Streambank Protection Design

Hard & Soft Applications & Techniques (Part I)

Speaker:
David T. Williams,
PhD, PE, PH, CFM, CPESC, D.WRE
DTW and Associates, LLC

David T. Williams

PhD, PE, PH, CFM, CPESC, D.WRE

President, DTW and Associates, LLC – David@dtwassoc.com

BSCE and MSCE (Environmental Civil Engineering), Univ. of CA, Davis

PhD. in River Mechanics, Dept. of Civil Engineering, Colorado State University

Worked at:

Airborne Combat Engineer Officer, U.S. Army, 7th Special Forces Group

U.S. Army Corps of Engineers as a Civilian

President/Co-founder of WEST Consultants, a nationally known 40 person water resources engineering firm

Taught Engineering and Computer programming at UC Davis and San Diego State University

National Director, Water Resources at PBS&J (now Atkins) and HDR

Agenda

Part One

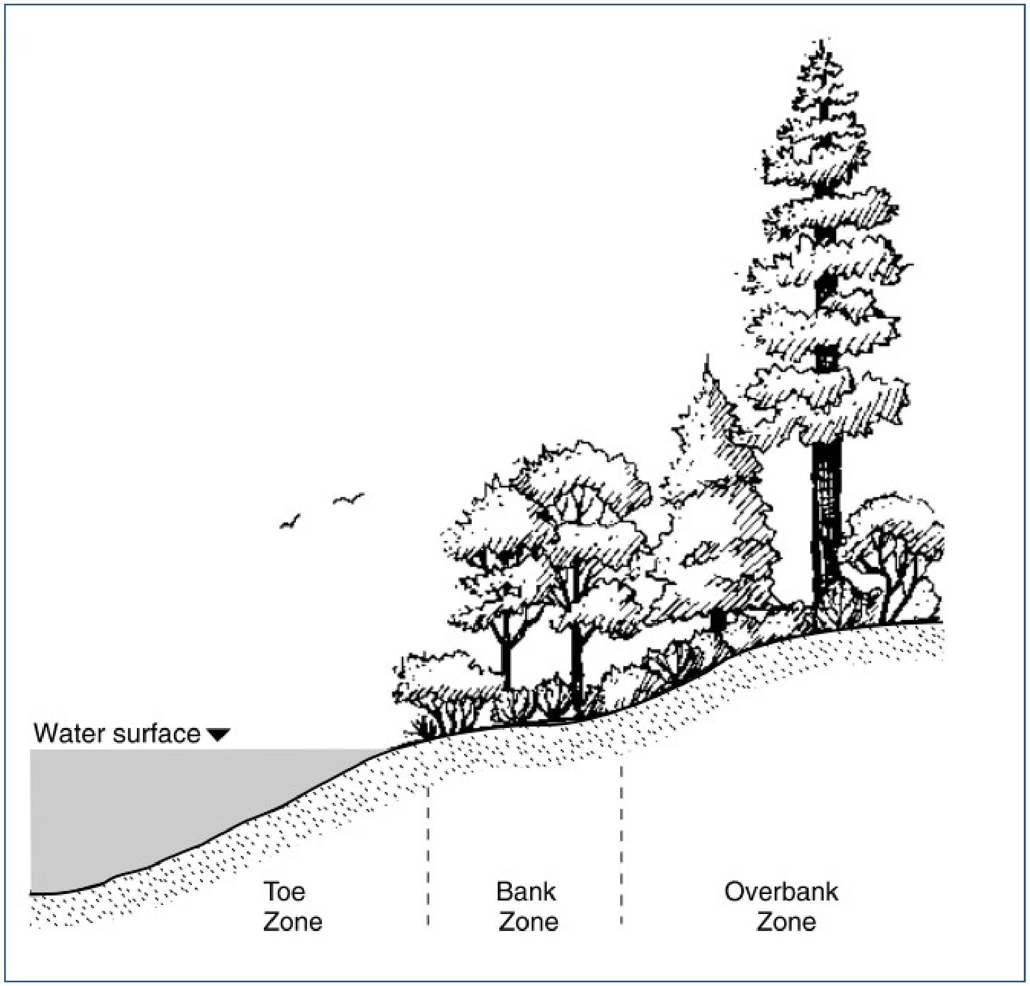
- Streambank Zones
- Total Scour at Streambank Toes
- Causes of Local Streambank Instability
- Basics of Toe and Bank Protection
- Design Considerations for Toe Protection

Part Two

- Redirective Methods
- Resistive Methods
- Bioengineering / Vegetative Methods
- Criteria for Use of Various Bioengineering/ Vegetative Methods

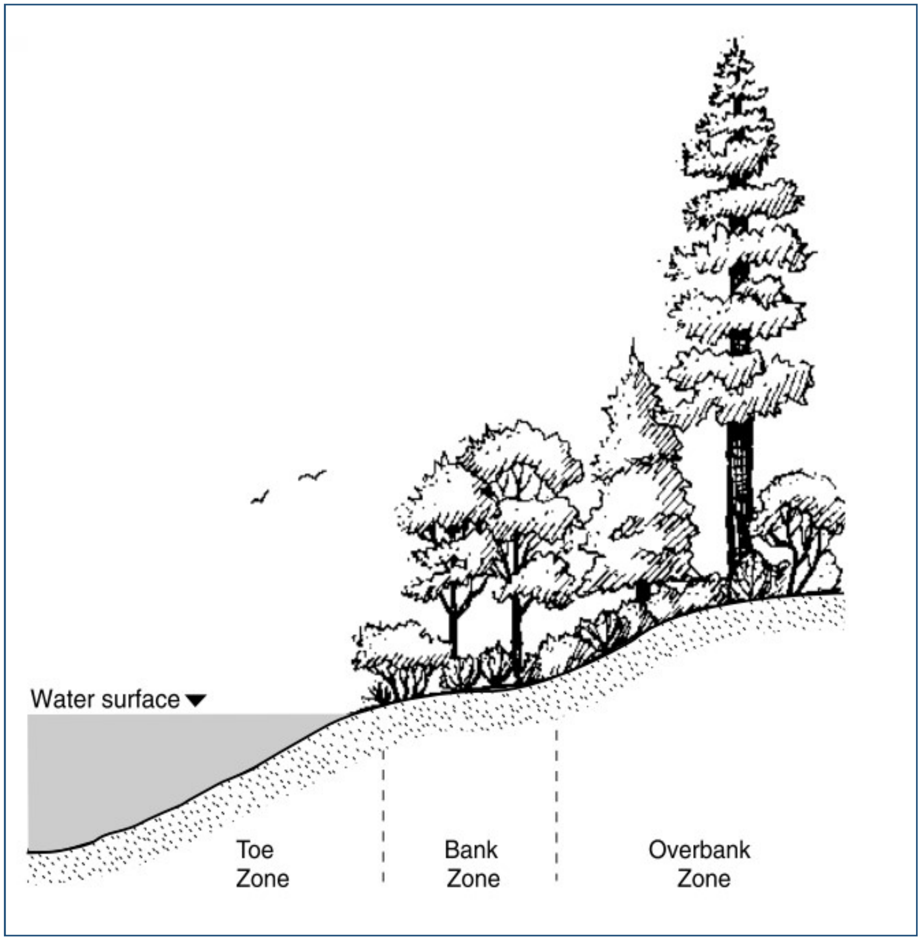
Streambank Zones – Toe Zone

- Between the ordinary high water (OHW) and low water levels.
- Most susceptible to erosion; exposed to strong currents, debris movements, and wet-dry cycles.
- Normally inundated throughout much of the year.
- Non-vegetative structural protection is normally required in this zone because few woody plants can tolerate year-round inundation.



Streambank Zones – Bank Zone

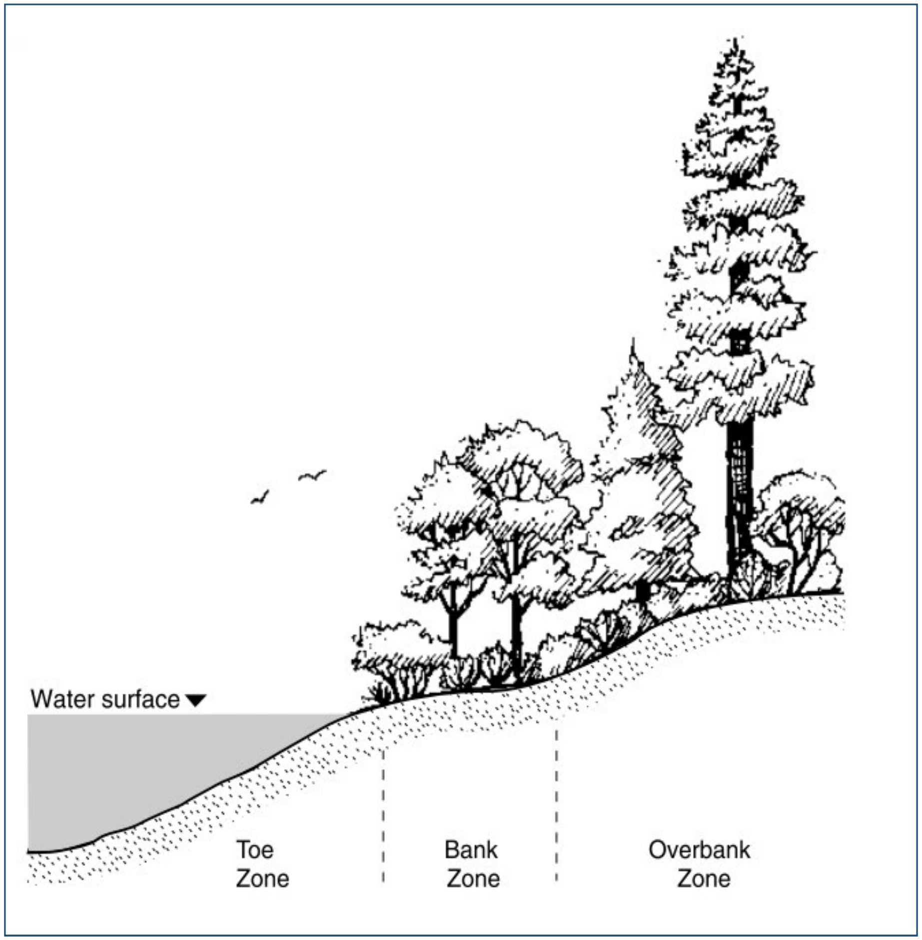
- Portion of the bank above the Ordinary High Water Mark (OHWM) that is inundated during periods of moderate flows (i.e., up to bankfull flow).
- Above OHWM, sites are still exposed to periodic erosive currents, debris movement, and traffic by animals and humans.
- The water table is frequently close to the soil surface because of its proximity to the river.



Streambank Zones – Overbank Zone

- Portion from the bank zone inland that is subjected to inundation or erosive action only during occasions of high water (i.e., greater than bank full flow).

- This area is also call a floodplain.



Need for Scour Estimates

- Toe-down depths for bank protection projects.
- Bridge pier and abutment foundation requirements.
- Lateral limits and depth of burial for utility crossings.
- Identify need for culvert outlet protection.
- Grade-control structure toe-downs.

Bank Protection Toe-Down

Bridge Foundations


Utility Line Protection
Overbank of Salt River, AZ

Total Scour

- Total scour is total depth of scour at a given location determined for a given flow event (usually the design event)
- Total scour is the sum of all scour components that are applicable for the given location
- This is used to determine the vertical extent of the required toe protection
- Factor of safety may be applied to some or all of the individual scour components

Determination of Total Scour

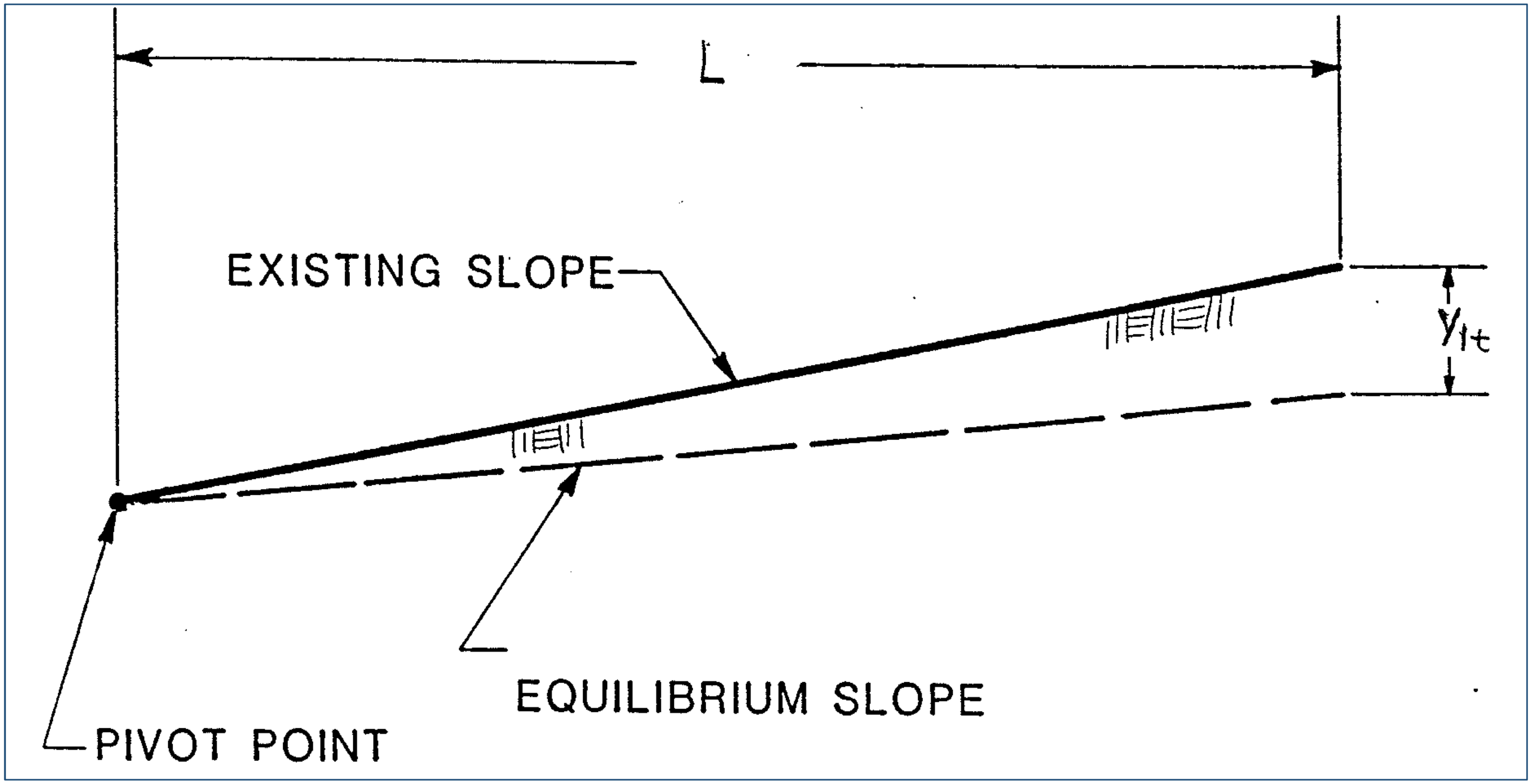
- Total scour is the sum of all scour components that apply to study site:
  - Long-term degradation
  - General scour (design flood event)
  - Local scour (e.g., pier, abutment, impinging flow)
  - Bend scour
  - Contraction scour
  - Bed form scour
  - Low-flow channel incisement

$$y_{ts} = y_{lt} + y_{gs} + y_{ls} + y_{bs} + y_{c} + y_{bf} + y_{lf}$$

Determination of Long-Term Degradation

- Degradation determined through:
  - Location of a downstream control point (e.g., bedrock outcrop, grade-control structure, etc.).
  - Pivoting the equilibrium slope around the control point.
  - Long-term degradation component = **(Existing slope – Equilibrium Slope) x Distance.**

Long-Term Degradation



General Scour

- Lowering of the streambed across the channel or stream over relatively short time periods

