheduled, and funded well in advance.
- *Emergency maintenance* requires immediate mobilization to repair or prevent damage. It may include measures such as replacement of plants that fail to establish in a soil bioengineered bank stabilization, or repair of a failing revetment. Where there is a reasonable probability that repair or replacement might be required (e.g. anything that depends on vegetation establishment), sources of funding, labor, and materials should be identified in advance as part of the contingency planning process.

Figure 3.132 Remedial maintenance. Soil bioengineering used to repair failing revetment [24]

Various agencies and utilities may have maintenance responsibilities that involve portions of the stream corridor, such as road and transmission line crossings. This work should be coordinated as necessary to ensure there are no conflicts with corridor objectives.

Channels and Floodplains

Corridor rehabilitation that includes reconfiguration of the channel and floodplain may require remedial action if the system does not perform as expected in the first few years after work has been completed. Any repairs or redesign, however, should be based on a careful analysis of the failure. Some readjustment is to be expected, and a continuing dynamic behavior is fundamental to successful rehabilitation. Because establishment of a dynamic equilibrium condition is usually the intent, maintenance should be limited to actions that promote self-sustainability.

Many traditional channel maintenance actions may be inappropriate in the context of stream corridor rehabilitation. In particular, removal of woody debris may be contrary to rehabilitation objectives (Figure 3.133). Appropriate levels of woody debris loading should be a design specification of the project, and the decision to remove or reposition particular pieces should be based on specific concerns, such as unacceptably accelerated bank erosion due to flow deflection, creation of log jams causing an increased chance for flooding, or concerns about safety in streams with high recreational use. In cases where woody debris sources have been depleted, periodic addition of debris may be a prescribed maintenance activity.

Figure 3.133 Accumulated woody debris to be maintained

Protection/Enhancement Measures

Early failure is an inherent risk of soil-bioengineered systems that are not fully effective until the plants are well rooted and the stems reach a particular size and density. Although a design weakness may be identifiable and should be corrected, more often the mechanism of failure will be that the measure has not yet developed full resistance to high-flow velocities or saturation of bank soils. Replanting should be an anticipated potential maintenance need in this situation.

In many stream corridor rehabilitation areas, the intent of streambank and channel measures is to provide temporary stabilization until riparian vegetation develops and assumes those functions. In such cases, maintenance of some structures might become less important over time, and they might eventually be allowed to deteriorate. They can be wholly or partially removed if they represent impediments to natural patterns of channel migration and configuration, or if some components (cables, stone, geofabrics) become hazards.

Vegetation

Maintenance plans should anticipate the need to replant in case soil-bioengineered bank protection structures are subjected to prolonged high water or drought before the plants are fully established. Techniques using numerous cuttings establish successfully, it might be desirable to thin the dense brush that develops to allow particular trees to grow more rapidly, especially if channel shading is a rehabilitation objective. Often, bank protection measures become popular points for people to access the stream (for fishing, etc.). Plantings can be physically removed or trampled. Replanting, fencing, posting signs, or taking other measures might be needed.

3.7.2 Monitoring Techniques for Rehabilitation Evaluation

Monitoring and evaluation help determine whether the design objectives have been met and on-course correction required. They also reveal the need for adjustments to design parameters, installation procedures and/or stabilization methods. Information collected should be made available to other rehabilitation professionals to ensure continued improvement in the field of stream rehabilitation, design and construction. Each stream-rehabilitation project should have a monitoring plan to (Watson et al. 2005)[143]:

- Determine if stabilization and grade-control structures are functioning properly;

- Determine whether on-coarse correction is required;
- Check channel stability by measuring dimension, pattern and profile; particle-size distribution of channel materials; sediment transport; and streambank erosion rates;
- Determine biological response (i.e. vegetation, macroinvertebrates and fish); and
- Determine if the specific objectives of the rehabilitation have been met.

This section examines monitoring from the perspective of evaluating the performance of a rehabilitation initiative. Such initiatives seek to restore the structure and functions discussed in earlier chapters. Designing a monitoring program that directly relates to those valued functions requires careful planning to ensure that a sufficient amount of information is collected. Such monitoring uses measurements of physical, biological, and chemical parameters to evaluate the effectiveness of the rehabilitation and to facilitate adaptive management where needed. Sampling locations, measurements to be made, techniques to be used, and how the results will be analyzed are important considerations in monitoring (Stream Corridor Restoration – Principles, Processes and Practices, 2001)[144].

3.7.2.1 Adaptive Management

The implementation, effectiveness, and validation components of performance monitoring provide a means to determine the need for adaptive management. Adaptive management is the process of establishing checkpoints to determine whether proper actions have been taken and are effective in providing desired results. Adaptive management provides the opportunity for on-course correction through evaluation and action.

3.7.2.2 Implementation Monitoring

Implementation monitoring helps to indicate whether the required rehabilitation measures have been done and done correctly. Evaluating the effectiveness of rehabilitation through physical, biological, and/or chemical monitoring can be time-consuming, expensive, and technically challenging. Time and partnerships are needed to build the capability for evaluating project effectiveness based on changes in ecological condition. Therefore, an important intermediate step to this goal is implementation monitoring. This comparatively simple process of documenting what was done and whether or not it was done properly can yield valuable information that promotes refinement of rehabilitation practices. The results can provide effective guidance for future projects and capacity building.

3.7.2.3 Effectiveness Monitoring

Effectiveness monitoring evaluates success by determining whether the rehabilitation had achieved the desired effect on the ecosystem. Monitoring variables focus on indicators that document achievement of desired conditions and are closely linked with project goals. It is important that indicators selected for effectiveness monitoring are sensitive enough to show change, are measurable, are detectable and have statistical validity. This level of monitoring is more time-consuming than implementation monitoring, making it more costly. To save time and money, monitoring at this level is usually performed on a sample population or portion of a project with results extrapolated to the whole population.

3.7.2.4 Validation Monitoring

Validation monitoring considers assumptions made during planning and execution of rehabilitation measures. This level of monitoring is performed in response to non-achievement of desired results once proper implementation is confirmed. A rehabilitation initiative that fails to achieve intended results could be the result of improper assumptions made in relation to ecological conditions or selection of invalid monitoring indicators.

3.7.2.5 Evaluation Parameters

Physical Parameters

A variety of physical parameters describing channels are appropriate for performance evaluation. The parameters presented in Table 3.20 should be considered for measurement of physical performance and stability. Stream pattern and morphology are a result of the interaction of eight measurable parameters viz. width, depth, channel slope, roughness of channel materials, discharge, velocity, sediment loads, and sediment size (Leopold et al. 1964)[146]. These parameters and several other dimensionless ratios (including entrenchment, width/depth ratio, sinuosity, and meander/width ratio) can be used to group stream systems with similar form and pattern. They have been used as delineative criteria in stream classification. Natural streams are not random in their variation. A change in any of the primary stream variables results in a series of channel adjustments, resulting in alterations of channel pattern and form, and attendant changes in riparian and aquatic habitat.

Table 3.20 Physical parameters as evaluation criteria for measurement of physical performance and stability [63]

Plan view	Sinuosity, width, bars, riffles, pools, boulders, logs
Cross sectional profiles - by reach and features	Sketch of full cross section
	Bank response angle
	Depth bankfull
	Width
	Width/depth ratio
Longitudinal profile	Bed particle size distribution
	Water surface slope
	Bed slope
	Pool size/shape/profile
	Riffle size/shape/profile
	Bar features
Classification of existing streams (all reaches)	Varies with classification system
Assessment of hydrologic flow regimes through monitoring	2-, 5-, 10-year storm hydrographs Discharge and velocity of base flow
Channel evolutionary track determination	Decreased or increased runoff, flash flood flows
	Incisement/degradation
	Overwidening/aggradation
	Sinuosity trend-evolutionary state, lateral migration
	Increasing or decreasing sinuosity
	Bank erosion patterns
Corresponding riparian conditions	Saturated or ponded riparian terraces
	Alluvium terraces and fluvial levees
	Upland/well-drained/sloped or terraced geomorphology
	Riparian vegetation composition, community patterns and successional changes
Corresponding watershed trends-past 20 years and future 20 years	Land use/land cover Land management
	Soil types
	Topography
	Regional climate/weather

Biological Parameters

Biological monitoring can cover a broad range of organisms, riparian conditions, and sampling techniques. In most cases, resources constraints will limit the diversity and intensity of evaluation methods chosen. Analytical methods for evaluating biological attributes are discussed in Section 3.4.2.4 - "Biological Characteristics" of this volume of Manual. Table 3.21 provides an example of the biological attributes of stream ecosystems that may be related to rehabilitation goals. Biological aspects of the stream corridor that may be monitored as part of performance goals include primary productivity, invertebrate and fish communities, riparian/terrestrial wildlife, and riparian vegetation.

Table 3.21 Examples of biological attributes and corresponding parameters for performance evaluation [63]

Biological Attribute	Parameter
Primary productivity	Periphyton
	Plankton
	Vascular and nonvascular macrophytes
Zooplankton/diatoms	
Invertebrate community	Species
	Numbers
	Diversity
	Biomass
	Macro/micro
	Aquatic/terrestrial
Fish community	Species
	Specific populations or life stages
	Numbers
Riparian wildlife/ terrestrial community	Amphibians/reptiles
	Mammals
	Birds
Riparian vegetation	Structure
	Composition
	Condition
	Function
	Changes in time (succession,
	Colonisation, extirpation, etc.)

Biological monitoring programs can include the use of chemical measures. For example, if specific stressors within the stream system, such as high water temperatures and low dissolved oxygen, limit biological communities, direct monitoring of these attributes can provide an evaluation of the performance of more intensive remedial practices, including point source pollution reduction.

Chemical Parameters

Monitoring is necessary to determine if a rehabilitation initiative has had the desired effect on water chemistry. The type and extent of chemical monitoring depends upon the goal of the monitoring program. A factor in designing a chemical monitoring approach is the amount of change expected in a system. For example a small change of say 5% reduction in salinity in a stream would be much more difficult to detect than a goal of reducing salinity by 50%.

Chemical monitoring can often be used in conjunction with biological monitoring. Biological parameters are often good integrators of several water quality parameters. Biological indicators are especially useful when determining the bioaccumulation of a chemical. Water chemistry samples are typically easier to replicate, can disclose slow changes over time, and can be used to prevent catastrophic events when chemical characteristics are near toxic levels. This aspect is useful as some aquatic organisms might not respond to this gradual change until the water becomes toxic. An ideal monitoring program would include both biological and chemical parameters.

Important chemical and physical parameters that might have a significant influence on biological systems include the following:

- Temperature

- Turbidity
- Dissolved oxygen
- pH
- Natural toxics (mercury) and manufactured toxics
- Nutrients
- Organic loading (BOD, TOC, etc.)
- Ammoniacal Nitrogen
- Faecal coliform
- Alkalinity/Acidity
- Hardness
- Total dissolved solids
- Total suspended solids
- Springs and ground water seeps

These parameters may be studied independently or in conjunction with biological measurements of the ecological community.

3.7.2.6 Reference Sites

Understanding the process of change requires periodic monitoring and measurement and scientific interpretation of the information as it relates to the stream corridor. In turn, an evaluation of the amount of change attributed to rehabilitation must be based on established reference conditions developed by the monitoring of reference sites. Reference may be made to Sections 3.4 and 3.5 "Stream Channel Rehabilitation" of this volume of the Manual for a description of reference reaches or sites. Reference sites provide examples of a properly functioning ecosystem. It is from these reference sites that desired conditions are determined and levels of environmental indicators identified. Environmental indicators become the performance criteria to monitor the success of an initiative.

3.7.2.7 Human Interest Factors

Human activities requiring use of a healthy environment may often be important factors for evaluating stream corridor rehabilitations (Figure 3.134). In these cases, the ability of the stream corridor to support the activity indicates benefits drawn from the stream corridor as well as adding insight into stream ecosystem condition. Many human interest-oriented criteria used in performance evaluations can serve the dual function of evaluating elements of human use and ecological condition together:

- Human health (disease, toxic/fish consumption advisories)
- Aesthetics (odor, views, transparency, sound, litter)
- Non-consumptive recreation (hiking, bird watching, whitewater rafting, canoeing, swimming, camping, picnicking, outdoor photography)
- Consumptive recreation (fishing, hunting)
- Research and educational uses
- Protection of property (erosion control, floodwater retention)

Figure 3.134 Human interest in the stream corridor. Aesthetics are a highly valued benefit associated with a healthy stream corridor. (Sg. Endau, Johor).

3.7.3 Rehabilitation Management

Management is the long-term manipulation and protection of rehabilitation resources to achieve the project goals, objectives including sustainability. Management priorities for the stream corridor ecosystem are set during the planning phase and refined during design. These priorities should also be subjected to ongoing revision based on regular monitoring and evaluation. Management needs can range from relatively passive approaches that involve removal of adverse impacts to intensive efforts designed to restore ecosystem functions through active intervention. Rehabilitation management is the collective set of decisions made to guide the entire rehabilitation effort to success (Leopold et al. 1964[146].

Management of a rehabilitation project can be a fairly straightforward process or a complex one if it involves numerous stakeholders (agencies, landowners, and interested citizens). Development of a management plan is less difficult when the corridor and watershed are under the control of a single owner or authority that can clearly state objectives and priorities. More commonly, stream corridor management decisions will be made in an environment of conflicting interests, overlapping mandates and regulatory jurisdictions, and complex ownership patterns, both in the corridor and in the surrounding watershed. Many smaller rehabilitation projects might be similarly diversified with management decisions involving a variety of participants. Participation and adherence to rehabilitation best management practices (BMPs) may be encouraged through various programs.

As rehabilitation is intended specifically to improve the condition of the stream corridor, an activity that is allowable initially might be regulated as the corridor condition improves. These changes should be anticipated to the extent possible in developing long-term management plans.

3.7.3.1 Stream Channel Management

In effect, stream corridor rehabilitation and ongoing monitoring constitute stream management. Many problems detected during monitoring can be resolved by manipulation of the stream corridor vegetation, land uses, where possible, and only occasionally, by direct physical manipulation of the channel. If large scale remedy of the channel system is necessary, it essentially becomes a redesign problem. Where lateral erosion occurs in unanticipated areas and poses an unacceptable threat to function, property, or infrastructure, another rehabilitation approach might have to be initiated (Stream Corridor Rehabilitation – Principles, Processes, and Practices, 2001)[148].

Where streamflow control is an option, it likely will be a significant component of the management plan to maintain baseflows, water temperatures, and other attributes. However, appropriate flow patterns should have been defined during the design phase, with components of corridor management prescribed accordingly. If hydrologic (including climatic) patterns change after the rehabilitation is established, significant redesign or management changes might be required for the entire corridor. Finally, a well-planned and prepared stream corridor rehabilitation design should predict and address the potential for hydrologic/ climatic change.

3.7.3.2 Streamside Forest Management

For streams in forested environments, the planning and design phases of rehabilitation should set specific objectives for forest structure and composition within the stream corridor. If existing forests are developing in the desired direction, no action may be needed. In this case, forest management consists of protection rather than intervention. In degraded stream corridor forests, achieving desired goals requires active forest management. Although stream corridor rehabilitation may accommodate some economic returns from forest management, the basic goal is to rehabilitate and maintain ecological functions. Therefore, reforestation efforts should emulate natural processes that normally occur in the corridor.

Recovery of degraded streamside forests can be encouraged and accelerated through replanting efforts. Streamside forests used as buffers to prevent nutrients from reaching streams may require periodic harvests to remove biomass and maintain net uptake. However, buffers intended to intercept and degrade herbicides might be most effective if they are managed to achieve old-growth conditions.

Management of corridor forests should not proceed in isolation from management of adjacent upland systems (Figure 3.135). Upland harvests can result in raised water tables and tree mortality in riparian zones. Coordinated silvicultural activities can reduce timber losses as well as minimize the need for roads.

Figure 3.135 Streamside forests and adjacent uplands

Forests managed by government agencies are usually subject to established restrictions on activities in riparian areas. Elsewhere, BMPs for forestry practices are designed to minimize nonpoint source pollution and protect water quality. BMPs typically include restrictions on road placement, equipment use, timber removal practices, and other similar considerations. The National Forestry Act 1984, First Schedule (Section 2 (1)) from Jabatan Perhutanan may be referenced for details on requirements of local practices (National Forestry Act 1984 {Act313} & Wood-based Industries Act 1984 {Act 314})[149].

3.7.3.3 Grazed Land Management

Livestock grazing is a very important stream corridor management issue in riparian areas. Uncontrolled livestock grazing, especially from unregulated cattle rearing, can have severe detrimental effects on streambanks, riparian vegetation, and water quality. Livestock naturally concentrate in the vicinity of streams; therefore, special efforts such as harded bed livestock crossing can be made to control access if stream corridor rehabilitation is to be achieved. (Figure 3.136)

(a) (b)

Figure 3.136 Hardened stream-crossing to control livestock access

Complete exclusion of livestock with barriers or fence is an effective approach to rehabilitate and maintain riparian zones that have been badly degraded by grazing. In some cases, exclusion may be sufficient to reverse the damage without additional intervention. In some degraded systems, removal of livestock for a period of years followed by a planned management program may allow recovery without permanent livestock exclusion. Systems not badly damaged might respond to grazing management involving herd size restrictions, off-channel or restricted-access watering, use of riparian pastures, herding, and similar techniques (Figure 3.137). Most states have enactments to regulate livestock grazing. Such acts are generally enforced by Jabatan Perkhidmatan Haiwan Daerah. Working together can achieve the desired objectives more effectively.

Figure 3.137 Fencing to control livestock grazing.

3.7.3.4 Fish and Wildlife Management

Habitat support animal life. It must provide the food, water, cover and other needs of the wildlife species it supports. Wildlife management takes into consideration ecological principles such as carrying capacity of the habitat. Most wildlife management is concerned with the preservation and control of habitat, but other techniques such as reforestation, predator control techniques such as trapping, re-introduction of species or hunting may also be used to help manage "desirable" or "undesirable" species. However, the long-term key to wildlife management lies not in direct control of numbers and populations of animals, but in the provisions of suitable quality habitat.

Accordingly, stream and vegetation care are the focus of many fish and wildlife management activities in the stream corridor. Hunting and fishing activities (Figure 3.138), nuisance animal control, and protection of particular species should be given due attention in the rehabilitated reaches. Numerous fish and wildlife management tools and techniques that address temporary deficiencies in habitat availability should be utilized as appropriate. Inappropriate or haphazard use of some techniques can have unintended detrimental effects. Working closely with the Fishery Department and Department of Wildlife & National Parks is the key towards achieving this objective.

Figure 3.138 Local fisherman. Fishing and other recreational activities must be considered in rehabilitation management.

3.7.3.5 Riparian Human Activity Management

Stream corridors in urban areas are usually used heavily by people and require much attention to minimize, control, or repair human impacts (Figure 3.139). In some cases, human disturbance prevents some stream corridor functions from being rehabilitated. For example, depending on the amount of degradation that has occurred, urban streams might support relatively few, if any, native wildlife species. Other concerns, such as water quality, might be improved through proper rehabilitation efforts. Addressing impacts from surrounding developed areas (such as uncontrolled storm water runoff) requires coordination with local authorities, the residents and citizen groups to minimize, prevent, or reverse damage.

Domestic wastes and bank erosion caused by the presence of illegal squatter communities along the river banks have been a long standing problem. It has been a great challenge to the local authorities to resettle these illegal dwellings. As an interim measure to reduce recolonization after resettlement, the local authorities may issue permits to nursery operators with appropriate conditions including a minimum buffer strips to ensure at least certain amount of care can be given to maintain the riparian vegetation. On the other hand, vegetable cultivation and the like, which involve tilling of soil should be strongly discouraged.

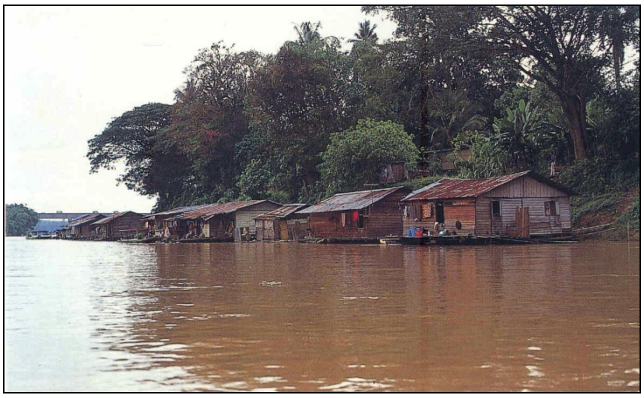


Figure 3.139 Raft dwellings in Sg. Kelantan has been a tradition for centuries.

Management of urban corridors might tend to emphasize recreation, educational opportunities, and community activities more than ecosystem functions. Community involvement can be an important aspect of urban stream corridor rehabilitation and management. Community groups can be initiated into participating in rehabilitation with the prospect of inculcating a feeling of ownership that can subsequently translated into monitoring input, management of oversight, and volunteer labor to conduct maintenance and management activities. It is essential that community groups be provided with adequate professional technical guidance. Inculcating awareness and sense of ownership is an important step towards achieving such objective.

In non-urban areas, recreation can usually be accommodated without impairing ecological functions if all concerned parties consider ecosystem integrity to be the priority objective. Strategies can be devised and techniques employed to minimize impacts from activities such as camping, hiking (trail erosion), boating, etc.

3.7.4 Pre-requisites for Good River Maintenance Management

3.7.4.1 River Database

As mentioned in Section 4.1,"River Information System (RIS)", of this Manual, the multi-objective, multi-discipline and multi-stakeholder nature of river management requires an efficient information system for the archival, updating and retrieval of various types of river information. This will enable morphological, chemical and biological assessments of the rivers to be carried out in an integrated manner and documented for effective long-term decision support provided to the river managers. This has been made possible by the establishment of the River Basin Information System (RBIS) currently being developed by DID. As of now, RBIS has been established for four pilot river basins of Sg. Kuantan, Sg. Muar, Sg. Moyong/Putatan, and Sg. Sarawak.

The capabilities of RBIS include web-based information sharing, differentiated levels of access for agencies and the public, integration with GIS and the most important of all the available data and information for system modeling and timely decision making. The latter is pertinent for forward planning, budgeting and resource allocation for an effective river maintenance program. Once pilot projects have been implemented successfully, they should be replicated to other river basins in the country. A very key factor to success is to ensure the sustainability of the systems. Towards this end, there is a need for a strong and continued commitment in the statutory setup, capacity building, and active participation of the stakeholders.

3.7.4.2 River Conditions Monitoring

The main components for river conditions monitoring comprise morphological, chemical (water quality) and biological monitoring. However, a minimum base flow or environmental flow is also essential for the healthy functioning of rivers. Section 4.5.4, "Principles of River Monitoring**"** and Section 3.7.2.5, "Evaluation Parameters" provide an account of the requirements for river monitoring pertaining to the above, whereas Section 3.5.4, "Environmental Flow Management" gives some details on environmental flow requirements. Baseline conditions for the rehabilitated river reaches and sites should be established using the same sampling procedures for comparison with potential future changes.

Morphological Monitoring

In river morphological monitoring, the data to be acquired include cross-sectional and longitudinal section profiles (step-pool details), bankfull discharge and velocity, bed particle size distribution, sediment loads, and channel patterns.

Chemical Monitoring

The Department of the Environment (DOE) has established water quality parameters and standards in Malaysia and has been carrying out river water quality monitoring since 1978. Currently 927 monitoring stations are located in 120 river basins around the country. The main parameters and the standards used for computing the Water Quality Index (WQI) are illustrated in Tables 4.5, 4.6 and 4.7 of Section 4.5.4, "Principles of River Monitoring**"**. Although this effort is commendable, the data collected would be much more useful for the overall river management and river maintenance purposes if the data collection stations can coincide with the vast network of gauging stations maintained by DID. This is important because no modeling of river water quality can be meaningful without the quantitative flow component being incorporated. Therefore a cooperative and integrated effort between DOE and DID to have common points of data collection for water quality parameters, sediment loads, and discharges will be a good step forward in the advancement of river water quality management, environment monitoring, assessment and prediction.

Biological Monitoring

Biological monitoring can cover a broad spectrum of organisms, riparian conditions, and sampling techniques. A brief account of biological parameter monitoring is given in Section 3.7.2.5, "Evaluation Parameters" while more detailed analytical methods for evaluating biological attributes are discussed in Section 3.5.2.4, "Biological Characteristics" of this Manual. Biological aspects of the stream corridor that may be monitored include primary productivity, invertebrate and fish communities, riparian/terrestrial wildlife, and riparian vegetation. This may involve monitoring habitat or fauna to determine the sustainability of revegetation efforts or in-stream habitat improvements.

The objective of environmental flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems. River ecosystem health deteriorates when natural flows of water, sediments and organic materials through a river system are substantially disrupted or modified by human activities. Dams and associated alteration of natural flow and sediment transport patterns and water temperature are now widely recognized as a leading cause of declines in freshwater biodiversity globally.

There are many different methodologies used to determine environmental flows. As appropriate references are not available in this country to assess the ecological effects resulting from such changes in flows, environmental flows were estimated based on percentages of low flows for the key components as suggested in Comprehensive Management Plan of Muda River Basin (JICA, 1995)[150] viz. flows required to: (1) conserve natural low flows; (2) maintain an acceptable water quality; (3) conserve river ecology; (4) to maintain river scenery; and (5) to prevent salt-water intrusion. Reference may be made to Section 3.5.4.4, "Methods of Determining Environmental Flow" for a more detailed description of the methods.

Data collection is carried out for the reference sites (baseline data) and regular data collection for river conditions monitoring undertaken at the project sites. Comparison can be made and the status of the river conditions at the project sites can thus be duly assessed. Counter-measures may then be meted out in a timely manner before the river condition deteriorates beyond reasonable repair.

3.7.4.3 Maintenance Planning

River Maintenance

The process of river rehabilitation maintenance is to ensure that once "rehabilitation" is completed in an area, it continues to meet the goals of the rehabilitation work. Rehabilitation without maintenance may be likened to "One Step Forward - Two Steps Back!". Funding for maintenance work is normally more difficult to come by as once the rehabilitation work is completed, the river reach is expected to take care of itself. However, the rehabilitated reach will take time to adjust to its new regime and recover its habitat. Therefore continuous monitoring and some degree of human intervention may be required to ensure it stays its intended course and all the rehabilitation effort rendered is not wasted. It is for this reason that proper planning for rehabilitation maintenance should be given due emphasis.

River maintenance is conducted to preserve the structures and functions of rehabilitated river reaches including river conditions monitoring (morphological, chemical and biological) and related remedial actions, Woody Debris Management (WDM), re-vegetation, introduction of new flora and fauna species and other activities as required.

Besides river condition monitoring, regular patrols are conducted to check on possible presence of illegal activities (e.g. land use without permits and unlawful waste disposal) in the river area. Verification is made to ensure that activities in the river corridor area conducted by landowners are not detrimental to river rehabilitation work.

All the above activities require personnel and facilities for coordination, supervision, monitoring, analyses, redesign, patrolling and of course funding. Maintenance planning would therefore provide a framework for more orderly and timely execution of these activities.

Rehabilitation Maintenance Planning

As with any project initiative, maintenance of rehabilitated rivers needs proper planning to see that work is carried out systematically and in good time to meet the goals and objectives of the project. The following elements may be taken into consideration in planning maintenance work:

- Setting goals and objectives;
- Scheduling and cost estimates;
- Setting priorities for specific works;
- Securing funding and budgeting;
- Staffing including recruitment of voluntary workers; and
- Performance measurements and review.

Setting of goals and objectives for the maintenance works would provide clear direction to all personnel involved so that all effort and resources can be geared towards maximizing the intended project outcome. Procedures and standards of works should be established and understood by all concerned. Although maintenance work seems open-ended in the sense that there is no project completion date, there is still a need for work identification, scheduling and cost estimation at least on a yearly basis. For a newly rehabilitated river reach, a program drawn up for a longer period of up to ten years may be preferred as more resources which are peaked at the beginning would dovetail gradually as the river structures and habitat stabilize.

Setting priority has become a necessity in carrying out maintenance work either due to budget constraint or urgency of a specific aspect of the works. Priority should normally be given to remedial works that have adverse impact on rehabilitation such as bank erosion or pest control. The total required fund value should be accrued from the scheduled cost estimates on work components identified, staff costs, overheads etc. and presented as a yearly budget.

Staff requirement for maintenance has always been overlooked, very often to the detriment of a project. This is partly attributed to the maintenance culture in our society at large. Staff is considered the most important asset in any organization as much effort and time are required for skill training as well as in inculcating the right work attitudes and in teamwork. At the minimum, suitably qualified and dedicated staff should be selected as key personnel to organize, coordinate, and guide the others, including voluntary works, in the day to day running of the maintenance work on site.

With the use of RB-IMS where possible, monitoring of the river conditions will provide continuous records of rehabilitated river reaches under maintenance. The documented data can then be compared with the baseline data of the predetermined referenced reaches to assess the performance of the rehabilitation work over time. Should any impending problem be identified, remedial measures may be proposed and reviewed by the specialists before follow-up action is undertaken. With proper costing of work kept for each river reach, the maintenance cost of each reach can also be computed both for future budget justification and for cost effectiveness comparison.

3.7.5 River Vegetation Management

Healthy riparian vegetation is an essential component of every wetland, creek and river. The vegetation plays an important role in the maintenance of good water quality within the waterbody and provides habitat for many fauna species (Figure 3.140). Unfortunately, most fringing vegetation is heavily infested with weeds, which are often very vigorous in the rich, damp soils surrounding waterbodies. Projects that aim to rehabilitate riparian vegetation need to take into account long-term management to ensure their success (Water and River Commission 2002)[151].

Figure 3.140 Riparian Vegetation along Malaysian rivers

A common problem with stream rehabilitation is the initial decision to rehabilitate a long reach of the stream. If a project is not carefully planned, the follow-up maintenance of the site can remain very high for a long time. The following guidelines will help to ensure that maintenance of the project site is reduced to a minimum as quickly as possible.

3.7.5.1 Initial Site Preparation

During initial site preparation for a revegetation project, it is important to estimate the resources available and the amount of follow-up work that need to be done. If resources are not available for follow-up work, it is often not worthwhile to start the project, as the rapid growth of weeds will quickly destroy all the initial work. For most well planned projects, the first three years will require fairly intensive maintenance and the work should decrease yearly thereafter. However, a low level of maintenance will always be needed. This usually takes the form of constant vigilance for new outbreaks of weeds, so they can be controlled at the earliest stage.

3.7.5.2 Weed Assessment and Control

Weed Assessment

Weeds found at the site should be listed and categorized into the following levels of priority for removal:

- *High Priority*. Weeds/shrubs that regenerate quickly and strongly from root stock (e.g. lallang, bamboo) (Figure 3.141) or rapidly invade and smother native plant communities (e.g. Silktree Mimosa). Within the waterway itself, fast growing water weeds such as water hyacinth also need urgent attention for removal (see Appendix N on control measures suggested).
- *Medium Priority.* Weeds which cannot be removed with a selective herbicide (e.g. Nightshade).
- *Low Priority.* Weeds that can be removed with a selective herbicide (e.g. grasses), or weeds that are not effective competitors with native species (e.g. Dandelions).

Figure 3.141 A field of thriving lallang (Imperata cylindrica)

Weed Control

It is essential to have good control of the high priority weeds before planting commences at a project site. The medium priority weeds also require good control before planting. These are the weeds that are most likely to increase your long-term maintenance of the site, and it is worth putting a lot of initial effort into control. Herbicide is quick, cheap and effective, however use of herbicide in waterway is restricted and needs to be carefully planned. Advice from a weed management specialist should be sought before the project starts. Once planting has started, manual control of weeds is often the only option. If insufficient labour resources are available to carry this out, the project site will deteriorate.

The low priority weeds may not need treatment at all, though they may require hand removal in situations where they are out-competing native germinants. Grassy weeds can be left in place until plantings have become established as they are easily removed with a selective herbicide (note: selective herbicide should not be used over or near water). It should also be noted that removal of a weed is often followed by a succession of new, more tenacious species and that early removal of grasses often creates bigger weed management problems.

3.7.5.3 Plant Selection, Planting and Timing

Plant Selection

Correct selection of plant species and adequate planting density can greatly reduce long-term maintenance. In very weedy sites, quick growing species which spread by rhizome can be chosen to out-compete unwanted species within a growing season. If clumping species are chosen in preference, it is important that the density is high, so that total cover is quickly achieved. Clumps or strips of sedges may be an option in high erosion sites. Shading reduces the growth of many weed species. In very weedy sites, tree and tall shrub species can be planted after the first weed control effort. Tree guards placed over these plantings will allow herbicide control to continue at the site, while the plants grow to create the shade necessary to reduce the weed problem in the long-term.

Mulching

Many weeds that depend on germination from seed will be prevented from regenerating through the provision of a thick layer (10cm) of good quality mulch. Instead the mulch layer can be created by slashing weeds that have been previously sprayed. Large, dense weed infestations are excellent for this purpose, as are thick beds of grass such as *lallang* or paddy straw etc. Mulch from soft-leaved species will probably give cover for six months. Comparatively, hard-leaved or woody species will last twice as long. Mulch is less effective in areas that are regularly flooded, as the mulch will rot quickly or be washed away.

Maintaining Plantings

Once a site has been prepared and planted, it should be checked every two weeks for the first six months. This will allow early detection of germinating weed species, monitoring of the success of plantings and maintenance of tree guards if these are used. Plantings in the drier zone surrounding waterbodies will have a higher success rate if regular watering is carried out during any prevailing period of dry weather. The effectiveness of the first planting should be monitored and the results used to determine the level of top-up planting to be carried out in the second year. Excessive deaths of particular species may have been caused through planting in the wrong hydrological zone.

Weed Control and Timing

Regular, timely weed control is essential in the second and third year of the rehabilitation project if the future maintenance of a site is to be minimized. Regular inspections to the site should be carried out, not only to monitor the reappearance of the weeds initially present, but also to detect invasions of new weed species. Timing of weed control is crucial to success.

Timetable for Maintenance

Once plantings are well established and good weed control is achieved, the need for maintenance of the site will decline. Even though there will be a reduction in the amount of resources needed to maintain the site, there will always be a need to monitor the area four to five times a year. Seasonal changes in the environment as well as unexpected events such as flood or increased human use can alter conditions at a site and allow increased weed invasion.

It is demoralizing when three years of hard work is wasted through the failure to carry out adequate monitoring and maintenance of a site. Therefore, every effort should be made to have regular surveillance to keep weed invasion in check.

Vegetation Diversity

It is possible to add further diversity to a site when it has reached a fairly stable state and most of the weeds are under control. Using a small amount of resources, additional species can be added to a site either by planting, transplanting or direct seeding. These may include plants that do not compete well against weed species, such as native grasses.

3.7.6 Desilting of Rivers

3.7.6.1 Sedimentation Process

Rivers carry suspended sand and soil along with them as they flow toward the sea. The higher the water velocity, the greater its energy and capacity to move sediment along with it. When the flow velocity decreases, it loses energy and the non-floating materials drop to the bed of the river (U.S. Army Corps of Engineers, 2004)[152].

As stream or river velocity slows, heavier materials, like sand and gravel, will settle out first. In rivers and streams that experience periods of high flow during the year, the formation of sand or gravel bars is common. Because they are finer particles, silt and clay particles do not settle out until the river has lost most of its energy and velocity. In still water, harbors, and backwater areas, like bayous and oxbows, silts and clay will settle out. For a more detailed account of sedimentation process in river, reference can be made to Chapter 2.3 -"River Characteristics and Morphology" in this volume of the Manual.

If enough sediment deposits to build a shallow spot on the river bed, it forms shoals. A shoal in a river used as a navigation channel can become a safety hazard to vessels. If a vessel grounds, or strikes the shoal, the vessel and its contents may be damaged. In serious situations, the environment can be damaged if the ship's liquid cargo is spilled into the waterway.

3.7.6.2 Desilting or Dredging

Dredging (or desilting as it is often called in this country) is the underwater excavation of rivers or other waterways. Dredging is carried out mostly for navigation purposes but at times is done to remove excessive sedimentation at the river mouths to enable speedy discharge of floodwater to the sea. After the initial excavation needed to establish a channel to its required dimensions, the periodic dredging that must be done to maintain the channel size is called maintenance dredging. Once sediments are dredged from the waterway, they are called dredged material.

A dredge is a machine that scoops or suctions sediment from the bottom of waterways or is used to mine materials underwater. People have been dredging channels in one way or another since earlier days to irrigate crops. Until the early 1900s, dredges were crude and barely effective in keeping channels and harbors clean. Keeping the dredge in position in the channel, knowing how deep a channel was being dug, and even making accurate surveys of the completed channel, were a mixture of art and science. Experienced dredge captains and hydrographic surveyors were able to produce remarkably good results, given the difficulty of their job.

Today, modern dredges use satellite information and computers to help dig channels. Until the 1970s, dredge captains used celestial navigation and markers placed on the riverbanks to guide their dredges. Now dredge captains use global positioning systems (GPS), which use satellite information to calculate the location of the dredge in the channel. On the dredge, information about the channel, the location of the shoal, and even the position of the dredge in the channel is likely to be displayed on a computer screen while they are working. Using computers to process and display information about the job and the dredge while they are working allows the dredging to be done with great efficiency. It saves time and money, and results in a better piece of work done.

Types of Excavators and Dredges

Desilting of streams or small rivers is generally carried out with an excavator. In the past, dragline excavator (Figure 3.142) was solely used to do the work. Although it has good reach with its use of swing bucket, it has lower output when compared with hydraulic excavator (Figure 3.143). As a result, a hydraulic excavator has almost totally taken over as the machine for most slope trimming and excavation work. However, even with a long arm excavator, the rate of excavation from a stream bed is limited by the bucket size while the distance of deposition of excavated material is normally on the stream bank. Multiple handling of the materials with additional machines can be undertaken to dump the materials to a greater distance from the bank or onto dump trucks to disposal site if so desired (U.K Marine SACs Project 2001)[153].

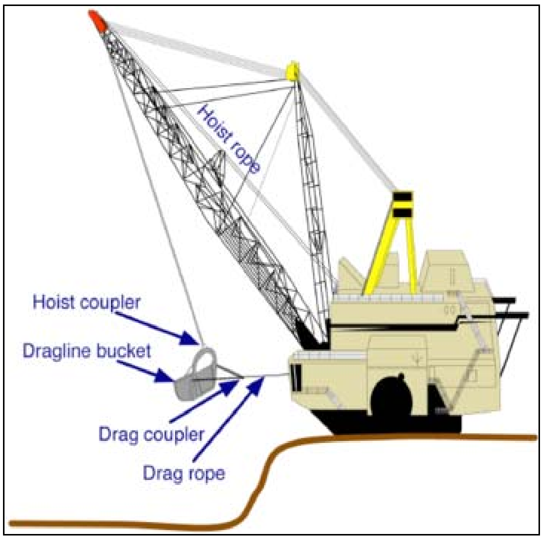


Figure 3.142 Typical dragline excavator

Figure 3.143 Hydraulic excavator for better output

With the advancement in technology, desilting (or dredging) work for bigger streams or rivers are normally undertaken with the use of dredges. Dredging is an excavation activity or operation usually carried out at least partly underwater, in big rivers or estuaries with the purpose of gathering bottom sediments and disposing of them at a different location, mostly to keep waterways navigable or to increase channel flow capacity. A dredge is a device for scraping or sucking the river bed or seabed, whereas a dredger is a ship or boat equipped with such a dredge.

During the process of dredging, spoils (dredged material) are conveyed to a location away from the dredged area so that spoil would not find its way back to the excavated area. Dredging can produce materials for land reclamation or other purposes (usually construction-related), and has also historically played a significant role in tin mining in this country.

While the onboard instrumentation of modern dredges is computer assisted, the basic excavation methods of dredges have remained the same since the late eighties. For river dredging, two main types of dredges i.e. mechanical dredges and hydraulic dredges are normally used.

Mechanical Dredges - Mechanical dredges remove material by scooping it from the bottom and then placing it onto a waiting barge or into a disposal area. The two most common types of mechanical dredges are dipper dredges (Figure 3.144) and clamshell dredges (Figure 3.145). They are named after the type of scooping buckets they employ.

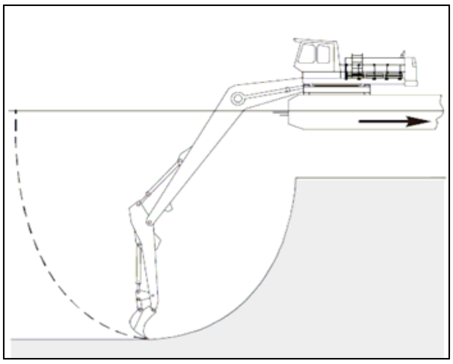


Figure 3.144   Backhoe or Dipper dredges

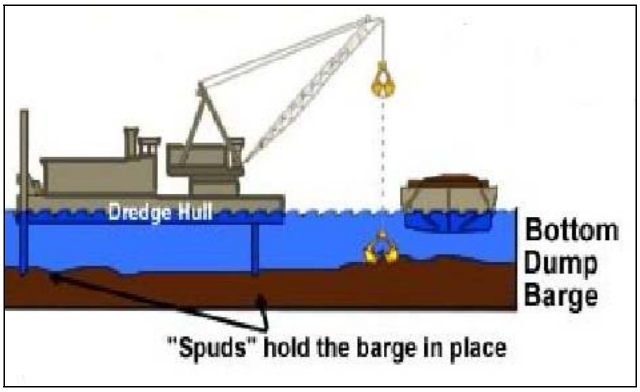


Figure 3.145   Grab or clamshell dredger in action

Mechanical dredges are rugged and can work in tightly confined areas. The dredge is mounted on a large barge and is not usually self powered, but is towed to the dredged site and secured in place by anchors or anchor piling, called spuds. They are often used in harbors, around docks and piers, and in relatively protected channels, but are not suited for areas of high traffic or rough waters. Usually two or more disposal barges, called dump scows, are used in conjunction with the mechanical dredge. While one barge is being filled, another is being towed to the disposal site. Using numerous barges, work can proceed continuously, only interrupted by changing dump scows or moving the dredge. This makes mechanical dredges particularly well suited for dredging projects where the disposal site is many kilometers away.

Mechanical dredges work best in consolidated, or hard-packed, materials and can be used to clear rocks and debris. Dredging buckets have difficulty retaining loose, fine material, which can be washed from the bucket as it is raised. Special buckets have been designed for controlling the flow of water and material from buckets and are used when dredging contaminated sediments.

Hydraulic Dredges - Hydraulic dredges work by sucking a mixture of dredged material and water from the channel bottom. The amount of water sucked up with the material is controlled to make the best mixture. Too little water and the dredge will bog down; at low concentrations, dredges will not be efficient. Pipeline and hopper dredges are the two main types of hydraulic dredges.

A pipeline dredge (Figure 3.146) sucks dredged material through one end, the intake pipe, and then pushes it out the discharge pipeline directly into the disposal site. Because pipeline dredges pump directly to the disposal site, they operate continuously and can be very cost efficient. Most pipeline dredges have a cutterhead on the suction end. A cutterhead (Figure 3.147) is a mechanical device that has rotating blades or teeth to break up or loosen the bottom material so that it can be sucked through the dredge. Some cutterheads are rugged enough to break up rock for removal. Pipeline dredges are mounted (fastened) to barges and are not usually self-powered, but are towed to the dredging site and secured in place by special anchor piling, called spuds.

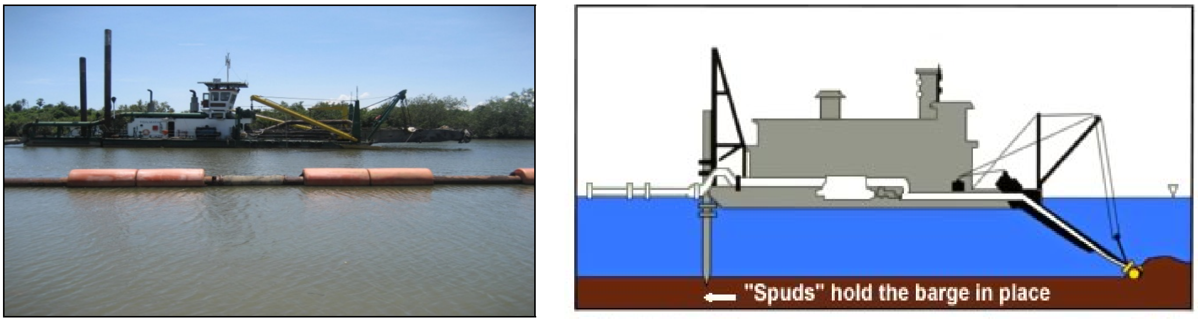


Figure 3.146 Cutter-suction Pipeline Dredge (Source: Tidalmarine Engineering)

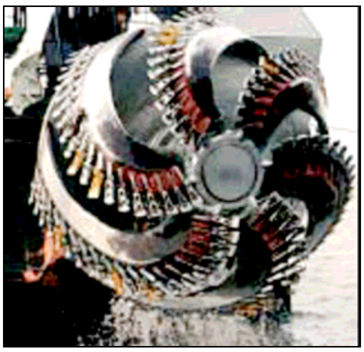


Figure 3.147 Close-up view of a cutterhead

Cutterhead pipeline dredges work best in large areas with deep shoals, where the cutterhead is buried in the bottom. Water pumped with the dredged material must be contained in the disposal site until the solids settle out. It is then discharged, usually back into the waterway. This method of dredging is not suitable in areas where sediments are contaminated with chemicals that would dissolve in the dredging water and be spread in the environment during discharge.

Because the discharge line for pipeline dredges is usually floated on top of the water, they are not suited to work in rough seas where lines can be broken apart or in high traffic areas where the discharge pipeline can be an obstruction to navigation. If there is a lot of debris in the dredging site, the pumps can clog and impair efficiency.

Hopper dredges are ships with large hoppers, or containment areas, inside. Fitted with powerful pumps, the dredge suctions dredged material from the channel bottom through long intake pipes, called drag arms, and stores it in the hoppers. The water portion of the slurry is drained from the material and is discharged from the vessel during operations. When the hoppers are full, dredging stops and the ship travels to an in-water disposal site, where the dredged material is discharged through the bottom of the ship.

Hopper dredges (Figure 3.148) are well-suited to dredging heavy sands. They can maintain operations in relatively rough waters and because they are mobile, they can be used in high traffic areas. They are often used at ocean entrances, but cannot be used in confined or shallow areas. Hopper dredges can move quickly to disposal sites under their own power, but since the dredging stops during the transit to and from the disposal area, the efficiency is best over short distances.

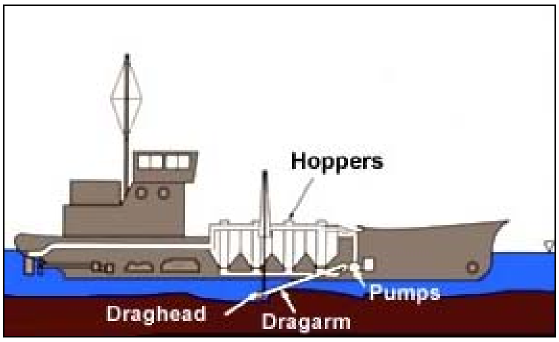


Figure 3.148 Hopper dredges

3.7.6.3 Disposal of Dredged Material

Disposal site selection for dredged material is one of the most important and challenging parts of planning a dredging project. The most common dredged material disposal methods are ocean placement, beach nourishment, confined disposal facilities (CDFs), flow-lane and within-banks placement, and capped disposal (U.K. Marine SACs Project 2001)[51].

Ocean Placement - Ocean Dredged Material Disposal Sites (ODMDS) are primarily used for material coming from inlets, coastal entrance bars, or main coastal navigation waterways. Typically, in ocean placement, a hopper dredge or towed barge moves to a designated area in the ocean, where the hull (bottom) of the vessel is opened. The dredged sediments settle to the bottom. Only clean dredged material may go to ocean sites.

Beach Nourishment - Beach nourishment is the placement of dredged material on or near the beach, usually to replenish an eroding beach or protect an eroding wetland. The dredged material is generally sand coming from inlets, coastal entrance bars, or main offshore waterways. Both hopper dredges and pipeline dredges can use beach nourishment sites. When hopper dredges place sand offshore along the beach, natural processes carry it onto the beach over a long period of time. Only clean dredged material can be used for beach nourishment. This method of dredged material disposal is considered a beneficial use of dredged sands. It is used in coastal areas all around the country.

Confined Disposal Facilities (CDFs) - In Confined Disposal Facilities (CDFs), dredged material is placed behind dikes, which contain and isolate it from the surrounding environment. There are three types of CDFs: Upland, Shoreline, and Island. A mixture of dredged material and water is pumped into an area that is divided into several smaller areas, called cells. The reduced velocity of the water moving between the cells causes the dredged material to settle out, and finally, clean water is discharged from the site. The difference in the three types of CDFs is their location. Upland CDFs are on land, above the line of high water and out of wetland areas. Shoreline CDFs are constructed over the sea or lake bottom and are attached to the shoreline on at least one side. Island CDFs are constructed offshore, but in relatively shallow water.

CDFs can be used for any type of dredged material, coarse or fine-grained. Usually, pipeline dredges pump material directly from the dredging site into the CDF, which is the least expensive way to put the material in the site. In special cases, where the CDF is far removed from the dredging site or a pipeline dredge is not used for the dredging, barges or hopper dredges may take dredged material to the site where it is re-pumped into the CDF.

Preparing and caring for a CDF requires a substantial commitment of time and money by local and Federal governmental agencies. Sometimes a CDF can be designed so that there can be other uses for the land during and after the site is used for dredged material disposal.

Flow-lane and Within-banks Placement - Some waterways are in high-energy river systems with rapidly flowing water and strong currents. The energy of the water causes shoals made of coarse sand to form, move along the bottom, and re-form relatively quickly. In these systems, flow-lane or within-banks disposal may be used.

For both methods, dredged material is placed in or along the river that is also subjected to the river's erosion. They are filled temporarily, until the energy of the river moves the sand out again. With-in banks disposal refers to the temporary use of eroding banks, the river thalweg, sandbars, or man-made islands. Pipeline dredges can be used in this disposal option.

Flow-lane disposal of dredged material refers to the placement of materials in water within or adjacent to the river channel. It is similar to the "thalweg" disposal (the thalweg of a river is the area where the water has its greatest velocity.) Flow-lane disposal can be used by both hopper and pipeline dredges.

Capped Disposal - Sometimes, but not often, dredged material is contaminated with metals, chemicals, or other substances. If the contamination is bad enough, it might be harmful to the environment to put the material in a typical in-water site or a typical CDF. In these cases special handling will be used to prevent the contaminants from re-entering the environment during dredging and disposal.

The objective of capped in-water disposal is to isolate contaminated material from the environment by capping, or covering, the contaminated material with clean material – usually sand. The contaminated dredged material is placed on a level bottom or in deep pits or bottom depressions. Then clean material is dropped on top. The cap is designed and carefully put over the contaminated sediment to ensure that it stays in place. Caps are designed so that currents, waves, or the burrowing bottom creatures will not erode the protective layer over time. In addition, the caps are continually monitored to look for signs of failure.

Capped disposal for the isolation of contaminated sediment is practiced worldwide. For example, in the United States, capped disposal sites have been used successfully in several places: Long Island Sound, in New Bedford, Massachusetts; Puget Sound in Washington state; the New York Byte; and other locations.

3.7.6.4 Impacts of dredging on the river environment

In gravel bed rivers there are permanent features which remain stable over a range of flows; for example, pools, riffles, point bars, floodplains and bankside vegetation. Dredging the channel bed usually destroys, or at least disrupts, these features, creating a more uniform, less stable and less diverse environment (Scottish Natural Heritage)[154].

The suspended sediment load and turbidity of a river are increased during the removal of bed or bank material (Figure 3.149) and as a consequence other water quality characteristics, such as temperature, are affected. The effects may persist for some distance downstream. Settling out of the material in suspension will alter the composition of the substrate.

If dredged material is deposited on the bankside it effectively creates a barrier between the floodplain and the river. In addition, this material may be eroded and washed back into the river if left unconsolidated. The loss and alteration of natural habitats caused by dredging operations can have serious ecological impacts, in both the short-and long-term.

