2022 Fish Passage Design for Road Crossings Workshop and Field Tour

A Concurrent Session at the 39th Annual Salmonid Restoration Conference held in Santa Cruz, California from April 19 – 22, 2022.

- **Session Coordinators:**
  - Michael Love, P.E., Michael Love & Associates, Inc.
  - Ross Taylor, Ross Taylor and Associates
  - Kristen Kittleson, County of Santa Cruz

This two-day workshop will focus on fish passage design approaches and techniques for road-stream crossings and other low-head barriers. The course will be structured around Part XII—Fish Passage Design and Implementation—of the CDFW California Salmonid Stream Habitat Restoration Manual. The workshop is intended for participants with a variety of backgrounds, including engineers, biologists, geologists, planners, and project managers.

Covered topics include:
- Biological imperative of providing passage
- Assessing geomorphic risk for a fi sh passage project
- Pre-design and selection of project approach
- Stream simulation design and reference reach characterization
- Roughened channel design
- Use of boulder and log weirs
- Retrofits and technical fishways

The workshop will have participants work on sample problems taken from real projects, including analysis of thalweg profiles, developing designs for a stream simulation culvert crossing, and sizing material for a roughened channel. Participants should bring a calculator and a ruler. The second half of Day 2 will include a field tour to a range of fish passage sites within Santa Cruz's Corralitos Creek. Sites include full replacements and retrofits of stream crossings and a fish ladder, illustrating the various design approaches covered in the workshop and described in CDFW Part XII

Presentations

Slide 4 – **Overview of Fish Passage Design Approaches,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 21 – **Fish Passage: What Is It and Why Is It Necessary?,** Ross Taylor, Ross Taylor and Associates

Slide 98 – **Assessing Geomorphic Risk for Stream Crossing Projects,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 133 – **The Pre-Design Phase: Geomorphic-based Stream Crossing Projects,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 174 – **Stream Simulation Design: A Geomorphic-based Approach for Aquatic Organism Passage at Road-stream Crossings,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 233 – **Traditional Hydraulic Designs for Fish Passage at Stream Crossings,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 264 – **Profile Control,** Michael Love, P.E., Michael Love & Associates, Inc.

Slide 353 – **Post-project Monitoring,** Ross Taylor, Ross Taylor and Associates

Slide 396 – **Corralitos Fish Passage Projects,** Kristen Kittleson, County of Santa Cruz

Overview of Fish Passage Design Approaches

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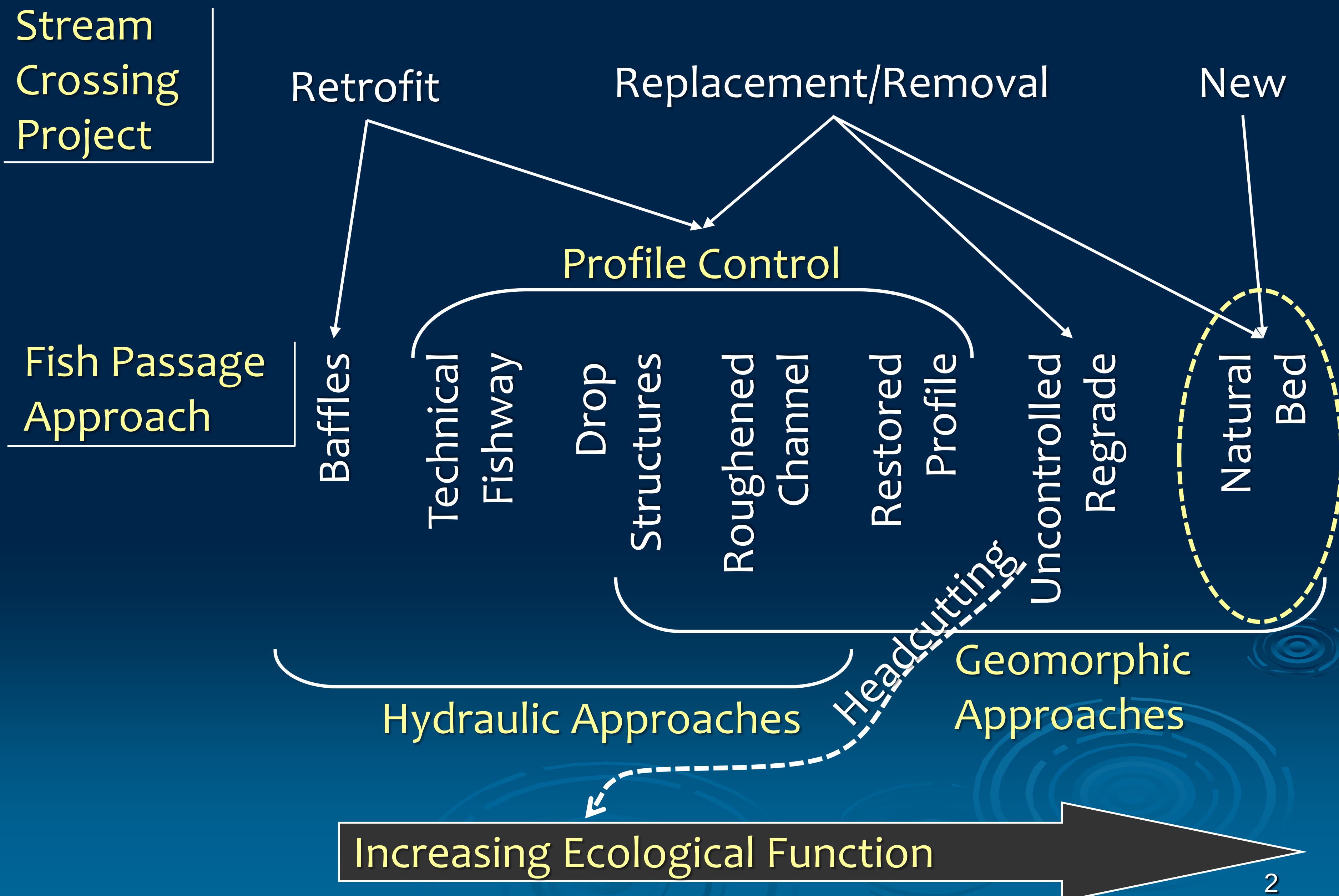
CDFW California Salmonid Stream Habitat Restoration Manual
Part XII : Fish Passage Design and Implementation

