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Technical Considerations for Evaluating Riverine/Riparian Restoration Projects

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Preface

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Overview

River/riparian restoration developed first and foremost as a practice rather than as a science. Progress has been on an ad hoc site- and situation-specific basis, but with little development of general theory or guiding principles, constraining the transfer of technology and knowledge. Recent advances in restoration technologies, integration of stream, riparian and watershed restoration procedures, and underlying principles based on ecosystem processes and functions have yet to be incorporated into mainstream restoration practice.

Districts invest considerable manpower interacting with applicants and resource agencies debating the merits of proposed restoration actions. These efforts are hampered by inconsistencies in the literature, poor performance records (i.e. projects often do not meet objectives), conflicting agency missions and directives, and insufficient guidance. Lacking a sound procedure for the objective evaluation of proposed restoration efforts, regulatory assessments often cannot ensure that the "public interest" criterion is met and that sufficient protection is afforded to the resource.

To address this problem, research was initiated under the Wetlands Regulatory Assistance Program (WRAP) to develop a technical framework for assessing Section 404 applications for stream and riparian restoration activities. The research effort also focused on the preparation of an annotated bibliography that could support regulatory decisions. The recommendations presented in this document are centered on the recognition that the character of stream systems (and, thus, their value or potential to support certain uses) is a function of a set of dynamic and interrelated processes referred to as *functions* in this report. Fifteen critical functions were identified by a committee of U.S. and international scientists, engineers, and practitioners, and were synthesized into a framework for ecosystem evaluation.

Understanding the basic functions of streams and riparian corridors provides regulators with a concise and effective basis from which to evaluate possible impacts of proposed projects, and offers regulators several powerful advantages over assessments that focus upon beneficial uses. Use of functions and processes can be elegantly incorporated within a *systems approach*, enhancing understanding, enabling predictions, and supporting management decisions. While the employ of a functional approach will most benefit the formulation of scientifically sound general permits, Districts can use the recommendations provided in this document at all stages of the regulatory process.

This report describes the status of current restoration practice, presents the functional framework, and discusses ways in which the framework can be applied to support the Corps' Regulatory Program. Where examples are provided, those examples are based on actual projects and situations, though the project location and some of the details are omitted or obscured for reasons of confidentiality.

Background

Decisions concerning infrastructure development and water resource management have historically focused on social and economic issues. Recently, consideration has also been given to selecting alternatives that best "fit" the environment and do not contribute to unnecessary impacts. But the focus remains centered on finding ways of implementing development and management plans, with the notion that if we avoid, minimize, and mitigate the associated impacts, we ensure environmental integrity. Lacking a comprehensive understanding of the many interdependent relations in river and riparian ecosystems, this paradigm calls into question the sustainability of some development and management practices.

The vast majority of environmental scientists recognize that the rules governing the dynamics of ecological systems ultimately set the constraints on allowable human activities. Thus, ecological sustainability is primary to all measures of sustainability. This does not mean that sustainability is exclusive of social and economic development, simply that social and economic systems are subsystems of the environment, not the other way around.

The result of this concern must be reflected in how water resource systems are planned and managed for the future. Design engineers and environmentalists, both of whom recognize the interdependence between infrastructure and the environment, are increasingly concerned about maintaining an appropriate balance between the two. Environmental laws have established a legal framework aimed at keeping development decisions consistent with that goal. Technical and policy frameworks must also be established to ensure decisions that promote sustainability.

The regulatory community plays a key role in this effort. They are, in most cases, the only mechanism to prevent development decisions that would irreparably damage ecosystems. A clear, objective procedure is needed to assist regulatory personnel in assessing proposed actions. The procedure should permit screening of permit applications to rapidly identify those unlikely to pose impacts, precluding the need for detailed data collection or analyses. The procedure must also be sufficiently robust to permit the quantification of specific impacts so that alternatives can be identified and compared, or mitigation needs established.

Given the realities of today's regulatory environment, an emphasis must be placed on formulating a procedure that is efficient and cost effective. The collection of unnecessary data and lengthy studies must be avoided. This report presents a framework for assessing river and riparian ecosystems that is based on evaluating the processes and characteristics of rivers and riparian zones – the fundamental building blocks that define these ecosystems.

Legislation and policies that guide regulatory activities refer frequently to the preservation of important *functions* and *values* of ecosystems. Many people use the terms interchangeably, even though functions and values are quite different. Functions are the physical, chemical, and biological processes occurring in and making up an ecosystem. Processes include, for example, the movement of water and sediment, the decay of organic matter and cycling of nutrients, and the growth and development of all the organisms utilizing the ecosystem. These processes generate ecosystem *characteristics* that vary in time and space, but that are unique to each system. Characteristics include, for example, the morphology of the stream, the size and distribution of sediments in the bed, the composition of the riparian vegetation community, and the hydrodynamic signature of the stream.

Values are an estimate, usually subjective, of worth, merit, quality, or importance. Ecosystem "values" are typically related to outputs that can be consumed directly, such as water, food, recreation, or timber; or indirect uses that arise from the functions occurring within the ecosystem, such as the provision of habitat, water quality, and flood control. Thus, values are derived from certain ecosystem characteristics that, in turn, are determined by the underlying functions. Though different, the value and function perspectives are closely related.

Both perspectives have limitations. Ecosystem valuation can be subjective, particularly the valuation of indirect use, future use, or existence values. Conflicts may also arise between public and private valuation. For example, society may attribute a value to the preservation of a particular species and regulate the development of the private property, although the property owner may not value the organism at all or values it less than he does other land uses. Technical considerations limit the use of a functional perspective. Previous efforts to identify critical functions have failed, in large part because of the complex and interrelated nature of ecosystem processes.

This document identifies a suite of functions that are critical to the sustenance of stream and riparian ecosystems. These functions are related to activities often encountered in the Section 404 Program, so as to establish a framework in which those activities may be evaluated. Within watersheds and ecosystems, human activities can cause depletion or pollution. The watershed and its ecosystems sustain our way of life, regardless of our understanding of the biology, chemistry, and geology involved. However, when decision makers do not understand ecosystem functions, they may make choices that result in long term and possibly irreversible damages that reduce the value of the ecosystem. A familiarity with the functions of an ecosystem can improve decision making today and protect values that may be held by future generations.

Society has a vested interest in sustaining ecosystem health for the value it may provide those future generations. How our stream and riparian systems are valued in the future will likely differ from today in ways that are not fully predictable. But history has shown that resource degradation invariably limits potential future uses. Concepts of *sustainability* are, thus, directly related to the “public interest” doctrine embodied in the Section 404 review process.

The overriding regulatory framework for stream restoration activities that fall under the jurisdiction of Section 404 of the CWA is the assessment of public interest. Public interest includes the maintenance of the quality of natural and water resources for environmental and human health. Public interest also allows for reasonable use of these natural resources. Balancing reasonable use and environmental quality requires the adoption of the principles of sustainable use. Sustainable use arises from the premise that the environment and development are interdependent, and that the impacts of some beneficial uses can so degrade the environment as to preclude other and future uses. These principles extend beyond the conventional sequence of avoidance, minimization and mitigation because they acknowledge that there are some impacts that simply cannot be mitigated.

Conventional Restoration Practice

Overview

Restoration is generally defined as "returning a site to a condition similar to one that existed before it was altered, along with its pre-disturbance functions and related physical, chemical and biological characteristics." Implicit is the goal to establish a system that is self-regulating and integrated within its landscape, which also means that the restored condition may differ from the pre-disturbance condition in some respects. These differences allow for the inevitable and, often, irreversible changes that accompany development and natural resource exploitation, as well as those associated with normal (i.e. natural) changes over time.

Most of the streams in the United States are degraded in one way or another. Recognition of this fact, and an increased appreciation for the value of healthy stream and riparian systems, have led to significant public desire to implement restoration programs. Some of these have been well conceived and address complex ecosystem interactions. However, most restoration projects focus on small-scale, site-specific concerns without regard for the broader ecosystem needs. The restoration aims are frequently centered on stabilization and on the creation of habitat for key species – goals that are clearly influenced by social values and that may not be in consonance with ecosystem needs.

Thus, restoration is inordinately focused upon tactics, with little regard for strategic issues in ecosystem management. Failure to address strategic issues inevitably leads to wasted resources, missed opportunities, misperceptions regarding success or failure, and an underestimation of risks and synergistic or cumulative impacts associated with multiple activities. Concerns about the impacts of well-intentioned restoration activities upon processes and conditions that extend beyond the project's boundaries has increased, but a framework from which to formulate and assess restoration plans has remained elusive – primarily because perceptions of the roles of ecosystems are constrained by our social values.

Tactical Restoration

The technical literature, government programs, and social perceptions have largely focused upon the techniques and tactics of stream and riparian restoration, rather than upon broader strategic issues. The reasons for this are easy to identify and include the following:

- Our understanding of ecological processes is limited, which presents technical challenges in assessing the numerous multi-scale, interdependent and sequential consequences of alterations to ecosystems.
- Our perceptions of "problems" and "benefits" are skewed by social perceptions that are not readily changed and that are complicated by difficulties in placing a "value" on processes or conditions that are difficult or impossible to monetize.

- The public, interest groups, and funding entities generally demand quick and visible results – a goal easier to achieve on small, focused projects than on broader ecosystem recovery strategies that may take decades.
- Even when broad ecosystem issues are identified, funding, time, user interests, land ownership and jurisdictional politics quickly narrow the focus of most restoration efforts.

Thus, the practice of restoration is centered upon tactical questions such as identifying problem reaches of streams that need to be "fixed" and finding the best tools with which to fix the problem. Streams and riparian corridors are generally viewed as consisting of "good" sections interspersed with "poor" segments, and it is often believed that the system can be improved or even optimized by making the poor segments good. The characteristics that determine if a section is good or poor vary, but often center on the presumed habitat needs of a single life stage of a single species. A very simple yet illustrative example is the plethora of stream "restoration" projects intended to improve habitat for adult brown trout (a non-native species in the U.S.), even though most of these projects have detrimental effects upon the native flora and fauna and the processes that create habitat for these species.

Another focus of restoration projects is the desire to stabilize the system. Despite all evidence to the contrary, the perception persists that ecologically healthy streams and riparian corridors are stable. In truth, dynamic processes such as erosion, deposition, flooding and drought that occur on healthy streams are critical for maintaining pathways and establishing new habitats. While it is true that investments in restoration activities often require the insurance of temporary stabilization, most conventional stream restoration projects differ from channelization practices of the 1950's only in the shape of the channels and the materials used for stabilization.

Determining how best to stabilize a stream reach while concurrently affording the greatest habitat for the species of interest, and even the desired age cohort of the species of interest, has become the focus of most restoration efforts. Practitioners become familiar with one or two stabilization/habitat improvement tactics and find ways to "fit" these approaches to each problem stream segment without regard for the suitability of the system as a whole to the change that the selected structures are intended to induce. Debates center on whether it is better to use vanes, boulder clusters, or rootwads, and how to design these to be stable, rather than upon the potential impacts of these devices upon the hydrodynamic and sediment regime of the system, and whether or not these impacts are consistent with maintaining other important processes for the system.

Another trend in tactical restoration is the justification of the project on the basis that it employs "Natural Channel Design Methods." The principles employed in these methods are both useful and relevant to stream restoration. However, natural channels are not "designed," they are created and maintained through natural processes. There is currently no design methodology that assures that a stream system will behave naturally, nor is it likely that one will ever exist. Thus, it is imperative that regulatory assessments focus upon the product of the restoration effort, not upon the objectives or the method used to achieve the design. (see Example 1)

A heightened awareness of the processes that occur within an ecosystem and the recognition that biotic and abiotic system components are inexorably linked has fostered recent calls for a systems approach to restoration. The systems approach emphasizes (1) viewing problems within the context of the entire watershed, (2) acknowledging that a range of conditions and characteristics are necessary to support all the trophic levels within a system, or (3) both.

Approaching restoration from a systems perspective immediately raises questions about tactical approaches because other opportunities to achieve restoration can be identified. These other opportunities give rise to strategic conservation and restoration approaches.

Example 1. Natural Channel Design

A stream restoration design was prepared as part of a mitigation package for a road development project. The stream had been gravel mined up to the mid-1970's, and the watershed had undergone extensive urbanization. The result of these disturbances was a stream with a channel geometry, sediment load, and hydrology that differed from historic (i.e. pre-impact) conditions. The stream was approximately 30 feet in width, the average height to the top of bank was about 3 feet, the bed material was gravels and cobbles with fine sediments in the interstices.

The restoration design was formulated using "Natural Channel Design Methods," and was hailed as a revolution in the region. The "restoration" project consisted of modifying approximately 400 feet of the channel to simulate the morphology of a reach on a nearby stream in a watershed with relatively few impacts. The primary change to the channel was the increase of channel sinuosity (from about 1.05 to about 1.5), accomplished through the excavation of new channel meanders. The outside of the meander bends were stabilized using rootwad revetments, and the overbank areas were seeded and planted with tree seedlings.

Although no evidence was presented that suggested the channel had ever existed a state similar to that of this design, and no analyses were offered that substantiated that this channel geometry was consistent with the prevailing hydrologic and sediment yield conditions, the plan was approved and implemented. During the first modest precipitation event following construction, the newly restored channel filled with sediment and the channel avulsed, cutting a new channel across the floodplain and destroying much of the channel stabilization and riparian restoration efforts. The newly avulsed channel had dimensions nearly identical to the pre-project conditions.

This approach, no matter how well intentioned, neglected to address the independent variables driving the system (e.g. sediment supply and hydrology), and was destined to fail. The increase in sinuosity reduced the channel slope by 50 percent, and the new channel was clearly incapable of conveying the volume of sediments delivered from upstream (the Corps Committee on Channel Stabilization visited the site immediately following construction and, without benefit of any computation, to a person deemed the failure from this cause inevitable). An explicit requirement to consider the project's impacts on sediment processes would have uncovered this oversight.

Strategic Restoration

Successful restoration is based upon more than an understanding of the immediate problem and the identification of techniques capable of addressing the problem. It is also based on understanding the interaction of the problem and proposed solutions with other ecosystem components, both locally and beyond the project's boundaries, and over varied temporal scales. Successful restoration is also based upon working creatively with social and economic realities and the recognition that restoration is but one component of a broader management plan that includes conservation and impact prevention strategies.

A social imperative to identify and focus upon the worst cases of stream degradation has perhaps diverted funds and attention from efforts that would yield greater benefits and has doubtless contributed to the persistence of tactical approaches to restoration. Jurisdictional constraints have proven to be a barrier to implementing strategic restoration as well. For example, the alteration of land use practices that lead to degradation is often not an option because landowner interests or agency mission areas are focused upon the consequences of the problem (e.g. erosion and habitat degradation of a stream reach), despite the fact that addressing the underlying land use problem is often more economical, sustainable, and poses lesser risk of project failure. Strategic restoration relies upon the identification and prevention of problems before they lead to ecosystem degradation and targets the incremental and cumulative benefits of addressing many small problems before they become large problems.

Implementing strategic restoration relies upon a synthesis of geomorphic, ecological, and social knowledge to formulate a reasonable understanding of the problem, the sequence of events that led to the problem, the likely response of the system with time, and the consequences of various remedial strategies. Strategic restoration involves the application of several principles:

- The avoidance of problems through the preservation and conservation of healthy stream and riparian systems is always more cost-effective and sustainable than efforts to restore these systems once degraded.
- Problems must be assessed within the context of the entire watershed, and sometimes multiple watersheds. Many disturbances propagate over considerable distances and multiple disturbances act synergistically and cumulatively. A stream's response to disturbance can take decades or centuries, so what we view today often reflects an *ongoing* change to historic conditions.
- Effective restoration treatments must address the underlying processes that cause system degradation. This requires rigorous analysis to identify the causal mechanisms and to evaluate the effectiveness of alternative restoration strategies.
- Recovery of degraded systems requires time – often decades – and usually relies upon the cumulative benefits of a number of actions that address multiple causes of degradation and link critical system segments or processes.
- Stream and riparian habitats and conditions are highly variable and patchy in space and time. Efforts to restore riverine systems should seek to restore the processes that create the temporal regimes and spatial diversity that characterize healthy systems. Restoration that produces homogeneous and temporally stable conditions contributes to system degradation.
- Successful restoration projects must secure existing or per-existing native populations by maintaining well-distributed, diverse habitats that provide critical refugia and recovery pathways. This can only be accomplished by securing the processes that create the needed conditions.
- Habitat conditions and biota are largely a consequence of physical and chemical processes that occur within sub-basin and basin contexts, and cannot be successfully manipulated independent of these contexts.
- Successful restoration should be self-sustaining, requiring minimal or no maintenance.

A common theme of these principles is the understanding of key processes that occur within a system to create conditions important to the ecosystem's character. In other words, we must know how the system operates, or *functions*, in order to make good management decisions. This concept is fundamental to restoring and managing ecosystems, and is reflected in many of the laws and policies that guide our actions. Although these regulations require that we address functions, previous efforts to identify the key stream and riparian ecosystems functions have not met with success. Regulatory personnel could derive significant benefit from the identification of these functions and their synthesis into a framework for ecosystem evaluation.

Ecosystem Functions – A Framework

Planners, managers and regulatory personnel often view watersheds in terms of the *beneficial uses* they support. This viewpoint stems from the philosophy that all watersheds can provide certain uses within limits. Current concepts of sustainability - i.e. "meeting the needs of current generations without compromising the needs of future generations" - are centered on this notion (United Nations, 1992). Beneficial uses and values, however, are not consistent across political boundaries, change with public perception and with time, and are difficult or impossible to measure (Brinson 1993, Brinson *et al*. 1995, Smith *et al*. 1995). Objective decisions regarding the implications of proposed ecosystem alterations thus require consideration of factors beyond an assessment of the potential impacts to other uses.

Although watershed characteristics vary from one area to another and over time, all watersheds support common physical, chemical and biological processes that interact to form and maintain streams and riparian zones. These processes, and certain characteristics of the ecosystems, can be termed *ecological functions*. The *functional* viewpoint evolves from the recognition that watersheds support ecosystem components that interact in complex ways to contribute to the continual restructuring of the watershed and its associated features. This is a dynamic, variability-based concept. A shift within the scientific community is underway in which a functional approach (rather than a beneficial use approach) is being advocated for stream restoration planning and design for the follows reasons:

- In contrast to beneficial uses, which are based on public perception and politics, functions have a scientific basis, can be measured using established ecological and physical methods, and do not change with public perception or political entities
- Based on processes and interactions, a functional assessment approach is capable of targeting the cause of impairment within a watershed, providing a sound basis to evaluate projects at the initial purpose and need level
- A functional assessment approach can identify similarities and dissimilarities between stream reaches, watersheds, and stream classes, establishing reference conditions, prioritizing watersheds for preservation or restoration, documenting and accounting for scale issues, and reducing error associated with natural variation in aquatic ecosystems
- A functional assessment approach supports predicting *and quantifying* the short- and long-term effects on ecosystem quality and quantity, establishing appropriate restoration that restores functionality, and identifying success criteria.
- Functional assessments permit the aggregation of process alterations to assess cumulative impacts, and foster the evaluation of ecosystem interdependencies
- A functional assessment has the unique ability to address impairment caused by maximum loading and can be used to identify thresholds
- A functional assessment approach, based on direct measures and surrogates of those measures, can be used to formulate hypotheses and identify research needs.

Assessments based on beneficial uses do not offer these powerful capabilities.

This report proposes a consistent yet flexible framework in which stream and riparian *functions* serve as the basis for evaluating activities regulated under Section 404 of the CWA on these ecosystems. This functional perspective should be employed in addition to the beneficial uses that are involved in decision making already, though it can implicitly address many potential impacts to uses.

The primary advantage of this functional systems approach is that it permits the rapid identification of practicable alternatives and the assessment of potential impacts from each. At the same time, the functional approach promotes an expanded perspective from 1) a species to an ecosystem level, 2) considering a specific site to the role of the site as a whole in the watershed, and 3) focusing on end products to focusing on the energy processes that created them. Viewing watersheds in terms of *beneficial uses* can result in unclear and often conflicting planning and management direction. Conversely, viewing them in terms of the *functions* they support can allow for a clear, consistent assessment of status and effects. We, therefore, propose the use of a functional framework as a basis for assessing watershed conditions and likely responses to management activities.

Function Categories

All waterways support and maintain basic functions associated with either structure or processes that result in a continual development or evolution of the watershed. These functions relate to the physical, biological, and chemical nature of waterways but do not relate directly to their social context, which is addressed later in the category of beneficial uses. The basic functions that streams and riparian corridors support can be divided into five categories:

- System dynamics,
- Hydrologic balance,
- Sediment processes and character,
- Biological support, and
- Chemical processes and landscape pathways.

Within each of these categories, three key components and processes (Table 1) were compiled from a preliminary list of over 60 functions identified by a scientific committee. The committee was well aware of the interconnection, interdependence, and integration of functionality expressed in aquatic ecosystems. To reduce bias, this paper discusses each function independently. An attempt is then made to re-couple the interdependence of functions. It is important to note also that not all functions will be of equal importance in individual watersheds, so interpretation of this framework will be required for each situation.

Tables 2 through 6 present an overview of each of the 15 primary functions. This overview is supported and augmented by the annotated bibliography presented in Appendix C, and is expanded upon in another document (Fischenich, 2003). Generally speaking, an individual tasked with processing a Section 404 permit application will be knowledgeable about only a few of these functions, and will require technical assistance in assessing the remaining functions. Understanding ecosystem functions will help regulators formulate the needed questions to be posed to those providing assistance. To help with this need, Tables 2 through 6 present lists of indicators commonly used to determine the presence/absence of a particular function, as well as lists of measures used to quantify the degree to which the functions are present.

Table 1. Summary of Primary Functions.

System Dynamics	*Hydrologic Balance*	*Sediment Processes and Character*	*Biological Support*	*Chemical Processes and Pathways*
Stream Evolution Processes	Surface Water Storage Processes	Sediment Continuity	Biological Communities and Processes	Water and Soil Quality
Energy Management	Surface / Subsurface Water Exchange	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Processes	Landscape Pathways

Indicators and Measures of Functions

There is consensus that the world's streams and riparian corridors are of fundamental importance to human health, that they are increasingly threatened by economic change and by environmental degradation, and that, consequentially, urgent and effective attention is needed. To provide this, it is important to assess accurately the current state of these aquatic systems, and to predict system trends inclusive of the consequences of various management alternatives. Addressing these needs requires both qualitative and quantitative approaches, through which the sustainability of relevant systems can be assessed and sometimes measured.