Figure 3.149 High suspended sediment concentrations resulting from dredging. Clear water on the left is from an unaffected tributary.

3.7.6.5 Impacts of dredging on In-stream Biota

Substrate removal will inevitably affect spawning, which takes place in gravel substrates, and juvenile fish which inhabit the substrate. Substrate siltation is the settling of fine sediment on to the substrate. This is known to affect the spawning, incubation and emergence of some species of fish. Fine sediment can reduce the suitability of gravels for spawning and as a habitat for young fish by (Scottish Natural Heritage[154]):

- Reducing the intergravel flow and therefore the oxygen supply, and increasing the temperature in the gravel;
- Infilling the interstitial spaces and thus trapping eggs and young fish; and
- Reducing cover and food source for mature fish; females may be prevented from digging a redd and laying eggs.

Suspended sediment in the water affects the respiratory system of fish. Growth may also be affected since food supply and feeding success are reduced in the turbid conditions. The varying nature and size of the suspended sediment, along with the sensitivity of different species, mean that impacts are also varied. Increased turbidity reduces light penetration and therefore primary productivity, which has a knock-on effect throughout the food chain. Most fish species will migrate under increased turbidity conditions and many will have a reduced capacity to find and capture prey.

Channel morphology alteration can have a number of impacts on local fish populations:

- Disturbance of bank vegetation or the substrate removes cover and shade; this makes fish more susceptible to predators, and increases light penetration and hence water temperature, which will cause fish to migrate;
- Loss of spawning area or nest in gravel substrates; and are usually situated at the upstream end of riffles/downstream end of pools, where there is a downward movement of water; and
- Reduction in areas of shelter from high velocity flows.

Macroinvertebrates

Substrate siltation. Species such as mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) are adapted to live in crevices beneath and between stones, particularly in riffle areas. The presence of silt on stones is capable of reducing invertebrate abundances for prolonged periods. The major impacts of siltation are to increase species mortality and to alter community structure by:

- Blocking interstitial spaces, causing oxygen-depletion and hence species mortality;
- Coating stones and thereby reducing the number of attachment points for larvae and reducing their feeding success;
- Allowing benthic species, such as Chironomidae (or non-biting midges), to survive in preference to attachment species, such as mayflies (Ephemeroptera); and
- Reducing interstitial volume available to invertebrates.

Suspended sediment and turbidity increases will:

- Reduce primary productivity, thus reducing the amount of energy available to macroinvertebrates and organisms higher up the food chain;
- Tend to induce invertebrate drift, thus reducing instream benthos populations in the dredged reach and possibly also downstream;
- Clog the food filtering and trapping apparatus of stream insects, for example blackflies (Simuliidae).

There is limited information on the physical habitat requirements of macro invertebrates, but shallower water depth will favour some species due to the associated increase in temperature.

Other wildlife

Reduced primary productivity and reduced invertebrate and fish populations can affect local mammal and bird populations which rely on these sources of food. Material deposited on the river banks affects the hydrological continuity which exists between the river channel and the floodplain. Wetlands in the riparian zone and floodplain provide habitats for invertebrate and other fauna. Dredging is therefore likely to disturb or destroy suitable feeding and nesting sites of these animals. Amphibians may lose habitat diversity and spawning areas, though drying out may also eliminate some predatory fish species.

Vegetation

River wetland plants are able to survive in a range of habitats. Dredging operations can physically disturb, or remove entirely, any vegetation situated instream or upon the banks.

3.7.6.6 Alternative Approaches and Recommendations

The impacts of dredging work can be minimized by a number of techniques. Bank stabilization and cover can be improved at water-level by the placement of temporary log or board overhangs, artificial metal or fibreglass overhangs, tree or brush retards and riprap. These may be used in conjunction with the revegetation of deposited material on the bankside. The structures can then be removed when the banks become stable and cover is re-established.
Deposition of dredged material should be away from the channel edge to limit damage to streamside habitats This also allows a degree of flooding to occur on the floodplain, thereby creating opportunities for wet grassland and scrub/wet woodland. Where possible biotechnical engineering, for example geotextiles, may be used to help stabilize the material and aid re-colonisation. Other possibilities include:

- Drying and spreading the spoil over adjacent land, which can improve soil fertility in some cases, but may also smother important flora and habitats;
- Excavating a trench and infilling it with spoil, thus minimising disturbance to agriculture and the local environment;

- Dumping off-site is possible but expensive, using spoil to create artificial wetlands.

If riprap is used for bank stabilization, it must extend below the toe of the underwater slope of the bank to prevent undercutting. The structure can also be covered by soil and re-planted to improve habitat diversity and aesthetic value.

Disturbance can be minimised if mechanical excavators work from one bank. If the channel is too wide, the digger must work within the channel. Disruption can be minimised by diverting the river down one side of the channel and dredging the other side while it is 'dry'. Smaller plant equipment generally limits the level of impact on bankside and instream habitats.

Selective scrub and vegetation removal, is preferable to total clearance. Similarly, sensitive spraying of herbicide can be achieved. The removed vegetation should be stored and replaced on unconsolidated banks, or native species re-planted. This should be timed to allow the vegetation to take root. If the channel margins are left untouched, a small amount of marginal vegetation and undredged bed will allow more rapid recolonisation.

Ultimately, implementation of mitigation techniques involves a trade-off between their lesser impacts and those of a more serious nature arising from dredging within the active channel. All work should be timed to avoid sensitive periods in the life-cycles of instream and riparian flora and fauna.

3.7.6.7 Contaminated sediments

Although generally not heavily contaminated, much dredged material is subject to some contamination. A variety of harmful substances, including heavy metals, oil, Tributyltin (TBT), Polychlorinated Biphenyls (PCBs) and pesticides, can be effectively 'locked into' the riverbed (mainly downstream reaches) or seabed sediments in ports and harbours. These contaminants can often be of historic origin and from distant sources. The dredging and disposal processes can release these contaminants into the water column, making them available to be taken up by animals and plants, with the potential to cause contamination and/or poisoning. The likelihood of this occurring depends upon the type and degree of sediment contamination, however, some remobilisation of very low levels of pollutants would be expected during many dredging operations (U.S Army Corps of Engineers 2004)[152].

The highest levels of contaminants generally occur in silts dredged from industrialised estuaries. If low level contaminants are released into the water column during disposal, they may accumulate in marine animals and plants and transfer up the food chain to fish and sea mammals.

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APPENDIX A

EQUATION FOR CALCULATION OF D50 SIZE OF PARTICLES OR STONES

APPENDICES

Appendix A Equation for Calculation of D_{50} Size of Particles or Stones

The median size D_{50} of soil is used for scour depth assessment for rivers or channels. In river engineering, the D_{50} stone size is often employed in riprap bank protection works. It is normally found by interpolation where the high and low of the range in which the percentile is found are used. For example, if 45% of the particles are smaller than 2 mm and 60% of the particles are less than 4 mm then the size of D_{50} is within the range of 2 to 4 mm. It also makes use of the cumulative percent of particles corresponding to those range endpoints.

Size values themselves are not used for interpolation because the traditional graphical method of determining percent smaller than sizes uses semi-log paper with size plotted on a log scale. Also the size ranges are a log base 2 series. The increments are 2^n and n which is linear is, $\log(2^n)$. The numerical interpolation to obtain S is as follows:

$$\frac{\log_2(S)-\log_2(S^-)}{[P-P^-]}=\frac{\log_2(S^+)-\log_2(S^-)}{[P^+-P^-]} \qquad (A.1)$$

$$\log_2(S) = \log_2\left(S^-\right)+\left[P-P^-\right]*\frac{\log_2(S^+)-\log_2(S^-)}{[P^+-P^-]} \qquad (A.2)$$

$$S = 2^{\log_2\left(S^-\right)+\left[P-P^-\right]*\frac{\log_2(S^+)-\log_2(S^-)}{[P^+-P^-]}} \qquad (A.3)$$

Where:
S = Particle or stone Size
S^+ = Size at the top of the range
S^- = Size at the bottom of the range
P = Percent smaller than such as 50% for D_{50}
P^+ = Percent of particles smaller than S^+
P^- = Percent of particles smaller than S^-

For ease of computation, the above equation may be entered into a spreadsheet such as Excel. In Excel this equation for *S* (D_{50} in this case) is as follows where S1:S24 are the sizes at the upper end of each range and P1:P24 are the cumulative percentage of particles less than the upper limit of each range.

```
=2^(LOG((INDEX(S1:S24,MATCH(0.5,P1:P24,1))),2)+(LOG((INDEX(S1:S24,MATCH(0.5,P1:P24,1)+1
)),2)-LOG((INDEX(S1:S24,MATCH(0.5,P1:P24,1))),2))*(0.5-
INDEX(P1:P24,MATCH(0.5,P1:P24,1)))/(INDEX(P1:P24,MATCH(0.5,P1:P24,1)+1)-
INDEX(P1:P24,MATCH(0.5,P1:P24,1))))
```

Reference:

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APPENDIX B

DESIGN GUIDELINES FOR STREAM BARBS

Appendix B Design Guidelines For Stream Barbs

Description

Stream barbs are low-sill (typically rock) structures that extend from the stream bank into the stream flow, angled in an upstream direction. They are very low structures that should be completely overtopped during channel-forming flow or bankfull flow events (approximately a 1.5 to 2.0 year flow event). Stream barbs redirect stream flow with a very low weir and disrupt the velocity gradient in the near-bank region. The low weir section is pointed upstream and forces the water flowing over the weir into a hydraulic jump. Flowing water turns to an angle perpendicular to the downstream weir face causing the flow to be directed away from the stream bank. The weir effect continues to influence the bottom currents even when the barb is submerged by flows greater than the channel-forming flow.

The disruption of the velocity gradient reduces channel bed shear stress and slows near bank flows, resulting in sediment deposition adjacent to the barb. Local flattening of the water slope upstream of the barb causes an eddy and sediment deposition. The flow separation caused by the hydraulic jump and flow redirection creates an eddy downstream of the barb, which also promotes deposition. Stream barbs are used for the following:

- Bank protection measures;
- Increase scour of point and lateral bars;
- Direct stream flow towards instream diversions and change the bed load transport and deposition patterns;
- Encourage deposition at the toe of a bank;
- Reduce width to depth ratio of a stream channel; and
- Provide pool habitat for fish.

Design Criteria

The following is a generalized discussion of design criteria specific to stream barb design. Since all designs in a riverine environment are site specific, the user is cautioned that there are certainly variants in many of the recommendations that are provided herein. Refer Figure B-1 to Figure B-3 for clarification and identification of terms

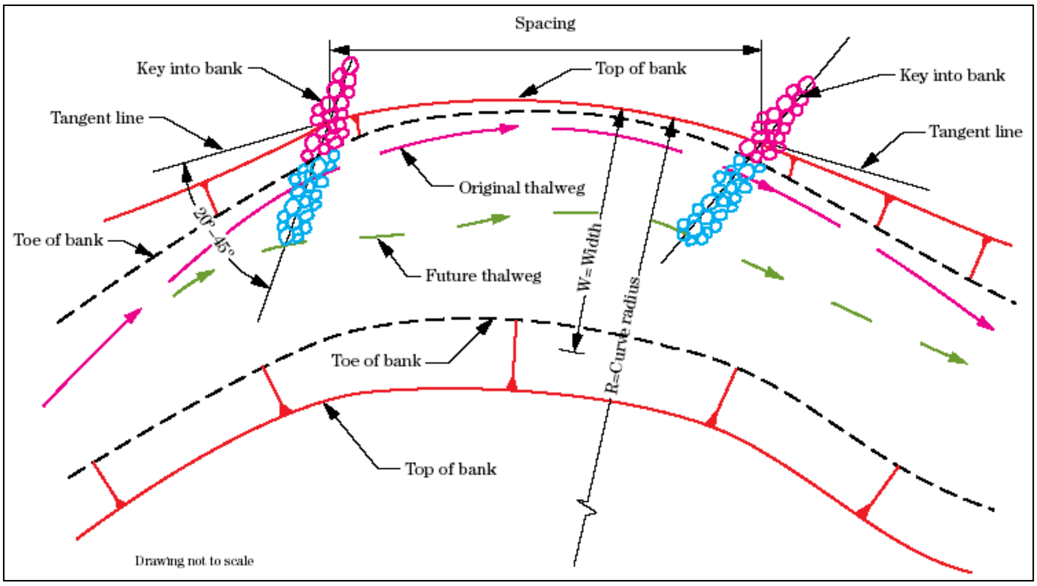


Figure B-1 Typical stream barb design layout

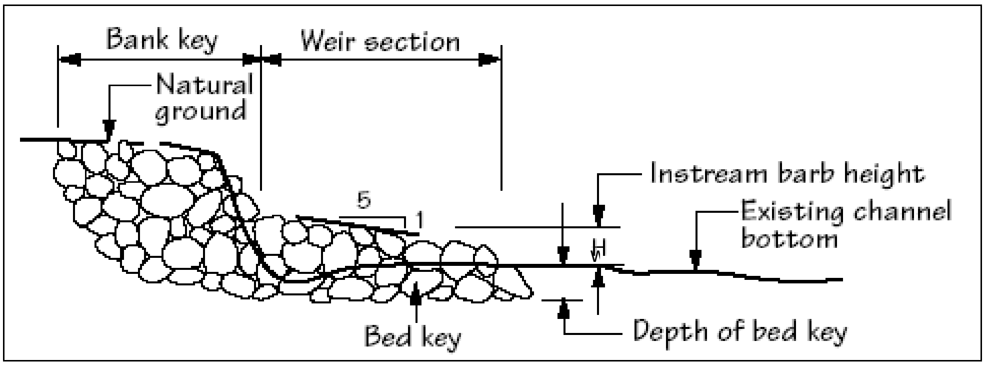


Figure B-2 Section normal to bank

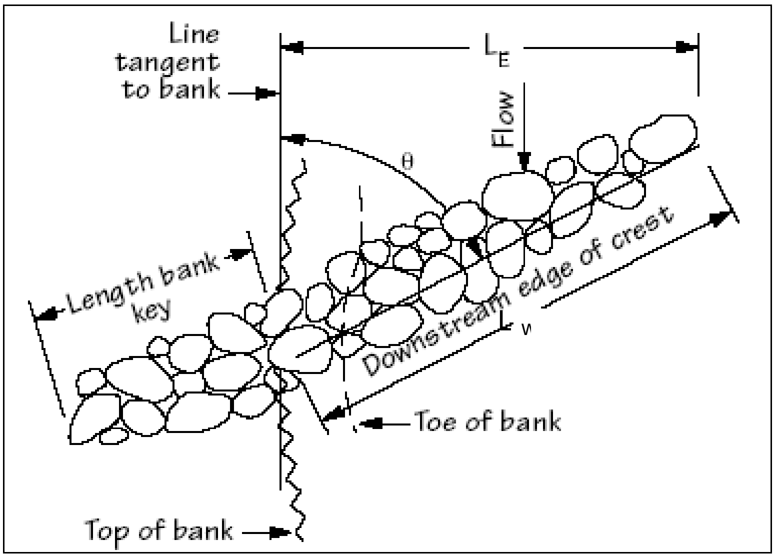


Figure B-3 Plan view

a) Channel Stability

eam barbs are not appropriate where the grade of channel is unstable. In degrading streams, foundation of the stream barb may be undermined. While in aggrading streams, the stream barb may be buried. Problems have been observed where these techniques have been applied in braided streams or stream systems that are prone to avulsions.

b) Channel Approach

Placement, length and alignment of barbs are dependent on the approach that the channel makes into the project area. Using stream barbs to make abrupt channel alignment changes should be avoided. For all significant design flow levels, stream barb should serve to redirect, rather than deflect or split the flow.

c) Location of Barbs

Stream barbs are appropriate for sites where mechanism of failure is toe and lower bank erosion. Stream barbs will not protect banks that are eroding due to rapid drawdown or mass slope failure. They are typically placed along the outside of a bend where thalweg (deepest part of the channel) is near the stream bank. Other bank protection measures should be considered if thalweg is in the center of the channel or away from the bank. The furthest upstream barb should be located just upstream of the area that is first impacted by active bank erosion. Often barbs do not need to extend to the downstream extent of the eroding bank, as upstream barbs will modify the angle and distribution of velocity that stop the erosion. In general, in a stream with moderately regular meander patterns, barbs should not be placed downstream of 3/4 of the turn length (refer to Figure B-4).

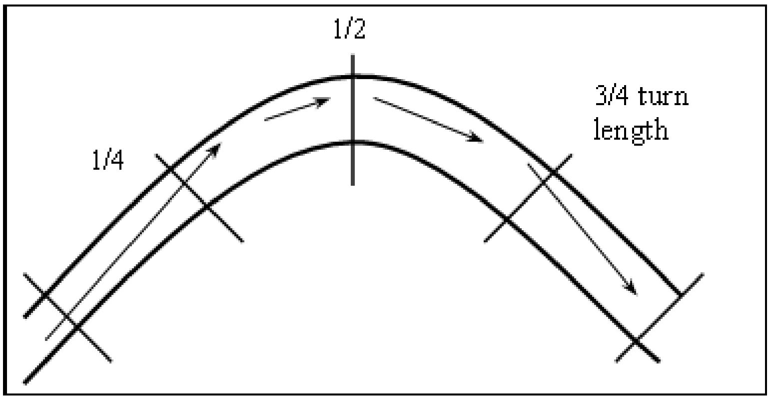


Figure B-4 Stream with moderately regular meander patterns

d) Bend Radius

Stream barbs may not perform satisfactory in sharp bend. When the meander bend radius divided by stream width is much less than three (R/W<3), there are often problems with erosion below the stream barb as a result of flow separation. This restriction may be relaxed by protecting the banks between the barbs, increasing the number of barbs and decreasing the angle between the barb and the bank. However, in appearance, this may result in nearly a fully rip-rapped bank.

e) Rock Size for Stream Barbs

Rock for barbs shall be durable and of suitable quality to assure permanence in the climate in which it is to be used. The rock shall be sound and dense, free from cracks, seams, and other defects that would tend to increase deterioration from weathering or other natural causes. Rock fragments shall be angular to subrounded in shape. The least dimension of an individual rock fragment shall not be less than one-third the greatest dimension of the fragment. Rock will have a minimum specific gravity of 2.5.

Material sizing should follow standard rip-rap sizing criteria for turbulent flow (see Riprap Design Appendix). The rock should be sized for the design flow and then modified in accordance with the following:

$$D_{50(barb)} = 2 \times D_{50(rip\text{-}rap)} \quad (B.1)$$
$$D_{100(barb)} = 2 \times D_{50(barb)} \quad (B.2)$$
$$D_{min} = 0.75 \times D_{50(rip\text{-}rap)} \quad (B.3)$$

Rock in the weir section of stream barb should be well graded in the D_{50} to D_{100} range; the smaller material may be incorporated into the bank key. The largest rocks should be used in the exposed weir section at the tip and for the bed key (footer rocks) of the barb.

f) Length of Barbs

There are two important length terms associated with stream barbs: weir length L_w and effective length L_e. Weir length defines the length of the weir section of the stream barb and is relative to how much flow can be redirected and energy dissipated. The longer the weir, the more stream flow affected and energy dissipated. Effective length is a function of the channel-forming flow width W and defines the perpendicular projection of the stream barb from the bank into the stream.

Maximum effective length, $$L_{e(max)} = \frac{W}{4} \quad (B.4)$$

Weir length,

$$L_w = \frac{L_e}{\sin\theta} \qquad \text{(B.5)}$$

Barbs that extend beyond $L_{e(max)}$ tend to alter the meander pattern of the stream and the stream flow could adversely impact the opposite bank. Suitable range of L_e for effective bank protection is:

$$\frac{W}{10} < L_e < \frac{W}{4} \qquad \text{(B.6)}$$

For stream barbs to affect the dominant flow pattern, they must cross the thalweg. Shorter barbs will affect only secondary, near-bank currents. If the calculated effective length results in barbs that do not influence the dominant flow path, then adjustments should be made to the barb length and subsequently the key length and barb spacing. If this is not feasible, other techniques should be considered.

g) Number and Spacing of Stream Barbs

The number of stream barbs required at any given site will be determined by the following:

- Barb spacing
- Length of the eroding meander bend
- Channel geometry
- Desired effect for overall watershed management

Proper spacing of barbs is necessary to prevent the stream flow from cutting between two barbs and eroding the bank. A vector analysis consists of plotting the proposed barbs with vectors projecting at right angles to the downstream side of the barb can give some indication of flow lines and flow interception by subsequent barbs. Given that the flow will leave the barb in a direction perpendicular to the downstream weir face, the subsequent barb should be placed so that the flow will be captured in the center portion of the barb before the stream flow intersects the bank. Since the flow direction is controlled by the alignment of the stream barb, the downstream side of the barb should be a straight, uniform line so that this direction can be better estimated. Typically, stream barbs influence the flow patterns for a distance downstream of 5 to 10 times L_e although there is much local variation. A limited stream barb spacing of 4 to 5 times L_e provides more consistent results.

h) Angle of Stream Barbs

The structure weir section must be oriented in an upstream direction such that the flow is directed away from the stream bank. The angle θ generally varies from 20° to 45° off a tangent to the bank, depending upon the curvature of the bend and the intended realignment of the thalweg. The tighter the stream bend, the smaller the angle, and for situations where R/W <3, it probably should be less than 20°. If the purpose is to maintain a deep thalweg near the stream bank, then a tight angle of 20° is required. A vector analysis, assuming a perpendicular flow direction from the weir alignment can be used to estimate the angle required to turn the flow.

i) Height of Stream Barbs

Height of the stream barb weir section H_w is related to the channel-forming or bankfull flow depth (approximately a 1.5 to 2.0 year flow event). The channel-forming or bankfull elevation is not necessarily the top of the bank. For most streams, bank full is equal to or slightly above ordinary high water. The height of the stream barb weir is generally limited as follows:

$$H_w = \frac{1}{3}D_a \text{ to } \frac{1}{2}D_a \qquad \text{(B.7)}$$

Where D_a= average channel-forming or bankfull flow depth

Once flows are more than 5 times the height of the stream barb, the relative effectiveness of the barb in redirecting flow is significantly reduced. The relative height between successive barbs is very important. The difference in height between barbs should approximate the energy grade line of the stream regardless of local variations in bed topography.

j) Width of Stream Barbs

Width of a stream barb generally ranges from 1 to 3 times the design D_{100} rock size. The width does not need to be more than two rock diameters and can even be the width of a single large rock at the tip of the barb. However, stream barbs with top width of a single stone are more susceptible to damage than structures which are multiple stones in width. Barb width may need to be increased (3 to 5 rock size) to accommodate construction equipment in large rivers or where necessary. Wider structures will result in a more uniform, stronger hydraulic jump. Therefore, wider structures should be used if a deep scour hole downstream of the barb is expected.

k) Profile of Stream Barbs

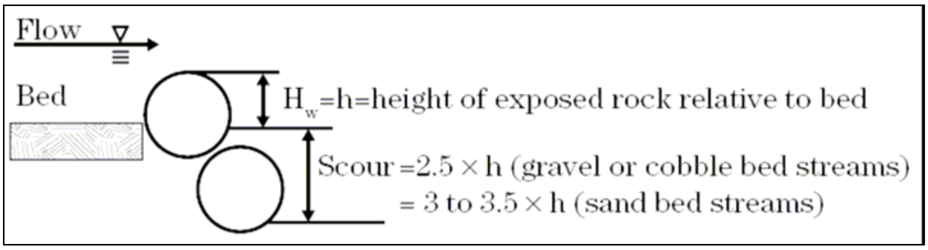
A stream barb is intended to function as a weir and therefore, the profile is nearly flat with a positive slope towards the bank (slope should not exceed 1V:5H). Stream barbs constructed with a negative slope or where rocks have been displaced resulting in a negative slope may force water closer to the bank, and thereby increase, rather than decrease erosion. The barb transitions from the weir section to the bank key on a steeper slope of 1V:1.5H to 1V:2H. The top of the key must be high enough to prevent water from flowing around and eroding behind the structure. Banks that are frequently overtopped will require a more extensive key that extends further back into the bank. Bank material will also need to be considered when designing the key dimensions.

l) Length of Bank Key

The purpose of the bank key is to protect the structure from flanking due to erosion in the near bank region. The length of the bank key is generally about half of the length of a short barb to $1/5^{th}$ the length of a long barb or 4 times the design D_{100} rock size. Bank key length should be at least 2.5m and not less than 1.5 times the bank height.

m) Depth of Bed Key

Bed key depth is determined by calculating the expected scour depth around the tip of the structure. Scour depth will likely exceed the depth of the thalweg. If a bed key is not incorporated, or if the bed key is too shallow, scour may erode the bed material downstream, causing the rock to fall into the scour hole. Higher barbs will result in greater flow convergence and thus greater scour depths. In order to reduce scour depths, the barb height should be decreased. The bed key is typically placed at a minimum depth of D_{100}. Scour depth can be estimated using the following:



If it is not feasible to excavate below the anticipated scour depth, the width of the weir section can be increased so that sufficient stone is available to launch into and armor the scour depth.

n) Hydraulics

The amount of flow forced over the stream barb can be approximated by the amount of channel area the barb crosses:

$$Q_b = \frac{A_b}{A_t} Q_t \quad \text{(B.8)}$$

Q_b = portion of channel-forming flow over the barb (m^3/s)
A_b = channel area the barb impacts (m^2)
A_t = total channel-forming flow area (m^2)
Q_t = total channel-forming flow (m^3/s)

In order for the barb to have an impact on the stream, $\frac{Q_b}{Q_t}$ should be greater than 0.1. The height of flow over the barb should be checked using a weir formula:

$$H = \left(\frac{Q_b}{CL_w}\right)^{2/3} \quad \text{(B.9)}$$

Q_b = flow over the barb (m^3/s)
C = broad crested weir coefficient (generally about 1.6)
L_w = weir length of barb (m).

The height of flow over the barb H added to the height of the barb H_w should not be more than 120% of the average channel-forming flow depth D_a, or excessive backwater effects will be created. The shallowest depth of water flow over the barb can be approximated by the formula:

$$y_2 = \frac{(D_a - h)}{2} \quad \text{(B.10)}$$

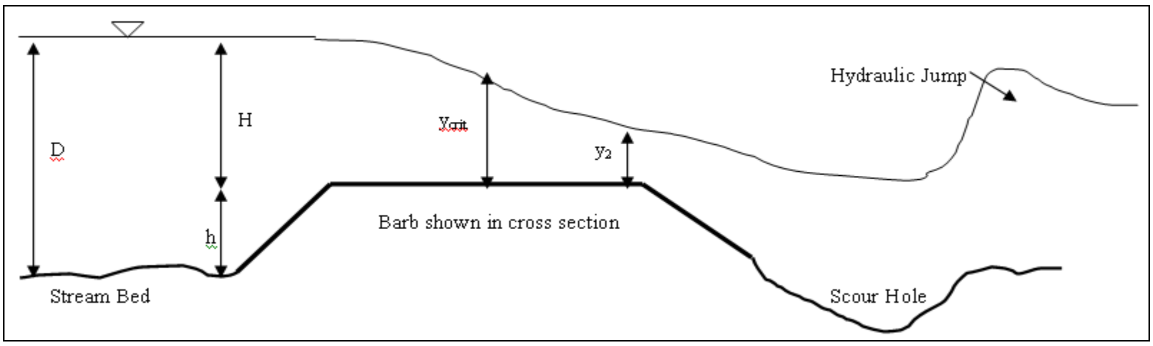
y_2 = the shallowest depth of flow passing over the barb (m)
D_a = average channel-forming flow depth upstream of the barb (m)
h = average height of the barb above the stream bed (m)

The force of the hydraulic jump can then be estimated by calculating the Froude number F :

$$F = \frac{Q_b}{L_w y_2 \sqrt{g y_2}} \quad \text{(B.11)}$$

g = acceleration due to gravity ($9.81 m/s^2$)

Froude number greater than 1.7 is required while Froude number greater than 2.5 is desired. To achieve a higher Froude number, increase the barb height H_w slightly.



APPENDIX C

VANE INSTALLATION GUIDELINES

Appendix C Vane Installation Guidelines

Guidelines for Installation of Vanes

Vanes are structures placed in an eroding streambed that cause the flow to be redirected, which results in the deposition of sediment on the eroding bank. When erosion occurs in the bend of a stream, the outside bank is significantly undermined by the flow from the straight portion of the stream colliding with the bank. The outside edge of the streambed is deepened as the bank erodes, but vanes stabilize the stream without affecting the sediment load and velocity of other parts of the stream.

Vanes are small, double-curved, patented structures (e.g. Iowa Vanes) for sediment management in rivers. They are designed to protect stream banks from erosion, maintain navigation depth and flood-flow capacity in rivers, and control sediment at diversions and water intakes.

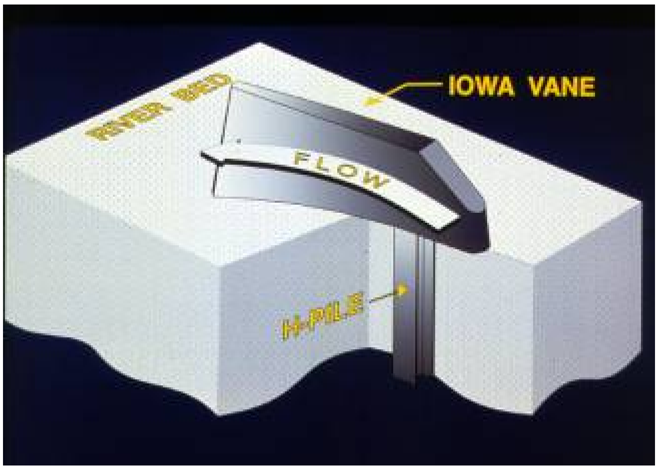


Figure C-1 A typical Vane

Use of vanes or panels for flow training was originally proposed by Russian engineers Potapov and Pyshkin in 1947. However, it is only more recently that efforts have been made to optimize vane design and document performance. The first known attempts to develop a theoretical design basis were by Odgaard and Kennedy (1983) and Odgaard and Spoljaric (1986). Odgaard and Kennedy's efforts were aimed at designing a system of vanes to stop or reduce bank erosion in river curves. In such an application, the vanes are laid out so that the vane-generated secondary current eliminates the centrifugal induced secondary current, which is the root cause of bank undermining. The centrifugal induced secondary current in river bends results from the difference in centrifugal acceleration along a vertical line in the flow because of the non-uniform vertical profile of the velocity. The secondary current forces high-velocity surface current outward and low-velocity near-bed current inward. The increase in velocity at the outer bank increases the erosive attack on the bank, causing it to fail. By directing the near-bed current toward the outer bank, the submerged vanes counter the centrifugal induced secondary current and, thereby, inhibit bank erosion. The vanes stabilize the toe of the bank. The vanes can be laid out to make the water and sediment move through a river curve as if it were straight. The upstream angle of the structure is critical.

Advantages and Disadvantages

- The toe of the bank is stabilized.
- Soil bioengineering should be used with the vanes to stabilize the bank. Once the sediment has been deposited at the bank, natural revegetation often occurs.
- The cross-section area and the sediment load upstream or downstream is not changed significantly.
- Iowa vanes are impractical in narrow stream channels; the channel width should be 5 to 6m.
- The vane system requires professional design.

- Iowa vanes should only be used in a sand bed channel.
- Vanes can tolerate debris because they are often submerged below the surface of the water.
- Vanes can cause damage to boats. They should be clearly labeled with signs and buoys.
- Various types of materials can be used to create a submerged vane.

Materials

- Preformed vanes or alternatively professionally designed vanes of materials such as wood, sheet pile, or concrete.
- Planks and pipe to construct vanes.
- Crane to lower prefabricated vanes into the water.
- Ram or hammer to drive the pipe into the streambed.

Preparation

- The simplest way to construct a stable vane is to use two metal tubes or pipes driven securely into the streambed.
- The pipes should be 2 to 3m apart and angled 20° to 25° toward the bank to establish the alignment of the vane against the stream.
- Planks should then be fastened between the tubes. Use the water surface as a reference point to level the planks.
- The length of each vane should be between 2 and 3m long (or about 3 times the vane height).
- The height of each vane should be about 300mm above average bed level and between 600 and 900mm (0.2-0.3 times design flow depth).
- Each vane should be no less than 25 to 75mm in thickness at the top of the vane.
- Each vane should be completely submerged in average flow.

Figure C-2 Installation of concrete vanes at low flow

Installation

- Installation of the vanes should begin at least one channel-width upstream from the bend where erosion is occurring.
- An array is a group of vanes next to each other; there should be 2 to 3 vanes in each array and at least three arrays before the area needing protection.
- The vanes within an array should be spaced 2 to 3 times the height of the vane.
- Between each array, there should be a distance of 15 to 30 times the height of a vane. The most upstream arrays can have a smaller amount of space between them, while those further downstream should have a greater distance between them, but not exceeding 30 times the height of the vane.
- Vanes do not need to be installed past the bend where erosion is occurring.

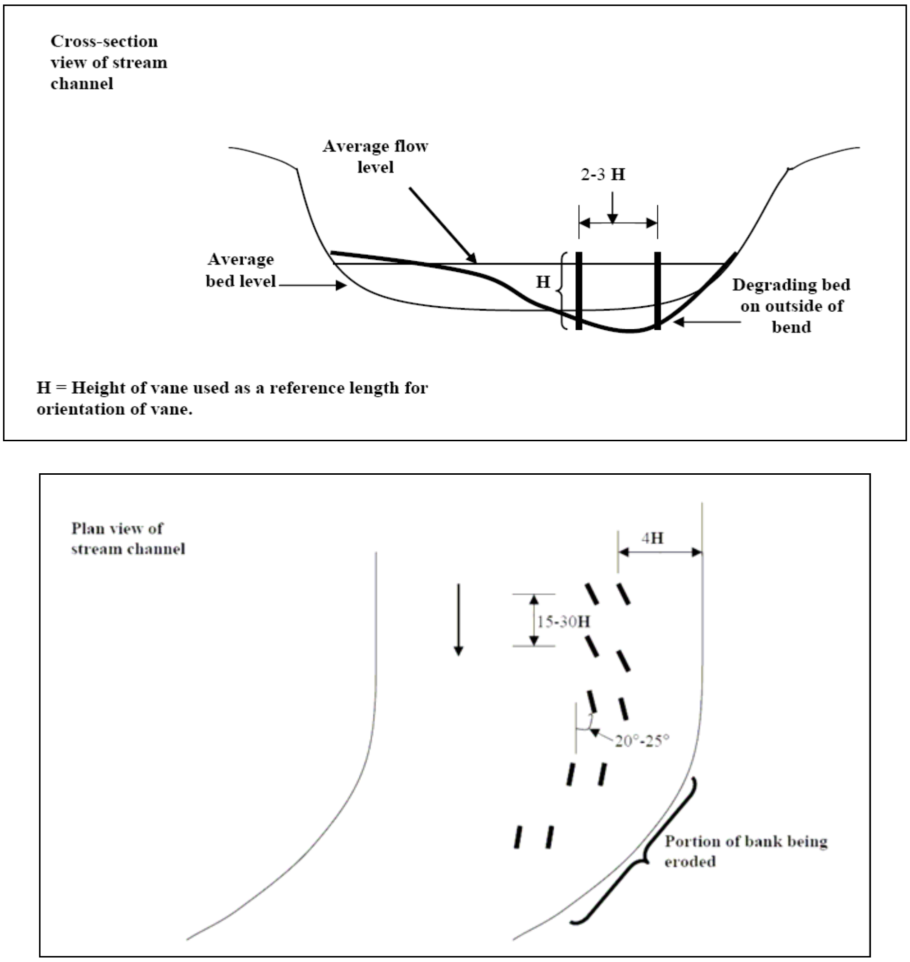


Figure C-3 Vane placement details

Figure C-4 Replacement of sediment on bank after installation of Vanes

References:

1. Odgaard, A. J., and Kennedy, J.F. (1983). "River-bend Bank Protection by Submerged Vanes." J. Hydr. Engrg., ASCE, 109(8), pp. 1161-1173.

2. Odgaard, A. J., and Spoljaric, A. (1986). "Sediment Control by Submerged Vanes." J. Hydr. Engrg., ASCE, 112(12), pp. 1164-1181.

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APPENDIX D

RIFFLE AND POOL (STEP-POOL) DESIGN EXAMPLE

Appendix D Riffle And Pool (Step-Pool) Design Example

A STEP-POOL STRUCTURE DESIGN PROCEDURES

Step-pool structures (vortex weirs) are being used to provide: (1) vertical stabilization during high flow; and (2) low-flow instream habitat in restoration of disturbed low-gradient streams. Features that purport to represent step-pool structures are being widely used to provide vertical stability in channel restoration projects and habitat enhancement in severely perturbed streams. Step-pool channels are characterized by an accumulation of cobbles and boulders into organized discrete transverse ribs spanning the channel (Montgomery and Buffington, 1997). The ribs form an alternating series of steps and pools resulting in a stepped, longitudinal stream profile. Step-pool structures are characteristic of relatively steep, coarse-grained (boulders), and confined mountain streams; they provide both grade control during high flows and instream habitat during low flows.

The alternating sequence of supercritical flow over the steps and subcritical flow in the pools provides the ability to overcome steep slopes by energy dissipation mainly through the formation of roller eddies. Under low-flow conditions, each step may be considered as a low-drop, grade-control structure, with a difference in elevation (H) between the upstream and downstream channel beds, at a discharge (Q), and a corresponding critical depth (y_C), such that the relative drop height, H/y_C, is equal to or less than 1. Step-pool formation requires: (1) near-critical to supercritical flow conditions over the bed and must be close to, but not exceed, the entrainment threshold for the larger particles (D_{90} or larger); and (2) high discharges and low sediment supply.

Spacing between steps is typically 1 to 4 channel widths; the spacing decreases with increasing channel slope and corresponds to maximum flow resistance. The spacing of natural step-pools can be approximated by

$$L = \frac{0.3113}{S^{1.188}} \tag{D.1}$$

Where: L is the average step length (m), and
S is the channel slope.

Large bed-forming material is mobilized during hydrologic events with recurrence intervals in the order of 20 to 50 years with the step-pools being reformed on the falling limb of the hydrograph. Field observations revealed several features common to most of the boulder-step structures. These features include the shape of the weir crest, arrangement and sizing of the boulders comprising the weir, and contraction-induced tailwater control for the pool (Figure D-1) (Table D.1). These features influence the hydraulic function of the structure and its habitat value.

The weir of the step-pool structure is generally composed of a few very large boulders that play a key role in the stability and function of the step. The "anchor" boulders are usually located at the ends of the weir, and/or may be dispersed along the weir. Anchor boulders are typically the largest size class found within the channel and are on the order of 1 m in diameter, providing stability to the weir and confinement of flow over the weir. Boulders are commonly arranged in a broad v-shape, with the apex of the weir pointing upstream. The number of anchor boulders per weir varied from 1 to 10, with an average of 4. Although no strong relation was found between the number of anchor boulders comprising the step and the channel width, the data indicate that wider channels have a greater number of anchor boulders per step. All sites should have at least 2 anchor boulders per structure. At channel widths greater than approximately 6 m, the minimum number of anchor boulders per structure is typically between 4 and 6.To determine the size of boulders for construction of man-made step-pool structures, the U.S. Army Corps of Engineers "steep slope riprap design" method was employed (COE, 1991). A D_{30} riprap size was computed using slopes of 2-, 5-, 7.5-, and 10-percent, and a unit discharge range from 0 to 4 m^2/s (Figure D-2). Unit discharge was multiplied by a concentration factor of 1.25 as outlined in the COE (1991) procedures. The data indicate that the minimum boulder sizes found in natural step-pool channels are in the same size range as specified by the riprap design procedure, but the mean natural step boulder size is significantly larger that the computed D_{30} size. It appears, therefore, that the COE riprap-sizing procedure can be used to compute the minimum rock sizes for constructed step-pool structures, but these should be supplemented with anchor boulders. It is recommended that anchor boulders be placed along the step-pool structure to provide additional support and stability.

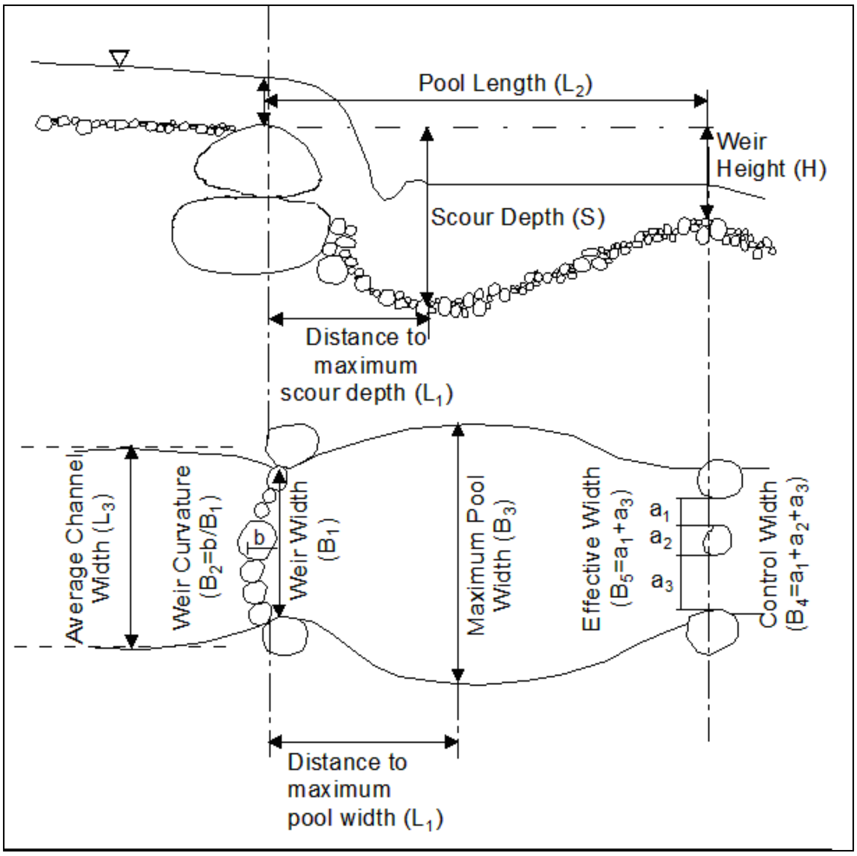

Figure D-1 Details of the measured dimensions of the step-pool unit. (Source: Thomas et al. 2000)

Table D.1 Summary of average dimensions of the step-pool structures.

Site Location	Step-Pool Dimensions (m)								
	Weir Width (B_1)	Weir Curvature (B_2)	Maximum Pool Width (B_3)	Width at Downstream Control (B_4)	Effective Width at Downstream Control (B_5)	Weir Height (H)	Scour Depth (S)	Pool Length (L_2)	Average Channel Width (L_3)
Browns Creek	3.1	0.0	4.0	3.5	3.1	0.2	0.3	3.9	3.5
Halfmoon Creek	6.9	0.1	6.1	4.8	4.8	0.6	0.5	7.0	8.8
Horn Creek	1.9	0.1	3.7	2.0	1.8	0.4	0.6	4.3	3.4
Little Cochetopa Creek	1.6	0.1	4.3	1.8	3.7	0.2	0.3	4.0	4.0
Middle Fork Cottonwood Creek	5.7	0.0	7.0	6.0	4.5	0.3	0.4	5.4	7.5
Newlin Creek	1.5	0.1	3.0	2.2	2.0	0.4	0.7	4.7	2.6
North Fork Lake Creek	7.0	0.1	8.0	7.7	5.9	0.2	0.3	5.3	8.9
Roaring River (RR-1)	4.6	0.0	5.8	6.4	5.3	0.2	0.5	6.6	4.6
Roaring River (RR-2)	6.4	0.0	6.4	4.3	4.3	0.1	0.3	3.1	4.6
San Miguel River	6.0	5.4	10.0	9.3	4.7	0.6	3.3	7.8	9.8

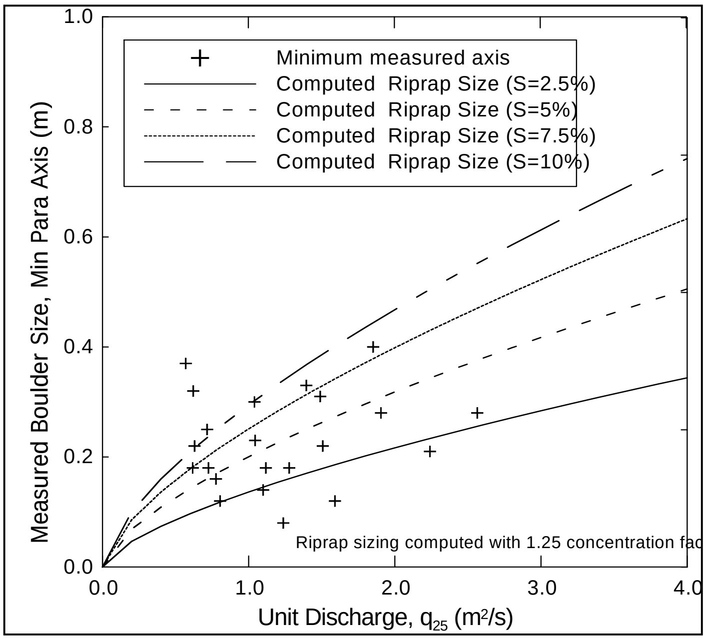

Figure D-2 Comparison of measured minimum parallel (to flow) boulder axis and computed D_{30} riprap sizing in m against 25 year unit discharge at different slopes.

The downstream tailwater control regulates the water-surface elevation of the pool, which in turn affects the energy dissipation and available habitat. The degree of downstream channel contraction is important in terms of function of the step-pool structure. Small amounts of contraction provide little control of the pool tailwater and create high velocities throughout the downstream pool. Too much contraction results in an elevated tailwater that may lead to sediment deposition within the pool and submergence of the weir. Statistical analysis (Thomas et al. 2000) of the natural steps indicated that the width of the downstream control should be approximately 90 percent of the weir width under low-flow conditions. The maximum pool width is approximately 20 percent larger than the weir width under low-flow conditions.

Design Procedure

The results from the above analysis were used to develop a design procedure for sizing step-pool structures. Spacing and step height criteria for constructed step-pool structures for grade-control purposes require a detailed investigation of the expected equilibrium gradient of the channel.

Step height is the independent variable in the design process. When constructing step-pool structures for channel stabilization purposes, the drop height will reflect the elevation loss that must be accommodated to stabilize the channel while meeting the low-drop criteria up to the 2-year discharge. Similarly, the step height may be chosen to determine habitat value in the downstream pool. The design process is as follows:

1. Determine the step height H required for the step-pool structure.
2. Calculate the existing average channel slope of the reach.
3. Calculate the active channel width for the reach.
4. Calculate the weir width.
5. Determine the 2-year and 25-year unit discharges for the weir.
6. Calculate the minimum D_{30} boulder size using the U.S. Army Corps of Engineers, 1991 procedure (Equation D.2) with the 25-year unit discharge q_{25}. The minimum rock size may have to be increased to allow for burial. This will reduce the potential for local scour on the downstream side of the weir.

$$D_{30} = \frac{1.95 S^{0.555}\ q^{2/3}}{g^{1/3}} \qquad \text{(D.2)}$$

Where: S = channel slope, and
q = unit discharge.

7. Compute the pool length using the Equation D.3:

$$\frac{\text{Pool Length}}{ACW} = 0.409 + 4.211\frac{H}{ACW} + 87.341\frac{S_0 q_{25}}{\sqrt{g}ACW^{3/2}} \quad : R^2 = 0.65 \qquad \text{(D.3)}$$

Where: ACW = active channel top width
q = unit discharge

8. Compute the scour depth using the Equation Equation D.4:

$$\frac{\text{Scour Depth}}{ACW} = -0.0118 + 1.394\frac{H}{ACW} + 5.514\frac{S_0 q_{25}}{\sqrt{g}ACW^{3/2}} \quad : R^2 = 0.69 \qquad \text{(D.4)}$$

Where: ACW = active channel top width
q = unit discharge

9. Compute the contraction at the downstream tailwater control for the 2-year discharge event using Equation D.5:

Effective Width at downstream control = 0.92 * Weir Width (D.5)

10. Compute the maximum pool width at the downstream tailwater control for the 2-year discharge event using Equation D.6:

Maximum Pool Width = 1.20 * Weir Width (D.6)

11. Compute the bank elevation to ensure all flow up to the design discharge is confined within the channel at the weir.

Reference Reach Design Approach

In this approach, a stable reach in nearby watershed with similar slope, channel dimensions, bed materials will be located for use as a reference. The reference reach should be surveyed with regards to details of pool shapes and sizes, step heights, slopes, bed material, etc. The data can then be used as blueprint for design.

Sizing Step-Pool with Rules of Thumb

General rules of thumb may also be used to help in sizing the step-pool dimensions as follows:

- Pool depths $\approx$ 600 to 1200 mm for most cases (almost can't make pools too deep)
- Pool widths $\approx$ 1.2 x upstream channel width
- In nature, $D_{90} \approx$ 600 to 900 mm at steps
- Max step height $\approx$ 450 to 600 mm (fish passage and stability)
- Step length $\approx$ 0.3113/(slope$^{1.118}$)
- Large boulders (900 mm) and logs are ideal constructed step materials
- Use "footer" boulders/logs offset 300 mm +/- downstream of "headers"
- Vary step height and length within stable range for natural appearance and function
- Backfill on upstream side of steps with on-site cobble or appropriately sized stone
- Channel side slopes 3:1 or flatter
- Install non-woven geotextile on upstream side of boulders/logs in step to prevent piping.

Example of of riffle-pool design

Stream data:

1 in 2 year discharge, Q_2:	17	m^3/s
1 in 25 year discharge, Q_{25}:	32	m^3/s
Average bed gradient, S:	0.03	
Bankful width, ACW:	9	m
Minimum flow:	0.05	m^3/s

Computations:

Step 1: Step height, H: 600 mm (Rule of thumb: 450-600)

Step 2: Average channel slope, S: 0.03

Step 3: Active channel width, ACW: 9 m

Step 4: Weir width: 6 m

Step 5: Unit discharge, q_2: 1.89 m^3/s

Unit discharge, q_{25}: 3.56 m^3/s

Step 6: Minimum boulder size, D_{30}: 0.3 m

Equation use:

$$D_{30} = \frac{1.95 S^{0.555}\ q^{2/3}}{g^{1/3}}$$

Step 7: Pool length: 7.20 m

Equation use:

$$\frac{\text{Pool Length}}{ACW} = 0.409 + 4.211\frac{H}{ACW} + 87.341\frac{S_0 q_{25}}{\sqrt{g}ACW^{3/2}} \quad : R^2 = 0.65$$

Step 8: Scour depth: 0.79 m (Rule of thumb: 600-1200mm)

Equation use:

$$\frac{\text{Scour Depth}}{ACW} = -0.0118 + 1.394\frac{H}{ACW} + 5.514\frac{S_0 q_{25}}{\sqrt{g}ACW^{32}} \quad : R^2 = 0.69$$

Step 9: D/s control width: 5.52 m (0.92 x channel width)

Step 10: Max. pool width: 7.2 m (1.2 x channel width)

Step 11: Step to step spacing, L: 20.9 m (Rule of thumb: 1 to 4 x width)

Equation used:

$$L = \frac{0.3113}{S^{1.188}}$$

Step 12: Water level at weir:

A backwater computation may be run using the Q_{25} discharge and the step-pool configurations to check that the water level does not exceed the bank level at the weir locations.