Design Approaches for Aquatic Organism Passage

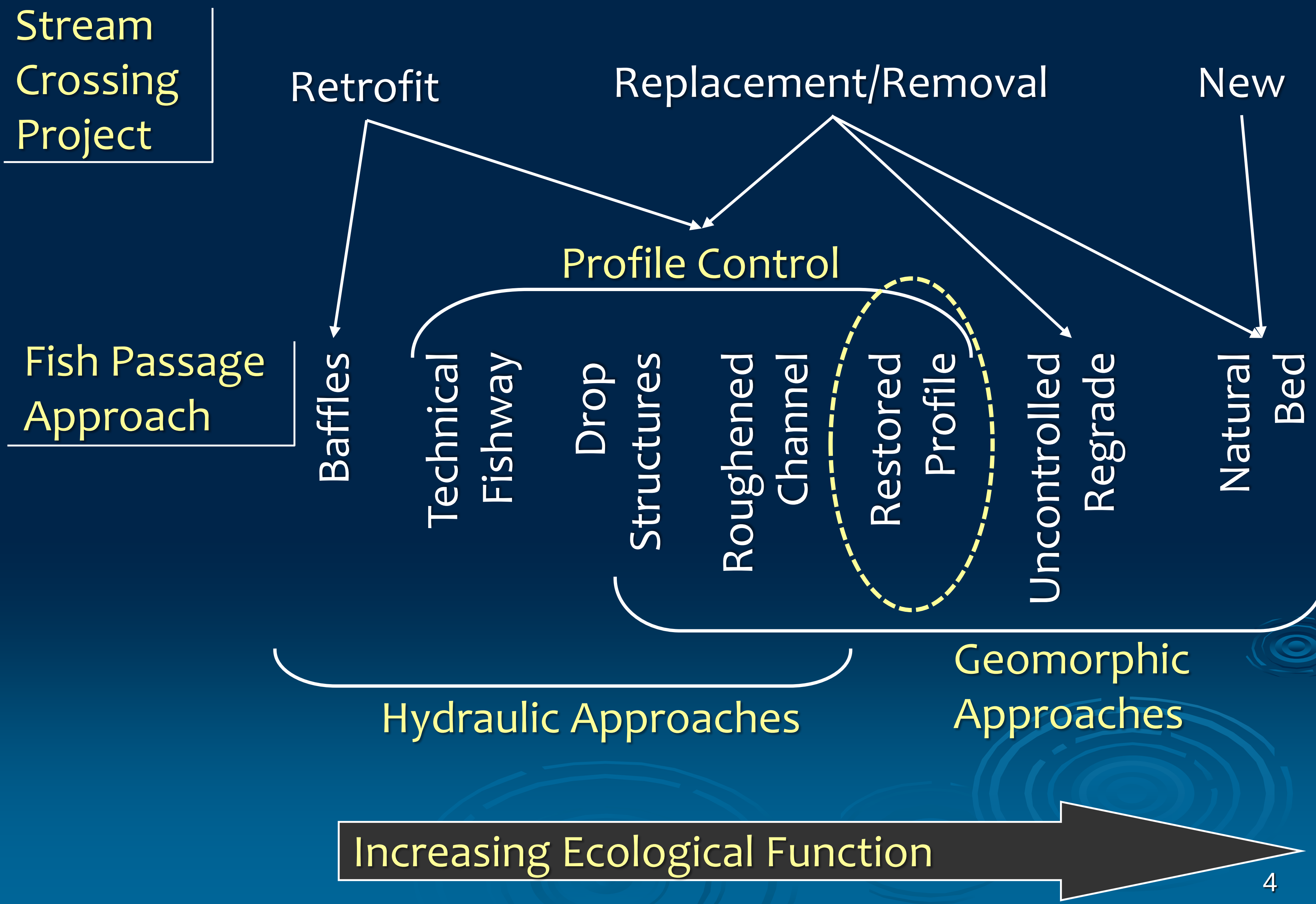


Stream Simulation

Natural Bed Options for Stable Streams

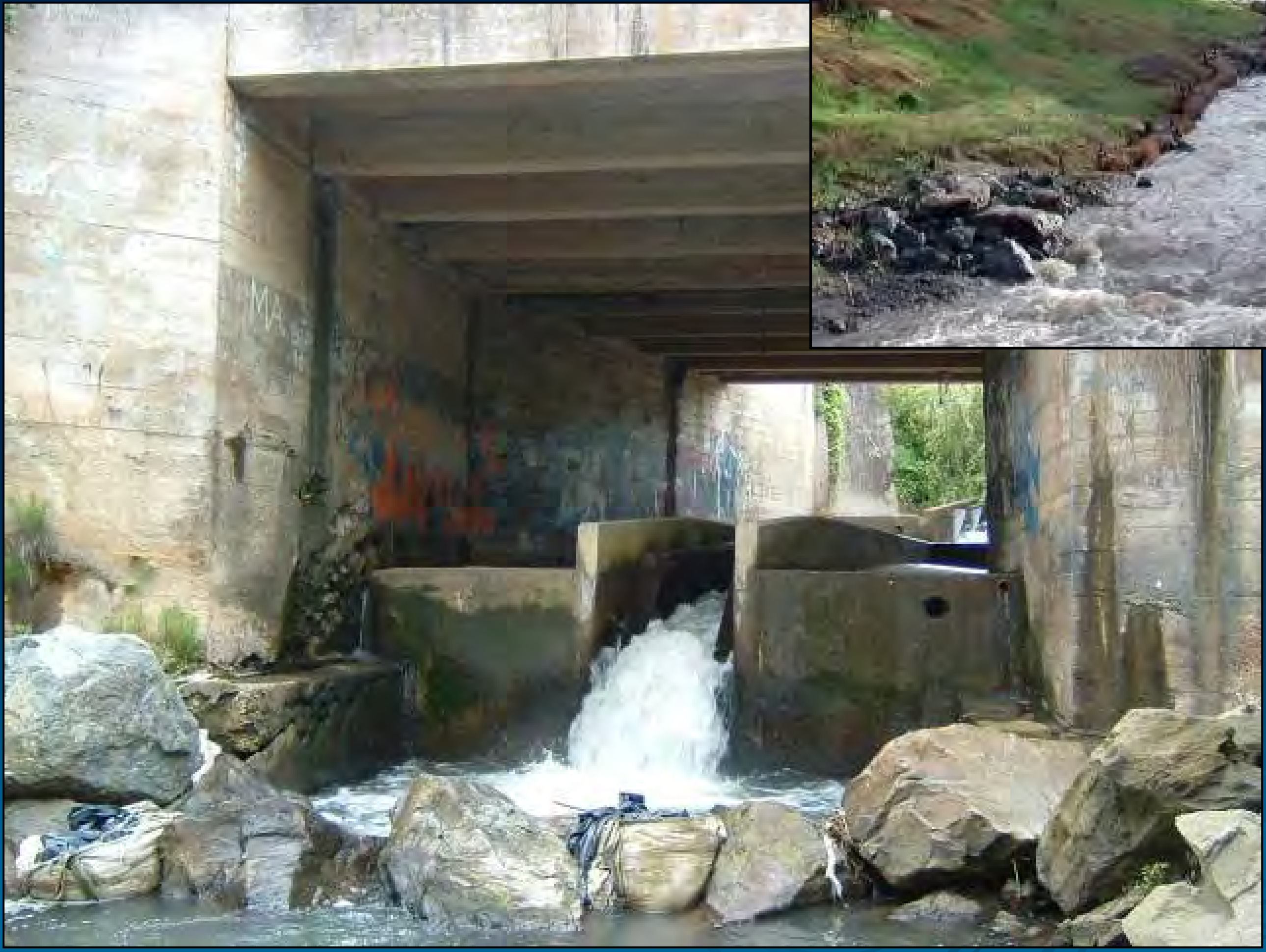
Sullivan Gulch Stream Simulation
Culvert Replacement

Design Approaches for Aquatic Organism Passage



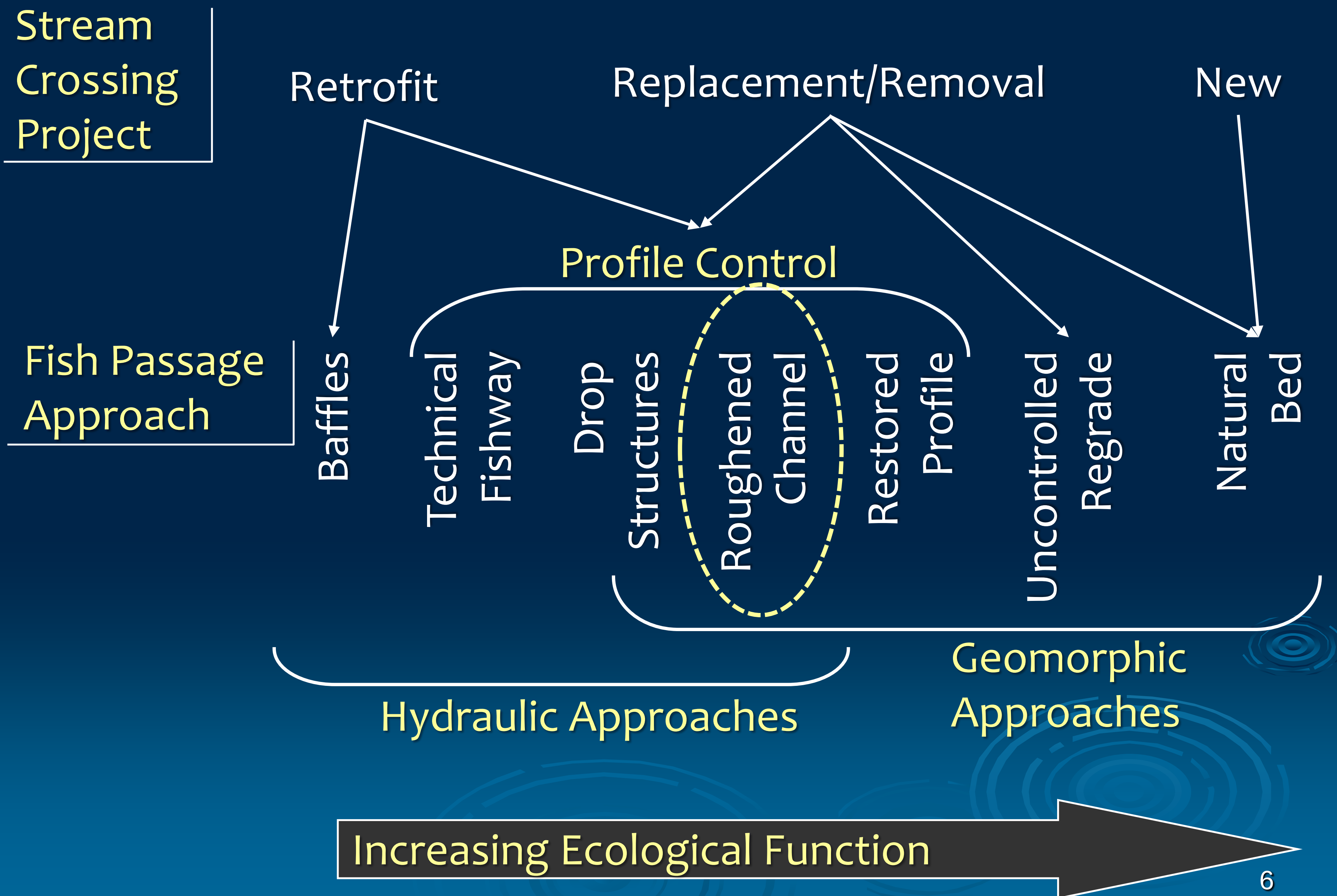
Profile Restoration

Restoring the profile of an incised channel downstream of a crossing



From Christine Chann
San Pedro Creek
Watershed Coalition

Design Approaches for Aquatic Organism Passage



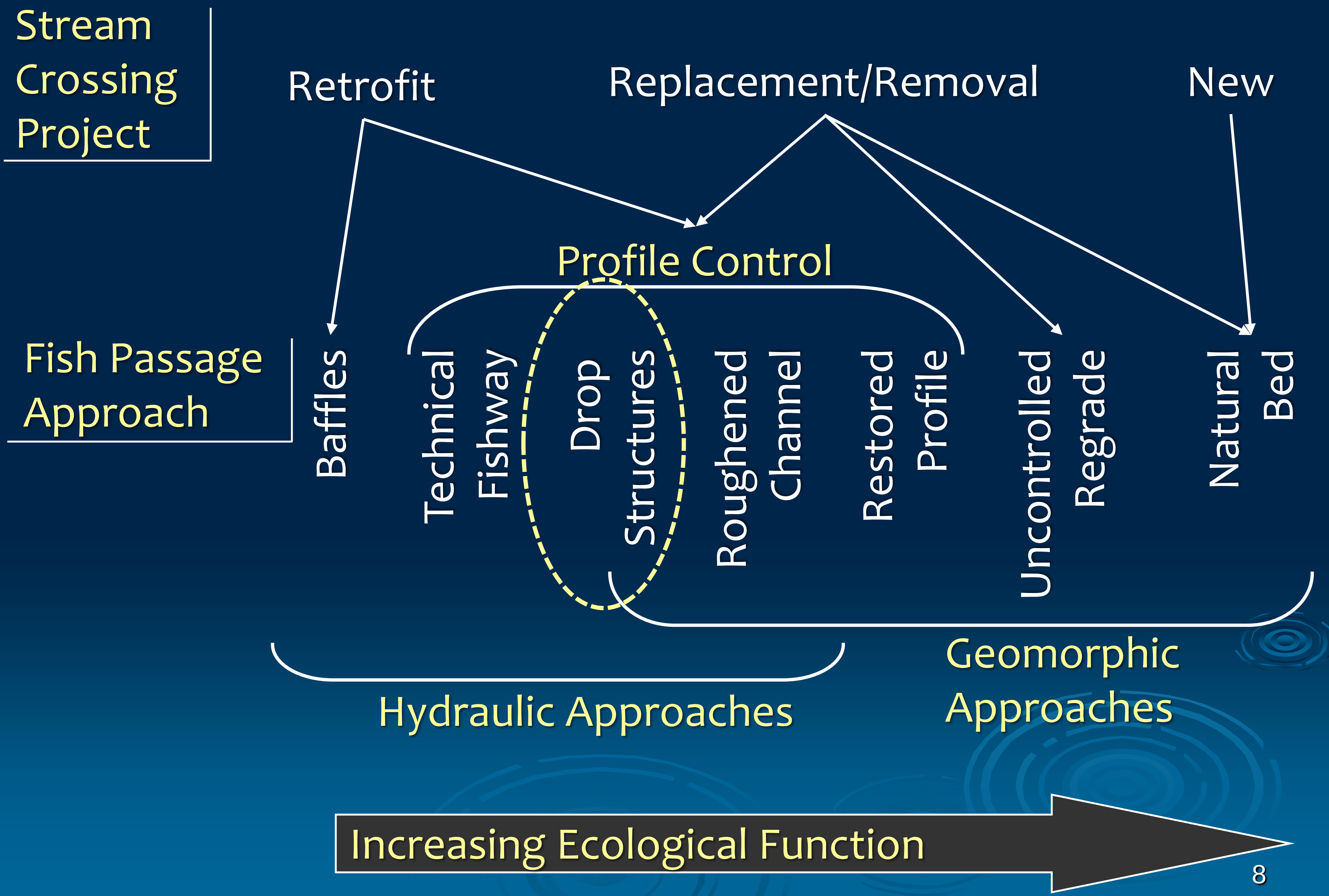
Nature-Like Fishways (Roughened Channels)

