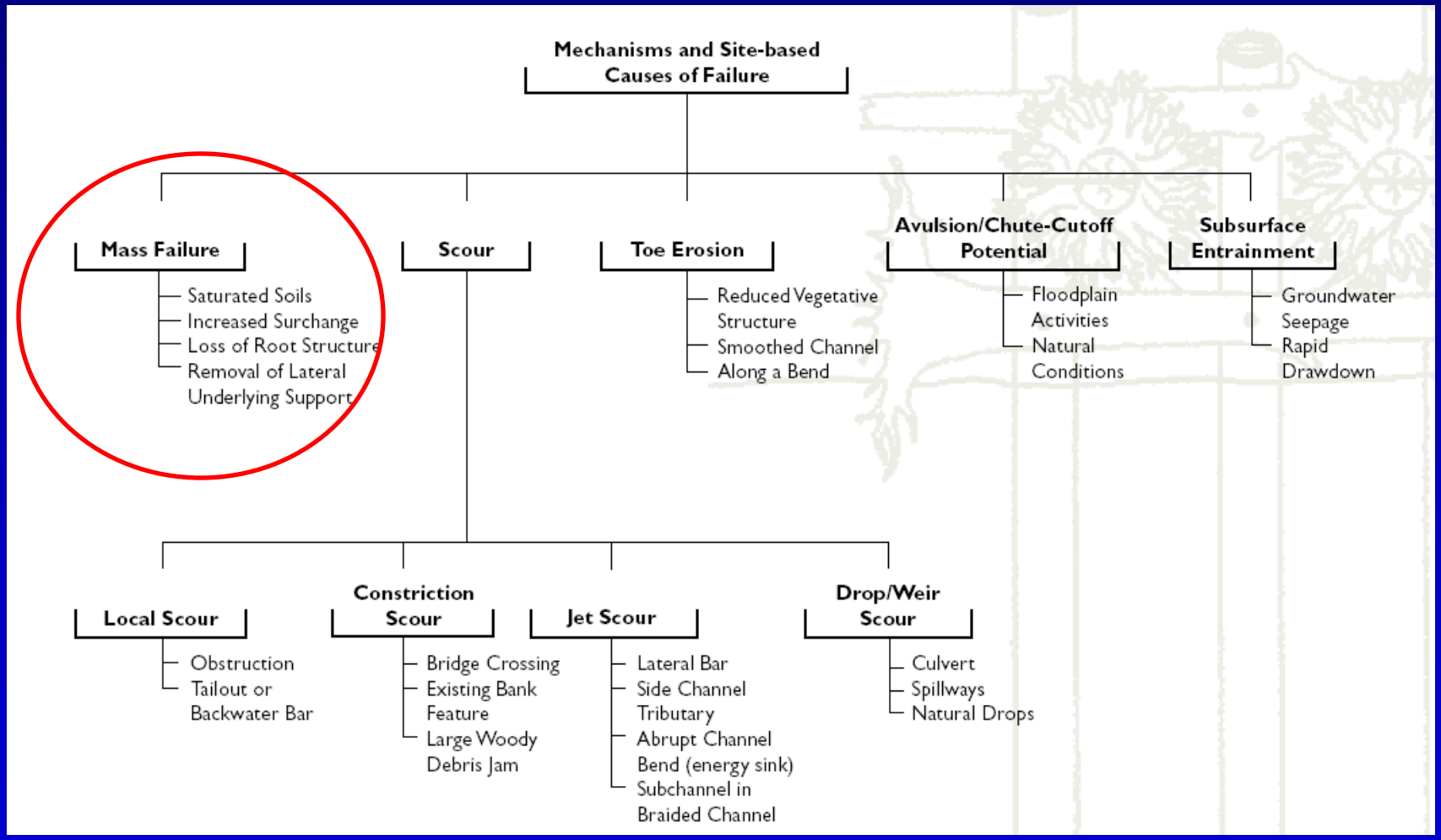
Estimating Scour

CIVE 510

October 21st , 2008

Causes of Scour

Site Stability

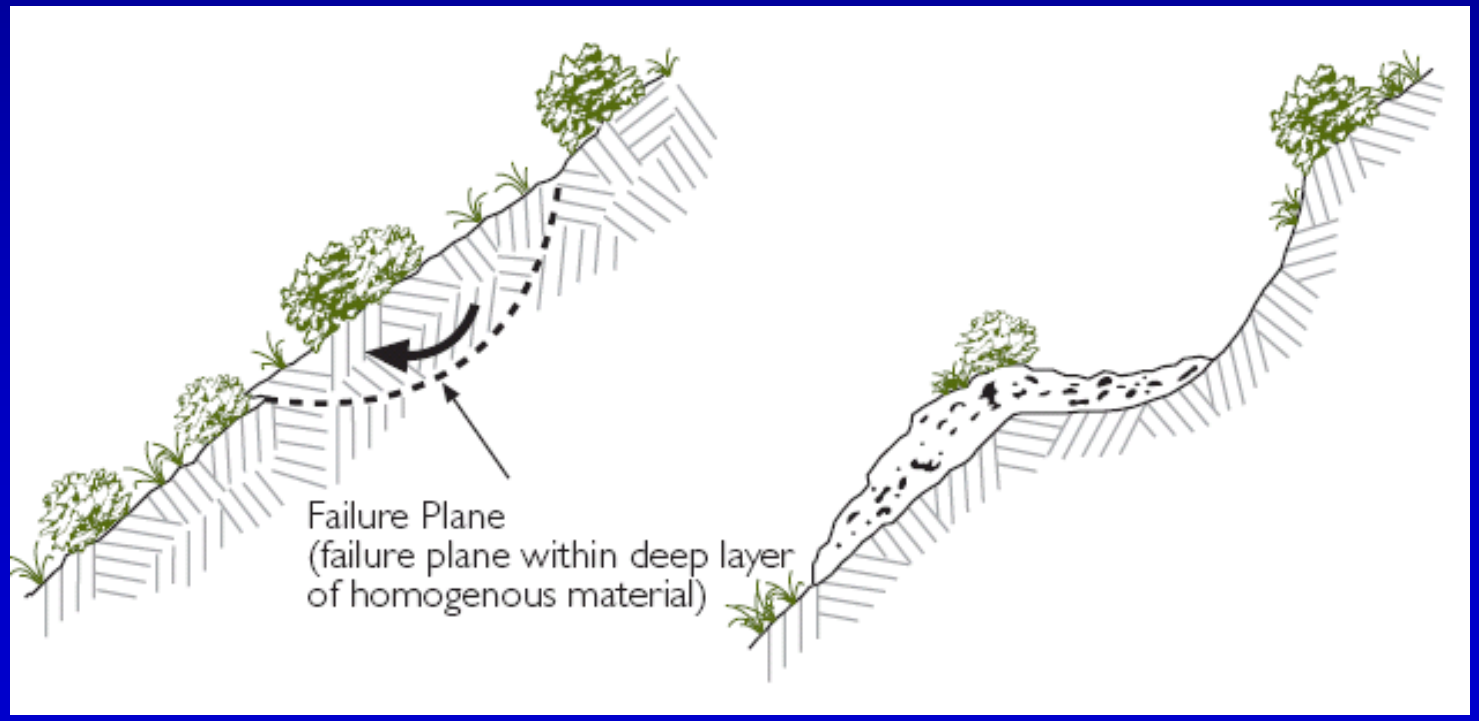


Mass Failure

- Downward movement of large and intact masses of soil and rock
- Occurs when weight on slope exceeds the shear strength of bank material
- Typically a result of water saturating a slide-prone slope
  - Rapid draw down
  - Flood stage manipulation
  - Tidal effects
  - Seepage

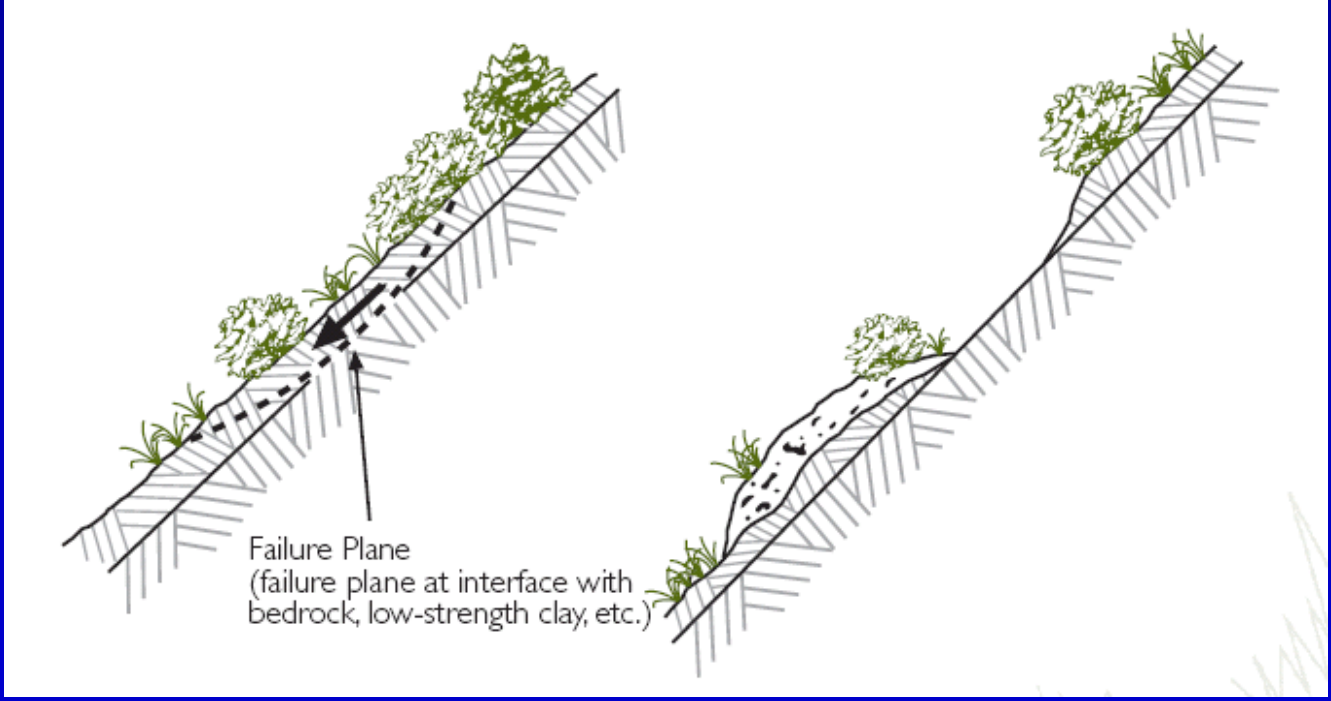
Mass Failure

- Rotational Slide
  - Concave failure plane, typically on slopes ranging from 20-40 degrees