- Cyclic and/or related to the passing of a single flood

- General scour is usually based upon the passing of the design flood

General Scour

Local Scour

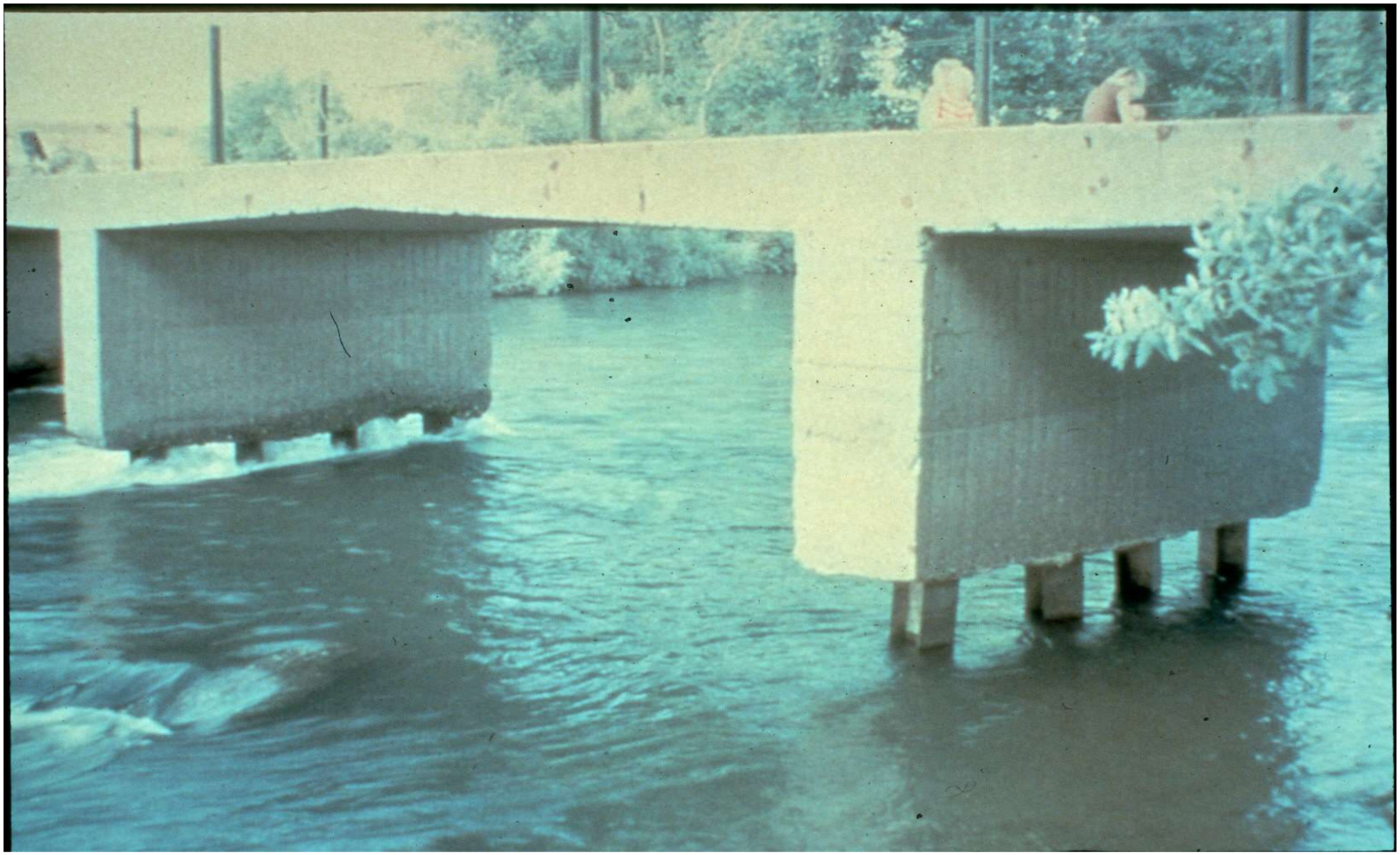
- Scour in a channel or on a floodplain that is localized at a pier, abutment, utility pole, or other obstruction to flow.

- Scour downstream of culvert, grade-control or drop structure.

Bend Scour

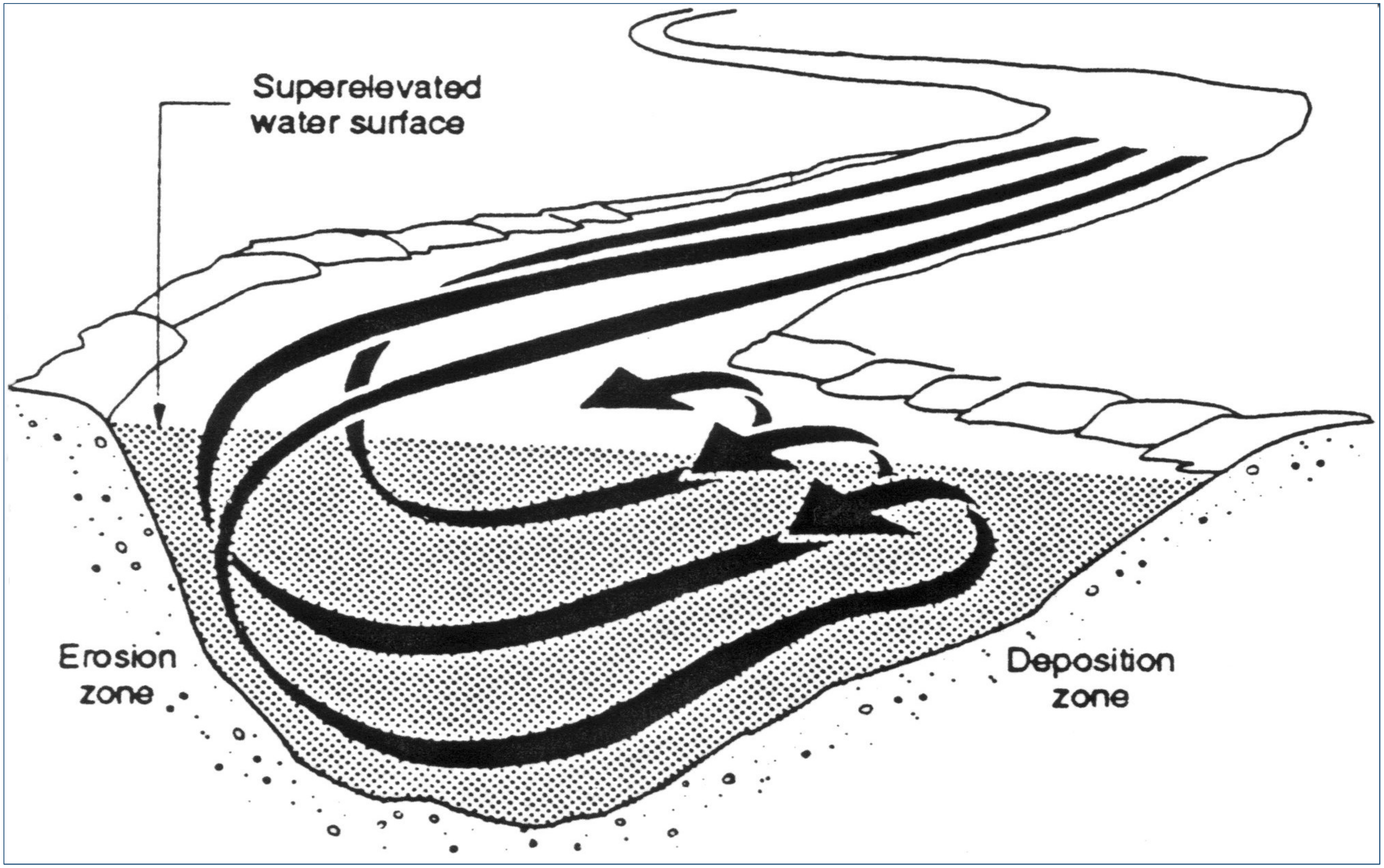
- Scour in a meandering channel that is the result of transverse or “secondary” currents which will scour sediment from the outside of a bend.

Local Scour – Pier




Local Scour – Abutment

Bend Scour and Shear Stress




Bend Scour

Shear Stress in a Bend

$$\tau_b = K\gamma_w R S_f$$

$$K = 2.5(R_c/W)^{-0.321}$$

Where:

τ_b = shear stress at the outside of a bend

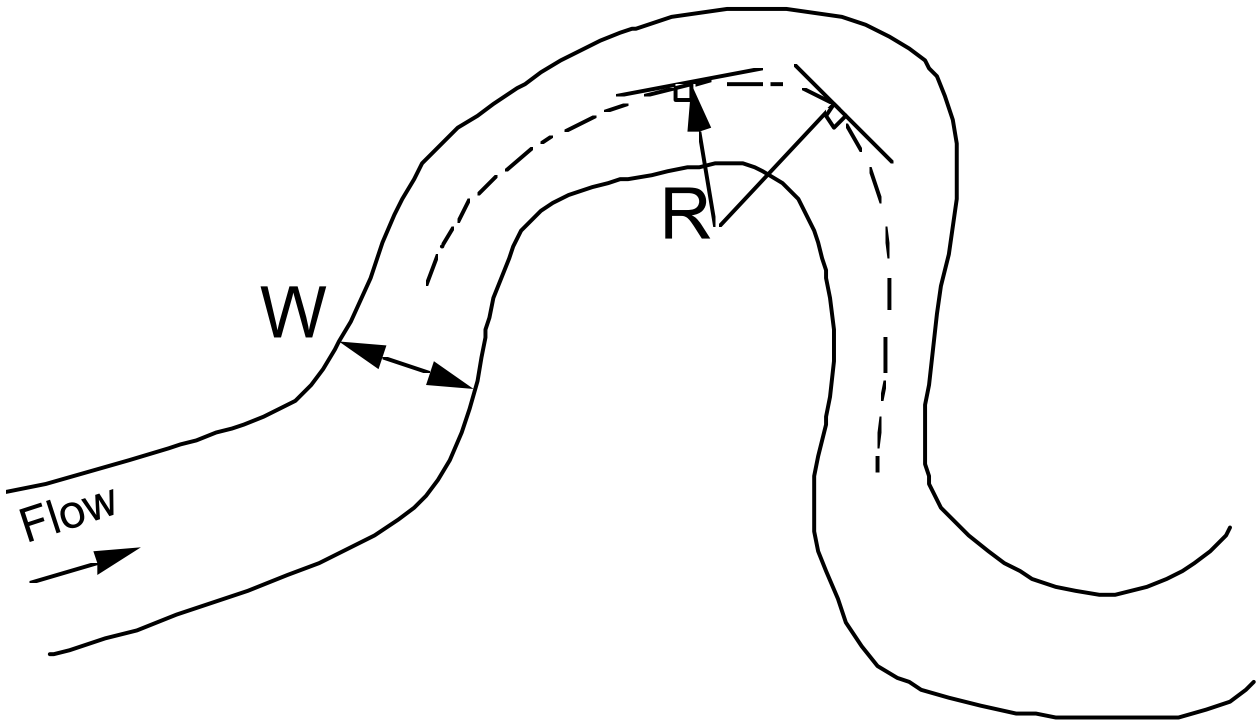
R = hydraulic radius

K = coefficient for bend shear stress related to R_c/W

R_c = bend curvature (radius of the bend)

W = top width of the channel

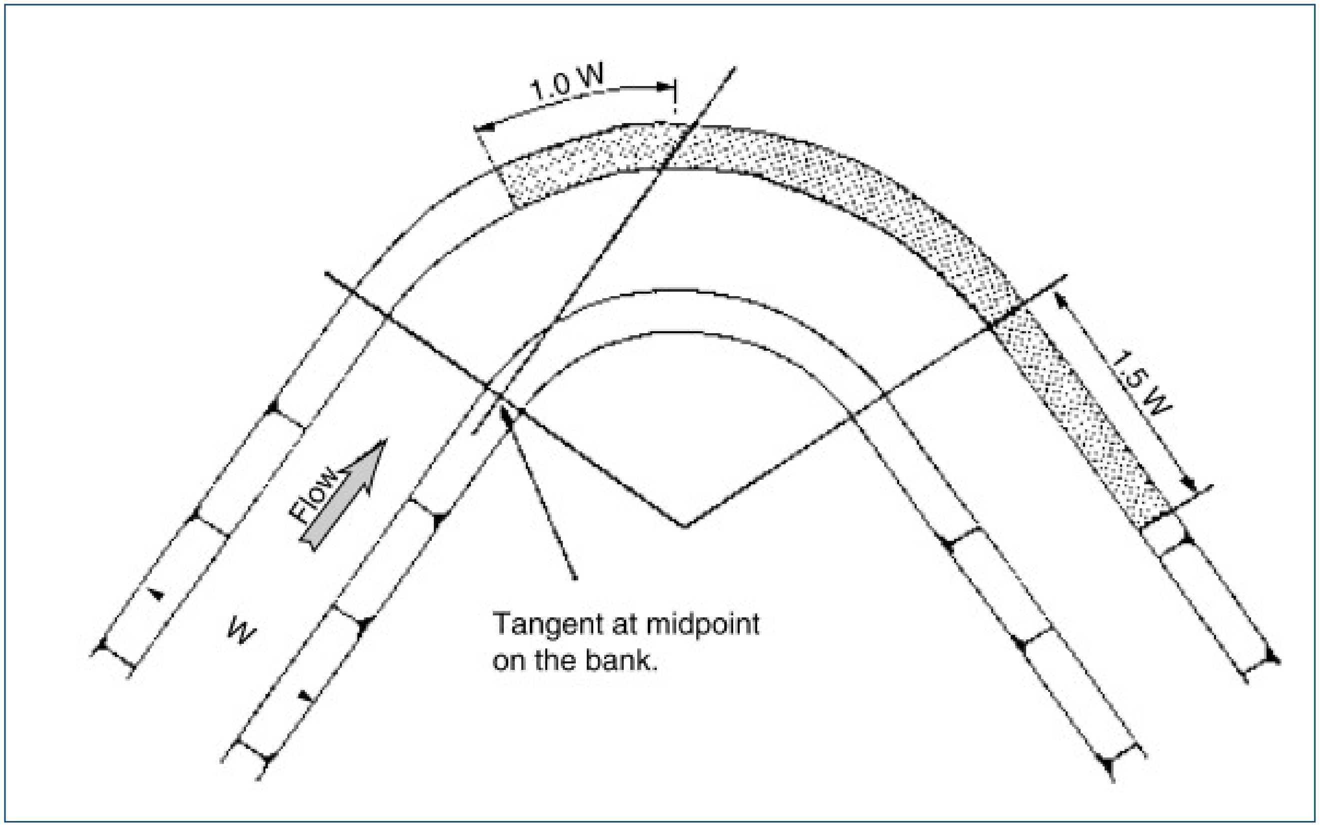
Determining Bend Radius



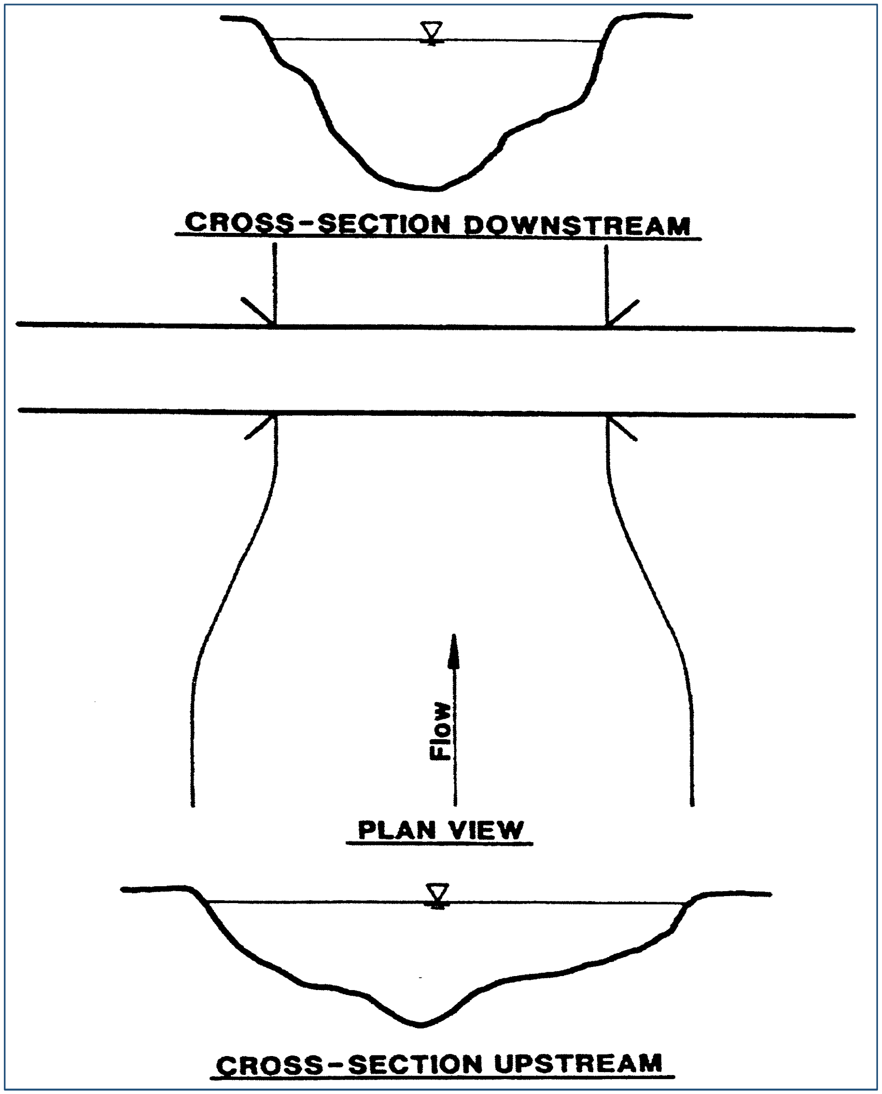
Draw tangents to river centerline along curve, make perpendicular lines from the tangents, find intersection closest to the centerline, and average the lengths of the two perpendicular lines.