Geomorphically-Based Profile Control

Before

After

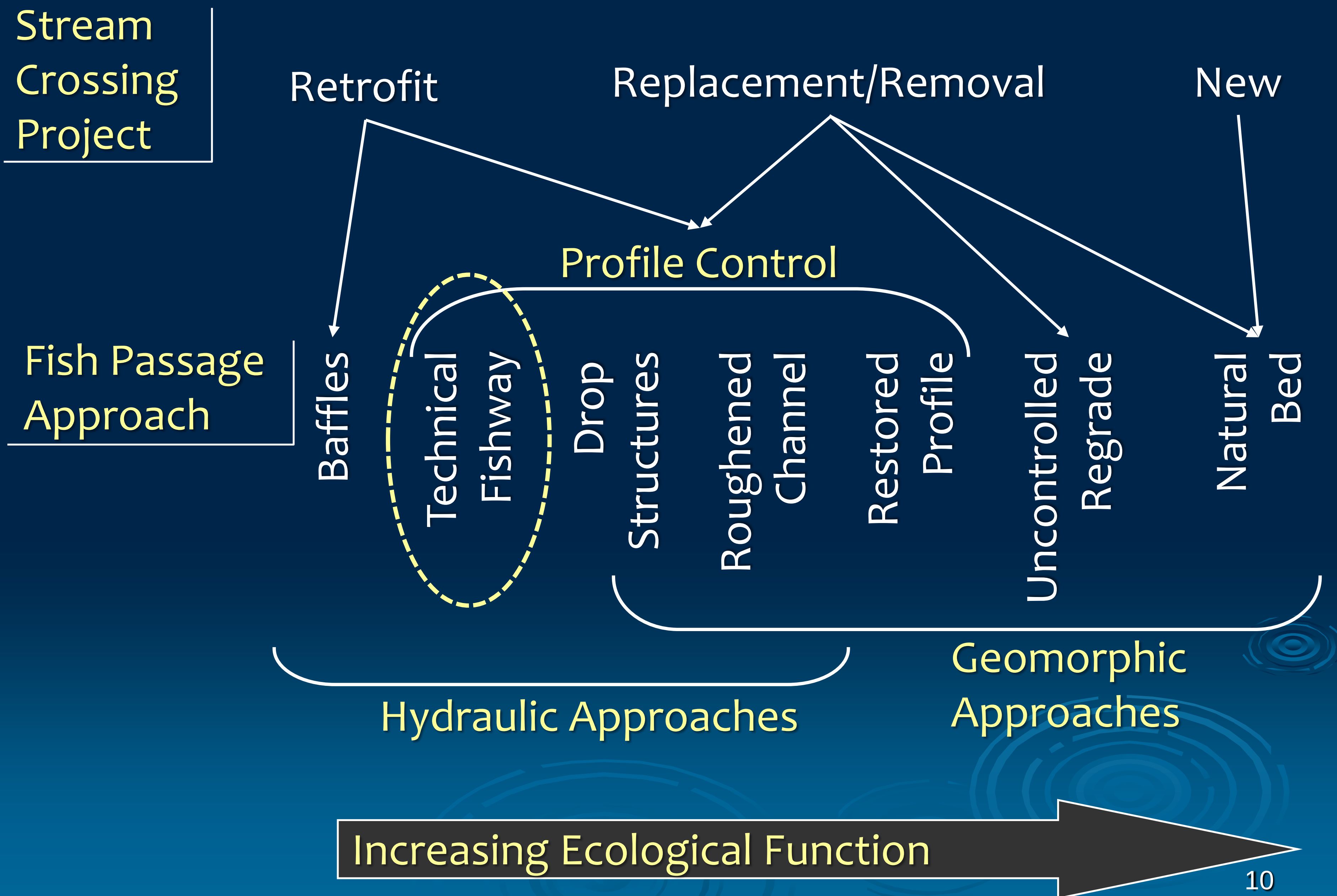
Design Approaches for Aquatic Organism Passage



Boulder and Log Weirs

Drop Structures for Profile Control

Design Approaches for Aquatic Organism Passage



Technical Fishways

Profile Control

Vortex
Pool & Chute
Fishway

Peacock Creek, Smith River, Calif.