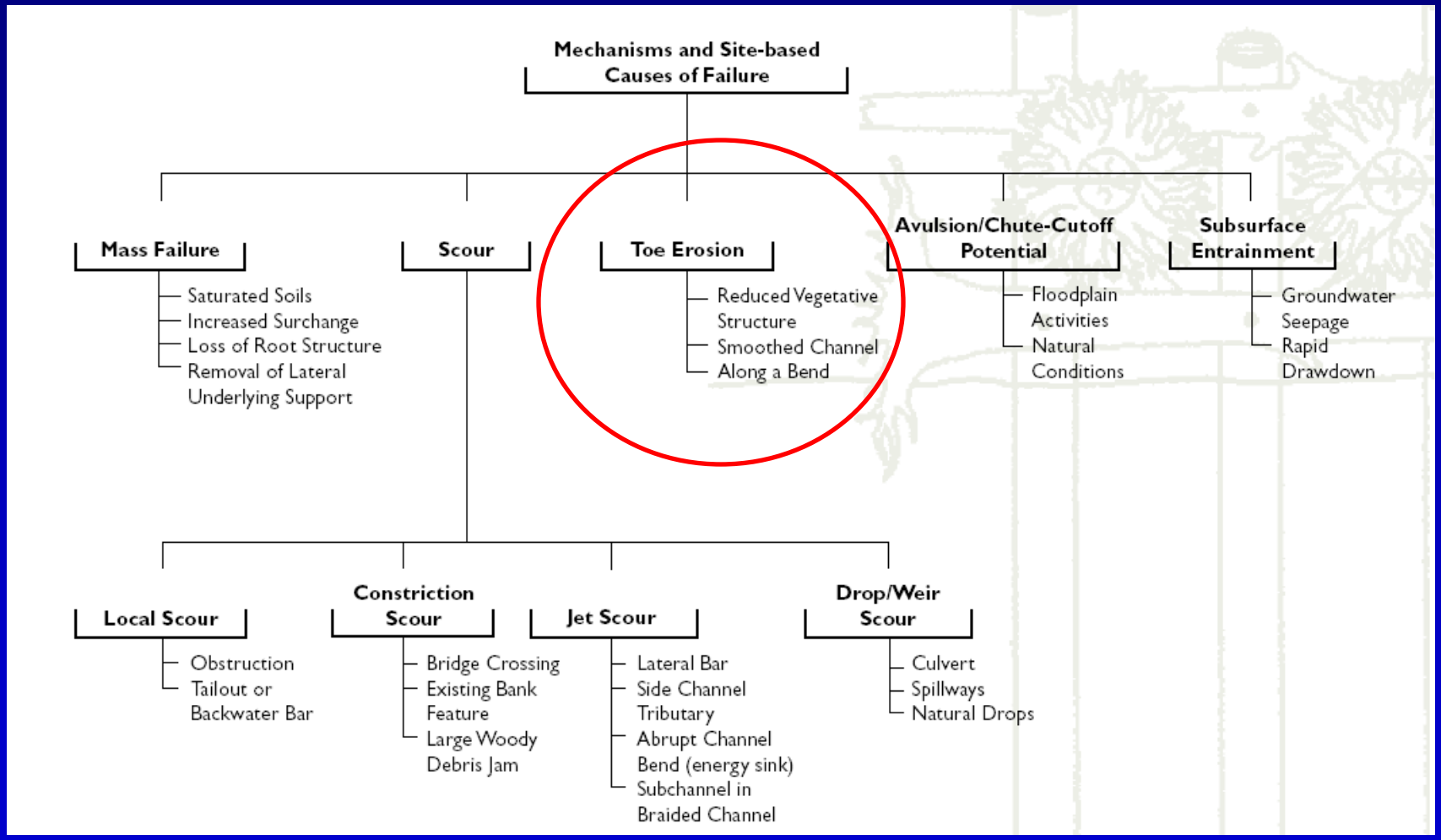


Mass Failure

- Translational Slide
  - Shallower slide, typically along well-defined plane



Site Stability

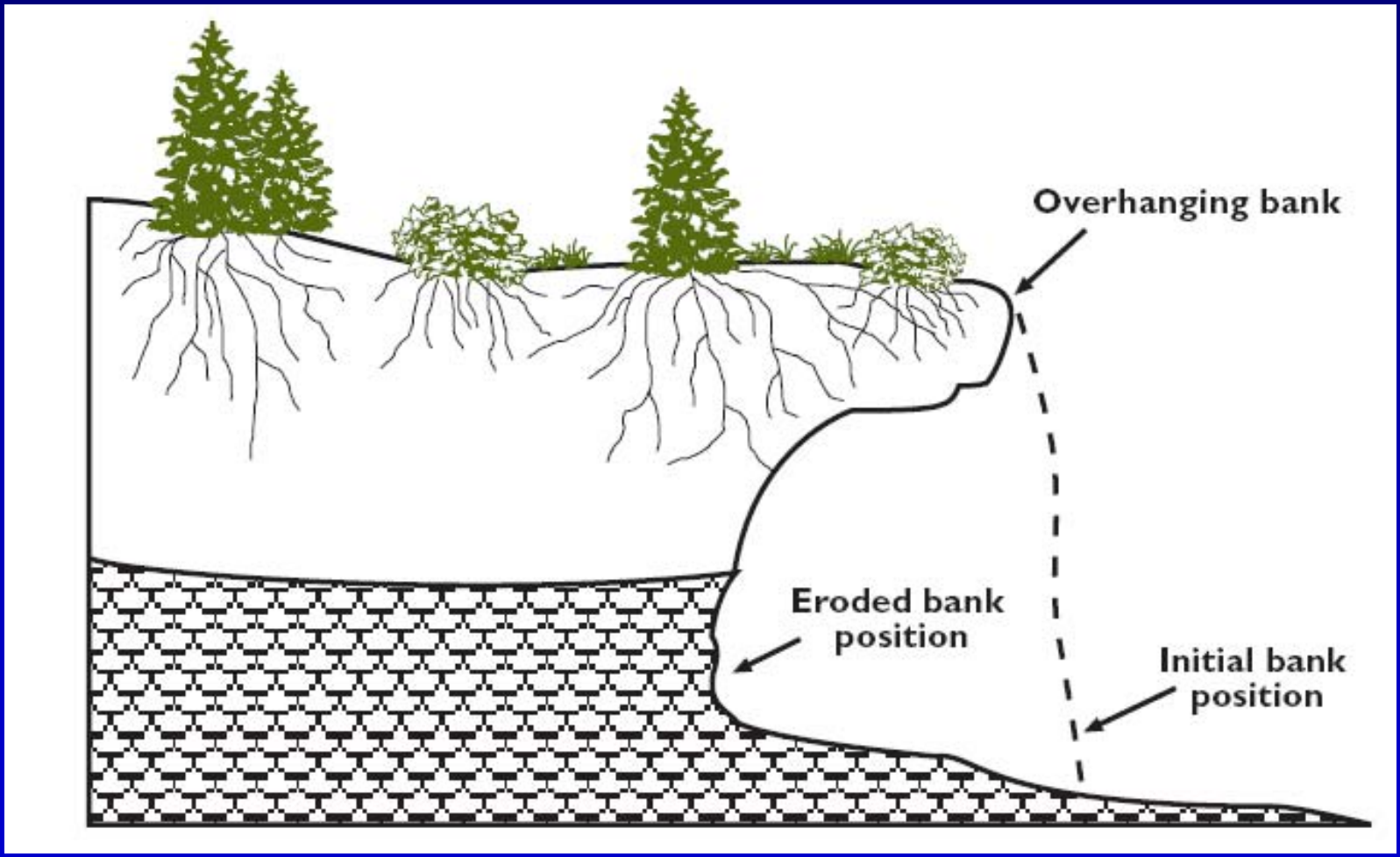


Toe Erosion

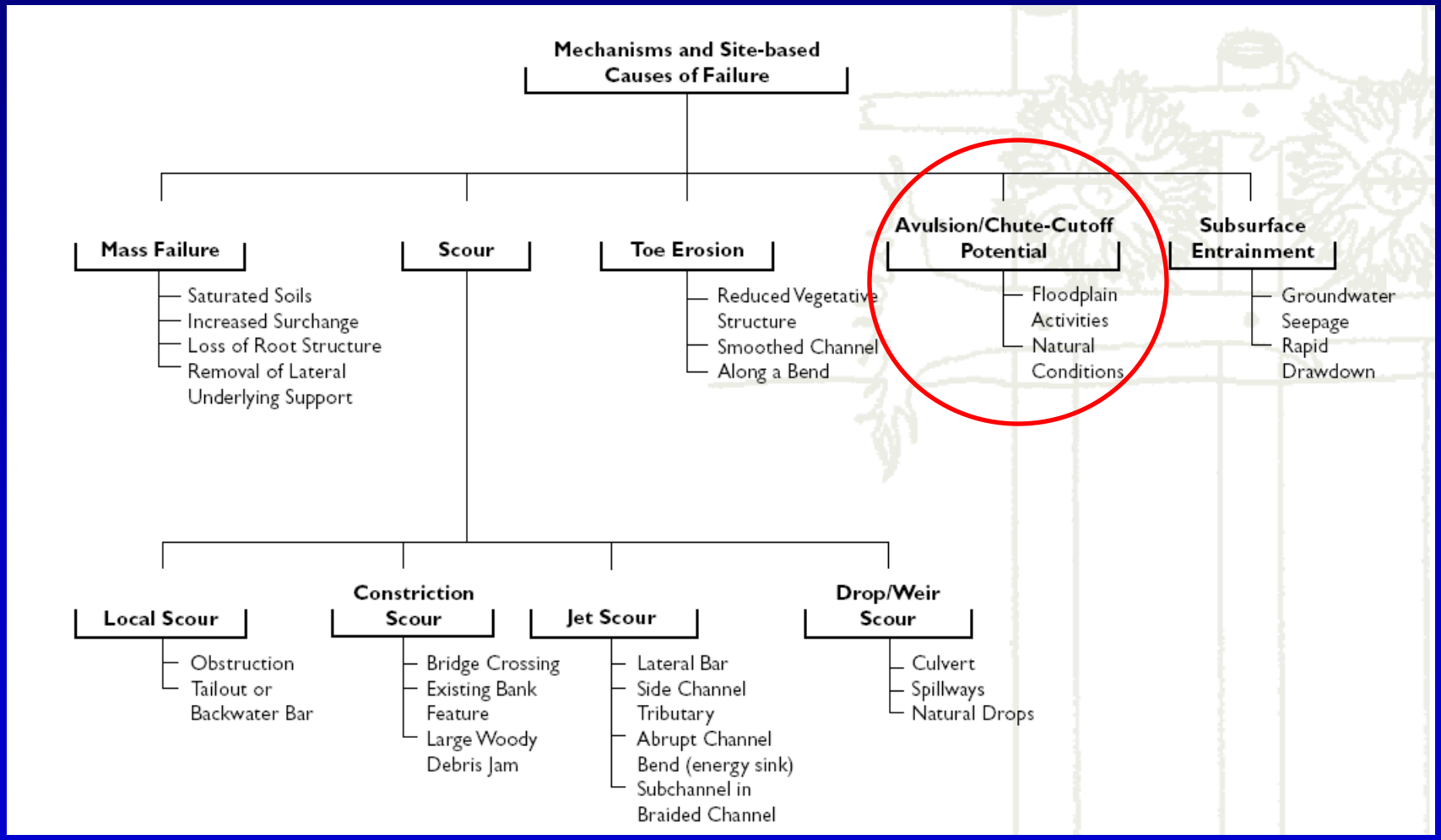
- Occurs when particles are removed from the bed/bank whereby undermining the channel toe
- Results in gravity collapse or sliding of layers
- Typically a result of:
  - Reduced vegetative bank structure
  - Smoothed channels, i.e., roughness removed
  - Flow through a bend

Toe Erosion

Toe Erosion


Overhanging bank
Eroded bank position
Initial bank position

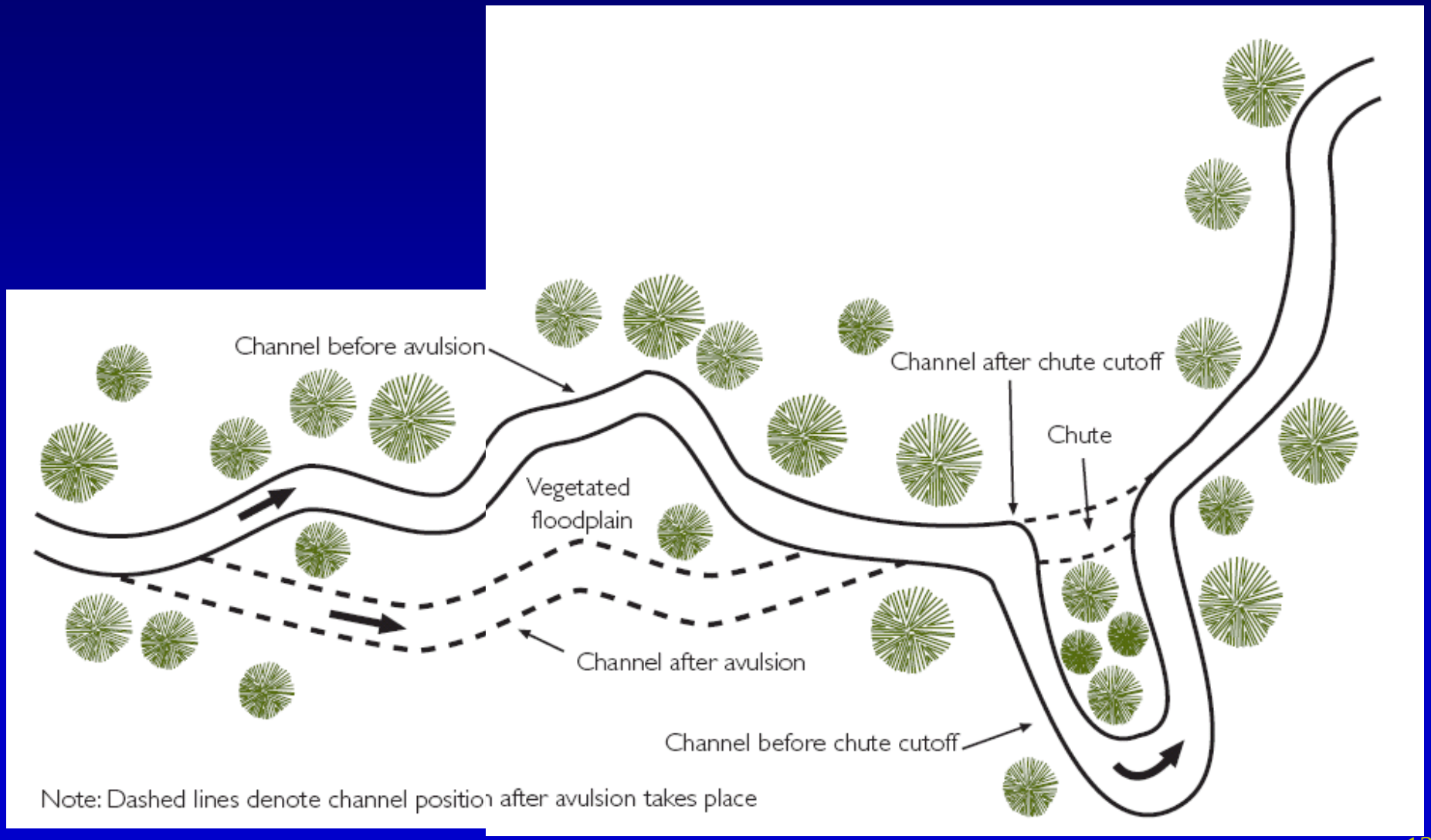
Site Stability



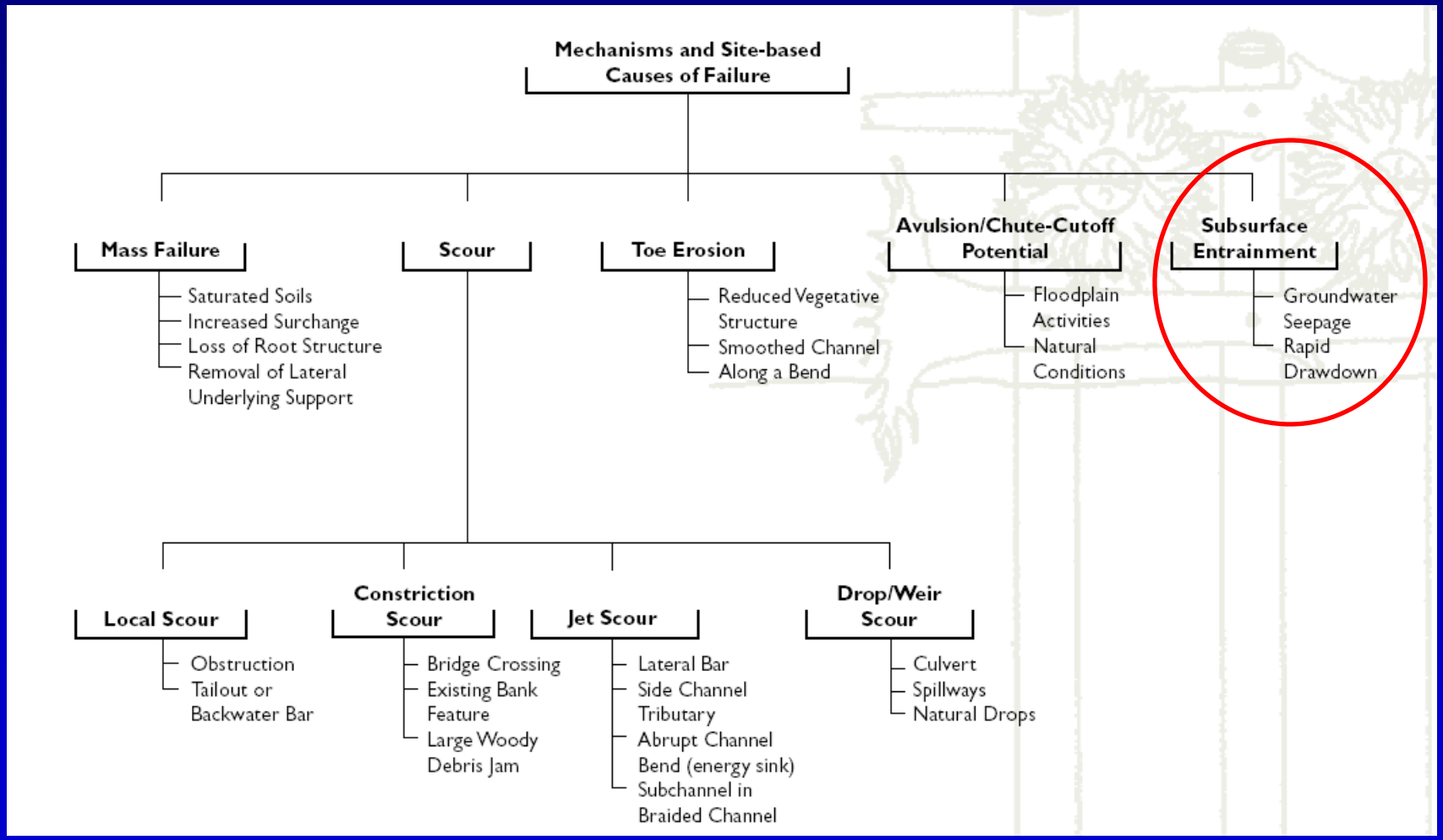
Avulsion and Chute Cutoffs

- Abrupt change in channel alignment resulting in a new channel within the floodplain
- Typically caused by:
  - Concentrated overland flow
  - Headcutting and/or scouring within floodplain
  - Manmade disturbances
- Chute cutoff – smaller scale than avulsion