Bend Shear Stress Extents

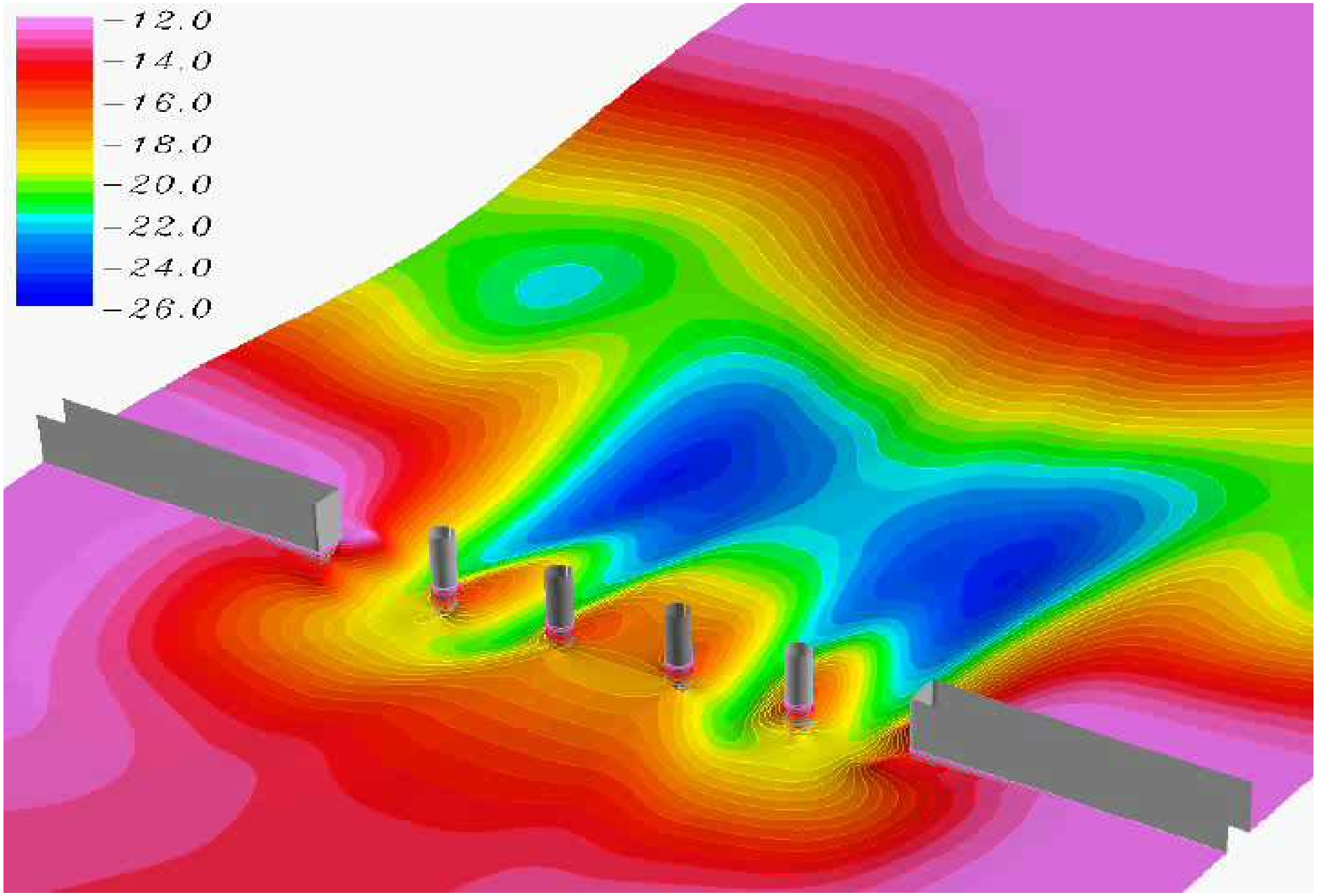
- Do not forget that the bend causes the water surface elevation to rise on the outside of the bend, so any protection should extend high enough to account for this.
- Federal Highway has a procedure for extensions
- At riight is a guideline for longitudinal protection extent at a bend



Contraction Scour

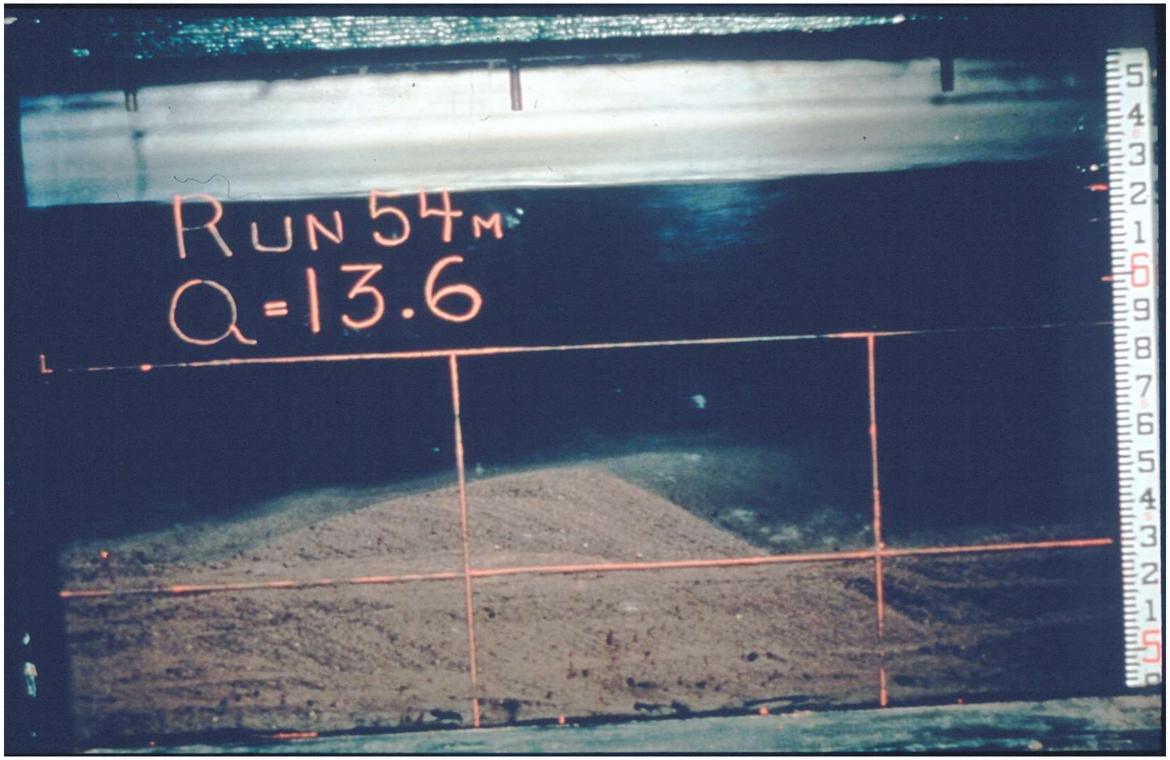


Contraction Scour

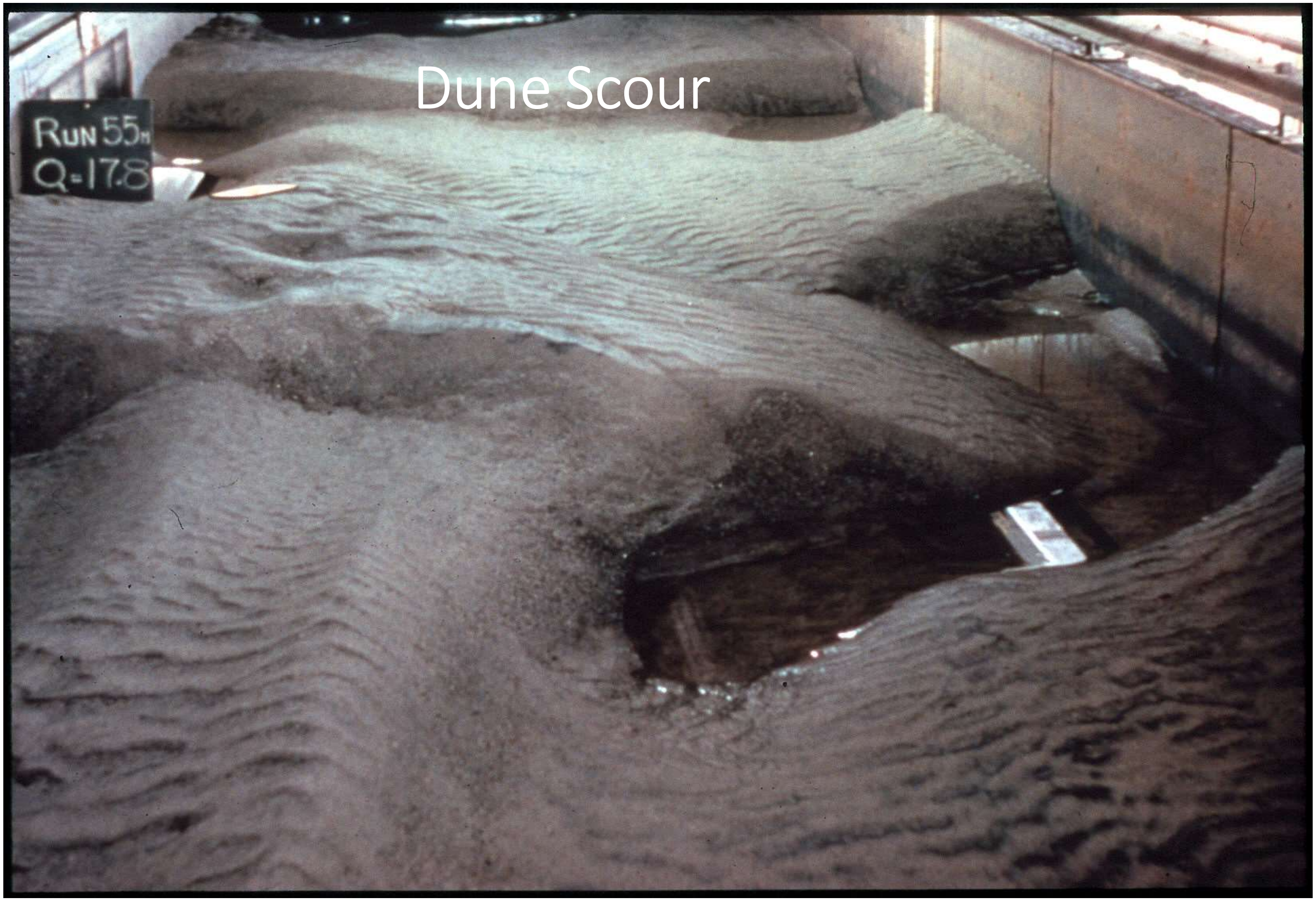


Bedform Scour

- Allowance for anti-dune or dune trough depths that occur in sand bed channels.



Dune Scour



Low-Flow / Thalweg Channel Incisement

- If the existing channel does NOT have low-flow incisement, but proposed channelization or other changes favor low-flow channel development, a reasonable incisement depth is ~ 1 to 2 ft. If topo is accurate enough, can use it to define incisement.

Safety Factor

- Safety factor application may be highly individualistic, established by client direction or agency guidelines.
  - Flood Control District of Maricopa County (FCD) Consultant Guidelines require toe-down elevations for bank protection shall be based on sum of all scour components, times a safety factor of 1.3.
  - FCD guidelines further require a factor of safety of 1.5 shall be used in cases where only one component of scour is present.
  - City of Tucson Standards Manual specifies a factor of safety of 1.3 to account for non-uniform flow distribution

Causes of Local Streambank Instability

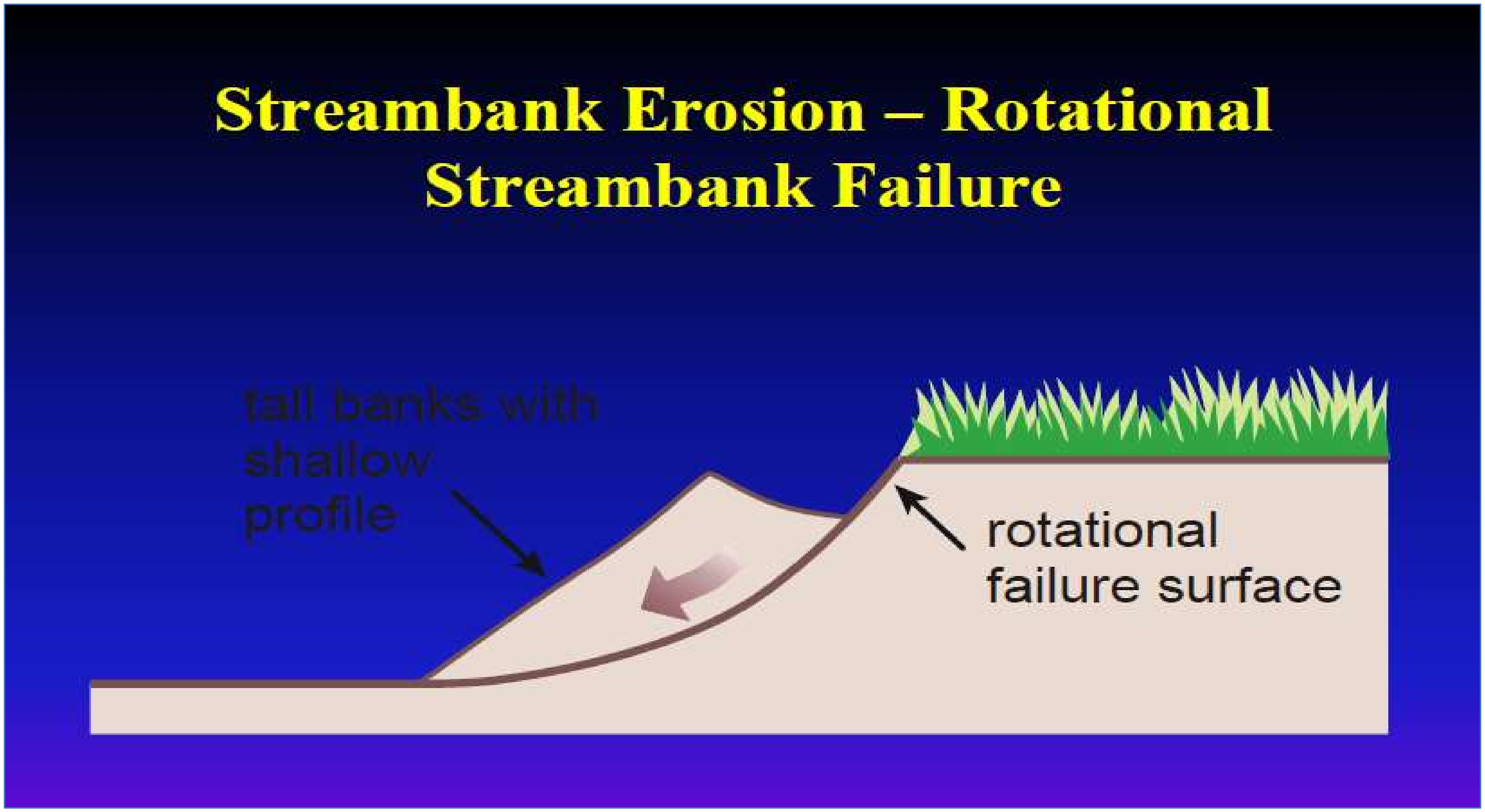
- Parallel Flow
- Impinging Flow
- Piping
- Sheet Erosion
- Rilling /Gullying
- Wind Waves
- Freeze/Thaw (tension cracks)