Stream Simulation

Example of a Small Stream Crossing Application

McGarvey Gulch

4-foot Dia. CMP on Low-Volume Road

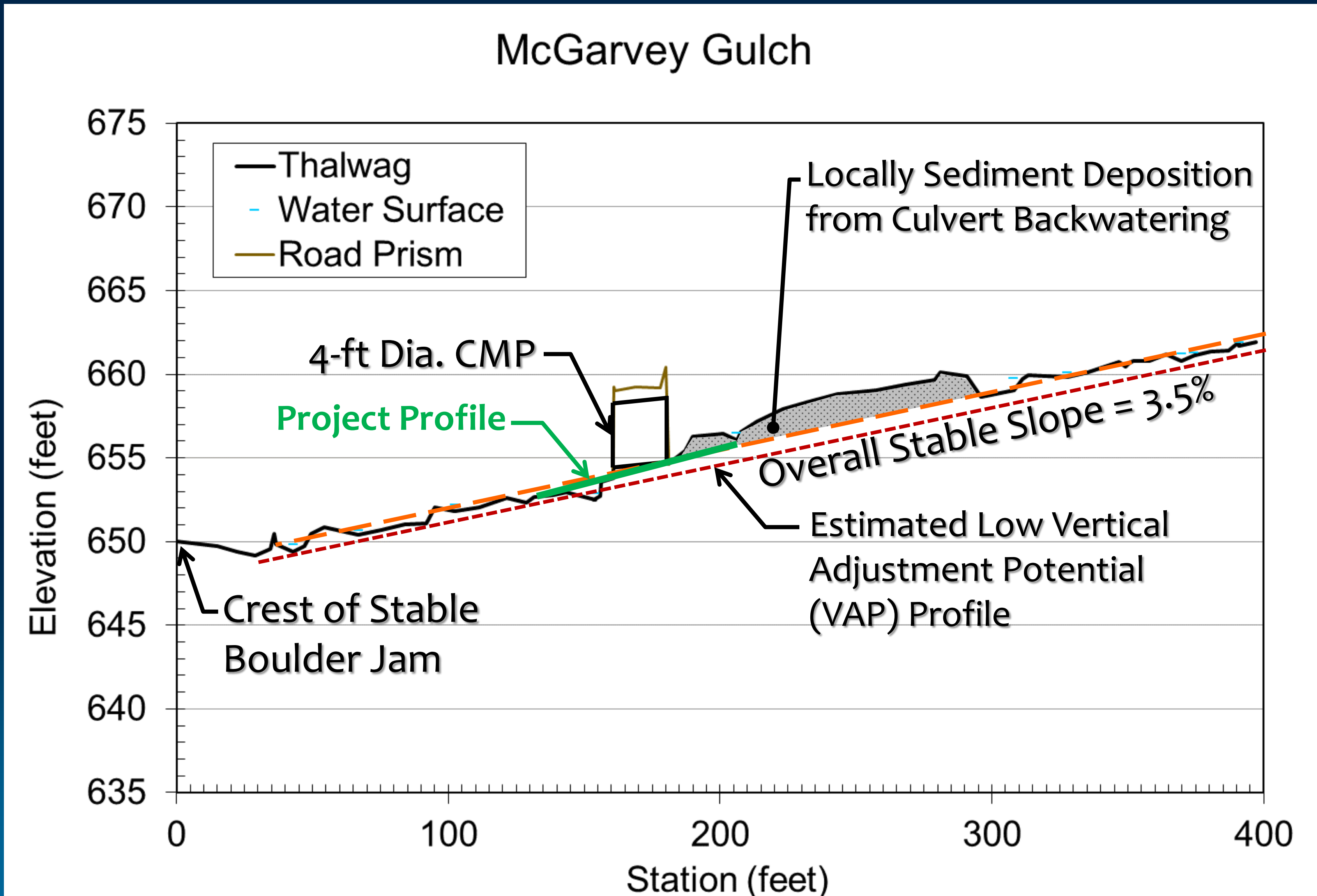
Steelhead Trout Stream

Inlet

Outlet Headwall and Apron

Stream Simulation

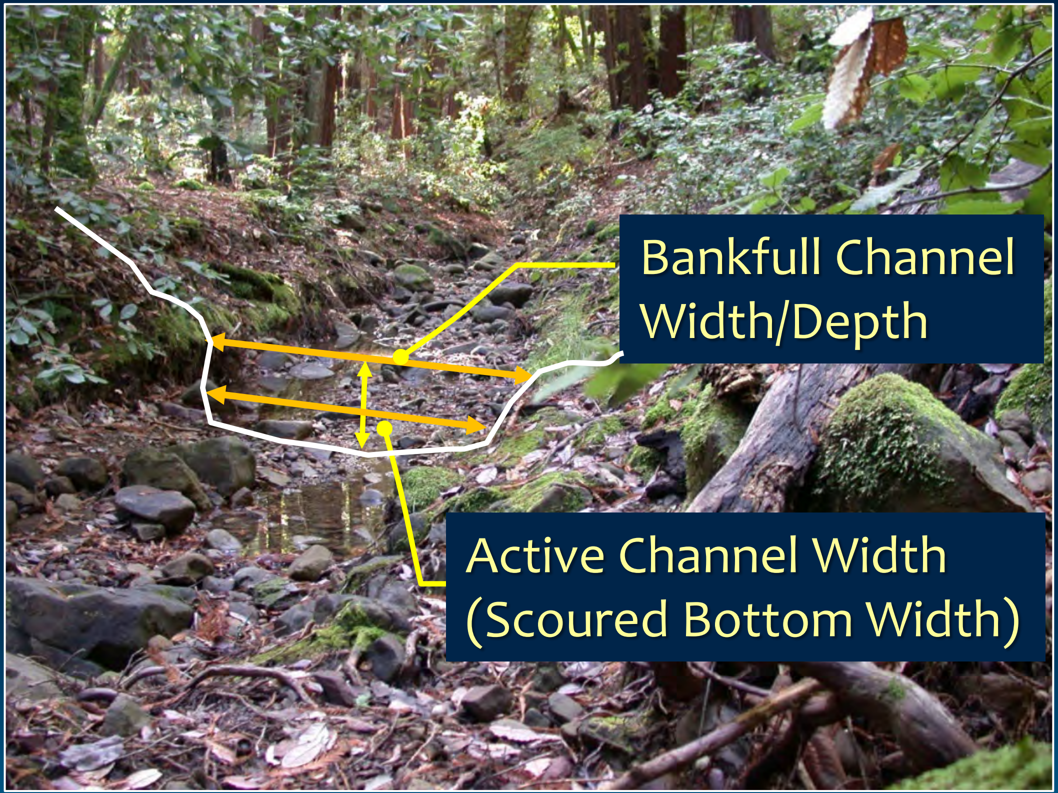
Example of a Small Stream Crossing Application



Stream Simulation

Example of a Small Stream Crossing Application

Upstream Channel (beyond culvert influence)
Serves as Reference Reach for Design



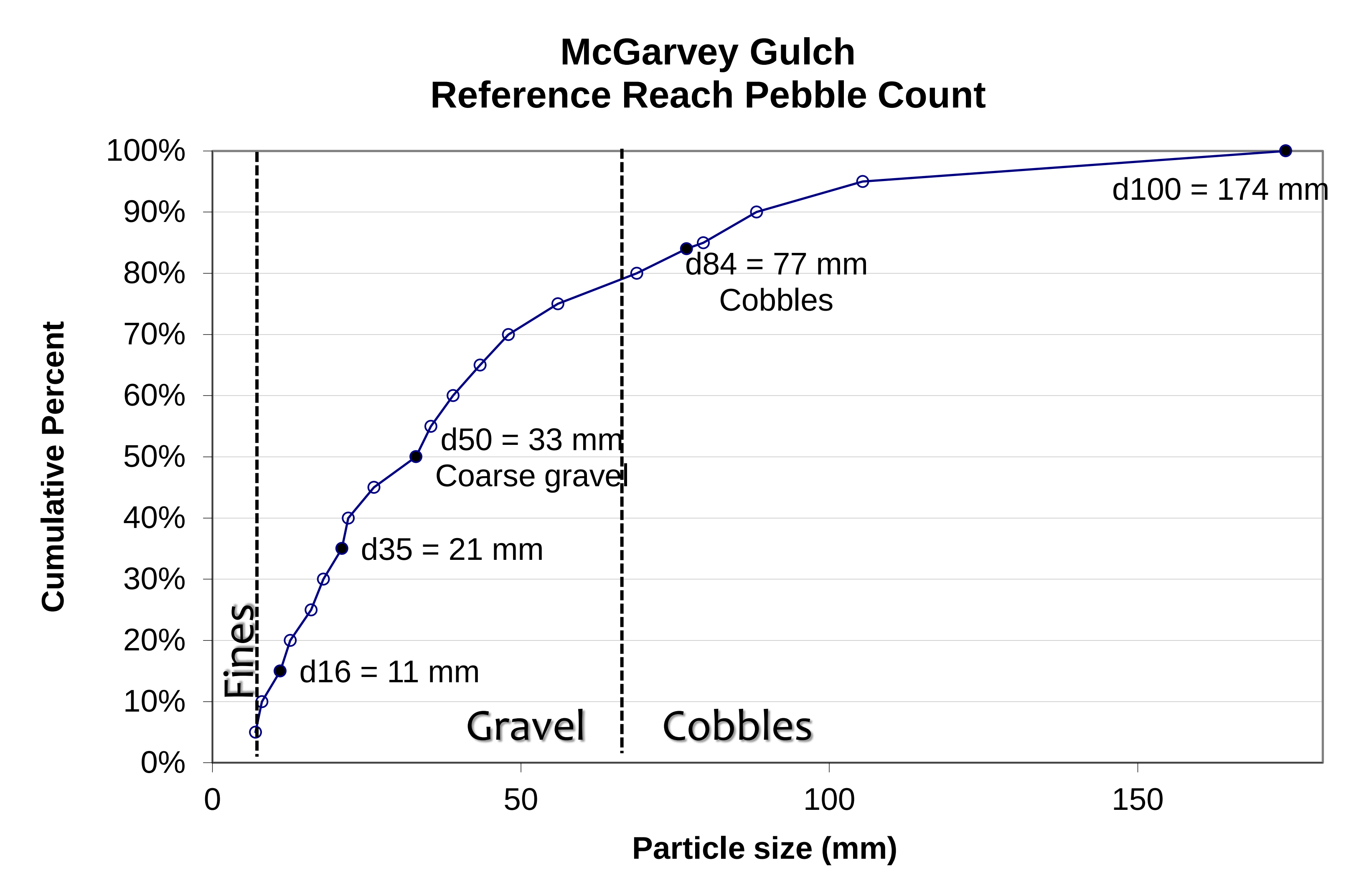
Reference Reach:

Channel Type: Plane Bed (rapid)
Channel Slope = 3.4%

Ave. Active Chnl Width = 5.4 ft
Ave. Bankfull Width = 7.5 ft

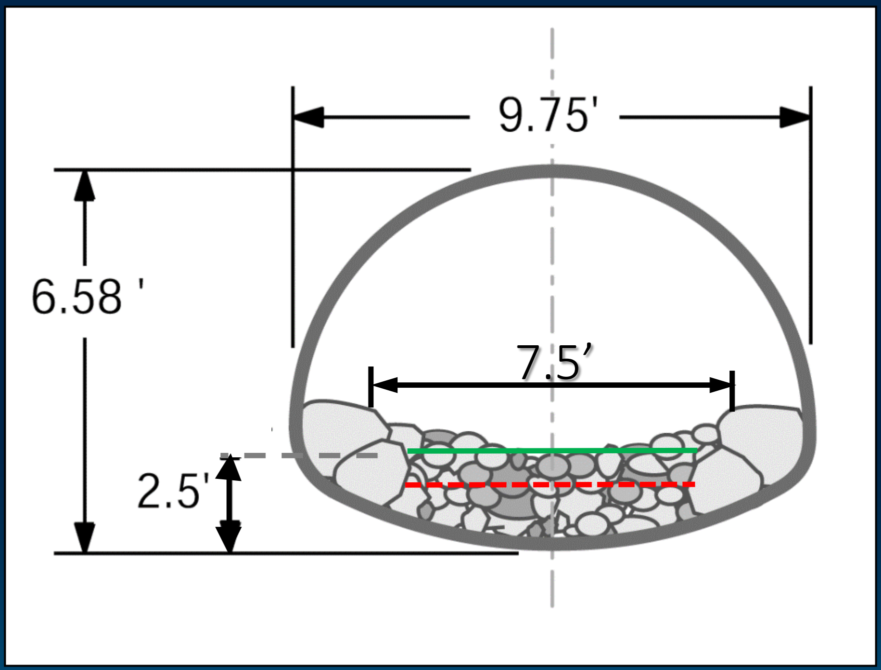
Stream Simulation

Example of a Small Stream Crossing Application



Stream Simulation
Example of a Small Stream Crossing Application

McGarvey Gulch Crossing Design

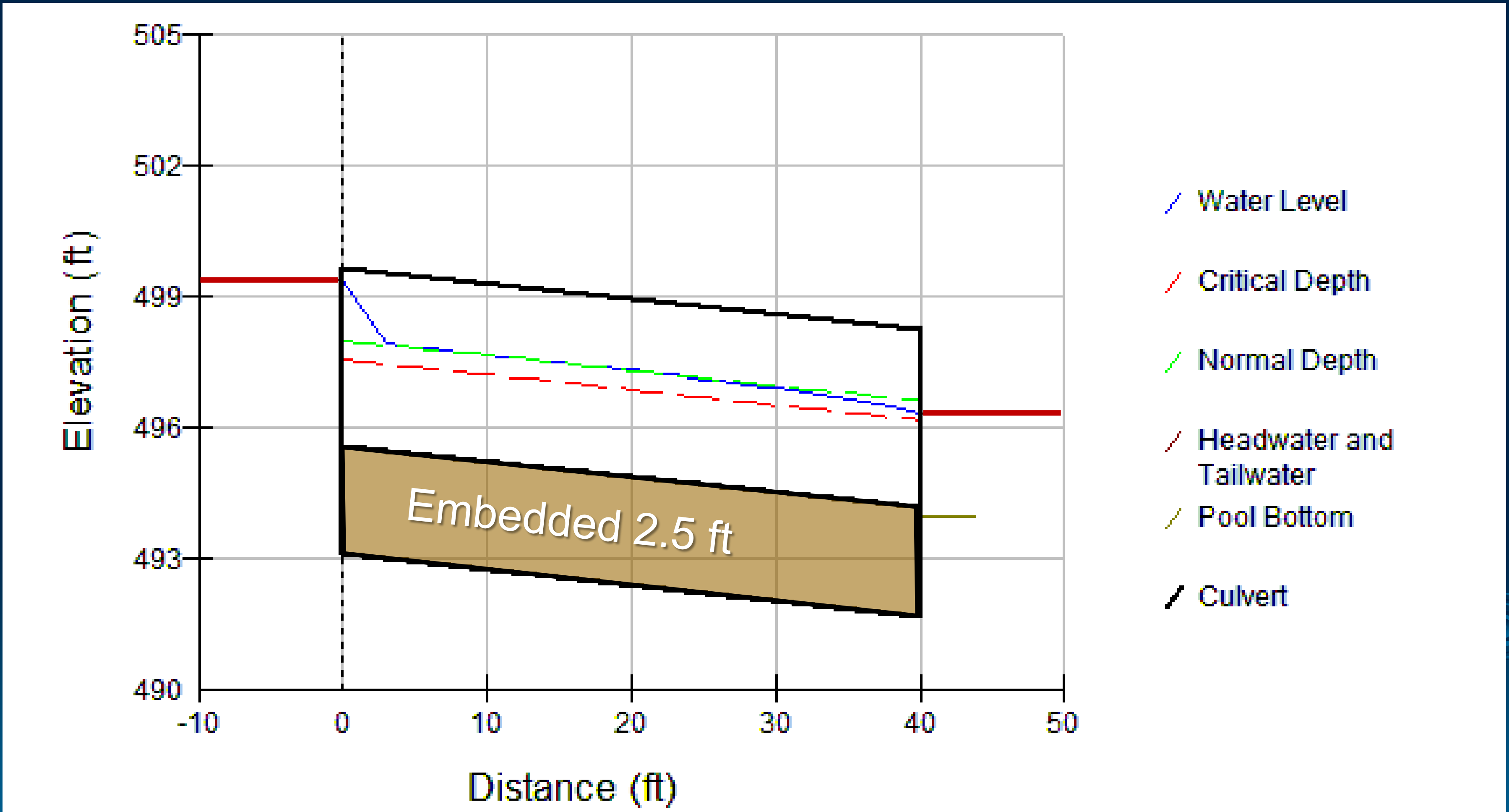


- Pipe-arch Metal Culvert
- Span = 1.3*Bankfull Width
- Invert Embedded 2.5 feet below Project Profile
  (1.5 feet below Low VAP Profile)
- Large Rocks inside along Culvert Walls form Banks

Stream Simulation

Example of a Small Stream Crossing Application

Checking Culvert Capacity at Q100 with FishXing



- ✓ HW/D<1.0 (Headwater below Soffit)
- ✓ Subcritical Flow in Culvert (Outlet Controlled)

Stream Simulation

Example of a Small Stream Crossing Application

McGarvey Gulch Post-Project

Photo: Matt Stoecker

Fish Passage: What is it and Why is it Necessary?

Ecological Connectivity

- A watershed is a network of channels that drain a common boundary.
- Channel characteristics formed by interaction of precipitation, geology, topography, and riparian vegetation.
- Inter-connected channels transport watershed products downstream and function as migration corridors for aquatic and riparian species.

Ecological Connectivity

- Stream channels and road networks are linear systems.

- Perpendicular orientation of stream channels and roads = many intersections.

- Both systems are at risk of disruption from each other.

Importance of Ecological Connectivity

- Disruption watershed processes.
- Disruption of migration patterns of numerous species.
- Loss of tributary habitat for spawning and rearing.
- Multiple impediments within single watershed = fragmentation.

Anadromous Salmonids in CA.

- Coho Salmon
- Chinook Salmon
- Coastal Rainbow Trout - resident and anadromous (steelhead)
- Coastal Cutthroat trout - resident and anadromous

General Salmonid Life History

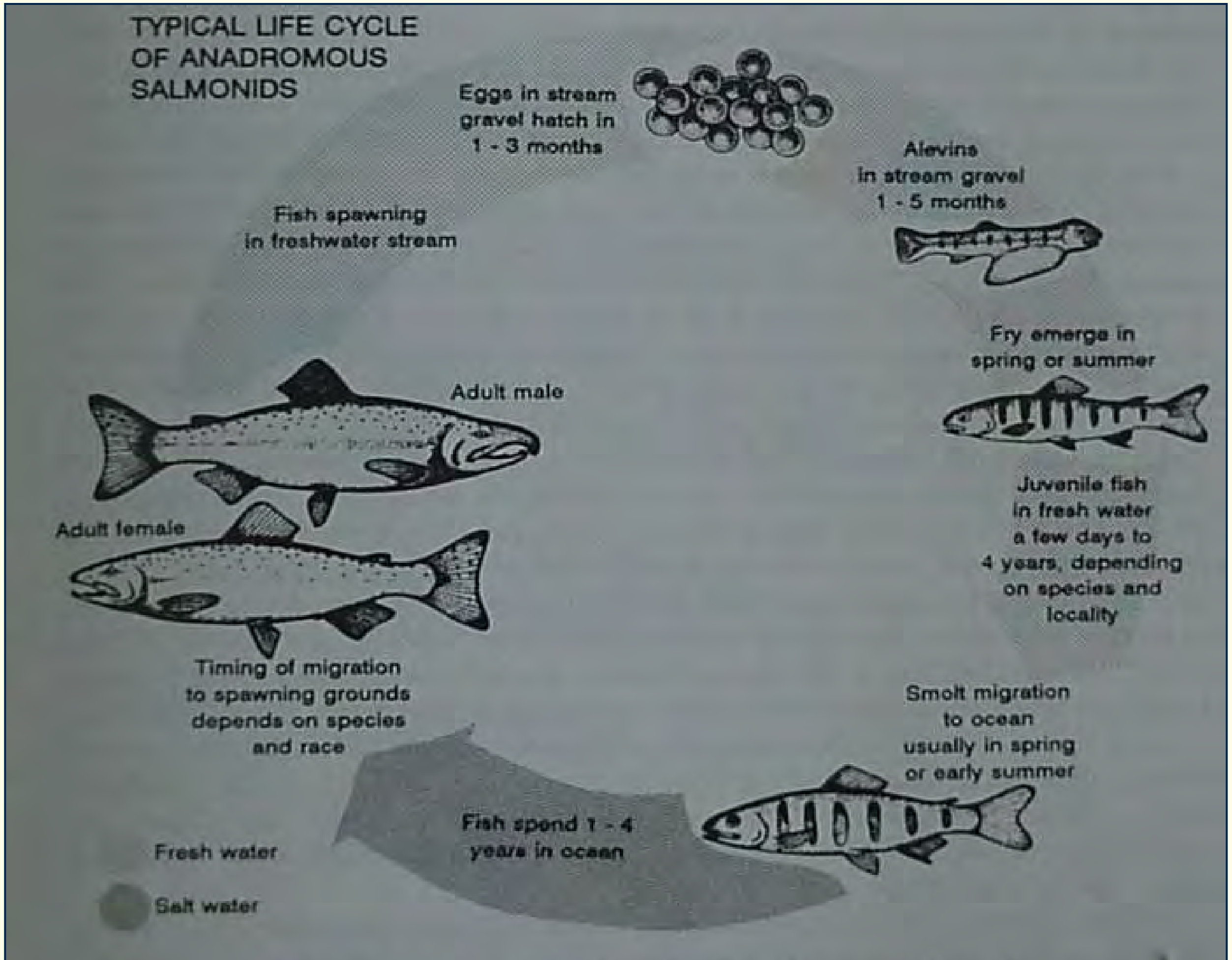


FIGURE 3.1.—Typical life cycle of anadromous salmonids.

Coho Salmon in CA.

- Oregon border to Santa Cruz County.
- Mostly three-year life cycle.
- Juveniles spend approximately 18 months in freshwater.
- Cool water temperatures and LWD.
- All Pacific salmon die post-spawn.

Coho Salmon

Chinook Salmon in CA.

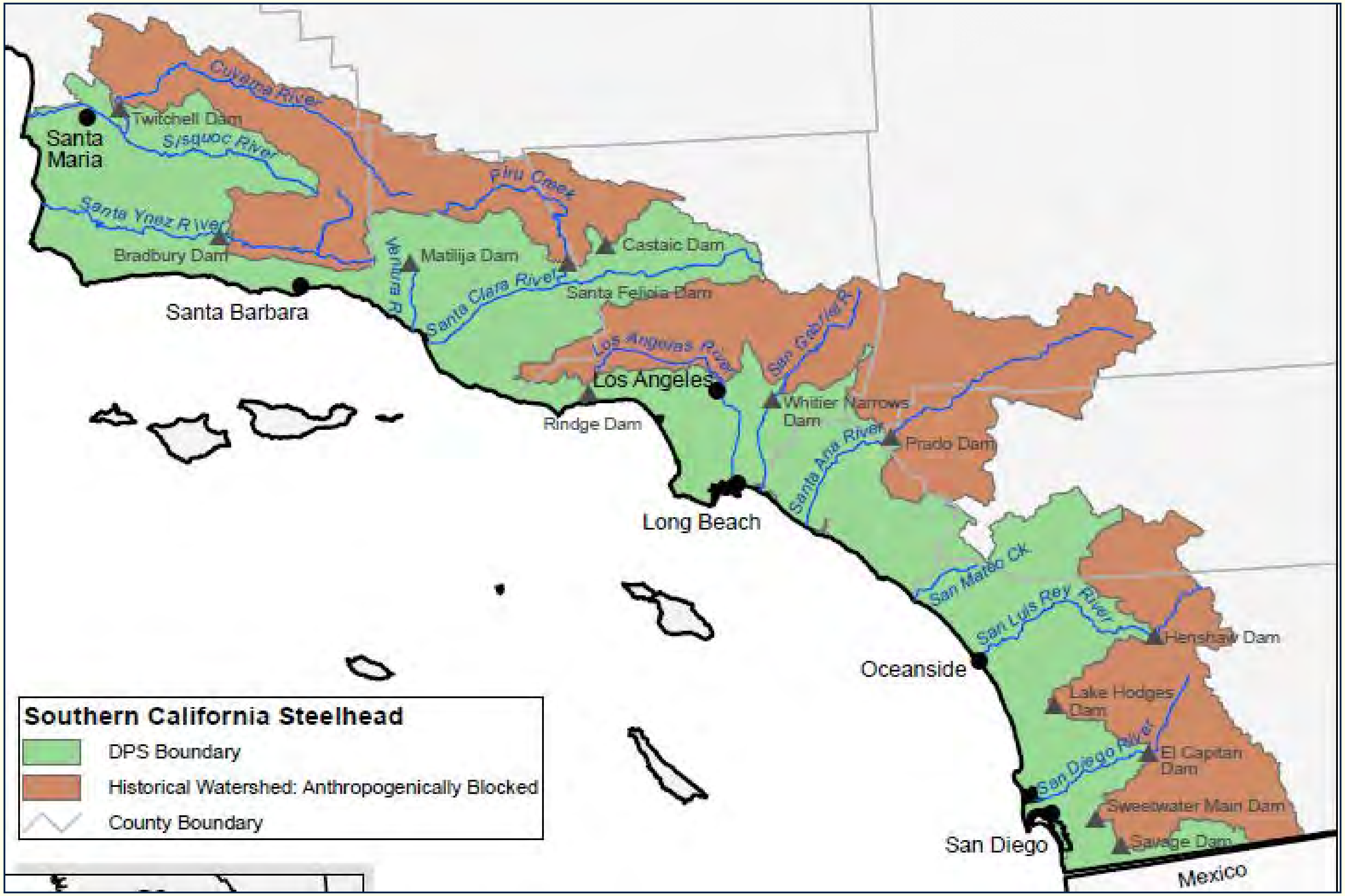
- Oregon border to Sacramento River.
- Largest of the Pacific salmon.
- Two to seven-year life cycle. Three to five years most common in CA.
- Fall-run and spring-run have distinctly different life history strategies.