The profile of the Design Example is as shown below (Figure D-3):

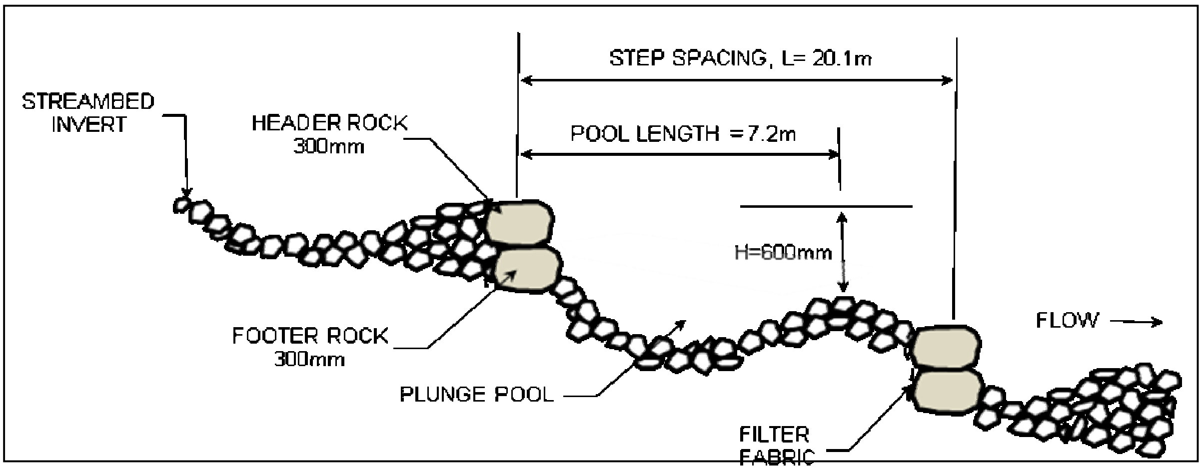

Figure D-3 Details of Step-pool Design Profile

References

1. Thomas, A., Abt, S., Mussetter, R.,and M. Harvey. (2000). "A Design Procedure for Sizing Step-Pool Structures", Joint Conference on Water Resource Engineering and Water Resources Planning and Management

2. Chin, A. (1989). "Step Pools in Stream Channels", Progress in Physical Geography. v. 13, pp. 391-407.

3. U.S. Army Corps of Engineers (1991). "Hydraulic Design of Flood Control Channels", EM 1110-2-1601.

4. U.S. Department of Transportation (1979). "Restoration of Fish Habitat in Relocated Streams", Federal Highway Administration.

5. Whittaker, J.G. and Jaeggi, M.N.R. (1982). "Origin of Step-pool Systems in Mountain Streams", Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 108, pp. 758-773.

APPENDIX E

DESIGN EXAMPLE FOR ROCK CHUTES

Appendix E - Design Example For Rock Chutes

DESIGN OF ROCK CHUTES

Rock chutes are used to safely convey water to a lower elevation in a river channel. These structures provide an alternative method of protecting the soil surface to maintain a stable slope and to dissipate a portion of the flow energy. Their applications are numerous such as channel stabilization, grade control, and embankment overtopping. Depending on the availability and quality of accessible rock materials, rock chutes may offer economic advantages over more traditional structures. Flow cascading down a rock chute is visually pleasing, and these structures offer aesthetic advantages for sensitive locations. A typical rock chute profile is shown in Figure E-1.

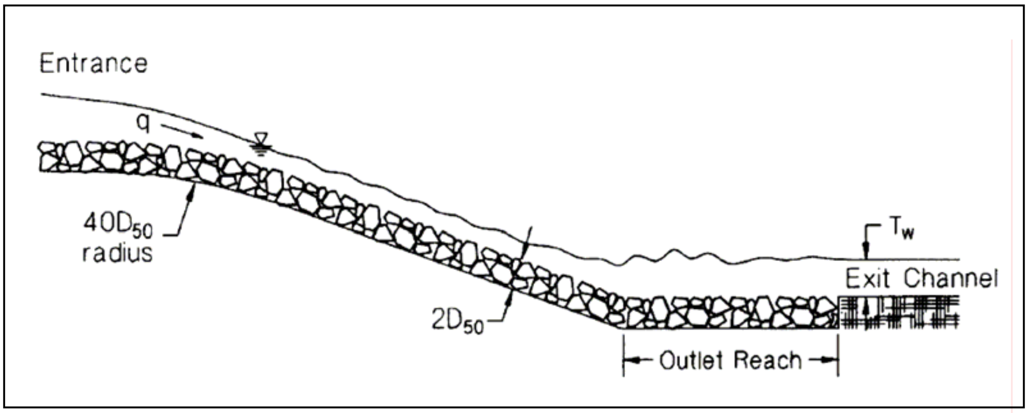

Figure E-1 Typical rock chute profile.

The following section on rock chute design is largely based on the review of previous work and testing carried out by Robinson et al. (1997). The tests were performed at the USDA-ARS Hydraulic Engineering Unit which focused on three specific areas: rock slope stability, roughness, and outlet stability.

Riprap Properties

The rock chutes testing was performed using predominantly angular crushed limestone with a D_{50} of 15 to 278 mm. The rock layers in all tests were $2D_{50}$ thick. The D_{50} is the particle size for which 50% of the material sample is finer. The median stone diameter and the D_{50} are considered equal. Rock used in this study displayed a coefficient of uniformity ($C_u = D_{60}/D_{10}$) of 1.25 to 1.73. The specific gravity of the stones ranged from 2.54 to 2.82. The geometric standard deviation ($\Phi_g = D_{84.1}/D_{50} = D_{50}/D_{15.9}$) ranged from 1.15 to 1.47 with all but one rock sample ranging between 1.31 and 1.47. The length to width ratio (L/B) ranged from 1.98 to 2.36. The geometric stone properties were similar for all rock sizes, and the gradations exhibited by these materials were more uniform than well graded.

Failure was defined as the flow condition that exposed the underlying geofabric or bedding material. The rock chute surface typically experienced the greatest damage just downstream of the crest on the sloping section. Test configurations used a $40D_{50}$ radius to improve the flow transition between the horizontal approach section and the sloping chute (see Figure E-1). While this radius provides improved flow conditions for the larger slopes, the influence of this radius diminishes as the slope decreases. While flow in these chutes tends to transition to normal depth relatively rapidly, the area most subject to failure is the upper reach of the chute just below the crest.

Rock chutes become more stable as the stone size increases and/or the slope decreases. A plot of the highest stable unit discharge (q) in $m^3/s/m$ versus the product of the median stone size (D_{50}) and the bed slope (S_o) in decimal form provides a convenient means of data separation (Figure E-2). A two-stage prediction equation was developed from the stability tests as follows:

$$q = 9.76E - 7D_{50}^{1.89}S_o^{-1.50} \quad S_o < 0.1 \tag{E.1}$$

$$q = 8.07E - 6D_{50}^{1.89}S_o^{-0.58} \quad 0.1 \le S_o \le 0.4 \tag{E.2}$$

Where
q = highest stable unit discharge ($m^3/s/m$)
D_{50} = particle size for which 50% of the sample is finer (mm)
S_o = decimal slope (dimensionless)

Equations E.1 and E.2 apply only to rock chutes constructed with angular riprap with a rock layer thickness of $2D_{50}$ These equations were developed for a rock specific gravity ranging between 2.54 and 2.82, and a geometric standard deviation ranging from 1.15 to 1.47. They have not been verified for slopes less than 2% or greater than 40%. These empirical functions, shown graphically in Figure E-2, envelope all of the ARS test data above a slope of 10% and most of the ARS data below 10%. Both equations produce the same results with minor roundoff error at a slope of 10%.

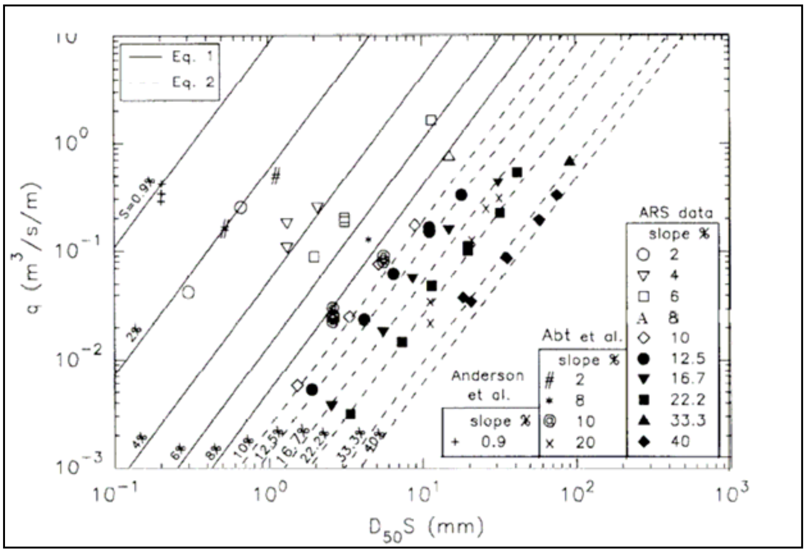

Figure E-2 Rock chute stability data
(Source: Robinson K.M., Rice C. E., Kadavy K. C. , 1997)

Data taken from Abt and Johnson (1991) are also plotted on Figure E-2 after converting their failure discharges to a highest stable discharge. This data agrees very well with the ARS data. Data from Anderson et al. (1970) for a slope of just under 1% is also plotted and it shows that it is reasonably predicted by Equation 1 (after adjustment made from rounded stone to angular stone). Equation E.1 and E.2 are simple and easy to apply. Caution should be exercised if Equation E.1 or E.2 are applied outside the data base from which they were developed. Equation E.2 should not be used for slopes greater than 40%.

Boundary Roughness

In the design of a rock chute, the Manning equation is used equation for expressing flow resistance in open channels.

$$n = \frac{R^{2/3}S^{1/2}}{V} \tag{E.3}$$

where:
n = Manning roughness coefficient
R = hydraulic radius (m)
V = average flow velocity (m/s)
S = energy gradient

Flow resistance is a function of the flow depth above the effective top-of-riprap elevation. While there is no recommended procedure for determining the effective top-of-riprap elevation, an accurate value is necessary to determine the Manning roughness coefficient. An error in the flow depth translates into a much larger error in the Manning coefficient. For example, a 10% error in the flow depth translates into a 17% error in the n value. The effective top-of-riprap elevation was determined using the measured unit discharge through the riprap, measured flow depths, and the Stephenson (1979) empirical equation for velocity through rock material:

$$V_m = n_p \left(\frac{S_o g D}{K'} \right)^{1/2} \qquad \text{(E.4)}$$

where:
V_m = velocity through rock (m/s)
n_p = porosity
g = gravitational acceleration (9.81 m/s^2)
K′ = a dimensionless friction factor
D = representative rock diameter in m (use D_{50} in m)

Abt et al. (1987) presented values for n_p of 0.44 to 0.46 for angular riprap. The factor K′ is defined by Stephenson (1979) as:

$$K' = K + \frac{800}{R_e} \qquad \text{(E.5)}$$

where:
K = 4 for crushed rock
R_e = Reynolds number ($dV/n_p\upsilon$)
υ = kinematic viscosity

The values of 800/R_e were small (< 0.01); therefore, it was assumed that K′ = K = 4. Using the measured flow depths at different percentage water coverage of the riprap, Equation E.4 was used to calculate the velocity through the rock materials. The maximum flow depth with good agreement between calculated q_m and measured q_m occurred at about 95% coverage of the riprap. The effective top-of-riprap elevation was selected as the flow depth for which 95% of the riprap was covered. For practical design purposes, the effective top-of-riprap elevation is considered to be at the top of the 2D_{50} thick layer.

The Manning n was calculated using the surface discharge and average depths measured in the middle third of the slope length. The stable discharges near failure of the riprap were used in the analysis, since these discharges should result in the highest flow resistance. Using the wide channel assumption where the hydraulic radius R = d and with V = q_s/d, and S = S_o Equation E.3 can be used to calculate n. With these substitutions Equation E.3 becomes:

$$n = \frac{d^{5/3} S_o^{1/2}}{q_s} \qquad \text{(E.6)}$$

where
d = flow depth above the effective top-of-riprap
q_s = surface unit discharge (q_t - q_m)

The data of Rice et al. (1998) and Abt et al. (1987) both show a strong tendency for n to increase as the channel slope increases. Rice et al. (1998) combined the two data bases and developed the following roughness relationship:

$$n = 0.0292 (D_{50} S_o)^{0.147} \qquad \text{(E.7)}$$

This relationship was developed for angular riprap on slopes between 2.8 and 33.3%. Rice et al. (1998) also expressed the combined data bases in terms of relative roughness $(8/f)^{1/2}$ and relative submergence (d/D_{84}):

$$\left(\frac{8}{f}\right)^{1/2} = 5.1\log\left(\frac{d}{D_{84}}\right) + 6 \qquad \text{(E.8)}$$

Equation E.8 should provide reasonable estimates of the Darcy-Weisbach friction coefficient (f) for loose, angular riprap.

Outlet Stability

The riprap size required for outlet stability was also examined in two separate flumes and two field-scale structures (Rice et al. 1998b). Angular riprap with a D_{50} ranging from 52 to 278 mm was tested at slopes ranging from 8 to 40%. For a specific discharge, rock size, and slope, the movement of riprap in the outlet section was observed for a range of tailwaters (Tw) to median stone size (D_{50}) ratios of 3.0, 2.0, and the minimum resulting from the horizontal riprap section and downstream channel resistance.

The centerline bed surface profiles were measured before and after each test flow. Typical water surface profiles in the outlet reach (Figure E-3) show that without a forced tailwater, the water surface stabilizes at a tailwater elevation slightly less than $2D_{50}$ due to the outlet reach and downstream channel resistance. No movement of the riprap was observed in the outlet reach of the chute for any test. These tests provide evidence that the riprap size required for stability along the bed slope will be stable for the outlet reach. Also, the results show that the minimum tailwater that occurs as a result of the outlet reach and downstream channel resistance is sufficient to ensure stability of the riprap in the outlet reach.

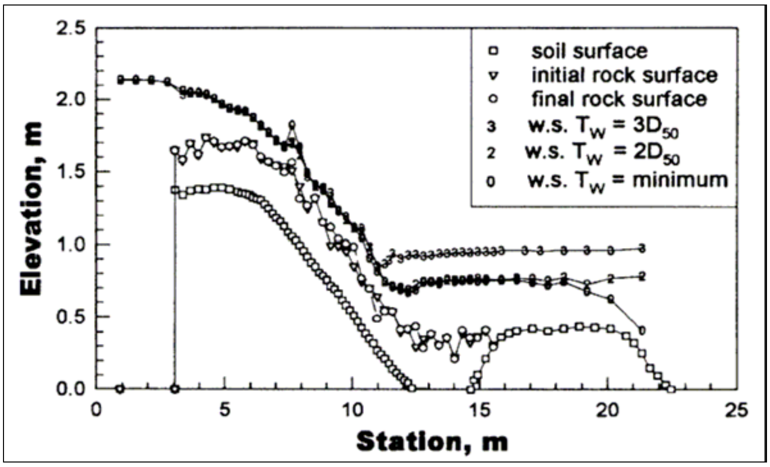

Figure E-3 Bed and water surface profiles, 22.2% slope, D_{50} =188 mm, and q = 0.351 $m^3/s/m$ (Source: Robinson K.M., Rice C. E., Kadavy K. C. , 1997).

Observations were made during each test to establish the required length of horizontal riprap downstream of the sloping section. For most tests, the primary attack on the riprap in the outlet reach extended to $12D_{50}$ downstream of the sloping section. In a limited number of tests, this attack continued to approximately $14D_{50}$ downstream. Therefore, a horizontal reach length of $15D_{50}$ or more is recommended downstream of the sloping chute. The elevation of the top of riprap at the exit of the outlet reach should be at or below the downstream channel bed elevation to prevent unraveling or sloughing of the riprap. Unraveling of the riprap in the outlet reach could result in failure of the rock chute. The potential for bed degradation downstream of a chute should be considered when establishing the riprap elevation.

EXAMPLE FOR ROCK CHUTE DESIGN

In most cases the design discharge is known, and the bed width is varied to accept this flow. The bed slope can also be adjusted to obtain a desired stone size.

Given:
Energy slope (S) = Bed slope (S_o) = 0.20
Channel bottom width (B) = 5 m
Channel side slopes (Z) = 2:1
Total discharge (Q) = 3.0 m^3/s

Find:
Required median stone size (D_{50})
Manning's roughness coefficient (n)
Unit discharge through the rock mantle (q_m) and surface unit discharge (q_s)
Flow depth (d)

The design is applicable for angular crushed rocks placed in a $2D_{50}$ thick layer. The effective top-of-riprap level is assumed to be $2D_{50}$ above the subgrade. Equation E.2 is used to determine the stone size required for rock slope stability.

The unit discharge (q) is 0.6 $m^3/s/m$. Since the channel is trapezoidal, the unit discharge will actually be slightly less. Rearranging Equation E.2 to solve for D_{50} yields the following expression:

$$D_{50} = \left(\frac{qS^{0.58}}{8.07E-6} \right)^{1/1.89} \qquad \text{(E.9)}$$

If q = 0.60 $m^3/s/m$ and S = 0.20, then D_{50} = 231 mm and from Equation E.7,

$$n = 0.0292(D_{50}S_o)^{0.147}$$

Substituting D_{50} = 231 mm and S_o = 0.20 into above equation yields a Manning roughness coefficient of n = 0.051. The surface flow unit discharge q_s = (q_t - q_m). The total unit discharge (q_t) is 0.60 $m^3/s/m$, and the unit discharge through the mantle (q_m) = V_m ($2D_{50}$). The velocity through the rock mantle (V_m) is determined from Equation E.4.

$$V_m = n_p \left(\frac{S_o gD}{K'} \right)^{1/2}$$

With n_p = 0.45, S_o = 0.20, g = 9.81 m/s^2, D = 0.231 m, and K' = 4, V_m is calculated to be 0.151 m/s.
Therefore, q_m = (0.151 m/s) (2) (0.231 m) = 0.070 $m^3/s/m$.
Also, q_s = 0.60 $m^3/s/m$ - 0.070 $m^3/s/m$ = 0.53 $m^3/s/m$.
From Equation E.6,

$$n = \frac{d^{5/3} S_o^{1/2}}{q_s}$$

Rearranging the equation to calculate the flow depth above the effective top-of-riprap (d) yields:

$$d = \left(\frac{nq^s}{S_o^{0.5}} \right)^{3/5} \qquad \text{(E.10)}$$

Using Equation E.10 the flow depth (d) = 0.186 m.

The horizontal length of chute, $15D_{50}$ = (15)(0.231m) = 3.46m.

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APPENDIX F

GUIDELINES FOR STREAM DEFLECTION/CONCENTRATION STRUCTURES

Appendix F Guidelines For Stream Deflection/Concentration Structures

A) ROCK TOE REVETMENT

Description

A rock toe revetment involves placing a course of properly sized riprap at and above the streambank toe. This technique provides protection against erosion and creates a stable toe for the bank.

Appropriate uses

- In areas of the lower streambank that are prone to erosion and require permanent, rigid toe protection.
- As the toe protection in an integrated bank treatment.

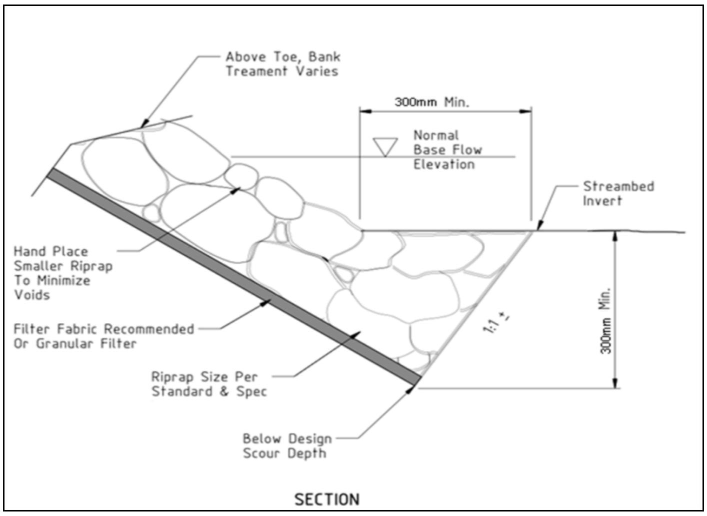

Figure F-1 Rock Toe Revetment

Limitations

- Toe protection should not be used on actively incising streams unless measures have been taken to promote vertical stability.
- Riprap in channels is perceived as "unnatural" and may not be considered favorable by some stakeholders.

Design Requirements and Procedures

- Refer to riprap design example in APPENDIX G for design requirements.
- Treatment must extend into the stream bed below the design scour depth and to an elevation above the normal baseflow elevation.

Material Specifications

- Riprap: Riprap per standard and specification for sill rocks, bank armoring, and toe protection.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be used in conjunction with a filter fabric.

Construction Recommendations

- Void spaces may need to be hand chocked to achieve aesthetic slope and structural stability.
- Requiring inspection of riprap or a gradation report prior to installation may prevent placing of improperly sized material.

- Requires the use of heavy equipment for excavating the trench along the toe of the bank and for placement of the rock.

Installation Guidelines

- Excavate a trench along the toe of the streambank to slightly below the design scour depth.
- Place filter cloth or install granular filter along backside of trench. Place filter fabric loosely and evenly on the prepared slope and secured with staples on 600mm centers. Adjacent strips should overlap 300mm and be stapled on 300mm centers. The upstream or upslope filter fabric should always be placed over the downstream or downslope filter fabric. If the filter fabric is torn or damaged, it should be repaired or replaced.
- Place riprap starting in the bottom of the trench working up the bank. Riprap may have to be hand placed in voids to achieve desired result. Use smaller rock (<D15) to fill voids.

B) ROCK CROSS VANES

Description

A rock cross vane is a stone structure consisting of footer and vane rocks constructed in a way that provides grade control and reduces bank erosion. The vane is composed of a center section perpendicular to the streambanks joined to two arms that extend into the streambank at the Q_{bkf} height. The rock vane accumulates sediment behind the vane arms, directs flow over the cross vane, and creates a scour pool downstream of the structure.

Appropriate uses

- Where stabilization of a vertically unstable stream bed requires grade control.
- To direct erosional forces away from the streambanks and to the center of the channel.
- When fish habitat enhancement and grade control are both desired.
- For bridge protection, cross vanes provide grade controls, prevent lateral migration of channels, increase sediment transport capacity and competence, and reduce footer scour.
- To enhance or create recreational paddling opportunities.
- Used in riffle and pool (step-pool) construction.
- Most suitable for rapid-dominated stream systems with gravel/cobble substrate.

Limitations

- The Qbkf height must be accurately located for the stream as the vane arm is set into the streambank at the Qbkf elevation.
- Rock cross vanes used in streams with a significant portion of sand, silt or clay in their beds must be sealed using filter fabric and/or a properly sized and placed open class aggregate.
- Large rock size requirements make it difficult to use in small streams.
- Requires heavy equipment and skilled operators to place rock correctly.
- Rock may sink or subside in streams with sand and clay beds, which makes proper construction difficult. Additional foundation design may be required.

Design Requirements and Procedures

- Vane arms should intersect the bank at an angle between 20 and 30 degrees. The angle is measured upstream from the tangent line where the vane intercepts the bank. A smaller angle produces a longer arm. A longer arm provides more linear length of bank protection.
- Vane arm slopes range from 2-15 percent. The center vane is flat (no slope). When designing cross vanes in larger systems, a 2-7 percent slope can result in excessive vane arm lengths. The designer can choose a steeper slope for the vane arms when practical. However, steeper vanes tend to be less stable.
- Specify elevation and offset values for both ends of the vane arms. This ensures exact placement of the structure by the contractor.

- Always use at least two vane rocks for the middle 1/3 of the structure. Streams have a tendency to erode around a single vane rock in the middle of the structure.
- Rock cross vanes may create blockages to fish migration. Vane rocks in the center 1/3 of the structure can be gapped to allow fish passage. However, when rocks are gapped, it is important to understand that the top of the footer rock becomes the invert elevation for grade control, not the top of the vane rocks.
- Designer must specify a design depth for the scour pool immediately downstream of the cross vane. A scour depth analysis is recommended to aid in specifying the depth.
- Cross vane arms must terminate at the Q_{bKf} elevation. If the top of bank is above Q_{bKf} elevation, then a floodplain bench should be created at the Q_{bKf} elevation.
- Rock cross vanes should be designed for a maximum vertical drop (protrusion height) of 150mm. If more than 150mm of drop is required over a short section of stream, use a series of step.
- For designs using multiple cross vanes to achieve grade control the following rule of thumb can be used to determine spacing of structures along the stream channel:

$$P_S=8.2513S^{-0.9799} \qquad \text{(F.1)}$$

Where P_S=the ratio of pool to pool spacing/Q_{bkf} width
S=Channel slope in percent

This relationship is derived from data on natural streams and rivers with slope generally greater than 2%.

Material Specifications

Rock: Footer and vane rocks must be large enough to achieve the design height and appropriately sized to resist movement due to stream flow characteristics. Rocks shall be relatively rectangular in shape, uniform in size, and have a minimum intermediate (b) axis greater than 500mm at a minimum. An example of rock size as a function of Q_{bkf} shear stress is given below:

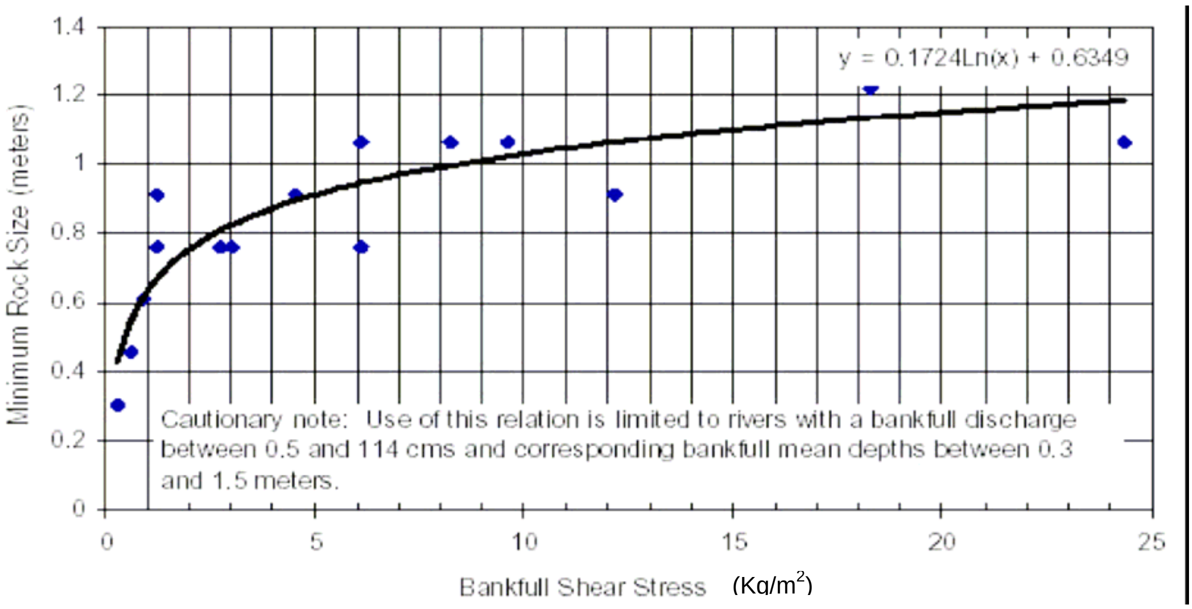

Figure F-2 Minimum Rock Size for Rock Cross Vane's as a function of Q_{bkf} shear stress (Source: Rosgen 2001).

- Riprap: Riprap per standard and specification for sill rocks, bank armoring, and toe protection.
- Open Class Aggregate: If used for sealing behind structure, should be properly sized to be minimally mobilized and displaced in supercritical flow events.

- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.

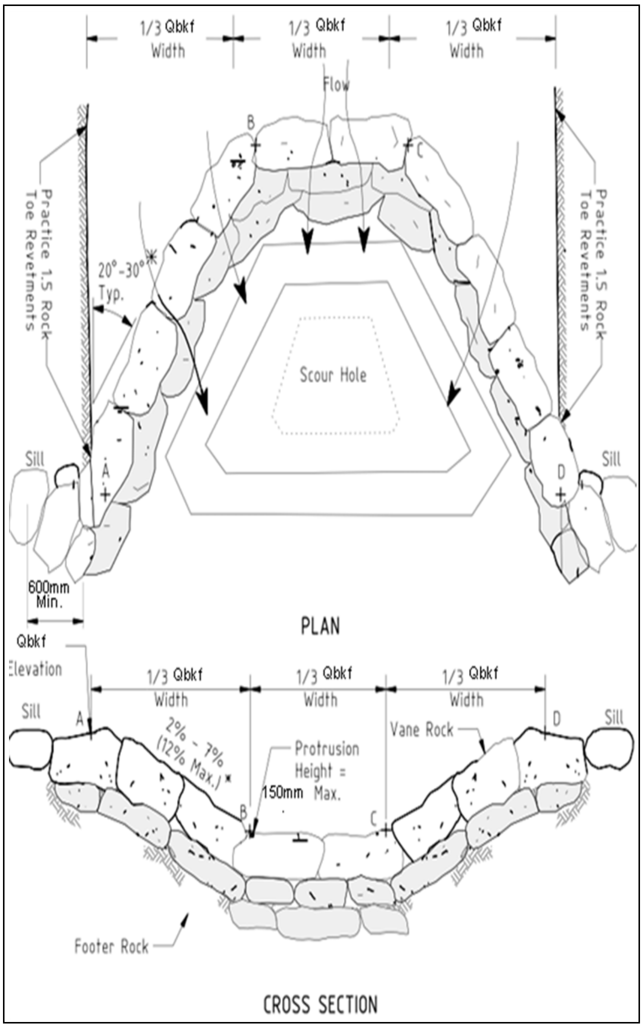

Figure F-3a Rock Cross Vane

Construction Recommendations

- Placement of rock requires a back hoe or hydraulic excavator.
- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- Rock cross vanes must be sealed with filter fabric, a properly sized and placed open class filter aggregate, and/or riprap if the channel bed material is fine enough to pass the structure. This is especially true in sand, silt, and clay stream beds. Material passing through the structure can fill the scour pool. In addition, passing of bed material undermines one of the key benefits of the structure, which is the accumulation of sediment behind the rock cross vane.
- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and to the Q_{bkf} elevation in the streambank for the center section and arms of the cross vane. The trench should be perpendicular to the streambanks in the middle 1/3 Q_{bkf} width for the center section and excavated to the design angle in the 1/3 Q_{bkf} width for each arm. The vane arms should be properly tied into the bank at the Q_{bkf} elevation. Excavate a Q_{bkf} bench if the top of bank is not at the Q_{bkf} elevation. The trench shall be excavated to the minimum footer rock depth.

- Place one or two courses of footer rocks to the minimum footer rock depth. The minimum footer rock is measured from the stream bed invert and is equal to a depth 3 times the protrusion height of the vane rock for cobble and gravel bed streams and 6 times the protrusion height for sand bed or finer streams. Be sure to leave space above the footer rocks for the below invert portion of the vane rocks.
- Place vane rocks on top of footer rocks so that each half of the vane rock rests on one half of a footer rock below. Offset the vane rock in the upstream direction and place so they slope slightly against the flow direction. A portion of the vane rocks should be below the stream bed invert with a portion above the invert to the specified protrusion height. The maximum protrusion height is 150mm.
- Extend the structure into the bank a minimum of 600mm at the Qbkf elevation, and armor with riprap upstream and downstream as needed for stability.
- At the Qbkf elevation, create a sill of placed rock perpendicular to the streambank extending away from the end of the vane arm. Construct the sill per Cut-Off Sills and Linear Deflectors. The rock should be smaller than the vane and footer rocks but large enough to resist displacement during high flow events.
- Seal the structure on the upstream side for streams with a high proportion of sand, clay, and silt bed material.
- Excavate the scour pool to the design depth.

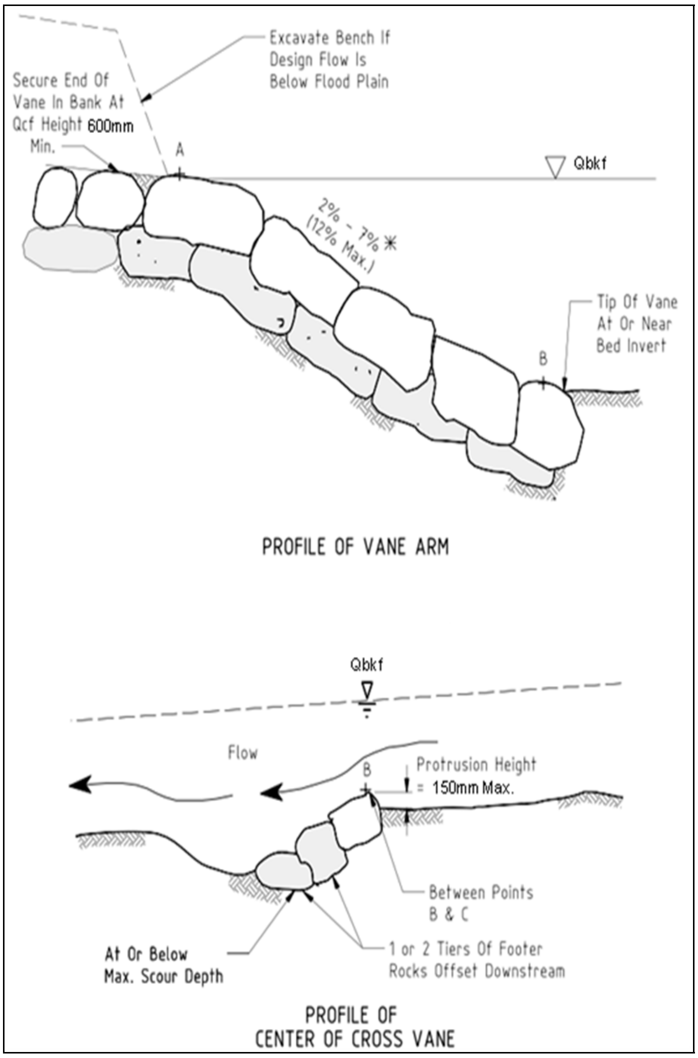

Figure F-3b Rock Cross Vane

C) ROCK VORTEX WEIRS

Description

A rock vortex weir consists of footer and vane rocks arranged to provide grade control, provide scour hole, and reduce bank erosion. The form of the rock vortex weir is parabolic and spans the Q_{bkf} channel width. The rock vortex weir accumulates sediment behind the weir arms and creates a scour pool downstream of the structure.

Appropriate uses

- Can be used in larger systems but also in smaller streams where the Q_{bkf} width limits the use of a rock cross vane.
- Where stabilization of an unstable stream bed requires providing a fixed stream bed elevation.
- To direct erosional forces away from the streambank and to the center of the channel.
- When fish habitat enhancement and grade control are both desired.

Limitations

- Vortex weirs can be used in place of cross vanes, but are more difficult to construct correctly, due to the critical spacing of the gaps in the structure.
- The Qbkf height must be accurately located for the stream, as the weir is set into the streambank at the Qbkf elevation.
- Vortex weirs used in streams with a significant portion of sand, silt or clay in their beds must be sealed using filter fabric or a properly sized and placed open class aggregate.
- Smaller rock sizes may be used due to size constraints of the stream; however, rock must be sized to withstand anticipated flow conditions as well as movement by the public.
- Rock may sink or subside in streams with sand and clay beds, which makes proper construction difficult.
- In urban watersheds and smaller streams, litter and debris may clog the gaps in the structure.

Design Requirements and Procedures

- Vortex weirs should intersect the bank at an angle between 20 and 30 degrees. The angle is measured upstream from the tangent line where the weir intercepts the bank. A smaller angle produces a longer arm. A longer arm provides more linear length of bank protection.
- Weir arm slopes are typically 2-7 percent. The designer can choose a steeper slope for the weir arms when practical. A higher slope can be used, but the structure will be less stable.
- Specify elevation and offset values for both ends and the center of the structure. This ensures exact placement of the structure by the contractor.
- Designer must specify a design depth for the scour pool immediately downstream of the vortex weir. A scour depth analysis is recommended to aid in this effort.
- The vortex weir must terminate at the Qbkf elevation. If the top of bank is above Qbkf, the weir arms should be properly tied into the bank at the Qbkf elevation and a Qbkf bench must be created at the Qbkf elevation.
- Rock vortex weirs should be designed for a maximum vertical drop of 150mm. If more than 150mm of drop is required over a short section of stream, use a series of step pools with 150mm drops as shown in section J) Step-pools below.
- For designs using multiple vortex weirs to achieve grade control, the following rule of thumb can be used to determine spacing of structures along the stream channel.

$$P_s=8.2513S^{-0.9799} \tag{F.2}$$

Where P_s=the ratio of pool to pool spacing/Q_{bkf} width
S=Channel slope in percent

This relationship is derived from data on natural streams and rivers with slope generally greater than 2%.

Material Specifications

- Rock: Footer and weir rocks must be large enough to achieve the design height and appropriately sized to resist movement during storm events.
- Riprap: Riprap per standard and specification as needed for bank armoring, and toe protection.
- Open Class Aggregate: Used for sealing behind structure. Should be properly sized to be minimally mobilized and displaced in supercritical flow events. Salvaged alluvial channel material can be substituted for aggregate if properly sized.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.

Construction Recommendations

- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and to the Qbkf elevation in the streambank for the vortex weir. The trench shall be excavated to the minimum footer rock depth. Excavate a Qbkf bench if the top of bank is not at the Qbkf elevation.
- Place one or two courses of footer rocks to the minimum footer rock depth. The minimum footer rock is measured from the stream bed invert and is equal to a depth 3 times the protrusion height of the apex weir rock for cobble and gravel bed streams and 6 times the protrusion height for sand bed or finer streams. Be sure to leave space above the footer rocks for the below invert portion of the weir rocks.
- Place weir rocks on top of footer rocks so that each half of the weir rock rests on one half of a footer rock below. Offset the weir rock in the upstream direction and place so the weir rock slopes slightly against the flow direction. A portion of the weir rocks should be below the stream bed invert with a portion above the invert to the specified protrusion height, typically 1/10th the Qbkf depth.
- Provide gaps in the weir rocks in the middle third of the structure. Ensure the middle third of the structure is properly shaped to direct the flow into the center of the channel.
- Extend the structure into the bank a minimum of 600mm at the Qbkf elevation, and armor upstream and downstream as shown in A) Rock Toe Revetment.
- At the Qbkf elevation, create a sill of placed rock perpendicular to the streambank extending away from the end of the vane arm. Construct the sill per I) Cut-Off Sills and Linear Deflector construction. The rock should be smaller than the vane and footer rocks but large enough to resist displacement during high flow events.
- Seal the structure on the upstream side for streams with a high proportion of sand, clay, and silt bed material as for B) Rock Cross Vanes.
- Excavate the scour pool to the design depth.

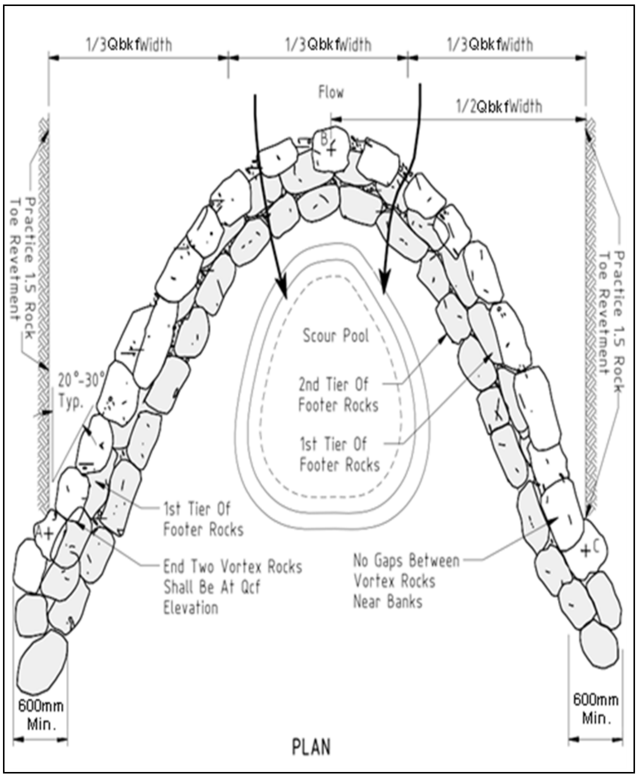

Figure F-4a Rock Vortex Vane

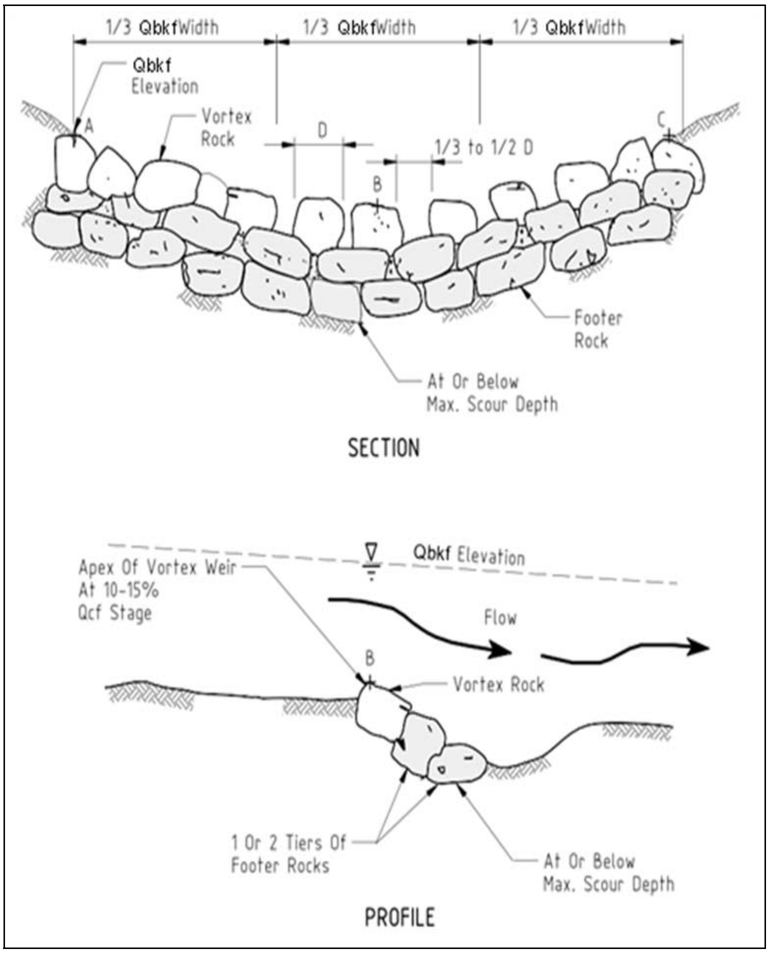

Figure F-4b Rock Vortex Vane

D) LOG DROPS AND V LOG DROPS

Description

Log drop structures are grade control structures made of wood logs that provide a fixed bed elevation and a downstream scour pool that provides habitat value. Log drop structures are typically used in high gradient (>3% slope), perennial and intermittent headwater streams, and ephemeral gullies.

Appropriate uses

- For use in channels with slope >3%, where step-pool morphology is desired. Log drops can be built in a series and function as Step Pools.
- Potentially useful in coastal plain streams. These streams are influenced by large, woody debris. Log drops more closely mimic naturally occurring grade control points in these stream systems than rock structures.
- For small erosional gully repair. Log drops can be built in series on these systems to provide grade control.

Limitations

- In flatter streams (<4% slopes) the channel tends to migrate around structure.
- Structure may biodegrade over time, but may last decades.
- Height of drop and width of log may create barriers to fish migration.

Design Requirements and Procedures

- Designer must determine maximum scour depth for scour pool.
- Maximum drop from bottom of notch to the water surface elevation should be less than or equal 300mm.

Material Specifications

- Logs: 300+ mm in diameter, rot-resistant logs for footer and drop log. Length should be equal to 1.8 times the channel width from toe of bank to toe of bank. If two logs are stacked, place flat to allow better stacking.
- Open class aggregate: Used for lining plunge pools. Aggregate should be properly sized to be minimally mobilized and displaced in supercritical flow events. Salvaged channel material can be substituted for aggregate if properly sized. For larger structures, riprap can be used.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.
- Anchors: 12mm diameter minimum rebar or drift pin for anchoring logs into place. Anchor must have sufficient length to pass through both logs and enter the ground at least 300mm.

Construction Recommendations

- Require an inspection of logs and anchors before they are placed. It is important that properly sized logs and anchors be installed to protect against structural failure.
- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.

Installation Guidelines

- Excavate a trench across the bottom of the stream bed and lower bank area to accommodate the log drop structure.

- Place the bottom course of footer logs below the maximum scour depth. Ensure that the logs extend into the banks for a distance equal to 0.4 times the width of the channel bottom.
- Place the notched drop log on top of the footer log. Ensure that the notch is in the center of the channel and is of appropriate dimensions to maintain the scour pool. Secure logs with anchors at a maximum spacing of 600mm on center. A single log can be both the footer and the drop log if it is a large enough diameter. For V-weir drops, attach the brace logs behind the drop log at a 90-degree angle with an anchor.
- Place filter fabric behind the drop log and along the bottom of the stream bed. Cover filter fabric with an appropriately sized open class aggregate or salvaged alluvial channel bed material.
- Excavate the scour pool to the design depth.

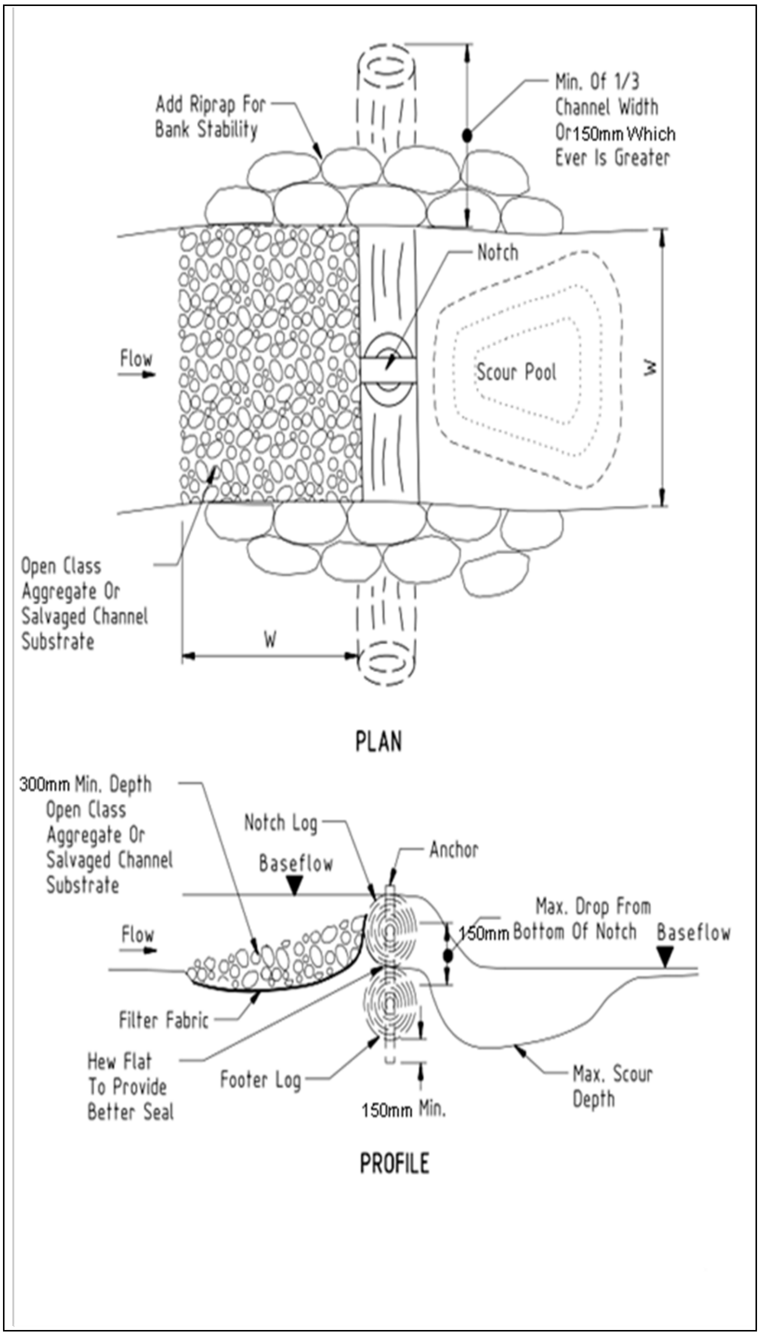

Figure F-5a Notch Log Drop

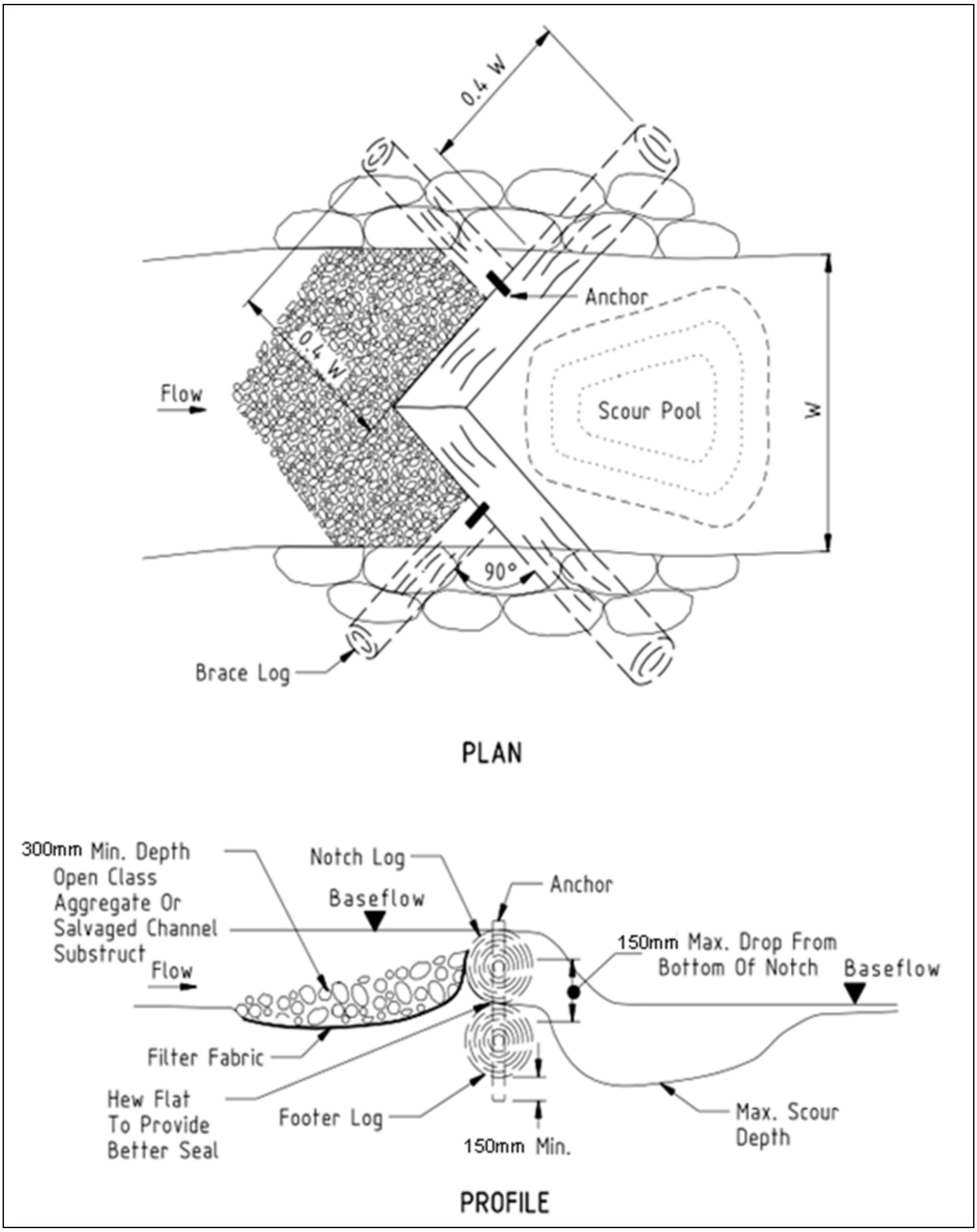

Figure F-5b V-Log Drop

E) ROCK VANES

Description

Rock vanes are used to deflect near-bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools.

Appropriate uses

- To deflect erosional forces away from the streambank at the upstream end of the outer mender bend or other unstable areas.

- Rock vanes are most appropriate in streams with gravel or larger substrate. In low gradient coastal streams, or sand-bed streams, consider use of log vanes.
- When fish habitat enhancement and/or flow deflection are desired.