Types of Local Instability Streambank Failure

- Rotational Slip (Slumps)
- Planar Slides
- Pop out Failure (Cantilever)
- Block Failure (Slab Failure)
- Soil / Rock Fall
- Wet Earth Flow
- Others

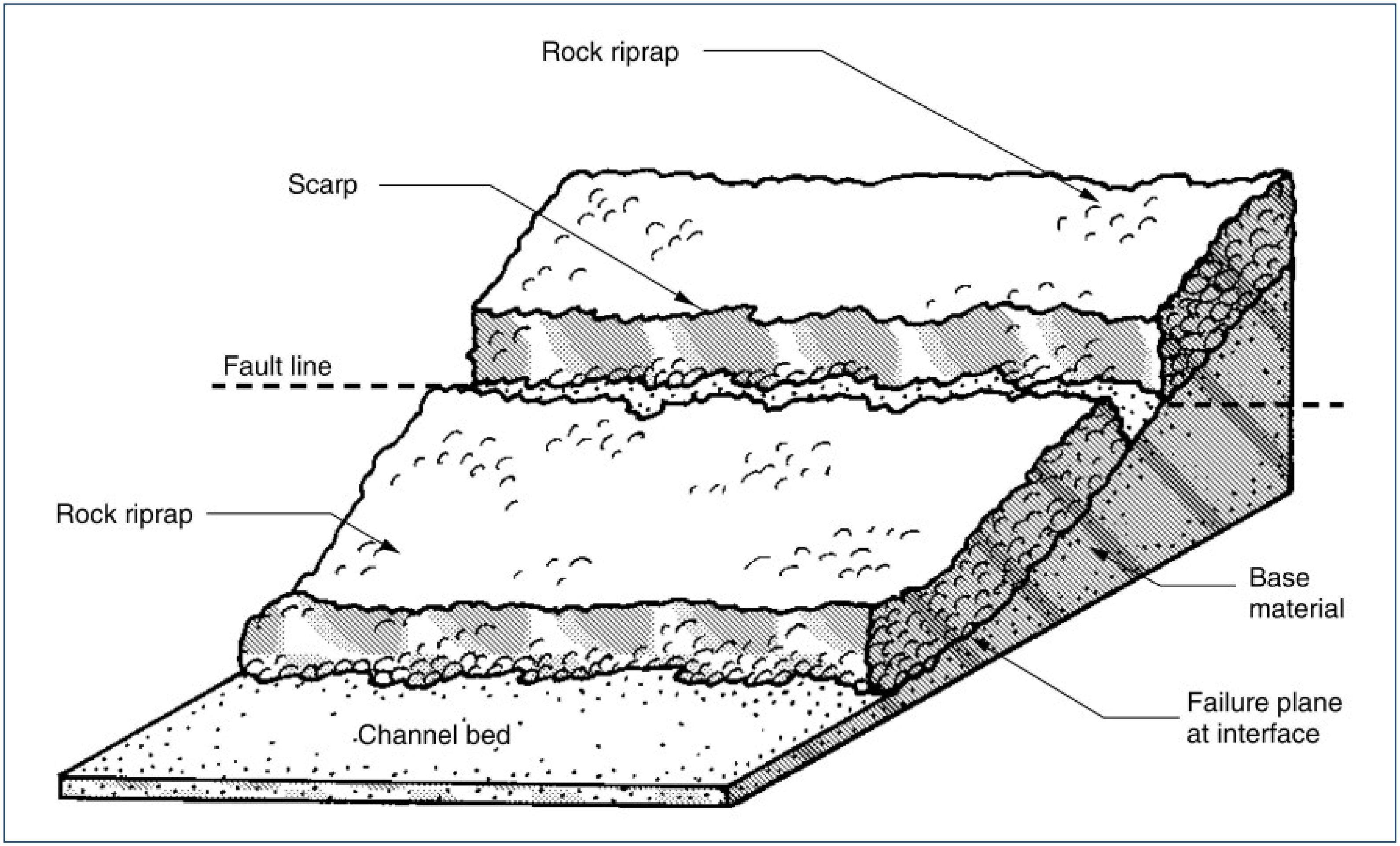
Rotational Failure

(Bank-Stability and Toe-Erosion Model (BSTEM), USDA)

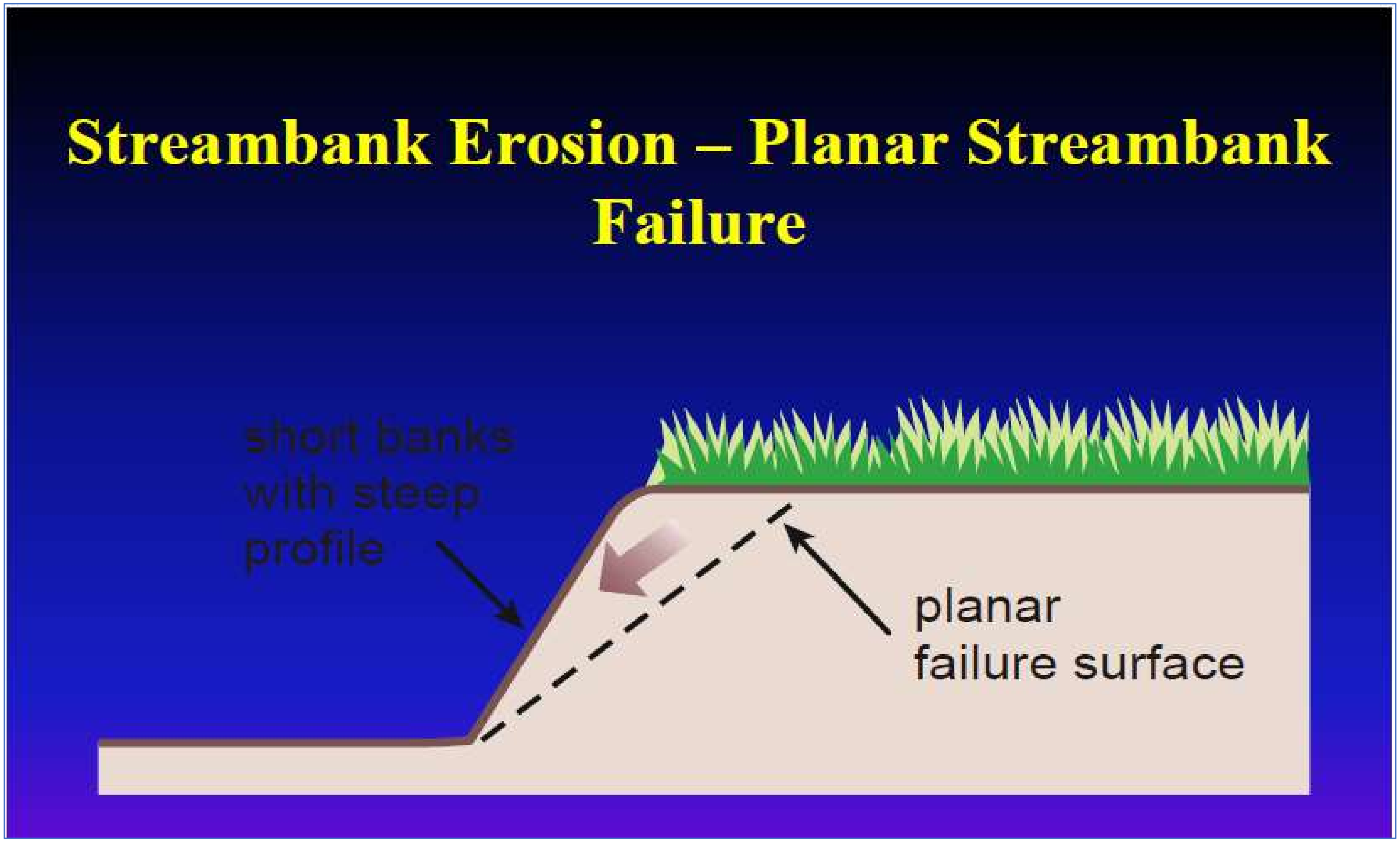


Rotational Slip

Translational and Planar Slides

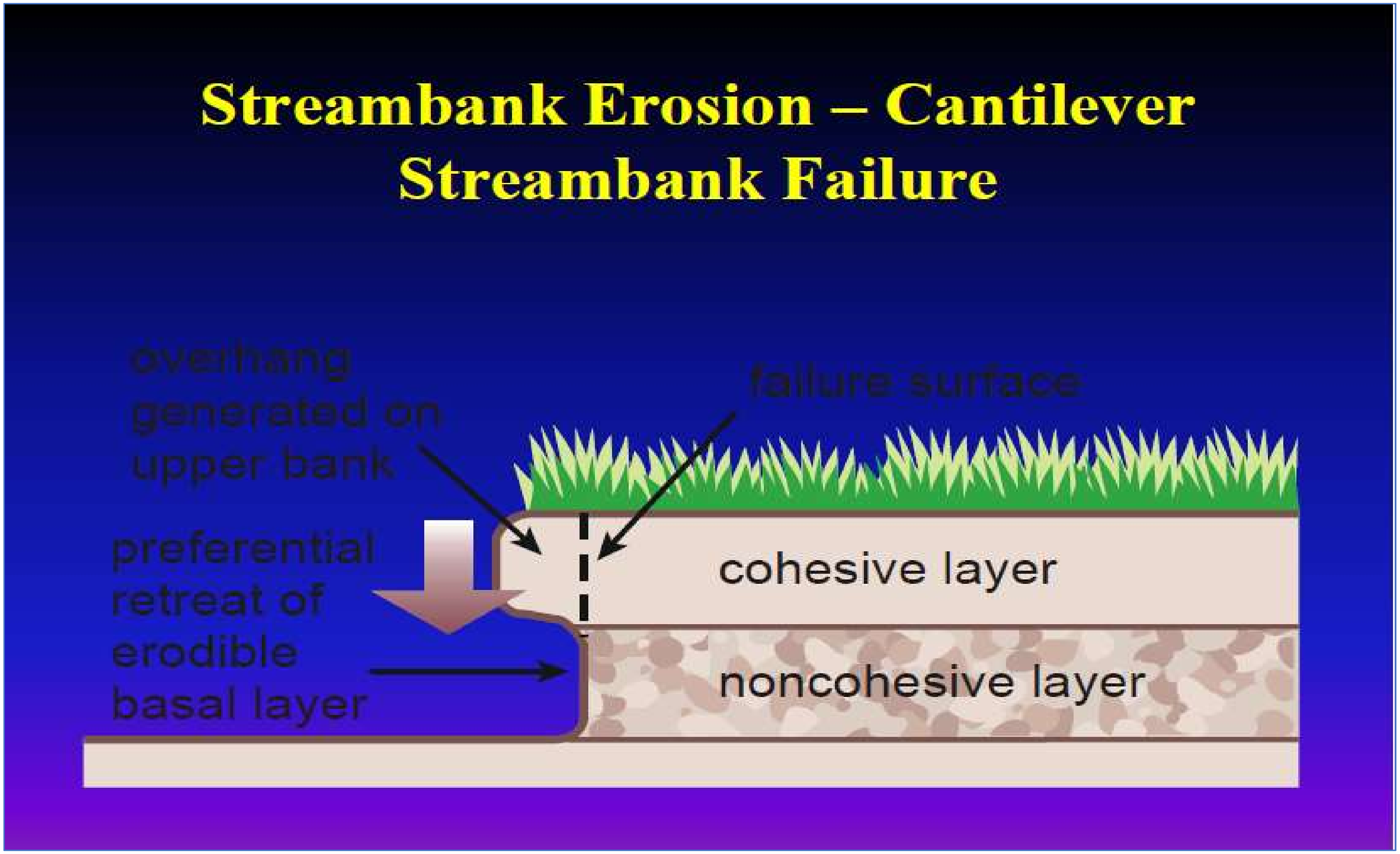


Planar Failure (BSTEM, USDA)



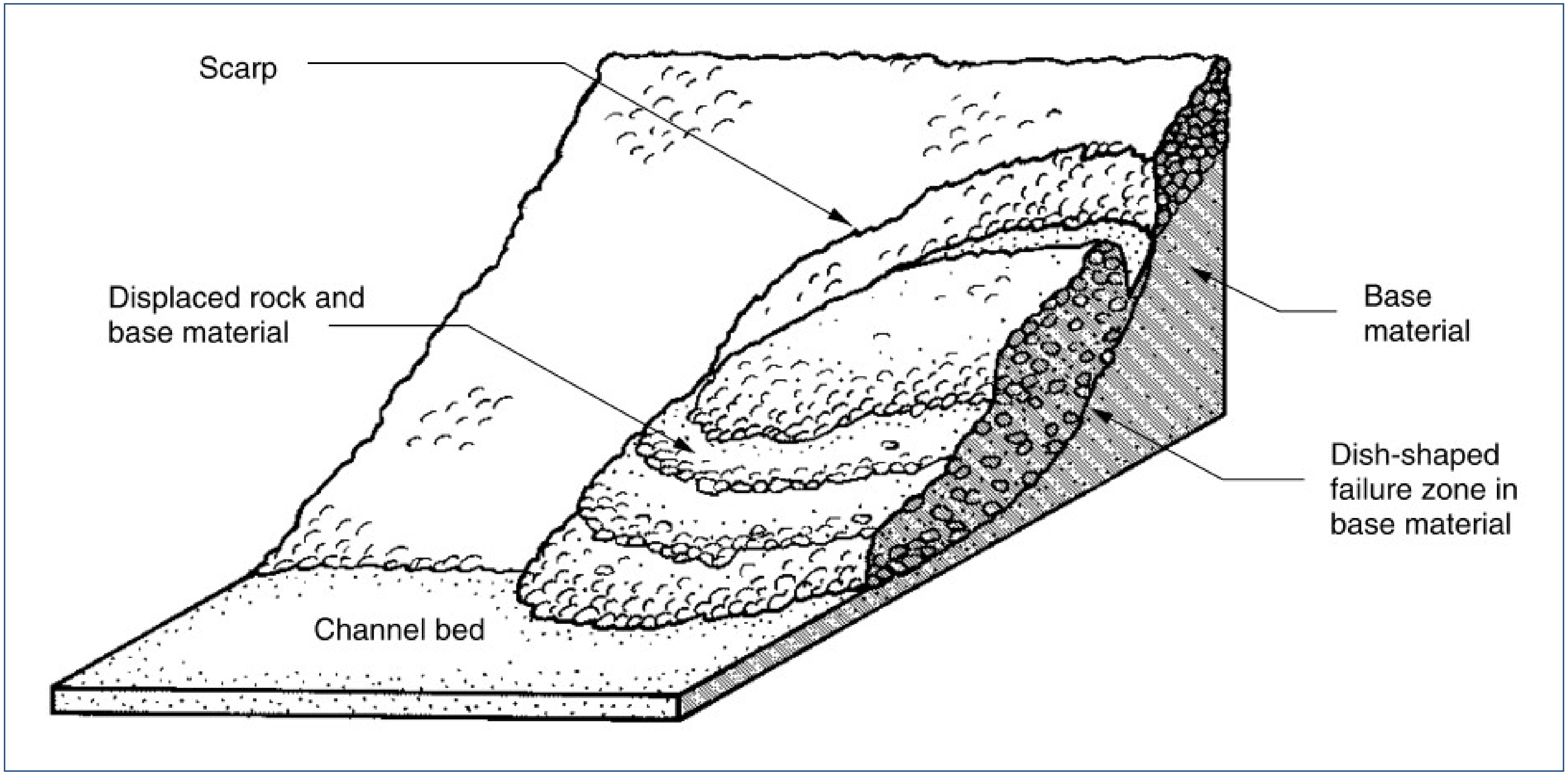

Shallow Planar Slide

Cantilever Failure (BSTEM, USDA)