Chinook Salmon

Steelhead in CA.

- Oregon border to San Diego County.
- Resident and anadromous inter-changeable.
- One to four years freshwater. One to two years most common in CA.
- Fall/winter-run and summer-run have different life history strategies.

Southern CA. Steelhead - Distribution



Southern CA. Steelhead - Adaptations

- Adapted to extreme conditions in marginal habitats.
- Lower smolt age and older ocean age.
- Use of non-natal streams for spawning.
- Complete life-cycle in freshwater.
- Delay adult return from ocean for years during severe drought conditions.

Southern CA. Steelhead - Declines

- Severe (>90%) population declines since 1950’s.
- 55,000 to less than 500 returning adults.
- Extirpated from approximately 14 larger drainages.

Southern CA. Steelhead - Impacts

- Dams and road crossings block more than 85% of historic spawning and rearing habitat.
- Loss/degradation of estuaries.
- Channelization and dewatering of mainstem migration corridors.
- Water pollution.

Coastal Rainbow-Steelhead

Coastal Cutthroat Trout in CA.

- Oregon border to lower Eel River.
- Resident and anadromous inter-changeable.
- One to six-year as juveniles in freshwater.
- Brief saltwater forays – never over-winters in ocean.

Coastal Cutthroat Trout

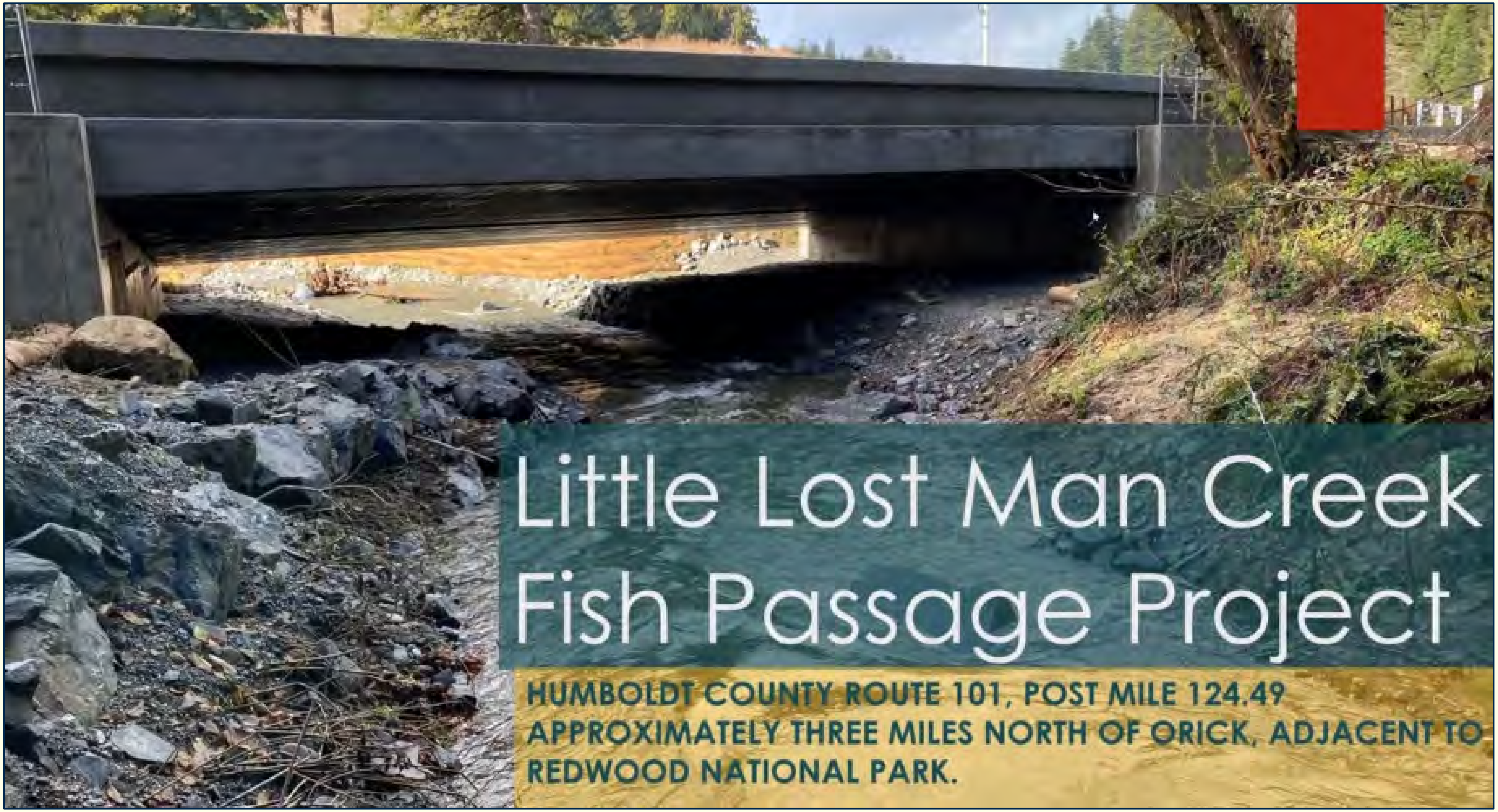

Coho Salmon


Coastal Rainbow Trout


Chinook Salmon

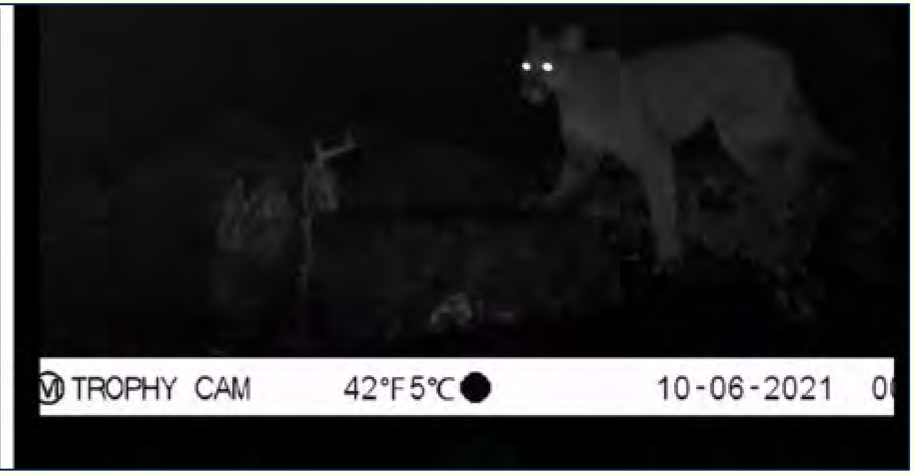

Coastal Cutthroat Trout

Passage of Terrestrial Species



Passage of Terrestrial Species

Passage of Terrestrial Species



Why Fish Need to Move - Migratory Patterns of Salmonids

Reasons for Migration

Adults

- Migration to spawning habitat.
- Spatially separate from competing species.
- Spatially separate throughout a basin.
- Reduce mortality from redd superimposition.

Reasons for Migration

Juveniles

- Migration to favorable over-wintering habitat.
- In CA. coho, steelhead, and coastal cutthroat trout.
- Following potential food source upstream.
- Summer migration to thermal refugia.