Limitations

- The Qbkf height must be accurately located for the stream as the vane is set into the streambank at the Qbkf elevation.
- Rock vanes used in streams with a significant portion of sand, silt or clay in their beds must be sealed using filter fabric or a properly sized and placed open class aggregate. Log Vanes may be more appropriate for these conditions.
- Large rock size requirements may make it difficult to use in small streams.
- May require heavy equipment and skilled operators to place rock correctly.
- Rock may sink or subside in streams with sand and clay beds, which makes proper construction difficult.
- Vanes should not be used in stream reaches with channel slopes greater than 3%.

Design Requirements and Procedures

- Vane arm should intersect the bank at an angle between 20 and 30 degrees. The angle is measured upstream from the tangent line where the vane intercepts the bank. A smaller angle produces a longer arm. A longer arm provides more linear length of bank protection.
- Vane arm slopes are typically 2-15 percent. When designing Rock Vanes in larger systems, a 2-7 percent slope can result in excessive vane arm lengths. The designer can choose a steeper slope for the vane arms when practical. However, steeper vanes tend to be less stable, and protect less of the bank.
- Specify elevation and offset values for both ends of the vane arm. This ensures exact placement of the structure by the contractor.
- Horizontal placement is typically along the outer bank on the upstream end of a meander bend. This placement reduces bank erosion along the outer meander.
- Designer must specify a design depth for the scour pool immediately downstream of the rock vane. A scour depth analysis is recommended to aid in this effort.
- The rock vane must terminate at the Q_{bkf} elevation. If the top of bank is above the Q_{bkf} elevation, the rock vane arms must be properly connected or entrenched into the bank and a floodplain bench must be created at the Q_{bkf} elevation.

Material Specifications

- Rock: Footer and vane rocks must be large enough to achieve the design height and appropriately sized to resist movement due to stream flow characteristics. Rocks shall be relatively rectangular in shape, uniform in size, and have a minimum intermediate axis greater than 500mm. An example of rock size as a function of Qbkf shear stress is given in the section on B) Rock Cross Vanes above.
- Riprap: Riprap per standard and specification as needed for bank armoring, and toe protection.
- Open Class Aggregate: Used for sealing behind structure. Should be properly sized to be minimally mobilized and displaced in supercritical flow events. Salvaged alluvial channel material can be substituted for aggregate if properly sized.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.

Construction Recommendations

- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.
- Placement of rock may require a back hoe or hydraulic excavator.

- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- Rock vanes must be sealed with filter fabric, open class aggregate, and/or riprap if a significant portion of channel bed material is fine enough to pass the structure. This is especially true in sand, silt, and clay bed streams. Material passing through the structure can fill the scour pool.
- The vane arm should span a maximum of 1/3 of the Q_{bkf} width. The larger the channel, the shorter the vane should be relative to the channel width.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and to the Q_{bkf} elevation in the streambank for the rock vane. Excavate a Q_{bkf} bench if the top of bank is not at the Qbkf elevation. The trench shall be excavated to the minimum footer rock depth. The rock vane arms should be properly tied into the bank at the Q_{bkf} elevation.
- Place one or two courses of footer rocks to the minimum footer rock depth. The minimum footer rock is measured from the stream bed invert and is equal to a depth 3 times the protrusion height of the apex rock for cobble and gravel bed streams and 6 times the protrusion height for sand bed or finer streams. Be sure to leave space above the footer rocks for the below invert portion of the vane rocks.
- Place vane rocks on top of footer rocks so that each half of the vane rock rests on one half of a footer rock below. Offset the vane rock in the upstream direction and place so they slope slightly against the flow direction. A portion of the vane rocks should be below the stream bed invert with a portion above the invert to the specified protrusion height. The maximum protrusion height is 150mm.
- Extend the structure into the bank a minimum of 600mm and armor upstream and downstream as needed for stability with riprap.
- At the Q_{bkf} elevation, create a sill of placed rock perpendicular to the streambank extending away from the end of the vane arm. Construct the sill as per I) Cut-Off Sill and Linear Deflector construction. The rock should be smaller than the vane and footer rocks but large enough to resist displacement during high flow events. Seal the structure on the upstream side for streams with a high proportion of sand, clay, and silt bed material.
- Excavate the scour pools to the design depth.

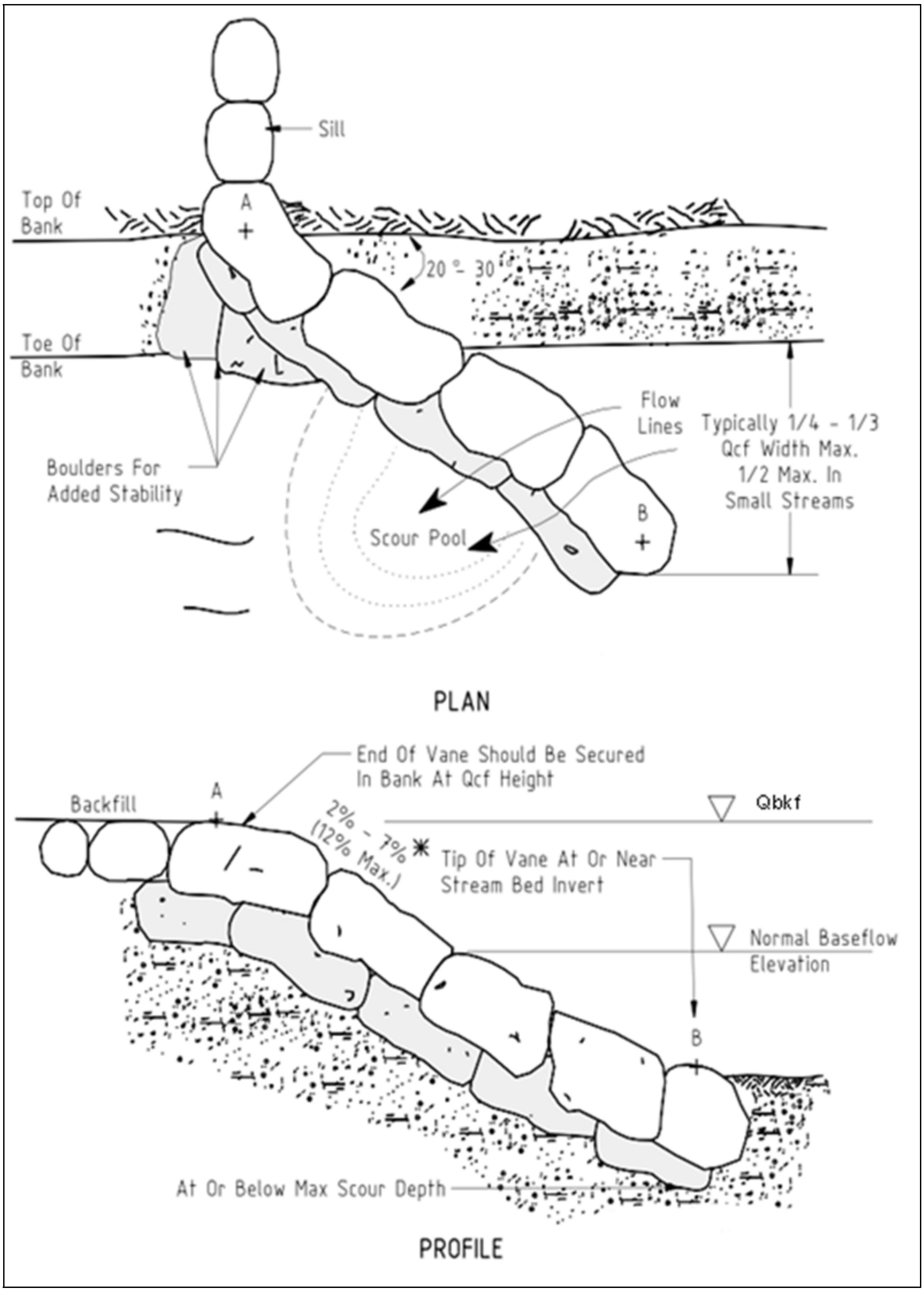

Figure F-6 Rock Vanes

F) J-HOOK VANES

Description

J-hook vanes are used to deflect near-bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools. The structure is identical to a rock vane with the addition of several gapped rocks placed in the middle third of the channel in a parabolic arc. The additional "J-rocks" create a scour pool with moderate to high fish habitat value.

Appropriate uses

- To deflect erosional forces away from the streambank at the upstream end of the outer meander bend.
- J-Hook vanes are most appropriate in streams with gravel or larger substrate. In low gradient coastal streams, or sand-bed streams, consider use of log vanes or combination of log and rock to create J-Hook Vane.
- When fish habitat enhancement and/or flow deflection are desired.
- Compatible with recreational boating in medium to large rivers.

Limitations

- The Q_{bkf} height must be accurately located for the stream as the top of the streambank must be at Q_{bkf} height or a Q_{bkf} bench must be created for use with J-hook vanes. The vane is set into the streambank at the Q_{bkf} elevation.
- J-hook vanes used in streams with a significant portion of sand, silt or clay in their beds must be sealed using filter fabric or a properly sized and placed open class aggregate. Log Vanes may be more appropriate for these conditions.
- Large rock size requirements may make it difficult to use in small streams. May require heavy equipment and skilled operators to place rock correctly. Rock may sink or subside in streams with sand and clay beds, which makes proper construction difficult.
- J-hook vanes should not be used in stream reaches with channel slopes greater than 3%.

Design Requirements and Procedures

- Vane arm should intersect the bank at an angle between 20 and 30 degrees. The angle is measured upstream from the tangent line where the vane intercepts the bank. A smaller angle produces a longer arm which in turn provides more linear length of bank protection.
- On large rivers, it is impractical to extend the vane to the 1/3 Q_{bkf} width, so a specific angle is selected.
- Vane arm slopes are typically 2-15 percent. When designing J-hook Vanes in larger systems, a 2-7 percent slope can result in excessive vane arm lengths. The designer can choose a steeper slope for the vane arms when practical. However, steeper vane arms tend to be less stable, and protect less bank.
- Specify elevation and offset values for both ends of the vane arms and the terminal "J-rock." This ensures exact placement of the structure by the contractor.
- Designer must specify a design depth for the scour pool immediately downstream of the rock vane. A scour depth analysis is recommended to aid in this effort.
- The J-hook vane must terminate at the Q_{bkf} elevation. If the top of bank is above Q_{bkf}, the J-hook vane must be properly connected or entrenched into the bank and a Q_{bkf} bench must be created at the Q_{bkf} elevation.
- Gap the "J-rock" 1/3 to 1/2 of the diameter of the rock.

Material Specifications

- Rock: Footer and vane rocks must be large enough to achieve the design height and appropriately sized to resist movement due to stream flow characteristics. Rocks shall be relatively rectangular in shape, uniform in size, and have a minimum intermediate axis greater than 500mm. An example of rock size as a function of Q_{bkf} shear stress is given in the section on Rock Cross Vanes above.
- Riprap: Riprap per standard and specification as needed for bank armoring, and toe protection.
- Open Class Aggregate: Used for sealing behind structure. Should be properly sized to be minimally mobilized and displaced in supercritical flow events. Salvaged alluvial channel material can be substituted for aggregate if properly sized.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.

Construction Recommendations

- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.
- Placement of rock requires a back hoe or hydraulic excavator.
- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- J-hook vanes must be sealed with filter fabric, open class aggregate, and/or riprap if a significant portion of channel bed material is fine enough to pass the structure. This is especially true in sand, silt, and clay bed streams. Material passing through the structure can fill the scour pool.
- The vane arm should span a maximum of 1/3 of the Q_{bkf} width and the J-hook rocks should span the center 1/3 of the Q_{bkf} width. The larger the channel, the shorter the vane should be relative to the channel width.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and to the Q_{bkf} elevation in the streambank for the J-hook vane. The vane arms should be properly tied into the bank at the Q_{bkf} elevation and a Q_{bkf} bench should be excavated if the top of bank is not at the Q_{bkf} elevation. The trench shall be excavated to the minimum footer rock depth.
- Place one or two courses of footer rocks to the minimum footer rock depth. The minimum footer rock is measured from the stream bed invert and is equal to a depth 3 times the protrusion height of the apex rocks for cobble and gravel bed streams and 6 times the protrusion height for sand bed or finer streams. Be sure to leave space above the footer rocks for the below invert portion of the vane rocks.
- Place vane rocks on top of footer rocks so that each half of the vane rock rests on one half of a footer rock below. Offset the vane rock in the upstream direction and place so they slope slightly against the flow direction. A portion of the vane rocks should be below the stream bed invert with a portion above the invert to the specified protrusion height. The maximum protrusion height is 150mm.
- Extend the structure into the bank a minimum of 600mm and armor upstream and downstream as needed for stability with riprap.
- At the Q_{bkf} elevation, create a sill of placed rock perpendicular to the streambank extending away from the end of the vane arm. Construct the sill as per I) Cut-Off Sills and Linear Deflector. The rock should be smaller than the vane and footer rocks but large enough to resist displacement during high flow events. Seal the structure on the upstream side for streams with a high proportion of sand, clay, and silt bed material.
- Excavate the scour pools to the design depth.

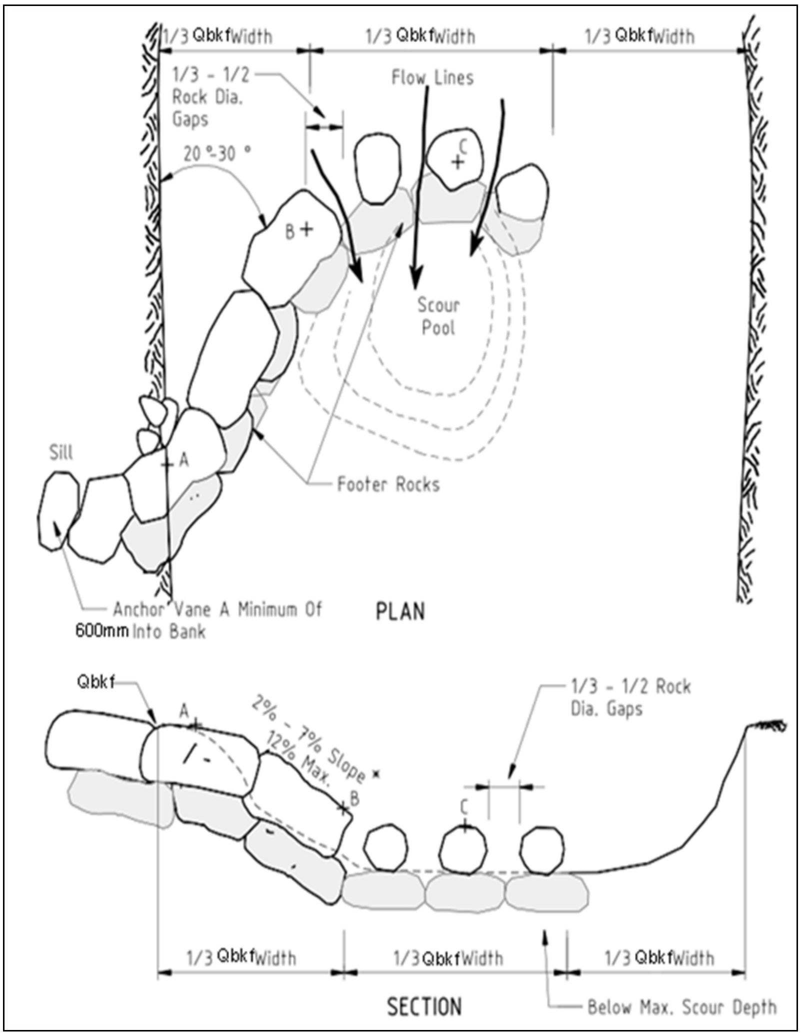

Figure F-7a J-Hook Vanes

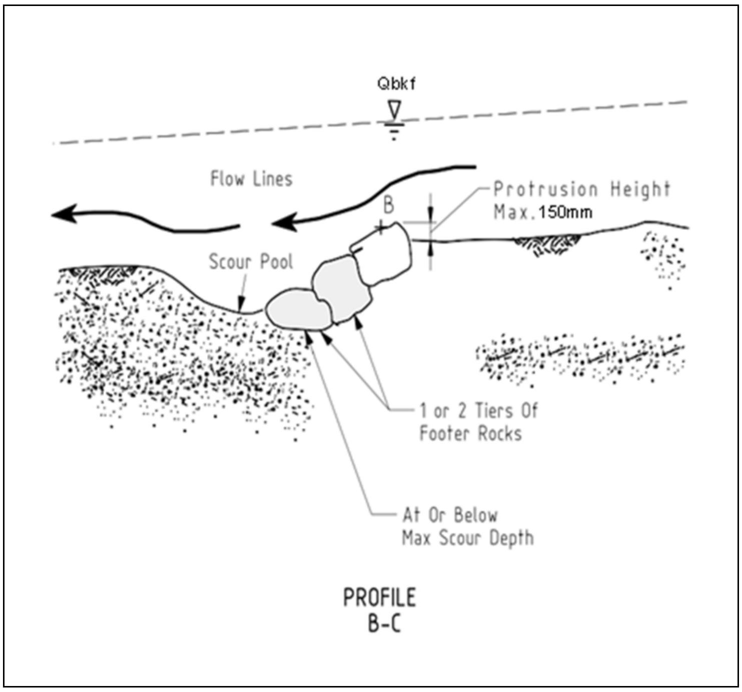

Figure F-7b J-Hook Vanes

G) WING DEFLECTORS

Description

Single or double wing deflectors are installed in the stream channel to provide a narrower base and low flow channel. Thereby, they accelerate normal flows through the constricted section. The deflector provides for improved competence and conveyance of low flows and improves habitat conditions by facilitating upstream deposition and creating scour pools.

Appropriate uses

- When channel adjustment processes have produced an overly widened baseflow channel.
- When an increase in depth and flow velocity are desired.
- In straight or riffle sections of predominately gravel/cobble bed streams.
- In streams with a channel slope of less than 3%.
- In streams that have adjusted to changes in watershed hydrology to the point where they exhibit relatively stable plan and profile form but do not have a clearly defined baseflow channel.
- Single wing deflectors can be placed in an alternating pattern to initiate meander development.

Limitations

- Deflectors should not be used in streams with large sediment or debris loads. The deflector may cause upstream deposition that can create channel blockages in high sediment load systems.
- Deflectors are ineffective in bedrock channels since minimal bed scouring occurs. In addition, streams with sand, silt, or clay beds may not be suited for deflectors because the scour potential in these systems may undercut and destroy the structure.
- Single wing deflectors may cause excessive erosion on the opposite streambank. Double wing deflectors may experience excessive erosion of both streambanks up and downstream of the structure.

Design Requirements and Procedures

- The designer should complete a scour depth analysis and ensure that the framing logs or rocks are placed below the design scour depth.
- No more than 150mm of the deflector should be above the normal baseflow level.
- Double wing deflectors are typically designed to reduce the stream width from 25 to 80 percent depending on specific site conditions such as relative bank stability, substrate size, and design flow with associated hydraulic characteristics.
- For single deflectors, the distance from the streambank to the tip of the deflector should be no more than 1/2 to 3/4 of the channel bottom width.
- For deflectors placed in series, refer to the spacing guidelines given in the section on Step Pools.
- When placed to initiate meander development, single deflectors should be spaced 5 to 7 Q_{bkf} widths apart and arranged on alternating banks.
- Deflectors should be placed not to exceed a downstream angle of 30 to 40 degrees with the streambank. The greater the flow velocity, the smaller the angle of deflection.
- Triangular deflectors may be constructed with only and "A" and "B" arms (see details below).

Material Specifications

- Logs: 200 to 300mm in diameter rot-resistant logs.
- Rock: Footer and vane rocks must be large enough to achieve the design height and appropriately sized to resist movement due to stream flow characteristics. Rocks shall be relatively rectangular in shape, and uniform in size. Uniform riprap may be used in smaller systems.
- Riprap or Coarse Aggregate: Appropriately sized to withstand flow conditions of the stream.
- Anchors: 12mm minimum rebar or drift pin for anchoring and connecting logs. Length should be 450mm at a minimum.

Construction Recommendations

- For log deflectors, all logs should be firmly anchored into the streambank for a minimum of 1.5 to 2m.
- All logs should be anchored into the stream bed to a depth greater than the design scour depth at a spacing of 1.5m centers. A minimum of 3 anchors per log shall be used.
- Footer rocks should extend to a depth below the design scour depth.
- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.
- Placement of rock may require a backhoe and hydraulic excavator.
- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- Reinforce the bank opposite of a single wing deflector as necessary to ensure bank stability.

Installation Guidelines

- Excavate a trench in the channel bed and toe of bank to a depth below the design scour depth.
- Place the footer rocks or logs. Place the arm rocks or logs on top of the footer course. Anchor logs per construction guidelines.
- Secure logs 1.5-2m into the banks. Secure rocks a minimum of 300mm into the banks.
- Fill the frame with riprap, coarse aggregate, or salvaged channel material. Pack tightly.
- Reinforce the opposite bank for single deflectors and the upstream and downstream bank for double deflectors as needed to prevent excessive erosion.

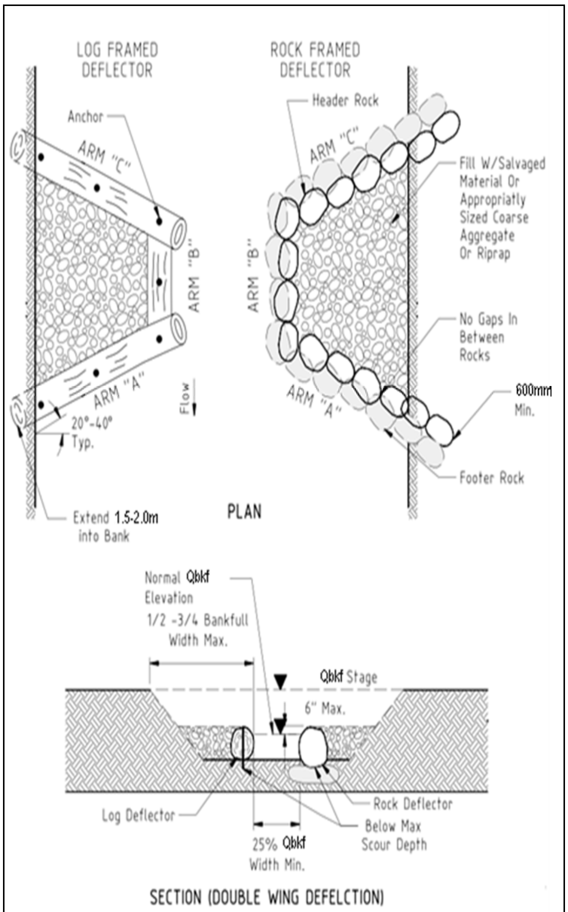

Figure F-8 Wing Deflectors

H) LOG VANES

Description

Log vanes are used to deflect near bank erosional forces away from unstable streambanks and to improve/create aquatic habitat through the formation of scour pools.

Appropriate uses

- To deflect erosional forces away from the streambank at the upstream end of the outer mender bend or other unstable areas.
- In sand, silt, and clay bed streams or in streams where a design preference for woody material is expressed.
- When fish habitat enhancement or flow deflection are desired.

Limitations

- The Q_{bkf} height must be accurately located for the stream as the vane is set into the streambank at the Q_{bkf} elevation.
- Vanes should not be used in stream reaches with channel slopes greater than 3%.
- Log vanes have limited lengths, so may not be suitable for large rivers.
- Logs degrade over time and may need to be periodically maintained or replaced.

Design Requirements and Procedures

- Log Vanes should intersect the bank at an angle between 20 and 30 degrees. The angle is measured upstream from the tangent line where the vane intercepts the bank. A smaller angle produces a longer arm. A longer arm provides more linear feet of bank protection.
- Log Vane slopes are typically 2-15 percent. Slopes are constrained by length of available logs. The steeper the slope of the vane, the less stable it may be.
- Specify elevation and offset values for both ends of the vane arms. This ensures exact placement of the structure by the contractor.
- Designer must specify a design depth for the scour pool immediately downstream of the log vane. A scour depth analysis is recommended to aid in this effort.
- The log vane must terminate at the Q_{bkf} elevation. If the top of bank is above Q_{bkf}, a Q_{bkf} bench must be created. The log vane must be properly connected or entrenched into the bank at the Q_{bkf} elevation.

Material Specifications

- Logs: 200 to 300+ mm in diameter rot-resistant logs.
- Anchors: 12mm minimum diameter, 1m long rebar or drift pins for anchoring and connecting logs.
- Support Pilings: 75 to 150mm in diameter logs with one angled and one flat end. Long enough to extend from the normal baseflow elevation to a minimum of 300mm below the design scour depth.
- Riprap: Riprap per standard and specification as needed for bank armoring, and toe protection

Construction Recommendations

- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.
- The log vane should span a maximum of 1/3 of the Q_{bkf} width.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and to the Q_{bkf} elevation in the streambank for the log vane. Excavate a Q_{bkf} bench if the top of bank is not at the Q_{bkf} elevation. The log vane must be properly connected or entrenched into the bank at the Q_{bkf} elevation.
- Anchor logs into the stream bed to a depth below the design scour depth. Logs should be anchored together with anchor rods at a spacing of 1.5m on center. Place an anchor on both sides of the support piling at the streamside end of the structure.
- Place the support piling on the downstream side of the log. The support piling should be driven into the bottom below the anticipated scour depth. Anchor the support piling to the log vane with one anchor per log comprising the vane.
- The log vane should extend into the bank a minimum of 1.5 to 2m. Riprap may be needed upstream and downstream of where the log vane enters the bank to enhance stability. If riprap is used, it should be designed and constructed per standard and specification for ripraps.
- Excavate the scour pools to the design depth.

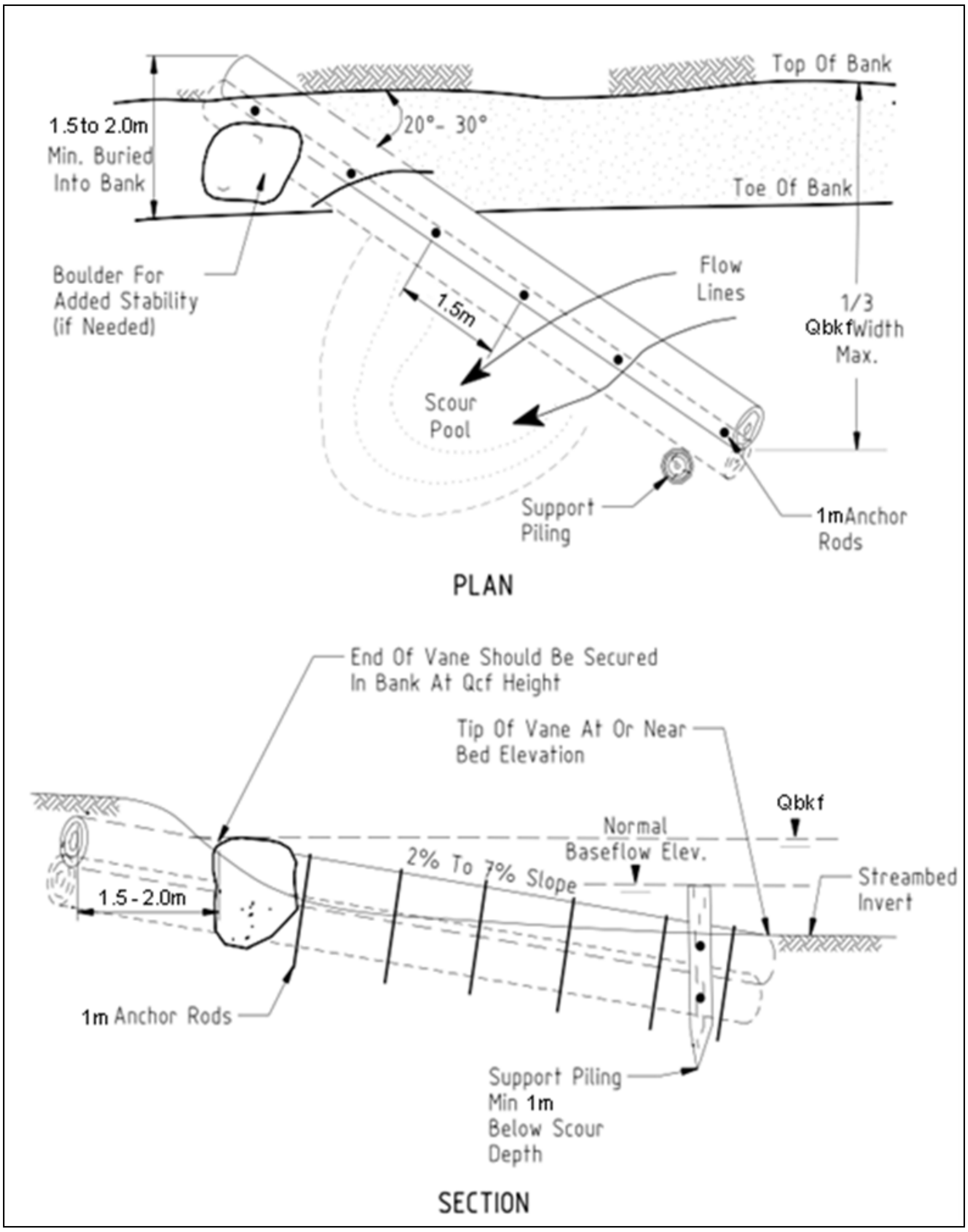

Figure F-9 Log Vanes

I) CUT-OFF SILLS AND LINEAR DEFLECTOR

Description

Cut off sills are installed in the stream channel to provide a narrower base and low flow channel and accumulate sediment behind the sills. The sills function similarly to wing deflectors with the key difference being that the frame formed by the sill is not filled. The sills are designed to build up over time by creating conditions for sediment deposition.

A linear deflector is simply a line of boulders placed within the stream channel rather than along the bank. The purpose of this structure is to narrow, deepen and as an optional measure to better define the low flow channel for Cut-off-sills.

Appropriate uses

- When channel adjustment processes have produced an overly widened baseflow channel and an increase in depth and flow velocity are desired.
- In straight or riffle sections of predominately gravel/cobble bed streams.
- In streams with a channel slope of less than 3%.
- In streams that have adjusted to changes in watershed hydrology to the point where they exhibit relatively stable plan and profile form but do not have a clearly defined baseflow channel.
- A linear deflector can be used to provide a stable feature to define the edge of the sill or the low flow section.
- A vegetative sill can be used for finer bed streams with lower erosional forces.

Limitations

- Sills are ineffective in bedrock channels.
- Requires a sediment load that will encourage deposition behind the sills. Low sediment load streams are not suited for cut-off sills.

Design Requirements and Procedures

- The designer should complete a scour depth analysis and ensure that sill rocks are placed at a depth below the design scour depth.
- No more than 150mm of the sill should be above the normal baseflow level.
- The terminal end of the sill should not extend further than 1/2 to 3/4 of the channel Q_{bkf} width.
- Sills should be placed not exceed a downstream angle of 20 to 30 degrees with the streambank. The greater the flow velocity, the smaller the angle of deflection.
- The top of the deflector generally does not extend above the bankfull elevation and is usually much below it.

Material Specifications

- Rock: rocks large enough to achieve the design height and sized to resist movement due to stream flow characteristics. Rocks shall be relatively rectangular in shape, and uniform in size. Uniform riprap may be used in smaller systems.
- Vegetation: Woven live cuttings or emergent plant material tied together at the base with wire or synthetic twine.

Construction Recommendations

- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often inappropriate material is installed and must be removed or ultimately leads to structural failure.
- All sill and deflector rocks should be placed to a depth below the design scour depth. Extend the sill a minimum of 300mm into the streambank.

- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.
- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.
- Reinforce the bank opposite of a cut-off sill as necessary to ensure bank stability.

Installation Guidelines

- Excavate a trench in the channel bed and toe of bank to a depth below the design scour depth. Place the sill rocks and anchor into the bank a minimum of 300mm.
- Place optional linear deflector if used.
- Reinforce the opposite bank for single deflectors and the upstream and downstream bank for double deflectors as needed to prevent excessive erosion.

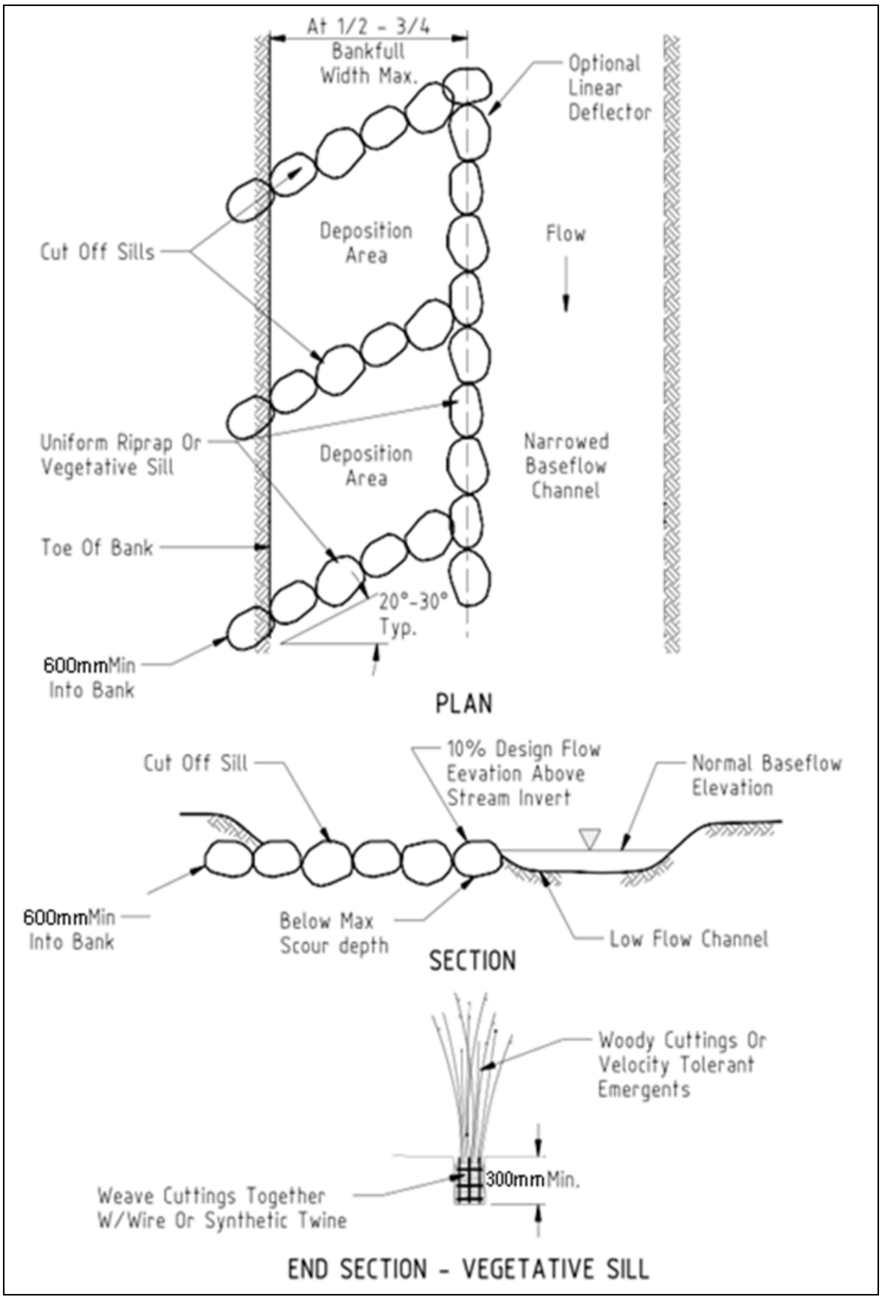

Figure F-10 Cut-off Sills & Linear Deflectors

J) STEP-POOLS

Description

Step-pools are rock grade control structures constructed in the stream channel that recreate natural step-pool channel morphology. Step pools are constructed in higher gradient channels where a fixed bed elevation is required. Step pools are built in series and allow for "stepping down" the channel over a series of drops. The steps are constructed of large rocks with the pools containing smaller rock material. As flow tumbles over the step, energy is dissipated into the plunge pool.

Appropriate uses

- Most appropriate for confined channels with slopes greater than 3%.
- As grade control structures with aquatic habitat value.
- For grade control applications requiring vertical drops greater than 150mm, such as arresting the movement of a headcut.
- Step-pools can be used to backwater a culvert, providing improved fish passage.
- Step-pools can be used to connect two reaches with different elevations.

Limitations

- Step-pools used in streams with a significant portion of sand, silt or clay in their beds must be sealed using filter fabric or a properly sized and placed open class aggregate.
- May require heavy equipment and skilled operators to place rock correctly.
- Rock may sink or subside in streams with sand and clay beds, which makes proper construction difficult.

Design Requirements and Procedures

- Designer may refer to APPENDIX 3.D for design of step-pool (riffle-pool) details such as maximum scour depth for all plunge pools, step height, and step length etc.
- Specify elevation and offset values for both ends and the center of the step. This ensures exact placement of the structure by the contractor.
- Step-pools must be sealed with filter fabric, properly sized and placed open-class aggregate, and/or riprap if a significant portion of channel bed material is fine enough to pass the structure. This is especially true in sand, silt, and clay bed streams.

Material Specifications

- Rock: Footer and step rocks must be large enough to achieve the design height and appropriately sized to resist movement due to stream flow characteristics. Rock should be relatively rectangular and uniformly sized. Step pools may also be constructed with woody material.
- Riprap: Riprap per standard and specification as needed for bank armoring, and toe protection.
- Open Class Aggregate: Used for sealing behind structure. Should be properly sized to be minimally mobilized and displaced in supercritical flow events. Salvaged alluvial channel material can be substituted for aggregate if properly sized.
- Filter Fabric: If used for sealing the structure, filter fabric shall consist of a material meeting the requirement for filter fabric used with riprap. A granular filter may be substituted for or used with filter fabric.

Construction Recommendations

- Require an inspection of the rock material before it is placed. Rock size and shape requirements are specific and often undersized material is installed and must be removed or ultimately leads to structural failure.
- Ensure no leakage/flow under or around the structure by properly grading, sealing, and compacting under and around the structure.

- After installation, check proper function/flow path by observing flow over structure. Repair as needed to ensure proper function.

Installation Guidelines

- Excavate a trench along the bottom of the stream bed and lower banks to accommodate the footer rocks of the step.
- Place footer rocks to an elevation below the maximum scour depth. Be sure to leave space above the footer rocks for the below invert portion of the step rocks.
- Place step rocks on top of footer rocks horizontally so that each half of the step rock rests on one half of a footer rock below. The step rock should rest on two footer rocks along the profile. Place step rocks so they slope slightly against the flow direction.
- Construction typically moves from upstream to downstream, constructing the step with the highest elevation first, since this step is controlling the invert of the upstream reach. When steps are complete, place open class aggregate in the plunge pool to the maximum scour depth.
- Extend the structure into the bank a minimum of 600mm and armor upstream and downstream as needed as shown in the section on A) Rock Toe Revetment above.
- Seal the structure on the upstream side of the step for streams with a high proportion of sand, clay, and silt bed material.

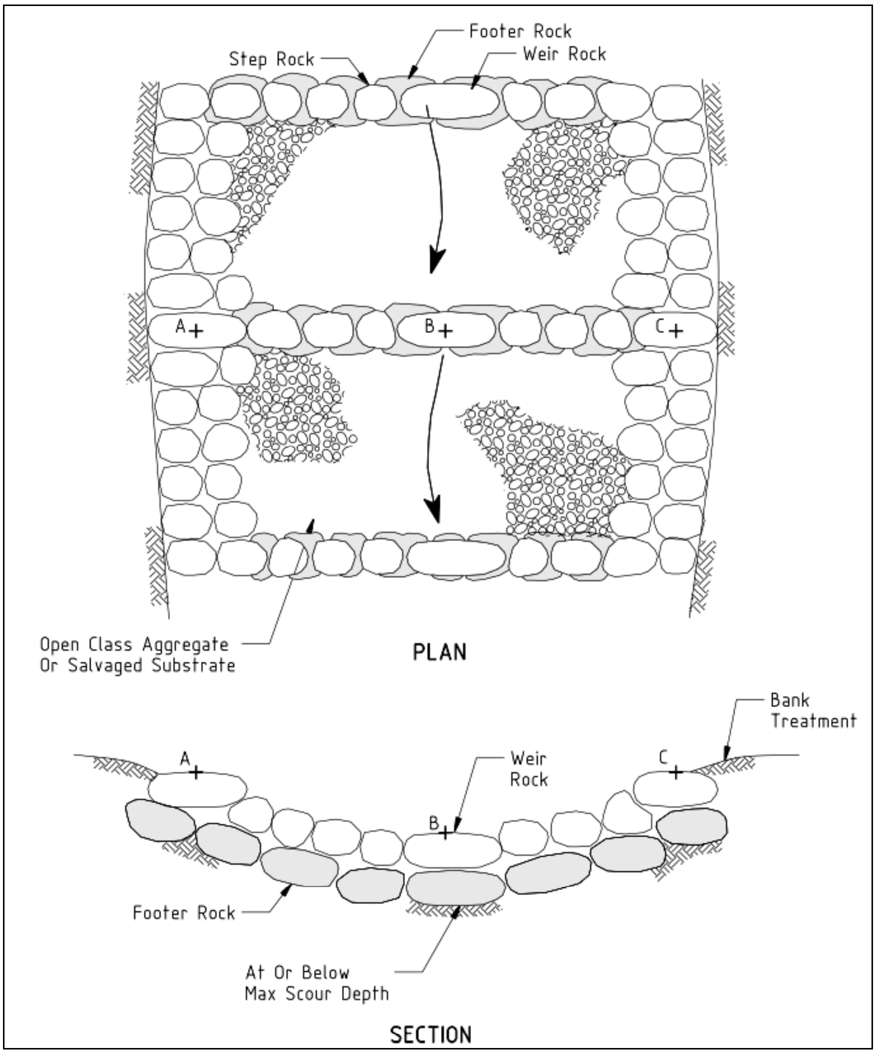

Figure F-11a Step-pools

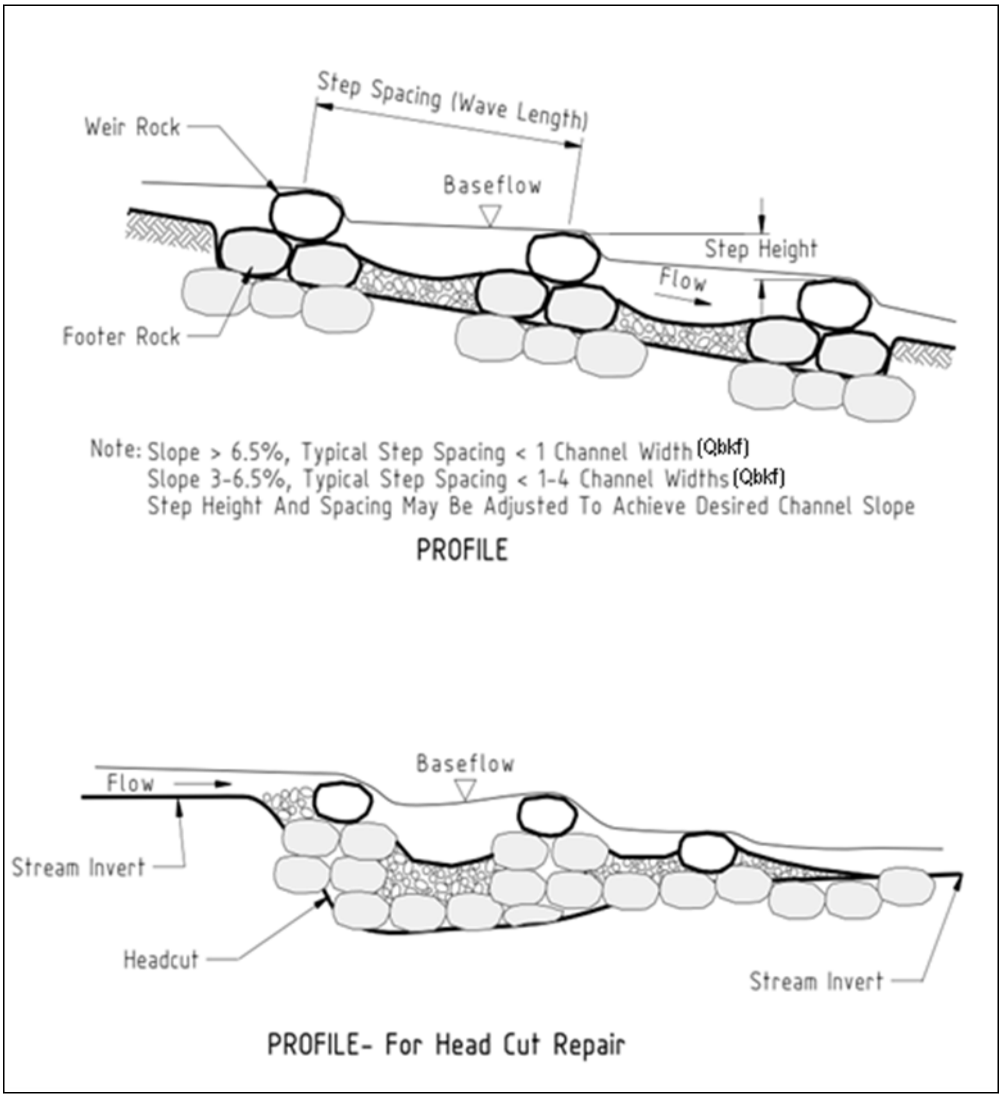

Figure F-11b Step-pools

References:

[1] Department of Conservation and Recreation (2004). "The Virginia Stream Restoration & Stabilization Best Management Practices Guide", Division of Soil and Water Conservation, Richmond, Virginia.

APPENDIX G

DESIGN OF REVETMENT FOR BANK PROTECTION

Appendix G Design Of Revetment For Bank Protection

General

The use of revetments, such as riprap, blocks and block mats, various mattresses is very common in river bank protection works. Through research on the stability of open slope revetments, much knowledge has been gained about the stability of rock under wave and current load. From the range of formulas available, the ones used extensively for current attack and wave are by Pilarczyk (1995), Escarameia and May (1992), and Maynord (1993). In the following paragraphs, two commonly used equations (Pilarczyk and Maynord) for sizing of riprap revetment will be described followed by a design example. It is also to be noted that these design formulae are primarily intended for the preliminary/conceptual phases of design and physical model studies may be required in some cases.

Independently of each other, Pilarczyk (PIANC,1987) and Maynord (1988) applied the general structure of the Neill's formula to fit the available experimental data, and they presented formulae as described below solve directly for D_c .

Pilarczyk

Pilarczyk (1995) presented a unified relationship between the required armourstone size for stability and the hydraulic and structural parameters. It combines various design formulae. Special factors and coefficients were added to the Izbash/Shields formula to derive Equation G.1 as a design formula for making a preliminary assessment of armourstone and alternative protection elements (such as gabions) to resist current attack.

$$D = \frac{\phi_{sc}}{\Delta} \frac{0.035}{\psi_{cr}} \frac{k_h K_T}{k_{sl}} \frac{U^2}{2g} \qquad \text{(G.1)}$$

where:

D = characteristic size of the protection element (m); $D = D_{n50}$ for armourstone
ϕ_{sc} = stability correction factor (-)
Δ = relative buoyant density of the protection element (-)
ψ_{cr} = critical mobility parameter of the protection element (-)
k_t = turbulence factor (-)
k_h = velocity profile factor (-)
k_{sl} = side slope factor (-)
U = depth-averaged flow velocity (m/s).

Parameters specific to this stability formula are outlined below and guidance on how to use Equation G.1 is given in Table G.1. For more information on this equation, see Pilarczyk (1995).

Stability correction factor, ϕ_{sc}:
Relationships for hydraulic stability of protection elements are based on continuous layers. However, in practice armourstone is not placed as an infinitely continuous layer and transitions are introduced, e.g. at edges or between gabions. By including the stability correction factor the influence of the geometry of transitions and the associated different hydraulic loadings are taken into account. The values given in Table G.1 are advisory values and can be applied as a first estimate. For systems less stable than a continuous armourstone layer: $\phi_{sc} > 1$.

Mobility parameter of the protection element, ψ_{cr}:
The mobility parameter expresses the stability characteristics of the system. The ratio $0.035/\psi_{cr}$ compares the stability of the system to the critical Shields value of loose stones, which is used as a reference. The ratio $0.035/\psi_{cr}$ thus enables a first impression (and not more) of the (relative) stability of composite systems such as gabions and this should always be verified in a model test.

Velocity profile factor, k_h:
The velocity profile factor, k_h(-), is related to the depth factor, Λ_h (-). Equation G.2 gives this relationship.

$$k_h = 33/\Lambda_h \qquad \text{(G.2)}$$

Generally the depth factor, Λ_h(-), is defined as $(18^2/2g)\log^2(12h/k_s)$, but for example for cases where the length of the rock structure is relatively short (near transitions) the logarithmic velocity profile is not fully developed, leading to higher velocities near the bed. In Table G.1 formulae are presented for a fully developed velocity profile and a non-developed profile, Equations G.3 and G.4, respectively:

Table G.1 Design guidance for parameters in the Pilarczyk design formula (Equation G.7)

Characteristic size, D	• armourstone and riprap: $D = D_{n50} \cong 0.84 d_{50}$ (m) • box gabions and gabion mattresses: D = thickness of element (m) Note: the armoustone size is also determined by the need to have at least 2 layers of armourstone inside the gabion.
Relative buoyant density, Δ	• rip-rap and armourstone: $\Delta = \rho_Y/\rho_W - 1$ • box gabions and gabion mattress: $\Delta = (1 - n_v)(\rho_Y/\rho_W - 1)$ where n_v = layer porosity $\cong$ 0.4 (-), ρ_Y = apparent mass density of rock (kg/m^3) and ρ_W = mass density of water (kg/m^3)
Mobility parameter, ψ_{cr}	• rip-rap and armourstone: $\psi_{cr} = 0.035$ • box gabions and gabion mattress: $\psi_{cr} = 0.070$ • rock fill in gabions: $\psi_{cr} < 0.100$
Stability factor, ϕ_{sc}	• exposed edges of gabions/stone mattress: $\phi_{sc} = 1.0$ • exposed edges of riprap and armourstone: $\phi_{sc} = 1.5$ • continuous rock protection: $\phi_{sc} = 0.75$ • interlocked blocks and cabled blockmates: $\phi_{sc} = 0.5$
Turbulence factor, k_T	• normal turbulence level: $K_T = 1.0$ • non uniform flow, increased turbulence in outer bends: $k_T = 1.5$ • non uniform flow, sharp outer bends: $K_T = 2.0$ • non uniform flow, special cases: $K_T > 2$
Velocity profile factor, k_h	• fully developed logarithmic velocity profile: $k_h = 2/\left(\log^2(1+12h/k_s)\right)$ (G.3) Where h = water depth (m) and k_s = roughness height (m); k_s = 1 to $3D_n$ for riprap and armourstone; for shallow rough flow ($h/D_n < 5$), $k_h \cong 1$ can be applied • **not fully developed velocity profile:** $k_h = \left(1 = h/D_n\right)^{0.2}$ (G.4)
Side slope factor, k_{sl}	The side factor is defined as the product of 2 terms: a side slope term, k_d and a longitudinal slope term, k_l: $K_{sl} = k_d\, k_l$ (G.5) where $k_d = (1-(\sin^2\alpha/\sin^2\phi))^{0.5}$ and $k_l = \sin(\phi - \beta)/(\sin\phi)$; α is the side slope angle (^{o}), ϕ is the angle of repose of the armourstone (^{o}) and β is the slope angle in the longitudinal direction (^{o}).

Maynord

Maynord (1993) has developed the US Army Corps of Engineers' Design Procedure and suggested a stability formula for riprap and armourstone that is not based on the threshold of movement criterion (unlike the Pilarczyk and the Escarameia and May formulas). It is instead based on not allowing the underlying material to be exposed and therefore takes the thickness of the stone layer into account. Equation G.6 gives the relationship between the characteristic stone sieve size, D_{50} (m), required for stability, and the relevant hydraulic and structural parameters.

$$D_{50} = \left(f_g\right)^{0.32} S_f C_{st} C_v C_T h \left(\frac{1}{\sqrt{\Delta}} \frac{U}{\sqrt{k_{sl} g h}}\right)^{2.5} \qquad \text{(G.6)}$$

where:
f_g = gradation (factor), = D_{85}/D_{15} (-)
S_f = Safety factor(-)
C_{st} = stability coefficient (-)
C_v = velocity distribution coefficient (-)
C_T = blanket thickness coefficient (-)
h = local water depth (m)
Δ = relative buoyant density of stone (-)
U = depth-averaged flow velocity (m/s)
k_{sl} = side slope factor (-).