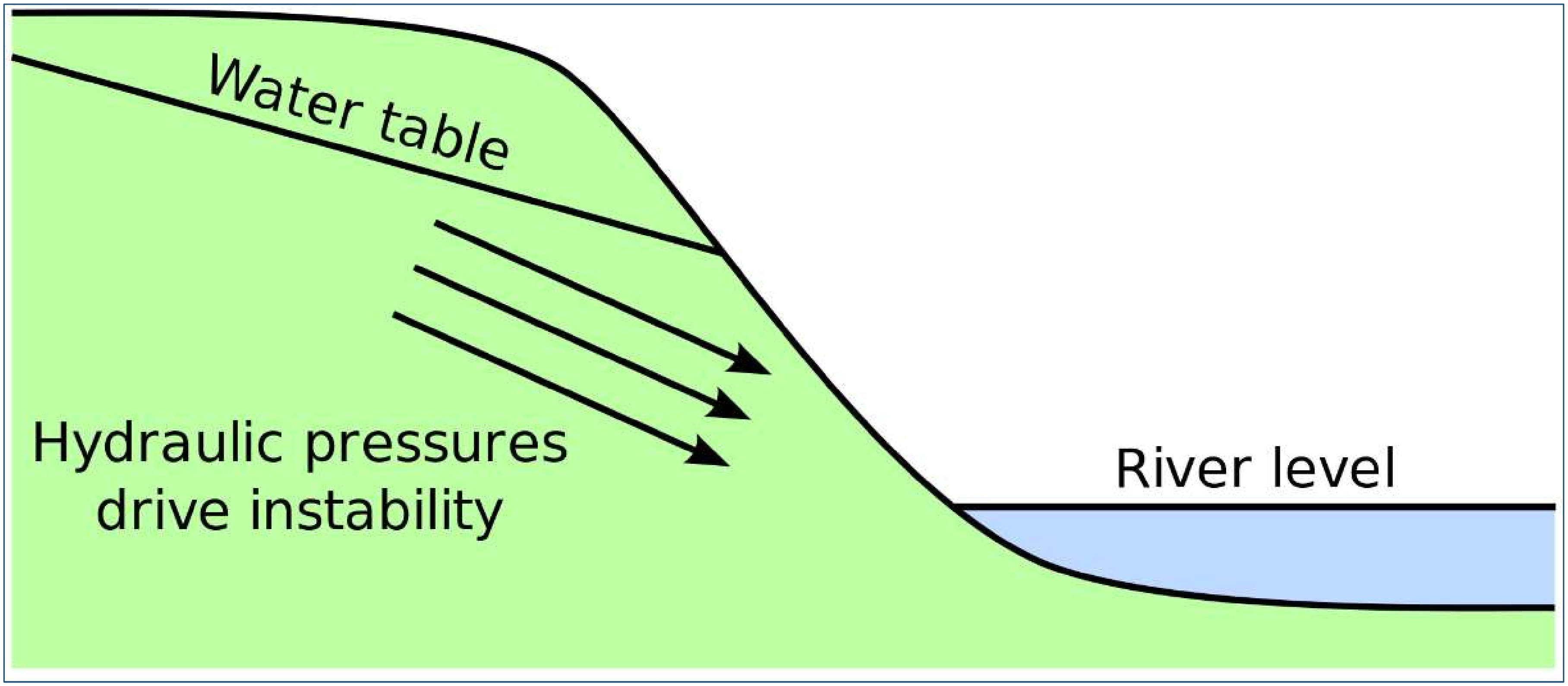

Cantilever Failure

Slump

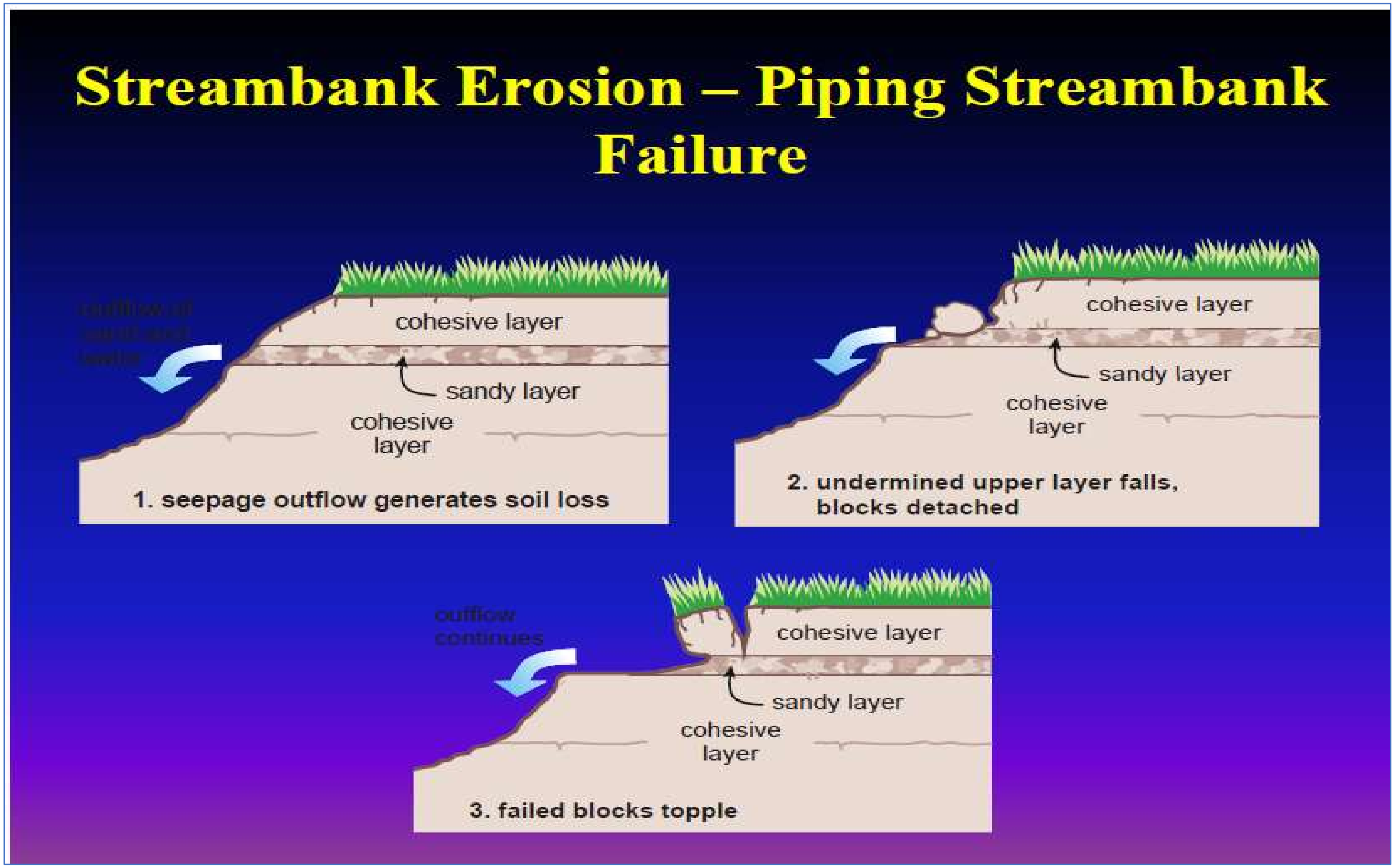

Scarp
Displaced rock and base material
Base material
Dish-shaped failure zone in base material
Channel bed


Slump Bank Failure

Pore Pressure / Pop Out / Piping Causes Falling River Level

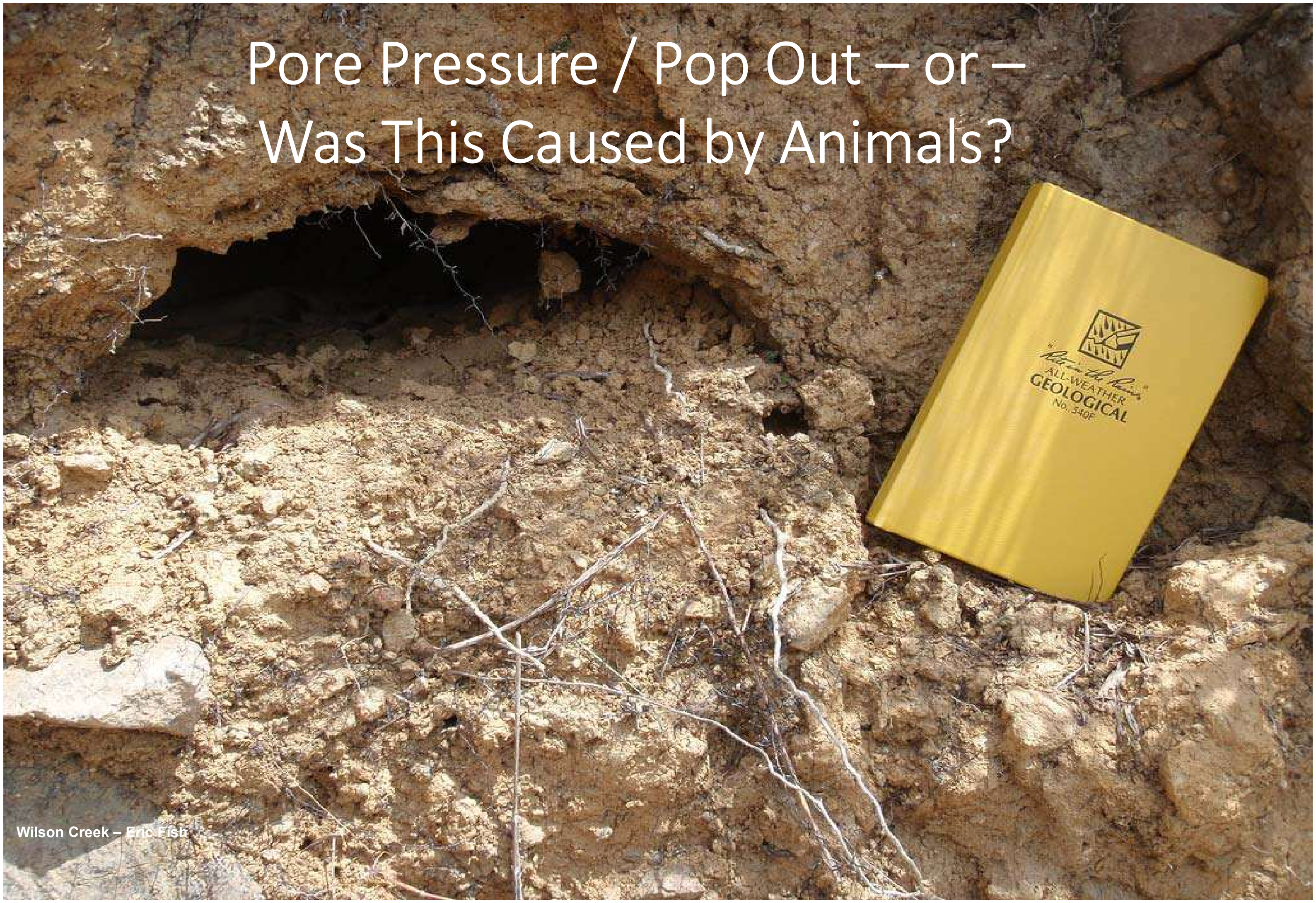


Piping Failure (BSTEM, USDA)



Piping Failure

Pore Pressure / Pop Out – or – Was This Caused by Animals?