Avulsion and Chute Cutoffs



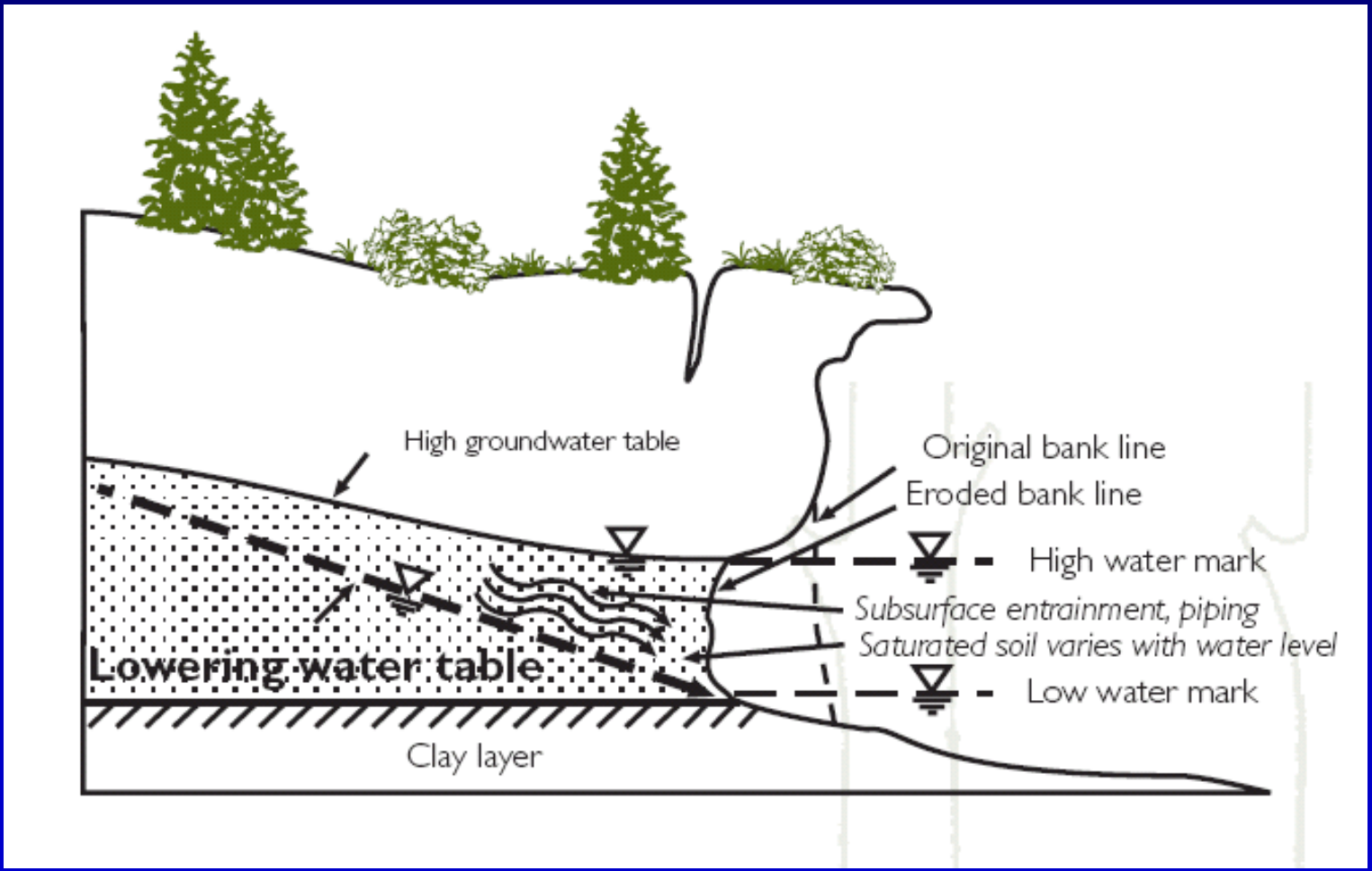
Site Stability

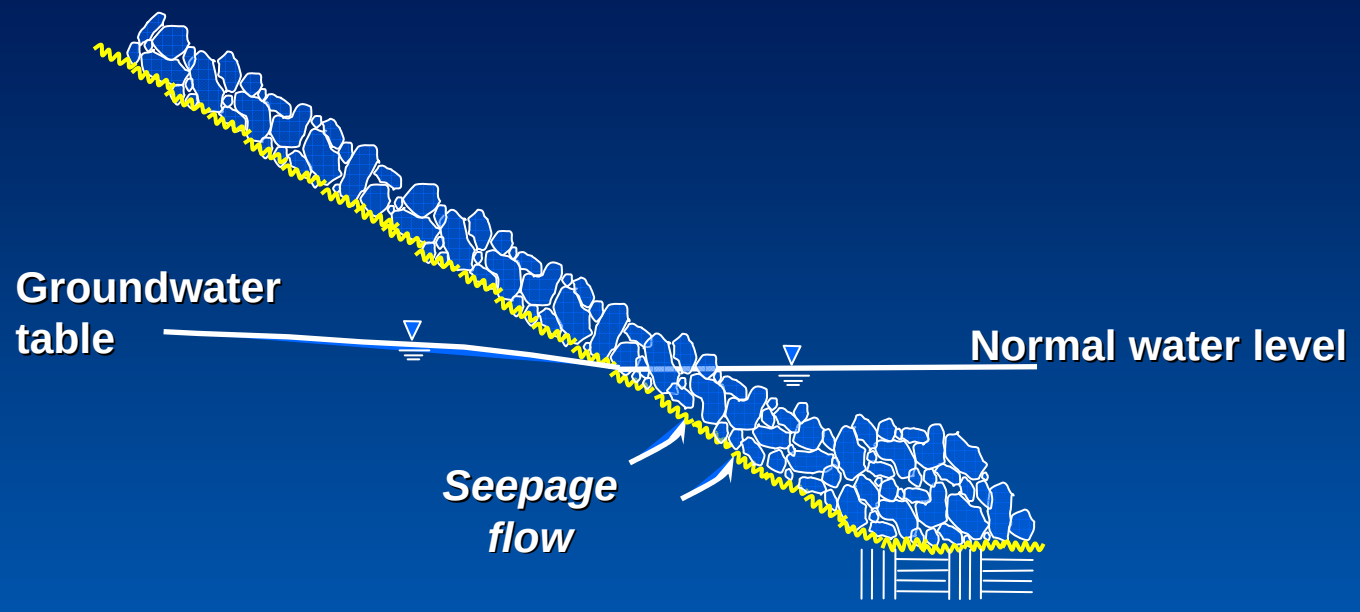


Subsurface Entrainment

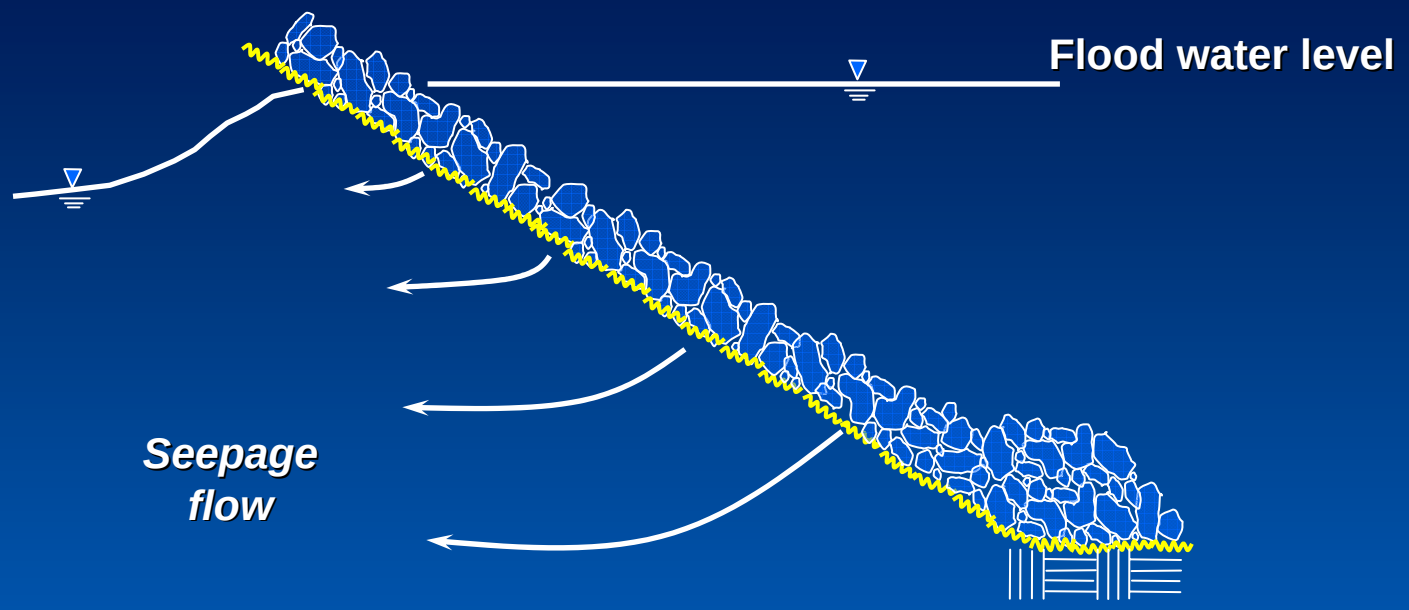
- Piping – occurs when subsurface flow transports soil particles resulting in the development of a tunnel.
- Tunnels reduce soil cohesion causing slippage and ultimately streambank erosion.
- Typically caused by:
  - Groundwater seepage
  - Water level changes

Subsurface Entrainment

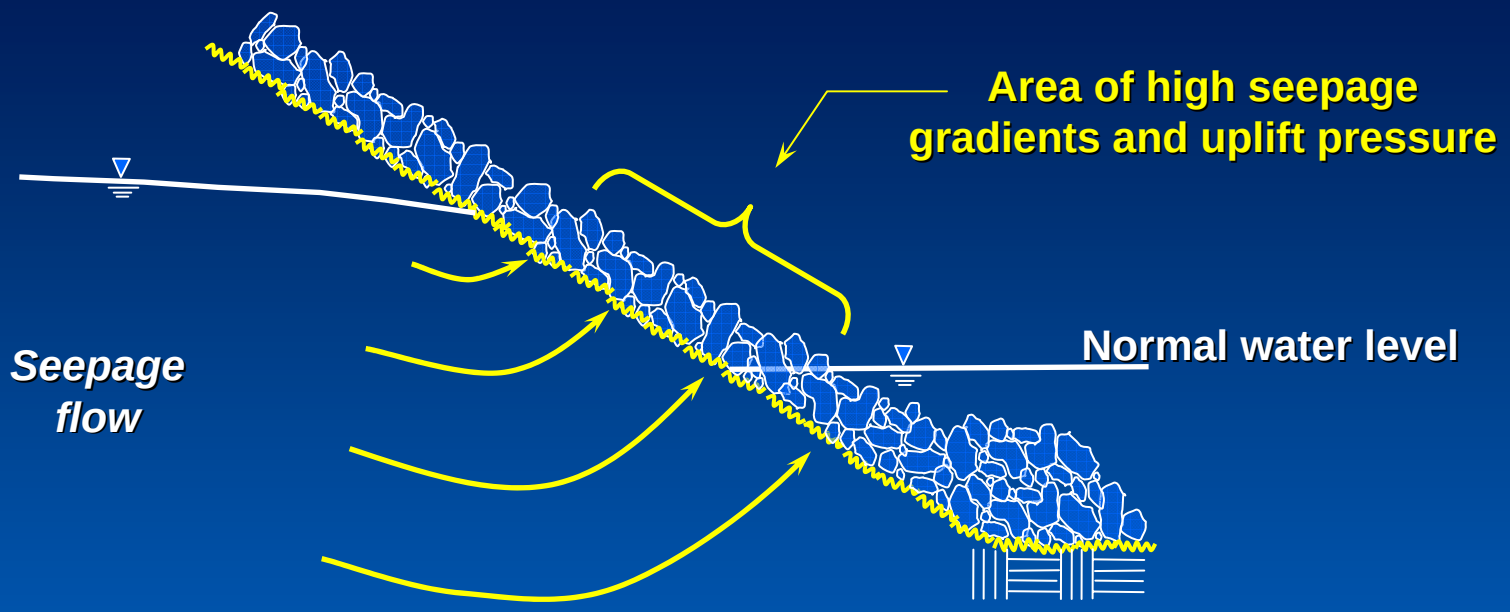




Normal (baseflow) conditions

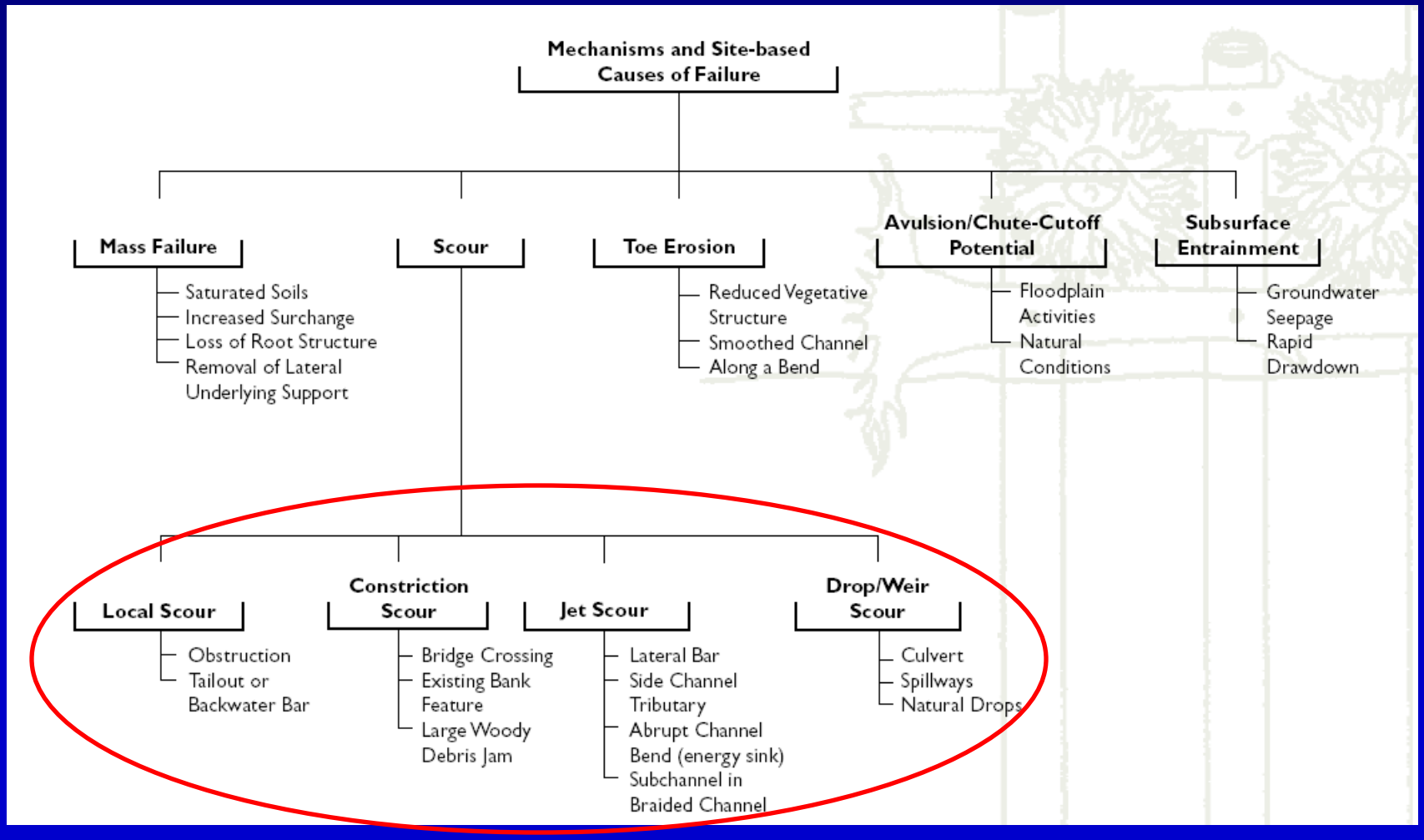


During flood peak



After flood recession

Site Stability



Scour

"Erosion at a specific location that is greater than erosion found at other nearby locations of the stream bed or bank."