Indicators are variables, features or attributes that allow for a reasonable and practical means of identifying the presence/absence of a particular function. They also serve to foster an understanding of cause/response relations at and between the various scales present on aquatic systems - not a simple matter given the complexity of ecosystems. Processes operate across scales and thus define critical linkages (e.g. runoff generation, sediment load and transport, erosion/deposition, and vegetative interaction/succession). These processes are assessed in terms of the physical variables, features and attributes that are manifested at the scales of watershed, reach and site. Indicators are generally qualitative, though they can be semi-quantitative as well. Measurement of certain attributes allows quantification of the degree to which a particular function is achieved in an ecosystem. Measures can be physical, ecological, economical, or social. Indicators and measures for the primary functions identified in the previous section are summarized in Tables 2 through 6.

Beneficial uses Perspective

The social aspects of stream and riparian ecosystems are addressed in this report as beneficial uses. With respect to *Uses* a distinction can be made between using the system as a Sink, a Source (consumptive use) or Indifferent (non-consumptive). Table 7 provides a list of common uses of rivers and riparian corridors and how they affect or are affected by the primary functions. The beneficial uses are presented without respect to priority or value, which would and must vary with time and by region.

Table 7 demonstrates the considerable interrelation between the primary functions and the common beneficial uses ascribed to the resource. A particular use can impact one or more functions, with consequent impacts upon other potential uses. Uses are not consistent across political boundaries, change with public perception, change with time, and are difficult or impossible to measure, but the fundamental processes (i.e. functions) that support them are less susceptible to these variations and difficulties.

Table 2. System Dynamics

Function	Description	Indicators	Measurements
Maintain stream evolution processes	➢ Necessary process to maintain appropriate energy levels in the system. ➢ Promotes normally occurring change necessary to maintain diversity and succession. ➢ Provides for genetic variability and species diversity of biotic communities.	Systemic changes to channel cross-section, planform, or grade. Magnitude, frequency, and duration of flow changes. Bed armoring or sorting. Evidence of bed erosion or deposition. Bank erosion. Diverse riparian vegetation and aquatic biota. Presence of pioneer vegetation species. Stream stability. Changes in the composition of the aquatic community.	Stability assessment techniques that quantify bed and bank stability. Channel evolution model stage and change. Rates of change of channel geometry parameters. Time-series aerial photo analysis of stream pattern. Quantity, densities, ages, types, % cover of different vegetation. Abundance and distribution of pioneer species, as well as rate of succession. Flood history polygons (exceedance intervals). Other disturbance process measures (e.g., fire).
Energy management processes	➢ Spatial and temporal variability in cross section, grade, and resistance allows for conversion between potential energy and kinetic energy through changes in physical features, hydraulic characteristics, and sediment transport processes. ➢ Provides habitat, generates heat, oxygenates flows.	Changes in physical stream features, such as width, depth, slope, and bed and/or bank roughness. Changes in flow state or condition. Erosion/deposition pattern change. Alternate and diverse reach classifications (riffle, pool, run). Watershed disturbance patterns. Changes in terrestrial and aquatic biota.	Determine energy grade line and hydraulic grade line and compare with bed slope at different flows. Quantify variability in physical stream features or hydraulic features along the channel and compare to reference channels. Measured channel/floodplain constrictions.
Provide for riparian succession	➢ Changes in vegetation structure and age promote diversity and ecological vigor by initiating change, which is important to long-term adaptation of ecosystems. ➢ Zones of mature riparian ecosystems are necessary for system stability, LWD recruitment, and nutrient cycling.	Presence of pioneer species. Diversity of vegetation. Varied age classes. New sediment deposition and active erosion.	Measures of species diversity, composition, age, and structure. Riparian zone width. Seedling distribution. LWD recruitment rate.

Table 3. Hydrologic Balance

Function	Description	Indicators	Measurements
Surface water storage processes	➢ Provides temporary water storage during high flows. ➢ Regulates discharge and replenishes soil moisture. ➢ Provides pathways for fish and macroinvertebrate movement. ➢ Provides low-velocity habitats. ➢ Maintains base flow and soil moisture. ➢ Provides contact time for biogeochemical processes.	Presence of perennial floodplain topographic features, such as floodplain lakes, ponds, oxbows, wetlands, and sloughs. Riparian wetlands, depressions, and microtopographic changes in active floodplain. Presence of floodplain-spawning fishes. Presence of macroinvertebrate and amphibian indicator species. Watershed % impervious surface. Riparian debris patterns. Detrital accumulations.	Backwater computations. Hydrologic routing models. Stream entrenchment surveys. Rating curves. Floodplain species spawning success. Topographic surveys. Infiltration rates, compaction surveys. Gage and well records.
Maintain surface / subsurface water connections and processes	➢ Provides bi-directional flow pathways from open channel to subsurface soils. ➢ Allows exchange of chemicals, nutrients, and water. ➢ Moderates low and high in-channel flows. ➢ Provides habitat and pathways for organisms. ➢ Maintains subsurface capacity to store water for long durations. ➢ Maintains base flow, seasonal flow, and soil moisture.	Invertebrates found in the hyporheic zone under floodplains. Presence of floodplain topographic features that connect the channel to groundwater recharge areas by free-draining soils. Occurrence of flows sufficient to allow connection. Presence of layers of silt or organics in soil profile. Moist soil conditions, hydrophytic vegetation. Adjacent wetlands, hydric soil indicators. Groundwater elevation fluctuations. Watershed % impervious surface.	Flux in groundwater levels. Stream baseflow. Hyporheic macroinvertebrate distribution, density, and diversity. Complexity of microtopography. Isotope dating. Soil porosity. Water chemistry profiles. Temperature recording. Texture, structure, moisture, redox, and porosity of adjacent soils.
General hydro-dynamic balance	➢ Rivers have a unique hydrologic signature important in ensuring proper flow conditions at the appropriate seasons for support of the biotic environment.	Presence of an active floodplain. Associated wetlands. Redoximorphic features and other indicators of hydric soils. Hydrophytic vegetation, drift line, and sediment deposits at appropriate elevations.	Flow duration analyses. Rating curves. Spawning success.

Table 4. Sediment Processes and Character

Function	Description	Indicators	Measurements
Sediment continuity	➢ Provides for appropriate erosion, transport, and deposition processes. ➢ Maintains substrate sorting and armoring capabilities. ➢ Provides for the establishment and succession of aquatic and riparian habitats. ➢ Important part of nutrient cycling and water quality maintenance.	Bed sediment character. Evidence of recent channel or floodplain sediment and detrital deposits. Recent bed or bank erosion. Channel planform, section, or grade changes. Active bars. Changes in supply, erosion and deposition patterns. Diversity in aquatic and riparian biota. Watershed disturbance patterns. Composition and diversity of macroinvertebrates. Changes in magnitude, duration, or frequency of flow.	Bed material sediment loads and gradations. Suspended sediment load assessments. Stability assessment techniques. Temporal changes in channel geometry. Sediment yield measures. Sediment transport modeling and/or incipient motion analysis. Lower bank angle surveys. Stream bed core sampling
Maintain substrates and structural processes	➢ Stream channels and riparian zones provide substrates and structural architecture to support diverse habitats and biotic communities. ➢ Complex habitats naturally attenuate the effects of irregular disturbance processes such as fire and floods.	Presence and health of indigenous biota. Distribution, abundance, health and diversity of biota. Relative complexity of substrates. Structural complexity and distribution. Abundance and distribution of large woody debris. Habitat diversity and complexity. Population trends of indicator species. Disturbance history.	Presence, composition, frequency, and distribution of physical characteristics such as pools, riffles, bedforms, specific depths and velocities, cover and substrate features, riparian corridor widths, etc. Aquatic and riparian habitat assessment methods such as PHABSIM, RCHARC, RBPS, HEP, IBIs. Distribution and frequency of key physical parameters. Riparian and in-channel woody debris surveys. Aquatic macrophyte surveys. Periphyton samples. Stream substrate composition. Soil compaction, displacement, or erosion. Detrital mass surveys. Bacterial counts. Fungal surveys. Fire and flood history mapping.
Quality and quantity of sediments	➢ Organisms often evolve under specific sediment regimes and these must be preserved for the ecological health of the system. ➢ Sediment yield and character are primary variables in determining the physical character of the system.	Change in banks, pools, and bars acceptable relative to other similar streams. Distribution, abundance, health, and diversity of biota. Presence of indicator species.	Sediment grain size distribution. Embeddedness. Sediment yield. Bedload. Suspended sediment load. Sediment concentration. Secchi depth. Armor layer size and thickness. Depth to bedrock. Sediment mineralogy. Macroinvertebrate surveys. Redd counts.

Table 5. Biological Support

FUNCTIONS	Description	Indicators	Measurements
Support biological communities and processes	➢ Provides for diverse assemblages of native species. ➢ Maintains natural predator/prey relationships. ➢ Maintains healthy physiological conditions of biotic communities. ➢ Maintains genetic diversity. ➢ Maintains age class and life form structures. ➢ Provides for natural reproduction and long-term biotic persistence.	Changes in population trends. Changes in health or condition of individuals or populations. Abnormal behaviors. Unbalanced predator/prey communities. Changes in growth or reproduction. Unbalanced age class or life form structures. Unusual species occurrence outside of normal ranges or preferred habitats. Presence of exotic species. Hybridization.	Population and individual growth rates and condition factors. Disease histories, bacterial and viral profiles. Species diversity and other IBIs. Species assemblages relative to reference conditions. Viability analyses. Population surveys, including density, age-class structure, life-form composition, etc. Bioassays. Stomach content analyses. Genetic testing and mapping. Species distribution relative to reference.
Provide necessary aquatic and riparian habitats	➢ Produces and sustains habitats to support vigorous aquatic and riparian biotic communities. ➢ Provides for basic food, air, light, water and shelter needs of dependant species. ➢ Provides habitats suitable for reproduction. ➢ Supports migration and staging areas. ➢ Provides key temporal habitats during periods of population stress.	Presence/absence/complexity of habitat features. Presence/absence/health of key indicator species, and native, non-native, surrogate, or invasive species. Observations of surrogate signs: remains, nests, dens, trails, feces, fur, prints, etc. Evidence of predator/ prey or reproductive, cooperative, or social behaviors. Presence of critical microhabitat features. Distribution, diversity, and quality of habitats throughout species ranges and over time. Secure recruitment pathways. Disease, extreme population fluctuations.	Measures from Rapid Stream Assessment Procedure, or other habitat modeling such as RCHARC, PHABSIM, HEP. Comparison of biotic counts to reference IBIs. Composition, structure, extent, variability, diversity, abundance of habitat features, key indicator species, native, non-native, surrogate, or invasive species relative to reference conditions. Habitat suitability, complexity, and diversity measures/models. Limiting habitat factor surveys. Refugia network mapping. Terrestrial and aquatic temperature studies. Corridor connectivity assessment. Habitat fragmentation surveys.
Maintain trophic structure and processes	➢ Promotes growth and reproduction of biotic communities across trophic scales. ➢ Maintains contact time for biotic and abiotic energy processes. ➢ Maintains equilibrium between primary autotrophs and primary microbial heterotrophs. ➢ Support food chain dynamics to convert energy to biomass. ➢ Support characteristic patterns of energy cascade and pooling. ➢ Provide nutrient levels capable of sustaining indigenous biologic communities.	Presence/ absence of producers and consumers. Evidence of periphyton growth on substrate. Evidence of detrital shredding and decomposition. Presence/absence of a balance and variety of nutrients and organisms to convert carbon, nitrogen, and/or phosphorus between forms. Presence/absence/abundance of snags, previous season's plants, leaf litter, detritus. Evidence of detrital shredding and decomposition. Organic horizon and organic layers in soil. Presence/absence/abundance of native, non-native, and invasive indicator species.	Aquatic and riparian vegetation density. Periphyton biovolume. Density, composition, and biomass of invertebrate consumers, diversity indices, and other IBIs. Measure of N:P ratios in water. Diversity and composition of stream biota. Measure of primary productivity. Measure of detritus production, CPOM, FPOM, DOM. Measure of large woody debris frequency and density. Comparison of above- and below-ground biomass R/S ratio. Biomass production of stream dependant species. Biomass profile.

Table 6. Chemical Processes and Pathways.

FUNCTIONS	Description	Indicators	Measurements
Maintain water and soil quality	➢ Water quality parameters are directly tied to support of biologic community. ➢ Riparian communities trap, retain, and remove particulate and dissolved constituents of surface and overland flow, improving water quality. ➢ Regulates chemical and nutrient cycles. ➢ Controls pathogens and viruses. ➢ Maintains chemistry and equilibrium conducive to reproduction, behavior, development and sustainability of a diverse aquatic ecosystem. ➢ Supports important chemical processes and nutrient cycles.	Watershed conditions and disturbance features. Stream order. Presence/absence/abundance of key indicator biota. Presence/absence of trophic indicators. Abnormal forms or behaviors; unusual mortalities of indicator species. Plant, fish, and invertebrate density, diversity, distribution, and health. Wetland and riparian aerial and positional changes. Geology and soils - availability of a range of surface textures and areas for reactions. Presence/ absence of riparian sediment deposits. Density, diversity, and distribution of microbial, fungal, and invertebrate communities.	Conventional water quality measures (e.g., D.O., pH, conductivity, turbidity, TDS, salinity, temperature, suspended sediment). Bacterial counts. Metals and trace element sampling. Nutrient (N, P) tests. Examination of soil profiles. Soil profile elemental composition surveys. Rates of sediment deposition in channel and riparian corridor. Detrital mass surveys. Large woody debris counts. Infiltration rates. Compaction, displacement, and erosion surveys. Bacterial counts. Trace element sampling. Nutrient (N, P) tests. COM levels.
Maintain chemical processes and nutrient cycles	➢ Provides for complex chemical reactions to maintain equilibrium and supply required elements to biota. ➢ Provides for acquisition, breakdown, storage, conversion, and transformation of nutrients within recurrent patterns.	Presence of seasonal debris in riparian area. Presence/ absence of indicator species and their health. Presence/absence of photosynthesis, fecal matter, biofilms, and decomposition products. Presence/absence of particulates on vegetation. Riparian vegetation composition and vigor. Changes in algae, periphyton, or macrophyte communities. Changes in trophic indicators.	BOD (CBOD & NBOD) and DOC. Stable carbon isotope analyses -- identify energy pathways. Cell counts, ATP concentration, respiration rates, uptake of labeled substances. Water and soil buffer capacity. Complexation. Redox potential. Ion exchange capacity. Adsorption capacity. Dissolution/precipitation rates. Decomposition rates. Plant growth rates, biomass production.
Maintain landscape pathways	➢ Maintain longitudinal and latitudinal connectivity to allow for biotic and abiotic energy process pathways. ➢ Serve as barriers, corridors, or buffers to plant and animal migration. ➢ Provide source and sink areas for maintaining population equilibrium of plant and animal species.	Presence of animal trails along corridor. Observations of migratory species use. Flood tolerance of vegetation species on floodplains. Presence/absence of key indicator species in portions of the adjacent landscape. Recent deposits of sediments and detrital matter in the riparian corridor. Distribution, density, diversity, and age class composition of riparian vegetation. Accumulation of species during high stress periods.	Relative scale of stream to riparian corridor as a function of stream order or slope. Width, density, and composition of riparian vegetation community. Frequency and duration of floodplain inundation. Migratory bird surveys. Measures of sediment deposition and detrital flux in the riparian corridor. Migration barrier surveys. Genetic analyses. Canopy cover measurements of various life forms. Temperature.

Table 7. Example Relations Between Beneficial Uses and Functions

Beneficial Uses	***Function***				
	System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Sink					
Cooling water	O	O	O	I	I/O
Drainage	O	I/O	I/O	I	I/O
Flood storage/ attenuation	I/O	I/O	I/O	I/O	I/O
Wastewater	O	O	O	I	I
Consumptive					
Aggregate withdrawal	I/O	I/O	I/O	I/O	I/O
Drinking water	O	I/O	O	I/O	I/O
Fishing and hunting	O	O	O	I/O	I/O
Hydropower	I/O	I/O	I/O	I/O	I
Industrial water supply	I/O	I/O	I/O	I	I/O
Irrigation	I/O	I/O	I/O	I	I/O
Groundwater withdrawal	-	I/O	-	I	I/O
Riparian timber harvest	I/O	I/O	I/O	I/O	I
Non-consumptive					
Aesthetics	O	-	O	-	-
Ecosystem protection	I/O	I/O	I/O	I/O	I/O
Housing	I/O	I/O	I/O	I	I
Landscape feature	O	-	O	I	I
Recreational boating	I/O	O	O	I/O	I/O
Commercial transport	I/O	I/O	I/O	I/O	I/O
Navigation service	I/O	O	I/O	I/O	I
Non-boating recreation	O	O	O	I/O	I/O
Spatial corridor	I/O	I/O	I/O	I/O	I/O

Key:

- **No Discernable Impact**
I **Use May Impact Indicated Function**
O **Use May Be Impacted By Indicated Function**

Many of the functions are interrelated such that impacts to one function can cause a cascade of impacts to other functions and to multiple uses. For example, actions that impact the surface/subsurface exchange of water will almost certainly impact the stream's hydrodynamic character, riparian succession, water quality, and habitat. Depending upon the nature and magnitude of the impact, surface water storage, chemical processes, biological communities and trophic structure might be also impacted, but the other functions are likely to remain largely unaffected.

Establishing a hierarchy of functions is difficult because no single function is unaffected by all the others. But the relative significance of each function can be inferred from an assessment of the number of other functions it could impact. The results of such an assessment are presented in Table 8. In this regard, the hydrodynamic character of the system is clearly the most significant of the functions as it directly affects 13 other functions and at least indirectly affects the other. Habitat – the focus of most restoration efforts – is the lowest ranked function because it affects only 3 other functions.

Table 8. Hierarchy of functions.

Rank	*Function*	*Functions Directly Affected*[1]	*Functions Indirectly Affected*[1]
1	Hydrodynamic Character	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	13
2	Stream Evolution Processes	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	9, 13
3	Surface Water Storage Processes	1, 4, 6, 10, 11, 12, 14, 15	2, 5, 7, 8, 9, 13
4	Sediment Continuity	3, 5, 6, 7, 8, 9, 11, 15	1, 13, 14
5	Riparian Succession	1, 2, 3, 4, 6, 12, 14, 15	9, 13
6	Energy Management	1, 2, 3, 4, 5, 7, 8, 15	-
7	Substrate and Structural Processes	1, 2, 4, 6, 7, 10, 15	5, 9, 11, 13
8	Quality and Quantity of Sediments	2, 4, 5, 6, 7, 10, 15	1, 9, 11, 14
9	Biological Communities and Processes	5, 11, 13, 14, 15	1, 2, 3, 7, 8, 10, 12
10	Surface / Subsurface Water Exchange	1, 5, 11, 15	3, 9, 12, 13
11	Water and Soil Quality	8, 9, 13, 14	5
12	Landscape Pathways	9, 13, 14, 15	6
13	Trophic Structures and Processes	9, 11, 14	8
14	Chemical Processes and Nutrient Cycles	8, 9, 13	6
15	Necessary Habitats for all Life Cycles	9, 12, 13	-

[1] Listed by number, according to ranking (e.g. Function #6 is Energy Management)

Note: The interactions among functions are such that the relations presented in Table 8 can change with the type of ecosystem, and the nature and magnitude of the impact, and the specific temporal and spatial scales utilized in the relevant analysis. This is particularly true for the indirect impacts.

Using Functions for Regulatory Program Support

The purpose of this research is the development of a framework to be used by Districts when evaluating proposed restoration projects. The framework should incorporate contemporary science, support multi-level assessments (at a gross scale for rapid, qualitative screening of proposed actions as well as at a fine resolution to quantify mitigation requirements for specific impacts), and should be applicable to the general permit development. This chapter discusses ways that the functional framework presented in the preceding chapter can be used to support regulatory activities.

General Considerations

Regulatory decisions often require balancing objectives for different users with each other and with the bearing capacity of the natural system. Thus, knowledge is needed about the crucial interactions between users and natural processes, spatial- and time-dependent scales, relevant thresholds, and critical boundaries. With this knowledge, regulatory personnel, with some assistance, can evaluate whether the specific effects are acceptable relative to existing conditions or the standards to be met. The maintenance of environmental health is contingent upon the maintenance of the functions outlined in the preceding chapter. These functions, therefore, can serve as the basis for the assessment of public interest in terms of balancing use and ecosystem health.

The application of the functional framework to regulatory decisions can occur on several levels and at all stages of the regulatory process. The list of functions helps focus assessments on the driving processes that define ecosystem character. This flexibility allows for the functional framework to be used to define objectives, identify information needs, screen alternatives, and determine impacts and needed mitigation. In some cases, this application must occur on a case-by-case basis, because universally applicable impact assessments are currently unattainable. However, the framework can also be used as the basis for the detailed assessments necessary to establish general permits and regional or resource-specific permit conditions.

A tiered approach to the application of the functional framework is recommended so that no more information gathering or study effort is expended than is necessary to make factual determinations. This allows optimal use of resources by focusing the least effort on applications where the potential (or lack thereof) for unacceptable adverse impact is clear, and expending the most effort on those applications requiring more extensive investigation to determine the impacts. It is necessary to proceed through the assessment only until information sufficient to make factual determinations has been obtained.

Pre-Application Consultation

Pre-application consultation usually involves one or more meetings between an applicant, Corps District staff, interested resource agencies (Federal, state, or local), NGOs, and sometimes the interested public. The basic purpose of such meetings is to provide for informal discussions about the pros and cons of a proposal before an applicant makes irreversible commitments of resources (funds, detailed designs, etc.). The process is designed to provide the applicant with an assessment of the viability of some of the more obvious alternatives available to accomplish the project purpose, to discuss measures for reducing the impacts of the project, and to inform him of the factors the Corps must consider in its decision-making process.

In the pre-application phase, the functional framework can help focus the discussion with the applicant and agencies in terms of project purpose, and affords an opportunity to express to the applicant that the project will be assessed in terms of the potential impacts to the 15 functions listed in Table 1. In some situations, it may be possible to request specific information from the sponsor that would assist in the assessments. District and division engineers are not authorized to develop additional information forms as part of the application process for Section 404 permits, but may request specific information on a case-by-case basis as allowed in Section 325.1(e) of 33 CFR Part 325. The applicant can be required to furnish additional information deemed essential in making a public interest determination or a determination of compliance with the section 404(b)(1) guidelines. This may include environmental data and information, such as the impact of the proposed activities on the functions listed in Tables 2 – 6.