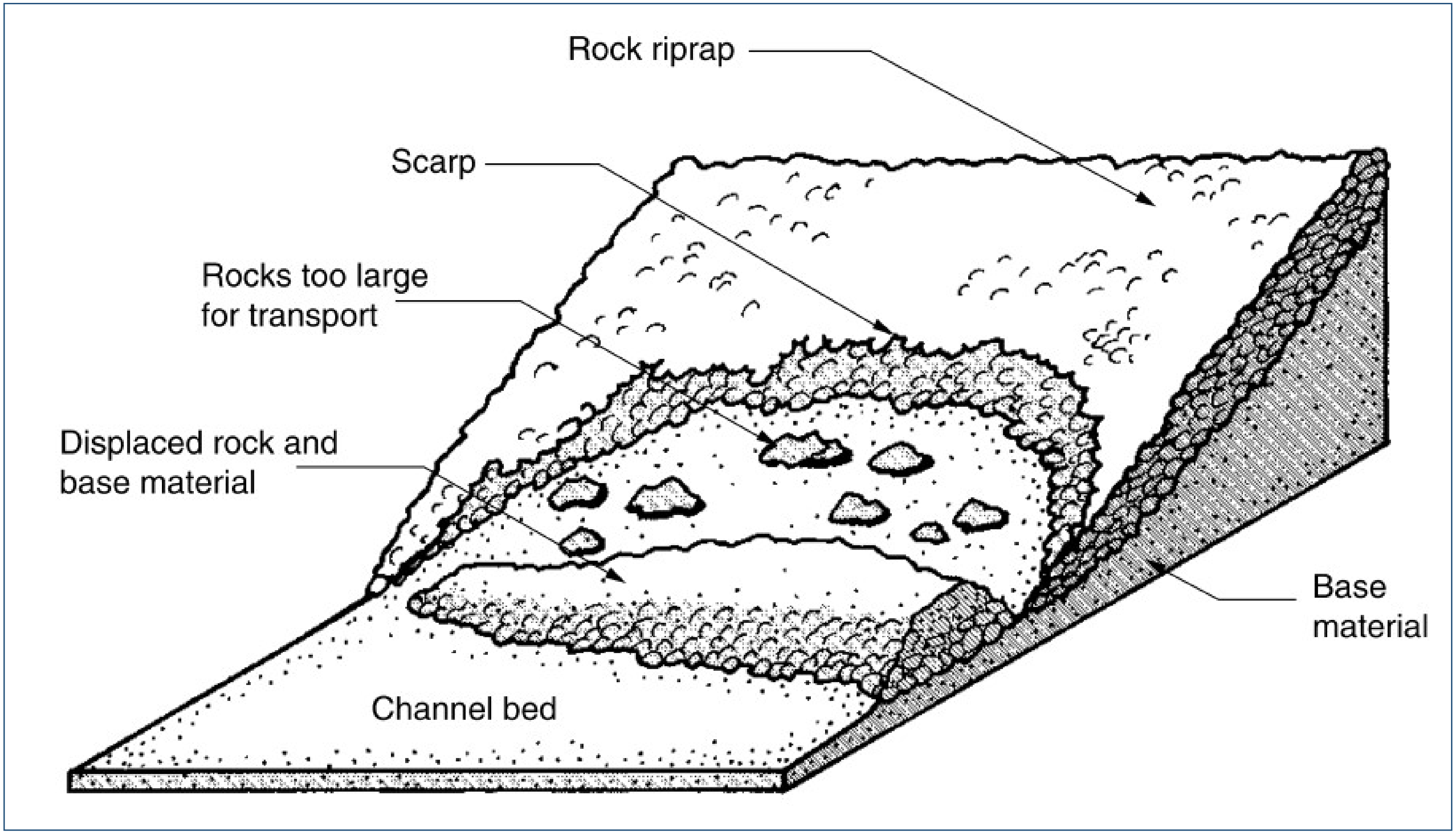


Wilson Creek – Eric Fish

Impinging Flow

Wind / Wave

Particle / Parallel Erosion



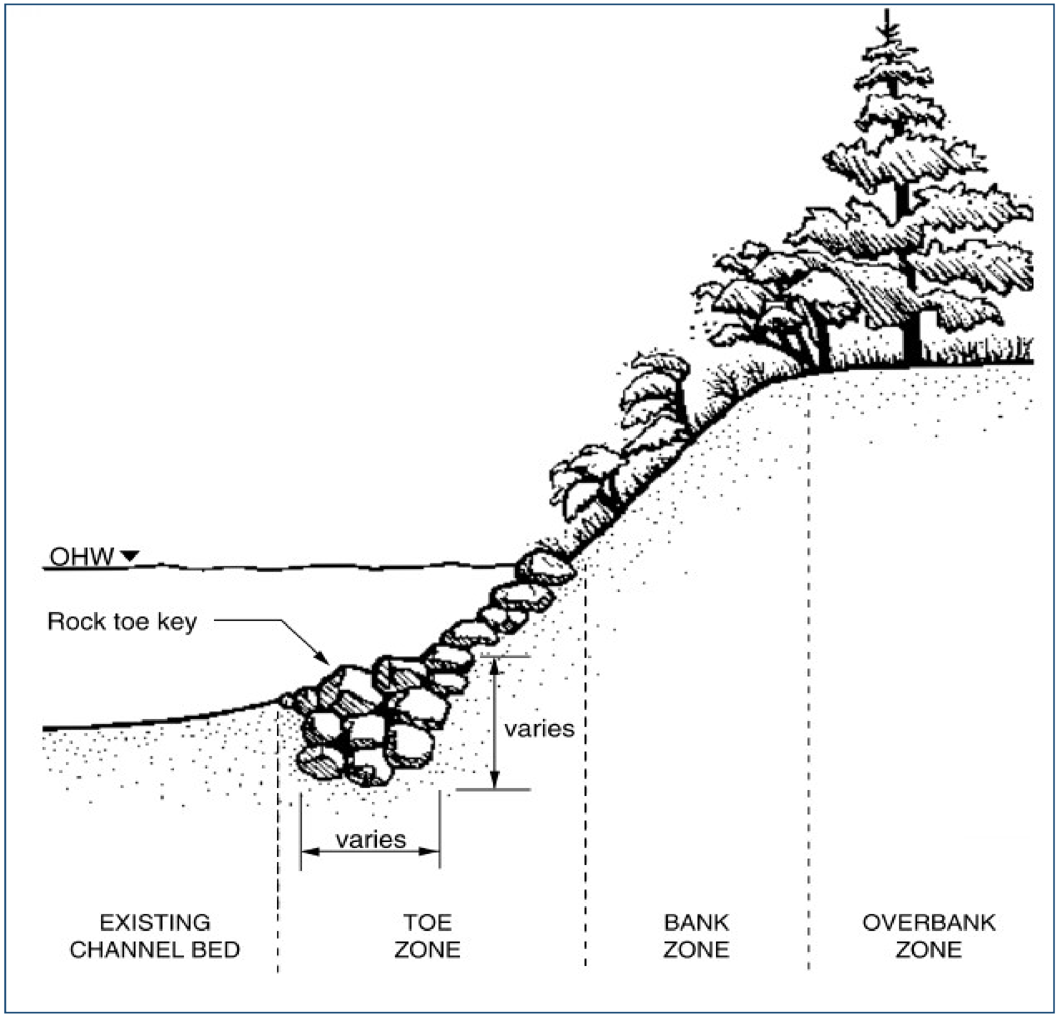
Parallel Flow

Bend Toe Scour

Gully and Rill Scour Entering Stream

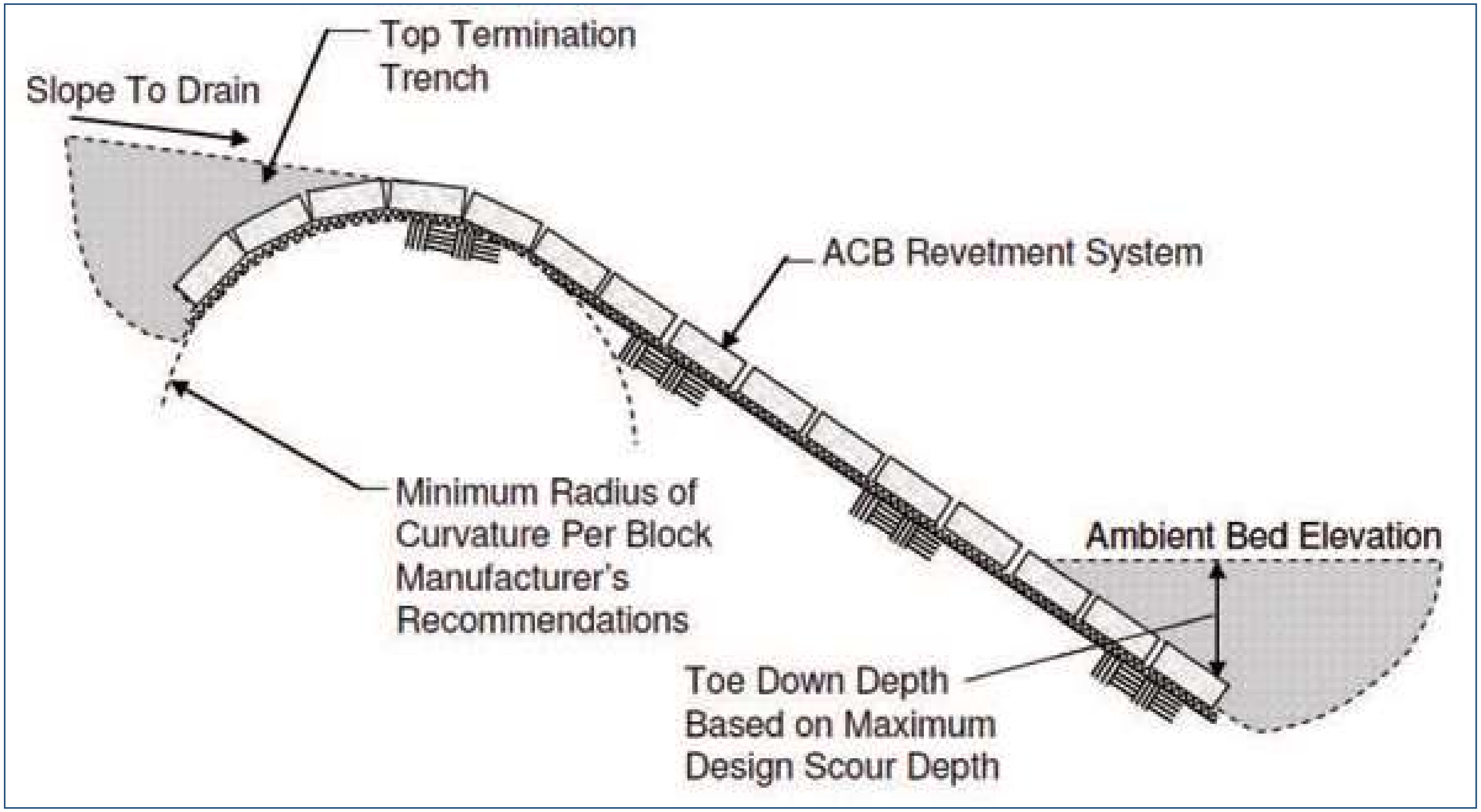
Basics of Toe and Bank Protection

- Bank stabilization methods can be categorized into three fundamental types: rock (structural), vegetative, and integrated (bioengineering).
- Protection methods in the toe zone are rock toe keys, cribwalls, and large woody debris.
- For bank zone, all three bank stabilization methods (rock, vegetative, and integrated) may be used in this zone.



Four Techniques to Prevent Undermining of Toe

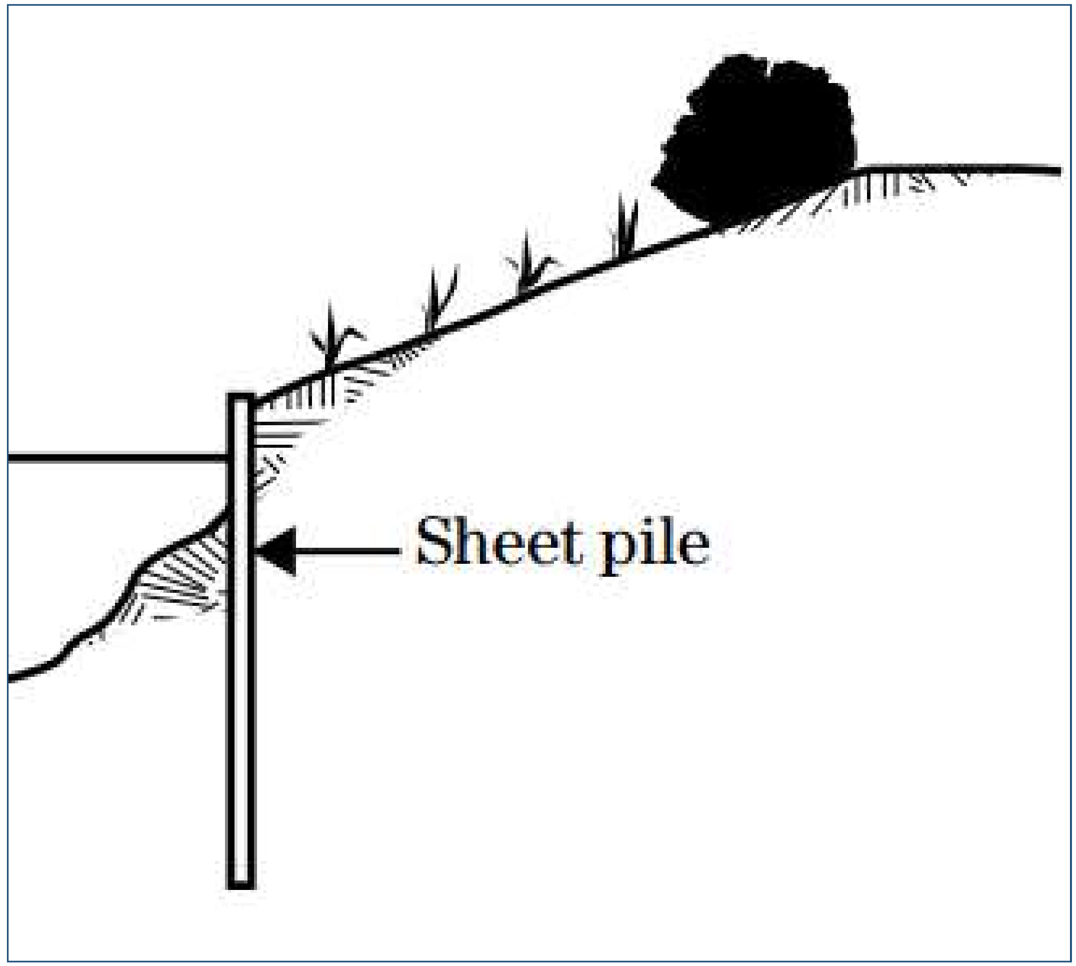
1. Excavate and continue revetment to non-erodible material or below depth of scour.



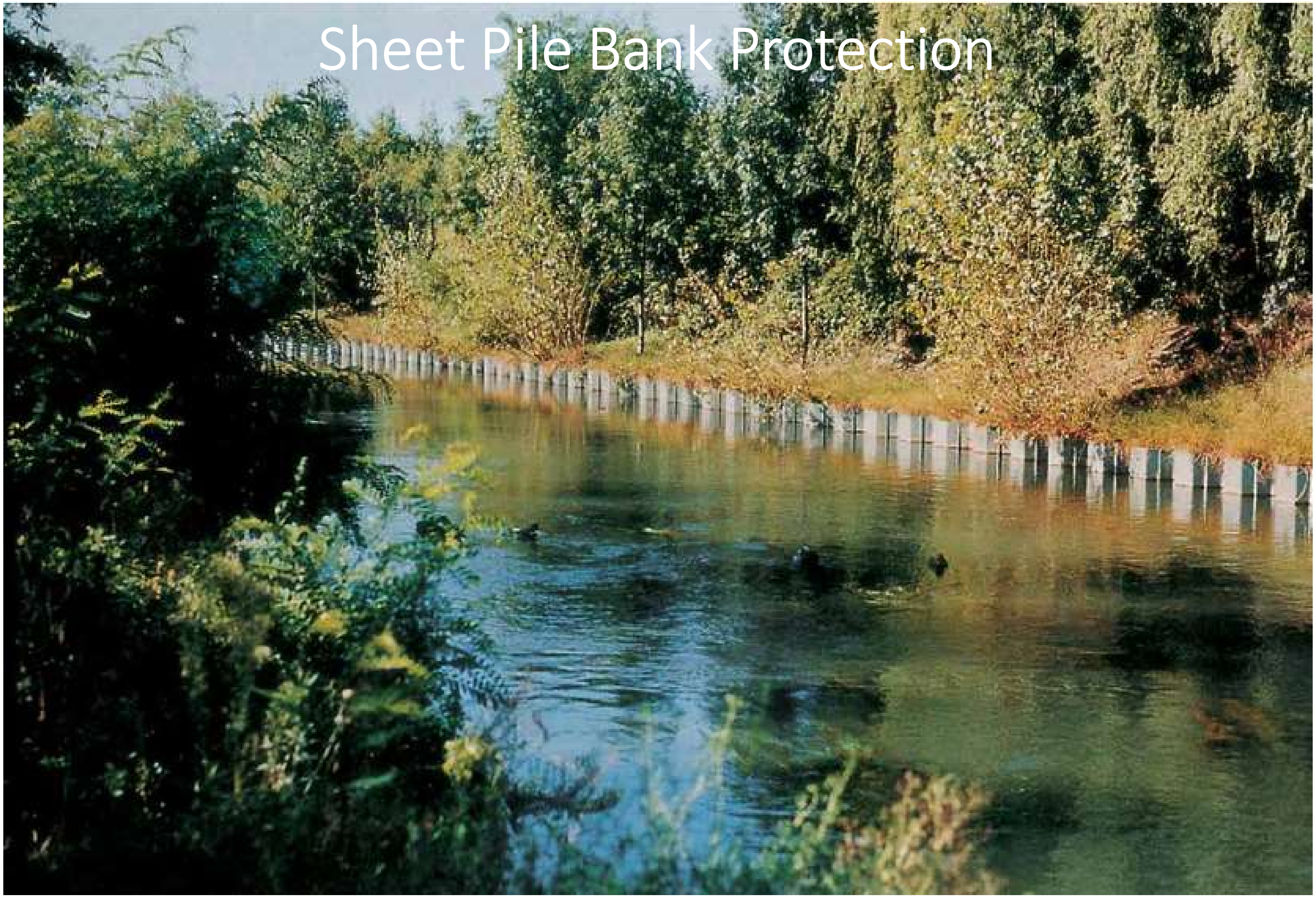

Santa Gertrudis River – Eric Fish

Four Techniques to Prevent Undermining of Toe

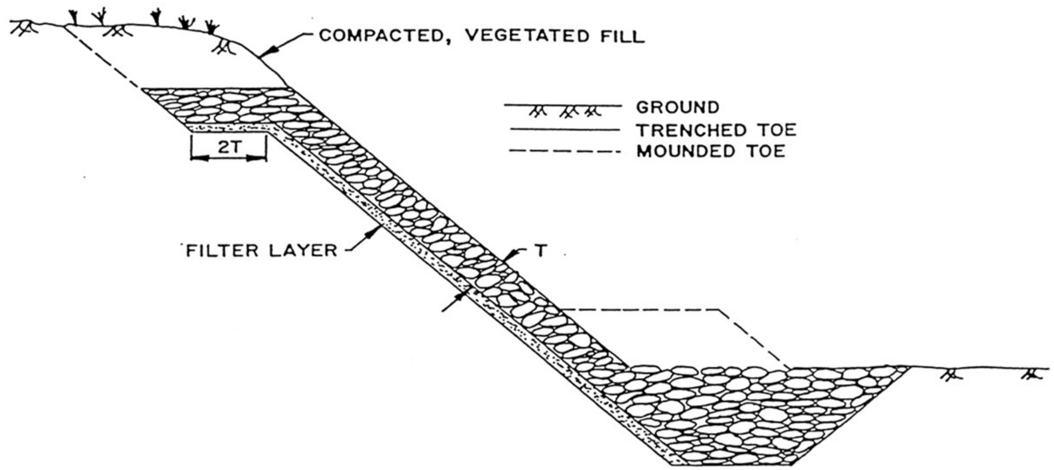
2. Drive a “cut-off wall” of sheet piling from toe of revetment to non-erodible material or below depth of scour.