Simons and Sentruk (1992)

Scour

- Scour depths needed for:
  - Revetment design
  - Drop structures
  - Highway structures
  - Foundation design
  - Anchoring systems
  - Habitat enhancement

Scour Equations

- All empirical relationships
- Specific to scour type
- Designed for and with sand-bed systems
- May distinguish between live-bed and clear-water conditions
- Modifications for gravel-bed systems

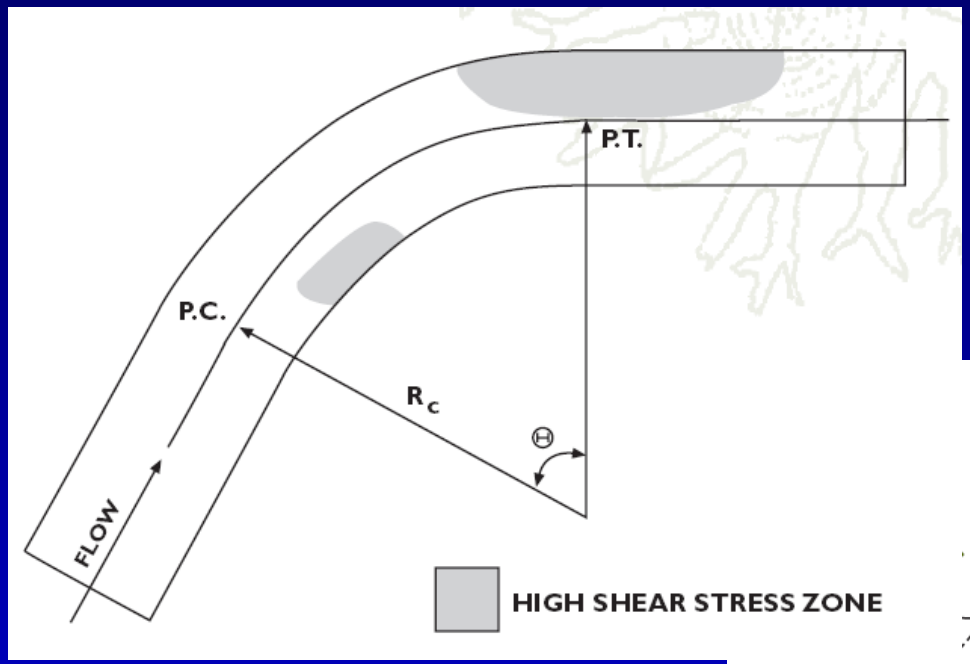
Calculating Scour

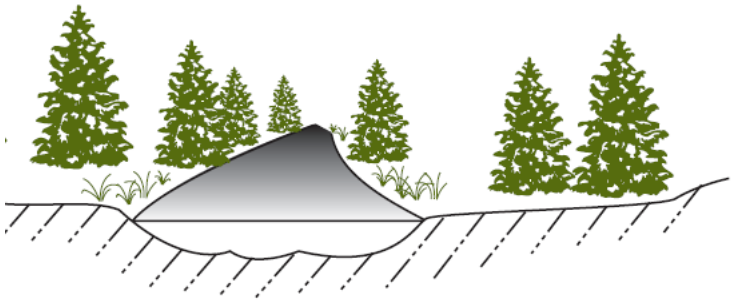
- Identify type(s) of expected scour
- Calculate depth for each type
- Account for cumulative effect
- Compare to any know conditions

5 Types of Scour

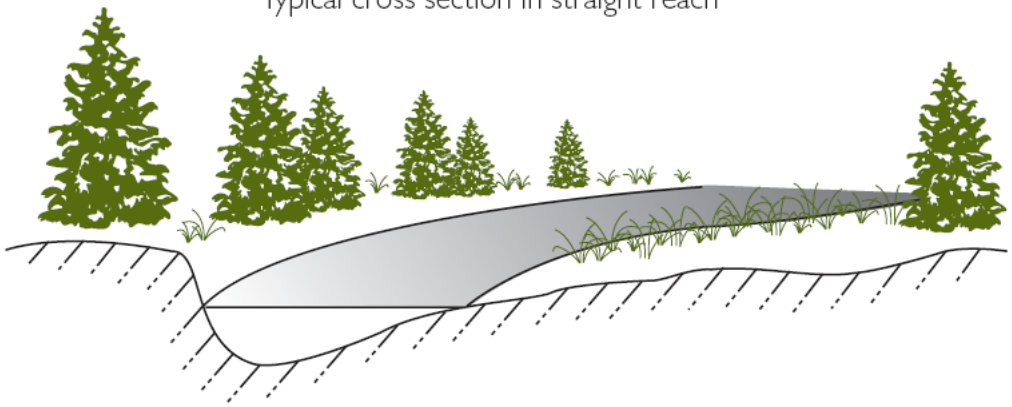
- Bend scour
- Constriction scour
- Drop/weir scour
- Jet scour
- Local scour

Bend Scour





Typical cross section in straight reach



Bend Scour

- Caused by secondary currents
- Material removed from toe
- Field observations can be helpful in assessing magnitude
- Conservative first estimate:
  - Equal to the flow depth upstream of bend
- Three empirical relationships

Bend Scour

- Three methods
  - Thorne (1997)
    - Flume and river experiments
    - D_{50} bed from 0.3 to 63 mm
    - Applicable to gravel bed systems
  - Maynord (1996)
    - Used for sand-bed channels
    - Provides conservative estimate for gravel-bed systems
  - Wattanabe (Maynord 1996)
    - Ditto

Thorne Equation

$$\frac{d}{y_1} = 1.07 - \log\left(\frac{R_c}{W} - 2\right)$$

- Where
  - d = maximum depth of scour (L)
  - y_1 = average flow depth directly upstream of the bend (L)
  - W = width of flow (L)
  - R_c = radius of curvature (L)

$$2 < \frac{R_c}{W} < 22$$

Maynord Equation

$$\frac{D_{mb}}{D_u} = 1.8 - 0.051\left(\frac{R_c}{W}\right) + 0.0084\left(\frac{W}{D_u}\right)$$

- Where
  - D_{mb} = maximum water depth in bend (L)
  - D_u = mean channel depth at upstream crossing (L)
  - W = width of flow at upstream end of bend (L)
  - R_c = radius of curvature (L)

$$1.5 < \frac{R_c}{W} < 10$$

$$1.5 < \frac{W}{D_u} < 10$$

Maynord Equation

$$\frac{D_{mb}}{D_u} = 1.8 - 0.051\left(\frac{R_c}{W}\right) + 0.0084\left(\frac{W}{D_u}\right)$$

- Notes:
  - Developed from measured data on 215 sand bed channels
  - Flow events between 1 and 5 year return intervals
  - Not valid for overbank flows that exceed 20 percent of channel depth
  - Equation is a "best fit", not an envelope – NO FOS
  - Factor of safety of 1.08 is recommended
  - English or metric units
  - Width is that of "active flow"

Wattanabe Equation

$$\frac{d_s}{D} = \alpha + \beta\left(\frac{W}{R_c}\right)$$

- Where
  - d_s = scour depth below maximum depth in bend (L)
  - W = channel top width (L)
  - R_c = radius of curvature (L)
  - D = mean channel depth (L)
  - S = bed slope (L/L)
  - f = Darcy friction factor

$$\alpha = 0.361X^2 - 0.0224X - 0.0394$$

$$X = \log_{10}\left(\frac{WS^{0.2}}{D}\right)$$

$$\beta = \frac{2}{\left\{1.226\pi\left[\left(\frac{1}{\sqrt{f}}\right) - 1.584\right]x\right\}}$$

$$x = \frac{1}{\left[1.5f\left\{\left(\frac{1.1}{\sqrt{f}}\right) - 1.42\right\}\sin\sigma + \cos\sigma\right]}$$

$$\sigma = \tan^{-1}\left[1.5f\left\{\left(\frac{1.1}{\sqrt{f}}\right) - 1.42\right\}\right]$$

Wattanabe Equation

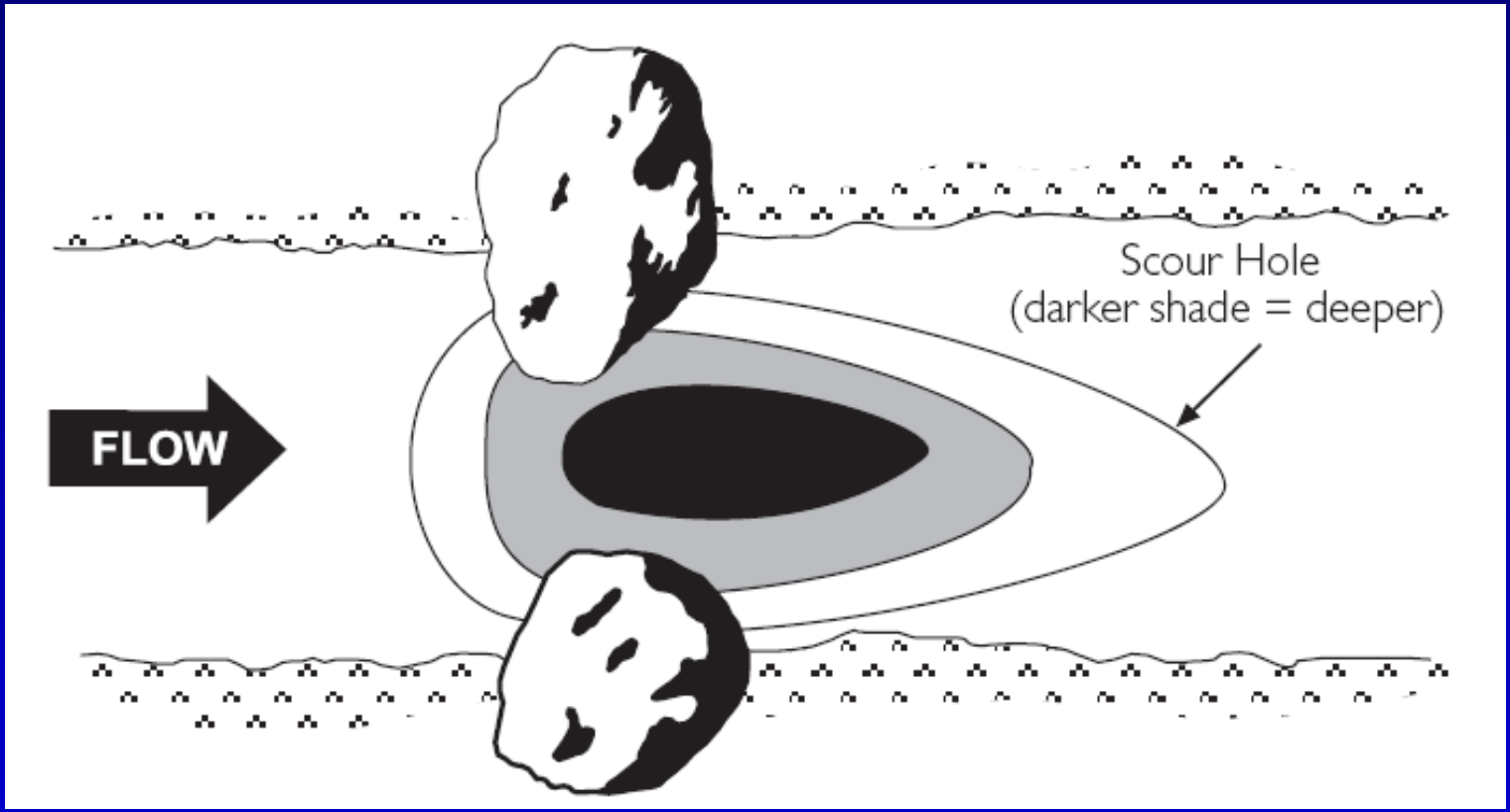
$$\frac{d_s}{D} = \alpha + \beta\left(\frac{W}{R_c}\right)$$

- Notes:
  - Results correlated will with Mississippi River data
  - Limits of application are unknown
  - FOS of 1.2 is recommended
  - English or metric units may be used

5 Types of Scour

- Bend scour
- Constriction scour
- Drop/weir scour
- Jet scour
- Local scour

Constriction Scour



Constriction Scour

- Occurs when channel features created a narrowing of the channel
- Typically, constriction is "harder" than the channel banks or bed
- Caused from natural and/or engineered features
  - Large woody debris
  - Bridge crossings
  - Bedrock
  - Flow training structures
  - Tree roots/established vegetation

Constriction Scour

- Scour equations
  - Developed from flume tests of bridge abutments
  - Equations can be applied for natural or other induced constrictions
  - Most accepted methods:
    - Laursen live-bed equation (1980)
    - Laursen clear-water equation (1980)

Constriction Scour

- Live-bed conditions
  - Coarse sediments may armor the bed
    - Compare with clear-water depth and use lower value
    - Requires good judgment!
  - Equation developed for sand-bed streams
  - Application to gravel bed:
    - Provides conservative estimate of scour depth

Laursen Live-Bed Equation

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{0.86} \left(\frac{W_1}{W_2}\right)^{A}$$

$$d = y_2 - y_0$$

- Where
  - d = average depth of constriction scour (L)
  - y_0 = average depth of flow in constricted reach without scour (L)
  - y_1 = average depth of flow in upstream main channel (L)
  - y_2 = average depth of flow in constricted reach after scour (L)
  - Q_2 = flow in constricted section (L^3/T)
  - Q_1 = flow in upstream channel (L^3/T)
  - W_1 = bottom width in approach channel (L)
  - W_2 = bottom width in constricted section (L)
  - *A* = regression exponent

Laursen Live-Bed Equation

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{0.86} \left(\frac{W_1}{W_2}\right)^{A}$$

$$d = y_2 - y_0$$

ω = fall velocity of D50 bed material (L/T)

U* = shear velocity (L/T)

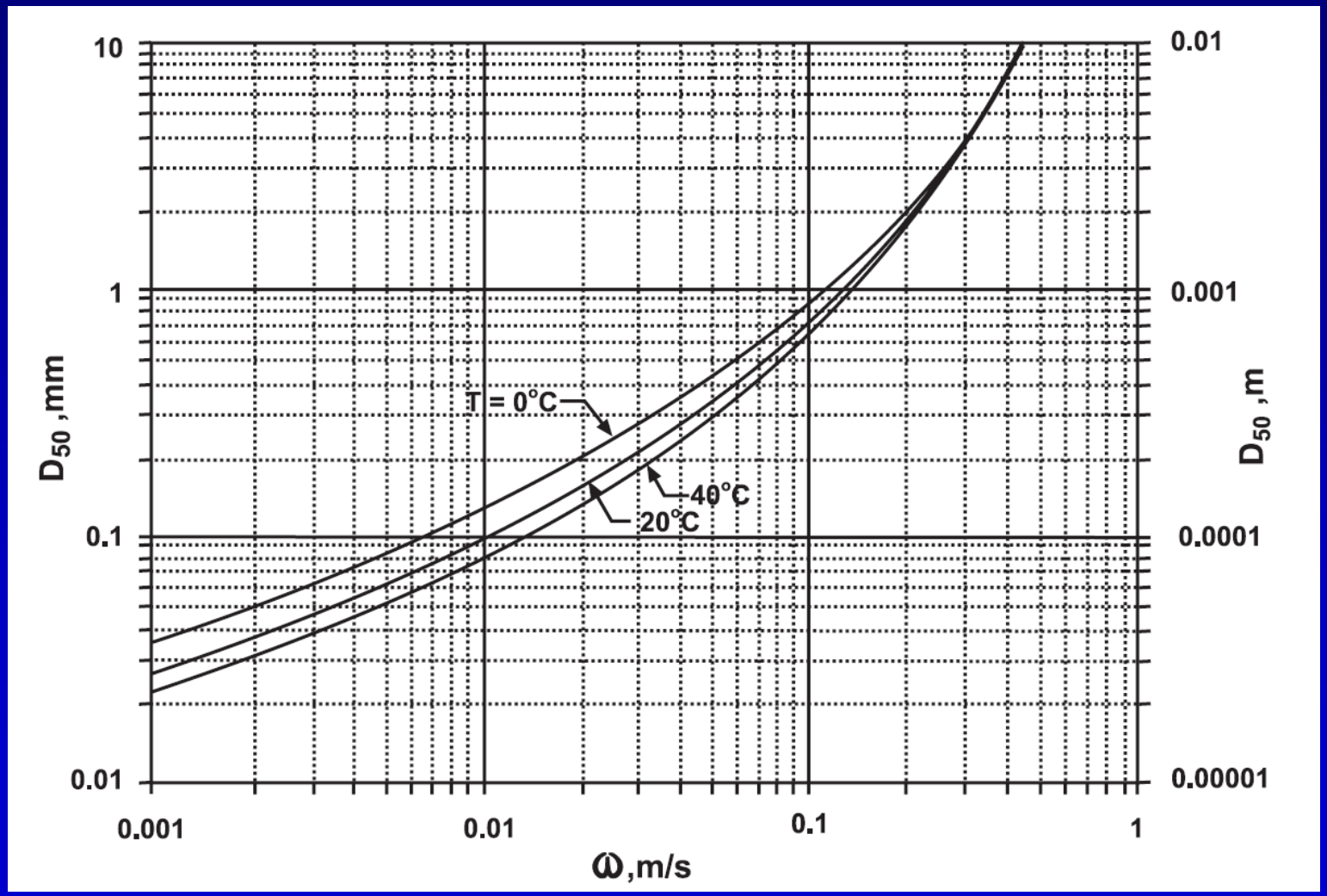
$= (gy_1S_e)^{0.5}$

g = acceleration due to gravity (L/T^2)

S_e = EGL slope in main channel (L/L)