Viewing a proposed project in the context of its effect upon the functions can help streamline the focus of identification of project impacts. Most project proposals fall into a pattern with one or two potential functional impacts, and not all impacts present problems. In situations where impacts are recognized, appropriate alternatives can often be rapidly identified (see Example 2), and the project design revised to avoid impacts prior to submission of a permit application.

Example 2. Identification of Practicable Alternatives During Pre-Application.

Seven years following a floodplain clearcut on both sides of the channel, a stream began to experience massive erosion of its banks. Lateral migration of the channel of up to and exceeding 60 feet per year was occurring in locations. A preliminary design to restore the channel and stabilize the banks was prepared. The preliminary design included realigning the channel to it's former (pre-clearcut) position and dimensions, and employed a number of in-channel and streambank stabilization devices.

Because the project was located on a stream with a spawning population of bull trout and it was uncertain if the proposed alternative would have significant impacts, a pre-application meeting was held., Potentially significant impacts identified during the meeting included those associated with the construction activities to relocate the channel and the possibility of the instream structures serving as a migration barrier. But discussions during the meeting revealed that an alternative consisting of stabilization of the most actively eroding banks and restoration of the riparian corridor would meet the project objectives and could be verified under NWP 27, provided certain conditions regarding construction were met. This alternative approach was adopted, the permit verified, and the project was successfully implemented.

Application Screening

Regulatory personnel should review all incoming applications to determine the need for a permit and to assess eligibility under regional General Permits (GPs) or Nationwide Permits (NWPs), or for authorization as a Letter of Permission (LOP). Criteria for these decisions are generally clear, and include (1) legally-defined activities that are exempt or require no permit, (2) activities occurring before certain dates or involving routing maintenance, and (3) classes of activities defined according to type, scope (e.g. material quantities or size), or location (see, for example, 33 CFR 323.4; 33 CFR 330.3; Section 404 (d) 1).

However, eligibility under these authorizations is generally provisional upon the degree of impacts (i.e. "minor" both cumulatively and locally), and is subject to other laws and regulations. In the screening phase, applications should be reviewed to ensure that they meet provisions related to, for example, threatened and endangered species, water quality, historic properties, and areas of special interest (33 CFR 330.4). Though not obliged to do so, it is also recommended that regulatory personnel inform applicants of other Federal, state, and local permits, approvals, or authorizations that may be required. The location of the activity can often serve as a "red flag" to help identify these needs or exclusions (see Table 9).

Table 9. Institutional Red Flags (from Ainslie et. al. 1999)

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	H
Areas protected by a Coastal Zone Management Plan	D
Areas providing Critical Habitat for Species of Special Concern	I
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	F
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	D
National wildlife refuges and special management areas	I
Areas identified in the North American Waterfowl Management Plan	I
Areas identified as significant under the RAMSAR Treaty	
Areas supporting rare or unique plant communities	
Areas designated as Sole Source Groundwater Aquifers	I
Areas protected by the Safe Drinking Water Act	
City, County, State, and National Parks	F, C, L
Areas supporting threatened or endangered species	B, C, E, G, I
Areas with unique geological features	
Areas protected by the Wild and Scenic Rivers Act	
Areas protected by the Wilderness Act	

Program Authority / Agency [1]
A = Bureau of Indian Affairs
B = National Marine Fisheries Service (NMFS)
C = U.S. Fish and Wildlife Service
D = National Park Service (NPS)
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Officer (SHPO)
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Administration
K = National Resource Conservation Service
L = Local Government Agencies

The provision of most GPs and LOPs that requires the local and cumulative impacts to be "minor" is typically addressed in the formulation of the criteria and guidance for GPs and LOPs. It is also implicitly reflected in the terms and conditions for those authorizations. However, stream systems respond to certain activities in different ways, and actions that generate only minor impacts on most systems may create significant impacts on some streams. This may be due to the high degree of sensitivity inherent to some types of streams, or because a physical or ecological threshold is exceeded. Thus, applications that otherwise meet the requirements for a GP or LOP should, nevertheless, undergo at least a qualitative screening to ensure that impacts to the key functions are "minor." Appendix B discusses potential impacts associated with some of the nationwide permits that could be used for stream restoration activities.

"Red flags" can also be associated with the certain types of activities that are known to impart adverse impacts to the functions listed in Tables 2 - 6. Table 10 lists specific actions that may be associated with stream or riparian restoration activities and the likely response of the system. Table 11 provides a summary of the nature of impacts to functions from several general categories of stream modification activities. Impacts in the table are listed as minor, indirect, and direct. Minor impacts that could be significant, depending on the nature of the project and the site conditions, are noted. Screening activities should focus upon the potential direct impacts listed in the table. Appendix C presents a discussion of these impacts with guidance for their identification and suggestions for mitigation measures.

Complete applications that pass this initial screening and that otherwise meet the requirements for a GP or LOP should be processed under those authorities. Permits can sometimes be issued or verified for activities that may have adverse impacts to one or more functions but that, with the addition of special conditions, those impacts are avoided or suitably minimized. Unresolved potential impacts identified in the screening process should be subjected to further assessment – generally during the permit review stage.

Example 3. Screening of Impacts

Following a major flood event, a channel avulsion occurred on a stream and initiated significant bank erosion that was threatening adjacent homes. Following a detailed investigation, it was determined that the cause of the instability related to the magnitude of the flood event, the site conditions at the time of the flood, and the proximity to the confluence of another large stream with a high sediment load. The instability was deemed localized, not systemic, so a plan was developed to restore the channel to its pre-flood position and condition, with a few minor modifications to prevent the recurrence of the channel avulsion.

The design required, among other activities, reconstructing the former channel (now largely filled with sediment) and the filling of the existing channel to the former floodplain elevation. Both the new channel and the floodplain fill were to be stabilized and several habitat features including vanes and weirs were included in the design. The initial review of the project raised several red flags. The vanes and weirs had been modeled to assess the impacts upon water surface elevations and did not pose a threat to migration or sediment movement. The bank stabilization measures were deemed appropriate as the magnitude of the ongoing erosion exceeded downstream sediment transport capacity and sediment deposits were adversely impacting the reach. However, the design necessitated construction "in the wet," and an existing minimum flow requirement ensured some release of sediments during construction. The resultant sediment concentration was assessed and deemed acceptable, and the permit was granted with conditions regarding the construction sequencing (the order of construction activities was specified to minimize adverse impacts and risks).

Table 10. Activity-Specific Red Flags

Red Flag Activities	***System Response[1]***	***Directly Impacted Functions***
Channel Relocation	Relocating a channel involves significant excavation within the floodplain with concurrent direct impacts to the floodplain and existing channel. The character of the relocated channel relative to the up- and downstream reaches will determine the impacts on the hydraulic and sediment transport character of the system.	Stream Evolution Riparian Succession Aquatic and Riparian Habitats Landscape Pathways
Increasing Channel Sinuosity	Increasing sinuosity reduces the channel slope, which in turn reduces hydraulic conveyance and sediment transport capacity. This can result in increased incidence of flooding, sediment deposition, and general channel instability.	Energy Management Sediment Continuity Riparian Habitat Landscape Pathways
Removal of Sediment Bars	Removing sediments deposited on bars in an effort to improve conveyance generally offers only short-term benefits (sediments will redeposit in these locations). In addition to the direct impacts to the substrate, bar removal can initiate channel degradation through locally increased velocities and reduced sediment yield downstream.	Stream Evolution Energy Management Sediment Continuity Substrates and Structure Aquatic Habitat
Addition of Vanes and Weirs	Vanes, weirs, and other aquatic habitat structures create form drag and raise upstream water surface elevations. They also modify the local flow field, often leading to significant (though generally localized) scour and deposition of sediments. They can prevent bed adjustments, potentially leading to increased bank erosion. Depending on the structure characteristics, they may create migration barriers.	Stream Evolution Energy Management Substrates and Structure Aquatic Habitat Landscape Pathways
Altering the Channel Cross-Section	Significant alterations to channel dimensions (e.g. decreasing the width of a braided stream) directly affect the hydraulic geometry and sediment transport characteristics of the channel, as well as the bed sediment characteristics. These impacts often extend well up- and downstream.	Energy Management Sediment Continuity Substrates and Structure Aquatic and Riparian Habitat
Bank Stabilization[2]	The stabilization of streambanks, regardless of the materials or methods used, reduces the potential for the stream to evolve through planform adjustment. It also reduces sediment yield to the system, though this is seldom significant as the stream is usually able to compensate through other sources. Local scour, bed armoring, and reduced riparian succession are common impacts.	Stream Evolution Riparian Succession Aquatic and Riparian Habitat Landscape Pathways
Temporal Considerations	Any restoration activity has the potential to generate adverse impacts if conducted at the wrong time of year. Consideration should be given to the implementation schedule relative to spawning and nesting, migrations, floods and droughts.	Any Listed Function

1 Listed response is general. Specific response and degree of response will vary with project and site characteristics.
2 See Fischenich (2001, 2002) for more specific details

Table 11. Examples of Potential Impacts Upon Functions from Select Activities

Activity	***Stream evolution***	***Energy management***	***Riparian succession***	***Surface water storage***	***Surface / subsurface water connections***	***Hydrodynamic balance***	***Sediment continuity***	***Substrates and structural processes***	***Quality and quantity of sediments***	***Bbiological communities and processes***	***Aquatic and riparian habitats***	***Trophic structure and processes***	***Water and soil quality***	***Chemical processes and nutrient cycles***	***Landscape pathways***
Channel Shortening	I	D	I	M	M[1]	I	D	I	I	I	D	I	M	M	D
Channel Lengthening	I	D	I	M	M[1]	I	D	I	I	I	D	I	M	M	D
Channel Enlargement	I	D	I	M[1]	M[1]	D	D	I	I	I	D	I	M	M	M[1]
Channel Constriction	I	D	I	M[1]	M[1]	M[1]	D	I	I	I	D	I	M	M	M[1]
Instream Sand/Gravel Mining	I	I	M	M	M	M	D	D	D	I	I	M	M	M	M
Clearing and Snagging	I	D	M	M	M	M	I	I	M	I	D	I	M	D	M
Levee Construction	I	D	D	M	M	D	I	I	I	I	D	M	M	I	D
Dam Construction	D	D	I	D	I	D	D	I	D	I	D	I	I	I	D
Diversions	I	D	I	D	I	D	I	I	I	I	I	M[1]	M[1]	M[1]	D
Stabilization[2]															
Armoring Techniques	D	M	I	M	M	M	M	M	M[1]	I	D	M	M	M	M[1]
Flow Deflection	D	M[1]	M[1]	M	M	M	M	M[1]	M	I	D	M	M	M	M
Grade Control	D	D	I	M[1]	M[1]	M[1]	M[1]	M[1]	M[1]	I	D	M[1]	M	M	D

Key:
D – Potential Direct Impacts
I – Potential Indirect Impacts (may be minor)
M – Minor or No Impacts

Notes:
1 – Impacts may be significant, depending upon site and project character
2 – See Fischenich (2001, 2002) for more specific details

Permit Assessments

Most applications will undergo an assessment, either as an extension of the screening process to confirm that impacts are minor, or more formally following the process for reviewing individual permits. During the permit assessment stage, the framework can serve as a basis to quantify and analyze impacts for various levels of assessment. Both quantification and analysis are necessary to determine if impacts are detrimental and to define alternatives or mitigation requirements, if needed.

In general, impacts to the functions listed in Tables 2 – 6 are determined through the quantification of one or more of the measures listed in the tables. The screening process outlined in the preceding section should help to limit the number of functions for which quantification of impacts is necessary. Procedures have been standardized for determining many of these measures, and the references listed in Appendix D provide guidance for their application. Thus, the quantification of the local impacts to a single function should not present an insurmountable challenge.

The determination of cumulative impacts (from several actions or from impacts to several functions) and the assessment of the relevance of the local and cumulative impacts is much more difficult. The former requires a means of aggregating impacts and the latter requires the interpretation of impacts relative to some ecosystem standard. Guidance is limited in both cases, but the application of the functional framework can assist for each.

The concept of cumulative impacts is easy to grasp for some situations. For example, the addition to a stream of several point source discharges of a pollutant could constitute a cumulative impact if the resultant concentration of the pollutant exceeded an established standard based upon the assimilative capacity of the stream, even if the individual discharges are minor in nature. Determining cumulative impacts for most actions associated with stream restoration is much more difficult because the cumulative impacts often involve secondary and tertiary pathways that are not fully understood, or involve several "types" of impacts that are measured differently.

For impacts to be cumulative, they must be both measurable and additive. This suggests that some common basis for measuring impact is required so that impacts can be meaningfully summed. Because of the interrelations among the functions listed in Table 1, it is often possible to establish a common basis of measure that can serve to define cumulative impacts, even those involving very different types of actions or impacts (see Example 4).

Analyzing the impacts requires an assessment of their importance with respect to the ecological condition of the stream. Not all impacts should be regarded as negative, and a change in a particular function may be necessary to bring the system into its proper ecological condition. Thus, an impact should be regarded as ecologically adverse only when the direction of change is away from the system's functional condition. Both absolute and relative assessments of impact are helpful when making permit decisions.

Example 4. Cumulative Impacts

A river system of intermediate size has been altered over many years to reduce flooding impacts. The alterations include the construction of levees and, where and when necessary, stabilization measures to protect those levees from erosion. These actions, along with numerous other stressors including dam construction, mining, etc., have adversely impacted the aquatic environment and have led to the decline of habitat for four listed species. Approximately 40 percent of the banks are stabilized and, although mitigation measures (including retroactive mitigation) have been required for the past decade, a programmatic assessment of the stabilization efforts is needed to guide future efforts.

Because the impacts are widespread, affect numerous functions, emanate from varied sources, and affect several life stages of several species, a means of reducing these impacts to a common metric was needed to assess cumulative impacts. It was determined that the impacts would be estimated in terms of "fish production" (measured as change in abundance × size) over specified time periods. An assessment methodology was established by scientific committee that included the modeling of impacts to each relevant function from various stabilization and management strategies, and conversion of these into the impact upon fish production. Six of the 15 functions identified in this report were explicitly included, two others were combined, and the remaining seven were either regarded as not significant or implicitly addressed.

The application of the assessment methodology will permit the identification of impact thresholds, help target the most significant impacts, and allow the quantification of necessary mitigation.

When assessing the implications of an impact, it is often helpful to relate impacts to thresholds. A threshold relates to an increasing or decreasing stimulus that provokes a specific response within a system. The idea of thresholds appears frequently in the literature and covers a wide range of fields from geomorphological processes to biological life requisites. Thresholds may also be socially derived. For example, actions that individually or cumulatively raise the water surface elevation of the stream in a flood hazard zone beyond an established standard (e.g. more than one foot for a 1 percent annual chance flood, per FEMA) may be prohibited.

A number of physical and biological thresholds have been identified for stream and riparian ecosystems, and could serve as a basis for assessing the implications of certain types of impacts. The links between thresholds and processes within stream systems is important especially with regards to erosion, transport and deposition. All of these have thresholds to which they will activate, and can be used to predict channel change. Examples of relevant thresholds for impact analysis include:

- Upper lethal limits for water quality parameters for specific species,
- Minimum viable population numbers to prevent extinctions,
- Maximum embeddedness values to permit successful spawning,
- Minimum flows (or flow conditions) needed to support aquatic life,
- Burst speed or jumping limits for passage of specific species at barriers,
- Discharge/slope relations that separate meandering and braided channel form,
- Minimum shear stress necessary to sustain sediment transport,
- Maximum shear stress to prevent scour or bank erosion,
- Maximum resistance characteristics to maintain conveyance,
- Minimum snag densities in riparian zones to support cavity dwellers, and
- Minimum riparian corridor dimensions to support specific communities,

In some situations, the absolute impacts are difficult to identify or irrelevant and, in these cases, it is often valuable to assess the relative impacts. This can be accomplished by contrasting potential functional impacts relative to (1) existing conditions, (2) future without project conditions, (3) conditions on a reference system, or (4) among alternatives, depending upon the circumstances. The first three are useful in determining if the proposed project is restorative or degradational, and can help to define specific impacts that should be mitigated through the inclusion of permit conditions. Relative comparisons of impacts among alternatives can be used to identify the least damaging alternative.

Any project for which an Environmental Assessment (EA) or Environmental Impact Statement (EIS) will be prepared should incorporate an evaluation of the impacts upon the functions listed in Table 1, following the procedures outlined in this and previous sections. The preparation of an EIS or EA is governed by regulations implementing the National Environmental Policy Act (NEPA). The application of the functional framework to determine impacts is consistent with the NEPA guidelines, though several additional factors must be considered in the decision process.

Permit Decisions and Conditions

At the end of the formal review process, the project manager must draft the appropriate documentation to support a recommended permit decision. The decision document includes a discussion of the environmental impacts of the project, the findings of the public interest review process, and any special conditions deemed appropriate for the authorized activity. Discussion of the environmental impacts can follow directly from the assessment presented in the preceding section.

The consideration of the public interest is of great importance in the decision making process and, while the argument has been made in this document that restoring and sustaining the functional characteristics of the ecosystem is intrinsic to public interest, there are other factors that must be considered. The public benefits and detriments of all relevant factors must be reviewed and weighed. Relevant factors may include economics, aesthetics, cultural values, values related to other uses, and any other issue judged important to the needs and welfare of the general public. Earlier sections of this document identified links between each of these and the functional framework.

In the absence of overriding national factors of the public interest, a permit will generally be issued following receipt of a favorable state determination provided the concerns, policies, goals, and requirements as expressed in 33 CFR Parts 320-324, and the applicable statutes have been considered and followed: e.g., the National Environmental Policy Act; the Fish and Wildlife Coordination Act; the Historical and Archeological Preservation Act; the National Historic Preservation Act; the Endangered Species Act; the Coastal Zone Management Act; the Marine Protection, Research and Sanctuaries Act of 1972, as amended; the Clean Water Act, the Archeological Resources Act, and the American Indian Religious Freedom Act.

A statement of findings (SOF) or a record of decision (ROD) is prepared, in which the probable effect of the proposed work on the public interest and conformity with the guidelines is presented. If a permit is warranted, any special conditions that should be incorporated into the permit are identified and specified. The functional framework and the analyses discussed in the permit assessment section of this document should serve as the basis for the specification of certain special conditions. These include actions aimed at avoiding or minimizing functional impacts, and the identification of necessary mitigation measures necessary to compensate for unavoidable impacts.

Functions could also be used to establish a lucid and cohesive programmatic basis for mitigation, especially where large projects or mitigation banking are involved. New mitigation sites could be identified on the basis of potential performance in the watershed system, and available sites could be assigned more realistic, performance-appropriate roles. Project sites could be designed and implemented around a set of formal components characterized by a foundation that encourages ecological process.

Development of General Permits

The Corps is authorized to issue general permits (GPs) on a nationwide or regional basis for categories of activities that have minimal individual and cumulative impacts. Programmatic permits may also be issued (by the Chief of Engineers, as well as District and Division Engineers) to other Federal, state or local agencies with the intention of providing appropriate environmental protection while avoiding unnecessary duplication of effort with the agency regulatory activities at issue. General permits allow certain activities to occur without individual Federal permit approval, provided the activity complies with standard conditions issued by the Corps. They eliminate individual review and thus allow certain activities to occur with little, if any, delay or paperwork.

General permits normally cover activities the Corps has identified as being substantially similar in nature and causing only minimal individual and cumulative environmental impacts. Thus, GPs not only streamline the regulatory process, they also provide environmental protection because applicants are "guided" toward the use of measures that reduce a project's environmental impacts to meet the minimal impact levels required of a general permit. This dual benefit makes the development and use of GPs very attractive.

General Permit development employs a process that closely parallels that for individual permits, with public notice, opportunity for hearing and detailed decision documentation. A functional framework can be used to craft GPs and permit conditions that effectively address the impacts, with a pragmatic basis in science and accepted trade practices. In developing GPs, the functional framework should be used to (1) define the need in ecological terms, (2) screen alternatives to identify the most practicable alternative, (3) screen types of systems to determine if exclusions should apply (e.g. excluding certain categories of streams), (4) quantify specific impacts from the covered activity, and (5) develop needed conditions to ensure that the impacts are minimal and that the activity complies with other statutes and regulations.

The use of the functional framework to develop and implement GPs may ultimately prove to be the most significant, as it concurrently improves decision making while reducing the regulatory burden. A number of regional- or resource-specific general permits could evolve from the quantitative application of the functional framework. In addition, the framework can be applied to assess existing GPs. General permits are issued for five-year periods and are reviewed upon expiration. Once issued, a general permit may be modified or revoked if the permitted activities are found to have had adverse environmental impacts. On a case-by-case basis, the permitting agency may invoke discretionary authority and require an application otherwise covered by a general permit to be processed as an individual permit.

Example 5. General Permit Development

Resource agencies expressed concerns over the potential local and cumulative impacts associated with bank stabilization activities on a large, braided river. The river was classified as a type D5, according to the Rosgen classification system, and was characterized by broad and unvegetated sandbars in the channel, wide and shallow flows, adjacent wet meadows, and very actively eroding banks. The bank erosion was of concern to adjacent landowners, who submitted numerous applications for permits to stabilize the banks. The nature of the erosion was such that it was seldom possible to address under a NWP, and the District was seeking to develop a GP for the system provided one could be established that minimized impacts.

The river system provided critical habitat for three listed species; two used the sand bars for nesting and the third required the adjacent wet meadows for feeding during migration. The river's erosion and sediment transport processes and hydrodynamic character sustained these features. Thus, these functions became the central focus of the analyses to develop a GP – activities that promoted vegetation development, channel narrowing, incision, or a lowering of the water surface during low flows would be excluded.

An assessment of the local impacts from a variety of stabilization measures was conducted through two-dimensional sediment and hydrodynamic numeric modeling. Results of these assessments were aggregated for the entire system using one-dimensional models. The impact threshold was established as a change in water surface elevation, mean channel bed elevation, or sediment load that exceeded measurement error. It was determined that, for armoring techniques, sediment supply from tributaries was sufficient to offset the armoring of 60 percent of the banks. For flow deflection measures, local and cumulative impacts occurred when the structure length exceeded 15 percent of the channel width, or occupied 10 percent of the flow area. Based upon these criteria, a GP was formulated for stabilization activities on the system.

Enforcement Actions

When the District Engineer becomes aware of any unauthorized activity still in progress, he must first issue a cease and desist order and then begin an investigation of the activity to ascertain facts concerning alleged violations. If the unauthorized activity has been completed he must advise the responsible party of his discovery and begin an investigation. The District Engineer's evaluation contains an initial determination of whether any significant adverse impacts are occurring that would require expeditious corrective measures to protect life, property, or a significant public resource. At this stage a qualitative assessment of functional impacts should be conducted, as discussed in the preceding sections.