Migration Timing

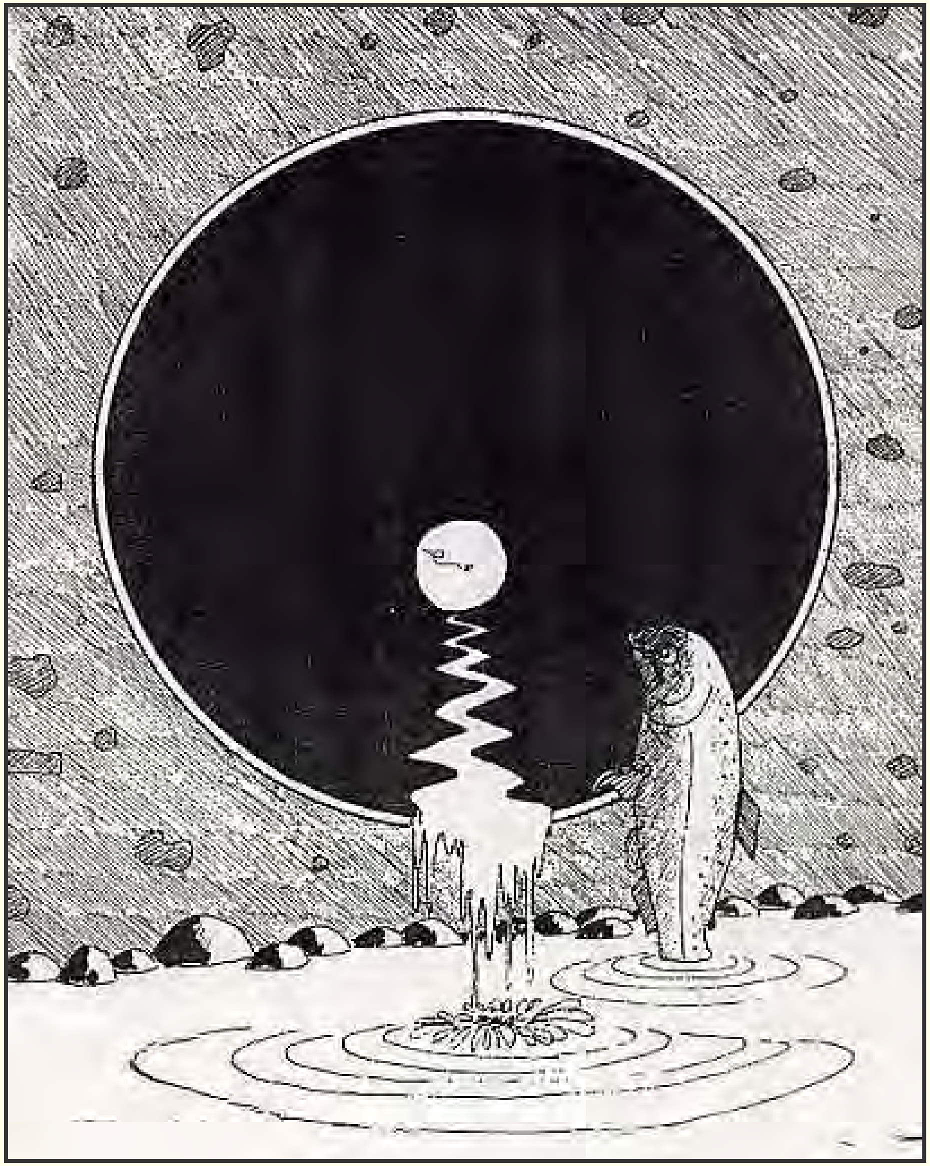
<u>Adults and Juveniles</u>

- Triggered by winter storms and stream discharge.

- Behavior dependent on storm magnitude and frequency.

- Falling limb of storm hydrograph.

Stream Crossing Characteristics that Create Migration Barriers



Types of Passage Problems

- Excessive velocity through crossing.
- Lack of depth w/in crossing.
- Perched crossing outlet.
- Lack of depth in outlet pool.
- Obstructions within crossing.
- Turbulence.

Types of Passage Problems

Velocity Barriers

- Crossing set at too steep of slope.
- Roughness reduced through crossing - varies with construction materials.
- Reduction of channel cross-sectional area - inlet drops.
- Length of crossing x velocity > fish swimming abilities.

Velocity Barrier - Steep Slope

Velocity Barrier - Concrete Floor

Velocity Barrier - Concrete Apron

Velocity Barrier - Inlet Drop

Types of Passage Problems

Perched Outlets

- Local scour of outlet pool by high-velocity flows exiting culvert/crossing.
- Crossings set in a static location within a dynamic system.
- Disrupts migration at heights less than observed maximum leaping abilities.
- Physical injury of migrating fish.

Perched Outlet - Freefall to Pool

Perched Outlet - Cascade over Boulder

Perched Outlet – Over Remnant Dam

Perched Outlet – Over Hardened Ford

Perched Outlet – Water Line Encasement

Types of Passage Problems

Lack of Depth within Crossing

- Wide, flat-bottomed structures.
- Concrete aprons.
- Reduces swimming abilities of partially submerged fish.
- Increases likelihood of injury or predation.

Lack of Depth - Concrete Bottom

Lack of Depth - Concrete Apron

Lack of Depth – Hardened Ford

Lack of Depth – Flood Control Channel

Types of Passage Problems

Lack of Depth in Outlet Pool

- Jump height to pool-depth ratio = 1:1.25-1.5
- Rip rap placed at outlet to dissipate stream flow.

Lack of Depth in Outlet Pool

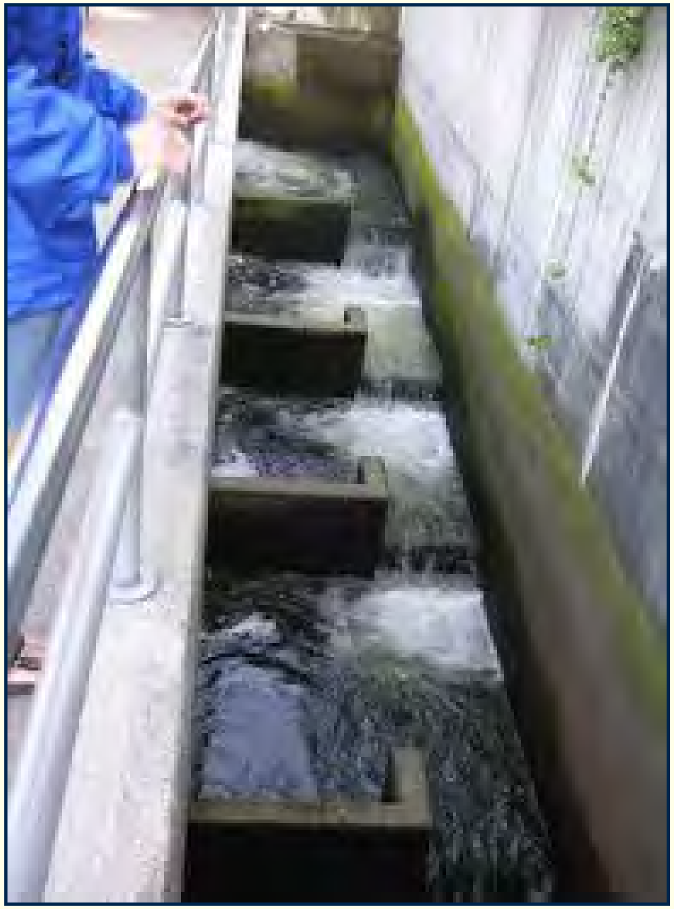
Types of Passage Problems

Obstructions within Crossing

- Storm debris.
- Create turbulence.
- Damage to crossing.
- Additional consequences.

Obstructions within Crossing

Turbulence within Crossing



Biological Effects of Migration Barriers

Effects on Salmonids

Barrier Types:

Temporal - impassable to one or more species or life-stages at certain flows.

Potential Impact: delays movement beyond barrier.

Partial - impassable to some species and/or life-stages at all flows.

Potential Impact: exclusion of certain species or life-stages from sections of a watershed.

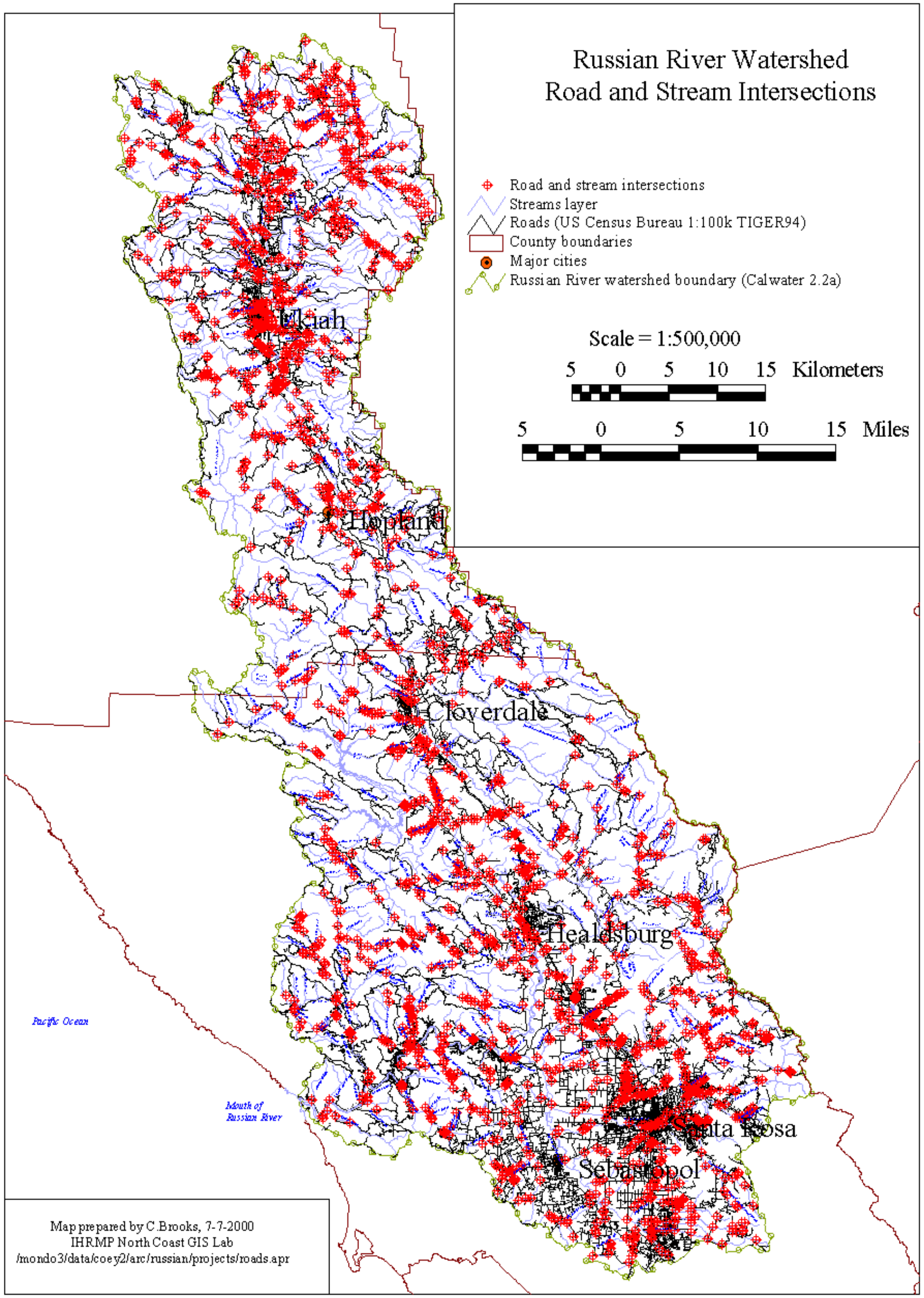
Total - impassable to all fish at all times.