Parameters specific to Maynord's formula, Equation G.6, are outlined below and guidance on the use of the different parameters is given in Table G.2. For more information on this equation, see Maynord (1993).

Velocity distribution factor, C_v:
The velocity distribution factor is an empirical coefficient to take into account velocity profile effects.

Blanket thickness coefficient, C_T:
The blanket thickness coefficient takes account of the increase in stability that occurs when stone is placed thicker than the minimum thickness ($1D_{100}$ or $1.5D_{50}$> for which C_T = 1.0 (see Table G.2).

Side slope factor, k_{sl}:

The side slope correction factor is normally defined by the relationship given in Equation G.7 (this definition is used in the Pilarczyk formula, Equation G.1). As results indicate that the use of this side slope is conservative for Equation G.6, an alternative relationship is recommended by Maynord, given here as Equation G.9.

$$k_{sl} = \frac{\cos\psi \sin\beta + \sqrt{\cos^2\beta \tan^2\phi - \sin^2\psi \sin^2\beta}}{\tan\phi} \qquad \text{(G.7)}$$

Where β = angle (^{o}) of sloping embankment with the horizontal; ψ = angle (^{o}) of flow to the upslope direction; ϕ = angle (^{o})of repose of submerged material (see Figure G-2 for the definition of angles). If the flow is down the slope (ψ = 180^o), Equation G.7 reduces to Equation G.8 below.

$$k_{sl} = k_l \frac{\cos(\phi - \beta)}{\sin\phi} \qquad \text{(G.8)}$$

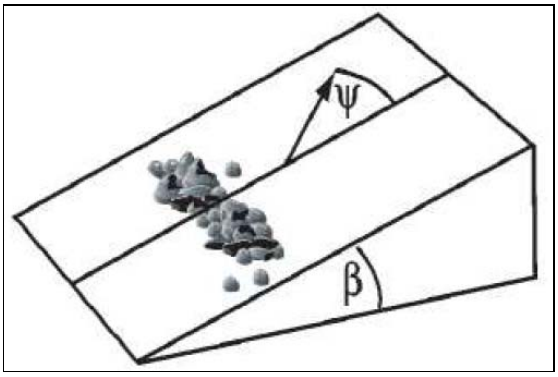

Figure G-2 Definition of Slope Angles

Table G.2 Design guidance for parameters in Maynord formula (Equation G.5)

Safety factor, S_f	minimum value:	$S_f = 1.1$
Stability coefficient, C_{st}	• angular armourstone: • rounded armourstone:	$C_{st} = 0.3$ $C_{st} = 0.375$
Velocity distribution Coefficient, C_v	• straight channel, inner bends: • outer bends: where r_b center radius of bend (m) and B = water surface width just upstream of the bend (m) • downstream of concrete structures or at the end of dikes:	$C_v = 1.0$ $C_v = 1.283$ 0.2 $\log(r_b/B)$ $C_v = 1.25$
Blanked thickness coefficient, C_T	• standard design: • otherwise: see Maynord (1993)	$C_T = 1.0$
Side slope factor, k_{sl}	$k_{sl} = 0.67 + 1.49 \cot^2\alpha - 0.45 \cot^2\alpha + 0.045 \cot^3\alpha$ (G.9) Where α = slope angle of the bank to the horizontal (^{o})	

Filters

In revetment structures geotextiles are mostly used to protect the subsoil from washing away by the hydraulic loads, such as waves and currents. Here the geotextile replaces a granular filter. Unfortunately, the mere replacing of a granular filter by a geotextile can endanger the stability of other components in the bank protection structure. The present section shows that designing a structure is more than just a proper choice of geotextile.

Filter structures can be realized by using granular materials (i.e. crushed stone), and geotextiles, or a combination of these materials. Typical filter compositions are shown in Figure G-3. In general, a geotextile is applied because of easier placement and relatively lower cost. The geotextile must allow the free passage of water (permeability function) whilst preventing the erosion and migration of soil particles into the armour or drainage system (retention function).

In principle, the geotextile must always remain more permeable than the base soil and must have pore sizes small enough to prevent the migration of the larger particles of the base soil. Moreover, concerning the permeability, not only the opening size but also the number of openings per unit area (Percent Open Area) is of importance (Pilarczyk, 1999).

It has to be emphasized that geotextiles cannot always replace the granular filter completely. A granular layer will often be needed to reduce (damp) the hydraulic loadings (internal gradients) to an acceptable level at the soil interface. After that, a geotextile can be applied to fulfill the filtration function.

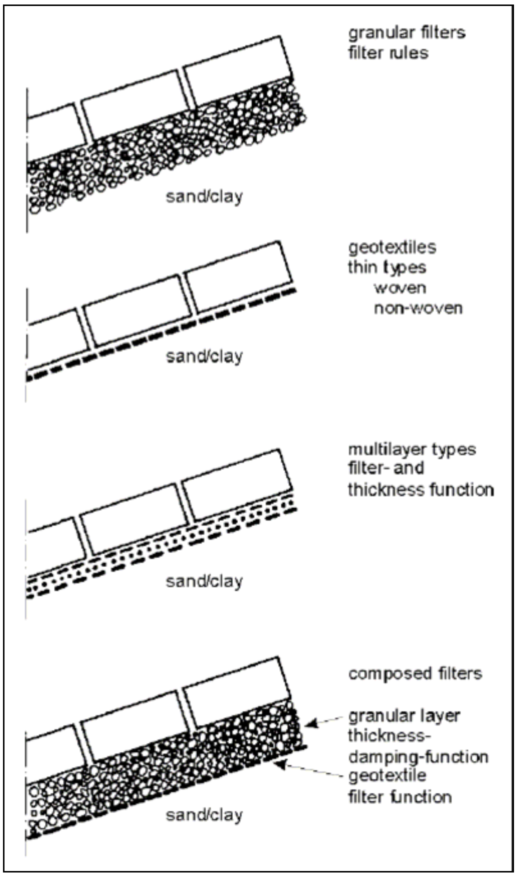

Figure G-3 Examples of filters

In respect to the filters for erosion control (granular or geotextile) the distinction can be made between:

- geometrically tight filters,
- geometrically open filters, and
- transport filters (when a limited settlement is allowed).

Only geometrically tight filters are discussed.

Design criteria for geometrically tight granular filters

In this case there will be no transport of soil particles from the base, independent of the level of hydraulic loading. That means that the openings in the granular filter or geotextile are so small that the soil particles are physically not able to pass the opening. This principle is illustrated in Figure G.4 for granular filters.

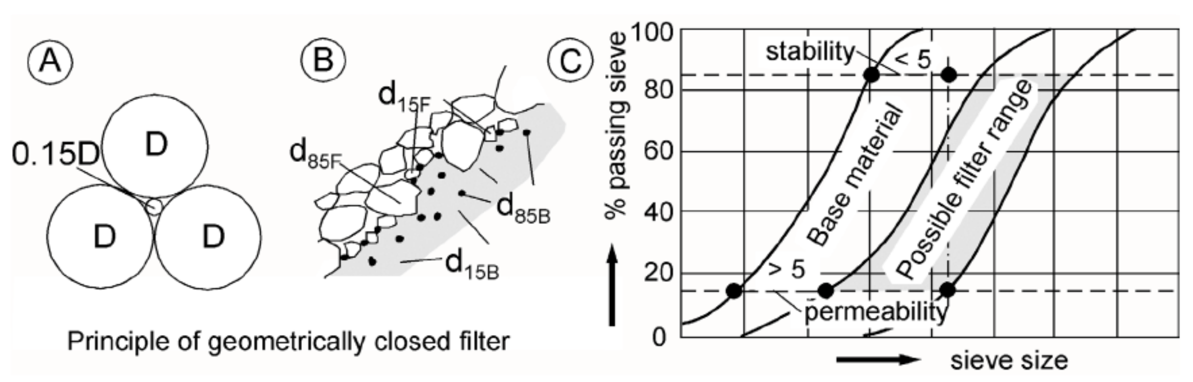

Figure G-4 Principles of geometrically tight filters

The main design criteria for geometrically tight (closed) granular filters and geotextiles are summarized below. More detailed information on design of geotextile filters is given in Pilarczyk (1999).

The soil tightness of the initial situation can be checked by means of the well-known criteria for granular filters:

- Interface stability (also called 'piping' criterion):

$$\frac{D_{f15}}{D_{b85}} \leq 4 \text{ to } 5 \tag{G.10}$$

where:
D_{f15} is the grain size of the filter layer (or cover layer) which is exceeded by 15 % of the material by weight in m;
D_{b85} is the grain size of the base material (soil) which is exceeded by 85 % of the material by weight in m.

The factor 4 in Equation G.10 was given by Terzaghi. The factor 5 is determined for normal wide-graded materials. This equation is recommended for general use. However, in the case of very 'wide' gradation the situation requires an additional check with respect to the internal migration. In this respect, an important parameter is the so-called 'uniformity coefficient' Cu, defined by Equation G.11 and the shape of the sieve curve:

$$Cu = \frac{D_{b60}}{D_{b10}} \tag{G.11}$$

- Internal stability can be roughly judged by the following rules (Equation G.12):

$$\begin{aligned} &D_{10}<4D_5 \\ &D_{20}<4D_{10} \\ &D_{30}<4D_{15} \\ &D_{40}<4D_{20} \end{aligned} \tag{G.12}$$

- Permeability criterion

$$\frac{D_{f15}}{D_{b15}} > 5 \tag{G.13}$$

Definitions for geotextile openings

There many definitions of the characteristic of geotextile openings. Moreover, there are also different test (sieve) methods for the determination of these openings (dry, wet, hydrodynamic, etc.) which depend on national standards. These all make the comparison of test results very difficult if not impossible. Some of the definitions are listed below:

O_{90} corresponds with the average sand diameter of the fraction of which 90% of the weight remains on or in the geotextile (or 10 % passes the geotextile) after 5 minutes of sieving (method: dry sieving with sand);

O_{98} corresponds with the average sand diameter of the fraction of which 98% of the weight remains on or in the geotextile after 5 minutes of sieving. O_{98} gives a practical approximation of the maximum filter opening and therefore plays an important role in the sand tightness criterion for a geotextile in strong cyclic loading situations. O_{98} is also referred to as O_{max}.

O_f filtration opening size (FOS). O_f is comparable with O_{95} (hydrodynamic sieve method);

AOS apparent opening size (acc. to ASTM method), also called EOS (effective opening size). The AOS is determined by sieving spherical glass particles of known size through a geotextile. The AOS, also frequently referred to as O_{95} (dry sieve method), is defined as a standard sieve size, x, mm, for which 5% or less of the glass particles pass through the geotextile after a specified period of sieving;

D_w effective opening size which corresponds with the sand diameter of the fraction of which 10 %, determined by the wet sieve method, passes through the geotextile. Dw is comparable with O_{95}.

As was mentioned before (Figure G-4), in a theoretical case when the soil is composed of spheres of one size diameter, all spheres can be retained if all apertures in the geosynthetic are smaller than the diameter of the spheres. Usually the soil consists of particles with different diameters and shapes, which is reflected in the particle-size distribution curves. Smaller particles can disappear straight across the geosynthetic by groundwater current. In this case the retained soil structure can function as a natural filter; see Figure G-5. The better the soil particles are distributed, the better the soil tightness of the soil structure is effected. Smaller soil particles get stuck into the spaces between larger ones and the soil structure prevents the flow of fine particles. When certain particle-size fractions are lacking, the soil structure is not stacked very well and cavities develop through which erosion can occur. The displacement of soil particles not only depends on the soil tightness but also on the hydraulic gradient in the soil structure.

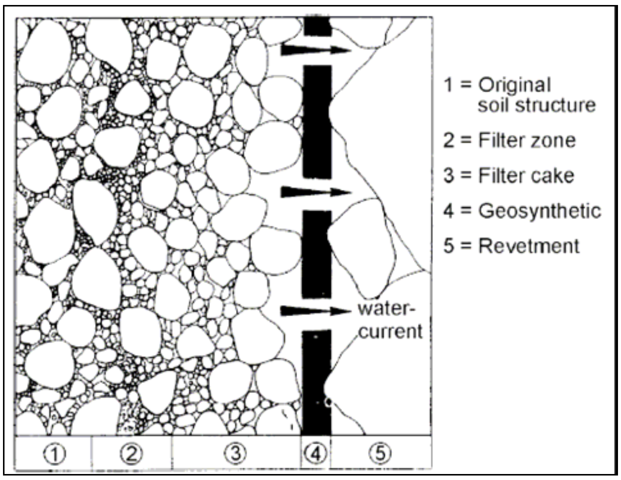

Figure G-5 Schematic representation of a natural filter with a soil-retaining layer

In order to judge the risk of wash-out of soil particles through the geosynthetics, some aspects have to be considered. An important factor is the internal stability of the soil structure.

In the case of a loose particle stacking of the soil many small soil particles may pass through the geosynthetic before a stable soil structure is developed near the geosynthetic. Also, a proper compaction of soil is very important for the internal stability of soil. The internal stability is defined by the uniformity coefficient Cu (see Equation G.11). It is defined as D_{b60}/D_{b10}. If this ratio is smaller than 6 (to 10), the soil structure is considered internally stable.

The shape of the sieve curve also influences the forming of a natural filter. Especially, when $C_u > 6$, the shape of the base gradation curve and its internal stability must be taken into account (Pilarczyk, 1999). For a self-filtering linearly graded soil, the representative size corresponds to the average grain size, D_{b50}. For internally unstable soils, this size would be equivalent to D_{b30} in order to optimize the functioning of the filter system. It is assumed that the involved bridging process would not retrogress beyond some limited distance from the interface.

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[2] Isbash, S.V. (1935). "Construction of Dams by Dumping Stone in Running Water", Moscow-Leningrad (also, Hydraulics of river channel closures, 1970, Butterworths , London).

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[4] Pilarczyk (PIANC, 1987). "Guidelines for Design and Construction of Flexible Revetments incorperating Geotextiles for Inland Waterways", Supplement to PIANC Bulletin no. 57, Brussels.

[5] Pilarczyk, K.W., (1999). "Geosynthetics and Geosystems in Hydraulic and Coastal Engineering", Published by A.A. Balkema, Rotterdam; balkema@balkema.nl.

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DESIGN EXAMPLE OF RIPRAP FOR RIVER BANK PROTECTION

An eroding river bend is in need of protection. Design a typical secion of riprap bank protection works with geotextile filter with the following provided data:

Flow velocity = 3 m/s
Flow depth = 4 m

Density of armourstones = 2630 kg/m^3
Internal angle of friction of armourstones = 40^o

Side slope of river bank = 2.5:1
Bed gradient = 1:500
Grain size distribution of bed material

A) SIZING OF RIPRAPS

Step 1 : Determine the minimum mean nominal diameter of stone, $(C_{n50})_{min}$ against current attack

Slope angle = 1V : 2.5 H
Slope angle, α = 21.80^o
Density of stone, ρ_s = 163 kg/m^3

Relative density, $\Delta = \frac{(\rho_s - \rho_w)}{\rho_w}$ = 1.63

Assume mean nominal diameter of stone $(D_{n50})_{min}$ = 0.75 m
Flow velocity, V = 3.4 m/s
Stability parameter, Φ = 1 (Refer to Table 1)
Critical parameter, Ψ = 0.035 (Refer to Table 2)
Turbulance factor, K_T = 2 (Refer to Table 3)
Water depth, h = 4 m
Equivalent roughness according to Nikuradse, k_s = 2 x D_{n50} = 1.5 m
(Refer to Table 4)
h/k_s = 2.667
Types of flow profile : Non-developed Profile (Referto table 5)
Depth parameter, K_h = 0.822

Option 1
Angle of internal friction of the revetment material, θ = 40^o (Refer to Table 6)
Transversal slope of the bank, α = 21.80^o

Slope parameter, $K_s = \sqrt{1 - \left(\frac{\sin\alpha}{\sin\theta}\right)^2}$ = 0.816

Option 2
Slope angel of river bottom (parallel along flow direction), α_b = 0.115^o
Slope parameter, K_s = cos α_b = 1.000

For slope parameter, Ks, select one of the option i.e. Option 1

Therefore, Slope parameter, K_s = 0.816

Using Pilarczyk's equation,

$$\Delta D = 0.035\frac{\Phi}{\Psi}\frac{K_T K_h}{K_s}\frac{U_{cr}^2}{2g}$$

Step 2 : Determine the 50% value of the mass distribution curve of stone, M_{50}
Density of stone, ρ_s = 2630 kg/m^3

$$Dn50 = \left(\frac{M_{50}}{\rho_s}\right)^{1/3}$$

Therefore, M_{50} = 1109.5 kg

Step 3 : Determine the thickness of the rip-rap armour layer

Note: Thickness of the rip-rap armour layer should not be <1.5 D_{n50}

Therefore, thickness of the rip-rap armour layer = 1.5 x D_{n50} = 1.125 m

Step 4 : Estimate the flow velocity witin the voids of rip-rap (for relatively uniformly sized material of mean size, D_{50})

Roughness coefficient representative of the base material, r_b = 0.023 (range from 0.02 to 0.025 for material up to gravel size)
Longitudinal hydraulic gradient, S = 0.005

$$V_b = \frac{1}{n_b}\left(\frac{D_{50}}{2}\right)^{2/3} S^{1/2}$$

Velocity at the interface with the base material, V_b = 1.634 m/s

Step 5 : Determine gradation of stones required

The upper and tower size limits are as follows :

$$\frac{M_{100}}{M_{50}} = 2 \text{ to } 5$$

$$\frac{M_{85}}{M_{50}} = 1.7 \text{ to } 3.3$$

$$\frac{M_{15}}{M_{50}} = 0.1 \text{ to } 0.4$$

$$\frac{M_{85}}{M_{15}} = 4 \text{ to } 12$$

Therefore, range of rocks required:

M_{100} =	2219	to	5548 kg
M_{85} =	1886	to	3661 kg
M_{50} =	1110 kg		
M_{15} =	111	to	444 kg

However, there is a need to check that M_{85}/M_{15} value (4 to 12) is complied.

Table 1 Some guide values for Stability parameter, Φ

Revetment Type	Continuous top layer	Edges and transitions
Riprap and placed blocks	1	1.5
Block mats, gabions, washed-in blocks, geobags and geomattresses	0.5 – 0.75	0.75 –1.0

Table 2 Shields parameter, Ψ

Type of materials	Shields parameter, Ψ
Riprap, small bags	0.035
Placed blocks, geobags	0.05
Blockmats	0.07
Gabions	0.07
Geomattresses	0.07

Table 3 Some guide values for Turbulence factor, K_T

Degree of turbulence	Turbulence factor, K_T
Normal turbulence : Abutment walls of rivers	 1.0
Increased turbulence : River bends Downstream of stilling basins	 1.5 1.5
Heavy turbulence : Hydraulic juimps Strong local disturbances Sharp bends	 2.0 2.0 2.0 – 2.5
Load due to water (screw) jet	3.0 – 4.0

Table 4 Equivalent rougness according to Nikuradse, k_s

Types of revetment/geosystem	Equivalent roughness according to Nikuradse, k_s
Riprap	One or twice he nominal diameter of the stones
Bags	Approximately equal to the thickness (d)
Mattresses : Smooth types Articulating mats	 0.05 About the height of the rib

Table 5 Depth Parameter K_h

Velocity Profile	Formula used for K_h
Fully developed	$\dfrac{2}{\left[\log\left[\dfrac{12h}{K_s}\right]\right]^2}$
Non-developed	$\left[\dfrac{h}{K_s}\right]^{0.2}$
Very rough flow ($h/K_s<5$)	1.0

Table 6 Angle of internal friction of the revetment material, θ

Type of revetment	θ
Riprap	40^o
Sand-filled system	$30^o – 40^o$
Stiff and anchored mortar-filled mattresses and (cabled) blockmats	90^o
Flexible non-anchored mattresses and blockmats (units without contact with the neighbouring units)	3/4 of the fricton angle of the sublayer
Geotextile mattress and blockmats connected to geotextile lying on a geotextile filter	$15^o – 20^o$

B) DESIGN FOR GEOTEXTILE FILTER LAYER

(Ref.:Permanent International Association of Navigation Congress (PIANC), 1987)

Data input for base material (subsoil):

D_{b10} = 0.15 mm
D_{b40} = 0.33 mm
D_{b50} = 0.40 mm
D_{b60} = 0.48 mm
D_{b90} = 1.40 mm

Permeability coefficient of bed material, k_b = 0.00001 m/s

Step 1: Determine the range of grain-size distribution for the sub-soil

Plot D_{b10}, D_{b40}, D_{b50}, D_{b60} and D_{b90} on Figure 1 and determine the range in which the grading curve falls.

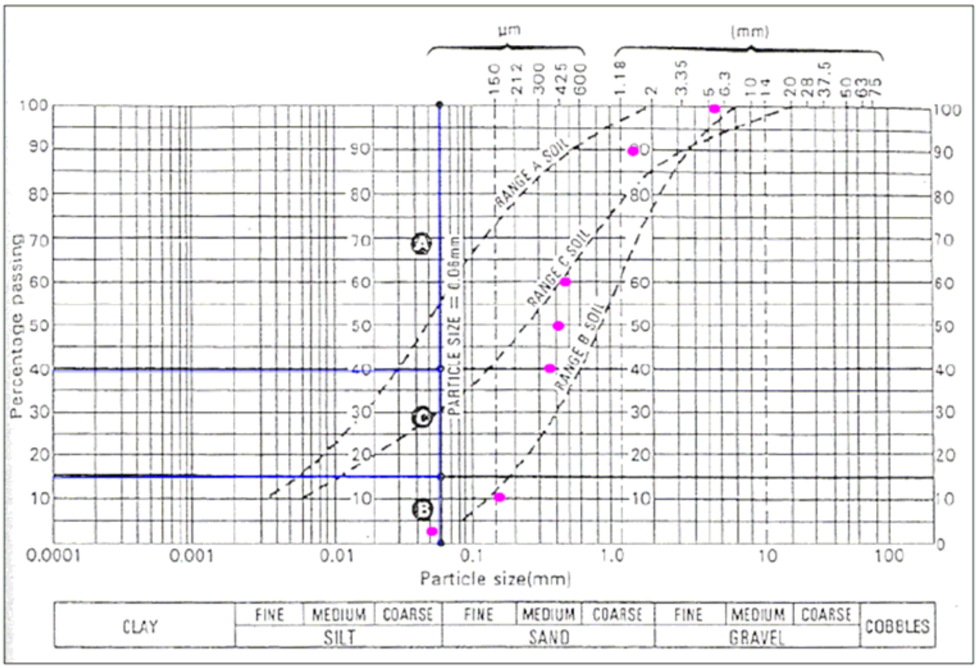


Figure 1 Soil Grading Ranges

Note: (i) The soil distribution curve should be classified as range A, B or C in accordance with the following rules:

(a) Range A: 40% or more of the soil prarticles will be smaller than or equal to 0.06mm

(b) Range B: 15% or less of the soil particles will be smaller than or equal to 0.06mm

(c) Range C: Between 15% and 40% of the soil particles will be smaller than or equal to 0.06mm.

(ii) Portion A lies above 40%, portion B lies below 15% and portion C lies between 15% and 40%.

(iii) Grading curve for soils falling into range A will either lie wholly to the left of the vertical line (grain – size equal to 0.06mm) or pass through portion A of the line.

(iv) Grading curve falls into tange B will eitier lie wholly ot the right of the vertical line (grain-size equal to 0.06mm) or pass thorough portion B only.

(v) Grading curve falls into range C will pass through portion C of the line.

Therefore, subsoil grading curve falls in range: B

Step 2: Determine the stability of soil (stable or unstable soil).
Note: Soil is defined as unstable if it is susceptible to down-slope migration (most apparent in silts, sandy and fine sands).

(a) Is there a proportion of the soil particles smaller than 0.06 mm? Yes

(b) Coefficient of uniformity, $C_u = \frac{D_{b60}}{D_{b10}} = \frac{0.48 \text{ mm}}{0.15 \text{ mm}} = 3.2 < 15$

(c) Are 50% or more of the soil particles lie in the range 0.02mm < D_b < 0.1 mm? No
As D_{b50} = 0.40

(d) Fulfillinf the applicable option?
Is PI available? No Therefore use Option 2

Option 1	Plasticity index, PI, known (Not applicable)
Liquid limit, LL = 0% Plastic limit, PL = 0% Plasticity index, PI = LL-PL = 0% - 0% = 0% < 0.15	
Option 2	Plasticity index, PI, unknown (Applicable)
Proportion of clay (D_b < 0.002 mm) = 0% Proportion of silt (0.002 mm < D_b < 0.06 mm) = 2% $\frac{\text{Proportion of clay}}{\text{Proportion of silt}} = \frac{0}{2} = 0.00 < 0.5$	

Besides a) is at least one of the condition from (b) to (d) satisfied? Yes

Therefore, the soil is unstable and susceptible to down-slope migration.

Step 3: Design of geotextiles for soil retention (geometrically soil-tight geotextiles) based on the value of effective opening size, O_{90}.
(Note: O_{90} value is determined by wet sieving analsis of the Franzius Institute for Hydraulic Reserarh and Coastal Engineering. This testing method is laid down in Swiss standard SN640550)

Soil type: unstable
Grain-size range: B
Type of loading: Stationary Loading

Option 1	(Not applicable)
(Soil type D_{b40} < 0.06 mm – Stationary loading & stable soil) Design criteria: $O_{90} < 10\ D_{b50}$ and $O_{90} < 2\ D_{b90}$ $10\ D_{b50}$ = 10 x 0.4 = 4 mm $2\ D_{b90}$ = 2 x 1.4 = 2.8 mm Therefore, O_{90} < 2.8 mm	

Option 2	(Not applicable)
(Soil type D_{b40} < 0.06 mm – Stationary loading & unstable soil) Design criteria: $O_{90} < 10\ D_{b50}$ and $O_{90} < D_{b90}$ $10\ D_{b50}$ = 10 x 0.4 = 4 mm D_{b90} = 1.4 mm Therefore, $O_{90} <$ 1.4 mm	
Option 3	(Not applicable)
(Soil type D_{b40} < 0.06 mm – Dynamic loading & unstable soil) Design criteria: $O_{90} < D_{b90}$ and $O_{90} <$ 0.3 mm D_{b90} = 1.4 mm Therefore, $O_{90} <$ 0.3 mm	
Option 4	(Not applicable)
(Soil type D_{b40} > 0.06 mm – Stationary loading & stable soil) Design criteria: $O_{90} < 5\ D_{b10}\ C_u^{1/2}$ and $O_{90} < 2\ D_{b90}$ $5\ D_{b10}\ C_u^{1/2}$ = 5 x 0.15 x $3.200^{1/2}$= 1.342 mm $2\ D_{b90}$ = 2 x 1.4 = 2.8 mm Therefore, $O_{90} <$ 1.342 mm	
Option 5	(Not applicable)
(Soil type D_{b40} > 0.06 mm – Dynamic loading & stable soil) Design criteria: $O_{90} < D_{b90}$ D_{b90} = 1.4 mm Therefore, $O_{90} <$ 1.4 mm	
Option 6	(Not applicable)
(Soil type Db40 > 0.06 mm – Stationary loading & unstable soil) Design criteria: $O_{90} < 5\ D_{b10}\ C_u^{1/2}$ and $O_{90} < D_{b90}$ $5\ D_{b10}\ C_u^{1/2}$ = 5 x 0.15 x $3.200^{1/2}$ = 1.342 mm D_{b90} = 1.4 mm Therefore, $O_{90} <$ 1.342 mm	

Option 7	(Not applicable)
(Soil type D_{b40} > 0.06 mm – Dynamic loading & unstable soil) Design Criteria: $O_{90} < 1.5\ D_{b10}\ C_u^{1/2}$ and $O_{90} < D_{b50}$ and $O_{90} < 0.5$ mm $1.5\ D_{b10}\ C_u^{1/2} = 1.5 \times 0.15 \times 3.200^{1/2} = 0.402$ mm D_{b50} = 0.4 mm Therefore, $O_{90} < 0.400$ mm	

Therefore, $O_{90} <$ 1.342 mm

Step 4: Design of geotextiles for water permeability based on type of geotextile

$\eta\ k_g \geq k_b$

where η = reduction factor
k_g = permeability of geotextiles
k_b = permeability of base materials (subsoil)

a) For needle-punched non-woven and other non-woven fabrics thicker than 2mm (measured at a normal stress of 2 kN/m^2),

$$\eta = \frac{1}{50}$$

b) For woven fabrics, reduction factor is dependent upon the permeability of geotextiles on D_{b10} of soil and can be found from Figure 2.

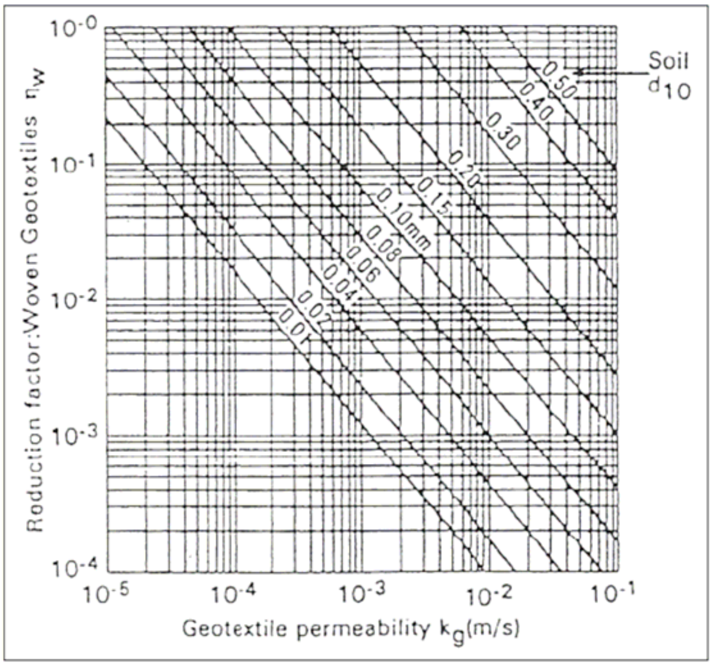


Figure 2 Permeability Reduction Factor

c) For thin non-woven geotextiles, no specific criteria is available. However, the filtering behaviour of these fabrics is to some extent similar to woven fabrics and it is therefore suggested that Figure 2 is used if no other information is available.

Type of geotextiles: Non-woven
Adopt η = 0.02 as in a) above

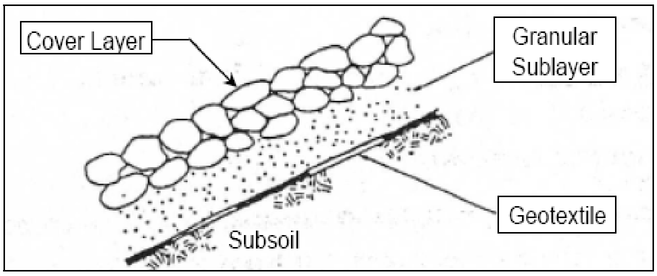
Required permeability of geotextile, $k_g \geq 50 \times 0.00001 \geq$ 5E-04 m/s

Step 5: Design for prevention of downslope migration

a) Provide a granlar sublayer between the geotextile and cover layer.
b) The granular material used for sublayer should:
   i) Ideally have ahigh unit weight and high internal friction (gained from angular-shaped particles). For example furnace slag and broken bricks.
   ii) Fine enough to provide an adequate damping effect yet coarse enough to be retained by the cover layer.
   iii) Permeability of the sublayer must be greater than the permeability of the subsoil.

The recommended thickness of the sublayer is 100 mm to 500 mm depending on the severity of hydraulic loading and soil conditions.

Therefore, adopted granular sublayer = 300 mm



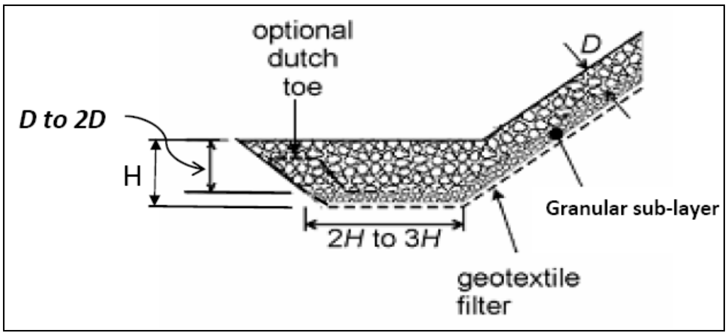
Recommended Filter Systems

Step 6: Design dimensions

Thickness of armour layer D:	1.125 m
Thickness of armour layer at toe (D to 2D):	1.688 m
Thickness of granular sub-layer:	0.300 m
Overall depth of toe, H:	1.988 m
Base width of toe (2H to 3H):	3.975 m

Geotextile filter:

type:	Non-woven
required permeability:	0.0005 m/s
min. thickness:	2 mm (actual thickness depends on riprap placement method used)



Cross-section of Riprap Slope Protection Works

APPENDIX H

REHABILITATION CHECKLIST

Appendix H Rehabilitation Checklist

During Planning...

- Have all potential participants been informed of the rehabilitation initiative?
- Have funding sources been identified?
- Has a decision structure been developed and points of contact identified?
- Have steps been taken to ensure that participants are included in the rehabilitation processes?
- Has the problem that requires treatment been investigated and defined?
- Has consensus been reached on the mission of the rehabilitation initiative?
- Have rehabilitation goals and objectives been identified by all participants in the rehabilitation effort?
- Has the rehabilitation been planned with adequate scope and expertise?
- Has the rehabilitation plan had an annual or midcourse correction point in line with adaptive management procedures?
- Have the indicators of stream corridor structure and function been directly and appropriately linked to the rehabilitation objectives?
- Have adequate monitoring, surveillance, management, and maintenance programs been specified as an integral part of the rehabilitation plan? Have monitoring costs and operational details been integrated so that results will be available to serve as input in improving techniques used in the rehabilitation work?
- Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparison in conducting the evaluation of the rehabilitation initiative?
- Have sufficient baseline data been collected over a suitable period of time on the stream corridor and associated ecosystems to facilitate before-and-after treatment comparisons?
- Have critical rehabilitation procedures been tested on a small experimental scale to minimize the risks of failure?
- Has the length of a monitoring program been established that is sufficiently long to determine whether the rehabilitation work is effective?
- Have risk and uncertainty been adequately considered in planning?
- Have alternative designs been formulated?
- Have cost-effectiveness and incremental cost of alternatives been evaluated?

During Project Implementation and Management...

- Based on the monitoring result, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
- Do the objectives or performance indicators need to be modified? If so, what changes might be required in the monitoring program?
- Is the monitoring program adequate?

During Post-rehabilitation...

- To what extent were rehabilitation plan objectives achieved?
- How similar in structure and function is the restored corridor ecosystem to the reference ecosystem?
- To what extent is the rehabilitated corridor self- sustaining (or will be), and what are the maintenance requirements?
- If all stream corridor structure and functions were not restored, have the critical structure and functions been restored?
- How long did the rehabilitation initiative take?
- What lessons have been learned from this effort?
- Have those lessons been shared with interested parties to maximize the potential for technology transfer?
- What was the final cost, in net present value terms, of the rehabilitation work?
- What were the ecological, economic, and social benefits realized by the rehabilitation initiative?
- How cost-effective was the rehabilitation initiative?

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APPENDIX I

ATTRIBUTES FOR DESCRIBING CONDITIONS IN THE STREAM CORRIDOR

Appendix I Attributes For Describing Conditions In The Stream Corridor

Hydrology • total (annual) discharge • seasonal (monthly) discharge • peak flows • minimum flows • annual flow durations • rainfall records • size and shape of the watershed Erosion and Sediment Yield • watershed cover and soil health • dominant erosion processes • rates of surface erosion and mass wasting • sediment delivery ratios • channel erosion processes and rates • sediment transport functions Floodplain/Riparian Vegetation • community type • type distribution • surface cover • canopy • community dynamics and succession • recruitment/reproduction • connectivity Channel Processes • flow characteristics • channel dimensions, shape, profile, and pattern • substrate composition • floodplain connectivity • evidence of entrenchment and/or deposition • lateral (bank) erosion • floodplain scour • channel avulsions/realignments • meander and braiding processes • depositional features • scour-fill processes • sediment transport class (suspended, bedload)	Water Quality • color • temperature, dissolved oxygen (BOD, COD, etc.) • suspended sediment • present chemical condition • present macroinvertebrate condition Aquatic and Riparian Species and Critical Habitats • aquatic species of concern and associated habitats • riparian species of concern and associated habitats • native vs. introduced species • threatened or endangered species • benthic, macroinvertebrate, or vertebrate indicator species Corridor Dimension • plan view maps • topographic maps • width • linearity, etc.

Reference:

1. The Federal Interagency Stream Restoration Working Group (2001). "Stream Corridor Restoration: Principles, Processes and Practices", Federal Agencies of the US Government. (http://www.usda.gov/stream_restoration)

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APPENDIX J

STANDARD CHECKLIST FOR PFC

Appendix J Standard Checklist For PFC

Name of Riparian-Wetland Area: ______________________________
Date: ______________ Segment/Reach ID: ______________________________
Km: ______________________ Ha.: ______________________________
ID Team Observers: ______________________________

Yes	No	N/A	HYDROLOGY
			1) Floodplain above bankfull is inundated in "relatively frequent" events
			2) Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region)
			3) Riparian-wetland area is widening or has achieved potential extent
			4) Upland watershed is not contributing to riparian-wetland degradation

Yes	No	N/A	VEGETATION
			6) There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery)
			7) There is diverse composition of riparian-wetland vegetation (for maintenance/recovery)
			8) Species present indicate maintenance of riparian-wetland soil moisture characteristics
			9) Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high streamflow events
			10) Riparian-wetland plants exhibit high vigor
			11) Adequate riparian-wetland vegetative cover is present to protect banks and dissipate energy during high flows
			12) Plant communities are an adequate source of coarse and/or large woody material (for maintenance/recovery)

Yes	No	N/A	EROSION/DEPOSITION
			13) Floodplain and channel characteristics (i.e., rocks, overflow channels, coarse and/or large woody material) are adequate to dissipate energy
			14) Point bars are revegetating with riparian-wetland vegetation
			15) Lateral stream movement is associated with natural sinuosity
			16) System is vertically stable
			17) Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition)

Reference:

1. The Federal Interagency Stream Restoration Working Group (2001). "Stream Corridor Restoration: Principles, Processes and Practices", Federal Agencies of the US Government. (http://www.usda.gov/stream_restoration)

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APPENDIX K

BANK WIDENING AND BANK FAILURE FREQUENCY CLASSIFICATION

Appendix K Bank Widening And Bank Failure Frequency Classification

Bank Widening and Bank Failure Frequency Classification

Bank stability charts may be produced by plotting the stability number (N_s) against bank angle (β) for different bank-material friction angles (ϕ) as shown in Figure K-1. The stability number is a function of the bank-material friction angle (ϕ) and the bank angle (β) as follows:

$$N_s = (4 \sin \beta \cos \phi) / [1 - \cos (\beta - \phi)] \quad \text{(K.1)}$$

The critical bank height H_c can then be calculated as:

$$H_c = N_s (c / \gamma) \quad \text{(K.2)}$$

where c =cohesion, and γ = bulk unit weight of soil.

Equations are solved for a range of bank angles using average or ambient soil moisture conditions to produce the upper line "Ambient field conditions, unsaturated." Critical bank height for worst-case scenarios (saturated banks and rapid decline in river stage) are obtained by solving the equations, assuming that ϕ and the frictional component of shear strength goes to 0.0 and by using a saturated bulk unit weight. These results are represented by the lowest line, "saturated conditions."

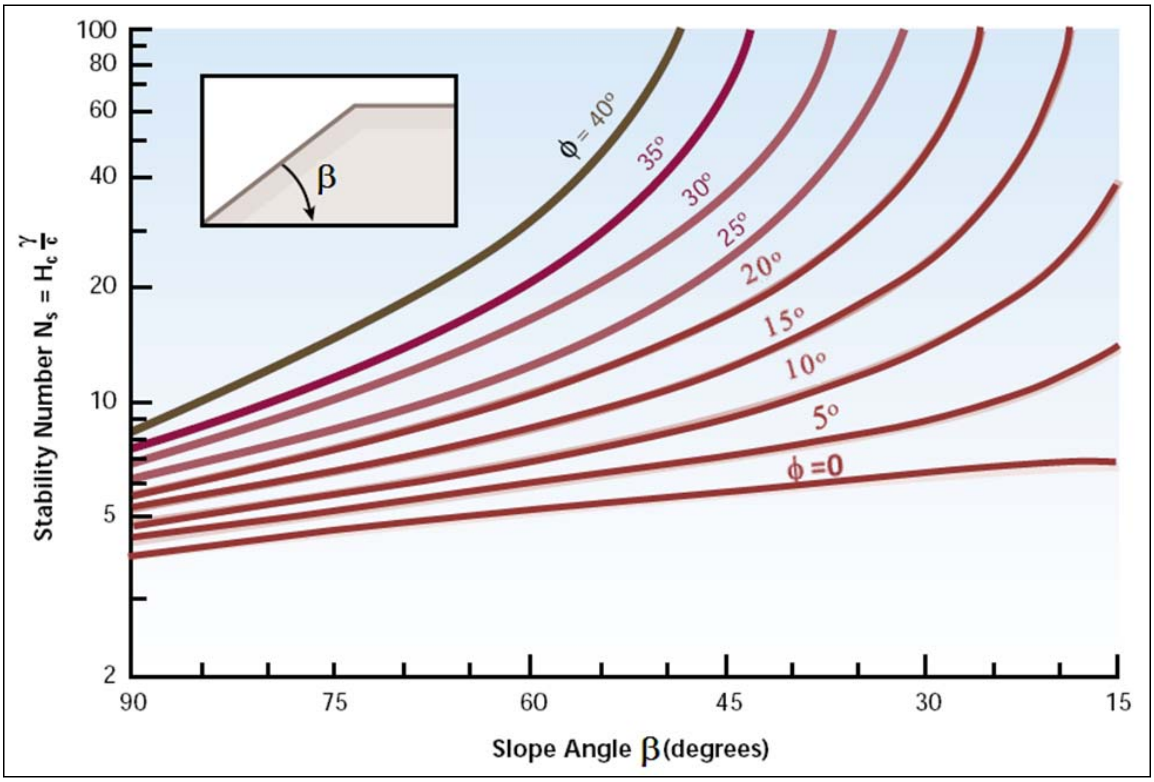

Figure K-1 Stability number (N_s) as a function of bank angle (β) for a failure surface passing through the bank toe (Source: Chen 1975)

The frequency of bank failure may be classified into three stability classes viz. unstable, at-risk, and stable. This method is subjective and based primarily on empirical field data (Figure K-2). An unstable channel bank can be expected to fail at least annually and possibly after each major stormflow in which the channel banks are saturated, assuming that there is at least one major stormflow in a given year. At-risk conditions translate to a bank failure every 2 to 5 years, again assuming that there is a major flow event to saturate the banks and to erode toe material.

Stable banks by definition do not fail by mass wasting processes. However, channel banks on the outside of meander bends may experience erosion of the bank toe, leading to oversteepening of the bank profile and eventually to bank caving episodes.

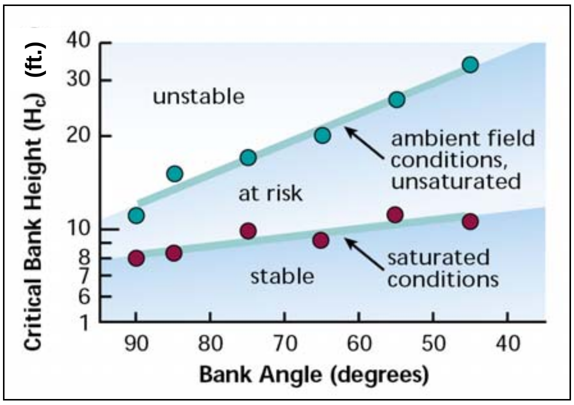

Figure K-2 Example of a bank stability chart for estimating critical bank height (H_c) (1 m = 3.28 ft). Existing bank stability can be assessed, as well as potential stable design heights and slopes. (Source: Chen 1975)

Generalizations about critical bank heights (H_c) and angles can be made with knowledge of the variability in cohesive strengths. Five categories of mean cohesive strength of channel banks are identified in Figure K-3. Critical bank heights above the mean low-water level and saturated conditions were used to construct the figure because bank failures typically occur during or after the recession of peak flows. The result is a nomograph giving critical bank heights for a range of bank angles and cohesive strengths that can be used to estimate stable bank configurations for worst-case conditions, such as saturation during rapid decline in river stage. For example, a saturated bank at an angle of 55 degrees and a cohesive strength of 12,065 N/m^2 (1.75 psi) would be unstable when bank heights exceed about 3 m (10 feet).

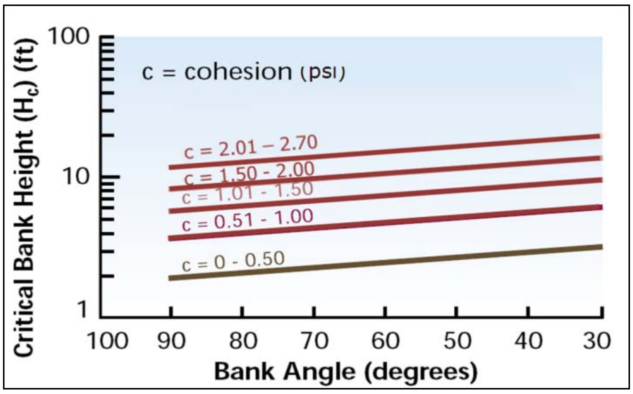

Figure K-3 Critical bank-slope configurations for various ranges of cohesive strengths under saturated conditions (1 psi = 6.9 kPa).

Predictions of Bank Stability and Channel Width

Bank stability charts can be used to determine the following:

- The timing of the initiation of general bank instabilities (in the case of degradation and increasing bank heights).
- The timing of renewed bank stability (in the case of aggradation and decreasing bank heights).

- The bank height and angle needed for a stable bank configuration under a range of moisture conditions.

Estimates of future channel widening also can be made using measured channel-width data over a period of years and then fitting a nonlinear function to the data (Figure K-4). A dimensionless hyperbolic function of the following form to estimate channel widening may be used (Williams and Wolman, 1984):

$$(W_i / W_t) = j_1 + j_2 (1 / t) \qquad (K.3)$$

where:
W_i = initial channel width (m);
W_t = channel width at t years after W_1(m);
t = time (years);
j_1 = intercept; and
j_2 = slope of the fitted straight line on a plot of W_i /W_t versus 1/t.

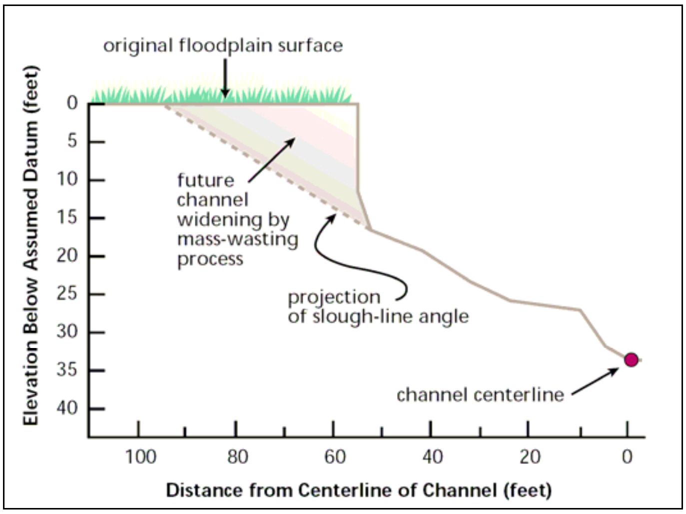

Figure K-4 Method to estimate future channel widening (10–20 years) for one side of the channel

Alternatively, a power function (Wilson and Turnipseed 1994) has been used to describe widening after channelization and to estimate future channel widening:

$$W = x\, t^{d} \qquad (K.4)$$

where:
W = channel width (m);
x = coefficient, determined by regression, indicative of the initial channel width;
t = time (in years); and
d = coefficient, determined by regression, indicative of the rate of channel widening.

Reference:

[1] The Federal Interagency Stream Restoration Working Group (2001). "Stream Corridor Restoration: Principles, Processes and Practices", Federal Agencies of the US Government. (http://www.usda.gov/stream_restoration)

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APPENDIX L

THE INDEX OF BIOLOGICAL INTEGRITY (IBI)

Appendix L The Index Of Biological Integrity (IBI)

The Index of Biological Integrity (IBI), the original multi-metric index, was first developed by Karr (1981) for use in small warmwater streams in central Illinois and Indiana, USA. The original version had 12 metrics that reflected fish species richness and composition, number and abundance of indicator species, trophic organization and function, reproductive behavior, fish abundance, and condition of individual fish (see Table L.1).

Table L.1 Index of Biological Integrity Metrics (Karr 1981)

Species Richness and Composition Metrics • Total Number of Fish Species (total taxa) • Number of Catostomidae Species (suckers)* • Number of Darter Species* • Number of Sunfish Species*	Reproductive Function Metrics • Percent of Individuals that Are Hybrids
Indicator Species Metrics • Number of Intolerant or Sensitive Species • Percent of Individuals that Are Lepomis cyanellus (Centrarchidae)	Abundance and Condition Metrics • Abundance or Catch per Effort of Fish • Percent of Individuals that are Diseased, Deformed, or Have Eroded Fins, Lesions, or Tumors (DELTs)
Trophic Function Metrics • Percent of Individuals that Are Omnivores • Percent of Individuals that Are Insectivorous Cyprinidae • Percent of Individuals that are Top Carnivores or Piscivores	

* Suitable local fish species may need to be identified in using IBI.

Each metric received a score of five points if it had a value similar to that expected for a fish community characteristic of a system with little human influence, a score of 1 point if it had a value similar to that expected for a fish community that departs significantly from the reference condition, and a score of 3 points if it had an intermediate value. Sites with high biological integrity had relatively high numbers of total fish species, both sensitive and intolerant species; high relative abundance of top carnivores and insectivorous cyprinid species; high overall fish abundance; and low relative abundance of the tolerant species, omnivores, hybrids, and fish with diseases or deformities. Expectations for species richness metrics increased with increasing stream order, and were derived from an empirical relationship between stream size and maximum number of species present, termed the maximum species richness (MSR) line. The total IBI score was the sum of the 12 metric scores and ranged from 60 (best) to 12 (worst).