U*/ω	A	Mode of bed Transport
< 0.5	0.59	Bed
0.5 to 2.0	0.64	Suspended
>2.0	0.69	Suspended

Laursen Live-Bed Equation



Laursen Live-Bed Equation

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{0.86} \left(\frac{W_1}{W_2}\right)^{A}$$

$$d = y_2 - y_0$$

- Notes:
  - Assumes all flow passes through constricted reach
  - Coarse sediment may limit live-bed scour
  - If bed is armored, compare with at clear-water scour
  - Both English and metric units can be used

Laursen Clear-Water Equation

$$y_2 = \left(\frac{Q_2^{\,2}}{C D_m^{\,0.67} W_2^{\,2}} \right)^{0.43}$$

$$d = y_2 - y_0$$

- Where
  - d = average depth of constriction scour (L)
  - y_0 = average depth of flow in constricted reach without scour (L)
  - y_2 = average depth of flow in constricted reach after scour (L)
  - Q_2 = flow in constricted section (L^3/T)
  - D_m = 1.25D50 = assumed diameter of smallest non-transportable particle in bed material in constricted reach (L)
  - W_2 = bottom width in constricted section (L)
  - C = unit constant; 120 for English, 40 for metric

Laursen Clear-Water Equation

$$y_2 = \left(\frac{Q_2^{\ 2}}{C D_m^{\ 0.67} W_2^{\ 2}} \right)^{0.43}$$

$$d = y_2 - y_0$$

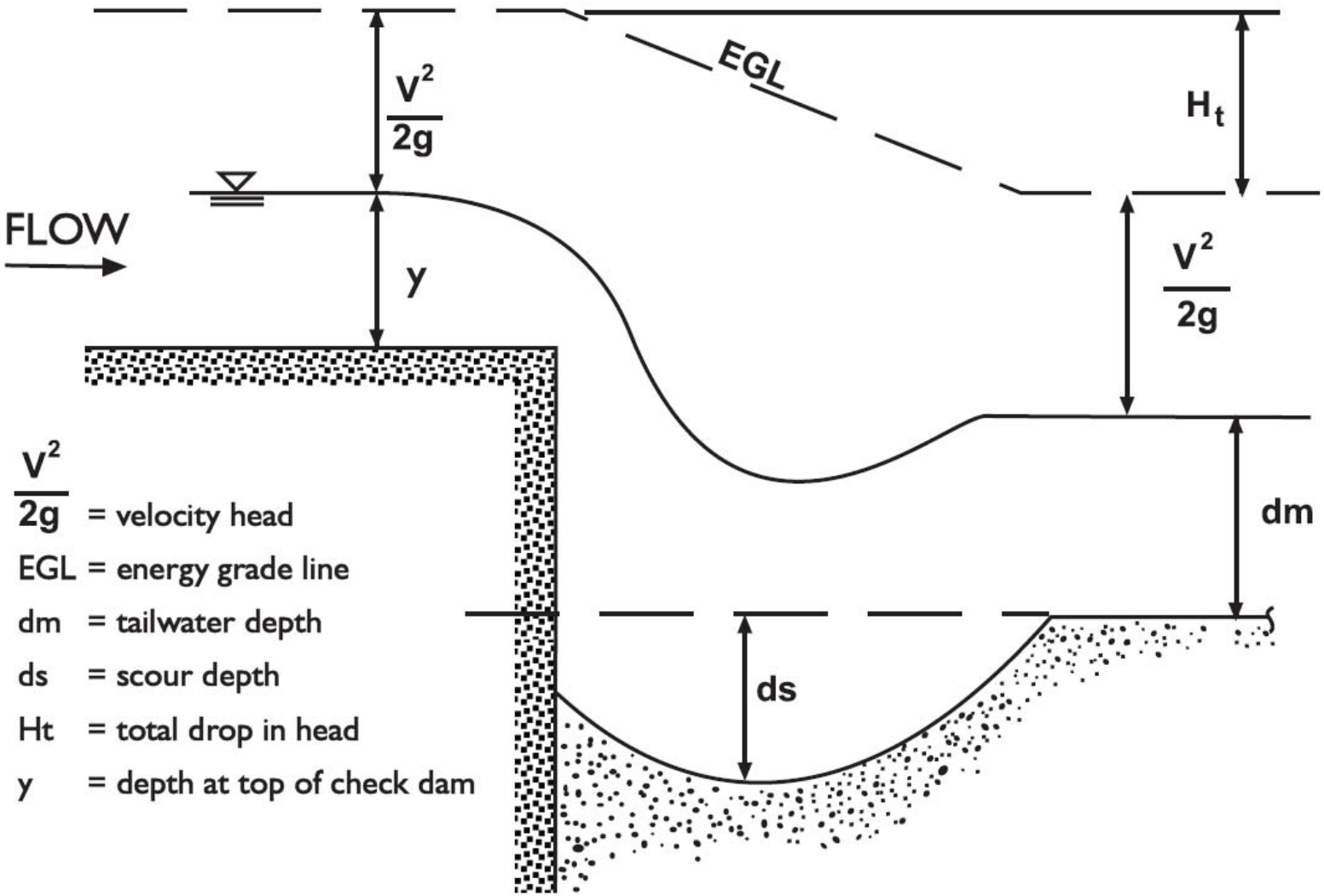
- Notes:
  - Only uses flow through constricted section
  - If constriction has an overbank, separate computation made for the channel and each overbank
  - Can be used for gravel bed systems
  - Armoring analysis or movement by size fraction

5 Types of Scour

- Bend scour
- Constriction scour
- Drop/weir scour
- Jet scour
- Local scour

17 OCT – address mistake on equation two slides ago

Drop/Weir Scour



Drop/Weir Scour

- Result of roller formed by cascading flow
- Caused from
  - Perched culverts
  - Culverts under pressure flow
  - Spillway exits
  - Natural drops in high-gradient mountain streams

Drop/Weir Scour

- Two methods
  - U.S. Bureau of Reclamation Equation – Vertical Drop Structure (1995)
    - Used for scour estimation immediately downstream of a vertical drop
    - Provides conservative estimate for sloping sills
  - Laursen and Flick (1983)
    - Sloping sills of rock or natural material

USBR Vertical Drop Equation

$$d_s = KH_t^{0.225} q^{0.54} - d_m$$

- Where
  - d_s = scour depth immediately downstream of drop (m)
  - q = unit discharge ($m^3/s/m$)
  - H_t = total drop in head, measured from the upstream to downstream energy grade line (m)
  - d_m = tailwater depth immediately downstream of scour hole (m)
  - K = regression constant of 1.9

USBR Vertical Drop Equation

$$d_s = KH_t^{0.225} q^{0.54} - d_m$$

- Notes:
  - Calculated scour depth is independent of bed-material grain size
  - If large material is present, it may take decades for scour to reach final depth
  - Must use metric units

Laursen and Flick Equation

$$d_s = \left\{ \left[4\left(\frac{y_c}{D_{50}}\right)^{0.2} - 3\left(\frac{R_{50}}{y_c}\right)^{0.1} \right] y_c \right\} - d_m$$

- Where
  - d_s = scour depth immediately downstream of drop (L)
  - y_c = critical flow depth (L)
  - D_{50} = median grain size of bed material (L)
  - R_{50} = median grain size of sloping sill (L)
  - d_m = tailwater depth immediately downstream of scour hole (L)

Laursen and Flick Equation

$$d_s = \left\{ \left[4\left(\frac{y_c}{D_{50}}\right)^{0.2} - 3\left(\frac{R_{50}}{y_c}\right)^{0.1} \right] y_c \right\} - d_m$$

- Notes
  - Developed specifically for sloping sills constructed of rock
  - Non-Conservative for other applications
  - Can use English or metric units

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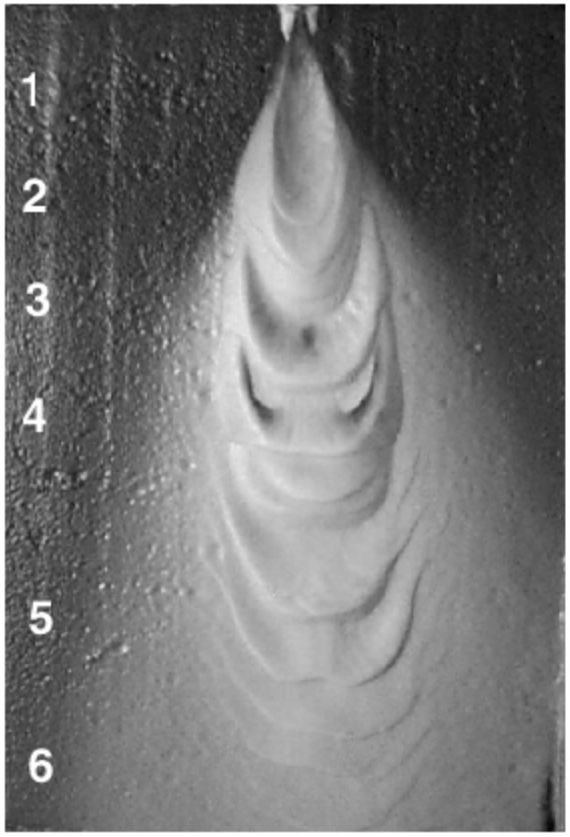
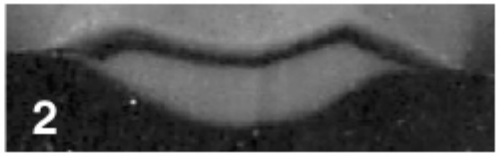
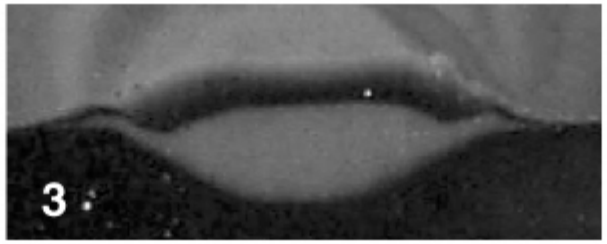
Jet Scour