If the District Engineer determines as a result of this investigation that one or more functions are adversely impacted, corrective measures could be then formulated on the basis of the specific functional impacts, he should issue an appropriate order to the parties responsible for the violation. Following the completion of any required corrective measures, the District Engineer could normally accept an after-the-fact permit application unless certain exceptions are applicable. Applications for after-the-fact permits should be processed in accordance with the applicable procedures in 33 CFR Parts 320-325, and following the guidelines outlined above.

It is expected that monitoring, compliance, and enforceability may be improved through application of the framework because functions can be assessed, specifically aggregated and measured. Screening during enforcement could be accomplished by assessing the presence or absence of the indicators listed in Tables 2 – 6. The quantification of potential impacts from unauthorized activities would follow the procedures identified in the preceding sections. Based upon the nature and degree of the impact, appropriate mitigation measures can be identified. Because the impacts will be specified in terms of quantifiable impacts to key functions, monitoring could be tangible in target, with subsequent compliance and enforceability more objective.

Relationship of Functional Framework to HGM Approaches

During the development of the functional framework presented in this report, questions arose as to its relationship to the Hydrogeomorphic (HGM) Approach. Both the functional framework and HGM rely upon the premise that an ecosystem's health and quality are a function of certain processes and characteristics. But the application of the two concepts differs in several respects.

HGM is a collection of concepts and methods that are used to develop and apply functional indices to the assessment of wetlands. The approach was initially designed for use in the Clean Water Act Section 404 Regulatory Program, including permit review to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. In this regard, HGM is very similar to the functional framework outlined in this document.

However, the application of HGM includes four integral components that are not required for the framework: 1) HGM classification of wetland types, 2) identification of and data collection from reference wetlands, 3) formulation of assessment models and indices, and 4) development of application protocols. The four components of the HGM Approach are integrated into Regional, Subclass-specific Guidebooks. Users then employ the Regional Guidebook during the Application Phase to conduct HGM functional assessments on project wetlands.

An example is the "Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky," (Ainslie, et. al. 1999). This document presents a procedure to assess eight functions determined to be of import to low gradient, riverine wetlands in western Kentucky. Some of these wetland functions are similar to those listed in this report (e.g. surface water storage, nutrient cycling, provision of habitat), while others are not particularly relevant to streams (e.g. retain particulates, remove and sequester elements and compounds).

As with other HGM applications, the functions in the Regional Guidebook are quantified by an index (Functional Capacity Index) that ranges from 0.0 - 1.0, based upon comparisons of conditions between the project and reference wetlands. The index is derived from specific algebraic computations involving 27 variables for which field data must be collected, then an index value established based upon conditions in the reference wetlands. The level of performance of the functions in the project wetland are, thus, characterized as an index relative to reference systems

Assessment needs for streams differ from those for wetlands in several respects, and these differences are reflected in the functional framework presented in this report. For example, the processes and characteristics (i.e. functions) of wetlands are somewhat different than those for streams. This is largely due to the significant differences in the energy environment for the two systems. While the functions listed in this report are appropriate for nearly all streams, they are not all relevant to wetland systems. The same can be said for the functions usually attributed to wetlands; while some are important to stream systems, many are not.

Whereas the HGM relies on the use of reference systems as a comparison standard, the functional framework presented in this report does not. Although reference systems *can* be used with the framework, they are not necessary. This flexibility is an intentional and necessary feature of the framework. Suitable references for stream systems are often not available, and the selection of inappropriate references is both common and catastrophic (see Example 1). With the framework, users may employ pre-impact conditions in the project reach as a reference, they can use adjacent reached of the project stream or other nearby and similar systems, or they can elect not to use a reference for comparison at all, depending on the needs and circumstances.

The HGM approach used indices to represent functional performance. While the framework can accommodate a similar strategy, it is also possible to directly measure or assess functional performance with the measures identified in Tables 2 – 6. Because indices are often difficult to translate into meaningful “real world” numbers, the capability to directly quantify impacts is a powerful added capability, particularly for determining mitigation needs and assessing impact thresholds.

In order to apply the HGM approach, significant data must be gathered by an assessment team for both the project site and for appropriate reference sites. For stream restoration projects, it is often sufficient to establish that the direction of change is toward restoration, which can generally be accomplished qualitatively and without the need for data collection and analyses. In situations where data and analyses are needed, the specific data requirements will vary by project, and it would be impossible to establish a common protocol without considerable (and often unnecessary) data collection. Because processes in streams occur across numerous scales (Table 12), data requirements also vary depending upon the scale of interest.

In general, the HGM approach is well suited to application for regional subclasses of wetland systems. The rigid procedures for the HGM help assure consistency in application and in results. In contrast, the functional framework for stream restoration is very flexible, allowing both qualitative and quantitative assessments for a variety of circumstances. The framework can be applied in virtually the same manner as the HGM, but offers the option of alternative applications, affording more flexibility in the analysis and comparison stages. Ultimately, the framework may benefit from the formulation of procedures for specific regions, stream types, or categories of activities. These could be cataloged into documents similar to the HGM Regional Guidebooks.

Table 12: A proposed hierarchy for the determination of the scale of measurement for geographic, geomorphic and biotic data collection and analysis within watershed systems based on Imhof et al. (1996).

System Level	*Linear spatial scale (m)*	*Aerial spatial scale (m^2)*	*Aerial and profile boundaries*	*Time scale of continuous potential persistence (years)*	*Time scale of persistence under human disturbance patterns (years)*	*Biotic Assemblage Scale*	*Life Activity and scale (variable time)*
Watershed	10^5	10^{10}	Drainage divides between tertiary watersheds	10^6-10^5	10^4-10^3	community species (migratory)	life cycle life cycle (<20 yrs.)
Subwatershed	10^4	10^8	Drainage boundaries of quaternary watersheds within tertiary drainage basins	10^4-10^3	10^2-10^1	community/ species	life cycle (1-8 yrs.)
Reach	10^4-10^1	10^5	Minimum of two full channel wavelengths, and defined by as a specific stream type based on the Rosgen (1994) classification. Active profile boundaries up to 1:20yr flow elevation, passive boundaries to 1:100yr flow elevation.	10^2-10^1	10^1-10^0	species	life cycle/ life stage (0.1-8 yrs.)
Site	10^1-10^0	10^2	Channel segment comprising either a riffle or pool, profile including bankside riparian vegetation up to bankfull elevation	10^0	10^0-10^{-1}	individual	life stage (0.1-0.4 yrs.)
Habitat element	10^0-10^{-1}	10^1	Zones of variable substrate types or characteristics, water velocity and depth within either a pool, step or riffle.	10^0-10^{-1}	10^{-1}-10^{-2}	individual	activity (10^{-3}-0.1 yrs.)

Summary

Quality stream ecosystems have healthy watersheds, good riparian corridors, active floodplains, suitable channel dimensions for the prevailing conditions, and an appropriate level of diversity and dynamics. Unfortunately, most of the streams in the United States do not benefit from all of these conditions. Anthropogenic activities have significantly degraded many stream and riparian systems.

Efforts to restore these degraded systems, while well intentioned, are often inappropriate or ineffective because they fail to address the underlying processes that create and maintain the elements listed above. Most conventional stream restoration projects are highly engineered efforts to stabilize streams while concurrently improving habitat for adult life stages of a few species – often to the detriment of native flora and fauna and to the sustainability of the system.

Regulatory oversight of restoration projects is intended to separate these ill-conceived projects from those that actually restore important ecosystem processes and characteristics, or that at least do no harm, and in so doing to ensure that the public interest is met. But the proper application of this oversight relies on the ability of the regulatory personnel to assess the ramifications of the proposed actions upon the system.

Most regulators understand intuitively that ecosystems consist of many linkages and, to fully comprehend the impacts of ecosystem alterations, we must understand these linkages. But they also recognize that existing technology limits such efforts, particularly for assessing systems at the watershed scale or to assess cumulative impacts. Should such technology exist, it is unlikely that it could be applied in the current regulatory climate given time, funding and data constraints. A framework that can be applied in a qualitative sense to screen for potential impacts and that could serve as a basis for more detailed quantitative study would provide regulators with a powerful tool.

This document identifies a suite of 15 functions that are critical to the sustenance of stream and riparian ecosystems. These functions are related to activities often encountered in the Section 404 Program, so as to establish a framework in which those activities may be evaluated. This framework can help regulators form a clear understanding of the cause/effect relationships that dictate system response to change, and can support decisions in every step of the regulatory process.

In the pre-application phase, the framework can help:

- Focus discussion with applicant and agencies in terms of project purpose
- Determine appropriate information requirements for a complete application
- Streamline the focus of identification of project impacts (most project proposals fall into a pattern with one or two potential functional impacts),

- Streamline identification of problems with proposed project impacts (i.e. not all impacts present problems)
- Identify more structurally appropriate solutions to problems

In the application screening phase, the functional framework could be used to more effectively determine candidacy for verification under a general permit by screening to ensure that impacts are "minor." During project evaluation under public interest review, the framework can be used to quantify and analyze impacts for various levels of assessment, completing requirements for public interest review.

Functions could be used to establish a lucid and cohesive programmatic basis for mitigation and restoration. New mitigation or restoration sites could be identified on the basis of potential performance in the watershed system; available sites could be assigned more realistic, performance-appropriate roles. Project sites could be designed and implemented around a set of formal components characterized by a foundation that encourages ecological process. Monitoring, compliance, enforceability may be improved through application of the framework because functions can be specifically aggregated and measured, with objective measures to support compliance and enforceability.

Finally, the framework can be used to craft general permits and permit conditions that effectively address the impacts, with pragmatic basis in science and accepted trade practices. This use may ultimately prove to be the most significant, as it concurrently improves decision making while reducing the regulatory burden. It is likely that a number of regional- or resource-specific general permits or permit conditions could evolve from the quantitative application of the functional framework.

In most cases, restoration projects are undertaken on stream and riparian systems that are degraded. Thus, the aim of any successful restoration project *must* be to impact the system. But the "impacts" should be favorable with respect to the ecosystem processes and character as opposed to adverse impacts. This document identifies the response of stream and riparian ecosystems to a number of activities associated with "restoration" projects, and discusses means of assessing these responses to determine if the impacts should be regarded as adverse or beneficial.

Watersheds and their ecosystems sustain our way of life, regardless of our understanding of the biology, chemistry, and geology involved. However, when decision makers do not understand ecosystem functions, they may make choices that result in long term and possibly irreversible damages that reduce the value of the ecosystem. A familiarity with the functions of an ecosystem can improve decision making today and protect values that may be held by future generations.

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Appendix A - Section 404 Program

Overview

The Clean Water Act (CWA) was enacted by Congress to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The CWA created three permit programs - Section 401 as a certification mechanism, and Section 402 and Section 404 to regulate the point-source discharge of pollutants into waters of the U.S. States may assume (and most of them have) the program administered by EPA under Section 401 and must grant, deny, or waive certification for activities permitted or conducted by USACE based on the potential impacts to water quality which may result from a discharge of dredged or fill material to waters of the U.S. The EPA administers Section 402, which established the National Pollutant Discharge Elimination System (NPDES) Program to regulate discharges of chemicals, heavy metals, and biological wastes, primarily in wastewater from industrial processes, publicly owned sewage treatment works, and stormwater discharges. The EPA and USACE each administer specific aspects of Section 404, which established a permit program and technical guidelines to regulate discharges of dredged or fill material. The USACE also administers a regulatory program under Section 10 of the Rivers and Harbors Act of 1899 (RHA), which regulates dredging and other construction activities in navigable waters.

Activities in waters of the United States that are regulated under Section 404 of the CWA include fills for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and conversion of wetlands to uplands for farming and forestry. The basic premise of the program is that no discharge of dredged or fill material can be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. In other words, permit applicants must

- take steps to avoid wetland impacts where practicable
- minimize potential impacts to wetlands
- provide compensation for any remaining, unavoidable impacts through activities to restore or create wetlands.

Regulated activities are controlled through a tiered permit review process. An individual permit may be required, but for certain activities determined to have only minimal adverse effects, the Army Corps of Engineers may grant or verify nationwide, regional, or state general permits, or letters of permission as a means to expedite the permitting process. Section 404(f) exempts some activities from regulation. These activities include many ongoing farming, ranching, and silvicultural practices.

The USACE has the primary responsibility for the Section 404 regulatory permit program and is authorized, after notice and opportunity for public comment, to issue permits specifying sites for the discharge of dredged or fill material. EPA has the primary role in developing the environmental guidelines, in conjunction with USACE [the Section 404(b)(1) Guidelines (Guidelines)], by which permit applications must be evaluated. EPA is also responsible for commenting on proposed USACE permits, prohibiting discharges with unacceptable adverse aquatic environmental impacts, approving and overseeing State assumption of the program, establishing jurisdiction, and interpreting exemptions. Both USACE and EPA share enforcement authority.

The USACE's evaluation of a Section 404 permit application involves determining whether the proposed project complies with the Guidelines (40 CFR 230) and USACE permit regulations (33 CFR 320-330), which require a "public interest" review of the project. [Public interest factors (listed in 33 CFR 320.4) include water quality, water supply and conservation, safety, and fish and wildlife impacts]. A permit is issued provided the proposed project complies with the Guidelines and is not contrary to the public interest. The USACE issues individual permits and general permits. Individual permits are issued on a project-by-project basis after the Guidelines compliance and public interest determinations are made for the specific project at issue. General permits, on the other hand, are issued for classes of activities after the USACE conducts the Guidelines compliance and public interest reviews and determines that issuance of the general permit will not result in more than minimal adverse impacts to the aquatic environment from either a site-specific or cumulative standpoint.

The Section 404(b)(1) Guidelines

The Guidelines provide the substantive environmental criteria used in evaluating proposed discharges of dredged or fill material into waters of the United States. Fundamental to these Guidelines is the precept that dredged or fill material should not be discharged into the aquatic ecosystem, unless it can be demonstrated that such a discharge will not have an unacceptable adverse impact either individually or in combination with known and/or probable impacts of other activities affecting the ecosystems of concern.

For proposed discharges of dredged material to comply with the Guidelines, they must satisfy four requirements found in Section 230.10 as follows. Section 230.10(a) addresses those impacts associated with the loss of aquatic site functions and values of the proposed discharge site, by requiring that the discharge site represent the least environmentally damaging, practicable alternative. Section 230.10(b) requires compliance with established legal standards (e.g., issuance or waiver of a State water quality certification). Section 230.10(c) requires that discharge of dredged material not result in significant degradation of the aquatic ecosystem. Section 230.10(d) requires that all practicable means be utilized to minimize adverse environmental impacts.

Public Interest (33 CFR 320.4)

No permit is granted if the proposal is found to be contrary to the public interest. The public benefits and detriments of all factors relevant to each case are carefully evaluated and balanced by the Corps in the review process. The decision whether to authorize a proposal, and, if so, the conditions under which it will be allowed to occur, are therefore determined by the outcome of this general balancing process. That decision should reflect the national concern for both protection and utilization of important resources. Relevant factors may include conservation, economics, aesthetics, wetlands, cultural values, navigation, fish and wildlife values, water supply, water quality, and any other factors judged important to the needs and welfare of the people. The following general criteria are considered in evaluating all applications:

1. The relevant extent of public and private needs;
2. Where unresolved conflicts of resource use exist, the practicability of using reasonable alternative locations and methods to accomplish project purposes; and
3. The extent and permanence of the beneficial and/or detrimental effects the proposed project may have on public and private uses to which the area is suited.

The specific weight of each factor is determined by its importance and relevance to the particular proposal. Accordingly, how important a factor is and how much consideration it deserves will vary with each proposal. For activities involving 404 discharges, a permit will be denied if the discharge that would be authorized by such permit would not comply with the Environmental Protection Agency's 404(b)(1) guidelines. Subject to the preceding criterion and any other applicable guidelines, a permit will be granted unless the District Engineer determines that it would be contrary to the public interest.

Relationship to Section 401 CWA Water Quality Certification

Section 401 of the CWA requires that all Federal permits and licenses, including those for the discharge of dredged material into waters of the United States, authorized pursuant to Section 404 of the CWA, must be certified as complying with applicable State water quality standards (WQS). The Guidelines at 40 CFR 230.10(b) state, in part, that the discharge of dredged or fill material shall not be permitted if it causes or contributes, after consideration of disposal site dilution and dispersion, to violations of any applicable State water quality standard. This applies at the edge of a State-designated mixing zone.

The process for adoption of State WQS is prescribed at 40 CFR 131. States must issue, condition, deny, or waive a Water Quality Certification for activities permitted or conducted by USACE, certifying that no adverse water quality impacts will occur based on determinations of compliance with applicable State WQS that have been adopted in accordance with the above regulation. State water quality standards consist of designated beneficial uses, narrative and numeric criteria designed to support those uses, and anti-degradation provisions. This testing manual is intended to provide guidance for the dredged material testing necessary to determine compliance with such State WQS. States may, at their discretion, include in their State standards policies generally affecting their application and implementation, e.g. mixing zones (40 CFR 131.13).

Appendix B – Nationwide Permits

This Appendix presents an assessment of the potential impacts associated with existing Nationwide Permits (NWP), for instances where the impacts may exceed classification as "minor". NWPs for which potential impacts to one or more of the functions listed in Tables 2 – 6 might occur are listed, and recommendations for additional evaluations are provided. Recommendations are presented with italicized text.

7. Outfall Structures. Activities related to construction of outfall structures and associated intake structures where the effluent from the outfall is authorized, conditionally authorized, or specifically exempted, or are otherwise in compliance with regulations issued under the National Pollutant Discharge Elimination System program (Section 402 of the Clean Water Act), provided that the permittee notifies the District Engineer in accordance with the "Notification" general condition. (Also see 33 CFR 330.1(e)). Intake structures per se are not included--only those directly associated with an outfall structure.

(While the construction of the outfall structure itself may not pose a long-term impact upon the receiving water body, the discharge of effluent could substantively alter the hydrodynamic character of the system, resulting in a cascade of impacts. Activities considered for approval under NWP7 should be assessed for their impacts upon the system hydrology).

12. Utility Line Discharges. Discharges of dredged or fill material associated with excavation, backfill or bedding for utility lines, including outfall and intake structures, provided there is no change in preconstruction contours. A "utility line" is defined as any pipe or pipeline for the transportation of any gaseous, liquid, liquefiable, or slurry substance, for any purpose, and any cable, line, or wire for the transmission for any purpose of electrical energy, telephone and telegraph messages, and radio and television communication. The term "utility line" does not include activities which drain a water of the United States, such as drainage tile; however, it does apply to pipes conveying drainage from another area. This NWP authorizes mechanized landclearing necessary for the installation of utility lines, including overhead utility lines, provided the cleared area is kept to the minimum necessary and preconstruction contours are maintained.

(The installation of utility lines within the riparian zone can impact the landscape pathways function of the ecosystem by altering the corridor characteristics. This impact is usually associated with clearing of riparian vegetation and may not be addressable under Section 404/10, but should be addressed by state or local agencies with jurisdiction over floodplain alteration. Projects considered for NWP12 approval should be assessed for impacts to the migration or movement or aquatic and riparian organisms).

13. Bank Stabilization. Bank stabilization activities necessary for erosion prevention provided the activity meets all of the following criteria:

a. No material is placed in excess of the minimum needed for erosion protection;
b. The bank stabilization activity is less than 500 feet in length;
c. The activity will not exceed an average of one cubic yard per running foot placed along the bank below the plane of the ordinary high water mark or the high tide line;
d. No material is placed in any special aquatic site, including wetlands;
e. No material is of the type, or is placed in any location, or in any manner, so as to impair surface water flow into or out of any wetland area;
f. No material is placed in a manner that will be eroded by normal or expected high flows (properly anchored trees and treetops may be used in low energy areas); and,
g. The activity is part of a single and complete project.

Bank stabilization activities in excess of 500 feet in length or greater than an average of one cubic yard per running foot may be authorized if the permittee notifies the District Engineer in accordance with the "Notification" general condition and the District Engineer determines the activity complies with the other terms and conditions of the NWP and the adverse environmental effects are minimal both individually and cumulatively.

(Bank stabilization can impact all 15 functions, but most notably influences (1) Stream Evolution; (2) Riparian Succession; (3) Substrate and Structural Processes; (4) Habitat; and, (5) Landscape Pathways. Although NWP13 aims to minimize the magnitude of the impact by limiting the scale of authorized activities, the potential for cumulative impacts from multiple projects is significant. Activities considered for approval under NWP13 should be assessed for potential cumulative impacts to these functions on both a reach and a system basis).

14. Road Crossings. Fills for roads crossing waters of the United States (including wetlands and other special aquatic sites) provided the activity meets all of the following criteria:

a. The width of the fill is limited to the minimum necessary for the actual crossing;
b. The fill placed in waters of the United States is limited to a filled area of no more than 1/3 acre. Furthermore, no more than a total of 200 linear feet of the fill for the roadway can occur in special aquatic sites, including wetlands;
c. The crossing is culverted, bridged or otherwise designed to prevent the restriction of, and to withstand, expected high flows and tidal flows, and to prevent the restriction of low flows and the movement of aquatic organisms;
d. The crossing, including all attendant features, both temporary and permanent, is part of a single and complete project for crossing of a water of the United States; and,

e. For fills in special aquatic sites, including wetlands, the permittee notifies the District Engineer in accordance with the "Notification" general condition. The notification must also include a delineation of affected special aquatic sites, including wetlands.

This NWP may not be combined with NWP 18 or NWP 26 for the purpose of increasing the footprint of the road crossing. Some road fills may be eligible for an exemption from the need for a Section 404 permit altogether (see 33 CFR 323.4). Also, where local circumstances indicate the need, District Engineers will define the term "expected high flows" for the purpose of establishing applicability of this NWP.

(Scientists have increasingly recognized that a number of impacts to stream systems can be directly related to roads and stream crossings. These impacts are primarily associated with (1) Stream Evolution; (2) Energy Management; (3) Surface/Subsurface Water Exchange; (4) Sediment Continuity; (5) Quality and Quantity of Sediments; (6) Biological Communities and Processes; (Chemical Processes and Nutrient Cycles; and (7) Landscape Pathways. While condition (c) is sufficient to address many of the concerns associated with the potential impacts upon these functions, it must be properly interpreted and implemented. The Corps, in conjunction with the USFS, is developing new guidelines for stream crossings that should be applied when assessing activities proposed under NWP14. The new guidelines will be published under the EMRRP Technical Note Series and can be downloaded at: http://www.wes.army.mil/el/emrrp/tnotes.html).