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APPENDIX M

DETERMINATION OF CHANNEL PLANFORM

Appendix M Determination Of Channel Planform

Planform

Planform design parameters include the meander wavelength, radius of curvature, sinuosity, and general alignment. Sinuosity is not a profile feature, but it does affect stream slope. Channel sinuosity is determined from the calculated channel slope and valley slope. Sinuosity is the stream length between two points on a stream divided by the valley length between the two points. For example, if a stream is 2,200 m long from point A to point B, and if a valley length distance between those two points is 1,000 m, that stream has a sinuosity of 2.2. A stream can increase its length by increasing its sinuosity, resulting in a decrease in slope. Analogy, hydraulic geometry, and analytical methods are employed to determine both the meander wavelength and a planform. To apply the analogy method, a reference or control reach is located on either the study stream or another suitable stream. From this reach, a template for the meander planform is developed (Stream Rehabilitation Design, 2007 [72]). Alternatively, meander wavelength can be determined using hydraulic geometry techniques. The most reliable hydraulic geometry relationship is wavelength versus width. As with the determination of channel width, preference is given to wavelength predictors from stable reaches of the existing stream either in the project reach or in reference reaches.

a) Hydraulic Geometry for Meander Wavelength

A composite relationship has been developed by Julien (2002) [80], and the meander wavelength (Figure M-1) is:

$$\lambda \sim 10\ W \tag{M.1}$$

where:
λ = meander wavelength
W = channel width in any consistent units of measurement
channel slope

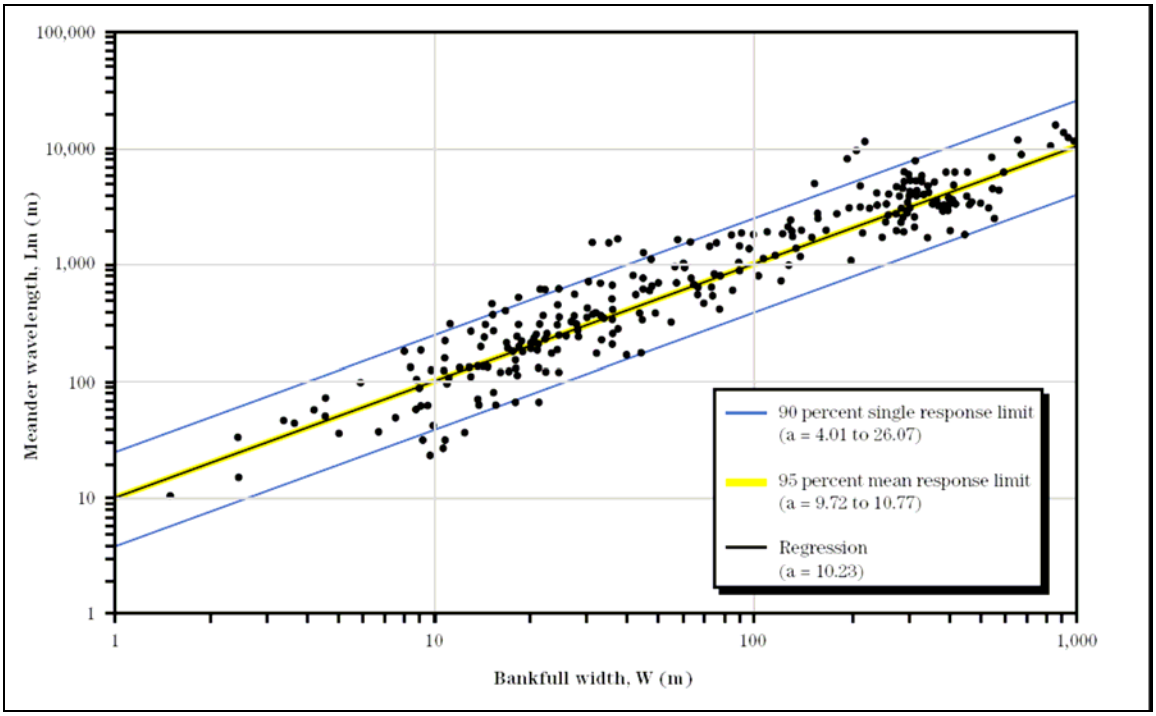

Figure M-1 Hydraulic geometry relationship for meander wavelength, λ = 10 W, with confidence intervals from Thorne and Soar (2001)

Definitions of planform descriptive variables are shown in Figure M.2. The channel meander length is simply the meander wavelength times the valley slope divided by the channel slope:

Channel meander length = wavelength x valley slope (M.2)

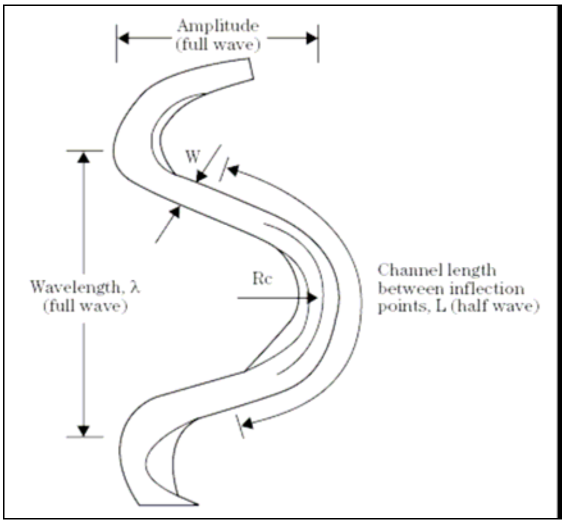

Figure M-2 Planform Description

b) Layout and sine-generated curve

Once the meander wavelength is determined, planform can be determined using an analogy method or by using the sine-generated curve. Using a reference reach as a guide, planform can be laid on a map with a string cut to the appropriate channel length. Assuming that the planform can be approximated by the sine-generated curve is a more analytical approach suggested by Langbein and Leopold (1966). The sine generated curve is defined in Figure M-3 and by the following dimensionless equation:

$$\phi = \omega \cos \frac{2\pi s}{M} \qquad \text{(M.3)}$$

where:
ϕ = angle of meander path with the mean longitudinal axis (degrees or radians)
ω = maximum angle a path makes with the mean longitudinal axis (degrees or radians)
s = curvilinear coordinate along the meander path (m)
M = meander arc length (m)

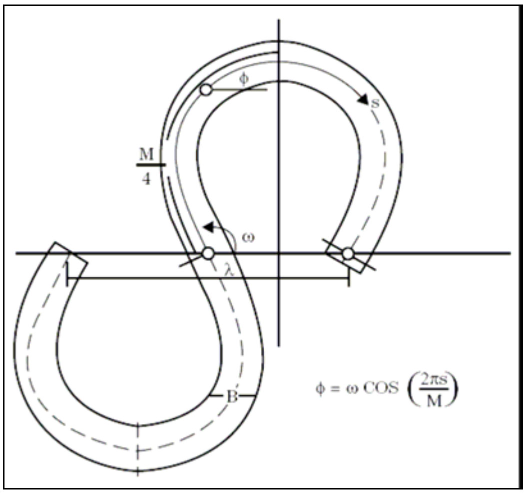

Figure M-3 Sine generated curve

The shape parameter, ω, is a function of the channel sinuosity, P, which can be solved by numerical integration, or may be approximated by the following equation (Langbein and Leopold 1966), in which ω is in radians:

$$\omega = 2.2\sqrt{\frac{P-1}{P}} \tag{M.4}$$

The sine-generated curve produces a very uniform meander pattern. The alignments of natural channels are rarely perfect sinusoids. Channels that are constructed as such, therefore, appear unnatural. A combination of the string layout method and the analytical approach would produce a more natural looking planform.

c) Radius of curvature

The radius of planform curvature is not constant in the sine-generated curve, but ranges from a maximum value at the inflection point to a minimum curvature around the bend apex. The average radius of curvature is centered at the bend apex for a distance of approximately a sixth of the channel meander length. Most reaches of stable meandering rivers have radius of curvature-to-width ratios between 1.5 and 4.5. Of the 438 sites used to derive the wavelength-width relationship in Figure M-3, radius of curvature is recorded for 263 of the sites. This subset was used to develop a cumulative distribution curve of radius of curvature-to-width ratios (Figure M-4). This figure shows that 33.5 percent, 52.9 percent, and 71.2 percent of the sites have radius of curvature-to-width ratios between 2 and 3, 2 and 4, and 1.5 and 4.5, respectively. The final planform layout should have ratios within the normal range.

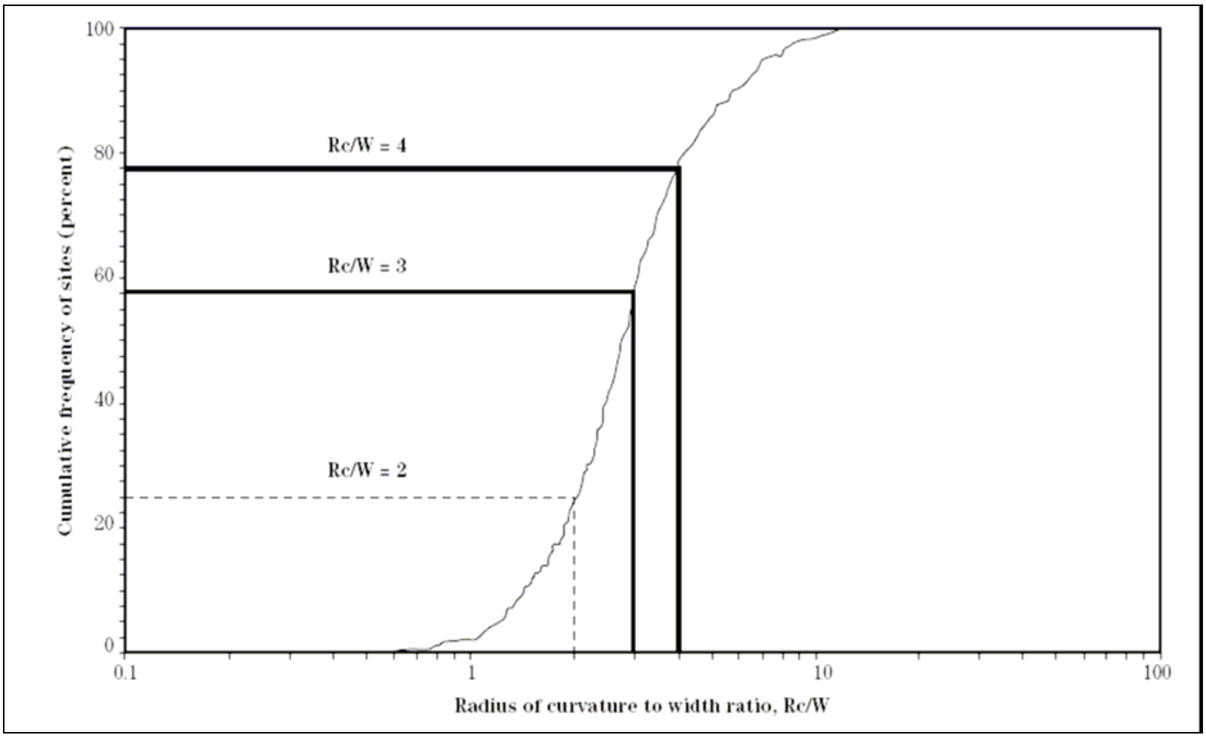

Figure M-4 Cumulative distribution of radius of curvature-to-width ratio derived from a composite data set of 263 sites

APPENDIX N

DETERMINATION OF CHANNEL VARIABILITY

Appendix N Determination Of Channel Variability

Natural variability

Natural variability in channel width and depth can either be allowed to develop naturally or can be part of the project design. Sand-bed streams have the ability to create natural variability in channel form rather quickly because they are characterized by significant bed-material sediment transport. Gravel-bed streams typically adjust much more slowly. If variability is to be included in the project design, dimensions for cross sections in riffles and pools can be obtained from stable reaches of the existing stream or from reference reaches.

a) Natural variability in width for gravel-bed rivers

Gravel-bed rivers are typically characterized by riffles and pools which correspond to bends and crossings in sand-bed rivers. Riffle spacing and width are determined from:

$$Z = 6.31\ W \qquad (N.1)$$

where:
Z = the riffle spacing (m)
W = the mean channel top width (m).

Most of the data fell between the equations as shown in Figure N-1.

$$Z < 10\ W \qquad (N.2)$$
$$Z > 4\ W \qquad (N.3)$$

Riffle spacing tends to be nearer 4 channel widths on steeper gradients, increasing to 10 channel widths with more gradual slopes. The riffle mean width, RW, was given as:

$$0.75\ W > RW = W \qquad (N.4)$$

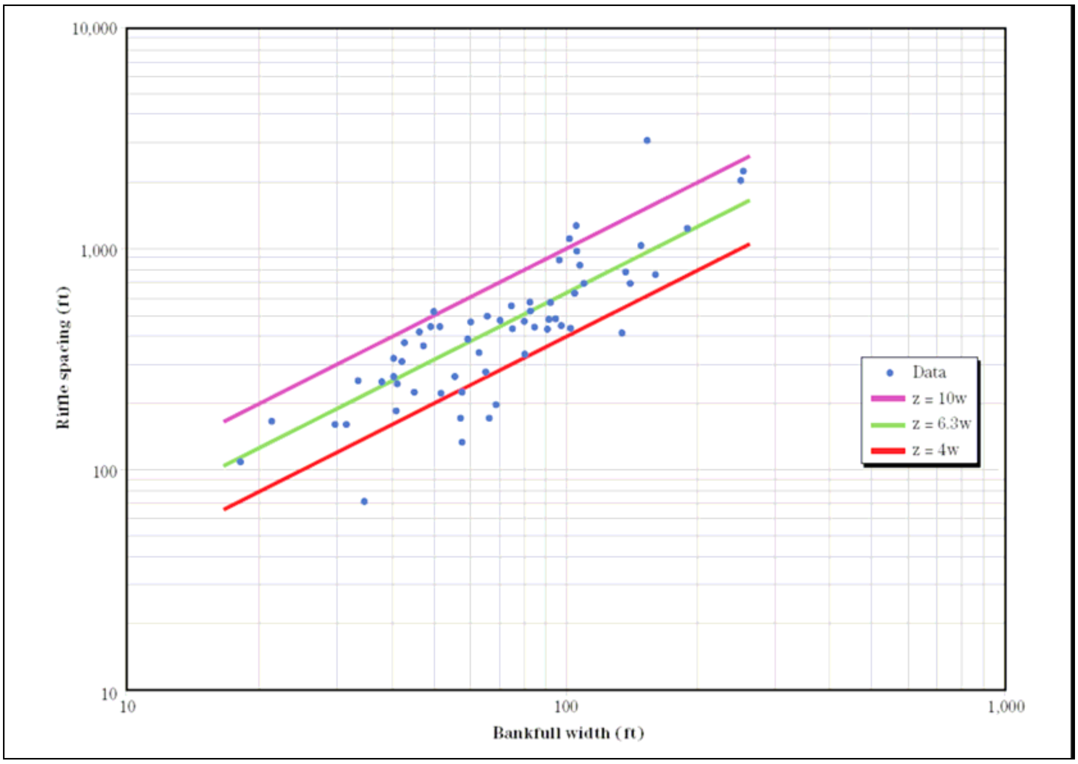

Figure N-1 Relation between riffle spacing, Z, and bankfull channel width, W *b) Riffle and pool spacing in nearly straight rivers*

In rivers that are nearly straight (sinuosity less than 1.2), riffle and pool spacing may be set as a function of channel width. The empirical guide of 5 to 7 channel widths applies here. Two times this riffle spacing gives the total channel length through one meander pattern.

c) Natural variability around meander bends

River bends can be classified according to the Brice (1975) classification system: equiwidth meanders, denoted as Type e (T_e) meanders (Figure N-2); meanders with point bars, denoted as Type b (T_b) meanders (Figure N-3); and meanders with point bars and chute channels, denoted as Type c (T_c) meanders (Figure N-4). The Red River meander bend geometry data set is shown in Table N-1.

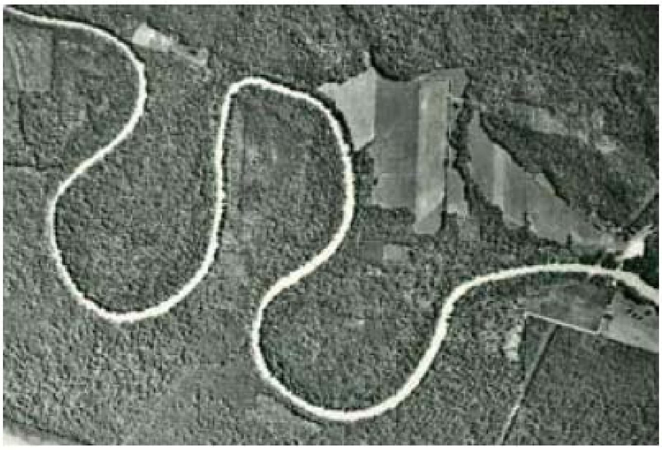

Figure N-2 Equiwidth meandering river, Type e (Te)

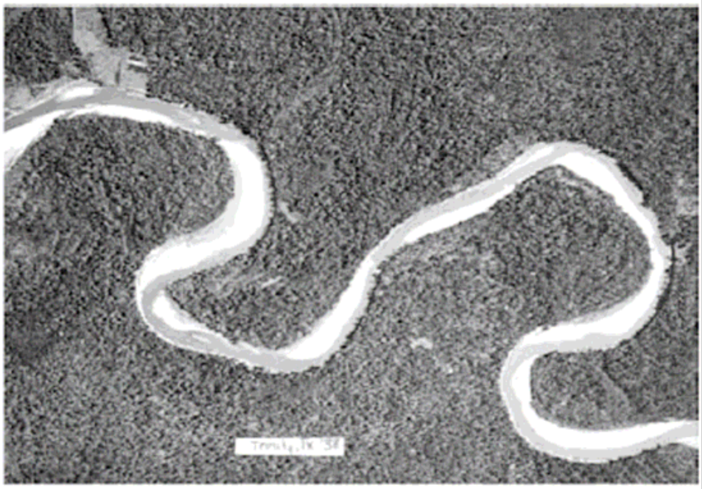

Figure N-3 Meandering with point bars, Type b (Tb)

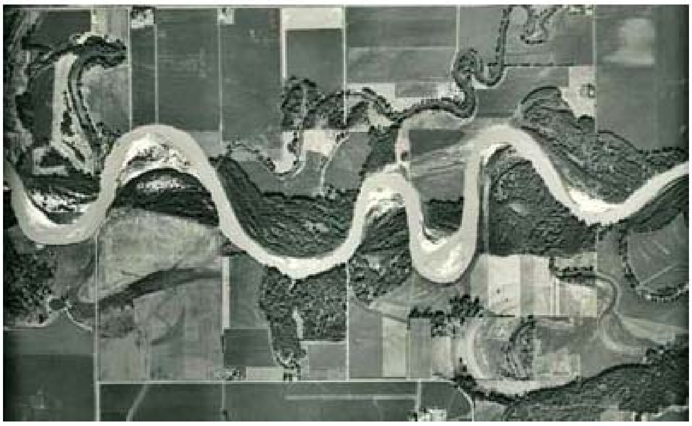

Figure N-4 Meandering with point bars and chute channels, Type c (Tc)

Table N.1 River meander characteristics and bend types of the 1981 Red River hydrographic survey between Index, AR, and Shreveport, LA. (Thorne and Soar 2001)

n		S (106)	P	W_i / d_m	d_{max} / d_i	R_c / W_i
Type e	20	65 to 268	1.0 to 2.1	34.2 to 74.1	1.6 to 2.4	0.9 to 9.3
	(8)	(133 to 268)	(1.2 to 2.1)	(38.3 to 74.1)	(1.7 to 2.4)	(0.9 to 5.2)
Type b	34	76 to 294	1.0 to 2.0	36.8 to 121.0	1.5 to 2.6	1.5 to 9.1
	(19)	(105 to 294)	(1.1 to 2.0)	(36.8 to 102.4)	(1.7 to 2.6)	(1.5 to 6.1)
Type c	13	91 to 201	1.1 to 2.3	33.5 to 88.2	1.6 to 2.4	2.2 to 6.8
	(10)	(91 to 201)	(1.2 to 2.3)	(33.5 to 88.2)	(1.6 to 2.4)	(2.2 to 5.2)

Note:
n = number of meander bends studied
S = water surface slope
P = sinuosity
W_i / d_m = inflection point width-to-mean depth ratio
d_{max} / d_i = maximum scour depth in pool-to-mean depth at inflection point
R_c / W_i = radius of curvature-to-inflection point width ratio
Values in parentheses refer to meander bends with sinuosity 1.2 or greater.

- *Equiwidth meandering* (Figure N-2) - Equiwidth indicates that there is only minor variability in channel width around meander bends. These channels are generally characterized by low width-to-depth ratios, erosion resistant banks, fine-grain bed material (sand or silt), low bed-material load, low velocities, and low stream power. Channel migration rates are relatively low because the banks are naturally stable.

- *Meandering with point bars* (Figure N-3) - Meandering with point bars refers to channels that are significantly wider at bendways than crossings, with well-developed point bars, but few chute channels. These channels are generally characterized by intermediate width-to-depth ratios, moderately erosion-resistant banks, medium-grained bed material (sand or gravel), medium bed-material load, medium velocities, and medium stream power. Channel migration rates are likely to be moderate unless banks are stabilized.

- *Meandering with point bars and chute channels* (Figure N-4) - Meandering with point bars and chute channels refers to channels that are much wider at bendways than crossings, with well-developed point bars and frequent chute channels. These channels are generally characterized by moderate to high width-to-depth ratios, highly erodible banks, medium to coarse-grained bed material (sand, gravel and/or cobbles), heavy bed-material load, moderate to high velocities, and moderate to high stream power. Channel migration rates are likely to be moderate to high unless banks are stabilized.

Practical channel design equations for meander bend geometry

It is possible to derive a mean band of uncertainty, u, suitable for all three types of meander bends and to provide a set of practical design equations. The cumulative effects of Type e, Type b, and Type c bends are represented by the binary parameters, T_e, T_b and T_c, respectively. The value of Te has a value of 1 for all three types of bend and represents the smallest planform width ratio. If point bars are present, but chute channels are rare, T_b is assigned a value of 1, and T_c is assigned a value of 0. If point bars are present and chute channels are common, both T_b and T_c are assigned values of 1. Obviously T_c can only be given a value of 1 when T_b has a value of 1.

Bend apex (P ≥ 1.2)

$$\frac{W_a}{W_i} = 1.05T_e + 0.30T_b + 0.44T_c \pm u \qquad \text{(N.5)}$$

Pool width (P ≥1.2)

$$\frac{W_p}{W_i} = 0.95T_e + 0.20T_b + 0.14T_c \pm u \qquad \text{(N.6)}$$

For all three bend types and sinuosities greater than 1, the pool offset ratio is given by:

Pool-offset (P>1.0)

$$\frac{Z_{a-p}}{Z_{a-i}} = 0.36 \pm u \qquad \text{(N.7)}$$

Values of u refer to confidence limits on the mean response as given in Table N.2.

Table N.2 Uncertainty, u, in estimates of width variability around meander bends and location of pools. Values refer to confidence limits on the mean response

Confidence limits (%)	W_a/W_i	W_p/W_i	Z_{a-p}/Z_{a-i}
99	0.07	0.17	0.11
95	0.05	0.12	0.08
90	0.04	0.10	0.07

A practical, safe design curve for maximum scour has been proposed as follows:

$$\frac{d_{max}}{d_m} = 1.5 + 4.5\left(\frac{R_c}{W_i}\right)^{-1} \qquad \text{(N.8)}$$

This equation is an asymptotic relationship with a theoretical minimum d_{max}/d_m of 1.5, representing pool scour depths expected in a straight channel with a pool-riffle bed topography. From this upper-bound relationship, d_{max}/d_m ranges from 4 to 3 for R_c/W_i between 1.8 and 3. For channels with an R_c/W_i less than 1.8, pool depth is independent of bend curvature. The recommended dimensionless scour depth should be 4. All three relationships are portrayed in Figure N-5 (Thorne and Abt 1993; Maynord 1996), which shows that this equation is a safe curve for both classes of W_i/d_m.

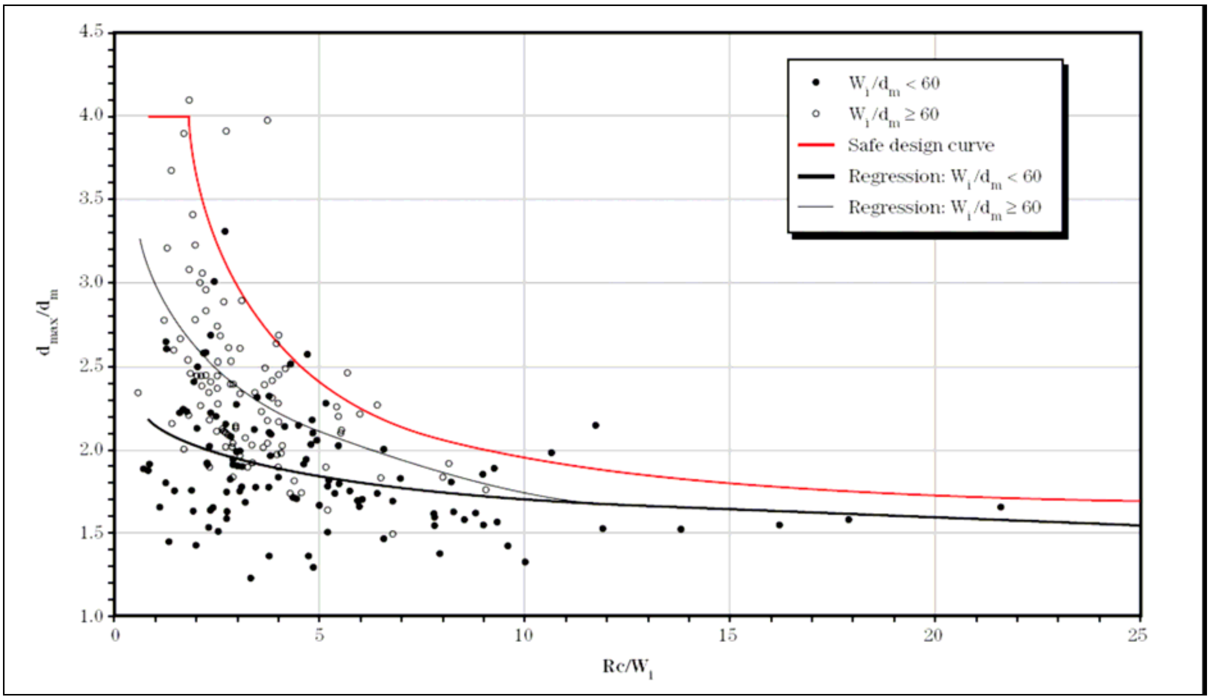

Figure N-5 Dimensionless maximum scour depth in meander pools as a function of radius of curvature-to-width ratio

Bankline migration

Bankline migration is a natural process associated with natural meandering channels. Meander loops tend to move downstream as river processes erode the outside of bends and deposit sediment on point bars. The ability to forecast adjustments in planform is important to the planning and design of any project where highways or structures could be damaged. The rate of bank migration at a given site is a function of erosional forces and resisting forces. The variables affecting erosional forces include discharge, cross-sectional geometry, sediment load, bed roughness, bedforms and bars, and the geometry of the bend itself. The variables affecting resistance forces include bank geometry, the composition of the bank, bank vegetation, pore water pressure, and wetting and drying. Due to the wide variability in significant variables, it is difficult to develop an algorithm that can reliably predict bankline migration rates.

Although empirical relationships were derived for sand-bed rivers, their application to river systems in a different locality may not be reliable. Hence, the most reliable method for predicting bankline migration rate is to estimate historical rates from aerial photos of the project river. It must be recognized that rates at a specific site will change as the planform changes. In addition, erosion rates change with cyclic climate changes and changes in the watershed.

REFERENCE

[1] USDA (2007). "Stream Restoration Design", Part 654 National Engineering Handbook. U.S. Department of Agriculture

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APPENDIX O

CONTROL OF SILKTREE MIMOSA AND WATER HYACINTH

Appendix O Control Of Silktree Mimosa And Water Hyacinth

2. CONTROL OF SILKTREE MIMOSA

Silktree Mimosa (Albizia Julibrissin) is a small to medium-sized tree that can grow up to about 3 to 4 m tall. It reproduces both vegetatively and by seed (Figure O-1). Mimosa tree seeds have impermeable seed coats that allow them to remain dormant for many years. One study showed that 90% of the seeds were viable after five years and, for another species of mimosa, a third of its seeds germinated after 50 years in open storage. Seeds are mostly dispersed below or around the parent plant, but can be dispersed further by water. Mimosa trees grow rapidly under good conditions but are short-lived and have weak, brittle wood. If cut or top-killed, trees resprout quickly and sprouts can grow over 1 m in a season. Mimosa tree can be controlled using a variety of mechanical and chemical controls. To prevent newly cleared land from threat of infestation, a fast thriving cover crop or close turfing /hydroseeding to cover the cleared area quickly coupled with initial manual weeding will greatly reduce the menace.

Figure O-1 Silktree Mimosa (Albizia Julibrissin)

1.1 Mechanical Control

Trees can be cut at ground level with power or manual saws. Cutting is most effective when trees have begun to flower to prevent seed production. Because mimosa spreads by suckering, resprouts are common after treatment. Cutting is an initial control measure and will require either an herbicidal control or repeated cutting for resprouts. Girdling is effective on large trees where the use of herbicides is impractical. Using a hatchet, make a cut through the bark encircling the base of the tree, approximately six inches above the ground. Be sure that the cut goes well below the bark. This method will kill the top of the tree but resprouts are common and may require a follow-up treatment with a foliar herbicide. Hand pulling will effectively control young seedlings. Plants should be pulled as soon as they are large enough to grasp, but before they are old enough to flower. Seedlings are best pulled after a rain when the soil is loose. The entire root must be removed since broken fragments may resprout.

1.2 Chemical control

Silk tree seedlings and small trees can be controlled by applying a 2% solution of glyphosate (e.g. Roundup) or triclopyr (e.g., Garlon) and water plus a 0.5% non-ionic surfactant to thoroughly wet all leaves. Systemic herbicides such as glyphosate and triclopyr can kill entire plants because the chemicals travel through a plant from the leaves and stems to the actively growing roots, where they prevent further cell growth. Use a low pressure and a coarse spray pattern to reduce damage from spray drift on non-target species. Use caution when applying these products, as glyphosate is a nonselective herbicide that may kill non-target plants that are only partially contacted. Triclopyr is a selective herbicide for many broad-leaved plant species and should be considered for sites where native or other desirable grasses are meant to be conserved.

The cut-stump and basal bark herbicidal methods should be considered when treating individual trees or where the presence of desirable species preclude foliar application. Horizontally cut stems at or near ground level. Immediately apply a 25% solution of glyphosate or triclopyr and water to the cut stump making sure to cover the outer 20% of the stump. For basal bark applications, apply a mixture of 25% triclopyr and 75% horticultural oil to the base of the tree trunk to a height of 300-400 mm from the ground. Thorough wetting is necessary for good control; spray until run-off is noticeable at the ground line.

3. CONTROL OF WATER HYACINTH

Water hyacinth (Eichhornia Crassipes) is an aquatic plant which can live and reproduce floating freely on the surface of fresh waters or can be anchored in mud (Figure O-2). Plant size ranges from a few inches to a metre in height. Its rate of proliferation under certain circumstances is extremely rapid and it can spread to cause infestations over large areas of water causing a variety of problems. It grows in mats up to 2 metres thick which can reduce light and oxygen, change water chemistry, affect flora and fauna and cause significant increase in water loss due to evapotranspiration. It also causes practical problems for marine transportation, fishing and at intakes for hydro power and irrigation schemes. It is now considered a serious threat to biodiversity.

Figure O-2 Water hyacinth (Eichhornia Crassipes)

The plant originated in the Amazon Basin and was introduced into many parts of the world as an ornamental garden pond plant due to its beauty. It has proliferated in many areas and can now be found on all continents apart from Europe. It is particularly suited to tropical and subtropical climates and has become a problem plant in many areas including South East Asia.

There are several popular control mechanisms for preventing the spread of, or eradication of, water hyacinth. The 3 main mechanisms used are biological, chemical and physical control. Each has its benefits and drawbacks. Chemical control is the least favoured due the unknown long-term effects on the environment and the communities with which it comes into contact. Physical control, using mechanical mowers, dredgers or manual extraction methods, is used widely but is costly and cannot deal with very large infestations. It is not suitable for large infestations and is generally regarded as a short-term solution. Biological control is the most widely favoured long-term control method, being relatively easy to use, and arguably providing the only economic and sustainable control. Each of these methods are briefly discussed below.

2.1 Biological control

Biological control is the use of host specific natural enemies to reduce the population density of a pest. Several insects and fungi have been identified as control agents for water hyacinth. These include a variety of weevils, moth and fungi. Biological control of water hyacinth is said to be environmentally benign as the control agents tend to be self-regulating.

Control programmes are usually inexpensive due to the fact that the control agents are known and only a small numbers of staff are required to run such programmes. One major drawback is that it can take a long time to initiate such projects because it can take several years for the insect population to reach a population density sufficient to tackle the pest problem. For example, in Kenya work is being carried out on the development of a biological herbicide from a locally found fungal pathogen. Similar program can be initiated locally by research institutions to develop such techniques.

2.2 Chemical control

The application of herbicides for controlling water hyacinth has been carried out for many years. The common herbicides are 2,4-d, Diquat and Glysophate. It has been found that there is a good success rate when dealing with small infestations but less success with larger areas. Application can be from the ground or from the air and requires skilled operators. As mentioned earlier the main concern when using herbicides is the environmental and health related effects, especially where people collect water for drinking and washing.

2.3 Physical control

Mechanical removal of water hyacinth is seen as the best short-term solution to the proliferation of the plant. It is however costly, using either land-based 'clamshell' bucket cranes, draglines or booms or, alternatively, water based machinery such as mowers, dredges, barges or specially designed aquatic weed harvesters (Figure N-3). Such methods are suitable for only relatively small areas. Many of these techniques require the support of a fleet of water and land-based vehicles for transporting the large quantities of water hyacinth which is removed. Manual removal of water hyacinth is suitable only for extremely small areas. It is a difficult and labour intensive work.

Figure O-3 Mechanical weed control, involving the use of weed cutting and harvesting boats and tractor-mounted weed cutting equipment

2.4 Possible Useful Applications of water hyacinth

Although water hyacinth is seen in many countries as a weed and is responsible for many of the problems in the water bodies, many individuals, groups and institutions have been able to turn the problem around and find useful applications for the plant. The plant itself, although more than 95% water, has a fibrous tissue and a high energy and protein content, and can be used for a variety of useful applications. Below are a number of possible uses for the plant, some of which have been developed while others are still in their infancy or remain as ideas only:

- Water hyacinth fibre is blended with waste paper or jut to make paper and fibre board.
- Fibre from water hyacinth stems is dried to make yarn and rope or to make baskets and matting for domestic use.
- Water hyacinth can be used on the land either as a green manure or as compost.
- Possibility of converting water hyacinth to biogas.
- In Southeast Asia some nonruminant animals are fed rations containing water hyacinth as also practiced locally in the rural areas.
- Water hyacinth can be used as fish feed as Chinese grass carps, tilapia and other fish which eats aquatic plants can be introduce to control this aquatic weed.

References:

[1] Plant Conservation Alliance's Alien Plant Working Group, Weeds Gone Wild: Alien Plant Invaders of Natural Areas (*http://www.nps.gov/plants/alien/*).

[2] Water Hyacinth Control and Possible Uses,
(http://itdg.org/docs/technical_information_service/water_hyacinth_control.pdf)

CHAPTER 4

RIVER CORRIDOR MANAGEMENT

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4 RIVER CORRIDOR MANAGEMENT

4.1 INTRODUCTION

A river corridor is an ecosystem comprising mainly the river channel, flood plains, and transitional upland fringes corridor. Being the transitional zone between a terrestrial and an aquatic ecosystem, it is a place where water and other materials (e.g., stormwater runoff, sediment and debris), energy (heating and cooling of water) and organisms (mammals, fish, insects, etc.) meet and interact over space and time. Through this movement and interaction, the river corridor provides important life-maintaining functions such as cycling nutrients, filtering pollutants from runoff, storing and gradually releasing floodwater, recharging groundwater and maintaining streamflows. [1]

There may be many features within a river corridor, with riparian (riverside) forest or shrub cover being a common one. Other features including both natural and man-made are:

- Wetlands;
- Agricultural land;
- Grassland;
- Oxbow lakes;
- Residential or commercial development; and
- Islands in the river.

In their natural state, river corridors are diverse in scale, situation, and character. They are very valuable resources of our nation as they help preserve qualities that make rivers suitable as habitats for wildlife, recreation, and sources of water for domestic and other uses. They also allow free movement of wildlife, control erosion and river sedimentation. The areas adjacent to rivers also possess important agricultural soils, wetlands, floodplains, and historic communities.

River corridor management involves management of overall channel morphology with its obstructions, rapids, meanders and adjacent wetlands, management of riparian land and management of floodplains. Since management of channel morphology has already been covered in Chapter 3, this chapter is confined to the following subjects:

- Definition, objectives, designation, issues and alternatives of River Corridor Management;
- Management of Riparian Land; and
- Floodplain Management.

Proper management of river corridors requires regular monitoring, good management information and clear management guidelines. As such, River Monitoring, River Information System and available River Management Guidelines are also covered in this chapter.

4.2 DEFINITION OF RIVER CORRIDOR

A River Corridor is defined as a river and the adjacent land that is set aside for specific purposes (e.g. preservation of plant and animal habitats, protection of water quality, temporary storage and velocity reduction of flood water, stabilization of streambanks, beautification and recreation, enhancement of property value, etc.) and that is substantially preserved in a natural state [2].

The River Corridor should not be confused with the River Reserve that is defined in the National Land Code as “land for the time being reserved for a public purpose (e.g. flood mitigation) in accordance with the provisions of Section 62 or of any previous land law”. A detailed discussion of River Reserve is given in section 4.5.

Figure 4.1 illustrates a cross-section of a River Corridor and its components in a natural state.

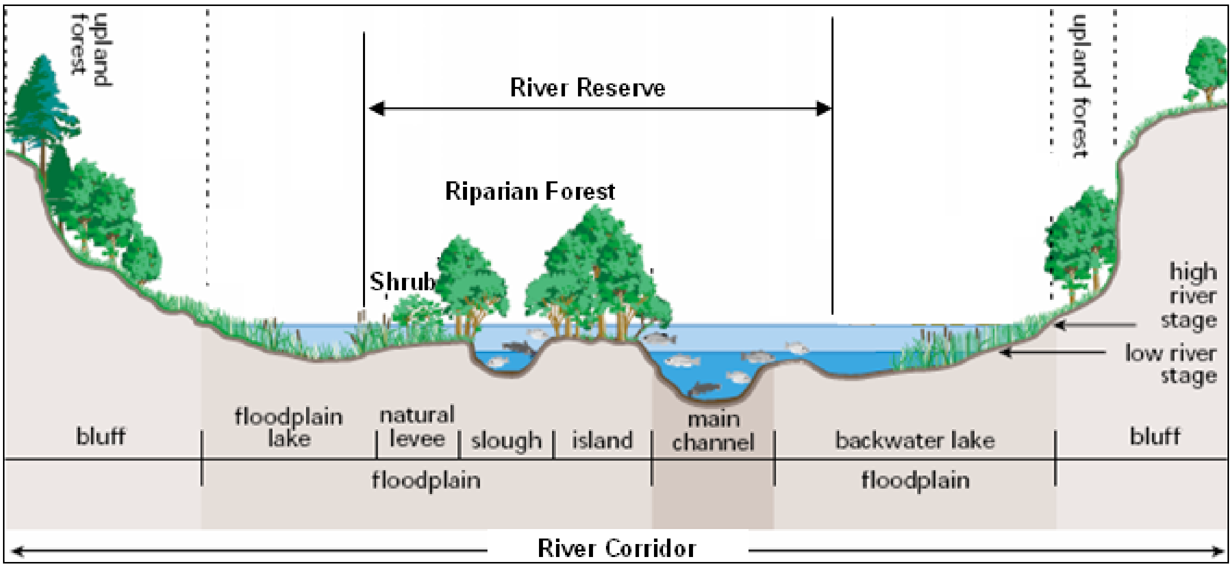

Figure 4.1 Cross-section of a River Corridor in a natural state.

4.3 RIVER CORRIDOR MANAGEMENT OBJECTIVES

Maintaining an adequate river corridor width will allow the river to evolve unimpeded by adjacent land use. The river's evolution should be monitored to adjust management practices as needed. In many segments of rivers in Malaysia, however, the riparian corridor is already developed to the point where it has confined the river's movement. Identifying and protecting undeveloped sections of the riparian corridor is essential to manage the river. As more and more of the river corridor is developed, the costs associated with maintaining the river and protecting property from flood and erosion hazards will increase. Avoiding development in sensitive areas not only will improve the quality of the habitat and water, it will also save cost.

There is now a growing public recognition that our rivers have many other values in addition to their traditional drainage and water supply uses. Recognizing the interdependencies of river and adjacent floodplain and wetland areas and of upstream and downstream areas, proper management of river corridor is vitally important so as to resolve conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner. Resolution of these conflicts will result in the realization of multiple objectives such as:

- Fluvial erosion hazard mitigation;
- Sediment and nutrient load reduction;
- Aquatic and riparian habitat protection and restoration;
- Preservation and enhancement of archeological, ethnographic, and historic resources;
- Enhancement of opportunities for public outdoor recreation, education, and scenic enjoyment;
- Preservation and enhancement of natural resources;
- Continued economic activity and development;
- Improvement of the public's understanding of the river and promoting public stewardship of its resources; and,
- Recognition and strengthening people's relationships with the river as a dynamic part of our heritage, our quality of life, and our legacy for future generations.

4.4 DESIGNATION OF RIVER CORRIDORS

There are a number of ways to designate river corridors. Important factors influencing the determination of the corridor width include wildlife/riparian habitat protection, flood protection, channel movement and meander path, and political and public interest and support.

Designation of a river corridor starts with the lateral extent of river meanders at a state of natural equilibrium. It provides space for sediment deposition, meander and floodplain development and serves to maximize river channel stability and minimize fluvial erosion hazards. The corridor can be expanded to account for the influence of the watercourse into the surrounding landscape which may include riparian forests, shrubland, flood plains and transitional areas to uplands.

There are a number of ways to designate river corridors. Important factors influencing the determination of the corridor width include:

- River health protection;
- Erosion control;
- Wildlife/riparian habitat protection;
- Flood hazard management;
- Channel movement and meander path;
- Preservation of cultural heritage;
- Recreational and educational needs; and
- Political and public interest and support.

Common approaches used in the designation of river corridors are:

- Site Specific Corridor Widths
  Larger rivers need wider corridors because they drain a larger area and their floodplains are larger. This type of corridor system is more complicated and may require increased attention. The public and affected landowners may perceive the variations as unfair or arbitrary.
- Variable Width Corridor
  Corridor widths extend from the 100-year flood line for a distance ranging from 15 to 60m. This allows for some discretion depending on the amount of a landowner's property that will be affected by the buffer.
- Either/Or Corridor
  This method requires a corridor width of say, 100m, or 30m beyond the 100-year floodplain, whichever is larger. Care must be taken to establish the 100-year floodplain.

The river corridor width may be expanded taking special environmental conditions into consideration. For instance:

- Impervious surfaces should not be taken into account as they detract from a stream corridor's ability to remove nutrients and, in addition, the pollutants that collect on paved surfaces run off into the stream. River corridors that have roads running parallel within them should have increased buffers to account for the increased runoff;
- Wetlands have long been recognized for their value in trapping sediment and nutrients. Because they are sensitive lands, their presence requires wider river corridor widths;
- The corridor width should be increased where steep slopes are encountered as they cannot effectively remove contaminants; and
- Where the flood plain is considered environmentally sensitive, the corridor width should be further extended.

The river corridor should be continuous along the river. A minimum corridor width is desirable to reflect natural heritage requirements for maintaining a full-range of natural corridor functions. Examples of minimum corridor width requirements are:

- Thames Valley (drainage area: 12,917 sq. km.) – 100m from the river water's edge [3];
- Manistique River, US (drainage area: 3,780 sq. km) – 120m from ordinary high water mark [4];
- Neuse River, US (drainage area: 16,146 sq. km.)– 45m from river bank [5];
- Red Deer River, US (drainage area: 45,100 sq. km) - 30m for small permanent water courses; 60m for large permanent water courses. [6].

Appropriate legislation should be enacted so that the appropriate authority can exercise the powers for the designation, delineation, protection and maintenance of river corridors and regulation of development within the corridors. Examples of river corridor legislation are: Wild and Scenic Rivers Act, Stream Corridor Ordinance and Zoning Ordinance in the US.

4.5 RIVER RESERVE

Not all river corridors would be included in river reserves, at least not in the short term. A minimum reserve should be established so that there is a clear authority to prevent unauthorized felling of trees or clearing of vegetation and undesirable activities affecting river banks. The required reserve width of a particular river should be the width as determined in the formulated Integrated River Basin Management Plan (if there is one), or the River Basin Flood Mitigation Plan, whichever is larger. In the absence of such plans, the distance specified should then be in accordance with the guidelines on river reserves [7], as shown in Table 4.1:

Table 4.1 Minimum River Reserve Width

Top Width of River	Minimum Reserve Width on Each Bank
> 40 meters	50 meters
30 - 40 meters	40 meters
20 - 30 meters	30 meters
10 - 20 meters	20 meters
5 - 10 meters	10 meters
< 5 meters	5 meters

Source: Pengwartaan Rizab Sungai, Department of Irrigation & Drainage, Malaysia

Every effort should be made to have the required *river reserve* gazetted under Section 62 of the National Land Code to ensure that State DID has the legal jurisdiction and full control over it. For this purpose, an application is to be submitted to the State Authority with the endorsement of the relevant State Executive Committee (varies according to states). The submission should contain the following:

- Describe the land to be reserved (Survey plan showing the exact location and extent of the land – preferably the final project Land Acquisition Plan);
- Specify the purpose (flood mitigation, river management) for which the land is reserved;
- Designate the Controlling Officer (DID State Director) of the reserved land; and
- Provide conclusive evidence that the land so described is reserved for a public purpose.

So far, the Department has not been successful to achieve this target.

Once gazetted, the reserved land shall not be disposed of by the State Authority except to the extent permitted by and in accordance with the provisions of (National Land Code):

- Section 63 (Power to lease reserved land): Either by the application of the Controlling Officer or other application but with his prior approval;
- Chapter 2 (Temporary Occupation of Land) (Power to License Temporary Occupation of State Land, Mining Land and Reserved Land): Section 65 (1) (c) only for reserved land not for the time being used for any purposes for which it was reserved; or
- Chapter 3 (Removal of Rock Material) (Power to Permit Extraction and Removal of Rock Material), Section 70 & 71 (d): Permit to extract, remove and transport rock material from reserved land shall be issued: (i) by the Land Administrator with the approval of the Controlling Officer; or (ii) by the Controlling Officer (whenever and to such extent as he may be authorized on that behalf by the State Authority).

The reservation of any land for a public purpose may be revoked by the State Authority at any time. For this purpose, the notice of proposed revocation shall be published in the Gazette together with the details of an enquiry (time, date & place) to be held by the State Director of Lands & Mines. The decision by the State Authority whether to revoke the reserve land shall then be taken after studying the Report (after enquiry) from the State Director of Lands & Mines setting out the nature of any objections to the proposal received at the enquiry, and his observations thereon. The notice on the decision to revoke the reservation of the land (Section 433) shall be (a) affixed in a conspicuous position – (i) on the land and on the Penghulu's office or "balai" in the area in which the land is situated; and (ii) in the area, on such court-houses and mosques and in such markets and other public places.

4.6 RIVER CORRIDOR MANAGEMENT ISSUES

4.6.1 Need for Strategic Management of River Corridors

There is a need for strategic management of our river corridors. This will include corridor-wide vision and consistent and comprehensive management strategies that all government agencies including Local Authorities endorse and actively implement. The management plan should be produced through a partnership of all major relevant stakeholders including Government agencies, private sector, local communities and the public. Meanwhile, the DID is actively pursuing the establishment of institutions for Integrated River Basin Management (IRBM) for major rivers in Malaysia [8]. Once established (e.g. Lembaga Urus Air Selangor), it would be the most effective channel for the preparation of the river corridor management plan.

4.6.2 Increasing Potential for Conflicts between Uses of Corridor Land

As the use of the river and adjacent land in a river corridor grows, there is increasing potential for conflicts among various users. Prevention or minimization of conflicts among different users and mechanism for conflict resolution should be included in the management plan for river corridors mentioned in Paragraph 4.6.1. Two common approaches for water-users conflict resolution are [9]:

- Multi-stakeholder dialogues – a participatory approach aiming at gathering all relevant stakeholders in a facilitated setting to identify and build common concerns and interests. The most important objective of Multi Stakeholder Dialogues is to find ways to turn situations of conflict and distrust into opportunities for mutual aid and cooperation.
- Rights-based Approach - the ultimate mechanism for conflict resolution, law-based and agreed upon legal procedures for settling conflicts. Intra-state water conflicts (more than trans-boundary conflicts), usually benefit from the existence of some formal institutions and/or legislation for problem-solving.

Important lessons learned overseas on water-users conflict resolution are:

- Importance of embedding conflict resolution mechanisms into larger water governance frameworks and the availability of institutionalized platforms/channels for conflict resolution. Transparent information policies & institutionalized information-sharing mechanisms;
- Scientific inputs for informed decision-making; and
- Long-term building of trust & dialogue among key stakeholders as imperative - when designing a project, it would thus be essential to include various activities that promote trust, dialogue etc. among relevant stakeholders. Some important recommendations in this regard include capacity building and formation of user groups.

4.6.3 Land Conservation

There should be a clear policy on land conservation within the river corridor beyond the river reserve. In this context, land conservation refers to conservation of undeveloped land and parks by Government Gazette under Section 62 of the National Land Code. (Please refer to paragraph 4.2.3.) There are many benefits of land conservation, such as:

- Improving quality of life;
- Contribution to bio-diversity;
- Protecting wild life and their habitat;
- Recreation;
- Protection of watershed and drinking water;
- Protection of historic and archeological sites.

There are enough laws and regulations related to land conservation in Malaysia, such as the following:

- Land Conservation Act 1960
- National Land Code 1965
- National Parks Act 1980
- National Forestry Act 1984
- Town and Country Planning Act 1976
- Parks Enactment 1984 (Sabah)
- Forest Enactment 1992 (Sabah)
- National Parks Ordinance 1956 (Sarawak)
- Forest Ordinance 1954 (Sarawak)
- Public Parks and Greens Ordinance 1993 (Sarawak)

Some strategies for effective land conservation include [10]:

- Strengthen the institutional framework for land conservation
- Strengthen and integrate conservation programmes
- Encourage private sector participation
- Enhance institutional and public awareness
- Exchange of information

The IRBM institution, once established, would be a giant step forward in the implementation of these strategies.

4.6.4 Preservation of Plants and Animal Habitats

Preservation of plant and animal habitats in the river corridor has become crucial in the presence of competing interests and uses such as recreation and residential and commercial development. These include upland, river land and in-stream habitats. Habitat preservation also includes the goal of maintaining natural riparian buffers to prevent soil erosion and maintain water quality. Preservation of these habitats also benefits many far-ranging animals such as migrating birds. Laws and regulations relating to the preservation of plants and animal habitats are:

- Environmental Quality Act 1974
- Fisheries Act 1985
- Pesticides Act 1974
- Plant Quarantine Act 1976
- Waters Act 1920
- Protection of Wildlife Act 1972
- Local Government Act 1976
- Fauna Conservation Ordinance 1963 (Sabah)
- Wildlife Protection Ordinance 1958 (Sarawak)
- Natural Resources Ordinance 1949 as amended by Natural Resources and Environment (Amendment) Ordinance 1993
- Water Ordinance 1994 (Sarawak)

The gazetting of land for the preservation of plants and animal habitats should be in accordance with section 62 of the National Land Code.

The strategies recommended for land conservation (paragraph 4.6.3) also apply to preservation of plants and animal habitats.

4.6.5 Preservation of Cultural Resources

Due consideration should be given to the preservation of cultural resources including historic and ethnographic resources in the establishment of land use policies and implementation of new

development programmes for river corridors. Our cultural heritage is a part of the irreplaceable wealth of humankind. As such, it is worthy of our greatest efforts to preserve and to maintain it.
As preservation of cultural resources is the responsibility of the Department of Museum and Antiquities and is governed by Antiquity Act (Act 168) 1976, the discovery of any antiquities should be reported to this Department.

4.6.6 Responsible Public Access to the River and Riparian Lands

Responsible public access should be made available to the river and riparian lands for education purpose. Private land owners should also be encouraged to allow public access and public education regarding the responsible use of private property and public resources. The river and its adjoining lands may have abundant and diverse fishery, scenic beauty, many stretches of boatable waters, excellent wildlife populations, camping, hiking and other recreational opportunities, and outstanding opportunities for private residential development. These opportunities may result in increasing pressure from recreational users and development interests. To help protect the pristine river resources, the river corridor management plan should have clear guidelines on the development and recreational use along the river. Well-spaced public access points along the river should be clearly identified so as to prevent resource damage, safety problems, user conflicts and trespass problems to adjacent private landowners caused by the use of informal access points created by users. This will also ensure that river quality will not be threatened due to erosion and sedimentation and cutting riparian or streamside vegetation. Proper management of public access sites is critical for the protection of the river corridor while simultaneously providing the public with opportunities for quality recreational experiences. A classic example of river access is given in [11] which relates to the planning of public accesses for the Upper Manistee River in Michigan in the U.S.