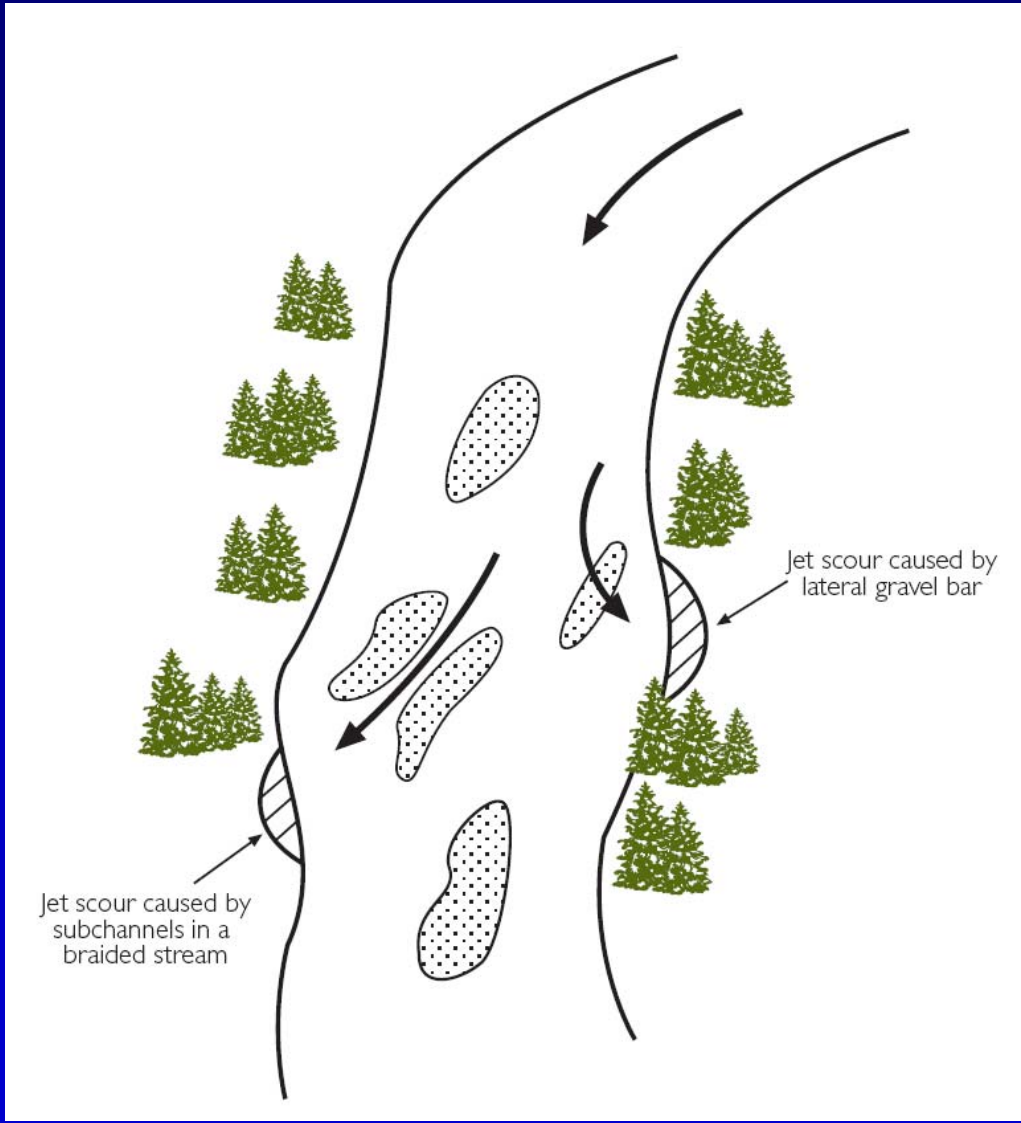






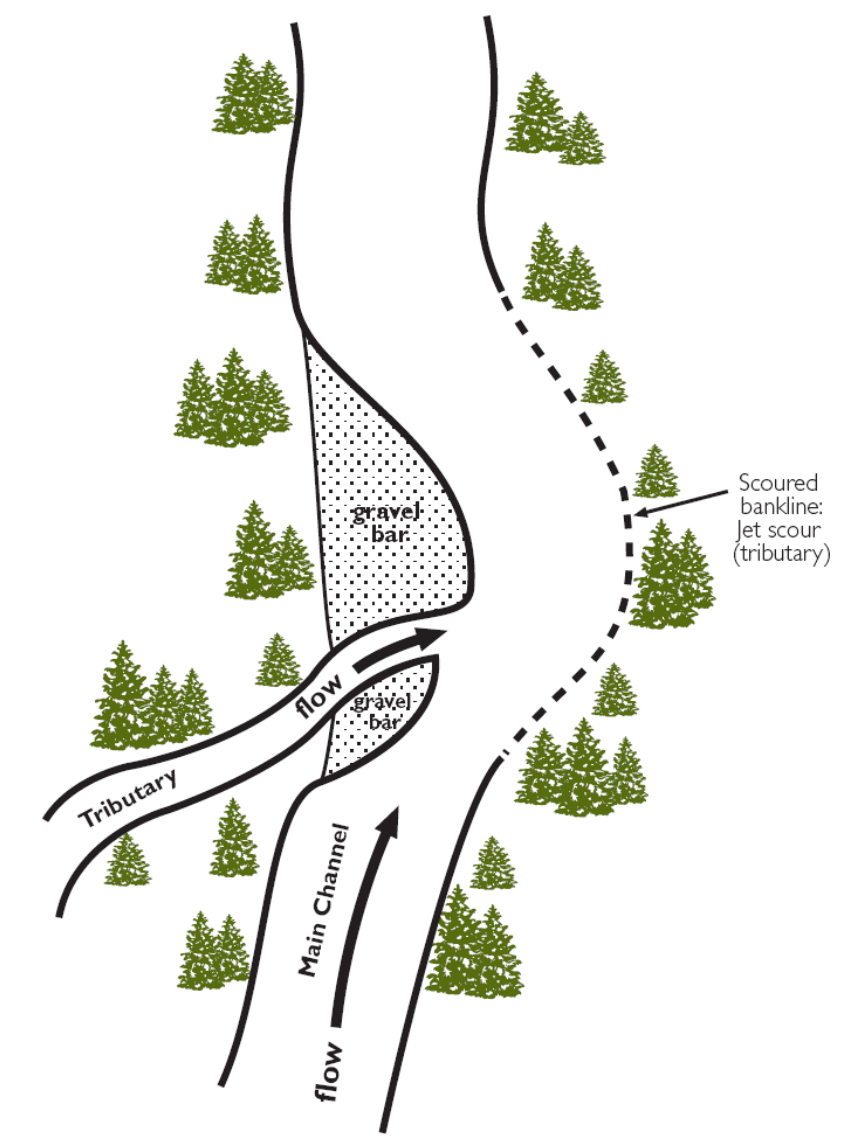
Jet Scour

- Lateral bars
- Sub-channel formation



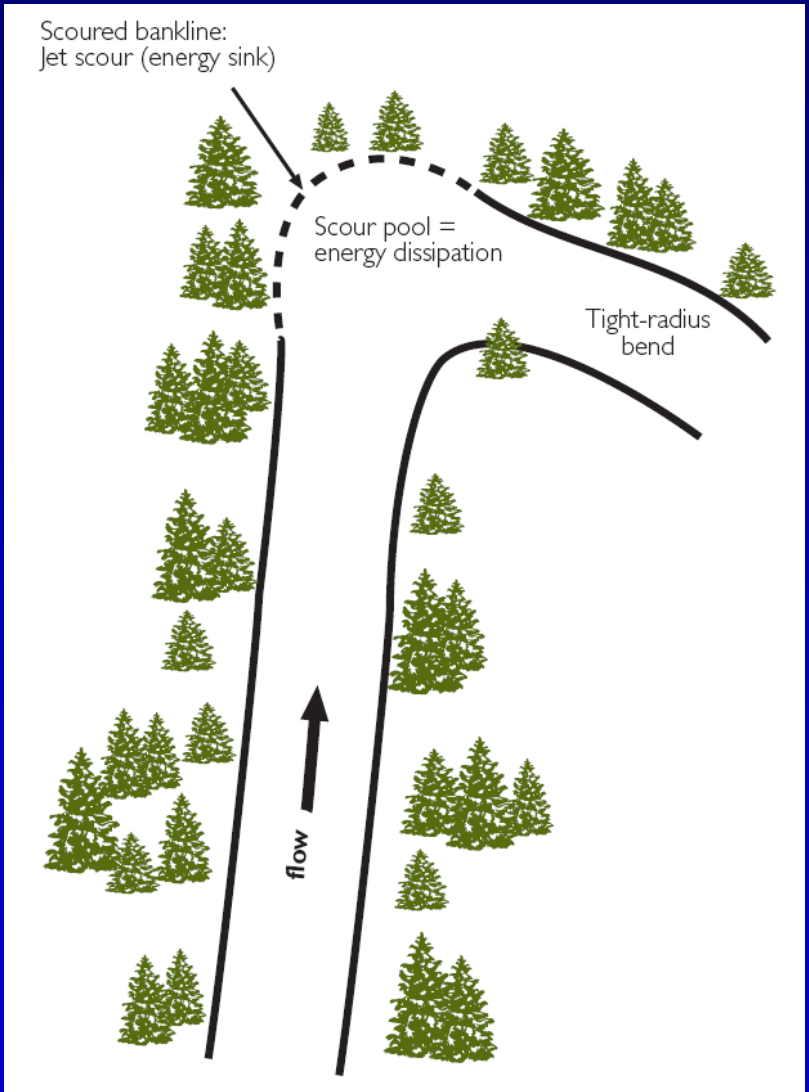
Jet Scour

- High energy side channel or tributary discharges



Jet Scour

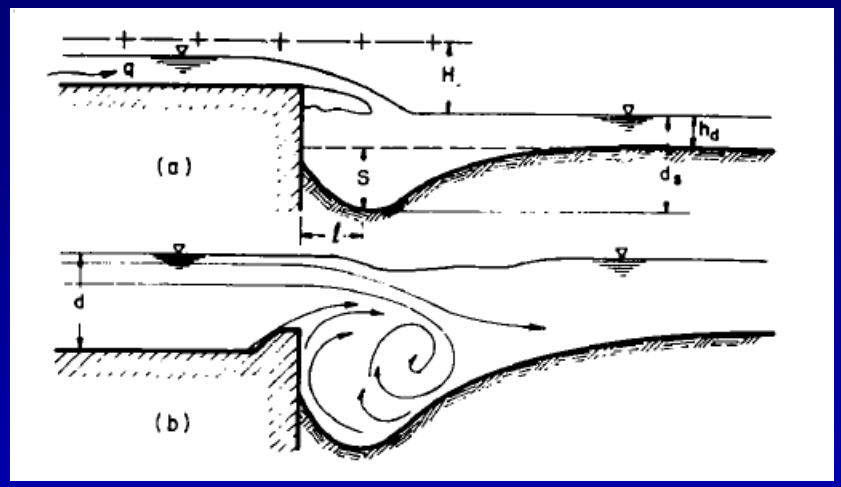
- Tight radius of curvature

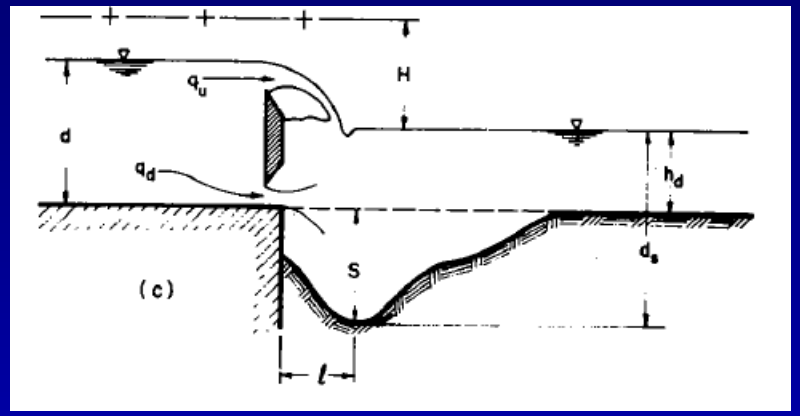


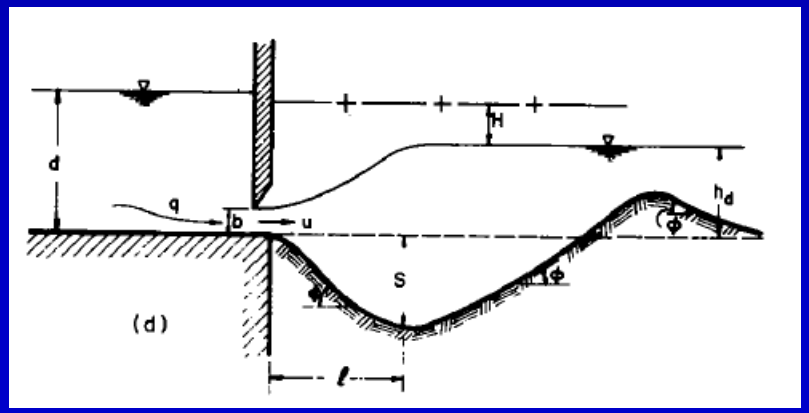
Jet Scour

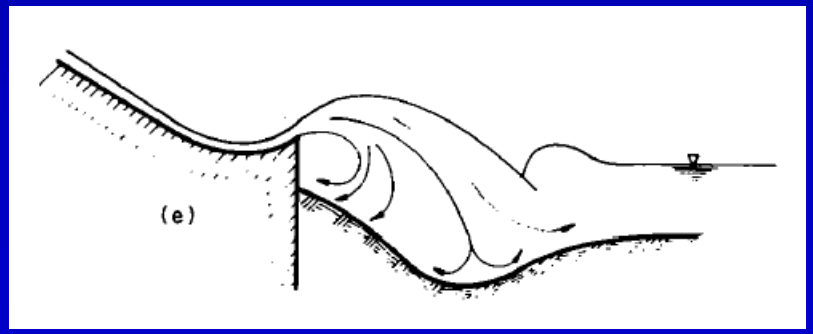
- Very difficult problem to solve
- Simons and Senturk (1992) provide some guidance
- Good case for adding a substantial FOS

Jet Scour









Jet Scour

TABLE 10.8
FORMULAS GIVING THE DEPTH OF THE LOCAL SCOUR

Type of Formula (cf. 10.18 for nomenclature)	Name of Author and Equations				
Scour Downstream of:	Schoklitsch (1932) (Eq.10.23)	Jäger (1939) (Eq. 10.27)	Eggenberger (1943) (Eq. 10.24)	Müller (1944) (Eq. 10.28)	Doddiah (1953) (Eq. 10.103)
Sharp-crested Spillway	$S = 4.75\frac{H^{0.2}q^{0.5}}{D_{90}^{0.32}} - h_d$	$S = a + b\left(\frac{d}{D_m}\right)q^{2/3}$	$S = 22.88\frac{H^{0.5}q^{0.6}}{D_{90}^{0.4}} - h_d$	$S = \frac{C'}{g^{0.3}}\left(\frac{\gamma}{\gamma_s'}\right)^{4/9}\frac{H^{0.5}q^{0.6}}{D_{90}^{0.4}} - h_d$	
Sharp-crested Spill and Sluice Gate			$S = C\frac{H^{0.5}q^{0.6}}{D_{90}^{0.4}} - h_d$		
Horizontal Jet					
Vertical Jet					$\frac{S}{b} = \left(\frac{q}{Hw}\right)^{2/3}\left[\frac{H}{b}\right]^2\left(\frac{q}{Hw}\right)^{1/16}\left[0.45 + 0.04\log\frac{qt}{H^2}\right]$
End of Apron					
Observations M = Metric System E = English System D = Dimensionless	M	a, b = constant, must be determined for each particular case M	cf. Eq. 10.26 for values of C M	C' can be otained as $C' = Cg^{0.8}(\gamma/\gamma_s')^{-4/9}$ M	w = fall velocity D

Jet Scour

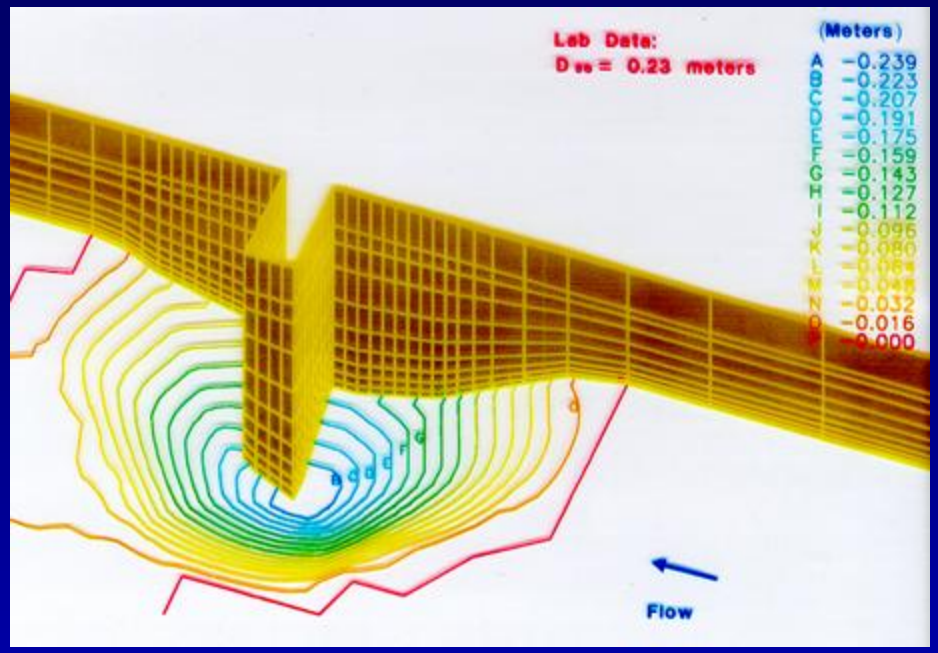
TABLE 10.8
CONTINUED

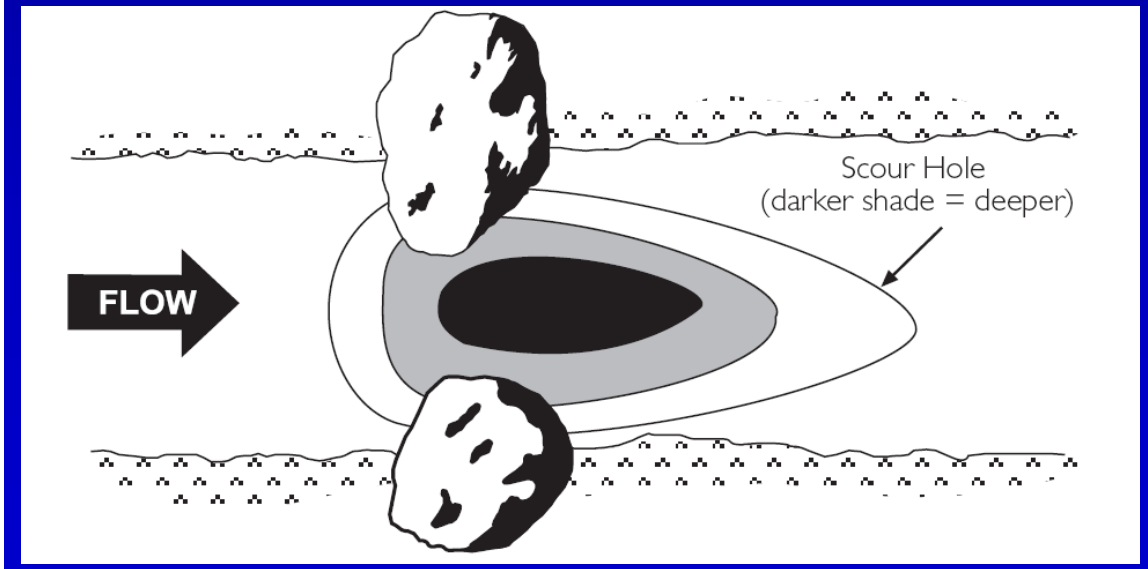
Type of Formula (cf. 10.18 for nomenclature)	Name of Author and Equations				
Scour Downstream of:	Franke (1960) (Eq. 10.102)	Carstens (1966) (Eq.10.29)	Valentine (1967) (Eq. 10.30)	Zimmerman and Maniak (1967) (Eq. 10.101)	Altinbilek and Okyay (1973) (Eq. 10.31)
Horizontal Jet		$\left(\frac{S}{b}\right)^6 = 2.85\times10^{-3}$ $(N_s^2-4)^{5/2}\tan\phi\left(\frac{D_g}{b}\right)\left(\frac{Ut}{b}\right)$	$\log\left(\frac{S}{b'}\right)=\frac{Fr_b-2}{4.7}$ $+0.55\log\frac{b'}{D_{90}}$		
Vertical Jet	$S=2.42\frac{H^{0.5}q^{0.67}}{D_{90}^{0.5}g^{1/3}}-h_d$				$\frac{S_T}{b}=\frac{30.5(U/w)^2(D_g/b)}{Fr(h/b)^{0.5}}$
End of Apron				$S=\frac{2.89q^{0.82}}{D_{85}^{0.23}}$ $\left(\frac{h_d}{q^{2/3}}\right)^{0.93}-h_d$	
Observations M = Metric System E = English System D = Dimensionless	M	cf. Eq. 10.29 for nomenclature D	cf. Eq. 10.30 for nomenclature M	with end sills M	cf. Eq. 10.31 for nomenclature D