18. Minor Discharges. Minor discharges of dredged or fill material into all waters of the United States provided that the activity meets all of the following criteria:

a. The quantity of discharged material and the volume of excavated area does not exceed 25 cubic yards below the plane of the ordinary high water mark or the high tide line;
b. The discharge, including any excavated area, will not cause the loss of more than 1/10 acre of a special aquatic site, including wetlands. For the purposes of this NWP, the acreage limitation includes the filled area and excavated area plus special aquatic sites that are adversely affected by flooding and special aquatic sites that are drained so that they would no longer be a water of the United States as a result of the project;
c. If the discharge, including any excavated area, exceeds 10 cubic yards below the plane of the ordinary high water mark or the high tide line or if the discharge is in a special aquatic site, including wetlands, the permittee notifies the District Engineer in accordance with the "Notification" general condition. For discharges in special aquatic sites, including wetlands, the notification must also include a delineation of affected special aquatic sites, including wetlands (Also see 33 CFR 330.1(e)); and
d. The discharge, including all attendant features, both temporary and permanent, is part of a single and complete project and is not placed for the purpose of a stream diversion.

e. This NWP cannot be used in conjunction with NWP 26 for any single and complete project.

(The conditions associated with NWP18 do not address the scale of system to which they apply. Most of the functions listed in Tables 2 – 6 could be impacted by fills of less than 25 cy on first- and second-order streams, depending on how the fills are placed in the system. The "pool and riffle" habitats associated with special aquatic sites would protect some of these streams, but would leave many open to potential adverse impact. A Level I screening of potential functional impacts is recommended for any action contemplated under NWP18).

21. Surface Coal Mining Activities. Activities associated with surface coal mining activities provided they are authorized by the Department of the Interior, Office of Surface Mining (OSM), or by states with approved programs under Title V of the Surface Mining Control and Reclamation Act of 1977 and provided the permittee notifies the District Engineer in accordance with the "Notification" general condition. The notification must include an OSM or state approved mitigation plan. The Corps, at the discretion of the District Engineer, may require a bond to ensure success of the mitigation, if no other Federal or state agency has required one. For discharges in special aquatic sites, including wetlands, the notification must also include a delineation of affected special aquatic sites, including wetlands. (Also see 33 CFR 330.1(e))

(All of the 15 functions listed in Tables 2 – 6 have the potential to be impacted by activities associated with surface coal mining. Although many of these activities do not fall under the jurisdiction of Section 404/10, the use of overburden as fill material within waters of the U.S. or other jurisdictional actions associated with NWP21 should be carefully assessed with respect to the potential for functional impacts).

27. Wetland and Riparian Restoration and Creation Activities. Activities in waters of the United States associated with the restoration of former non-tidal wetlands and riparian areas, the enhancement of degraded wetlands and riparian areas, and creation of wetlands and riparian areas; (i) on non-Federal public lands and private lands, in accordance with the terms and conditions of a binding wetland restoration or creation agreement between the landowner and the U.S. Fish and Wildlife Service or the Natural Resources Conservation Service (NRCS) or voluntary wetland restoration, enhancement, and creation actions documented by the NRCS pursuant to NRCS regulations; or (ii) on any Federal land; or (iii) on reclaimed surface coal mined lands, in accordance with a Surface Mining Control and Reclamation Act permit issued by the Office of Surface Mining or the applicable state agency. (The future reversion does not apply to wetlands created, restored or enhanced as mitigation for the mining impacts, nor Such activities include, but are not limited to: installation and maintenance of small water control structures, dikes, and berms; backfilling of existing drainage ditches; removal of existing drainage structures; construction of small nesting islands; plowing or discing for seed bed preparation; and other related activities. This NWP applies to restoration projects that serve the purpose of restoring "natural" wetland hydrology, vegetation, and function to altered and degraded non-tidal wetlands and "natural" functions of riparian areas. This NWP does not authorize the conversion of natural wetlands to another aquatic use, such as creation of waterfowl impoundments where a forested wetland previously existed.

Reversion. For restoration, enhancement and creation projects conducted under paragraphs (ii) and (iv), this NWP does not authorize any future discharge of dredged or fill material associated with the reversion of the area to its prior condition. In such cases a separate permit at that time would be required for any reversion. For restoration, enhancement and creation projects conducted under paragraghs (i) and (iii), this NWP also authorizes any future discharge of dredged or fill material associated with the reversion of the area to its documented prior condition and use (i.e., prior to the restoration, enhancement, or creation activities) within five years after expiration of a limited term wetland restoration or creation agreement or permit, even if the discharge occurs after this NWP expires. The five year reversion limit does not apply to agreements without time limits reached under paragraph (i). The prior condition will be documented in the original agreement or permit, and the determination of return to prior conditions will be made by the Federal agency or appropriate state agency executing the agreement or permit. Prior to any reversion activity, the permitee or the appropriate Federal or state agency must notify the District Engineer and include the documentation of the prior condition. Once an area has reverted back to its prior physical condition, it will be subject to whatever the Corps' regulatory requirements will be at that future date.

(NWP27 addresses an array of activities intended to restore natural hydrology, vegetation and functions. These activities have the potential to impact each of the functions listed in Tables 2 – 6. Because the NWP scope relies upon "intent," and the intent is assumed to be environmentally beneficial, activities under NWP27 may not receive adequate scrutiny.)

31. Maintenance of Existing Flood Control Facilities. Discharges of dredged or fill material for the maintenance of existing flood control facilities, including debris basins, retention/detention basins, and channels that were (I) previously authorized by the Corps by individual permit, general permit, or by 33 CFR 330.3 and constructed or (ii) constructed by the Corps and transferred to a local sponsor for operation and maintenance. The maintenance is limited to that approved in a maintenance baseline determination made by the district engineer (DE). The prospective permittee will provide the DE with sufficient evidence for the DE to determine the approved and constructed baseline. Subsequent to the determination of the maintenance baseline and prior to any maintenance work, the permittee must notify the DE in accordance with the "Notification" general condition.

All dredged material must be placed in an upland site or a currently authorized disposal site in waters of the United States, and proper siltation controls must be used. This NWP does not authorize the removal of sediment and associated vegetation from natural water courses. (Activities that involve only the cutting and removing of vegetation above the ground, e.g., mowing, rotary cutting, and chainsawing, where the activity neither substantially disturbs the root system nor involves mechanized pushing, dragging, or other similar activities that redeposit excavated soil material, does not require a Section 404 permit in accordance with 33 CFR 323.2(d)(2)(ii)). Only constructed channels within stretches of natural rivers that have been previously authorized as part of a flood control facility could be authorized for maintenance under this NWP.

In determining the maintenance baseline, the DE will consider the following factors: the approved facility, the actual constructed facility, the Corps constructed project that was transferred, the maintenance history, if the facility has been functioning at a reduced capacity and for how long, present vs. original flood control needs, and if sensitive/unique functions and values may be adversely affected. Revocation or modification of the final determination of the maintenance baseline can only be done in accordance with 33 CFR Part 330.5. This NWP cannot be used until the DE determines the maintenance baseline and the need for mitigation and any regional or activity-specific conditions. The maintenance baseline will only be determined once and will remain valid for any subsequent reissuance of this NWP. However, if the project is effectively abandonned or reduced to lack of proper maintenance, a new determination of a maintenance baseline would be required before this NWP could be used for a subsequent maintenance.

In determining the need for mitigation, the DE will consider the following factors: any original mitigation required, the current environmental setting, and any adverse effects of the maintenance project that were not mitigated in the original construction. The DE will not delay needed maintenance for completion of any required mitigation, provided that the DE and the applicant establish a schedule for the identification, approval, development, construction and completion of such required mitigation.

(All of the 15 functions listed in Tables 2 – 6 have the potential to be impacted by activities associated with NWP31. Although the need to protect life and property must be given deference in maintaining flood control channels, actions associated with NWP31 should be carefully assessed with respect to the potential for functional impacts so that appropriate mitigation can be identified).

41. Reshaping Existing Drainage Ditches. Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, to modify the cross-sectional configuration of currently serviceable drainage ditches constructed in waters of the US. The reshaping of the ditch cannot increase drainage capacity beyond the original design capacity. Nor can it expand the area drained by the ditch as originally designed (i.e., the capacity of the ditch must be the same as originally designed and it cannot drain additional wetlands or other waters of the US). Compensatory mitigation is not required because the work is designed to improve water quality (e.g., by regrading the drainage ditch with gentler slopes, which can reduce erosion, increase growth of vegetation, increase uptake of nutrients and other substances by vegetation, etc.).

The permittee must notify the District Engineer in accordance with General Condition 13 if greater than 500 linear feet of drainage ditch will be reshaped. Material resulting from excavation may not be permanently sidecast into waters but may be temporarily sidecast (up to three months) into waters of the US, provided the material is not placed in such a manner that it is dispersed by currents or other forces. The District Engineer may extend the period of temporary sidecasting not to exceed a total of 180 days, where appropriate. In general, this NWP does not apply to reshaping drainage ditches constructed in uplands, since these areas are generally not waters of the US, and thus no permit from the Corps is required, or to the maintenance of existing drainage ditches to their original dimensions and configuration, which does not require a Section 404 permit (see 33 CFR 323.4(a)(3)). This NWP does not authorize the relocation of drainage ditches constructed in waters of the US; the location of the centerline of the reshaped drainage ditch must be approximately the same as the location of the centerline of the original drainage ditch. This NWP does not authorize stream channelization or stream relocation projects.

(All of the 15 functions listed in Tables 2 – 6 have the potential to be impacted by activities associated with NWP41. The potential impacts associated with these activities are often overlooked because of the scale of the impact, but the cumulative nature of the impacts and the likelihood of maintaining numerous ditches within a watershed warrants a careful assessment of the impacts).

43. Stormwater Management Facilities. Discharges of dredged or fill material into non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters, for the construction and maintenance of stormwater management facilities, including activities for the excavation of stormwater ponds/facilities, detention basins, and retention basins; the installation and maintenance of water control structures, outfall structures and emergency spillways; and the maintenance dredging of existing stormwater management ponds/facilities and detention and retention basins, provided the activity meets all of the following criteria:

a. The discharge for the construction of new stormwater management facilities does not cause the loss of greater than «-acre of non-tidal waters of the US, excluding non-tidal wetlands adjacent to tidal waters;

b. The discharge does not cause the loss of greater than 300 linear-feet of a stream bed, unless for intermittent stream beds this criterion is waived in writing pursuant to a determination by the District Engineer, as specified below, that the project complies with all terms and conditions of this NWP and that any adverse impacts of the project on the aquatic environment are minimal, both individually and cumulatively;

c. For discharges causing the loss of greater than 300 linear feet of intermittent stream beds, the permittee notifies the District Engineer in accordance with the "Notification" General Condition 13. In such cases, to be authorized the District Engineer must determine that the activity complies with the other terms and conditions of the NWP, determine the adverse environmental effects are minimal both individually and cumulatively, and waive this limitation in writing before the permittee may proceed;

d. The discharges of dredged or fill material for the construction of new stormwater management facilities in perennial streams is not authorized;

e. For discharges or excavation for the construction of new stormwater management

facilities or for the maintenance of existing stormwater management facilities causing the loss of greater than 1/10-acre of non-tidal waters, excluding non-tidal wetlands adjacent to tidal waters, provided the permittee notifies the District Engineer in accordance with the "Notification" General Condition 13. In addition, the notification must include:
(1) A maintenance plan. The maintenance plan should be in accordance with state and local requirements, if any such requirements exist;
(2) For discharges in special aquatic sites, including wetlands and submerged aquatic vegetation, the notification must include a delineation of affected areas; and
(3) A compensatory mitigation proposal that offsets the loss of waters of the US. Maintenance in constructed areas will not require mitigation provided such maintenance is accomplished in designated maintenance areas and not within compensatory mitigation areas (i.e., District Engineers may designate non-maintenance areas, normally at the downstream end of the stormwater management facility, in existing stormwater management facilities). (No mitigation will be required for activities that are exempt from Section 404 permit requirements);
f. The permittee must avoid and minimize discharges into waters of the US at the project site to the maximum extent practicable, and the notification must include a written statement to the District Engineer detailing compliance with this condition (i.e. why the discharge must occur in waters of the US and why additional minimization cannot be achieved);
g. The stormwater management facility must comply with General Condition 21 and be designed using BMPs and watershed protection techniques. Examples may include forebays (deeper areas at the upstream end of the stormwater management facility that would be maintained through excavation), vegetated buffers, and siting considerations to minimize adverse effects to aquatic resources. Another example of a BMP would be bioengineering methods incorporated into the facility design to benefit water quality and minimize adverse effects to aquatic resources from storm flows, especially downstream of the facility, that provide, to the maximum extent practicable, for long term aquatic resource protection and enhancement;
h. Maintenance excavation will be in accordance with an approved maintenance plan and will not exceed the original contours of the facility as approved and constructed; and
i. The discharge is part of a single and complete project. (Section 404)

(Because stormwater detention facilities directly affect the hydrodynamic character of the receiving water body, all of the 15 functions listed in Tables 2 – 6 have the potential to be impacted by activities associated with NWP42. Actions associated with NWP31, particularly those involving the placement of fill in existing channels, should be carefully assessed with respect to the potential for functional impacts before a NWP is issued).

Appendix C – Impacts From Stream Alteration Activities

Channels may be modified from their natural state for beneficial uses such as flood control, navigation, and water supply, to treat the impacts of channel instability (bed degradation and excessive sedimentation), or to restore ecological character. These modifications can result in adverse impacts to channel and riparian ecology. This appendix presents general descriptions of channel modification projects, activities, and practices along with associated impacts on channel stability and ecology. In stream and riparian restoration projects, exceptions are the norm, so the generalizations presented in this appendix will not always reflect actual impacts. More specific information can be obtained from the references cited in the bibliography.

GENERAL CHANNEL RESTORATION

The goal of most stream restoration projects is to accelerate biological recovery through the use of various techniques and methodologies, generally focused upon habitat creation or enhancement. To be successful, these must be designed so as to not adversely impact the stability of the stream. In-stream structures are used to increase habitat diversity by altering flows, changing channel morphology and substrate, and providing cover. Artificial structure such as boulders, or woody debris can be randomly placed in the channel to provide zones of reduced velocity, scour holes, and cover. Sills can be constructed across the waterway to create pools above and scour holes below the structure. Sediment scoured from below the sill may redeposit some distance below to form a riffle area. A series of sills installed in the stream can help to form a pool and riffle sequence that is highly desirable for providing feeding and resting areas for fish and aquatic organisms. Channel modification usually results in poorly sorted, finer, less stable bed material (Shields and Palermo, 1982). A study reported by Arner *et al*. (1976) indicated that fine, poorly sorted sediments in a modified segment of the Luxapalila River, Mississippi resulted in a reduction in the quality and quantity of aquatic organisms. The replacement of natural bed sediments following project completion may speed the biological recovery. This is more successful when well-sorted gravels replace unsorted sediments (Hjorth and Tryk, 1984). Substrate reinstatement was used to speed the biological recovery of a stream relocated to allow for coal mining. Gore and Johnson (1980) reported that material excavated from a coal mining operation was used to line the relocated channel with layers of topsoil, gravel, and cobbles. Benthic organism populations were rapidly established in the channel by colonization from undisturbed stream reaches. Low flows in enlarged channels may be too shallow to support fish and be devoid of pools. Shallow channels can be excavated within modified channels to convey low flows and provide the necessary depth for supporting fish and other aquatic organisms. A study conducted by McCall and Knox (1978) described the environmental benefit of utilizing a low flow notch design in a modified channel for Rock Creek in north-central Indiana. One year after completion, 23 species of fish were found in the low flow channel, compared to 16 species collected from the natural channel upstream of the low flow channel section. Grade control structures such as weirs and drop structures obstruct fish movement and migration in the channel. Additionally, culvert and shallow channel sections in which the flow is too slow or swift impede the natural movement of fish. Fishways or fish ladders are designed to allow fish to either by-pass or pass through channel obstructions.

In some cases, it may be justified to restore the former sinuosity to the modified stream. This action is taken assuming that the engineering function for which the channel was originally modified is either no longer required or will not be impacted, and that no major watershed changes have occurred since initial straightening that would disrupt the equilibrium of the restored channel. In Southern Denmark, a new channel was constructed to replace an 800-meter section of severely degraded channel (Brookes, 1987). The original sinuosity was determined from historical maps, comparison of other neighboring streams, and field reconnaissance of the watershed. Native grasses and woody vegetation were planted for stabilization, with riprap used for bend stabilization before vegetation became established. The new sinuous channel restored morphologic and hydrologic diversity, with colonization by a number of flora and fauna. In West Germany, Glitz (1983) described the restoration of the sinuosity of the Wandse River in Hamburg-Rahlstedt, a lowland river about 1.5 meters in width. A partial restoration was performed assuming that the stream would eventually adjust naturally. A survey conducted two years later indicated that pool and riffle formations were limited, probably due to the low energy of the stream. Management practices may be implemented to preserve the morphological and ecological aspects of the channel without modifying the existing channel to accomplish engineering goals. The concept of floodplain corridors provides sufficient land area on both sides of the stream to allow for natural migration of bends and general channel shifting across the floodplain. This allows the natural formation of habitat enhancement features such as pools, riffles, and point bars. Future watershed planning and management activities are possible with the channel confined to a fixed position on the floodplain.

Potential Impacts

The use of channel restoration techniques to enhance stream ecology is growing. Many of the restorative methods have a limited influence on hydraulics of the channel. The use of artificial structures and sills to create a pool and riffle habitat do not have a significant impact on stream hydraulics, particularly at high flows for which the structures are inundated and no longer function as intended (Brookes, 1988). However, the use of in-channel vegetation can significantly increase the roughness and consequently reduce the discharge capacity of the stream. Wilson (1973) determined that vegetation such as willows and shrubs can reduce the discharge capacity up to 50 percent after only one year of growth. The use of vegetation within stream channels for purposes such as restoration or bank protection requires a thorough hydraulic and sediment transport analysis during the project design phase. Low energy stream systems with moderate flows and low sediment transport are more amenable to vegetative projects. The survival of vegetation in high-energy channels with high peak flows and substantial sediment transport is questionable.

Activities and practices implemented for stream restoration should have a positive impact on stream ecology. The introduction of artificial habitats into modified channels provides the diversity necessary to support a wide variety of aquatic organisms and fish in otherwise unsuitable habitat. Modifications to channel morphology in terms of restoring stream meander or sinuosity must be carefully planned to avoid creating channel stability problems. The examples presented above on restoring sinuosity were for low energy channels that under natural conditions do not actively migrate. Additionally, if watershed changes occur that alter the sediment and water discharge of the original watershed, attempts to alter channel morphology may disrupt the equilibrium of the restored channel.

CHANNEL ENLARGEMENT

Channel enlargement activities are generally implemented when a larger increase in channel flow capacity is required. Snagging and clearing operations are undertaken when decreasing flow resistance can achieve the desired effect on flow capacity. Channel clean out involves changing the channel width, depth, or both to support both flood control and navigation efforts. In small non-navigable streams, the channel is generally accessed from the bank, with dragline operations used to increase channel width and depth. For navigable streams or rivers, a floating dredge plant, either hydraulic or mechanical, is used. The degree of excavation can range from removal of a few shoals to an order of magnitude change in channel geometry. The design of the new channel geometry is based on the desired flow rates, sediment transport characteristics, and bank stability.

Potential Impacts

Channel enlargement operations result in a significant change in flow capacity, and potentially impact channel stability. These channel modifications typically increase the cross sectional area (channel width and depth) and decrease channel roughness due to removal of debris and vegetation, thus increasing flow capacity. The concept of Lanes Balance presented earlier in chapter 3 indicates that for equilibrium the supply of sediment must equal the flow capacity. For high flow events, the probable result of increasing flowrate with the same sized sediment in the channel is a degradation of the bed and increased bank erosion. Both upstream and downstream reaches are affected. The increased velocity in the enlarged reach will result in scour from the bed and banks upstream, with the sediment delivered and deposited downstream. For nominal flows that characterize the majority of the flow events, widening the river results in an over-designed channel with an increased flow area. This results in reduced velocities, thus decreasing the sediment transport capacity that results in sediment deposition. In severe cases of over-widened streams, channel bars or braided flow can occur at low discharges (Brookes, 1988). Deepening the channel can lower tributary base levels, thus increasing tributary slopes. According to Lane's Balance, if the slope is steepened, the sediment transport rate must increase for stability. This results in an upstream migration of degradation of the channel bed often referred to as headcutting. Material excavated from the channel and associated banks during cleanout operations can be used to build berms along the banks for additional flood protection, but may further confine flows, thus exacerbating stability problems.

Like snagging and clearing, removing material from the banks and the channel decreases habitat diversity, thus negatively impacting the aquatic community. Typically, an enlarged channel will have a uniform cross section, which destroys pools and riffles associated with natural channels. The associated loss of habitat diversity can manifest itself by a reduction in species diversity or composition, a reduction in size, distribution, and condition of the population, or unnatural seasonal variations in populations (Gorman and Karr, 1978). The uniform geometry along with the banks denuded of vegetation gives the appearance of a uniform, linear ditch that has very little aesthetic value. When channel clean out operations are conducted from the bank, riparian vegetation can be damaged or removed that reduces habitats and potentially increases streambank erosion. Low flows in enlarged channels may not have the pools necessary for aquatic organisms to thrive. Because of the low velocities in enlarged channels, vegetation may invade the channel and create a future channel maintenance problem. Material excavated from the enlargement operations may be used to construct levees as a management tool for providing additional flood protection. In Louisiana, material excavated from channels was used to prevent saltwater intrusion into a brackish coastal marsh (Scott, 1972). Levees will reduce overbank flows, thus potentially interfering with groundwater recharge and floodplain plant diversity. Shields and Palermo (1982) list the following environmental consequences that should be considered when enlarging a stream:

1) Placement of excavated or dredged material;
2) Cross-sectional shape and uniformity;
3) Changes in substrate and substrate diversity;
4) Removal of channel armor;
5) High and low flow depths and velocities in the modified channel;
6) Increased peak flows downstream; and
7) Changes in stream-floodplain-groundwater interactions.