4.6.7 Prevention of Loss of Wetlands

Preservation of wetlands such as mangroves, mudflats, nipah swamps, fresh-water swamps, peat swamps, lakes including ox-bow lakes, marshes, etc., should be given priority in river corridor landuse policy as wetlands serve many beneficial functions such as:

- Maintaining stream and river flow duration;
- Serve as drought relief;
- Reduce flood peaks and therefore flood damage;
- Soil erosion protection;
- Water quality improvement;
- Wild life protection;
- Renewable economic benefits (such as timber and wildlife);
- Recreation and education, e.g. Figure 4.2.

Figure 4.2 Recreational areas at Tasik Chini

Malaysia became a contracting party to the Convention on Wetlands of International Importance Especially as Waterfowl Habitat, better know as the Ramsar Convention, in November 1994. The importance Malaysia gives to Wetland conservation and management for sustainable development was emphasized during the International Conference on Wetlands and Development held in Kuala

Lumpur in October 1995 when, in the Opening Speech delivered by the Malaysian Prime Minister, acknowledged that "... wetlands and their resources play a critical role in supporting the lives of millions of people throughout the world. Wetlands not only provide a wide range of valuable products to society, including fish, fodder and timber, but also perform a number of natural biophysical functions such as flow regulation and groundwater recharge. They are therefore relevant for research and understanding to ensure that their contributions to the development of the ecosystems are maintained."

Many organizations are involved in wetlands research and management, including Asian Wetland Bureau of the Institute of Advanced Studies, University of Malaya and Malaysian Wetland Working Group. The latter is responsible for putting up the National Wetlands Policy which was adopted by the Government in 2004. A number of Non-Government Organizations are also involved, the pertinent ones being Wetlands International, Malayan Nature Society and World Wide Fund for Malaysia.

Laws and legislation related to wetlands include the National Parks Act 1980, the Protection of Wild Life Act 1972, the National Forestry Act 1984, the Local Government Act 1976, and the Town and Country Planning Act 1976.

4.6.8 Stormwater Runoff Quality Management

Rain water carries sediment, plant nutrients and toxic substances from development activities (such as construction sites) and developed areas (such as lawns and paved areas) to surface water. BMPs to address these are available in MSMA [12] and listed as follows:

- Filtration – use of biofilters to remove low concentrations and quantities of TSS, heavy metals, hydrocarbons and nutrients, and media filtration for removing conventional pollutants. Please refer to MSMA (Volume 12) for details on this BMP;
- Oil Separators – use of API tanks and plate separators for the removal of oil in urban stormwater runoff. For details of this BMP, please refer to MSMA (Volume 12, Chapter 32);
- Gross Pollutant Traps – for the removal of litter, debris and coarse sediment from stormwater. Please refer to MSMA (Volume 13) for details of this BMP;
- Ponds and Wetlands – use of wet ponds, extended detention basins and constructed wetlands for the removal of sediment and nutrients from stormwater. For details, please refer to MSMA (Volume 13).

4.6.9 Prevention of Soil Erosion

The prevention of soil erosion resulting from development is very important in river management recognizing that the loss of soil from construction sites, logging tracks, or any unstable excavation areas has dual impacts like on-site loss of soil potential and sedimentation of streams and rivers. Measures should be taken to ensure that developers and contractors implement BMPs that reduce soil erosion and control sedimentation according to MSMA (Volume H). Typical BMPs are shown in Table 4.2.

Table 4.2 Erosion and Sediment Control Measures and Objectives

BMP CATEGORY	BMP OBJECTIVES						
	Practice Good House-keeping	Contain Waste	Minimize Disturbed Area	Stabilize Disturbed Area	Protect Slopes and Channels	Control Site Perimeter	Control Internal Erosion
Site Planning Considerations							
- Scheduling	□	□	□	□	□	□	□
- Preservation of Existing Vegetation			□	□	□	□	
Vegetative Stabilization							
- Seeding and Planting				□	□		
- Mulching				□	□		
Physical Stabilization							
- Geotextiles and Mats				□	□		
- Dust Control	□		□	□		□	
- Temporary Waterway Crossing	□		□	□	□		
- Construction Road Stabilization	□		□	□	□		
- Construction Access Stabilization	□		□	□		□	
Diversion of Runoff							
- Earth Bank		□			□	□	□
- Diversion Channel					□	□	□
- Slope Drain					□		
Flow Velocity Reduction							
- Drainage Outlet Protection					□		
- Check Dam					□		
Sediment Trapping/Filtering							
- Sediment Fence						□	□
- Sand Bag Barrier					□	□	□
- Brush or Rock Filter					□	□	□
- Drainage Inlet Protection						□	□
- Sediment Traps							□
- Sediment Basins							□

Source: MSMA (Volume H), Department of Irrigation and Drainage.

4.6.10 Enhancement of Cooperation among Government, Private Organizations and Academia

There are many groups and individuals with interest, expertise and resources to act on river corridor management issues. Networking among Federal, State and Local Government bodies, schools, colleges and institutions of higher learning, business organizations and NGOs should be enhanced to improve the effectiveness of management through integration of river basin management.

4.6.11 Public Education to Promote Stewardship

The protection of any resource will become a way of life where there is a highly developed sense of shared ownership, appreciation and responsibility for that resource. The challenging task of developing public understanding, appreciation, and stewardship of the natural resources in the river corridor should be the primary objective of river corridor management. To this end, the “Love Our River” campaign should be part of the long-term action plan for river corridor management. While adoption of river reaches by the private sector is to be encouraged, emphasis should be towards school-based education programmes that raise awareness of the young regarding river pollution and encourage them to take action to restore and protect the river.

4.6.12 Land Use Controls for Development on Steep Slopes

Steep slopes are land with slopes greater than 25°. There are a number of issues associated with development on steep slopes, hillsides, and ridgelines. Foremost among them are health, safety, and environmental considerations that arise when planning development in steep areas. Another factor is the aesthetic quality of hillsides and ridgelines that can be lost when they are developed. Protecting hillsides and steep slopes from development helps to preserve those unique environmental qualities that people value. Furthermore, development on steep slopes can have an adverse effect on water quality as a result of increased erosion and sedimentation. In this connection, the problem of soil erosion and reservoir sedimentation in Cameron highlands is a well-known example. Thus, it is recommended that agricultural development on slopes above 25° should be avoided [13]. All development on hill-slopes should adhere to the Land Conservation Act 1960 and other prevailing guidelines such as "Garispanduan Perancangan Pembangunan Kawasan Bukit" of the Town and Country Planning Department.

4.6.13 Protection of Ground Water

Groundwater, though limited in Malaysia, is an alternative source of water supply. Measures to protect groundwater against pollution (e.g. Figure 4.3) are therefore essential. Control to prevent over-extraction is also important as ground water contributes to the flow of streams and rivers. Over-extraction also leads to ground subsidence.

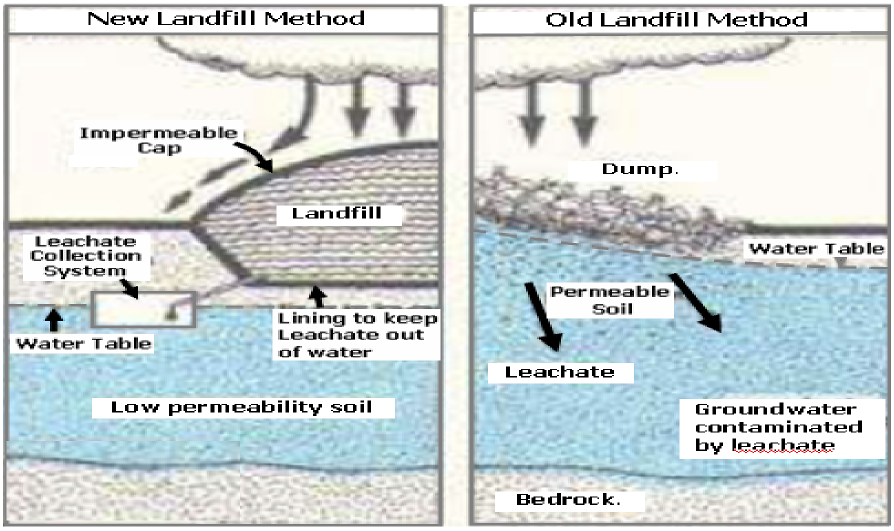

Figure 4.3 Protection of groundwater contamination by landfill leachate

Groundwater monitoring is carried out by the Department of the Environment under the National Groundwater monitoring Programme. According to the 2006 Environmental Quality Report [14], 88 monitoring wells had been established at 48 sites in Peninsular Malaysia, 19 wells in Sarawak and 15 wells in Sabah. The number of wells according to land-use is as follows:

- Agricultural Areas 12
- Urban/Suburban Areas 12
- Industrial Sites 18
- Solid Waste Landfills 27
- Golf Courses 7
- Radioactive Landfill 1
- Rural Areas 5
- Ex-mining Areas (Gold Mine) 3
- Municipal Water Supply 11
- Animal Burial Areas 16
- Aquaculture Farms 9
- Resorts 1

A total of 340 samples were taken from these wells. Based on the National Guidelines for Raw Drinking Water Quality from the Ministry of Health (Revised December 2000) (Table 4.3) as the benchmark. Iron (Fe) levels exceeding the benchmark were recorded in all water samples taken. Between 15 percent and 100 percent of samples taken from the respective areas showed manganese (Mn) levels in excess of the benchmark. Between 5 percent and 13 percent of samples in rural areas (5%), landfills (5%), municipal water supply (5%), golf courses (7%), agricultural areas (9%) and industrial areas (13%) were found to exceed the nitrate benchmark except in urban/suburban, ex-mining areas and radioactive landfills. Arsenic levels exceeding the benchmark were recorded at radioactive sites (100%), ex-mining areas (67%), solid waste landfill (44%), municipal water supply (36%) and agricultural areas (20%). All samples except those from rural areas did not meet the required standard for coliform.

Table 4.3 National Guidelines for Raw Drinking Water Quality from the Ministry of Health (Revised December 2000)

Parameter	Symbol	Benchmark
Sulphate	SO4	250 mg/l
Hardness	CaCO3	500 mg/l
Nitrate	NO3	10 mg/l
Coliform	-	Must not be detected in any 100 ml sample
Manganese	Mn	0.1 mg/l
Chromium	Cr	0.05 mg/l
Zinc	Zn	3 mg/l
Arsenic	As	0.01 mg/l
Selenium	Se	0.01 mg/l
Chloride	Cl	250 mg/l
Phenolics	-	0.002 mg/l
TDS	-	1000 mg/l
Iron	Fe	0.3 mg/l
Copper	Cu	1.0 mg/l
Lead	Pb	0.01 mg/l
Cadmium	Cd	0.003 mg/l
Mercury	Hg	0.001 mg/l

Source: Ministry of Health, Malaysia

The results indicate that urgent action is required to address the groundwater quality issue.

4.6.14 Preservation of Agricultural Land

Agricultural land has many significant economic and environmental values such as:

- Ensuring agricultural production for national food security;
- Providing local food choices;
- Maintaining groundwater recharge ability;
- Mitigating air pollution, ozone, and greenhouse gas emissions; and
- Providing community buffers or greenways.

Due to the rapid pace of urbanization, a large proportion of agricultural land has given way to residential, commercial and industrial development. Strategic land-use planning through zoning should be implemented to preserve agricultural land. This will help to preserve the local agricultural potential, its rural character and protect open space for habitat and landscape views, e.g. Figure 4.4.

Figure 4.4 Paddy Field on the floodplain of Sg. Muda

As a guide, preservation of agricultural land should be prioritized based on the following considerations:

- Soil quality and productivity;
- Agricultural infrastructure;
- Farming methods, including conservation practices;
- Unique or critical land quality;
- Critical size of a parcel for a viable agricultural operation;
- Proximity to other protected land for a critical mass to achieve effectiveness;
- Importance to local agricultural and economic vitality; and
- Importance to provide environmental or economic benefits, such as
  - Open space and scenic beauty;
  - Economic opportunity, such as agro-tourism;
  - Wildlife habitats;
  - Community buffers or greenways;
  - Clean air or carbon sequestration;
  - Historical or cultural significance; and
  - Recreational opportunities.

4.6.15 Control and Prevention of Development of Flood Plains

The use of flood plains for agricultural purpose does not preclude its hydrologic values. However, urbanization of agricultural lands does. Building and paving on flood plains have led to loss of flood storage and increased downstream flooding. Most of the flood flows are now restricted within river bunds. With the limited reserve, lining of rivers using concrete sections have been carried out rendering them environmentally unfriendly. Perhaps the time has come that further development of flood plains be controlled /prevented (with land use zoning) with the objective of preserving the flood plains as they are, allowing seasonal flooding. This is further discussed in paragraph 4.9.

4.6.16 Integration of Corridor Management Plans with Structure & Local Plans

Inclusion of policies and measures in structure and local plans to address the issues identified in river corridor management plans is an important step to fulfill the goals of the plans. This should be possible with the inclusion of the State and Local Authorities as members of the IRBM institution.

4.7 RIVER CORRIDOR MANAGEMENT ALTERNATIVES

The most important objective of managing the river corridor is to resolve or minimize conflicts between river dynamics and land use expectations. To this end, the alternative approaches available to the river corridor manager include [15]:

- Active Geomorphic;

- Passive Geomorphic;
- Channelization;
- Do nothing; and
- Combinations of the above.

The active geomorphic approach as shown in Figure 4.5 restores or manages rivers to a geomorphic state of dynamic equilibrium through river restoration measures including human-constructed meanders, floodplains, bank protection and stabilization techniques so that dynamic equilibrium is achieved in a relatively shorter period of time. Chapter 3 provides examples of such measures.

Active riparian buffer revegetation and long-term protection of a river corridor are essential to this alternative. Section 4.8 shows details of riparian buffer requirements.

Figure 4.5 Active Geomorphic Approach: Bank Protection of the Klang River.

This approach involves the design and implementation of practices intended to resolve conflicts and meet the goal of protection and/or restoration of properties, social values and ecological functions. The primary ecological functions include:

- River dynamics involving river evolution, energy management and riparian succession;
- Hydrologic balance involving water storage, surface/subsurface water exchange and seasonal flow condition;
- Sediment processes involving sediment continuity, substrate and structural processes. and quantity and quality of sediment;
- Biological support involving biological communities, necessary habitats for all cycles of life, and trophic structures and processes; and
- Chemical processes and pathways involving water and soil quality, nutrient cycles and landscape pathways.

This approach is a highly preferred alternative due to the benefits associated with long term economic and ecological sustainability. It may be applied where conflicts are high, but is tempered by the fact that short-term costs and risks are also high due to construction and maintenance, as well as the land use changes that may be engendered. The construction of a river channel and its floodplain may be the most cost effective and preferred alternative in a post-flood situation where avulsions and property damage are severe and remediation costs are already high. Maintenance costs may be minimal where river corridor protection and channel management rights have been secured and little or no future conflict on all or part of the restored channel is anticipated.

The passive geomorphic approach as illustrated in Figure 4.6 allows rivers to return to a state of dynamic equilibrium by the removal of constraints from a river corridor thereby allowing the river to utilize its own energy and watershed inputs to re-establish its meanders, floodplains, and self-maintaining, sustainable equilibrium condition over an extended period of time.

Figure 4.6 Stream Restoration: Passive Geomorphic Approach.

This approach involves all the assessment and design elements of an active geomorphic project with the exception of human constructed channel and floodplain geometry. The stream bed and banks are not treated, and the channel evolution process is allowed to proceed unimpeded. It may be the most preferred alternative due to the lower risk and maintenance costs associated with its implementation and the long term economic and ecological sustainability that is accrued. But, due to the costs associated with changes in land use and/or buyouts, the passive geomorphic approach may be preferred more often where conflicts are in the minor to moderate range. There are also risks to upstream and downstream reaches and adjacent landowners (associated with active adjustment processes) that should be taken into account. The channelization approach in Figure 4.7 maintains rivers in a channelized state through excavation/dredging and bank protection techniques.

Figure 4.7 Channelization Approach at Sg. Kerayong.

This approach involves the design and implementation of practices intended to resolve conflicts and meet the goal of protecting property and certain other social values. New channel straightening efforts are rarely permitted today, but many dredge, berm, and armour practices are carried out on channels that were historically straightened. They are essentially projects implemented to re-establish the flow capacity of the altered channel and/or rip rap banks that have begun to fail. All river channels move over time, and therefore any project that attempts to lock in the plan form or meander geometry of a river is, in part, a channelization project. An armoured or fixed channel that has or is constructed to have the dimension, pattern, profile, and median sediment size of its equilibrium condition will perform more ecological functions than one that is armoured as a straightened channel. Any type of channelization project is prone to repeated failure in dynamic channels, where the sediment load is high and transport capacity is limited. This approach may be preferred and offer the only viable alternative where conflicts are high or extremely high and land use conversions are not possible.

The <u>do nothing approach</u> literally involves doing nothing at all until conflict resolution becomes imperative. It may be preferred where land use conflicts are low to non-existent. The do-nothing approach is not a preferred alternative where conflicts are in the moderate to high range and its selection only postpones the implementation of a different alternative and/or adversely affects fluvial processes in upstream and downstream reaches. Delays in resolving conflicts typically result in higher costs and fewer management options.

The combination approach use combinations of alternative approaches to accommodate the varying constraints that typically occur along a river reach. Prior to the selection of any management alternative, geomorphic assessment of the river stretch including upstream and downstream reaches should be carried out to understand the economic and ecological consequences to both on-site and off-site areas, properties and infrastructure. In addition, it is essential to protect, maintain or restore essential riparian values by establishing and maintaining a wooded buffer between the channel and adjacent land uses.

Long term success will primarily depend on our ability to solve problems at the watershed and river corridor level, and secondarily, on how we resolve conflicts at individual erosion sites. From a geomorphic standpoint, we need to give recognition that rivers transport and deposit sediment and that natural stability and balance in the river system will depend on the river's opportunity to build and access a floodplain and create depositional features such as point bars, steps, and riffles to evenly distribute its energy and sediment load in a sustainable manner, e.g. Figure 4.8.

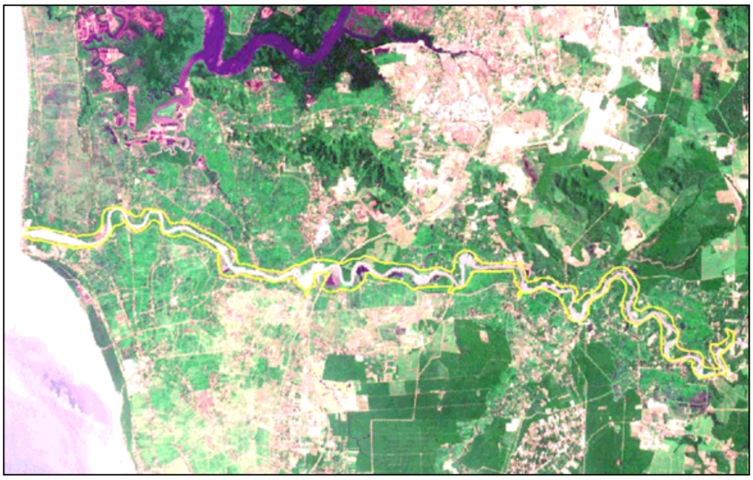

Figure 4.8 Example of River Corridor for Sg. Muda [16]

From a watershed point of view, as smaller rivers in the upper watershed zone compose a major proportion of the length of channels in a watershed and serve as the major area of interface between river corridors and the surrounding watersheds, effective management of small river corridors offers higher benefits per river segment affected. The management of river corridors in the lower reaches of a watershed will also be more effective when the headwater river corridors are properly taken care of.

As financial resources are never sufficient to permit all possible management interventions in a watershed, the scarce resources available must be allocated to those activities which together contribute most to overall system maintenance, the well-being of local populations, and to downstream water resource users. River corridor management, particularly along smaller rivers in both upper watersheds and lowlands, can be a cost-effective contribution to a watershed management program.

An integrated two-step ecological engineering approach to river corridor management is recommended. The first step involves the establishment or preservation of the filtering capacity of the corridor vegetation that serves as the buffer between the river itself and the rest of the watershed. This is discussed in detail in Section 4.8. The second is the maintenance of the biological and physical integrity of the river ecosystem and involves protecting the river from direct impacts such as channelization, waste dumping, and livestock watering. If this approach is effective in maintaining the integrity of the corridor with its riparian and aquatic components, then the maximum range of goods and services of local or downstream value (fisheries and wildlife, recreation, water for domestic, agricultural and industrial use, and waste removal and treatment) can be provided.

4.8 MANAGEMENT OF RIPARIAN LAND

4.8.1 Definition

Riparian land can be defined as any land which adjoins, directly influences, or is influenced by a river [13]. River riparian land includes the land immediately alongside the river, including the river bank itself and areas surrounding lakes and wetlands on river floodplains which interact with the river in times of flood.

4.8.2 Objectives of Riparian Land Management

For some time in the past, the important linkages between land and water in riparian areas were not well recognized by land users. They believed that streams and rivers function as drains to remove problems from their land. However, it is now understood that waterways are similar to arteries and support the land around them. Because of its position, riparian land can be seen as a 'last line of defense' for aquatic ecosystems. Riparian vegetation acts as a filter strip to trap sediment and nutrient and reduce their movement into the river in order to sustain water quality, protect native instream biota, and help to maintain flow capacity, e.g. Figure 4.9.

Figure 4.9 Healthy Riparian Vegetation (Sg. Lawau, Sabah)

Activities that affect water quality include removal of natural vegetation for cultivation of annual or forage crops and livestock grazing within the river riparian land. Problems arising from river bank erosion include loss of valuable land, damage to properties and infrastructure, sedimentation, and changes to flow regimes with potential for increased flooding, e.g. Figure 4.10.

Figure 4.10 Bank erosion due to removal of riparian vegetation

Riparian vegetation protects river banks from surface erosion by rain, water flow or stock. The roots of riparian vegetation can help to dry and reinforce bank soils to prevent cracking and slumping. Recognizing the many potential benefits that can be achieved, many landholders, community groups and government agencies have in recent years become actively involved in improving riparian management to [17]:

- Reduce erosion of river banks and loss of valuable land;
- Maintain river light and temperature levels for healthy in- stream ecosystems;
- Provide a source of food and habitat for aquatic ecosystems;
- Provide for conservation and movement of wildlife;
- Enable sustainable agricultural productivity; and
- Provide recreation and deliver aesthetically pleasing landscapes.

4.8.3 Alternatives in Riparian Land Management

4.8.3.1 Maintaining an Adequate Riparian Buffer Zone along the River Corridor

Wherever possible, protect, preserve, improve or re-establish existing vegetation, or to create new vegetation to provide a riparian buffer zone along the river bank, e.g. Figure 4.11.

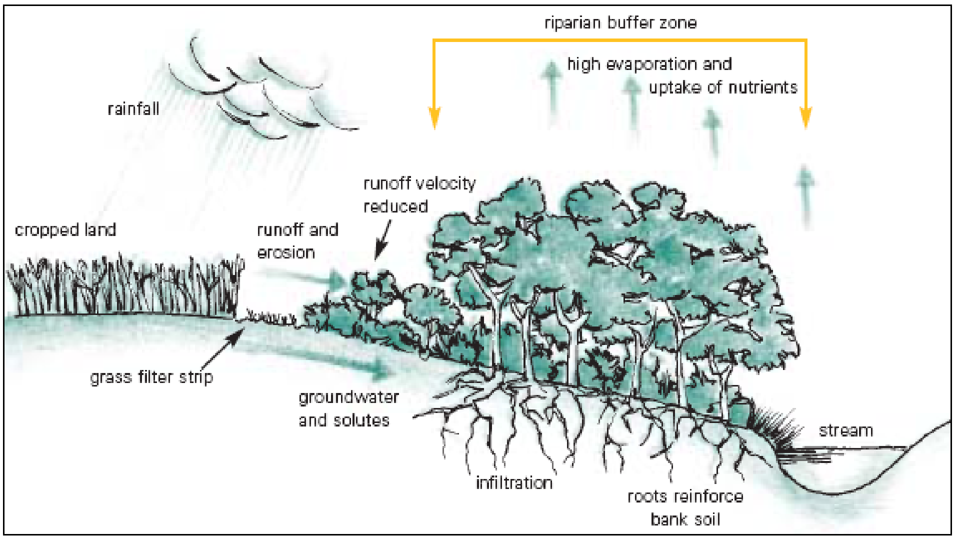

Figure 4.11 Example of Riparian Buffer Zone

The first priority is to identify and protect areas of existing riparian vegetation assessed to be in good condition. Areas can be compared with local undisturbed or reference sites, and/or assessed for their capacity to provide crucial riparian zone functions and to self-regenerate. The next priority is to promote natural regeneration or recolonisation where this is possible. This may require checking for availability of seeds in the soil or on plants, removal of threats such as grazing animals or weeds, and sometimes deliberate action to promote regeneration. [18]

Design of Riparian Buffer Zone

There are two approaches for the determination of the width of river riparian buffer zone, namely the fixed-width approach and the variable-width approach. The fixed width approach had been popular in the past mainly due to ease of administration and enforcement. However, as it tends to be biased towards a single parameter or function and often fails to provide for many ecological functions, it is being phased out. The trend now is towards variable-width buffer zones designed for a variety of functions and tailored to suit site-specific conditions by having widths adjusted along the length of the river and depending on the type of vegetation, topography, hydrologic conditions and adjacent landuse [19].

Design Considerations

There is no “one-size-fits-all” ideal riparian buffer zone that will serve all ecological functions. Rather, the width should be based on the intended objectives of the buffer zone. Besides, the ability of a buffer zone to meet specific objectives is a function of its position within a watershed, the composition and density of vegetation and species, buffer width, length and slope.

Position Within Watershed

Water quality in a river is strongly influenced by land-use practices in the upper reaches of the river. As such, riparian buffer zones situated at headwater reaches have much greater effects on the overall water quality than those in downstream reaches. Even the best buffer zones along large rivers have little or no significant effects on water quality. However, as the buffer zones along the larger rivers tend to be longer and wider, they offer significant habitats for wildlife and their movement. Thus, in order to ensure significant impacts, it is necessary that critical areas requiring buffer zones be identified. As interactions between aquatic, riparian and terrestrial ecosystems are a function of valley-floor morphology (soil and type of valley-floors), digitized GIS data on valley-floor morphology are useful in delineating areas with high erosion potential.

Buffer Composition

In general, a suitable mix of native trees, shrubs and herbaceous plants that are well-adapted to the climatic, soil and hydrologic conditions of the site is recommended. Table 4.4 which indicates the effectiveness of different vegetation in meeting specific objectives within a riparian buffer zone can be used for the mix design. The help of a botanist should be sought in the selection of the species and diversity most likely to meet the intended objectives and to ensure their proper placement in the flood plain.

Table 4.4 Relative Effectiveness of Different Vegetation Types for Providing Specific Benefits

Benefit	Vegetation		
	Grass	Shrub	Trees
Stabilizes bank erosion	Low to Medium	High	Medium to High
Traps sediment	High	Low to Medium	Low
Filters nutrients, pesticides, microbes			
- sediment-bound	High	Low	Low
- soluble	Medium	Low	Medium
Provides aquatic habitat	Low	Medium	High
Provides wildlife habitat			
- range/pasture wildlife	High	Medium	Low
- forest wildlife	Low	Medium	High
Provides economic products	Medium	Low	Medium
Provides visual diversity	Low to Medium	Medium	High
Prevents bank failures	Low	Medium	High
Provides flood conveyance	High	Low	Low

Source: Adapted from [19] (US Army Engineering and Research Center and [20] (NRCS Planning and Design Manual).

Trees Suitable for Planting Along Riverbanks

In collaboration with the Malaysian Forest Research Institute, the DID has published a guide on planting of trees along riverbanks [21]. Suitable trees recommended are:

- Medang Teja (Cinnamomum Iners)
- Janda Merana (Salix Babylonica);
- Pokok Pukul Lima (Samanea Saman);
- Dedap (Erylthrina Orientalis);
- Bungor (Lagerstroemia Floribunda);
- Gelam, Kayu Putih (Melaleuca Cajuputi);
- Tembusu Padang (Fagraea Fragrans)
- Kayu Raja (Cassia Fistula);
- Kasai (Pometia Pinnata);
- Gapis (Saraca Thaipingensis); and
- Ara, Beringin (Ficus Benjamina).

Buffer Width and Length

Riparian buffer zone width is measured from the river bankfull discharge edge. Recommended widths of buffer zones to meet different objectives are given in Table 4.5.

Table 4.5 Recommended Widths for Riparian Buffer Zones

Management Objective	Recommended Width	Remarks
Protect Water Quality	5 – 30 m	Low slopes (0-10%) - Dense grassy or herbaceous buffers intercept runoff, trap sediments, remove pollutants and promote ground water recharge. Moderate slopes (10-20%) – most filtering occur within the first 10 m. Greater widths are required for: steeper slopes; where the buffer comprise mainly trees and shrubs; where soils have low permeability; or where NPSP loads are particularly high.
Reduce Bank Erosion	10 – 20 m	Riparian vegetation enhances bank stability by moderating soil moisture and providing tensile strength through the root system. Greater width may be necessary where there is active bank erosion. Excessive bank erosion may require additional bio-engineering techniques described in Chapter 3.
Provide Food Input/Aquatic Habitat and Maintain Light/Temperature Level	5 – 10 m	Leaves, twigs and branches falling into the stream are an important source of nutrients and aquatic habitat. Native riparian vegetation provides shade which is crucial for maintaining natural levels of light intensity and temperature for healthy in-stream ecosystems.
Provide Terrestrial Habitat	30 - 500 m	Buffers comprising diverse stands of shrubs and trees provide food and shelter for a wide range of riparian and aquatic wildlife.
Enable Agricultural Production	10 – 30 m	Riparian land is often a highly productive part of the landscape. It can be managed directly for commercial products such as timber or honey, or indirectly so that it improves production by providing habitat for pollinators or acting as windbreak for commercial crops and domestic stock. When acting as windbreak, the length should be at least 20 times the width.
Downstream Flood Attenuation	20 – 150 m	Riparian buffers promote floodplain storage through backwater effects. They increase water flow time by interception, resulting in reduced flood peaks.

Source: Adapted from [19] (US Army Engineering and Research Center) and [22] (Land & Water, Australia).

In delineating the buffer zone, one should bear in mind the following important principles:

- Think at watershed scale when planning for or managing riparian buffer zones; many upland species may at some stages of their life cycle use the buffer zones as habitat, for movement, or dispersal;
- Buffer zones that maintain or restore natural connectivity are better than new ones that link historically unconnected areas;
- Long, continuous buffer zones are more effective than fragmented strips of greater width in moderating temperatures, reducing gaps for protection from NPSP, and providing habitat and movement corridors for wildlife;
- Wider buffer zones are better than narrow ones;
- Riparian buffer zones are more valuable than other types of corridors as the former offers heterogeneity and provides food and water;
- Several buffer zone connections are better than a single connection;
- Structurally diverse buffer zones are better than structurally simple ones; and
- Native vegetation in buffer zones is better than non-native vegetation.

For urban areas, the Urban Storm Water Management Manual for Malaysia (MSMA) recommends widths of riparian buffer zones according to functions such as riparian habitat island, wildlife corridor and filter buffer. For details, please refer to MSMA (Volume 17).

In deciding the widths of riparian zones, judgment should be exercised by taking into account the conditions of the site and sources of sediments and pollutants. In general, minimum riparian zone widths of 10 m should be provided in order to achieve multiple objectives of water quality protection, stream bank stability and aquatic habitat functions. The widths should be increased to minimum 20 m for meeting additional needs of flood attenuation, and further increased to 30 m or more for terrestrial wild life habitat.

4.8.3.2 Use of Multi-zone Riparian Buffer [19, 20]

Depending on the objectives, a two- or three-zone riparian buffer system may be implemented. Figure 4.12 shows a two-zone model implemented in the Upper Peninsula of Michigan, U.S., with an emphasis on protecting water quality and quality of life. In this case, a 15 m buffer is recommended for both sides of a river. The buffer is divided into two distinct zones: a Stream Zone, and an Outer Zone. No cutting of trees is allowed in the Stream Zone. Harvesting of mature trees is allowed in the Outer Zone, but shrubs and herbaceous ground-cover should remain for intercepting surface run-off.

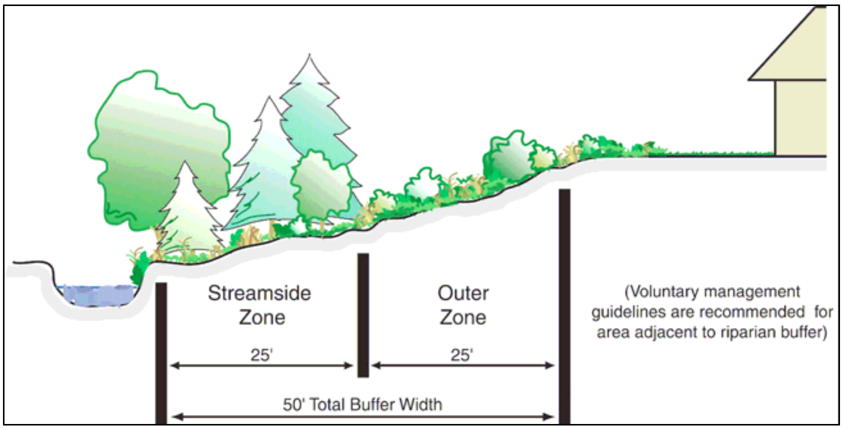

Figure 4.12 Two-zone riparian buffer for protection of water quality and quality of life. (Note: lengths in feet with 1 m = 3.28 ft)

Figure 4.13 depicts a typical three-zone buffer. Zone 1, with a width of 5 - 8 m, consists of undisturbed vegetation; it fulfills multi-objectives of river bank stabilization, provision of habitat for both aquatic and terrestrial organisms, shade and detritus input to the aquatic ecosystem, flood attenuation, and removal of some sediments and nutrients. Zone 2, extending upslope from Zone 1 for a width of 15 – 30 m, comprises mature native vegetation and provides passive recreation and stormwater management facilities. Limited tree clearing is allowed in this zone. Zone 3, extending for about 5 - 8 m and consisting of herbaceous plants and grass, provides the greatest water quality benefits by slowing runoff, infiltrating water and filtering sediment and associated chemicals.

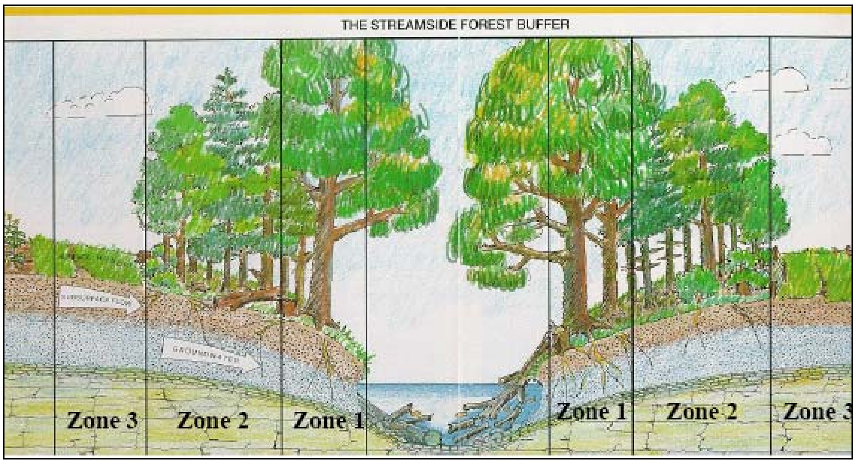

Figure 4.13 Three-zone system for long-term management of forested riparian buffers.

Figure 4.14 illustrates a three-zone model for urban rivers as recommended by the U.S. Center for Watershed Protection. It is made up of:

- Streamside zone – Minimum 8 m plus wetlands and critical habitat, with undisturbed mature forest (to be reforested if grass). Used for: footpaths, utility right-of-way, flood control;
- Middle zone – 15 to 30 m depending on stream order, slope and 100-year flood plain, with managed forest and some clearing allowed. Used for: recreation, stormwater BMPs, bike paths, tree harvesting; and
- Outer zone – Minimum 8 m setback to structures, usually with grass turf. Used for: yards, garden, compost, most stormwater BMPs.

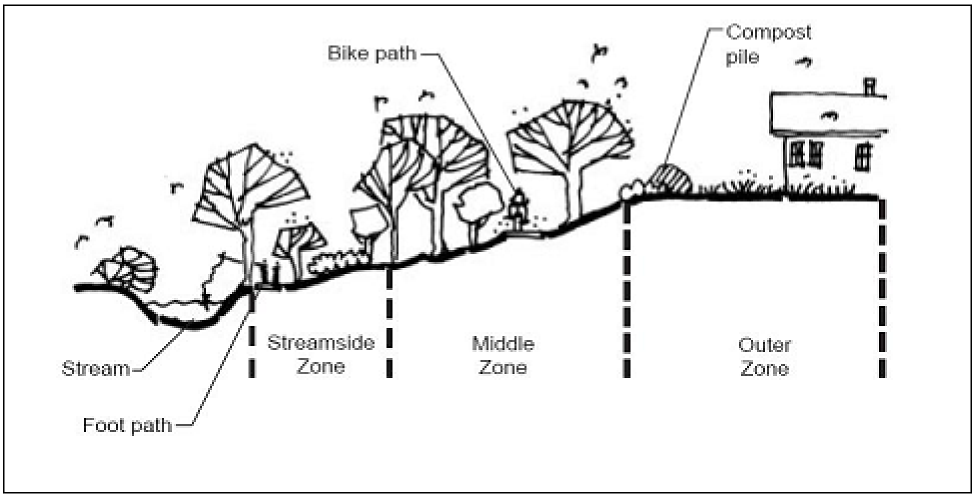

Figure 4.14 Three-zone urban river riparian buffers system.

The three-zone urban model is also suitable for riparian buffers for agricultural areas.

4.8.3.3 Use of Fencing To Control Access of Stock To Riparian Areas

Where necessary, fencing (e.g. Figure 4.15) should be constructed with a minimum set-back of 5m from the top of river bank to control stock access to riparian areas. The set-back should be increased where the existing river bank is eroding or where periodic flooding occurs.

Figure 4.15 Fencing for Controlling Access of Stock to Riparian Area

4.8.3.4 Complementary Engineering Works

Contour banks, farm dams, and hedges of upright grasses or other dense species may be needed in areas of concentrated flow. Where engineering work is appropriate (for example, where confined runoff results from road and laneway drainage, stockyards and stock tracks), drainage should be set back at least 30 m from the stream. Runoff should be allowed to disperse immediately downslope of the source and then pass through a grass filter strip. Forest buffers are probably not capable of trapping significant amounts of sediment from confined sources. Additional structural works can help cope with intense confined sources. Such measures might include farm dams, settling ponds, wetlands, contour banks, straw bale barriers, and sediment control fences.

4.9 FLOODPLAIN MANAGEMENT

4.9.1 Definition

For the purpose of this manual, flood plain means any land adjacent to a river that is formed chiefly of river sediment and is susceptible to flooding by water overflowing the banks of the river as illustrated in Figure 4.16.

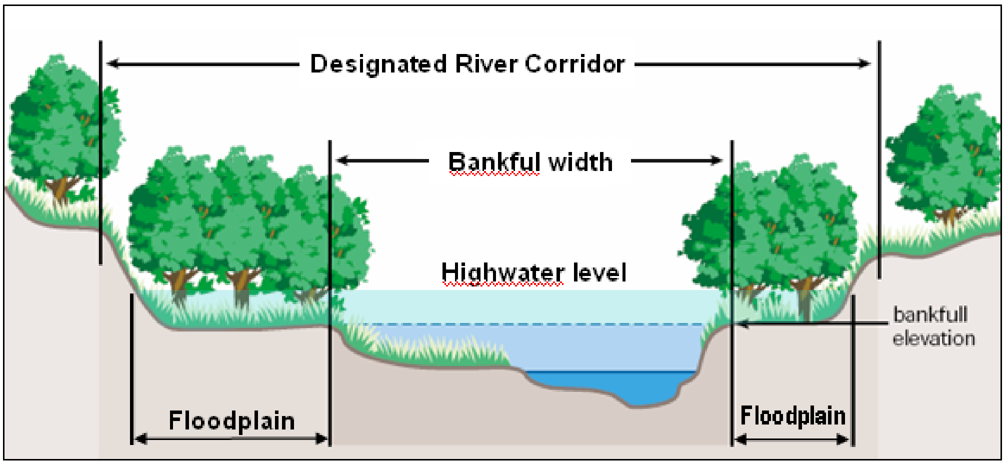

Figure 4.16 A River's Floodplains.

4.9.2 Natural Values of Floodplains

Natural floodplains support productive and diverse biota that is adapted to alternating high and low water flows that may occur on a regular cycle. Floodplains provide areas where floodwaters can spread out to be temporarily stored, thereby reducing downstream flooding. This reduces flood peaks and the resulting flood velocities that can cause erosion and property damage. Floodplains maintain or improve water quality in streams and reservoirs. A vegetated flood plain slows surface runoff, causing it to drop most of its sediment load on the valley floor. This filtering process adds nutrients to floodplain soils that are retained within the floodplain limits by the vegetation, biotic life, and/or wetlands that are present. Floodplains serve an important role in ground water recharge during low flow periods to the rivers and streams.

4.9.3 Objectives of Floodplain Management

Inappropriate development of land in floodplains has historically taken place due to the natural tendency for settlers to utilize land in the vicinity of water bodies. Unfortunately, due to the flood potential of such development which is recognized only much later, large expenditure on flood mitigation measures has been necessary to control future flooding, carry out remedial works and provide compensation.

These problems would not arise if development in the floodplains is properly managed. Hence the primary objectives of floodplain management are to:

a) Limit the effect of flooding on the well-being, health and safety of flood-prone individuals and communities to an acceptable level;
b) Limit damage caused by flooding to private and public properties to an acceptable level;
c) Ensure that the natural function of the floodplain to convey and store water during a flood is preserved and where necessary enhanced, along with any associated flood-dependent ecosystems;
d) Encourage the planning and use of floodplains as a valuable and sustainable resource capable of multiple but compatible land uses of benefit to the community.

4.9.4 Integrated Approach In Floodplain Management

Proper management of the floodplain involving management of people, landuse and the environment can minimize flood damages in most flood hazard areas. This is a complex multi-objective process that requires consideration of many inter-related issues (such as community aspirations regarding the use of flood-prone land, social, ecological and economic costs and benefits of alternative land uses and management measures, and hazard cost and social disruption caused by flooding). It also requires the commitment and cooperation of all individuals and local communities. As such, the institution for IRBM is the best machinery to run it.

Best practice floodplain management requires that an appropriate integrated mix of floodplain management measures is identified and implemented. Several alternatives are available to improve management of the floodplains as discussed in the following paragraphs. [23] [24] [25]

4.9.4.1 Structural Measures

Structural measures such as dykes, dams and detention basins are expensive but they may still be required to provide flood protection to existing developments in the floodplain. These measures must be designed, constructed and maintained to a certain standard in order to be effective. However, with the exception of dams, they are normally designed for a Design Flood Event (DFE) (usually one that recurs once in 100 years on average). As such, all structural measures will be overtopped at some time or another when the DFE is exceeded. An appropriate Flood Emergency Action Plan (see 4.9.4.2) is necessary to address this contingency.

4.9.4.2 Non-structural Measures

Non-structural measures refer to measures that contribute towards reducing losses of life and damage to properties and reduce susceptibility to future flooding. They include the following:

- *Flood Preparedness Measures* consisting of a series of sub-plans such as flood forecasting and warning, raising public awareness, setting development policy, landuse regulation, flood proofing and relocation, land treatment and preservation of natural values;
- *Legislation* – Where necessary, flood preparedness measures should be supported by appropriate legislation in the form of national flood control laws, regulations and local ordinances; and
- *Flood Emergency Action Plan (FEAP)* comprising communication and public information management, search and rescue co-ordination, shelter management, stockpiling and distributing of food and supplies, contacting and requesting additional support, debris management, financial management, volunteers co-ordination and donations management.

Flood forecasting and warning are most effective for large rivers due to the longer lead time available. Forecasts must be timely and accurate and must be combined with a *community awareness program* that teaches people what to do after receiving the warning.

Clear *policy* on the development of floodplains should be established. There are three basic alternatives of floodplain development:

- Restricting the use of the flood plain and leaving it in its original unoccupied state;
- Preventing development from constricting floodway and allowing the flood fringes to be preserved for agricultural or recreational purpose; or
- Preventing development from constricting floodway and allowing the flood fringes to obtain housing, commercial or industrial purpose as long as the encroachment results in only insignificant increase in the water surface elevation.

Where development is allowed, *land use regulation* is the most cost-effective means for reducing future flooding susceptibility. By providing direction to growth and change, landuse regulation is well suited to preventing unwise floodplain occupancy. In fact, wise land use should also be applied to areas other than floodplains, bearing in mind that increased rates of runoff caused by impervious surfaces such as parking lots, roads, and roofs can cause more frequent and severe flooding.

Flood proofing can be used for existing structures in the floodplain as well as for new construction. It consists of raising buildings above the design flood elevation. Existing buildings can be jacked up and foundations and plumbing extended. Relocation may be more practical for some houses. Each could be moved a short distance to a site which would be higher that the design flood elevation.

Land Treatment refers to the use of vegetation to protect the soil from the impact of raindrops, and the root system to bind the soil, thus reducing erosion. Conservation land treatment practices can be applied to reduce sediment delivery to stream channels. Adequate vegetative cover reduces runoff and erosion by allowing rainfall to penetrate open spaces around roots and to be absorbed by plant roots. Additional water is stored in the later of humus formed by decaying organic matter. Some of this water is put into the atmosphere by plant transpiration, thus reducing runoff. Application of the proper management practices (e.g., tree and grass planting, lime and fertilizer application) may reduce runoff and sediment from sediment producing areas such as unpaved roads and trails and road banks, idle land and abandoned pastures.

Sediment deposited in the stream reduces channel capacity, thereby increasing the amount of flooding. As the uplands change from agriculture and forest to more urban uses, the ensuing concentration of buildings, paved parking lots, roads, and other impervious surfaces will increase the amount and rate of runoff. This will result in more severe flooding in the floodplain. Thus, wise land use management of the uplands can be an important step toward controlling flooding on the lowlands.

Preservation of Natural Values

Serious consideration should be given to preservation of wetlands, unique areas, undeveloped floodplains, and bluffs adjacent to the streams which have high values for education, recreation, natural water treatment, ground water recharge, and moderation of floods. Preservation of archaeological and historical sites should be considered an important part of land use planning.

Floodplains moderate flooding by providing areas where floodwater can spread out and be temporarily stored. Vegetated floodplains slow the rate at which incoming overland flow reaches the channel. Practices such as clearing, compacting, paving, filling, and building within the floodplain can cause increased flood elevations and frequencies. The adverse impact of this increased flooding must be considered. By maintaining the natural floodwater carrying capacity of the floodplain, many future flood problems may be avoided.

Flood Emergency Action Plan

The purpose of a FEAP is to address residual flood risks. Best practice guidelines in a FEAP include:

- recognizing that residual flood risks generally exists across the flood plain and needs to be addressed by a FEAP;
- recognizing that FEAP and floodplain management plan are complementary to each other; and
- the need to assess the behaviour and consequences of a range of flood events up to and including the probable maximum flood when developing a FEAP.

4.9.4.3 Combination of Structural and Non-structural Measures

By using a combination of development and land use policies, structural and non-structural measures, flood management solutions for different situations in the land development process can be formulated. The following are some examples:

- For protecting existing development:
  - Structural measures;
  - Flood forecasting, warning and evacuation; and
  - Flood proofing.

- For removal or conversion of existing development:
  - Land acquisition;
  - Urban redevelopment;
  - Non-conforming uses;
  - Conversion of use or occupancy; and
  - Reconstruction of public facilities.

- For discouraging development:
  - Public information;
  - Installation of warning signs;
  - Tax-assessment practices;
  - Financing policies; and
  - Public facility extensions.

- For regulating flood plain use:
  - Zoning ordinances;
  - Waste disposal regulation;
  - Groundwater quality protection regulation;
  - Subdivision ordinances;
  - Building ordinances;
  - Reduction of population densities;
  - Regulation of squatter settlement in flood prone areas;
  - Prohibiting specific functions of land;
  - Relocating elements that block the floodway;
  - Regulating building material; and
  - Providing escape routes to higher places.

4.10 RIVER MONITORING

River monitoring is an important component in river management for assessing the impact of any conservation, protection and restoration measure, change in land-use, etc., on the river environment and providing important feed-back information for sustainable river management. Figure 4.17 illustrates an output of river water quality monitoring in Peninsular Malaysia. It provides the River Manager with the current status of river water quality in various states and indicates areas where he should direct attention towards river water quality improvement.

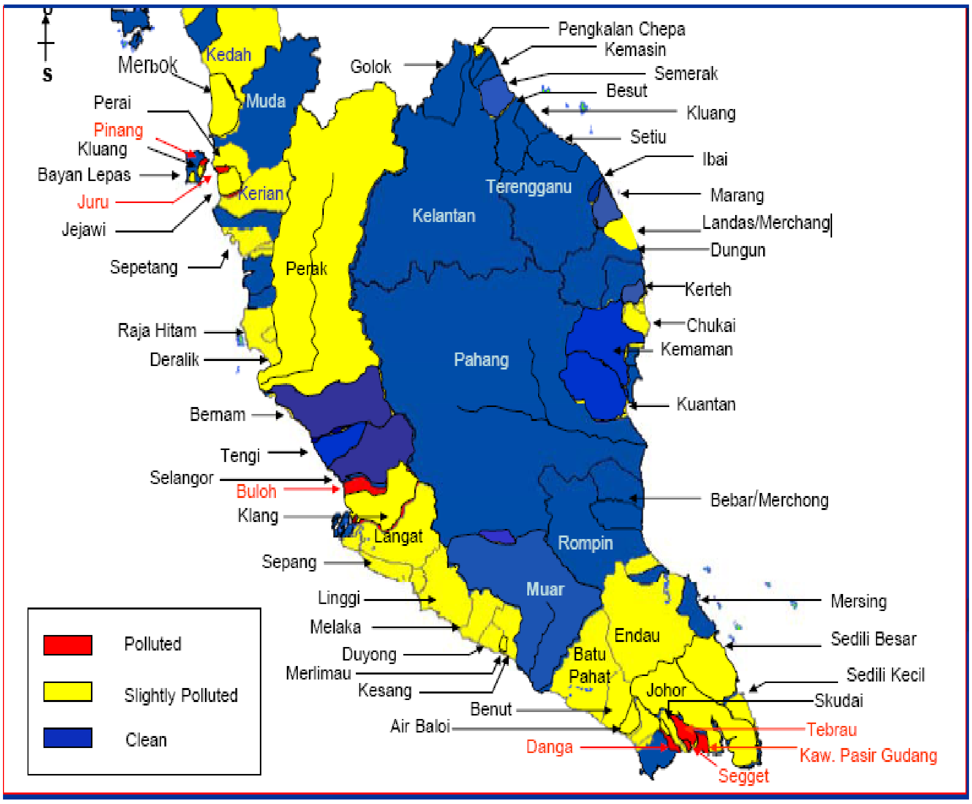

Figure 4.17 General Status of River Water Quality in Peninsular Malaysia
(Source: Department of Environment, Malaysia)

4.10.1 Need for River Monitoring

River monitoring fulfils the following needs for sustainable river management:

- Provides an assessment of the status of rivers and associated water bodies;
- Provides evidence to drive river basin planning;
- Reduces uncertainties in risk assessments; and
- Looks for changes in status over time in response to any measures implemented.