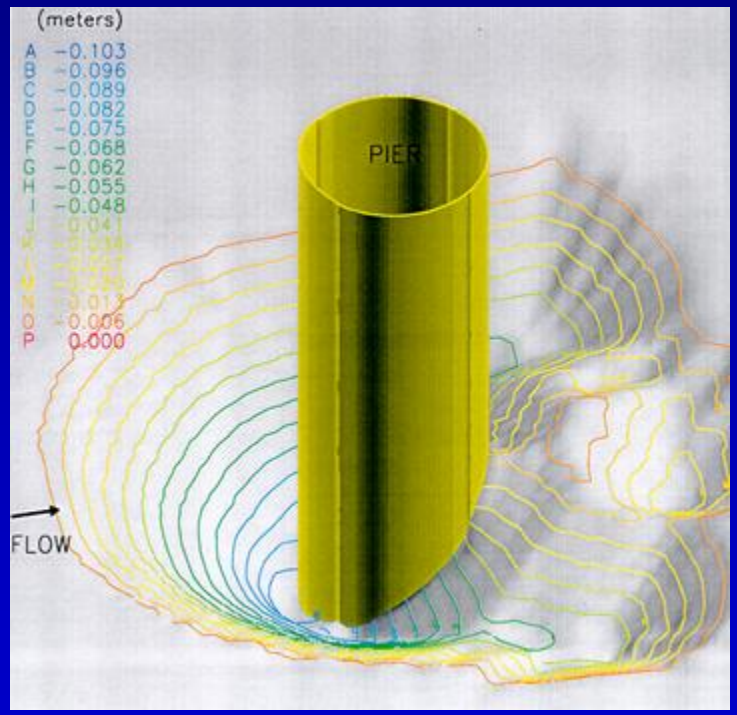
5 Types of Scour

- Bend scour
- Constriction scour
- Drop/weir scour
- Jet scour
- Local scour

Local Scour


Lab Data:
D50 = 0.23 meters
(Meters)
A -0.239
B -0.223
C -0.207
D -0.191
E -0.175
F -0.159
G -0.143
H -0.127
I -0.112
J -0.096
K -0.080
N -0.032
O -0.016
P -0.000
Flow


Scour Hole
(darker shade = deeper)
FLOW

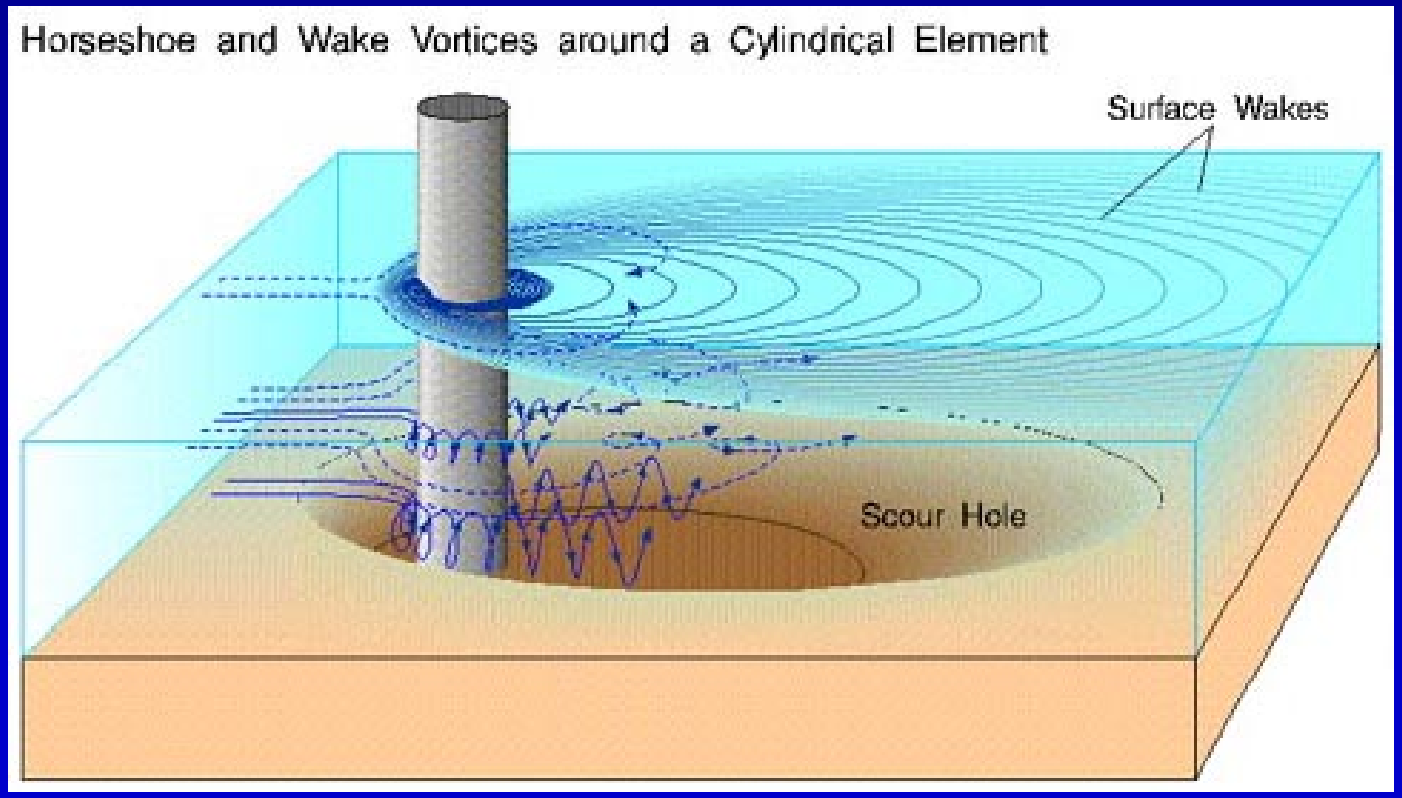

(meters)
A -0.103
B -0.096
C -0.089
D -0.082
E -0.075
F -0.068
G -0.062
H -0.055
I -0.048
O -0.006
P 0.000
PIER
FLOW

Local Scour

- Appears as tight scallops along a bank-line
- Depressions in a channel bed
- Generated by flow patterns around an object or obstruction
- Extent varies with obstruction
- Can be objective of design

Local Scour

- Pier Scour Equations



Local Scour

- Pier Scour Equations
  - Developed for sand-bed rivers
  - Provides conservative estimate for gravel-bed systems
  - Can be applied to other obstructions
  - Assumes object extends above water surface
  - Colorado State University Equation

Local Scour

- Colorado State University Equation
  - Can be applied to both live-bed and clear-water conditions
  - Provides correction factor for bed material > 6 cm – gravel beds
  - Field verification shows equation to be conservative

CSU Pier Scour Equation

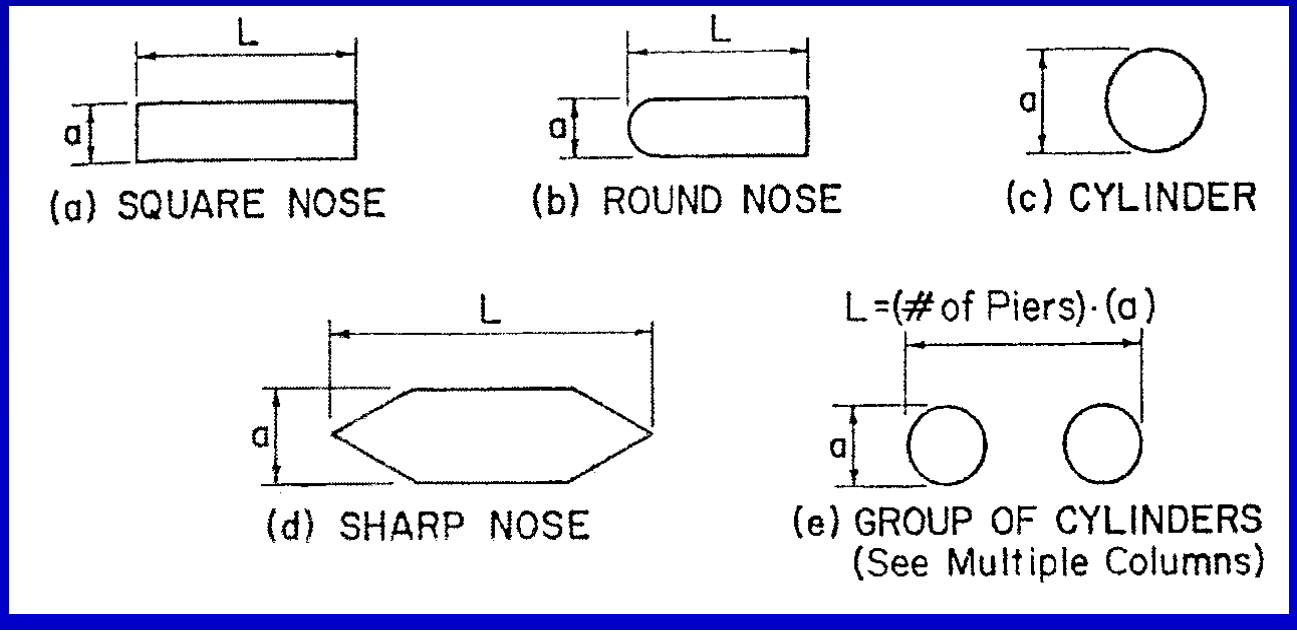
$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- Where
  - d = maximum depth of scour, measured below bed elevation (m)
  - y_1 = flow depth directly upstream of pier (m)
  - b = pier width (m)
  - F_r = approach Froude number
  - K_1 – K_4 = correction factors

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_1 = correction factor for pier nose shape



CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_1 = correction factor for pier nose shape
  - For angle of attach > 5°, K_1 = 1.0
  - For angle of attach < 5°
    - Square nose K_1 = 1.1
    - Circular K_1 = 1.0
    - Group of cylinders K_1 = 1.0
    - Sharp nose K_1 = 0.9

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_2 = correction factor for angle of attach of flow

$$K_2 = \left(Cos\theta + \frac{L}{b} Sin\theta\right)^{0.65}$$

- Where
  - L = length of pier (along flow line of angle of attach) (m)
  - b = pier width (m)
  - Θ = angle of attach (degrees)

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_2 = correction factor for angle of attach of flow

Θ	L/b = 4	L/b = 8	L/b = 12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.8	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_3 = correction factor for bed conditions
  - Selected for type and size of dunes
  - Use 1.1 for gravel-bed rivers

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_3 = correction factor for bed conditions

Bed Condition	Dune Height (m)	K_3
clear water scour	n/a	1.1
plane bed/anti-dune	n/a	1.1
small dunes	0.6 to 3	1.1
medium dunes	3 to 9	1.2
large dunes	>9	1.3

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- K_4 = correction factor for armoring of bed material
  - K_4 varies between 0.7 and 1.0
  - $K_4 = 1.0$ for $D_{50} < 60$ mm, or for $V_r > 1.0$
  - $K_4 = [1 - 0.89(1-V_r)^2]^{0.5}$, for $D_{50} > 60$ mm

$$V_r = \frac{(V - V_i)}{(V_{c90} - V_i)}$$

$$V_i = 0.65\left(\frac{D_{50}}{b}\right)^{0.053} V_{c50}$$

$$V_c = 6.19 y_1^{1/6} D_c^{1/3}$$

CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

$$V_r = \frac{(V - V_i)}{(V_{c90} - V_i)}$$

$$V_i = 0.65 \left(\frac{D_{50}}{b}\right)^{0.053} V_{c50}$$

$$V_c = 6.19 y_1^{1/6} D_c^{1/3}$$

- Where
  - V = approach velocity (m/s)
  - V_r = velocity ratio
  - V_i = approach velocity when particles at pier begin to move (m/s)
  - V_{c90} = critical velocity for D_{90} bed material size (m/s)
  - V_{c50} = critical velocity for D_{50} bed material size (m/s)
  - Y_1 = flow depth upstream of pier (m)
  - D_c = particle size selected to compute V_c (m)

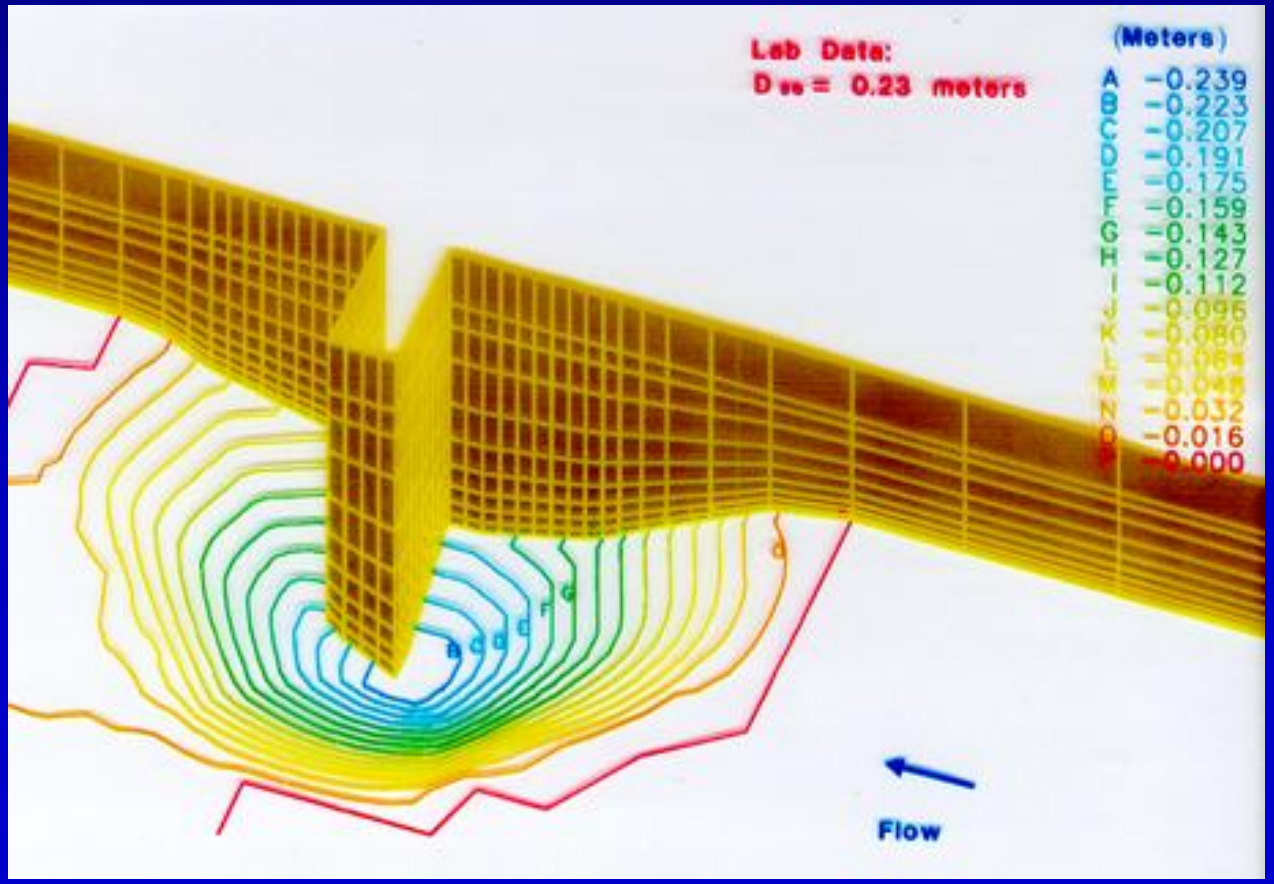
CSU Pier Scour Equation

$$\frac{d}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{b}{y_1}\right)^{0.65} F_r^{0.43}$$

- Where
  - d = maximum depth of scour, measured below bed elevation (m)
  - y_1 = flow depth directly upstream of pier (m)
  - b = pier width (m)
  - F_r = approach Froude number
  - K_1 – K_4 = correction factors

Local Scour

- Abutment scour



Local Scour

- Abutment scour
  - Developed for sand-bed systems
  - Provides conservative estimate for gravel-bed systems
  - Can be applied to other obstructions
  - Results can be reduced based on experience
  - Froelich Equation

Local Scour

- Froehlich Equation
  - Predicts scour as a function of shape, angle with respect to flow, length normal to flow and approach flow conditions
  - Provides conservative estimate for gravel-bed systems
  - Can be applied to other obstructions
  - Assumes object extends above water surface