Remedial Practices

A method of enlargement that can reduce instability problems is the use of side berm cuts to form a two-stage channel (USACE, EM 1110-2-1418, 1994). Although it has the disadvantage of using more adjacent land than simply enlarging the channel, it is more effective in conveying bed material because higher velocities are maintained at moderate discharges. The level of the berms should correspond to the channel forming discharge under modified conditions. The side berm design is described by Nunnally and Shields (1985) as a high flow channel. Before any environmental improvement projects are undertaken, the system stability must be addressed. The key to successful project implementation is to design a stable channel before enlarging operations take place. A complete analysis of the hydrologic, hydraulic, and sediment transport requirements of the enlarged channel should be evaluated before channel modifications commence. Anticipated stability problems can then be addressed and resolved to prevent problems upstream and downstream of the affected reach. A systematic approach to channel rehabilitation is presented in Chapter 2 of this manual. Placing environmental enhancements such as artificial structures in an unstable reach of the channel can result in a total loss of the structures or inefficient or ineffective operation. Efforts to reduce environmental impacts should be incorporated into the design of channel enlargement projects. Consideration should be given to reproducing or improving the habitat diversity of the existing stream, or preserving a part of the natural stream. In-stream diversity can be improved in post-construction channels by use of artificial structures. The purpose of artificial structures is to restore habitat and habitat diversity conducive to the growth and re-population of desirable species. In enlarged channels with shallow depths and uniform unvarying substrates, artificial structures can reproduce the diversity of the natural channel by creating alternating pool and riffle areas. Examples of artificial structures include randomly placed boulders, small check dams, artificial riffles, bank covers, and current deflectors (Shields and Palermo, 1982). Care must be taken to avoid creating additional channel instability problems due to increased roughness or scouring when using artificial structures. Single bank construction is the preferred technique for lessening environmental impacts of channel enlargement (Nunnally, 1985). The existing channel alignment is followed with enlargement confined to one side. Vegetation on the opposite bank is left undisturbed. The disturbed bank is revegetated to reduce erosion and sedimentation in the channel. Erosion of the stream bank can be addressed with bank protection works. Concrete lined channels have been employed, but are typically much more expensive than stone covers and further reduce the in-stream and riparian habitat.

CHANNEL REALIGNMENT

Channel alignment is often performed in conjunction with clearing and snagging. It is the process of taking a sinuous channel and straightening it for the purpose of flood control, infrastructure protection, or navigation. Additionally, channel realignment activities are implemented to reduce loss of land by meander migration. Channel realignment can be implemented in varying degrees. An improved stream alignment can be accomplished by removing shoaling areas such as point bars. For flood control applications, the channel may be straightened to increase the slope and reduce flow resistance, thus increasing the capacity of the stream to convey floodwaters. This practice may involve cutting off large meanders of the river, thus actually shortening the river. The resulting cutoff generally results in slope adjustments for the affected reach. In some environments, streams with stable meanders, flat slopes and erosion resistant boundaries can withstand considerable realignment without serious impacts on system stability (Brice, 1981). In other systems, it can lead to serious problems of channel degradation, bank erosion, and tributary incision. Lane (1947) describes the response of an alluvial channel to a single cutoff. The channel upstream of the cutoff will degrade as the channel slope flattens to re-establish an quilibrium slope at a lower elevation. The reach downstream of the cutoff aggrades due to the increased sediment supply from the degrading reach. A comprehensive description of the impacts of man-made cutoffs on the Lower Mississippi River is provided by Biedenharn (1995). The benefits for flood control are increased conveyance of floodwaters. For navigation, a straight channel reduces transit time and the need for dredging point bars adjacent to bends in the river. Channel realignment may be necessary to protect an infrastructure located near or on the stream bank.

Potential Impacts

Changes to a fluvial system, whether manmade or natural, tend to be absorbed by the system through a series of channel adjustments (Simon and Hupp, 1987). Realignment of channels by creating cutoffs generally reduces the sinuosity and increases the slope. According to Lanes's Balance, if the slope increases and the water discharge and median grain size remains constant in the stream, the sediment transport capability of the stream increases. To approach equilibrium, the additional sediment must be obtained from either bed or bank degradation. As the bed continues to degrade, the zone of increased slope will migrate upstream. The additional sediment load transported through the realigned reach will then be deposited in lower reaches where the slope was not increased. Channel erosion migrates upstream in the form of a headcut, which is a vertical discontinuity in the streambed. The headcutting process is described in Chapter 3. Bank erosion in the steepened reaches and aggradation in the lower reaches tends to increase the width/depth ratio. This sequence is the classic response to cutoffs described by Lane (1947).

The environmental impacts of realigning channels include many of the impacts of channel enlargement and snagging and clearing. Overall, the habitat diversity is reduced in the channel as well as on the banks due to access problems with heavy equipment and clearing of vegetation. The major problems unique to channel realignment are increased channel slopes due to reduction in channel length and the reduction in habitat diversity caused by creating cutoff meanders. The increased channel slope results in an increased sediment transport capacity. The additional sediment requirement is met by degradation of the bed and stream bank. The degradational process increases sediment loads and turbidity levels that are detrimental to both benthic and in-stream aquatic organisms. Sediment deposition downstream of the unstable reach may smother benthic organisms. Unstable, shifting substrates are not conducive to maintaining macro invertebrate populations. Because of the decrease in light penetration in turbid waters, photosynthesis is reduced and plant populations are impacted. Fish populations are directly impacted by the loss of food resources. Channel realignment activities can result in a significant loss of aquatic habitats. Cutoff meanders resulting from channel straightening activities are a significant backwater habitat. If the meanders are not maintained, these will become isolated from the main channel due to sediment deposition at the confluence with the main channel. The resulting oxbow lake will eventually fill with runoff sediment and become terrestrial habitats. If the realigned channel is maintained, new meanders will not form to replace the lost aquatic habitat. A large-scale reduction in aquatic habitats will reduce the productivity of the system and may impact the diversity and population of native aquatic organisms.

Remedial Practices

The environmental impacts of channel realignment should be included in project design considerations. An estimation and evaluation of the losses of aquatic and riparian habitat should be considered if cutoffs will be formed during channel realignment. Flow should be maintained, if possible, through the old meanders to prevent them from filling with sediment. The upstream migration of channel degradation due to increased slopes resulting from shortening the channel is the most significant impact on channel stability. It must be addressed before habitat restoration practices are applied. To mitigate bed and bank erosion, grade control structures and bank stabilization techniques are implemented.

DREDGING AND MINING

Dredging is the process by that sediments are removed from channels for the purpose of maintaining existing navigation (maintenance dredging) or deepening existing channels for deep draft navigation (new work dredging). Dredging is also utilized in bays and harbors located along rivers or at the river outlets that continuously shoal with fine sediments. Additionally, dredging operations are used for mining sand and gravel from rivers. Generally, two different types of dredging operations are used for riverine dredging. Hydraulic dredging operations consist of a floating plant that removes and transports sediments from the channel bed using large centrifugal pumps. The pump suction line extends to the channel bed where the sediment is hydraulically entrained, passed through the pump, and discharged to disposal. Disposal areas can either be within banks or located at inland confined sites. For loosely flowing coarse sediments, a plain suction head is used to entrain the sediments. For more consolidated sediments, a rotating cutterhead is employed to loosen the material and feed the suction line. In some riverine environments, hopper dredges are used. The hopper dredges are deep-draft seagoing vessels used primarily for maintenance dredging in harbors or river outlets. Hopper dredges make successive passes over the problem area, deepening progressively on each pass. The pumped material is stored in hoppers in the dredge, and when fully loaded, the dredge travels to a designated dump site in the ocean. It is only effective for dredging loose, unconsolidated material. Mechanical dredging operations are generally conducted in shallow areas containing loose or consolidated sediments. The operation involves excavating sediment with either a barge mounted power shovel (dipper) or a clamshell bucket operation. Bucket capacities range from 1 to 12 cubic yards. The material is excavated and loaded into an adjacent barge that is towed to disposal.

Potential Impacts

Continuous dredging causes a riverbed to degrade until the balance between sediment load supplied to the river reach and the sediment transport capacity is restored (Brookes, 1988). Deepening the river channel will lower tributary base levels, thus increasing tributary slopes. Channel instability within the tributary will result in degradation of the channel bed, increased sediment transport, and ultimately deposition of sediment within the river. Channel deepening also reduces the sediment transport capability of the river, thus deepened sections act as sediment traps and encourage sediment deposition. A study reported by Griggs and Paris (1982) described increased sediment deposition due to channel deepening. Within 10 years of completion of the U.S. Army Corps of Engineers flood channel on the San Lorenzo River at Santa Cruz in California, 350,000 cubic meters of sediment had been deposited. This reduced the carrying capacity of the river from the designated 100-year flood to a 25-30 year flood. The channel had been deepened by some 0.9 to 2.1 meters below the original bed elevation. Mining operations that remove sand and gravel from the channel bed result in a localized lowering of the bed. This has the effect of increasing the slope upstream of the mining operation that in turn increases the sediment transport capability of the river. Bed degradation advances upstream with sediment aggradation occurring downstream. If sand and gravel mining is performed at many locations along a river, the rate of sediment removed may exceed the rate of replenishment. This can result in a significant lowering of the bed that increases the potential for undermining foundations and bridge piers during major floods. Frequent mining operations can also remove the coarser fractions of sediment that are important for armoring the bed and stabilizing the banks along the river. From Lane's balance described earlier, a reduction of sediment grain size can result in degradation as the channel flattens the slope in order to satisfy the increased transport requirements.

Dredging operations may increase turbidity at the point of dredging. Suspended sediment plumes can migrate to sensitive areas such as fish and shellfish spawning grounds. Generally, hydraulic dredging operations with plain suction intakes operating in coarse sediment environment produce very little turbidity. Cutterhead dredging operations do tend to resuspend sediments around the rotating cutterhead, particularly when working in fine sediments. The turbidity generated can be minimized by reducing the speed of the cutterhead and the swing rate of the dredge ladder (suction line). Mechanical dredges have the highest probability of re-suspending sediments**.** Sediments are resuspended by leaking buckets and through the uplift of sediments from the excavation area when the bucket or dipper is raised. Environmental dredge buckets are available that have a positive pressure seal to prevent leakage. The major impact of dredging on biological communities is the removal and subsequent changing of the substrate. For maintenance dredging in major river systems that have a continually moving and shifting bed, this is a minor concern. For new work dredging in channels that have historically had a stable substrate, the impacts can be severe and permanent. Not only is the substrate removed, the deepening will make the area more conducive for sedimentation, and thus periodic dredging will be required to maintain project depth. A stable substrate will no longer be available thus the diversity and suitability of the habitat will be reduced, with native aquatic organisms displaced. Turbidity generated by dredging operations can impact nearby fish and shell fish spawning grounds and inhibit plant growth.

Remedial Practices

To protect adjacent sensitive areas such as spawning grounds or vegetation, restrictions can be placed on dredge operations. Restrictions on dredge type and minimum turbidity generated can be specified in dredging contracts to insure that environmentally sensitive areas are not impacted. Physical barriers such as silt screens can be used to contain the suspended sediment plume to the immediate area surrounding the dredge. Specialty dredges designed to minimize turbidity are available. Dredging induced channel instability is similar to that resulting from channel enlargement and realignment. Grade control structures and bank stabilization practices may be necessary to address bed and bank erosion and ultimately stabilize affected reaches.

SNAGGING AND CLEARING

Snagging and clearing activities are implemented to increase discharge capacity of channels for flood control and drainage purposes and to prevent hazards to navigation or bridges. The increased flow resistance due to the presence of vegetation and debris may increase the frequency and duration of overbank flows. The goal of the practice is to remove sufficient vegetation, debris, logs, sediment blockages, large rocks, and other obstructions from the channel and adjacent banks to decrease flow resistance. These obstructions retard flow by reducing the effective cross-sectional area of the channel, increasing the channel roughness, and trapping additional debris, particularly during high flows (Shields and Palermo, 1982). Various methods are used for removing channel debris and obstructions. For flood control on small streams, conventional practice has been to remove all obstructions from the channel and to clear all significant vegetation within a specified width on both sides of the channel (Nunnally and Shields, 1985). For small streams, clearing of the channel is accomplished with heavy equipment such as bulldozers. On navigable streams, a floating plant may be utilized for the clearing operation. Comprehensive guidelines and practices for removing obstructions from streams are presented by the Stream Renovation Guidelines Committee, The Wildlife Society and American Fisheries Society (1983). This guidance is intended to aid in correcting stream flow problems caused by obstructions in an environmentally sound manner and to maintain natural stream characteristics.

Potential Impacts

The extent of the effect of clearing and snagging operations on channel discharge capacity is related to the degree of blockage prior to clearing. Potential stability and sedimentation responses to clearing and snagging are associated mainly with increased velocities, increased transport capacity, and with removal of vegetation that may have acted locally as erosion protection. Effects on stability may be adverse in some locations and beneficial in others. The qualitative effect on stability was demonstrated using Lanes Balance as described in Chapter 3.

The removal of snags and debris reduces habitat diversity in the channel. Increased velocities allow deposits of leaves, twigs, and fine grained sediments to be washed downstream. These deposits are an important habitat for many benthic species and in channels with sandy, shifting substrates form the only suitable habitat. Removal of the vegetative canopy from streambanks may result in decreased shade and resultant high stream temperatures, decreased input of organic matter such as leaves, and increased photosynthesis in the stream (Shields and Palermo, 1982). The removal of snags increases the mean velocity of the stream, which may affect plankton production or erode away fine sediment that provides substrates for specific kinds of benthic organisms. Impacts on the macro invertebrate community will ultimately affect fish populations that depend on invertebrates for food. The change in food resources may result in a fish population reduction or an undesirable change in species composition. Additionally, fish may be adversely affected by the removal of snags that serve as cover and shelter. Clearing large amounts of terrestrial vegetation can affect terrestrial communities. Populations of mammals and reptiles that utilize streambank vegetation for shelter and feeding areas will decrease accordingly. Studies in Vermont (Dodge *et al*., 1977) and Mississippi (Arner *et al*., 1976) found mammal track counts along natural streams were almost twice as great as mammal track counts along streams that had vegetation removed by snagging and clearing operations.

Remedial Practices

Adverse environmental effects may be greatly reduced with little loss in flood control by limiting the type and amount of snags and vegetation removed and by using construction methods that create only minimal disturbance (Nunnally and Shields, 1985). Specific obstructions are designated for removal while environmentally valuable logs, snags, and vegetation that have little or no effects on flow capacity are left in place. Planning and design of clearing and snagging operations should include an evaluation of the importance of the canopy to the stream community. Specifications may be written to restrict the amount and type of terrestrial vegetation to be removed. Additionally, the type of equipment used and the access to the stream can be controlled by specification.

CONSTRUCTION OF LEVEES

Levees fall into the general category of embankments. Embankments, also known as flood banks, levees, bunds or stopbanks (Brookes, 1988), are constructed to artificially increase the capacity of a channel to confine high flows that otherwise would overtop the banks and spread over the floodplain. Some of the largest river systems in the world have extensive levees. Levees extend more than 1,000 km along the Nile River and 1,400 km on the Red River in Vietnam. In the United States, levees are key components of a basin wide a flood control plan implemented to protect communities and agricultural areas within the floodplain. Levees are used in conjunction with reservoirs, floodways, control structures, and various channel modification activities to reduce and control the extent and duration of flooding. The design elevation of levees is based on containing a design discharge, generally for a short period of time. The levee cross section is generally designed as a trapezoid, with an access road running along the levee crown. To control seepage, a long, tapering berm may be extended on the landside of the levee. Fill material for levees is generally obtained locally from borrow areas adjacent to the riverside of the embankment. Although the local materials may not be ideally suitable for construction, economic necessity dictates its use. Less than ideal materials can be compensated for by constructing larger levee sections.

Potential Impacts

Levees can confine river flows to a narrower cross section, thus higher stages and discharge result during flood flows. If levees are not set back from the main channel, the hydraulic connectivity of the river is lost with the floodplain, thus confining flows and putting more energy into flow. A study reported by Schumm (1977) estimated that levees and dikes on the middle Mississippi River had increased the stage for a discharge of 800,000-900,000 cfs by approximately 10 ft at St. Louis, Missouri. On un-leveed streams, flood flows spread out over the floodplain. The floodplain acts as storage for the additional flows. The construction of levees decreases the floodplain storage, thus increasing the peak discharge. Channel instabilities may arise from leveed streams because degradation of the bed and banks may occur. Debate continues on the effect of levees on the Mississippi River. Aggradation may occur due to the increased sediment load in the main channel and the lack of available floodplain sediment storage. The precise response is complex and is a function of the width of levees, the effects on duration of flows, and other factors. The Midwest flood of 1993 initiated efforts to define a long term, nationwide approach to floodplain management. The results of this effort are summarized in a document commonly referred to as the Galloway report (IFMRC, 1994). It presents an overview of floodplain management, current risks, and the application of structural measures such as levees to minimize flood impacts. Seepage is a major problem with levees during high water. When water is contained on one side, a head differential exists across the levee. This tends to force water through the porous soil, eventually seeping out to the landward side of the levee. This seepage carries both fine and coarse particles through the levee. This internal erosion of the levees can lead to piping through the levee and catastrophic failure. To prevent excessive seepage, impervious barrier materials such as clay can be built into the levee. Flows from tributaries that are cut off from the river system due to levees must be addressed to prevent flooding on the landward side of the levee. Pumping stations can be applied to divert tributary flows.

Levees act as a barrier for overbank flows. On un-leveed streams, flows periodically flow onto the floodplain depositing sediment, flushing riparian aquatic environments, and generally providing valuable habitat for aquatic organisms and waterfowl. The flora and fauna are adapted to periodic flooding and the unique environment that it creates. Confining stream flows within a levee system creates a dryer environment on the landside of the levee system and a wetter environment on the stream side. The dryer environment results in changes in both flora and fauna that occupy the floodplain. Studies indicate that after levee systems are constructed, upland trees and vegetation colonize the floodplain. The lands between the levee and the stream bank will experience more prolonged flooding with more extreme fluctuations in water level. This may inhibit the growth of ground cover, thus reducing the available habitat for ground-dwelling mammals (Fredrickson, 1979). For economical considerations, material used to construct the levees generally are excavated from areas within the floodplain, resulting in vegetation removal and loss of the habitat. The flat slopes used for levees in rural areas require large land requirements for the embankments and berms.

Remedial Practices

To offset changes in riparian habitat, consideration is being given to the habitat provided by the levees themselves and the adjacent borrow pits. Traditionally, the vegetation on levees is kept to a minimum. Management of vegetation on levees was investigated on a project along the Sacramento River (Davis *et al.*, 1967). The results of the study indicated that with proper maintenance, certain species of shrubs and plants could be allowed to grow without affecting the integrity of the levee. Additionally, the study showed that the cost of maintaining vegetation on the levee was roughly twice the cost of traditional levee maintenance (no vegetation), and that vegetation on levees provides the habitat for burrowing animals that must be controlled. Borrow pits remaining from levee construction can serve as valuable aquatic habitat. Normally, the pits will fill with rainwater or groundwater after construction. Riverside borrow pits will exchange water with the river system, thus recharging the pit with fish and other aquatic organisms. Thus borrow pits partially compensate for the loss of aquatic habitat in the floodplain. Additionally, siting levees further from the channel will conserve wetland environments between the levee and the river.

DAMS

Impoundments are constructed for multiple uses. In canalization projects, dams are constructed along with locks for navigation purposes. Dams and associated reservoirs are built on rivers primarily for flood control, with secondary functions such as recreation, water supply, and power generation. Sediment retention dams are utilized as flow control to reduce sediment loading to downstream areas (USACE, GDM-54, 1990a). One or more dams are constructed in the upper watershed to trap sediments and thus reduce bed material load downstream. Additionally, dams reduce the sediment load by changing the flow duration curve for the stream. Controlled releases through the dam reduce the flood peaks and subsequently reduce the sediment load downstream. Peterson (1986) describes the social and environmental impacts of dams on a number of river basin projects. The beneficial uses for which a dollar value can be assigned were for flood control, hydropower generation, irrigation, and recreation. For the Columbia River dam projects the adverse environmental impacts were primarily due to the dams blocking the salmon migration routes. Because of the multipurpose nature of some dams, it is difficult to optimize the beneficial aspects of each use. From the flood control viewpoint, it is necessary to reduce flood peaks downstream. This practice may result in inadequate flows for power generation and disrupt fish spawning. Dams change the flow and sediment transport characteristics of the river. The backwater extends upstream of the dam, acting as a sediment retention basin. Regulated flows through the dam along with reduced sediment transport below the dam may affect downstream channel stability.

Potential Impacts

The primary effect of dams on system stability is to reduce peak discharges and sediment supply to the downstream channel. Upstream effects of a dam and associated reservoir include delta formation, gradual raising of stream levels in the backwater zone, and a more pronounced meandering (USACE, EM 1110-2-1418, 1994). Downstream effects result from flow control through the dam and retention of sediment. A reduction in peak discharge often reduces bank instability downstream by inducing deposition at the channel margin in the form of berms. The channel adapts to a lower channel forming discharge by shrinking. Reducing peak discharge and lowering the flowlines in the downstream channel may also induce tributary instability by lowering their effective base level. Channel degradation in the form of a head cut advances up the tributaries and ultimately increases the sediment supply to the main river. However, reducing the sediment supply to the stream through reservoir retention also often induces channel degradation downstream, which can actually lead to mass instability of the banks by increasing bank heights. This may trigger a reversal of main channel response and lead to eventual aggradation due to increased sediment supply from tributaries (Biedenharn, 1983). System response to flow control and sediment retention aspects of dams are very complex and cannot be easily predicted or generalized. Factors affecting channel response:

a. Magnitude and frequency of flow duration;
b. Degree of sediment retention;
c. Downstream controls such as geologic outcrops, man-made structures, armor layers and backwater from another lake or river;
d. Reduced sediment transport capacity of the channel as a result of slope reduction due to channel degradation;
e. Sediment input from tributaries and bed and bank erosion;
f. Vegetation and vegetative encroachment; and

g. Tributary response.

The construction of dams results in a decrease in terrestrial habitat through backwater flooding. However, case studies of dams on selected river basins presented by Peterson (1986) indicate that reservoirs have had a lesser impact on wildlife than urbanization and agriculture. Green and Eiker (1983) reported that while the reservoirs on the Columbia River basin did decrease the habitat for some mammals, waterfowl habitats increased. Babcock (1980) reported that on the Arkansas River Navigation Project, the environmental quality actually improved due to construction of the project. The water quality improved with a reduction in suspended solids. Dam outflows generally are at a lower temperature than existing channel flows. The lower water temperature may be suitable for specific species of fish such as trout and deleterious for native warm water fish populations, and the fishery diversity may be permanently altered. Aquatic and terrestrial habitats are impacted by a reduction of flushing flows through the dam. In periods of low flow through the dam, fish and other aquatic organisms that depend on higher flows for food and habitat are affected. Terrestrial habitat along the stream that experienced frequent overbank flows in predam conditions may be dry for prolonged periods of time, thus potentially displacing wildlife dependent on a more wet environment. Additionally, flows through the dam will be based on needs such as hydropower, flood control, and recreation. This will result in a change in the channel forming discharge that will alter channel morphology and subsequent habitat features. Throughout the country, such as the Northwest, fish passage around dams is a serious environmental concern. Dams block migrating fish such as salmon from completing spawning runs.