4.10.2 Scope of Monitoring

A comprehensive river monitoring program typically comprises several sub-programs, including Chemical Monitoring, Biological Monitoring, and Morphological Monitoring that are established to meet their specific needs as listed below:

4.10.2.1 Needs of Chemical Monitoring

- Measure compliance with water quality standards and criteria;
- Assess and characterize the impacts of urban runoff discharges identify sources of pollution;
- Provide measurement for the success of any storm-water quality improvement measure;
- Assess the performance and effectiveness of wastewater treatment facilities; and

- Assess the overall health and long term trends in receiving water quality.

4.10.2.2 Needs of Biological Monitoring

- Assess the integrated effects of water pollution on aquatic organisms;
- Assess improving or deteriorating trends in water and riverbed sediment quality;
- Provide information on the presence and abundance of 4 groups of aquatic organisms: attached algae (periphyton), immature insects, worms and clams (macroinvertebrates), floating algae (phytoplankton) and floating microcrustaceans (zooplankton), each of which represents a different portion of the aquatic community in a river ecosystem.

4.10.2.3 Needs of River Morphological Monitoring

- Facilitate flood forecasting and warning;
- Assess impact of land use changes that reduce vegetation and increase the amount of impervious area;
- Assess impacts of activities that modify the floodplain (e.g. clearing, filling, grading, mining, etc.);
- Assess impacts of the construction of culverts and bridges;
- Assess impacts of activities that would modify the characteristics of the main stream channel (e.g. sand-mining, desilting, channelization; diversions, water supply intakes, bank protection, etc.);
- Assess the impacts of agricultural and urban land-use changes on rivers; and
- Assess the influence of climatic variations on biogeochemical and water cycles
- Provide data for linkage to biological assessment

In addition, monitoring is essential to establish environmental flows that support ecological functions and provides guidance for river restoration and adaptive management for degraded rivers, while scientifically designed monitoring of the outcomes of these activities is needed to test the underlying hypotheses guiding decision making. Monitoring also helps in understanding riparian areas that are also affected by changes in flow, sediment, and nutrient compositions.

4.10.2.4 Principles of River Monitoring

The effectiveness of river monitoring depends on a few key factors discussed as follows:

- Clear Objectives and Goals
  It is important to set clear objectives and goals from the onset as the requirements for river monitoring such as data, hardware and software, frequency of monitoring, budget, publication and dissemination of data and results, etc., depend to a large extent on the objectives and goals of the monitoring. For instance, the requirements for monitoring the impacts of river improvement works such as groins would be very different from those of monitoring the impacts of changes in land-use.
- Partnering with other Organizations
  One of the fundamental implementation challenges for a nationally relevant river monitoring program is to leverage data resources to avoid duplication and target data collection activities to support the portfolio of data needs and uses. Although the focus of this manual is on DID's activities in river monitoring and data management, coordination and cooperation among Federal agencies and their state partners is imperative because of the scope, scale, and intensity of data needed to support river management. Plans for interagency collaboration need to be an integral part of any DID river management and data archiving activity. No single Federal agency can collect, quality assure, manage, and disseminate all data and observations relevant for river management. Yet all Federal agencies, state partners, and stakeholders with an interest in river and resource management will benefit from access and availability of accurate, reliable, and well-documented data.
- Measurement Technologies.
  Accuracy and timeliness of data is important for subsequent evaluation and assessment. The use of appropriate technologies of measurement is required to suit specific needs. For instance,

the one-dimensional velocity measurement frequently used in river gauging is sufficient to determine the river flow, but it is inadequate for monitoring of velocity distribution between river groins, which requires reasonably accurate two- and three-dimensional velocity information in a timely manner.

- Data Processing and Management
  Sound management decision requires efficient data collection, processing and management. Depending on the number and size of data required, data processing and management can range from simple spreadsheet solutions to more complex ones incorporating GIS.
- Publication and Dissemination of Data and Results
  Documentation is important for keeping track of changes to river conditions over time. Thus, there is a need to publish and disseminate monitoring reports to all decision makers and stake-holders in a timely manner.

4.10.3 Monitoring Strategy and Classification

The "reach-based" approach adopted in many parts of the world is recommended for river monitoring. The advantage of this approach is its suitability for stakeholder participation and integration. The steps involved in river monitoring are:

- Identify the river to be monitored;
- Select river reaches to be monitored;
- Identify monitoring objectives;
- Identify the data requirement;
- Establish baseline/reference data for each reach;
- Carry out data collection and assessment at desired intervals.

To provide a management perspective in the assessment of monitoring results, it is recommended that a consistent classification scheme be followed based on an integration of morphological, chemical and biological conditions.

4.10.3.1 Chemical Conditions

So far, water quality management in Malaysia has been based on the monitoring of chemical determinants (e.g. pH, ammonia, suspended solids, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, and other parameters as required); and sampling for chemical quality has been based on monthly spot sampling at selected sites throughout the country.

Using this information, a general classification approach has been used – the Water Quality Index (WQI). Based on WQI, rivers lengths are classified into one of five categories (I, IIA, IIB, III and IV). The management aim is based on reducing the river lengths in the lower classes and protecting those in the higher classes.

The classification used by the Department of the Environment for the Interim National Water Quality Standards for Malaysia is listed in Table 4.6:

Table 4.6 Classification for Water Quality Standards in Malaysia

Class		Purpose & Treatment Required
I		Conservation of natural environment
	a	Water Supply – Practically no treatment necessary
	b	Fishery – Very sensitive aquatic species
IIA	a	Water Supply – Conventional treatment necessary
	b	Fishery – Sensitive aquatic species
IIB		Recreation use with body contact
III	a	Water Supply – Extensive treatment required
	b	Fishery – Common, of economic value, and tolerant species; livestock drinking
IV		Irrigation

Source: Department of Environment, Ministry of Natural Resources and Environment, Malaysia.

4.10.3.2 Biological Conditions

It was recognized in the late 1960's and early 1970's that biological information provided a more integrated measure of river quality than chemical monitoring, especially in terms of the polluting effects of mixtures of chemicals and the continuous monitoring that in situ flora and fauna provided.

Biological monitoring can be carried out based on periphyton (algae), benthic macro-invertebrate, or fish information to assess the ecological status of a river. Macro-invertebrates are the most widely used as they are abundant in aquatic ecosystems, relatively immobile, have a life-span of a year or more, and are good integrators of the environmental conditions. Besides, sampling of macro-invertebrates is inexpensive and easily done with just a few people using simple gear. This group of aquatic organisms is also used by DID in the assessment of river water quality. A guide is available and is described in Section 4.12.

An appropriate classification should be used for biological assessment of river water. The classification used by DID is given in Table 4.7.

Table 4.7 River Water Quality Classification According to ASPT

Class	Condition	Permissible Use of Water
A	Very clean (Sangat baik)	Can be used as drinking water without treatment.
B	Good (Baik)	Can be used for bathing. Requires conventional treatment for drinking purpose.
C	Fair (Sederhana)	Requires intensive treatment for drinking purpose.
D	Polluted (Kotor)	Can be used for irrigation and domestic animal drinking purpose.
E	Very Polluted (Sangat Kotor)	Cannot be used for purposes stated above.

Source: "Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai", DID.

As a comparison, the biological classification used in the UK [26] is shown in Table 4.8:

Table 4.8 Biological Classification of Rivers in the UK

Class	Condition	Characteristics
A	Very good	Similar to or better than that for an average, unpolluted river
B	Good	Minor differences from Class A; small reduction in number of taxa sensitive to pollution and moderate increase in tolerant taxa
C	Fairly good	Many sensitive taxa are absent or reduced in number; in many cases there is marked rise in number of tolerant taxa
D	Fair	Sensitive taxa are scarce and only small in numbers; a range of tolerant taxa exists and some may have high numbers
E	Poor	Restricted to tolerant animals with some taxa dominant in numbers; sensitive taxa is rare or absent
F	Bad	Small number of very tolerant taxa or absence of life if toxicity is high

Source: Environment and Heritage Service (EHS), Department of the Environment, UK

For more details on biological assessment, please refer to Chapter 3 of this manual.

4.10.3.3 Morphological Conditions

To understand, predict and describe each of the processes that shape and maintain the river channel in the present climate is a challenge to the river engineer. One approach to resolve this problem is facilitated by quantitative knowledge about reaches of rivers that have shown to be stable over a period of time. Such a stable reach of river may be used as the state to which restoration should aim. Such a channel segment, called a reference reach, can be described in quantitative terms from field studies. Such studies provide design variables for applications in stream restoration based on field data that quantitatively describes morphological features stratified by reach-specific stream type (e.g. Figure 4.18).

Figure 4.18 We study intact reaches of healthy streams and rivers to determine reference conditions. Reference reaches help us to understand how a system has degraded and what it will take to restore it.

Morphological monitoring is best carried out with a classification system in order that variables are grouped by morphological similarity and statistical variance between the groups reduced. It also allows for development of dimensionless ratios from measurements of the natural stable form for a particular river type. The dimensionless ratio data can be extrapolated for applications in natural channel design, assuming the data from the reference reach is associated with the same valley type and potential river type as the river to be restored. Chapter 3 provides a detailed discussion of morphological monitoring.

4.10.4 Data Collection & Sampling

4.10.4.1 General

The data requirement differs among the river monitoring components as described in the following paragraphs. In each case baseline conditions for selected river reaches and sites should be established using the same sampling procedures for comparison with potential future changes. One example of data collection involving sediment sampling is illustrated in Figure 4.19.

Figure 4.19 Suspended load (left) and bedload sampling (right) at Sg. Muda

4.10.4.2 Chemical Monitoring

The Department of the Environment has established water quality parameters and standards for rivers in Malaysia. The department has been carrying out river water quality monitoring since 1978. At the time of writing, a total of 927 manual stations and 15 automated stations located within 120 river basins throughout Malaysia had been established. The main parameters and the standards used for computing the Water Quality Index (WQI) are illustrated in Tables 4.9:

Table 4.9 Main Parameters for River Water Quality Monitoring and WQI Standards

Parameter	Unit	Classes				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/l	< 0.1	0.1 – 0.3	0.3 – 0.9	0.9 – 2.7	> 2.7
Biological Oxygen Demand	mg/l	<1	1 – 3	3 – 6	6 – 12	> 12
Chemical Oxygen Demand	mg/l	<10	10 – 25	25 – 50	50 – 100	> 100
Dissolved Oxygen	mg/l	>7	5 – 7	3 – 5	1 – 3	< 1
pH	mg/l	>7.0	6.0 – 7.0	5.0 – 6.0	< 5.0	> 5.0
Total Dissolved Solids	mg/l	<25	25 – 50	50 - 150	150 - 300	> 300
Water Quality Index		> 92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	< 31.0

Source: Department of the Environment

Other parameters and corresponding standards that are measured according to site requirements are shown in Table 4.10 and Table 4.11:

Table 4.10 National Water Quality Standards for Malaysia

Parameter	Unit	Classes				
		I	II	III	IV	V
Al	Mg/l	NATURAL LEVELS	-	- (0.06)	0.5	LEVELS ABOVE CLASS IV
As	Mg/l		0.05	0.4 (0.05)	0.1	
Ba	Mg/l		1	-	-	
Cd	Mg/l		0.01	0.01* (0.001)	0.01	
Cr(IV)	Mg/l		0.05	1.4 (0.05)	0.1	
Cr(III)	Mg/l		-	2.5	-	
Cu	Mg/l		0.02	-	0.2	
Hardness	Mg/l		250	-	-	
Ca	Mg/l		-	-	-	
Mg	Mg/l		-	-	-	
Na	Mg/l		-	-	3 SAR	
K	Mg/l		-	-	-	
Fe	Mg/l		1	1	1 (Leaf) 5 (Others)	
Pb	Mg/l		0.05	0.02* (0.01)	5	
Mn	Mg/l	NATURAL LEVELS	0.1	0.1	0.2	LEVELS ABOVE CLASS IV
Hg	Mg/l		0.001	0.004 (0.0001)	0.002	
Ni	Mg/l		0.05	0.9*	0.2	
Se	Mg/l		0.01	0.25 (0.04)	0.02	
Ag	Mg/l		0.05	0.0002	-	
Sn	Mg/l		-	0.004	-	
U	Mg/l		-	-	-	
An	Mg/l		5	0.4*	2	
B	Mg/l		1	- (3.4)	0.8	
Cl	Mg/l		200	-	80	
Cl_2	Mg/l			- (0.02)	-	
CN	Mg/l		0.02	0.06 (0.02)	-	
F	Mg/l		1.5	10	1	
NO_2	Mg/l		0.4	0.4 (0.03)	-	
NO_3	Mg/l		7	-	5	
P	Mg/l		0.2	0.1	-	
Silica	Mg/l		50	-	-	
SO_4	Mg/l		250	-	-	
S	Mg/l		0.05	- (0.001)	-	
CO_2	Mg/l			-	-	
Gross – alfa	Bq/L		0.1	-	-	
Gross – beta	Bq/L		1	-	-	
Ra – 226	Bq/L		< 0.1	-	-	
Sr – 90	Bq/L		< 1	-	-	
* = At hardness 50 mg/l $CaCO_3$						
# = Max.(unbracketed) and 24 – hour average (bracketed) concentrations						

Table 4.11 National Water Quality Standards For Malaysia

Parameter	Unit	Classes				
		I	II	III#	IV	V
CCE	ug/l	NATURAL LEVEL OR ABSENT	500	-	-	-
MBAS/BAS	ug/l		500	5000 (200)	-	-
O & g (Mineral)	ug/l		40; N	N	-	-
O & G (Emulsified edible)	ug/l		7000; N	N	-	-
PCB	ug/l		0.1	6 (0.05)	-	-
Phenol	ug/l		10	-	-	-
Aklrin/Dieklrin	ug/l		0.02	0.2 (0.01)	-	-
BHC	ug/l		2	9 (0.1)	-	-
Chlordane	ug/l		0.08	2 (0.02)	-	-
t – DDT	ug/l		0.1	(1)	-	-
Endosulfan	ug/l		10	-	-	-
Heptachlor / Epoxide	ug/l		0.05	0.9 (0.06)	-	-
Lindane	ug/l		2	3 (0.4)	-	-
2,4 – D	ug/l		70	450	-	-
2,4,5 – T	ug/l		10	160	-	-
2,4,5 – TP	ug/l		4	850	-	-
Paraquat	ug/l		10	1800	-	-
N = Free from visible film sheen, discoloration and deposits.						
# = Max. (unbracketed) and 24 – hour average (bracketed) concentrations						

Source: Department of the Environment

4.10.4.3 Biological Monitoring

Biological monitoring based on benthic macro-invertebrates involves sampling, identification and counting of aquatic organisms belonging to the following families:

- Nymphs;
- Larvae;
- Insects;
- Crustacea;
- Molluscs; and
- Worms.

Please refer to "Panduan Pengunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai" published by DID for species of organisms in each family.

4.10.4.4 Morphological Monitoring

The main data requirement for river morphological monitoring is as follows:

- Cross-sections at 100-metre intervals
- Longitudinal profile
  - slope
  - riffle/pool characteristics
- Existence of floodplain
- River discharge/velocity
- Bankfull discharge
- Bed particle size distribution
- Suspended sediment load
- Pattern

– Sinuosity, meander lengths, radius of curvature

4.10.5 Frequency of River Monitoring

4.10.5.1 Chemical Monitoring

In Malaysia, the Department of the Environment (DOE) is responsible for the chemical monitoring of river water quality under the Malaysian River Water Quality Monitoring Programme. The frequency of sampling at selected sites varies from monthly to quarterly. Other Government agencies involved in river water quality monitoring are:

- Department of Irrigation and Drainage - involved in chemical monitoring at DID river stations in connection with water resources development. Sampling is taken at fortnightly intervals; and
- Ministry of Health - involved in chemical monitoring of river water quality for public water supply. Sampling is taken at water treatment plants at intervals varying from weekly to once in three months.

So far the frequencies of chemical monitoring compare well with those adopted in other parts of the world. For instance, sampling frequency varies from fortnightly to 1 months in the US, while a minimum of 3 months is adopted in the European Community [27]. It is therefore recommended that the current practice be maintained and the programme can be expanded to cover more sites and more rivers as the need arises.

4.10.5.2 Biological Monitoring

The monitoring frequency should be selected in order that year-to-year variability resulting from natural events is minimized, and sampling gear effectiveness and accessibility of targeted assemblage are maximized. In addition, it is also necessary to take into consideration the life cycles of organisms and the ability for their populations to recover from sampling activities which might totally remove all species. Therefore, for biological quality monitoring using macro-invertebrates, it is recommended that sampling frequency be limited to once a year.

Sampling and comparisons of data from the same season as the previous year's sampling provides some correction and minimization of annual variability. The season of the year during which sampling gear is most effective is an important consideration for selecting an index period. For example, low flow conditions may hamper the ability to sample with the selected gear, and high flow conditions may make the targeted organisms inaccessible. Therefore seasons with such conditions should be avoided.

4.10.5.3 Morphological Monitoring

Morphological monitoring requires extensive data collection and incurs high expense. As such it is recommended that morphological monitoring be carried out at 5-year intervals.

4.11 RIVER INFORMATION SYSTEM (RIS)

The multi-objective, multi-discipline and multi-user nature of river management requires an efficient information system for the archival, updating and retrieval of various types of river information. This will enable chemical, biological and morphological assessments of the rivers to be carried out in an integrated manner and effective decision support provided to the river managers and decision makers.

In this connection, Agenda 21 of UNCED (1992 Rio World Summit on Environment and Development) emphasizes that effective management relies essentially on reliable and adequate information on how the environment behaves under natural and man-made impacts. In particular, Chapter 40 of Agenda 21 on *Information for Decision Making* emphasizes the importance of improved availability of information on all aspects of environment and development. It specifically underlines the need for improved presentation of data and information in a format that will facilitate policy and decision making by governments. The chapter states: *Special emphasis should be placed on the transformation of existing information into forms more useful for decision-making and on targeting information at different user groups. Mechanisms should be strengthened or established for transforming scientific and socio-economic assessments into information suitable for both planning and public information.*

Substantial amounts of data already exist on various processes occurring in the natural environment. However, the mode of adoption of integrated approaches for sustainable river basin management has certainly changed information expectations and, hence, the types and the amounts of data needed. Now, more and different types of data have to be collected to describe the status and trends of, not only water resources, but also of the ecosystem, other natural resources, pollution, and socioeconomic variables. As environmental problems extend to surface and ground water, land resources, coastal zones, urban air, desertification, soil degradation, biodiversity, and other habitats, data are required on all these media so that such problems can be assessed and managed.

Conventional river information systems comprise hydrological and meteorological data such as rainfall, river levels and flows, lake and reservoir levels, groundwater levels, sediment concentrations and loads, and water quality (physical, chemical, and bacteriological variables) of surface and groundwater. As rivers are now considered a part of the environmental continuum comprising air, soil and water components that are interactive in complex ways, there is a need to collect data on the wider environment, including the following:

- Watershed characteristics such as vegetation patterns, soil moisture, topography, climate, and aquifer characteristics;
- Environmental data such as sources of pollutants, accidental spills, irrigation return flows, eutrophication of lakes, and the status of estuarine and coastal ecosystems; and,
- Data describing water use by man, i.e., the volumes of water required for domestic, industrial and agricultural use, and characteristics of rivers related to catchment area uses such as recreation, navigation and fishery habitats.

In addition, these data should reflect the true nature of the environment. Environmental processes are, by nature, heterogeneous, dynamic, nonlinear and anisotropic. They are marked by spatial variability as well as temporal variability. Accordingly, collected data should reflect these characteristics of the environment along with the spatial and temporal variability of environmental processes to be representative of nature.

Agenda 21 also points out that there is a significant gap between information needs on environment and information produced by current systems of data collection and management. Recognition of this gap has brought focus to current monitoring systems, databases, data validation and data use. Accordingly, major efforts have been initiated at regional and international levels to improve the status of existing information systems. The purpose of these efforts is to ensure that the data made available to users are accurate and reliable.

The major problems associated with available environmental data are summarized as follows [28]:

- Significant lack of integration among different procedures applied in data collection and in transfer of data into information;
- Shortcomings often encountered in data reliability, accuracy, completeness (missing values), homogeneity, length of record, and spatial extent;
- Lack of measurements of sampling error indicated along with available data;
- Significant problems associated with data presentation and reporting:
    - Data from different sources are not compatible and comparable due to the use of different formats and units used in data presentation;
    - Incompatibilities between different data acquisition and retrieval systems;
    - Accessibility of data is often a problem in most countries;
    - Different disciplines use different nomenclature or jargons in data presentation;
    - Reporting of data is often poorly achieved as specifications of particular variables (e.g., NH3-N, NO3, PO4 ...) regarding their laboratory analyses are not disclosed;

- Explanation on methods of laboratory analysis not provided with presented data such that the users cannot assess the compatibility of the methods;
- Current networks collect a lot of data but these data are not validated.

It follows from the above that a sound information system is the initial and possibly the most crucial step in river basin management.

An efficient information system must satisfy the following conditions [28] [29]:

- Information must be available when needed;
- Information must be easily accessed by the user;
- Information should be available in a form that is easy to understand and use;
- The system must be capable of handling geo-spatial information which have geographic references that can be specified in terms of a Cartesian Coordinate System;
- Data structure and information management must reflect the differentiation of the river basin's "real world" subsystems;
- The system must be capable of integrating the different kinds of data and information to meet the needs of decision-making processes, with advanced display, mapping, query and presentation capabilities.

To meet these criteria, an integrated river basin information system should have the following characteristics:

- It is web-based;
- It comprises integrated databases established using common data formats;
- All data are validated before being included in the relevant databases;
- It ensures data consistency by avoiding duplication;
- It uses GIS integration.

In this connection, the DID had initiated a study on National Register of River Basins in 2001 [30] which developed a draft framework of the proposed River Basin Information Management System (RB-IMS). Testing and refinement of the framework was carried out and completed through implementation of pilot-scale operational RB-IMS for four selected river basins in a follow-up study in 2007.

The four river basins are:

- Sg. Kuantan in Pahang
- Sg. Muar in Johor/Negeri Sembilan;
- Sg. Moyong/Putatan in Sabah; and
- Sg. Sarawak in Sarawak

The outcome of the proposed RB-IMS is summarized as follows:

- Operational RB-IMS for the respective river basins, covering national and state information models and framework including populated databases, river basin GIS with GIS layers and attribute tables, and basic hardware and software;
- Information up-dating system for DID covering national, state and, where applicable, district secretariats;
- RB-IMS information classification and security system;
- Master plan for implementation of the RB-IMS throughout Malaysia;
- Training of DID personnel on the RB-IMS.

The information system consists of the following thematic databases relating to the real-life environment:

- Governance – Laws, standards and guidelines, institutions and policies;
- Natural Resources Environment – Land resources, water resources and biological resources;

- Economic Development Environment – Land & infrastructure, water extraction activities, water polluting activities, water body management activities and environmental management activities;
- Social development Environment – Population & housing, Squatters, Orang Asli and community stake-holders; and
- Others – Artifacts & document summary.

The RB-IMS has the following features:

- The system is web-based to facilitate information sharing;
- The system allows four levels of access: public/inter-agency/intra-agency/restricted access to designated individual within an agency;
- The database encompasses most, if not all, environments affecting or affected by the river;
- The system allows integration with GIS;
- The system allows access to different kinds of data and information to facilitate dynamic system modeling and decision making.
- Updating of databases is performed by the respective River Basin Secretariat only to ensure data consistency.

As a supporting feature to the RB-IMS, the study also developed a National River Register for all river basins (RRB) in Malaysia with basic river data and river-related GIS layers corresponding to DID functions. Ultimately the RBIMS and RRB will form the backbone of DID's River Basin Decision Support System (RB-DSS).

4.12 RIVER CORRIDOR MANAGEMENT GUIDELINES

This manual serves to complement existing guidelines on river management. A compilation of available guidelines is listed in Table 4.12.

Table 4.12 Guidelines on River Management

No.	Title	Author	Year of Issue
1	River Front Development Concept (Konsep Pembangunan Berhadapan Sungai)	DID	1995
2	River Crossings (Memproses Permohonan dan Menetapkan Syarat-syarat Bagi Jambatan & Lintasan – Deraf Akhir)	DID	
3	Processing of Applications For Gas Pipe line Crossings At Rivers, Drains & Canals	DID	1993
4	Sand Mining Application (Memproses Permohonan & Menetapkan Syarat-syarat Pengambilan Pasir Sungai) Plants Suitable For River Bank (Penanaman Pokok-pokok Yang Sesuai di Tebing Sungai)	DID	1993
5	Development Involving River and River Reserve (Pembangunan Melibatkan Sungai & Rizab Sungai)	DID	
6	Riverfront and In-river Development (Pembangunan Di Hadapan Sungai & Di dalam Sungai)	DID	
7	Plants Suitable For River Bank (Penanaman Pokok-pokok Yang Sesuai di Tebing Sungai)	DID	1995
8	River Bank Landscaping (Kerja-kerja Pengindahan Kawasan Pinggir Sungai – Deraf Pertama)	DID	
9	River Reserve as Part of Public Open Space (Rizab Sungai Sebagai Sebahagian Tanah Lapang Awam)	Town & Country Planning Department	
10	Guidelines for Installation of Billboards in River Reserves (Garispanduan Permohonan dari Pihak Swasta untuk Pemasangan Papan Iklan dalam Rizab Sungai)	DID	2006
11	Guide to Water Quality Monitoring Practices in Malaysia	Malaysian IHP	2007
12	Guide on Use of Macroinvertebrates in River Water Quality Assessment (Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai)	DID	First Edition

4.12.1 River Front Development Concept (Konsep Pembangunan Berhadapan Sungai)

This guideline was drawn up in 1995 and it aims to assist planning and other authorities in the planning, design and approval of new development in the vicinity of a river so that the development is sustainable and in harmony with the river environment. The guideline provides important requirements such as the following:

- River reserve requirements;
- Conservation of river reserve;
- Restrictions on use of river reserve and open spaces in its vicinity;
- Restriction on river realignment;
- Provision of detention and/or retention ponds;
- Building platform levels;
- Suggestions on frontage and location of access roads;
- Responsibility of developers for beautification and contribution towards river maintenance cost; and
- Minimum clearance for bridge crossings

4.12.2 Processing of Applications for River Crossings (Memproses Permohonan dan Menetapkan Syarat-syarat bagi Jambatan & Lintasan – Deraf Akhir)

This guideline serves to assist State and Local Authorities in the processing and approval of applications for river crossings such as bridges and culverts. The guideline contains the following:

- Documentary requirement;
- Hydrological and hydraulic design requirements;
- Clearance requirement for bridges; and
- General conditions of approval.

4.12.3 Processing of Applications for Gas Pipe Line Crossings at Rivers, Drains Canals

This guideline was issued in 1993, following a rapid growth in gas pipeline construction in Malaysia, to assist State and Local Authorities in the processing and approval of applications for gas pipeline crossings. The guideline covers the following requirements:

- Hydrological and hydraulic design requirements;
- Pipeline position and scour depth;
- Waterway reserves; and
- General conditions of approval

4.12.4 Processing of Applications for Sand Mining (Memproses Permohonan & Menetapkan Syarat-syarat Pengambilan Pasir Sungai)

This guideline was issued through Department's Directive JPS 1/2003 in view of numerous applications for sand extraction due to the fast pace of development taking place throughout Malaysia. The objective of this guideline is to enable the processing and approval of such applications to be carried out in a consistent manner by all Local Authorities. The guideline covers the following:

- Highlight on potential damages of sand mining to the river and its environment & requirement for river protection; and
- Technical considerations and criteria for processing of sand mining applications

4.12.5 Development Involving River and River Reserve (Pembangunan Melibatkan Sungai & Rizab Sungai)

This guideline was prepared by DID for two purposes:

- Assist State and Local Authorities in the processing and approval of development projects involving rivers and river reserves; and
- Serve as a reference for both the public and private sectors either directly or indirectly involved in such development.

The guideline provides the following:

- List of legislation related to rivers and river reserve;
- Importance of river reserve in flood mitigation, river maintenance and environmental protection.
- River reserve width requirements;
- Highlight on the need to gazette river reserves;
- General guidelines on
  - measures to minimize impact on river morphology;
  - protection of river habitats;
  - protection of river banks;
  - detention ponds;
  - silt traps;
  - regulation of logging operations;

  - regulation of aquacultural activities;
- Requirement on riverfront and in-river development;
- Requirement on installation of utilities along or across rivers;
- Requirement on mining activities;
- Requirement on water abstraction from rivers;
- Requirement on jetties; and
- Measures river bank erosion control.

4.12.6 Riverfront and in-River Development (Pembangunan di Hadapan Sungai & di dalam Sungai)

This guideline was issued in DID Directive JPS 1/2005 to enable processing of applications for riverfront and in-river development by State and Local Authorities to be carried out in a consistent manner. The guideline covers the following subjects:

- Applications for development involving landscaping, recreational facilities, commercial, housing, mixed development, agriculture, and river crossings;
- Applications for installation of utilities along or crossing rivers;
- Applications for mining;
- Applications for water abstraction;
- Applications for construction of jetties; and
- Applications for construction of floating restaurants/buildings.

In each case, the guideline spells out information and technical requirements to be fulfilled and, if approved, the conditions to be complied with.

4.12.7 Plants Suitable for River Banks (Penanaman Pokok-pokok yang Sesuai di Tebing Sungai)

This guideline is contained in a colourful brochure (Figure 4.20), published by the DID in collaboration with the Forestry Research Institute of Malaysia, with the objective of assisting developers in the selection of suitable plants for river banks. The brochure provides the following information:

- Types and illustrations of plants and suitability for planting; and
- Recommendation on planting and maintenance

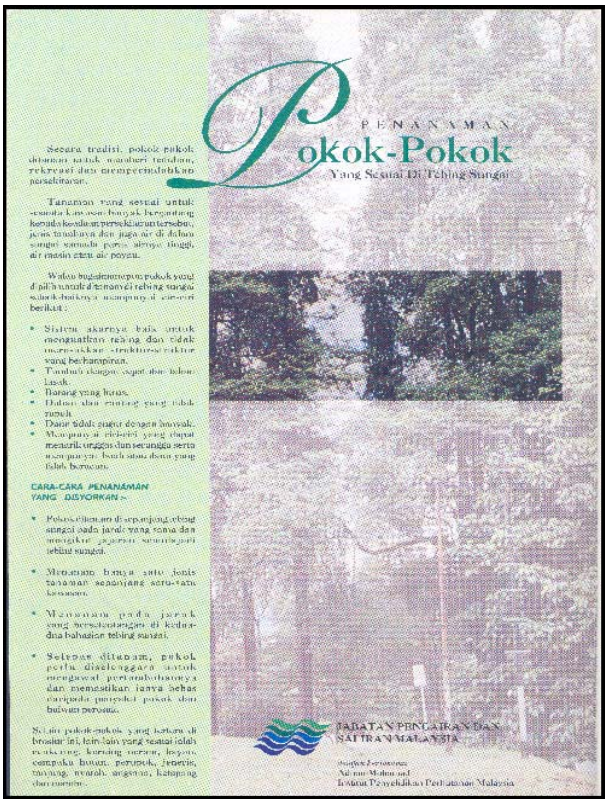

Figure 4.20 Guideline on Plants Suitable for River Banks

4.12.8 River Bank Landscaping (Kerja-kerja Pengindahan Kawasan Pinggir Sungai)

This guideline, still in draft form, is prepared by the DID in collaboration with the Forestry Research Institute of Malaysia, with the objective of assisting developers in landscaping river banks.

4.12.9 Guidelines for Installation of Billboards in River Reserves (Garispanduan Permohonan dari Pihak Swasta untuk Pemasangan Papan Iklan dalam Rizab Sungai)

This guideline, issued through Circular Letter JPS BIL. 1/2006, provides a unified procedure for processing applications received from private sectors for the installation of billboards in river reserves by all State and District DIDs. The guideline covers the following:

- Definition of River Reserve;
- DID's policy on installation of billboards within river reserves;
- Documents to be submitted;
- Conditions of Approval;
- Minimum distance from river bank/road and between billboards;
- Safety requirements;
- Management and maintenance of billboards; and
- Agreement, validity period and rate of rental.

4.12.10 River Reserve as Part of Public Open Space (Rizab Sungai Sebagai Sebahagian Tanah Lapang Awam)

This guideline was drawn up by the Department of Town and Country Planning to assist State and Local Authorities and developers in the preparation of Structure Plans and Local Plans. The objective of the guideline is to ensure that river reserves are taken into consideration in the provision of public open spaces in development areas. The guideline provides the following:

- Highlight on importance of rivers on the environment, for recreation, and in development;

- Policy on implementation of open spaces, detention ponds, river master plans, and the need to adopt holistic approach in river management.
- Condition of approval based on conformance to DID's guideline on riverfront development; and
- Guideline on use of river reserves as public open spaces

4.12.11 Guide to Water Quality Monitoring Practices in Malaysia

This guide (Figure 4.21) was prepared by the Technical Committee on Coordination and Standardization of Hydrological Practices under the Malaysian International Hydrological Programme to serve as a reference for practicing engineers and scientists involved in water quality data collection. The guide covers the following:

- River pollution issues in Malaysia;
- Agencies involved in water quality data collection;
- Water quality stations in Malaysia;
- Sampling Techniques and water quality monitoring practices; and
- Water classification and National water quality standards.

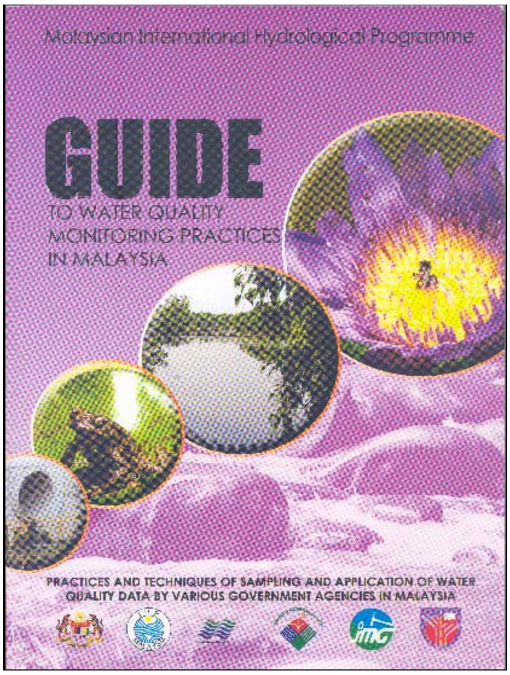

Figure 4.21 Guide to Water Quality Monitoring Practices in Malaysia

4.12.12 Guide on Use of Macroinvertebrates in River Water Quality Assessment (Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai)

This publication (Figure 4.22) by the DID serves as a guide to assist river managers in the use of aquatic organisms and insects in biological monitoring of river water quality in Malaysia. It can also be used to assist in the teaching of Biology in schools. The guide covers the following:

- Basis of using macro-invertebrates in biological monitoring of river water;
- Types of aquatic macro-invertebrates used;
- Biological indicator used – ASPT;
- Sampling equipment and procedure;
- Method of identification and calculation including an example;
- Biological classification of river water quality; and
- River water quality in Malaysia based on ASPT.

Figure 4.22 Guide on Use of Macroinvertebrates in River Water Quality Assessment

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CHAPTER 5

CONCLUSION AND FUTURE DIRECTION

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5 CONCLUSION AND FUTURE DIRECTION

5.1 CONCLUSION

This river management manual attempts to incorporate practical tools, methods and guidelines for engineers and personnel of the Department of Irrigation and Drainage Malaysia (DID) in carrying out their duties. The material presentation is concise and informative, and as comprehensive and clear-cut as possible. Appropriate references are also provided for the reader to seek ample and detailed additional information.

Malaysia should continue to develop new holistic approaches towards River Management. Besides flood control issues, environmental considerations have been gaining stronger attention and popular support in recent years. Integrated river management policies, future directions, state-of-the-art in methodology and practices and stakeholders as well as non-governmental organizations (NGOs) participation are still undergoing active evolution. In Malaysia, there are not many local best management practices (BMPs) in this field. The development and systematic documentation of demonstration projects and success case studies could become very useful examples to speak of in the near future.

5.2 RESEARCH AND DEVELOPMENT

Due to the current lack of documented local practices and examples, many of the guidelines are adopted (with modification to suit local environments) based on practices from other countries. There is an urgent need for DID to:

- Identify the departmental overall Research and Development (R&D) requirements (inclusive of immediate and long-term needs in river management;
- Identify and evaluate current ongoing R&D programmes (including those by other agencies);
- Identify gaps in knowledge and understanding of rivers in Malaysia and identify research needs;
- Formulate a comprehensive R&D programme (inclusive of demonstration/ BMPs projects) to fulfil its own requirement in river management in this country; and
- Implement the programme. The results and findings will then be documented and used to upgrade and enhance this river management manual in the future.

There are many local institutions of higher learning that can actively participate in these R&D activities. The main areas of knowledge to be further developed include:

- River Classification Systems / Channel Assessment Validation;
- River Ecosystems & River Health;
- River Rehabilitation & Restoration;
- Climate Change and its impacts; and
- Environmental Flow Management.

For instance, the formation and support of research institutes through institutions of higher learning and universities could lead to the development of new technology for the analysis of river management. Physical modelling of rivers could also be developed while the private sector can continue to apply the cutting-edge technological methods and design structures appropriate to the improvement of the river system. This integrated environment can promote the development and direct application of new technology linked with the education of the next generation of scientists, managers and engineers. In this process, the management of rivers could aspire to become more fully integrated.

5.3 STAKEHOLDERS, NGOS AND GENERAL PUBLIC PARTICIPATION:

Active participation of stakeholders, NGOs and General Public participation is one of the key success factors in the effective implementation of IWRM. The BUS (bottom-up strategy) rather than the traditional “top-down” approach should be adopted. The stakeholders, especially the private sector with their resources can enhance and contribute tremendously towards the government efforts in the sustainable development within a particular river basin. The local community, if inculcated with the strong sense of belonging & "gotong-royong" spirit can "protect & guard" the rivers and their environments well. On the other hand, the NGOs, generally on the "opposite" side of the authorities, can work closely and complement the government's efforts towards sustainable development. Under the current institutions and legislation, it is nearly impossible for the regulatory agencies to carry out round-the clock enforcement. Working together instead of the "policeman approach" can go a long way to achieve the IRBM long-term objectives/ goals.

Towards this end, more efforts and measures should be focused on creating awareness, inculcating the sense of belonging, training and capacity building. The concept of capacity building should be explored through the interaction of different groups of the society.

5.4 SAND/ GRAVEL MINING:

Rivers throughout the country have always been the main source of sand for the construction industry. In some areas, river pebbles are also mined. Several river basin studies had indicated that such activities left unregulated are detrimental to the well being of rivers. As an example, the "Comprehensive Management Plan of Muda River Basin, March 1995" Study by JICA [1] had reported that the annual quantity of sand mined (2 million m^3) far exceeded the amount (300,000 m^3) brought in from the catchment. The excessive sand mining rates have been extremely detrimental to the river environment. Some of the long-term problems associated with the excessive sand mining include significant lowering of the river bed (e.g. by over 3m over a 30-year period). Riverbed degradation had caused serious problems including:

- Riverbank instability;
- Instability of bridge foundation, bridge piers and bridge abutments;
- Significant drop in water level elevations requiring pumping heads for irrigation and water supply;
- Salt-water intrusion in the river calling for the construction of river estuary barrages;
- Major increases in turbidity and fine sediment in suspension in river estuaries with subsequent alterations of the aquatic habitat and bio-diversity of the river environment (Figure 5.1).

This finding was further reinforced by the "Design Option of the Flood Mitigation Plan of Sg Muda, Sg Muda, Kedah Sept 2006" by REDAC [2]. A study by KTA Tenaga for the "Sungai Langat Integrated River Basin Management Study, 2005" [3] also indicated similar problems.

Figure 5.1 Sand Mining At Sg Muda, Kedah & Its Impacts

In striving to achieve "natural rivers" through river restoration and rehabilitation programs, it is the prerequisite that the rivers should be least interfered or disturbed. In-stream sand and gravel mining in rivers should be gradually reduced and eventually stopped. Other sources of sand and gravel should be explored. For instance, off-stream sand and gravel mining operations on the river flood plains should be explored. The sand and gravel borrow areas can eventually be turned into wet detention storage areas that would be beneficial to the attenuation of flood waves during floods, and also meet the double objective of providing wetlands for aquatic species. Off-stream sand and gravel mining offers an alternative to current practices that could be very welcome in a way that would decrease water turbidity enhance fisheries, increase the stability of river structures, circumvent the need for estuary barrages and pumping stations as well as providing recreational and environmental areas in the broad river corridor.

In the mean time, mining activities should only be allowed at ‘predetermined” suitable locations and the volume to be mined be determined to have a minimal impact on the sediment transport rates from upstream sources. Methods of mining and their impacts on the river regime and river environments should be studied and well regulated. The existing guideline on sand mining “MEMPROSES PERMOHONAN DAN MENETAPKAN SYARAT-SYARAT PENGAMBILAN PASIR SUNGAI – 1993” [4] should be adhered to.

5.5 RIVER WATER QUALITY IMPROVEMENT (GRAVEL CONTACT OXIDATION PROCESS)

In Malaysia, sewerage has been identified as one of the main sources of river water pollution. Various measures have been adopted to overcome this problem. However such measures are generally expensive and are long-term measures requiring time to see the impact & results. In Japan, the gravel contact oxidation process has been successfully and widely utilised as a short-term low cost measure to carry out secondary and tertiary treatment of sewerage water (after the primary treatment by the sewerage treatment plant). The system is based on the natural self-purification mechanisms of rivers as illustrated by Figure 5.2. A demonstration pilot project carried out (by DID) under the cooperation with Japan Infrastructure Development Institute in 2003 to 2005 for Sg Kuyoh at Bukit Jalil (Figure 5.3) had produced encouraging results (transparency, suspended solids, dissolved oxygen, biochemical oxygen demand & ammoniacal nitrogen). This topic should be explored further whether it can be adopted as an effective measure to purify our polluted river water.

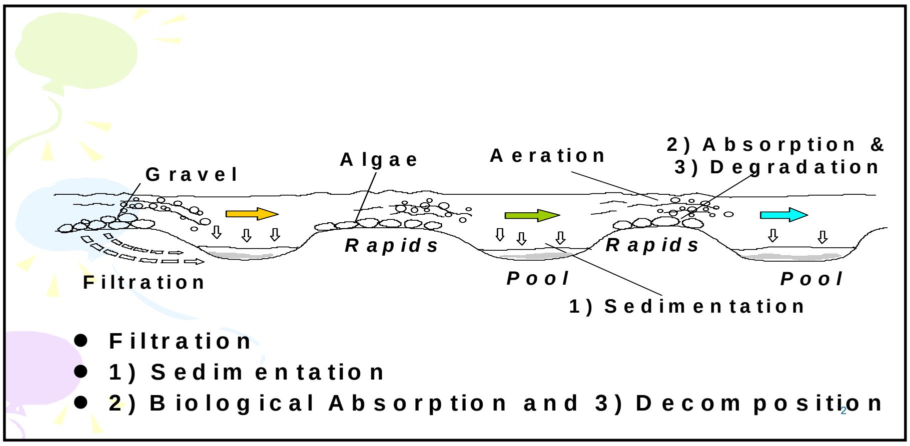

Figure 5.2 Natural Self-Purification of Rivers

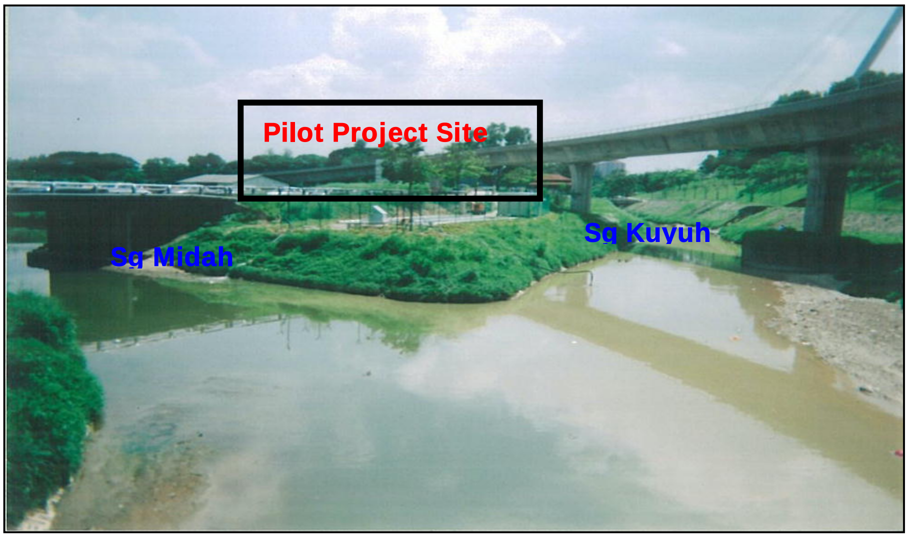

Figure 5.3 Pilot Project Site @ Bukit Jalil

5.6 SOLID WASTE MANAGEMENT

The rapidly growing industrialisation and urbanisation in our country has been accompanied by a rapid increase in waste generation. Rubbish which is indiscriminately disposed of finally enters the river systems (Figure 5.4). Illegal dumping of industrial, commercial and construction wastes entering the rivers also contribute to and worsen the situation. The heavy loads of solid waste in the rivers not only reduce the aesthetic and environmental qualities of the rivers, but also substantial contributor to river water pollution as well as presenting health hazards to the human population. Solid waste also contributes to urban flooding where localised accumulation can significantly reduce the flood-carrying capacity of the stormwater drainage systems and river channels. Currently, it is common practice to construct rubbish booms to trap and remove solid waste from rivers. However such moves should only be treated as short-term and immediate measures. The long-term measures should be achieved through public education and enforcement. Experiences gained from adopting the new urban storm water management approaches in several locations including the new government administrative centre of Putrajaya should be compiled and documented to serve as model for the implementation of such better policies and practices. The topic is also addressed in the Urban Storm Water Management Manual (MSMA) [5].

Figure 5.4 Rubbish-Rubbish Everywhere (Klang River)

5.7 RIVER CORRIDOR / RESERVE – THE WAY FORWARD

There is a need to have a paradigm shift in river and river corridor management perspective in order to achieve the vision of “natural rivers” in urban, suburban and rural settings in Malaysia. There is no point talking about them without being able to implement and ensure that the “dreams” can become reality. In planning and managing our rivers, one must first ensure that the rivers fulfil the designated functions expected of them, such as flood mitigation, water resources (irrigation, Industrial and domestic water supply), navigation, aquaculture, recreation and environmental needs. Very often, we come across comments and remarks that “we have limited land”, “land is very costly”, “we can’t afford to have such a wide river reserve”, etc. On the other hand, we also want to promote “natural rivers” and rehabilitate the “disturbed” rivers as much as possible. These statements may be true now, but one must start somewhere.

The perception of rivers should be totally changed. The so-called “natural river” should be confined to the low-flow section of the river, while the flood flow section to accommodate the designed flood discharges be confined to within the “river reserve / river right-of-way” (A typical recommended section is as shown in Figure 5.5 & Figure 5.6). As far as possible, this low-flow river section should not be interfered with (except for some bank protection works if the bank erosion & scouring becomes excessive). No deepening, widening or straightening should be encouraged. This section should preferably be capable of handling the discharge of 1.5 to 2 year ARI only. It should also be maintained in a natural state as much as possible. This “river” should be allowed to meander and find its own way and regime within the “reserve” area. Let nature find its own equilibrium.

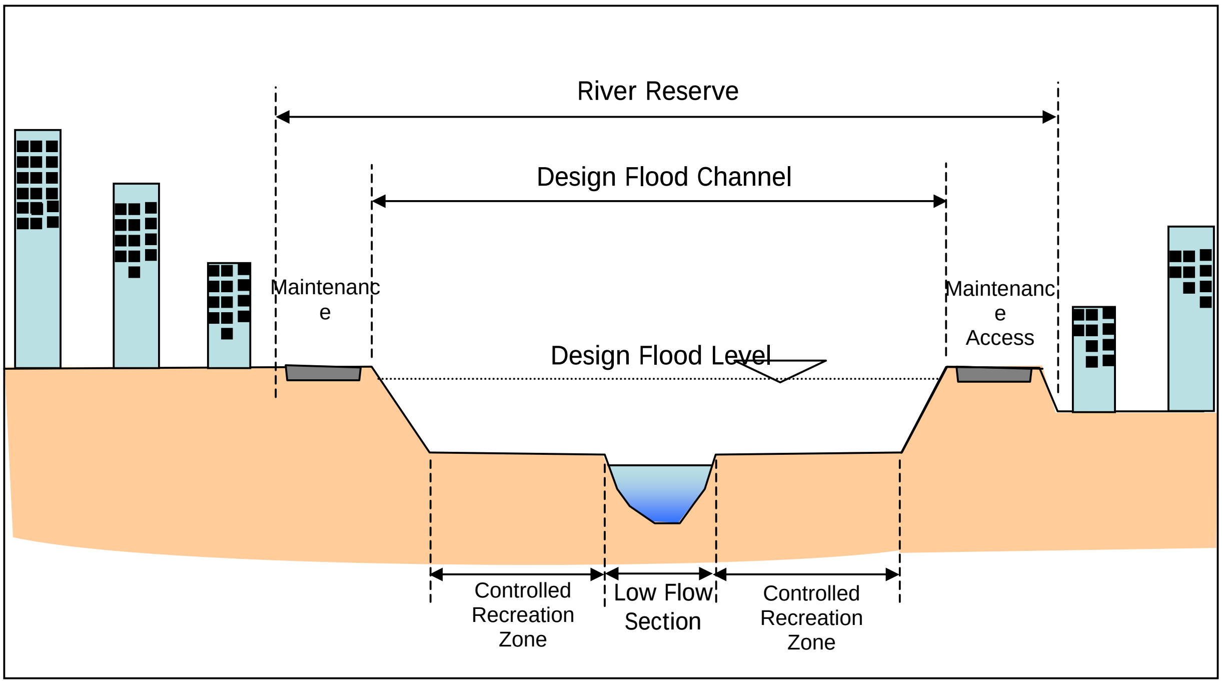

Figure 5.5   Recommended River Reserve Section

Figure 5.6 Urban River Reserve Vision

It is agreed that such conditions and requirements are not achievable currently in most of the developed urban centres. However, through future landuse planning & zoning mechanism, such vision is still achievable in the far future. For a start, besides new development areas, all these requirements should be incorporated in the preparation of the landuse, development and structure plans for the proposed 5 economic development corridors (mostly are still in rural or undeveloped settings). All future structure and local development plans should adopt similar measures.

5.8 "RIVER MANAGERS"

The new integrated river management concept requires not only the services of engineers, but also those of other disciplines. Cooperation and working together with the other relevant agencies and partners is essential. At the same time, for DID to perform effectively, it is recommended that the River Division of DID should also engage other disciplines in the management of our rivers. For instance, stream ecologists, watershed scientists, geoscientists, aqueous chemists and aquatic biologists … are encouraged to work in collaboration with river engineers to achieve the goals set by the River Division of DID.

5.9 CLIMATE CHANGE

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and large water bodies in an environment full of life. The climate is perhaps too often defined as the daily weather. However, it can be described over long periods of time in terms of mean and variability in temperature, wind and precipitation. The complex interaction between land, climate and anthropogenic impacts such as deforestation, plantations, and urbanization will definitely impact the future management of the river environment in Malaysia.

The combined effects of climate change with anthropogenic effects also need to be closely examined in the future. For instance, the potential increase in the frequency of high intensity rainstorms from climate change with deforestation can have devastating consequences in terms of landslides and tremendous sediment production that can significantly reduce the life expectancy of reservoirs and cause major problems for water supply, flood control and stream stability at a larger scale. The example of Cameron Highlands has to be kept in mind in this regard. Additionally, the example of increased rainfall precipitation in the Kuala Lumpur area as a result of heat generation from buildings can cause serious problems in terms of the increased frequency and magnitude of flash floods in the Klang River Basin.

Climate change has a big impact on water bodies including rivers. The impacts of these changes have to be taken into consideration. Currently, there is not much research and studies been conducted in this area. This should be one main topic to be undertaken under research and development

5.10 PERIODIC REVIEW

As advances in the fields of water resources as well as river management are still ongoing rapidly, this Manual should be viewed as a living and dynamic document which requires regular reviewing and updating. It is recommended to update and review this Manual every five years.

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