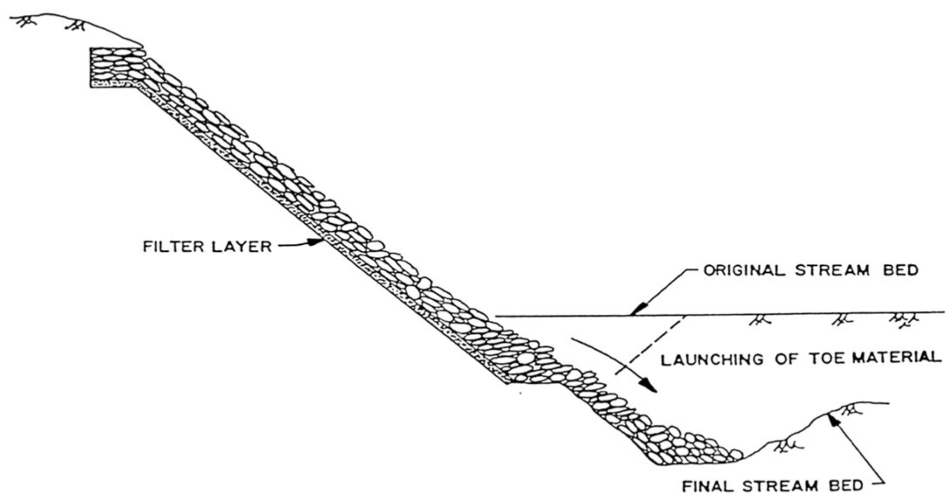
Sheet Pile Bank Protection



3. Lay a flexible "launching apron" horizontally on bed at foot of revetment.
   - Most economical for cohesionless material
   - Applicable for deep scour
   - Includes trench toe and mounded toe for riprap
   - Good for when dewatering is an issue



Typical riprap installation: end view (bank protection only)

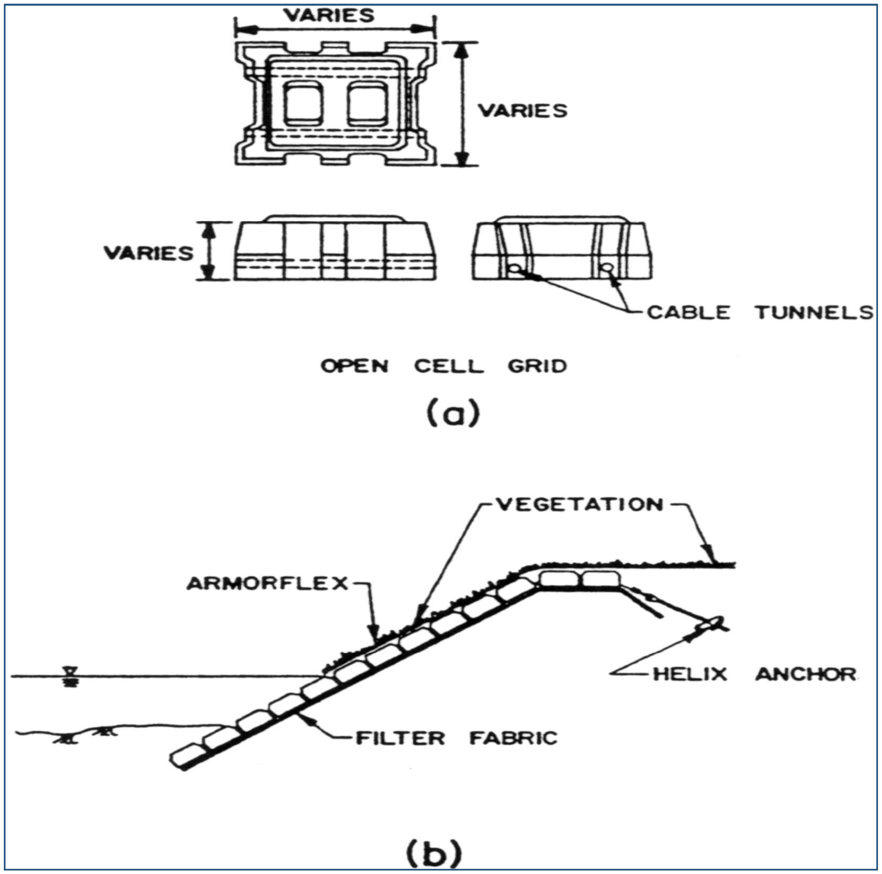


Launching of riprap toe material

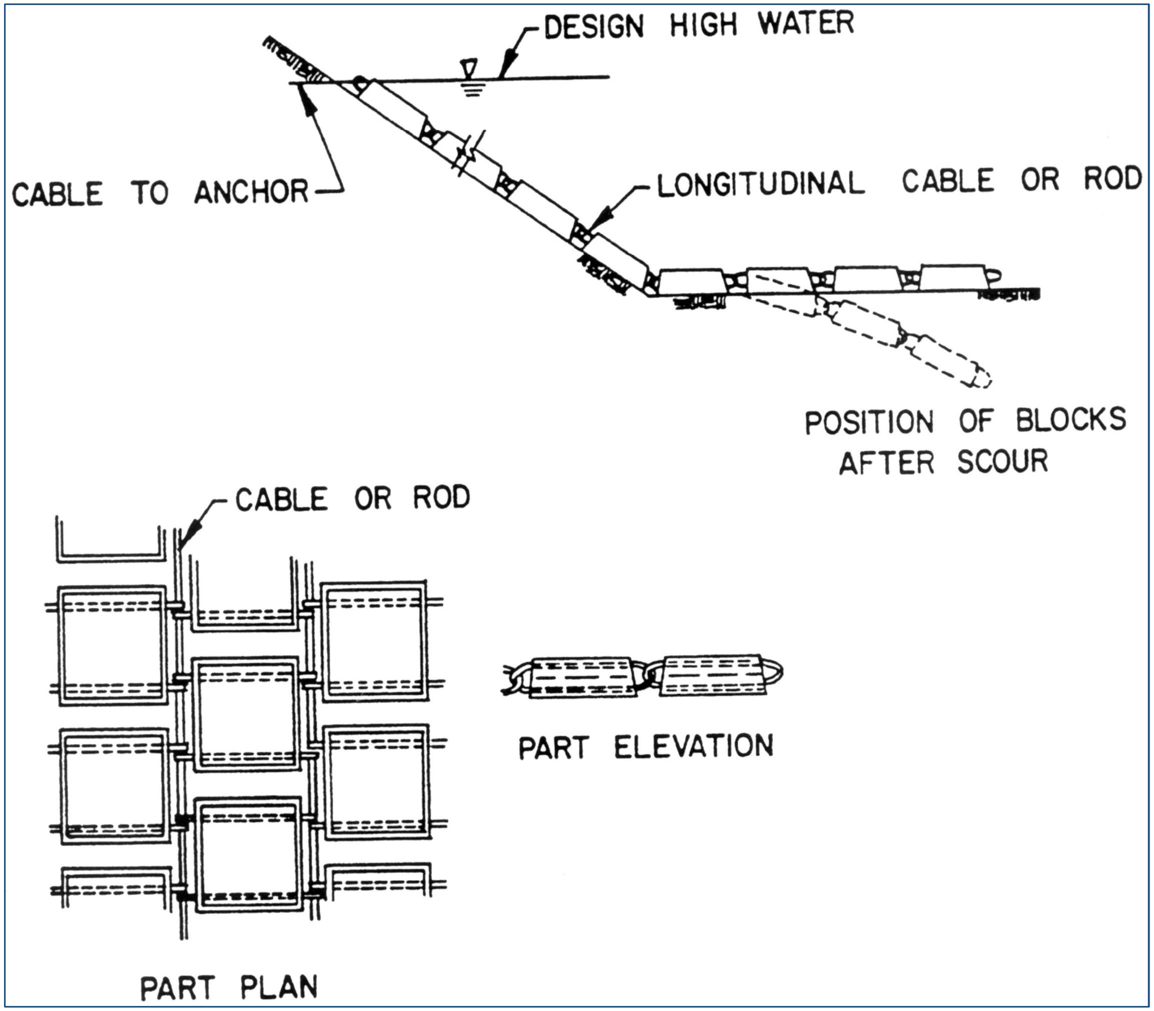
Launching Riprap
San Luis Rey River, CA

4. **Pave entire bed across cross section** (economical only for small streams).

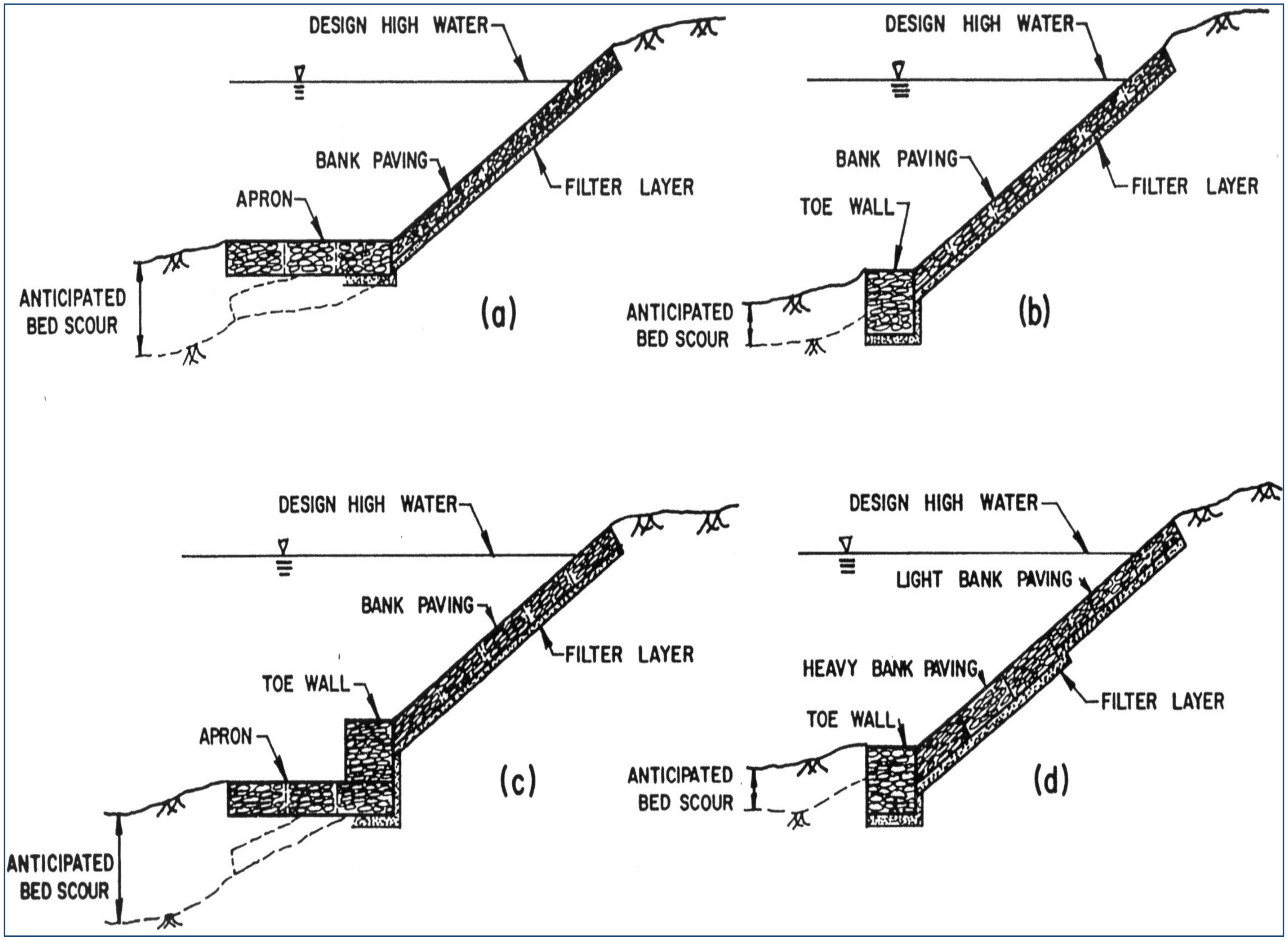
Toe Protection:
Articulated Concrete Blocks (ACB), with Vegetation