Remedial Measures

The construction of dams can adversely impact downstream channel stability. Channel and streambank remediation techniques may be required to reduce erosion and deposition of sediments resulting from fluctuating flows and reduced sediment transport through the dam. Changes in dam operating procedures can be made to accommodate environmental needs. Periodic flushing flows can be released to enhance downstream aquatic and terrestrial habitats. Fishways or fish ladders can be used to allow migrating fish to bypass dams. On the lower Snake River in Washington, salmon are bypassed around dams using barges. In some cases, dam removal is advocated to restore a rivers natural and recreational value.

DIVERSION CHANNELS

Diversion channels are constructed to divert waters from the main channel for purposes such as flood control, municipal water supply, and irrigation. A type of diversion channel used for flood control is a flood bypass channel or floodway. It is a separate channel into which flood waters are directed to lessen the impact of flooding on the main river system. Diversion channels on large river systems such as the Mississippi River can consist of adjacent low-lying areas or old river courses. Control structures may be located at the head of the diversion channel to divert flows during periods of high water and return flows during low water. Some diversion channels bypass the flood flows into an adjacent waterway, while others return the flows back into the same stream a distance downstream from the point of the diversion. Diversion channels are often used in urban areas where it is not possible to widen the existing channel due to development. Diversion channels may be used to provide a means of diverting floodwater across the neck of a meander or series of meanders (Acheson, 1968). Major design considerations for diversion channels include: 1) determining if the channel should convey partial or all flows 2) design of appropriate controls 3) sizing of the channel to convey the design discharge and 4) design to reduce maintenance (Nunnally, 1985). To be effective in reducing the flood stage, the distance between the point of diversion and point of return to the main channel must be of sufficient length to prevent backwater effects. Additionally, it is essential to consider potential morphologic effects on both the main channel and receiving channel.

Potential Impacts

According to Nunnally and Shields (1985), diversion channels generally have steeper slopes than the main channel. This can lead to stability problems such as erosion of the channel bed and banks. The bed of tributary channels may be higher than that of the floodway channel, and bed degradation may migrate upstream of the tributary, resulting in excessive sediment transport and deposition in the floodway. Methods to mitigate channel instability such as grade control, channel lining, and bank stabilization may be required on diversion projects. Additionally, diversion flows can have an adverse impact on the main channel. From Lane's Balance, it can be seen that reducing the river flow in the main channel due to a diversion, with the slope and particle size remaining constant, will result in a decrease in sediment transport capability, thus aggradation could occur in the channel between the point of the diversion and the point of re-entry. If too much bed material is diverted, the sediment transport capability of the stream may increase, thus accelerating channel instability. Flow returning to the main channel from a diversion can also result in accelerated erosion of the channel and banks. Vanoni (1977) reported that in Alkali Creek in Wyoming, flow returning to the main channel from a diversion resulted in bed erosion. The channel eroded down to an armored layer of large gravel and cobbles, after which the banks began to erode, resulting in the implementation of bank stabilization measures. It is essential that a detailed geomorphic and sediment transport analysis be conducted at the design stage of a diversion project to plan for potential problems.

It is environmentally beneficial to use diversion channels as an alternative to modifying the main channel to convey flood flows. The original stream substrate and meanders are maintained, as well as instream cover and riparian vegetation. If it is designed only for periodic flood flows, the diversion channel can have multiple benefits such as an urban greenbelt, recreation, pasture for grazing, and a wildlife food source (Little, 1973). If the invert of the diversion channel is too low, it will convey both low and high flows, thus continually staying wet. This will inhibit grass growth and increase the possibility of erosion of the substrate. If adjacent low-lying areas or old abandoned river courses are used for diversion purposes, some terrestrial habitat may be lost or converted to a wetland habitat.

Remedial Practices

The diversion system must be carefully designed and constructed to prevent channel instability in the main channel and the diversion channel. Channel design must take into account the design flows and sediment transport to insure bed and bank stability. The hydraulic design of diversion channels can be accomplished with standard hydrology and hydraulics analysis techniques, while determinations of sediment transport through the diversion are much more difficult. Because the floodway invert is higher than that of the main channel, there is a tendency for the channel to become unstable and degrade. Grade control structures may be necessary on the downstream end of the floodway to prevent upstream migration of bed degradation, and on any perched tributaries that are hydraulically connected to the diversion channel.

ARMORING

As discussed in Chapter 3 of this manual, the instability and subsequent failure of stream banks commonly result from a combination of hydraulic, geomorphic, and geotechnical factors. Scour occurring on the outside of channel bends increases bank heights and subsequently leads to bank failures. The terms streambank erosion and streambank failure are often used to describe the removal of bank material (Biedenharn *et al.*, 1997). Erosion generally refers to the hydraulic process where individual soil particles at the banks surface are carried away by the tractive force of the flowing water. Therefore, the erosive forces are generally greater at higher flows. The primary erosion processes are parallel flow, impinging flow, piping, freeze thaw, sheet erosion, rilling and gullying, wind waves, and vessel forces. Streambank failure differs from erosion in which a relatively large section of bank fails and slides into the channel. Streambank failure is often considered to be a geotechnical process. A geotechnical failure involves the movement of a relatively large and possibly intact segment of soil. There are two distinct classes of bank failure: the slow moving creep and the catastrophic shear failure. The slow moving creep failure occurs over long periods of time, whereas the catastrophic shear failure occurs instantaneously. Channel instability can ultimately result in system-wide bank instability. As channel degradation proceeds through a system, the channel bank heights and angles are increased, which reduces the bank stability with respect to mass failures under gravity. If degradation continues, eventually the banks become unstable and fall. Bank failures may no longer be localized in bendways, but rather may also be occurring along both banks in straight reaches on a system-wide basis. Fluctuating flows through channels and localized runoff can also contribute to accelerated erosion of the banks. System-wide instability is treated with channel stabilizing methods described above. Localized bank erosion and failure is treated with a variety of methods designed to either directly or indirectly protect the bank (Shields and Palermo, 1982). Bank stabilization projects address local problems such as meander migration and constricted reaches and are not a remedy for system instability. Direct bank protection methods are placed in contact with the bank to prevent erosion. Indirect protection methods are designed to deflect flows from the affected area or reduce turbulence and encourage sediment deposition. Example of direct methods are stone riprap, trench fill revetment, concrete paving, articulated concrete mattresses, and vegetation. From an environmental viewpoint, vegetation is the preferred treatment when hydraulic conditions allow its use. Woody vegetation is usually restricted to banks, but grass linings may be used if properly maintained and not exposed to excessive velocities (Nunnally and Shields, 1985). Indirect methods include dikes, fences, and jacks. More detailed information concerning design and placement of channel and bank stabilization methods is provided in the *WES Stream Investigation and Streambank Stabilization Handbook* (Biedenharn *et al.*, 1997). The primary purpose of reservoir construction is usually flood control or water supply, but reservoirs may also be designed specifically to induce channel stability and subsequently stabilize banks. The effect of reservoirs is to reduce peak discharges and sediment supply to the downstream channel. A reduction in peak discharge often reduces bank instability by inducing deposition at the channel margin in the form of berms. In effect the channel adapts to a lower effective or dominant discharge by shrinking. Bank failure upstream of reservoir impoundments will be decreased by the reduction in flow velocities and bank shear stresses for the length of the channel affected by the impoundment.

Potential Impacts

Indirect bank stabilization methods act to deflect flows from affected areas or reduce current velocities adjacent to banks. After eroding banks are stabilized, the sediment discharge is reduced in the system. If the reduction of sediment discharge is significant, the system may adjust by eroding and degrading the channel bed. The operation of reservoirs to accomplish bank stability by reducing peak discharge and lowering the flowlines in the downstream channel may result in tributary instability be lowering their effective base level. Additionally, the reduction of sediment supply downstream from reservoirs may induce channel degradation downstream. This can result in increased bank heights and bank instability.

Direct methods of streambank protection initially involve some bank preparation and removal of vegetation. This initial adverse impact on the riparian ecology is offset by the benefit of halting the existing erosion. Bank protection can increase habitat diversity if the bank is re-vegetated with environmentally beneficial plants as part of the bank protection scheme. Extensive streambank protection works can result in a reduction of channel migration, which reduces habitat diversity.

Remedial Measures

Currently, environmentally compatible methods of stream bank protection are based on extensive use of vegetation, particularly used in combination with structural applications. Allen (1978) describes the use of plants to control erosion of streambanks, reservoir shorelines, and other areas. Shields and Palermo (1982) indicate field studies were conducted on the Missouri, Sacramento, Willamette, and Lower Mississippi Rivers on the environmental effects of bank protection projects and methodologies to reduce adverse environmental effects. Demonstration projects were conducted in the Ohio and Yazoo River Basins for testing various combinations of vegetation and structure. The reduction in habitat due to paved channels can be alleviated by the use of riprap as a lining, with the voids between the riprap filled with stream gravel.

FLOW DEFLECTION STRUCTURES

Dikes are free standing structures of stone, pile clusters, or pilings with stone fill placed within waterways either parallel or transverse to the channel, and are generally constructed to constrict the channel at a specific location for the purpose of concentrating flow in a narrower, deeper channel. The reduced cross sectional area results in an increase in flow velocities thus increasing the sediment transport capability of the stream. In navigable rivers the decrease in shoaling reduces dredging requirements. Dikes have been used extensively on the Lower Mississippi River to maintain navigation channels, and can be used in conjunction with other measures such as floodways, cutoffs, bank protection and levees to aid in flood control, maintain navigation, and stabilize river systems. Additional applications include cutting off side channels and chutes, concentrate a braided river into a single channel, realigning a river reach, and streambank protection. A variety of materials can be used to construct dikes. Stone dikes and pile dikes are the most common type in use, but soft dikes consisting of sand filled geotextile containers have been used successfully on the lower Mississippi River. Dikes may be constructed either parallel or perpendicular to the flow. Spur dikes, which are sometimes referred to as transverse or cross dikes, are the most common types of dikes used on major streams (Shields and Palermo, 1982). Dikes are generally constructed in groups perpendicular to the flow, extending outward from the bank toward the center of the channel. Spacing between dikes in a dike field is generally a function of the location of the next dike downstream (Peterson, 1986). Longitudinal dikes extend downstream and parallel to the flow. The primary purpose is for reducing the curvature of sharp bends and provides erosion protection for the adjacent bank. L-head dikes consist of both a section perpendicular to the flow extending from the bank, and a section parallel to the flow extending downstream from the end of the perpendicular section. L-head dikes are designed to reduce sedimentation behind the dike and can be used to reduced sedimentation in specific areas such as harbor entrances.

Potential Impacts

Dikes are designed and constructed to confine flows in a narrow channel and induce an increase in sediment transport through the channel. Depending on design, dikes can affect the flow in a number of ways. For example, spur dikes, which extend perpendicular to the flow, are used to constrict the flow and concentrate the flow within the constricted reach. Longitudinal dikes are arranged downstream and parallel to the flow, and are used to reduce the curvature of sharp bends, develop stable channel alignments, and provide erosion protection for the adjacent bank. Because of the increased velocities, localized scour and undercutting occurs at the end of the transverse dike. Incorporation of design criteria such as improved profile slope and dike angle can reduce the effects of scour. At low water, sediment deposition occurs in the slack water between dikes.

Shields and Palermo (1982) report work by Thackston and Sneed (1980) and Johnson *et al*. (1974) which identified three areas of environmental impacts due to dike fields: 1) impacts associated with dike construction, 2) changes in water surface area and aquatic habitats, and 3) increased water-level fluctuation. Because the majority of dike construction occurs in depositional zones near the bank, some benthic habitat is lost during construction. Additionally, construction techniques may temporarily increase localized turbidity. Dikes increase the habitat diversity. The areas between the stones and downstream of the dike provide feeding and resting areas for fish. Slack water between dikes provides additional aquatic habitat unless excessive sedimentation occurs. A gradual build-up of sediment occurs in the slack-water areas between dikes during high flows. At low flows, the shoals may be out of water, thus allowing vegetation such as willows to colonize the area. During high flow events, the increased vegetation effectively increases the roughness thus further encouraging sediment deposition. This results in a decrease in aquatic habitat and an increase in terrestrial habitat. Brookes (1988) reports a study by Morris *et al*. (1968) that reported that the construction of pile dikes on the Missouri River in Nebraska reduced the width from 720 to 240 meters and reduced benthic habitat by approximately 67 percent. Habitat diversity may be reduced by stabilizing the stream with dikes.

Remedial Measures
Although a reduction in sedimentation in dike fields can be achieved by varying the length and height of dikes, constriction gaps or notches in dikes are presently the most widely used environmental restoration method (Shields, 1983). Notched dikes are used to mitigate the loss of aquatic habitat due to sedimentation on the downstream side of dikes. Stone is removed from the dike to a specific width and depth to create a gap allowing flow to pass through the dike. The flow through the gap induces scour that removes sediment deposits and restores aquatic habitat. The notch width, shape, and depth design can varied to provide varying degrees of habitat restoration. Notch openings should be adequate to provide the necessary effect of creating habitat without causing excessive erosion or deposition. The Missouri River Division of the Corps of Engineers has used notched dikes to restore aquatic habitat on the Missouri River (Shields and Palermo, 1982). Small gaps in the Missouri River dikes were observed to produce small chutes and submerged bars behind the dikes, whereas large openings created open-water habitat.

GRADE CONTROL

The most common method of establishing grade control is the construction of in-channel grade control structures. There are basically two types of grade control structures. One type of structure is designed to provide a hard point in the streambed that is capable of resisting the erosive forces of the degradational zone. This is somewhat analogous to locally increasing the size of the bed material. Lanes's relation would illustrate the situation by $QS_{+} \alpha Q_s D_{50+}$, where the increased slope (S_+) of the degradational reach would be offset be an increase in the bed material size (D_{50+}). This is referred to as a bed control structure. Sills are placed across the channel at or just above the bed elevation to control scour. Materials such as concrete rubble, stone, or locally available non-erodible materials can be used. The sill acts as a hard point in the channel that resists erosion, thus stabilizing the bed. Channels may be completely stabilized by lining the channel with non-erodible material such as concrete or stone. This is a more expensive alternative, but it may be necessary in urban areas where land costs are high, thus narrow channels with steep side slopes are desirable. The second type of grade control structure is designed to function by reducing the energy slope along the degradational zone to the point that the stream is no longer capable of scouring the bed ($QS_{-} \alpha Q_s D_{50}$), which requires establishing a hydraulic control at the structure. Examples of hydraulic control structures are weirs and drop structures. Weirs are placed across the channel to control the water level thus controlling the stream energy gradient. For large discharges or significant changes in bed elevation, drop structures are employed. Drop structures are designed to limit and stabilize channel bed slope by means of a vertical drop.

Potential Impacts

The function of hydraulic grade control structures is to reduce the energy slope along the degradational zone, thus reducing the ability of the river to scour the bed. This results in a backwater above the structure and a subsequent lowering of the velocity. These areas typically are more conducive to sedimentation, thus the affected reach is transformed from degradational (erosive) to aggradational (depositional). This sediment trapping affect along with the desired affect of reducing bed erosion will deprive downstream reaches of sediment, thus possible affecting downstream stability. Grade control structures can affect the flood potential of the stream. Hydraulic grade control structures are often designed to be hydraulically submerged at flows less than bankfull so that the frequency of overbank flooding is not affected. However, if the structure exerts control through a wider range of flows including overbank, then the frequency and duration of overbank flows may be impacted. Another factor that must be considered when siting grade control structures is the safe return of overbank flows into the channel. This is particularly a problem when the flows are out of bank upstream of the structure but still within bank downstream. The resulting head differential can cause damage to the structure as well as severe erosion of the channel banks depending upon where the flow re-enters the channel.

Grade control structures can provide direct environmental benefits to a stream. A study was conducted by Cooper and Knight (1987) on fisheries resources below natural scour holes and man-made pools below grade control structures in north Mississippi. The study results conclude that although there was greater species diversity in natural pools, there was increased growth of game fish and a larger percentage of harvestable-size fish in the man-made pools. Shields *et al*. (1990) reported that the physical aquatic habitat diversity was higher in stabilized reaches of Twentymile Creek, Mississippi than in reaches without grade control structures. Jackson (1974) documented the use of gabion grade control structures to stabilize a high-gradient trout stream in New York. She observed that following construction of a series of bed sills, there was a significant increase in the density of trout. The most serious negative environmental impact of grade control structures is the obstruction to fish passage. In cases where drop heights are small, fish are able to migrate upstream past a structure during high flows (Cooper and Knight, 1987). However, where structures are impassable, openings, fish ladders or other passageways must be incorporated into the structure design to allow fish migration.

Remedial Measures

When designing hydraulic control structures, overbank flooding concerns must be addressed. The potential for causing overbank flooding may be the limiting factor with respect to the height and amount of constriction at the structure. If the structure exerts control through a wider range of flows including overbank, then the frequency and duration of overbank flows may be impacted. The impacts must be quantified and appropriate provisions such as acquiring flowage easements or modifying structure plans should be implemented. The safe return of overbank flows must be considered when siting the structure. One method is to design the structure to be submerged below the top bank elevation, thereby reducing the potential for a head differential to develop over the structure during overbank flows. Direct means of controlling overbank flows include constructing an earthen dike or berm extending from the structure to the valley walls to prevent flows from passing around the structure and constructing an auxiliary high flow structure that will pass overbank flows to a specified downstream location.

Appendix D – Annotated Bibliography

*Numbers indicate the major thrust of the reference, based on the following:

1. Supports the "functions" approach
2. Supports the "use" approach
3. Riparian oriented
4. Biological (non-riparian) oriented
5. Geomorphology oriented
6. Hydrology oriented
7. HGM specific
8. Case study

+ Reference may be particularly useful

Abbe, T.B., Mongomery, D.R., and Petroff, C. (1997) "Design of stable in-channel wood debris structures for bank protection and habitat restoration: an example from the Cowlitz River, WA," Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 809-814.

(Most bank protection structures are not designed to improve aquatic or riparian habitat and restoration projects often lack sufficient engineering and geomorphic analysis. This project demonstrated that engineered log jams can meet erosion control objectives while restoring riverine habitat in large alluvial rivers. There is good potential for integrating natural processes into river engineering in ways that will meet human objectives for limiting bank erosion while maintaining habitat.) 2,4*

Benke, S.C., Henry, R.L., III, Gillespie, D.M., and Hunter, R.J. (1985) "Importance of snag habitat for animal production in southeastern streams," Fisheries, 10-5, 8-13.

(This study showed that snagging operations, as performed by many agencies over the years in order to enhance navigation or modify channels, can be devasting to much of the fish community. Furthermore, removal of the snags can increase water velocity, adversely affect stream channels and riparian vegetation, reduce the frequency of floodplain inundation, and alter nutrient and organic matter pathways.) 1,4

Beschta, R.L., and Platts, W.S. (1986) "Morphological features of small streams: significance and function," Water Resources Bulletin, 22-3, 369-379.

(Where channel morphology is modified or structural features are added, stream dynamics and energy dissipation need to be considered. Understanding each stream feature individually and in relation to all others is essential for proper stream management. Although engineered structures for modifying habitat may alter stream characteristics, channel morphology must ultimately be matched to the hydraulic, geologic, and [especially] vegetative constraints of a particular location.) 4,5,6

Boeters, R. E. A. M., Verheij, H. J., and van der Wal, M. (1991) "Environmental-friendly bank protections," Environmental Hydraulics, Lee & Cheung (eds), Balkema, Rottendam, pp. 1437-1442.

(With increased public awareness, more environmental-friendly solutions have been leading to greater attention for design criteria for protective structures allowing the presence of vegetation. This paper looks at other studies dealing with the current environmental bank protection research in the Netherlands.) 2,4,8

Bravard, J.P., Amoros, C. and Patou, G. (1985) "Impact of civil engineering works on the successions of communities in a fluvial system," Oikos, 47-1, 92-111.

(Fluvial dynamics determine the habitat diversity by the erosion-deposition processes that create biotopes. Contemporary impacts, such as navigational embankments, hydroelectric projects, and the protection of agricultural land halt the fluvial dynamics by restricting the extension of the area of active geomorphology. The absence of lateral erosion prevents the initiation of succession and leads to the disappearance of communities corresponding to the first stages of the sequence.) 1,5

Buer, K., Forwalter, D., Kissel, M., and Stohler, B. (1989), "The Middle Sacramento River: Human Impacts on Physical and Ecological Processes Along a Meandering River," Proceedings of the California Riparian Systems Conference Held in Davis, California on September 22-24, 1988: Protection, Management, and Restoration for the 1990's, USDA Forest Service Gen. Tech. Rep. PSW-110, 22-32.

(This is an on-going study that focuses on changes in bank erosion, bank composition, river length, depth, width, sinuosity, and floodplain deposition. Completed studies indicate that bank protection and dams have significantly affected the river habitat; reduction of salmon spawning gravel from freshly eroded banks was of special concern. While both the dams and riprap were implicated, it appears that the major causal effect was reduced erosion rates from lower flows associated with dam construction). 2,4,5,6

Burke, T. D., and Robinson, J. W. (1979) River structure modifications to provide habitat diversity," A National Workshop on Mitigating Losses of Fish and Wildlife Habitats, General Technical Report RM-65, Colorado State University, pp. 556-561.

(Discussion of beneficial and detrimental effects of Missouri River Bank Stabilization and Navigation Project and description of structure modifications used to improve fish and wildlife habitats, flood carrying capacity, and for controlling accretions. Methods include notched, rootless, and low elevation structures.) 4,8

Chamberlain, F.W., and Meyers, M.S. (1995) "A Case Study of the Use of Riprap in Rochester, Minnesota," River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone, John Wiley & Sons Ltd., 591-605.