Froehlich Equation for Live-Bed Scour at Abutments

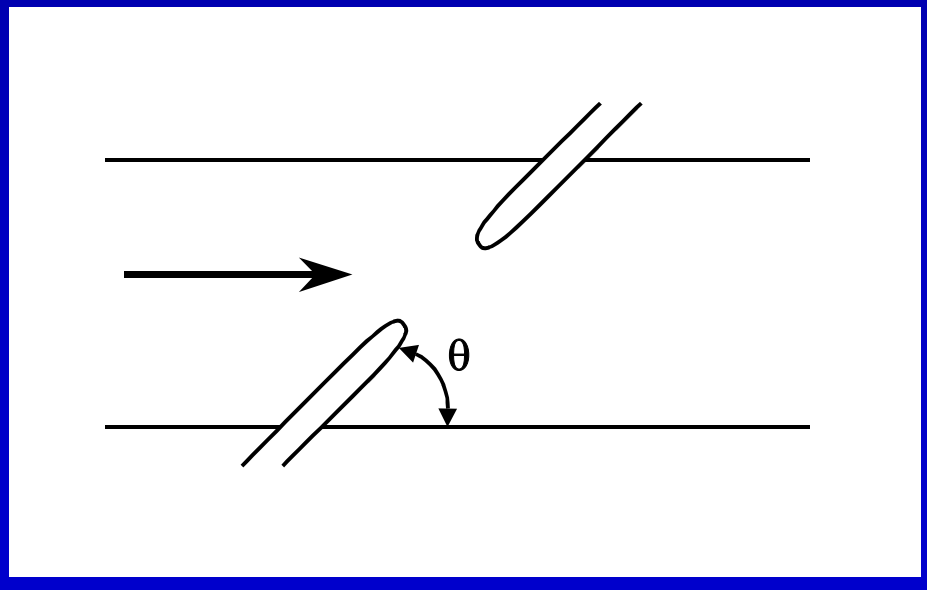
$$\frac{d}{y} = 2.27 K_1 K_2 \left(\frac{L'}{y}\right)^{0.43} F_r^{0.61} + 1.0$$

- Where
  - d = maximum depth of scour, measured below bed elevation (m)
  - y = flow depth at abutment (m)
  - F_r = approach Froude number
  - L' = length of abutment projected normal to flow (m)
  - K_1 – K_2 = correction factors

Froehlich Equation for Live-Bed Scour at Abutments

$$\frac{d}{y} = 2.27 K_1 K_2 \left(\frac{L'}{y} \right)^{0.43} F_r^{0.61} + 1.0$$

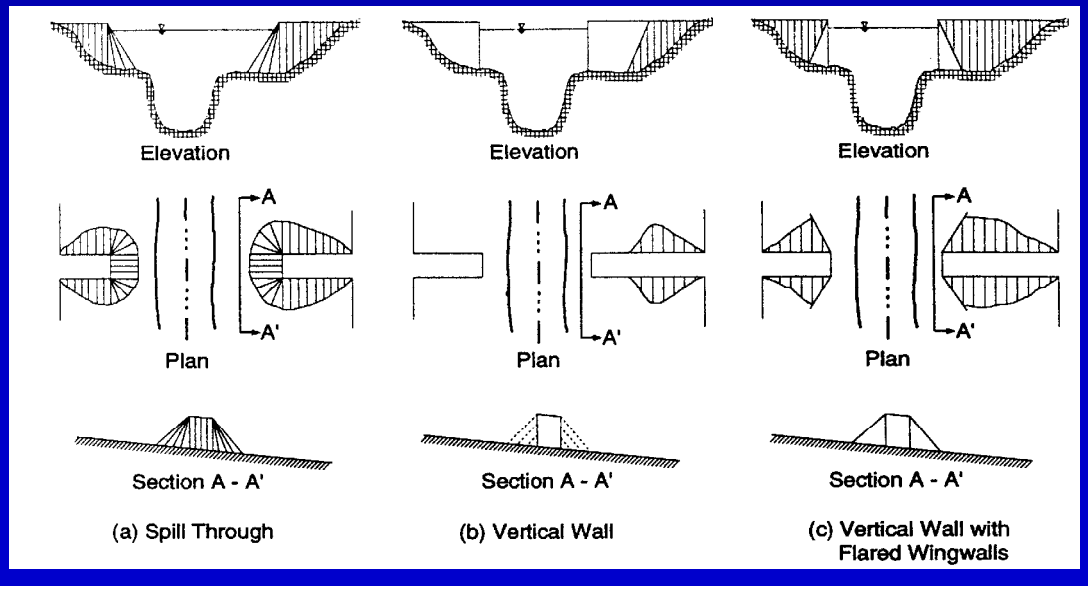
- L' = length of abutment projected normal to flow (m)



Froehlich Equation

$$\frac{d}{y} = 2.27 K_1 K_2 \left(\frac{L'}{y}\right)^{0.43} F_r^{0.61} + 1.0$$

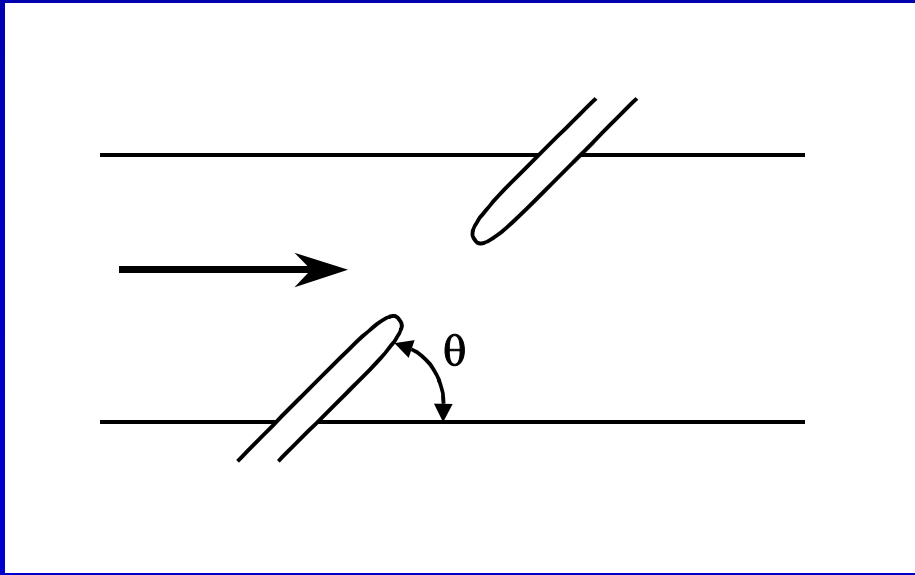
- K_1 = correction factor for abutment shape
  - K_1 = 1.0 for vertical abutment
  - K_1 = 0.82 for vertical abutment with wing walls
  - K_1 = 0.55 for spill through abutments



Froehlich Equation

$$\frac{d}{y} = 2.27 K_1 K_2 \left(\frac{L'}{y} \right)^{0.43} F_r^{0.61} + 1.0$$

- K_2 = correction factor for angle of embankment to flow



Froehlich Equation

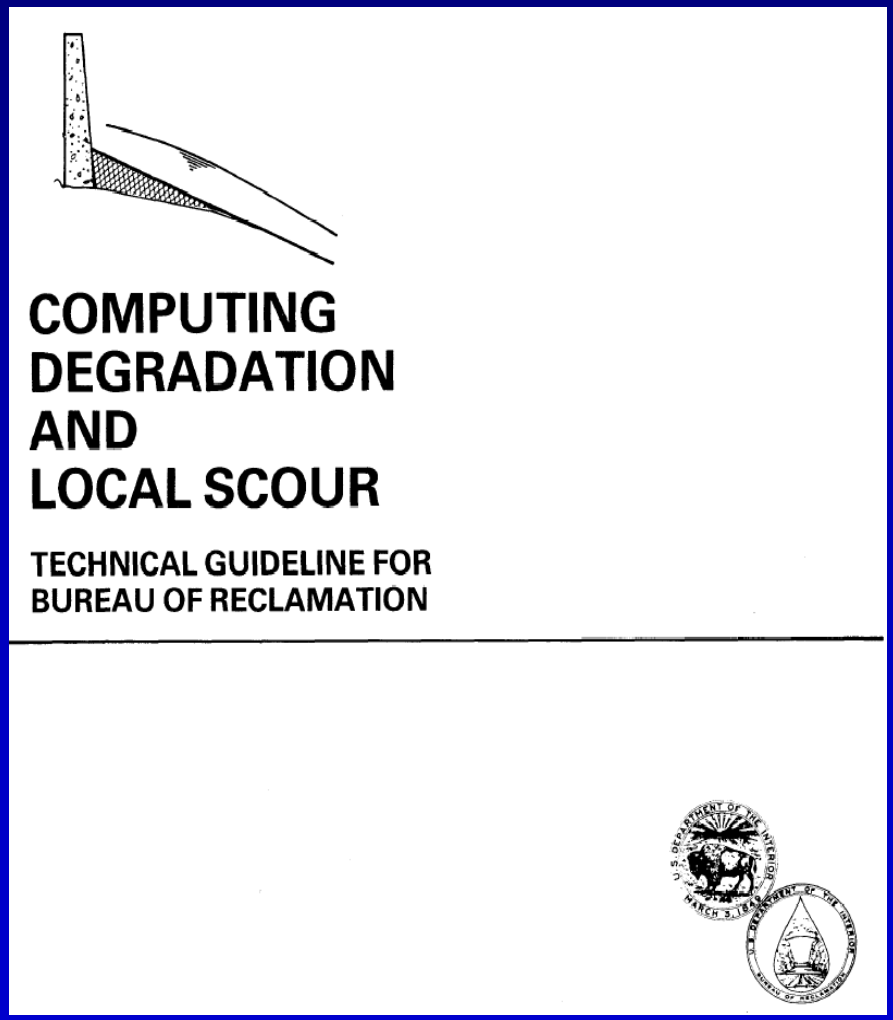
$$\frac{d}{y} = 2.27 K_1 K_2 \left(\frac{L'}{y}\right)^{0.43} F_r^{0.61} + 1.0$$

- K_2 = correction factor for angle of embankment to flow

$$K_2 = \left(\frac{\theta}{90}\right)^{0.13}$$

- Where
  - θ = angle between channel bank and abutment
  - θ is > 90 degrees of embankment points upstream
  - θ is < 90 degrees if embankment points downstream

Check Method
U.S. Bureau of Reclamation



Check Method
U.S. Bureau of Reclamation

- Provides method to compute scour at:
  - Channel bends
  - Piers
  - Grade-control structures
  - Vertical rock banks or walls
- May not be as conservative as previous approaches

Check Method
U.S. Bureau of Reclamation

- Computes scour depth by applying an adjustment to the average of three regime equations
  - Neil equation (1973)
  - Modified Lacey Equation (1930)
  - Blench equation (1969)

Neil Equation

$$y_n = y_{bf}\left(\frac{q_d}{q_{bf}}\right)^m$$

- Where
  - y_n = scour depth below design flow level (L)
  - y_{bf} = average bank-full flow depth (L)
  - q_d = design flow discharge per unit width (L^2/T)
  - q_{bf} = bankfull flow discharge per unit width (L^2/T)
  - m = exponent varying from 0.67 for sand and 0.85 for coarse gravel

Neil Equation

$$y_n = y_{bf}\left(\frac{q_d}{q_{bf}}\right)^m$$

- Obtain field measurements of an incised reach
- Compute bank-full discharge and associated hydraulics
- Determine scour depth

Modified Lacey Equation

$$y_L = 0.47\left(\frac{Q}{f}\right)^{3.3}$$

- Where
  - y_L = mean depth at design discharge (L)
  - Q = design discharge (L^3/T)
  - f = Lacey's silt factor = 1.76 $D_{50}^{0.5}$
  - D_{50} = median size of bed material (must be in mm!)

Blench Equation

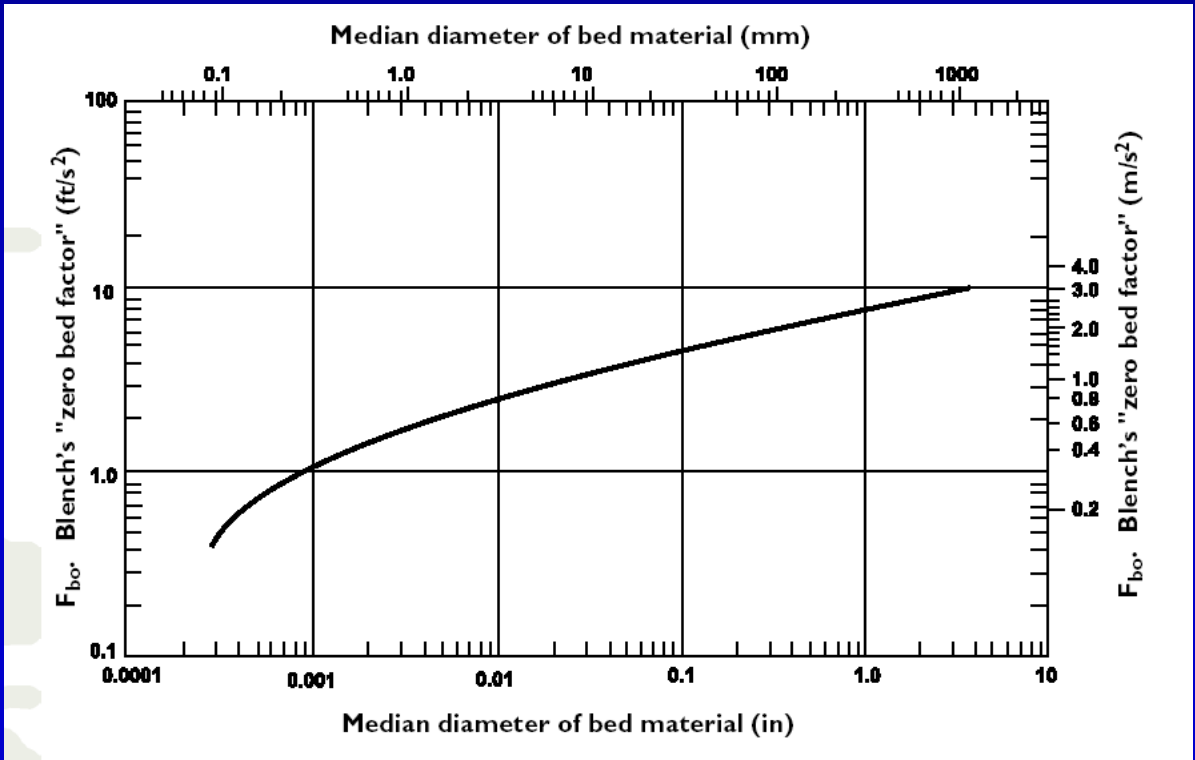
$$y_B = \frac{q_d^{\ 0.67}}{F_{bo}^{\ 0.33}}$$

- Where
  - y_B = depth for zero bed sediment transport (L)
  - q_d = design discharge per unit width (L^2/T)
  - F_{bo} = Blench's zero bed factor

Blench Equation

$$y_B = \frac{q_d^{\,0.67}}{F_{bo}^{\,0.33}}$$

F_{bo} = Blench's zero bed factor



Check Method
U.S. Bureau of Reclamation

- Computes scour depth by applying an adjustment to the average of three regime equations
  - Neil equation (1973)
  - Modified Lacey Equation (1930)
  - Blench equation (1969)
- Adjust as follows…

Check Method
U.S. Bureau of Reclamation

$$d_N = K_N y_N$$

$$d_L = K_L y_L$$

$$d_B = K_b y_B$$

- Where
  - d_N, d_L, d_B = depth of scour from Neil, Lacey and Blench equations, respectively
  - K_N, K_L, K_B = adjustment coefficients for each equation

Check Method
U.S. Bureau of Reclamation

K_N, K_L, K_B

Condition	Neil-K_N	Lacey-K_L	Blench-K_B
Bend Scour			
Straight reach (wandering thalweg)	0.50	0.25	0.60
Moderate bend	0.60	0.5	0.60
Severe bend	0.70	0.75	0.60
Right-angle bend	-	1.00	-
Vertical rock bank or wall	-	1.25	-
Nose of Piers	1.00	-	0.50 – 1.00
Small dam or grade control	0.4 - 0.7	1.50	0.75 – 1.25

Check Method
U.S. Bureau of Reclamation

$$d_N = K_N y_N$$

$$d_L = K_L y_L$$

$$d_B = K_b y_B$$

- Average values and compare to results of previous methods
- Appropriate level of conservatism??

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