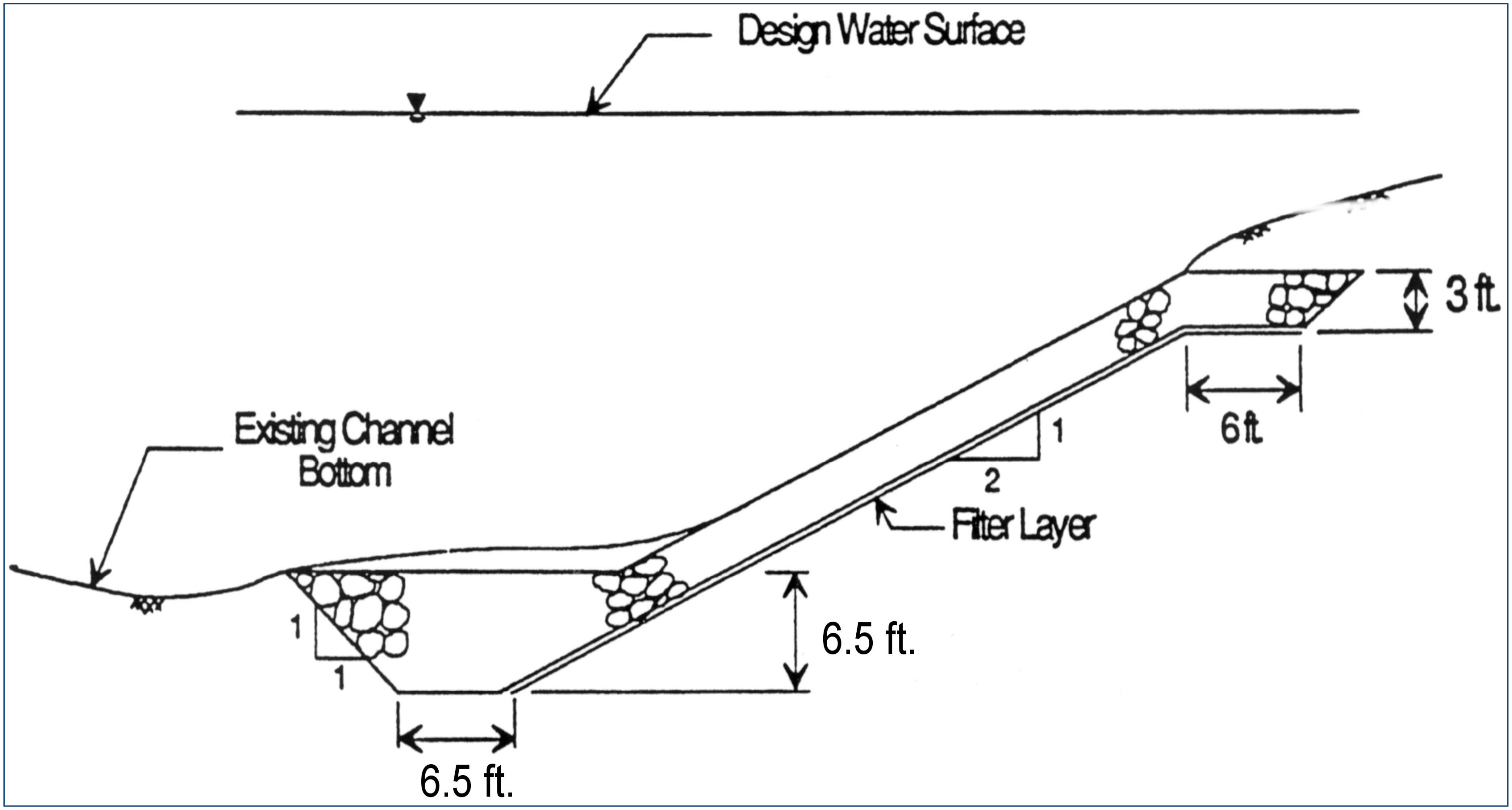
Toe Protection: Flexible ACBs



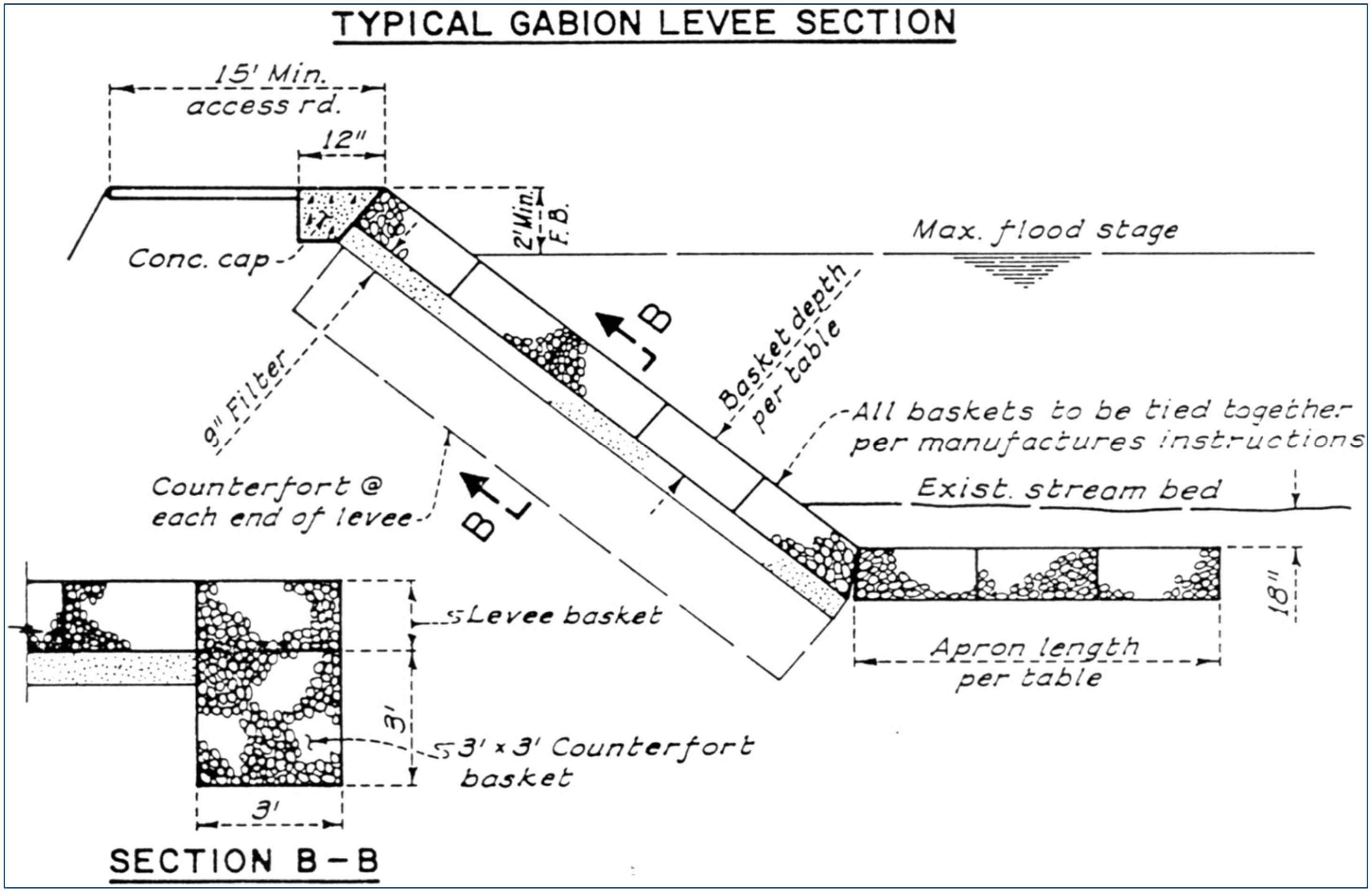
Toe Protection Configurations



Design Considerations for Toe Protection



Design Considerations for Toe Protection, Gabions



Gabion Bank Protection (Reno Mattress) Installation

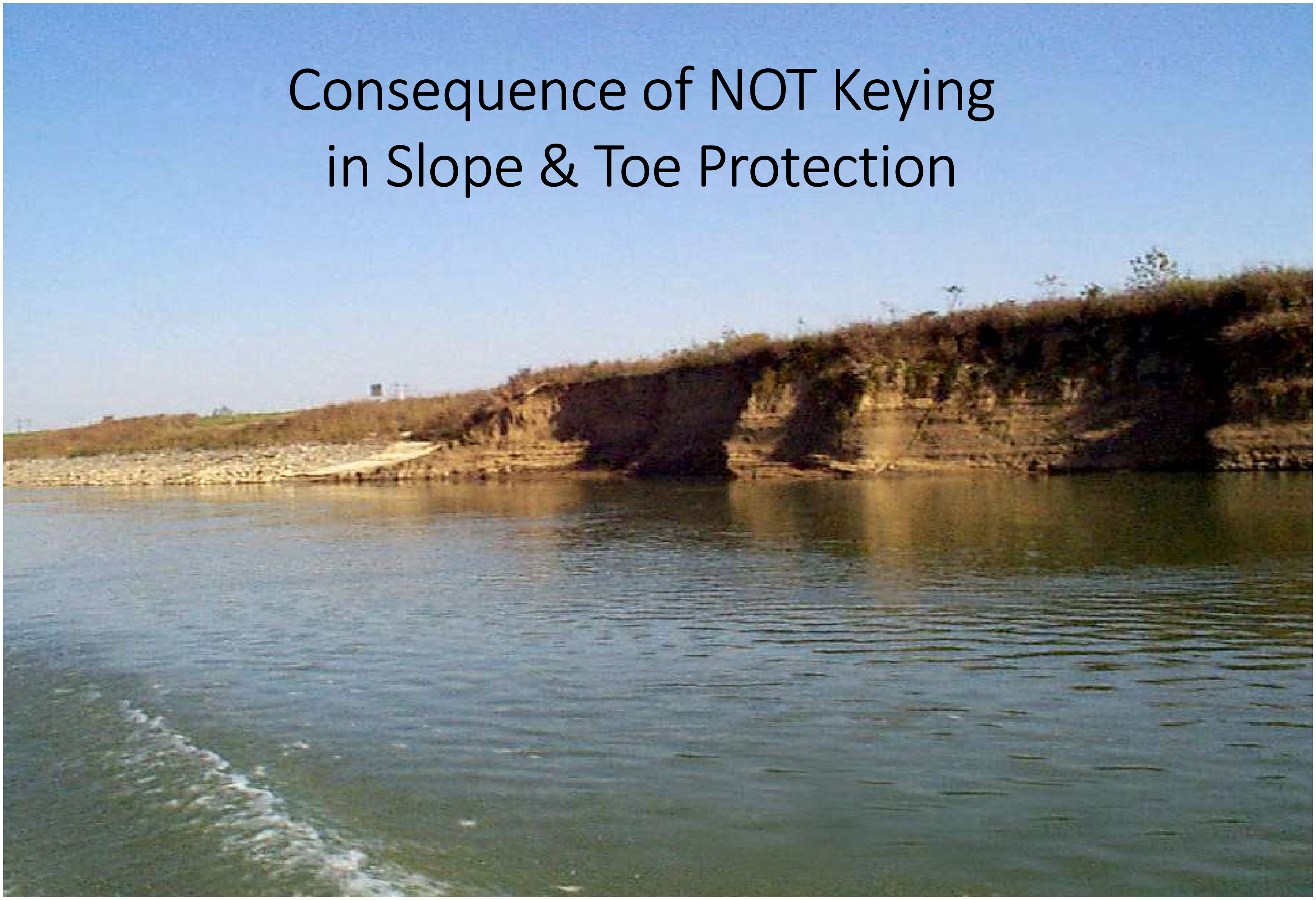
Design Considerations for Toe Protection

- **Design Flow**
  - Usually examine a range of flows up to 100-year event
  - Bankfull or overtopping event may generate greatest velocities and tractive forces
- **Design Velocities**
  - Use local velocity, not average channel velocity (unless specified in equation)
  - Local velocity along outside of bend may be 60% greater than the average velocity in the approach channel *(Thorne, et al., 1995)*

Design Considerations for Toe Protection

- **Rock Toe Keys** *(Johnson and Stypula, 1993)*
  - Rock is keyed in – not end dumped
  - Placed to potential scour depth or a minimum of 5 feet below the original streambed elevation *(Lagasse, et al., 1995)*
  - Minimum rock dimension of 2 feet or minimum weight of 500 pounds for stability
  - Use quarried (angular) rock which tends to interlock
  - For high banks, consider construction bench and set back upper bank

Consequence of NOT Keying in Slope & Toe Protection



Design Considerations for Toe Protection: Live Crib Wall

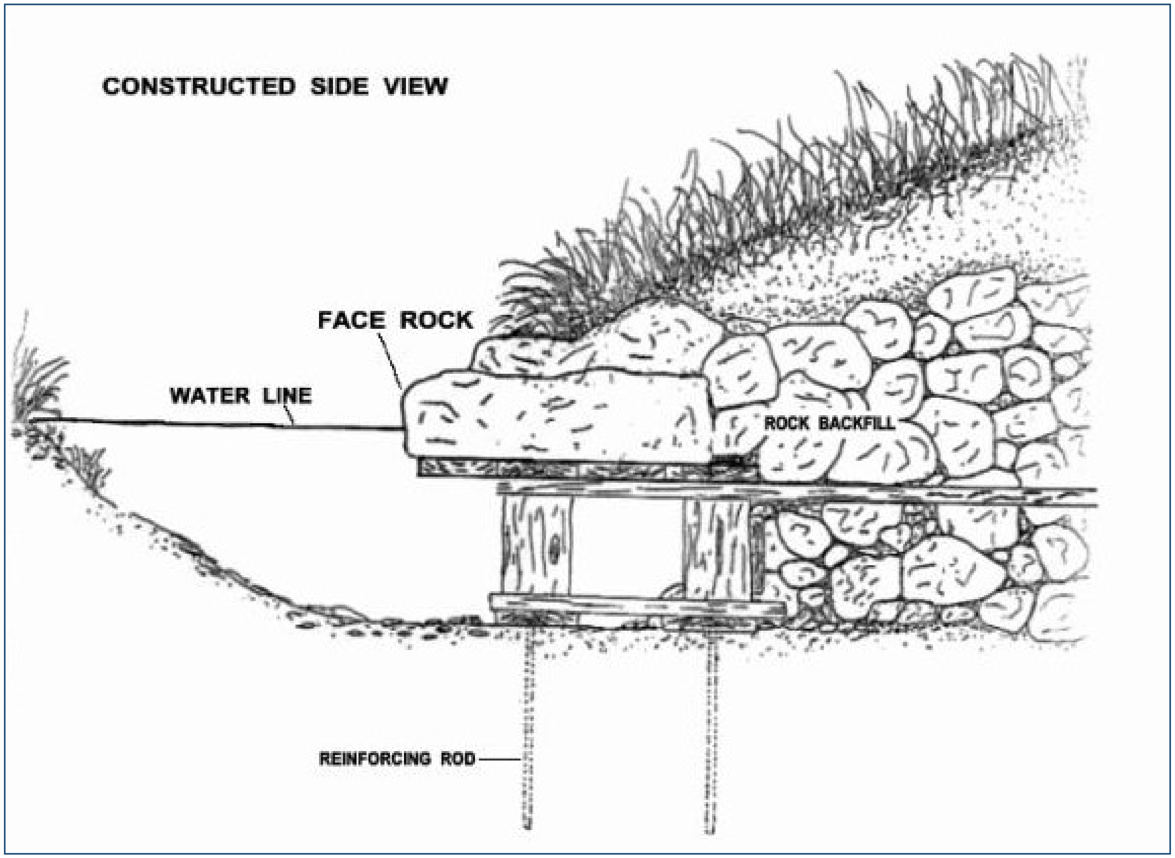
- Rectangular framework of logs or untreated timber, rock, and woody cuttings
- Useful when space is limited and slopes cannot be cut back
- May have finished streamside slopes as steep as 1H:10V
- Useful for restoring lost banks
- Construction details discussed in Gray and Leiser, 1982
- May require rock toe key outside of structure

Live Crib Wall:
Under Construction and 1 Year Later

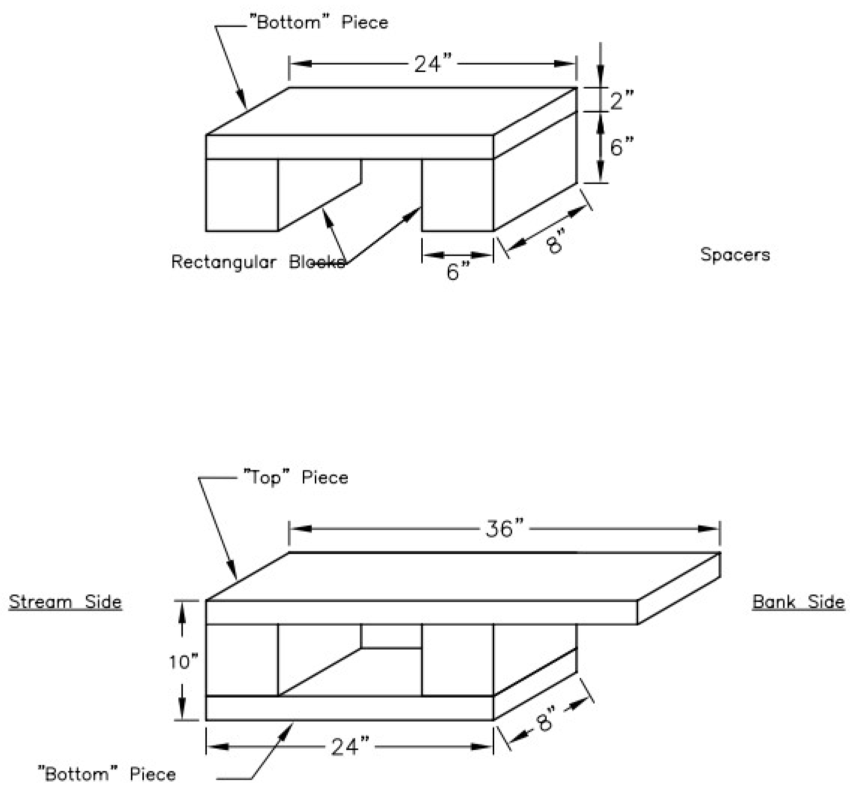
LUNKERS:

Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids

- Provides overhanging shade and protection for fish
- Stabilizes the toe of a streambank
- Made from treated lumber, untreated oak, or materials made from a combination of plastic and wood



Construction of LUNKERS



Step 1: Bulid SPACERS

Build 3 equal spacers as shown using oak or other wood that is strong and rot resistent. Use 20d nails min.

Summary

Today's Session

- Streambank Zones
- Total Scour at Streambank Toes
- Causes of Local Streambank Instability
- Basics of Toe and Bank Protection
- Design Considerations for Toe Protection

Next Session

- Redirective Methods
- Resistive Methods
- Bioengineering / Vegetative Methods
- Criteria for Use of Various Bioengineering/ Vegetative Methods