(This paper presents a case study of the use of riprap for an on-going flood control project. Primary concerns of safety, cost-effectiveness, reliability, and efficiency are addressed, along with considerations for the environmental and social aspects of the design. Design details and construction procedures are presented and discussed.) 2,8

Downs, P.W., and Thorne, C.R. (2000) "Rehabilitation of a lowland river: reconciling flood defense with habitat diversity and geomorphological sustainability," J. of Environmental Management, 58, 249-268.
(The authors concluded that true restoration was neither possible nor desirable on the River Idle in the United Kingdom. Management objectives are geared towards environmental enhancement through rehabilitation. The requirement to reconcile environmental enhancement with the river's on-going flood defense function remains a challenge, while the desire to produce a sustainable solution influences long-term planning.) 2,6,8

Ehrenfield, J.G. (2000) "Defining the limits of restoration: the need for realistic goals," Restoration Ecology, 8-1, 2-9.

(This paper describes the advantages and disadvantages of restoration project goals at three different levels: species, ecosystem functions, and ecosystem services. It provides quantifiable components of selected ecosystem processes that are part of the ecosystem functions, and a list of various ecosystem services that have been proposed in recent publications.) 1,4

Everest, F. H., and Sedell, J.R.. (1984). "Evaluating effectiveness of stream enhancement projects," Hassler, T.J. (ed.), Proceedings, Northwest Stream Habitat Management Workshop, California Cooperative Fishery Research Unit, Humboldt State University, Arcata, California, 246-256.

Field, J. J. (1997) "Channel modifications along an artificially constructed channel designed to provide salmon habitat," Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 822-827.

(Channel modifications along an artificially relocated reach of Schell Creek near Ferndale, WA damaged 68 percent of the 59 habitat improvement structures placed in the channel. Damage resulted from channel aggradation, bed erosion, and bank scour. All of the damage occurred in the first year during three bank full or near bank full flows. Future attempts at stream location should allot time for the channel to reach a quasi-equilibrium condition before placing habitat structures in the channel. Evaluation of stream enhancement projects is critical if past mistakes are to be avoided in future projects.) 2,5

Fischenich, J.C., 1990. "Cumulative Impacts Analysis of a Midwest Fluvial System," Proceedings of the 1990 ASCE Hydraulic Engineering Conference, San Diego, CA.

(Summarizes an analysis of the cumulative impacts of bank stabilization activities along 314 miles of the Platte River in Nebraska. The study defines limits of bank stabilization actions before causing impacts to sediment transport, bed level, and water surface elevation.) 5,8

Fleming, N.S., and Daniell, T.M. (1993) "Sustainable water resources management: an Australian perspective," Paper presented at the International Conf. On Environmentally Sound Water Resources Utilization, Bangkok, Thailand, 8-11 November, 1993.

(Evidence is mounting that current methods of natural resource use and development are unsustainable, which impacts economic efficacy and causes serious environmental degradation. To achieve sustainability in water resources requires a focus on the integrated use of land and water resources, with the aim of insuring a high level of water quality; use of water within the sustainable yield of the resource; and maintenance of biological diversity.) 4,6

Goldsmith, W., and Buchanan, D. (1999) "Practical bioengineering applications in watershed management," Land and Water, July/August, 1999, 11-15.

(This is more of a philosophical paper, and contains no hard data or literature. However, it espouses the theory that our streams and rivers have suffered tremendous and largely unnecessary damage due to poor management and a lack of understanding of basic ecological principles. It also contains a table showing characteristics of healthy and impaired watersheds, and potential restoration objectives.) 1,4

Gore, J. A., and Shields, F. D., Jr. (1995) "Can large rivers be restored," BioScience, 45-3, 142-152.

(Although restoration of large rivers to a pristine condition is probably not practical, there is considerable potential for rehabilitation, that is, the partial restoration of riverine habitats and ecosystems. Renewal of physical and biological interactions between the main channel, backwaters, and floodplains is central to the rehabilitation of large rivers.) 1,4,6

Griggs, G.B., and Paris, L. (1982) "Flood control failure: San Lorenzo River, California," Environmental Management, 6-5, 407-419.

(The problem of flooding cannot simply be resolved by engineering. Large flood control projects provide a false sense of security and commonly produce unexpected channel changes. Any engineering protection is both limited and temporary. In the case of the San Lorenzo River project, the channel was excavated below the natural grade and levees were constructed to contain the 100 year flood. The natural response of the river to return to it's equilibrium condition resulted in significant sedimentation and reduction in flood control capability.) 6,8

Gwin, S.E., Kentula, M.E., and Shaffer, P.W. (1999) "Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles," Wetlands, 19-3, 477-489.

(Landscape profiles describing the pattern of diversity of wetlands in a region can serve as a standard for characterizing the resource and quantifying the effects of management decisions. The authors used HGM classification to generate landscape profiles to evaluate the effects of mitigation in the Portland, OR area.) 7

Goff, K. (1999) "Designer Linings," Erosion Control, 6-5, 58-65.

(The indiscriminate use of riprap to prevent scour and erosion, the lining of once-vegetated riverbanks with concrete, and too many locks, levees, and dams are perceived by most to be undesirable vestiges of past environmental folly. Therefore, it is time to reassess our traditional approaches to waterway stabilization and develop a systematic approach to the problem of stream bank erosion. Combining armor-type protection with softer, bioengineered techniques is proving to be a viable approach to many embankment stabilization problems. In fact, the effectiveness of armoring techniques is improved when vegetation is included in stabilization projects.) 1,5

Gorman, O. T., and Karr, J. R. (1978) "Habitat structure and stream fish communities," Ecology, 59-3, 507-515.

(Increasing community and habitat diversity followed stream-order gradients. Natural streams supported fish communities of high species diversity, which were seasonally more stable than the lower-diversity communities of modified streams. After disturbances such as channelization, seasonal peaks in species diversity attain levels typical of undisturbed streams.) 4

Haltiner, J. (1995) "Environmentally sensitive approaches to river channel management," River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone, John Wiley & Sons Ltd., 545-556.

(Traditional engineering approaches to river channel erosion and flood hazards have focused on single-purpose, structurally intensive solutions such monolithic riprap or concrete-lined channels, and drop structures. While often successful in reducing erosion, they provide little or no environmental, aesthetic or recreational value. However, biotechnical approaches integrating riprap or other structural measures with vegetation provide a range of bank and channel stabilization methods consistent with a multi-objective approach.) 1,4,5

Hauer, F.R., and Smith, R.D., (1998) "The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A.," Freshwater Biology, 40,517-530.

(The authors describe the development of the HGM approach and potential applications for protecting and monitoring riparian wetlands. Assessment models for fourteen alluvial wetlands functions are described.) 7

Heede, B.H. (1986) "Designing for dynamic equilibrium in streams," Water Resources Bulletin, 22-3, 351-357.

(Streams are dynamic systems, so steady state does not exist for any appreciable period of time. Meanders and degradation/aggradation of the bed are adjustment processes of the stream. If humans interfere with the processes, other adustment processes will be initiated. However, by working with on-going processes, success is attainable with less effort and lower cost.) 4,5,6

Henderson, J. E. (1986) "Environmental designs for stream bank protection projects," Water Resources Bulletin, 22-4, 549-558.

(Adverse environmental impacts have been minimized and enhancement of existing habitat and aesthetics has been achieved through the development of new, innovative designs or modifications to existing designs and through use of construction and maintenance practices that promote habitat and aesthetics. Use of vegetation for bank protection is most effective when used in combination with structural components.) 2,4

Hickey, J.T., and Diaz, G.E. (1999) "From flow to fish to dollars: and integrated approach to water allocation," J. of the American Water Resources Association, 35-5, 1053-1067.

(This paper presents the results of a case study on the value and application of a conceptual integration of economic, salmonid population, physical habitat, and water allocation models.) 4,6,8

Hill, M.T., Platts, W.S., and Beschta, R.L. (1991) "Ecological and geomorphological concepts for instream and out-of-channel flow requirements," Rivers, 2-3, 198-210.

(Alteration of streamflow for power production, irrigation, flood control, and other purposes adversely affects aquatic resources. The authors examined various concepts concerning the broad interactions of fluvial-geomorphic processes, riverine-riparian habitat, and their geographic setting.) 4,5

Hobbs, R.J., and Norton, D.A. (1996) "Towards a conceptual framework for restoration ecology," Restoration Ecology, 4-2, 93-110.

(Key processes in restoration include identifying and dealing with the processes leading to degradation in the first place, determining realistic goals and measures of success, developing methods for implementing the goals and incorporating them into land management and planning strategies, and monitoring the restoration and assessing its success. To become a useful tool, restoration ecology must become a landscape-scale endeavor.) 1,4

Inoue, M., and Nakano, S. (1999). "Habitat Structure Along Channel-Unit Sequences for

Juvenile Salmon: A Subunit-Based Analysis of In-Stream Landscapes," Freshwater Biology, 42, 597-608.

(This study examined habitat structure and habitat use by juvenile masu salmon in small streams in Northern Hokkaido, Japan. Results of the study suggest that habitat value should be determined not only by the habitat itself, but also by the characteristics of adjacent habitats. To that end, the use of the habitat by the fish should be studied in the context of the total in-stream landscape.) 1,4

Johnson, B.L., Richardson, W.B., and Naimo, T.J., (1995) "Past, present, and future concepts in large river ecology," Bioscience, 45-3, 134-141.

(Despite the importance of large rivers, understanding of how they function and how human activities influence river processes is limited. There are currently two primary hypotheses of how lotic systems function: the river continuum concept with its corollaries and the flood-pulse concept. Neither of these explains system function in all large rivers.) 1,6

Karouna, N. (1991) "Stream restoration and bio-engineering techniques," Conference Paper presented: Restoring Our Home River: Water Quality and Habitat in the Anacostia, College Park, MD.

(This paper presents a comprehensive summary of structural methods that can be used to stabilize eroding stream banks and improve aquatic habitat within degraded urban stream systems. Many of the basic techniques were derived from work traditionally associated with the restoration of un-developed watersheds.) 2,4

Klingeman, P. C. (1984) "Evaluating hydrologic needs for design of stream habitat modification structures," Proceedings of the Pacific Northwest Stream Habitat Workshop, Arcata, CA.

(This paper describes the needs and uses of basic hydrologic, hydraulic, and geomorphic information for designing a stream habitat modification structure at a site. Also, common types of stream habitat modification structures are described.) 2,5,6

Kondolf, G.M. (2000) "Some Suggested Guidelines for Geomorphic Aspects of Anadromous Salmonid Habitat Restoration Proposals," Restoration Ecology, 8, 48-56.

(Stream restoration projects to improve habitat for anadromous salmonids must be justified on the basis of geomorphology as well as biology. At the watershed scale, the geomorphic setting should be addressed by specifying changes in the flow regime or sediment yield; at the reach scale, geomorphic setting and process should be addressed by indicating the basis for design channel form and dimensions, calculating the frequency of bed mobilization, and assessing existing gravel quality for spawning. Provisions should be made for post-project performance evaluation.) 1,4,5,6

Kondolf, G.M. (2000) “Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals,” Restoration Ecology, 8-1, 48-56.

(To be successful, river restoration projects must account for geomorphic processes at both the watershed and reach scales. In streams with sufficient energy and sediment load to recreate a natural channel morphology during floods, aquatic habitat might best be served by no direct physical intervention beyond removing those factors that negatively influence habitat [e.g., close levees, riprapped banks, etc.].) 1,4,5,+

Montgomery, D.R. (1995) “Input- and output-oriented approaches to implementing ecosystem management,” Environmental Management, 19-2, 183-188.

(Input-oriented landscape management provides the foundation for implementing ecosystem management based on current knowledge of processes and linkages among biological and physical components of an ecosystem and the influences of human actions on those processes and linkages. Defining the priorities between resource use or extraction and acceptable changes in ecosystem condition is a component of any land management framework.) 1

Morrow, J.V., Jr., and Fischenich, J.C., 1999. Habitat Requirements for Freshwater Fish. TN SR-99-6, USACE WES, Vicksburg, MS. April, 1999.

(With very few exceptions, stream restoration projects will have consequences for fish communities and the user groups associated with those communities. An organism’s habitat must contain all the physical, chemical, and biological features needed for that organism to complete its life cycle. For fishes this may include a variety of parameters such as water temperature regimes, pH, amount and type of cover, substrate type, turbidity, depth, water velocity, inorganic nutrient levels, and accessibility to migration routes. Habitat quality affects health of individual fishes, fish populations, and communities, and changes in habitat will usually result in changes to the species composition of a fish community. This technical note characterizes fish habitat and habitat requirements and preferences. It is designed to help water resource managers who may have little or no training in fishery science to better understand problems associated with freshwater fish habitat.) 1,4

Moyle, P.B., and Randall, P.J. (1998) “Evaluating the biotic integrity of watersheds in the Sierra Nevada, California,” Conservation Biology, 12-6, 1318-1326.

(The authors contend that one problem with the selected watershed approach to conservation is that it implies that watersheds can be systematically rated so that those with the highest biodiversity values can be the focus of whole-watershed protection efforts. They present an alternated method, called the watershed index of biotic integrity [W-IBI], for identifying watersheds with high conservation potential over a much larger area.)   4

Naiman, R.J., Bilby, R.E., and Bisson, P.A. (2000) "Riparian ecology and management in the Pacific coastal rain forest," Bioscience, 50-11, 996-1011.

(This paper discusses the role of the many dynamic processes affecting riparian zones within the Pacific coastal rain forest. There have been dramatic changes in the management of riparian areas, driven by new understandings of riparian processes. These new insights include: restoring biophysical properties of riparian zones improves all natural resource values; protecting interactions between surface flows and groundwater is essential to aquatic-riparian integrity; allowing streams and rivers to migrate laterally is necessary for habitat development; incorporating natural flow regime characteristics in regulated rivers promotes aquatic and riparian diversity and resilience; and control of exotic species depends on reestablishing natural land-water interactions in riparian areas.) 1,3,5,+

Newbury, R., and Gaboury, M. (1993) "Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour," Freshwater Biology, 29, 195-210.

(Rivers and streams are integrated flowing systems that create and maintain aquatic habitats within the structure of their flow as well as on and below their wetted boundaries. The combination of elements from geomorphology, open-channel hydraulics, and hydraulic habitat requirements of stream fish form the basis for an ecologically sound "soft engineering" of river channels. Two project examples were used to demonstrate how this "soft engineering" approach enhanced the fish habitat.)   1,4,5,6,8

Nunnally, N. R., and Sotir, R. B. (1994) "Soil bioengineering for stream bank protection," Erosion, 1-5, 38-44.

(Stream bank protection and stabilization measures work either by reducing the force of flowing water, by increasing the resistance of the bank to erosion, or by some combination of the two. Soil bioengineering systems are natural in appearance; they provide shade, overhanging cover, and organic debris for aquatic ecosystems; and they provide good riparian habitat.)   2,4

Office, Chief of Engineers, U. S. Army (1989) "Environmental Engineering for Local Flood Control Channels," Engineer Manual 1110-2-1205, Washington, DC.

(This manual provides guidance for incorporating environmental considerations in the planning, engineering, design, and construction of flood control channels, levees, and associated structures. Channel modifications for flood and erosion control include clearing and snagging; channel straightening; channel enlargement; stream bank protection; channel lining; and construction of grade control structures, culverts, levees, and floodwalls.)   2

Pastorok, R. A., MacDonald, A., Sampson, J. R., Wilber, P., Yozzo, D. J., and Titre, J. P.

(1997) "An ecological decision framework for environmental restoration projects," Ecological Engineering, 9, 89-107.

(Ecosystem restoration projects require planning and monitoring, yet projects completed thus far have been planned on an ad hoc, consensus basis and are virtually ignored after revegetation at the site is complete. A process was developed to integrate a fundamental understanding of ecological principles into the existing project planning framework used by the U. S. Army Corps of Engineers in their growing role in restoration of aquatic habitats, but it should be applied to terrestrial habitats as well.) 1,4

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and Stromberg, J.C. (1997) "The natural flow regime," Bioscience, 47-11, 769-784.

(Historically, the protection of river ecosystems has been limited in scope, emphasizing water quality and only one aspect of water quantity: minimum flow. Five critical components of the flow regime regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions. By defining flow regimes in these terms, the ecological consequences of particular human activities that modify one or more components of the flow regime can be considered explicitly. To manage rivers from this new perspective, some policy changes are needed with regard to narrow regulatory focus and conflicting mandates of multiple agencies.) 1,6, +

Prichard, D. (1998) Riparian Area Management, Technical Reference 1737-15, USDI Bureau of Land Management, National Applied Resource Sciences Center, Denver, CO.

(This report describes a methodology for determining the Proper Functioning Condition [PFC] for riparian-wetland areas. Various functions and processes that the wetland should be able to address are used to determine the condition of the area.) 1,3

Reiman, B.E., Lee, D.C., Thurow, R.F., Hessburg, P.F., and Sedell, J.R. (2000) "Toward and integrated classification of ecosystems: defining opportunities for managing fish and forest health," Environmental Management, 25-4, 425-444.

(The goals of aquatic and terrestrial conservation and restoration are often viewed as being in conflict. The authors used recent information on forest and fish communities to classify river sub-basins across the region and explore the potential conflict and opportunity for a more integrated view of management. The classification indicated that there are often common trends in terrestrial and aquatic communities that highlight areas of potential convergence in management goals.) 1,4

Rosgen, D. L. (1997) "A geomorphological approach to restoration of incised rivers," Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 12-29.

(Geomorphologic concepts are described as integrated into incised river restoration projects. A range of restoration design concepts are presented including; returning the stream to its original elevation and re-connecting floodplains, widening the belt width to construct a new channel at the existing elevation, changing stream types, and stabilizing the existing incised channel in place.) 1,5

Shaffer, P.W., Kentula, M.E., and Gwin, S.E. (1999) "Characterization of wetland hydrology using hydrogeomorphic classification," Wetlands, 19-3, 490-504.

(Because hydrology is an important determinant of many wetland functions, resource managers using restoration and mitigation to offset wetland losses should strive for project design and siting that re-establish the hydrogeomorphology of natural wetlands to improve the likelihood of replacing wetland functions. This study provided a test of HGM classification as a tool for characterizing wetlands in a geographic region in which HGM has not been previously applied. Results suggest the potential to use the classification to generalize results from a relatively small sample to the larger population of wetlands within the landscape.) 7

Shields, F. D., Jr., and Hoover, J. J. (1991) "Effects of channel restabilization on habitat diversity, Twentymile Creek, Mississippi," Regulated Rivers: Research & Management, 6, 163-181.

(Twentymile Creek was channelized prior to 1910, in 1938, and in 1966. Straitening and enlargement in 1966 resulted in channel instability, rapid bed degradation and cross-section enlargement. Grade control structures and various types of stream bank protection were constructed along the channel in the early 80's to restore stability. This paper studies the effects of restabilization of Twentymile Creek on aquatic habitats.) 2,4

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1998) "Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi," Hydrobiologia 382, 63-86. 2,4

(A study of incised warmwater stream rehabilitation was conducted to develop and demonstrate techniques that would be economically feasible for integration with more orthodox, extensively employed watershed stabilization techniques. During the study two reaches were modified by adding woody vegetation and stone structure to rehabilitate habitats degraded by erosion and channelization. These experiments suggest that major gains in stream ecosystem rehabilitation can be made through relatively modest but well-designed efforts to modify degraded physical habitats.) 1,2,5

Shields, F.D., Jr., and Smith, R.H. (1992) "Effects of large woody debris removal on physical characteristics of a sand-bed river," Aquatic Conservation: Marine and Freshwater Ecosystems, 2, 145-163.

(Results suggest that benefits of proposed LWD removal projects should be carefully analyzed in the light of costs and environmental impacts. Removal of

LWD in the study reaches decreased the friction factor for near-bankful conditions by about one third and increased bankful flow capacity by about one fourth. Erosion triggered by LWD removal may increase channel maintenance costs.) 2,4,6

Shields, F. D., Jr., Cooper, C. M., and Knight, S. S. (1995) "Experiment in stream restoration," Journal of Hydraulic Engineering 121-6, 494-502.

(Aquatic habitats in a deeply incised sand-bed channel were modified by adding stone and planting dormant willow posts. Restoration structures were designed as complements to existing channel stabilization works. Fish numbers tripled, median fish size increased by 50 percent, and the number of species increased from 14 to 19.) 2,4

Sotir, R. B., and Nunnally, N. R. (1995) "Use of riprap in soil bioengineering stream bank protection," River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone, John Wiley & Sons Ltd., 577-589.

(Stream bank protection systems that incorporate woody vegetation provide additional benefits over those that do not. Soil bioengineering, employs woody vegetation as the major structural component in stream bank protection designs. Although, in some applications, adequate protection against erosion can be provided by vegetation systems alone, most applications require the use of some rock in conjunction with vegetation to prevent damage to the system that would impair its effectiveness or reduce its environmental benefit.) 2,4,5
http://www.sotir.com/pubs/publist/riprap/riprap.html

Sparks, R.E., (1995) “Need for ecosystem management of large rivers and their floodplains,” Bioscience, 45-3, 168-182.

(The author describes the importance of large river-floodplain ecosystems and the consequences of altering their natural processes, functions, and connectivity.) 1,4,+

U. S. Department of Transportation (1979) Restoration of fish habitat in relocated streams, FHWA-IP-79-3.

(This manual provides guidelines for the design and construction of relocated channels, and describes measures that will lead to rapid recovery of new channels by natural processes. Good design, and implementation of these measures can greatly reduce the adverse effects of stream relocation.) 2

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E. (1980). “The river continuum concept,” Canadian Journal of Fisheries and Aquatic Science, 37,130-137.

(Physical variables within a river system present a continuous gradient of physical conditions. The river continuum concept provides a framework for integrating predictable and observable biological features of the lotic systems. Although the model was developed specifically in reference to natural, unperturbed stream ecosystems, it should accommodate many unnatural disturbances, as well.) 1,4

Wesche, T. A., (1985) "Stream channel modifications and reclamation structures to enhance fish habitat," The Restoration of Rivers and Streams, Chapter 5, Butterworth Publishers.

(Many of the detrimental effects of channelization can be avoided, with little compromise in channel efficiency, by employing channel design guidelines that do not destroy the hydraulic and morphologic equilibrium that natural streams possess. These guidelines include minimal straightening; promoting bank stability by leaving trees, minimizing channel reshaping, and employing bank stabilization techniques; and, emulating the morphology of natural stream channels.) 1,5,6

Wissmar, R.C., and Beschta, R.L. (1998) "Restoration and management of riparian ecosystems: a catchment perspective," Freshwater Biology,40, 571-585.

(This paper examines approaches and perspectives for restoration of riparian ecosystems. Sound restoration strategies require an understanding of the processes, functional attributes, and the landscape connectivity of riverine habitats, both temporally and spatially. The process of developing a restoration strategy also requires an understanding of the influences of present-day human land and water uses and management practices.) 1,3