Potential Impact: exclusion of certain species or life-stages from sections of a watershed.

Effects on Salmonids

Cumulative Effects:

- Multiple crossings within a fishes migration corridor.
- Delays at lower crossings may prevent passage at other crossings.
- Effects of delays more apparent in years or areas of CA with sporadic rainfall.


Russian River Watershed
Road and Stream Intersections
Road and stream intersections
Streams layer
Roads (US Census Bureau 1:100k TIGER94)
County boundaries
Major cities
Russian River watershed boundary (Calwater 2.2a)
Scale = 1:500,000
5 0 5 10 15 Kilometers
5 0 5 10 15 Miles
Ukiah
Hopland
Cloverdale
Healdsburg
Santa Rosa
Sebastopol
Pacific Ocean
Mouth of Russian River
Map prepared by C.Brooks, 7-7-2000
IHRMP North Coast GIS Lab
/mondo3/data/coey2/arc/russian/projects/roads.apr

Effects on Salmonids

<u>Adults:</u>

- Disrupts spawning migrations.
- Under-utilization of tributary habitat.
- Over-crowding of available spawning habitat.
- Increased likelihood of stress, injury, or predation/poaching.
- Limits spatial separation of competing species.

Effects on Salmonids

Juveniles:

- Limits or prevents use of over-wintering habitat in tributaries.
- Increases predation in outlet pools.
- Limits or prevents summer migration from thermally-stressed main-stems to cool-water refugia.

Culvert Hydraulics vs Fish Abilities

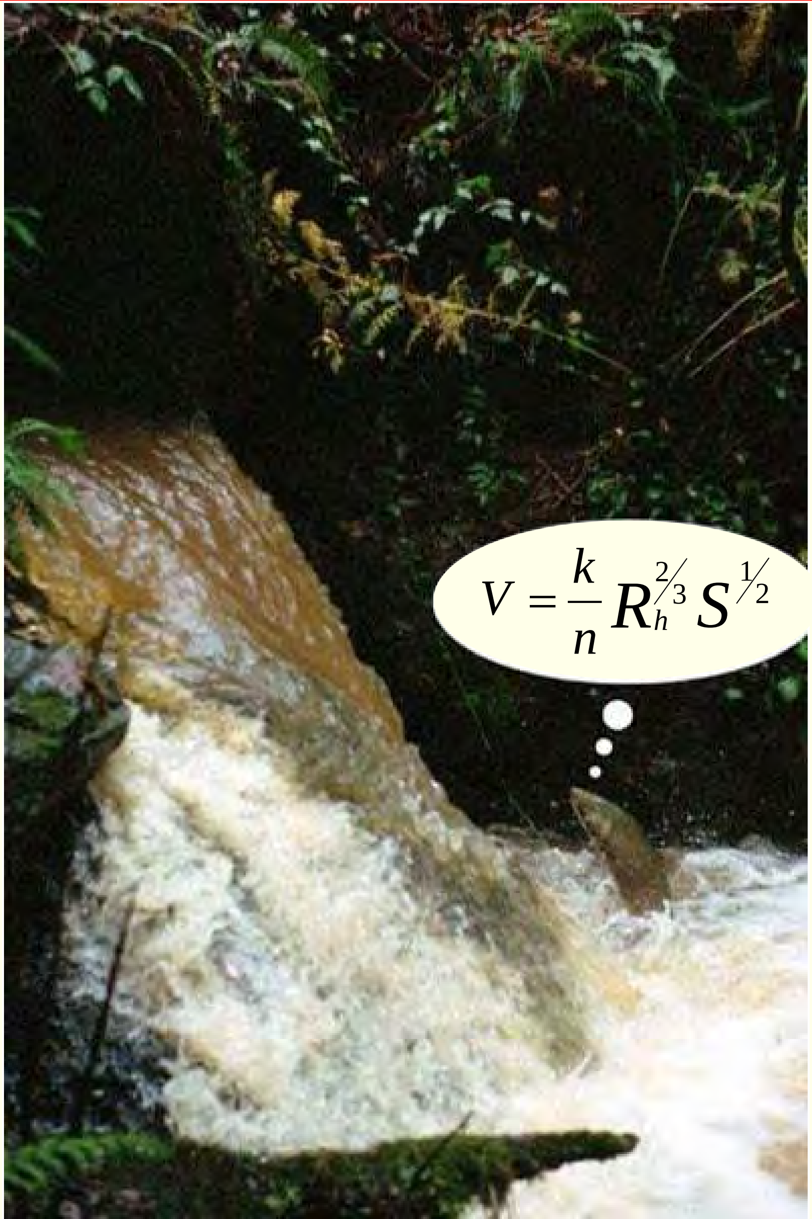
<u>Leaping and Swimming Abilities:</u>

• Size and condition of fish.

• Level of exertion required – sustained, prolonged or burst.

• Other – water temperature, water quality, leap conditions.

The “Design” Fish



The “Design” Fish

Factors to Consider:

- Selection of an appropriate species or age-class.

- Is designing for a single species or age-class a valid approach?

- Timing, behavior, and variations of individual abilities lead to uncertainties.

Swimming Abilities and Requirements

Types of Swimming Modes:

- Sustained – maintained indefinitely.
- Prolonged – maintained for 20 seconds to 200 minutes.
- Burst – highest velocity mode, maintained for < 20 seconds.

Salmonid Performance Criteria

CDFW : Assessment Criteria

Species or Lifestage	Minimum Water Depth	Prolonged Swimming Mode		Burst Swimming Mode		
		Maximum Swim Speed	Time to Exhaustion	Maximum Swim Speed	Time to Exhaustion	Maximum Leap Speed
Adult anadromous salmonids	0.8 feet	6.0 ft/sec	30 minutes	10.0 ft/sec	5.0 sec	15.0 ft/sec
Resident trout and juvenile steelhead trout >6”	0.5 feet	4.0 ft/sec	30 minutes	5.0 ft/sec	5.0 sec	6.0 ft/sec
Juvenile salmonids <6”	0.3 feet	1.5 ft/sec	30 minutes	3.0 ft/sec	5.0 sec	4.0 ft/sec

Salmonid Performance Criteria

CDFW : Hydraulic Design Criteria

Species/Lifestage	Maximum Average Water Velocity (fps)	Minimum Flow Depth (ft)
Adult Anadromous Salmonids	See Table 6	1.0
Adult Non-Anadromous Salmonids	See Table 6	0.67
Juvenile Salmonids	1	0.5
Native Non-Salmonids	Species specific swimming performance data is required for the use of the hydraulic design option for non-salmonids. Hydraulic design is not allowed for these species without this data.	
Non-Native Species		

Table IX-A- 5. Maximum average water velocity and minimum depth of flow.

Culvert Length (ft)	Adult Non-Anadromous Salmonids (fps)	Adult Anadromous Salmonids (fps)
<60	4	6
60-100	4	5
100-200	3	4
200-300	2	3
>300	2	2

Table IX-A- 6. Culvert length vs. maximum average water velocity for adult salmonids.

Salmonid Performance Criteria

CDFW : Hydraulic Design Criteria

Maximum Outlet Drop - Hydraulic drops between the water surface in the culvert to the pool below the culvert should be avoided for all cases. Where fish passage is required and a hydraulic drop is unavoidable, its magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown in Table IX-A-7. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Lifestage	Maximum Drop (ft)
Adult Anadromous Salmonids	1
Adult Non-Anadromous Salmonids	1
Juvenile Salmonids	0.5
Native Non-Salmonids Non-Native Species	Where fish passage is required for native non-salmonids, no hydraulic drop shall be allowed at the culvert outlet unless data is presented which will establish the leaping ability and leaping behavior of the target species of fish.

Table IX-A- 7. Maximum drop at culvert outlet.

CDFW Stream Crossing Ranking

Ranking Objectives:

- A first-cut, sorting of evaluated sites using “scored” criteria.

- Division of sites into groups of: high, medium, and low priority.

- Consideration of other factors prior to selection of sites for remediation.

- Identification of restoration sites vs. maintenance sites.

CDFW Stream Crossing Ranking

Ranking Criteria:

- Species diversity and listing status.
- Extent of barrier for three groups of salmonid age classes.
- Quantity and quality of potential upstream habitat.
- Sizing and condition of current crossing.

CDFW Stream Crossing Ranking

Other Factors to Consider:

- Additional stream crossings or migration barriers.
- Current diversity of species versus historic diversity.
- Presence of fish at stream crossing during migration periods.
- Costs of treatment options.
- Opportunity.
- Scheduling of other road maintenance projects.
- Amount of road fill at undersized and/or poor condition stream crossings.

California Fish Passage Forum

FISH*Pass* is a web-based decision-support tool designed to help users identify fish passage barriers for remediation. FISH*Pass* is an optimization model that uses barrier information from the California Passage Assessment Database (PAD), accounts for spatial layout of the barriers in the network, cumulative barrier passability, potential upstream habitat, and optionally, estimated costs.

Why is Fish Passage Important?

- Improve transportation network.
- Safety.
- Comply with ESA regulations.
- Restore fish populations.

Why is Fish Passage Important?

Why is Fish Passage Important?

Why is Fish Passage Important?

FIGURE 11. Fishing for salmon with drift gill nets at the mouth of the Klamath River. *Photograph by Hazeltine, 1913.*

Why is Fish Passage Important?

Fish Passage Resources

CA Fish Passage Forum:

The mission of the Fish Passage Forum is to protect and restore listed anadromous salmonid species, and other aquatic organisms, in California by promoting collaboration among public and private sectors for fish passage improvement projects and programs.

http://www.cafishpassageforum.org/

Fish Passage Resources

Passage Assessment Database: (PAD)

The Passage Assessment Database (PAD) is an ongoing map-based inventory of known and potential barriers to anadromous fish in California, compiled and maintained through a cooperative interagency agreement. The PAD compiles currently available fish passage information from many different sources, allows past and future barrier assessments to be standardized and stored in one place, and enables the analysis of cumulative effects of passage barriers in the context of overall watershed health.

http://www.calfish.org/tabid/420/Default.aspx

CalFish

A California Cooperative Anadromous Fish and Habitat Data Program

Fish Passage Resources

CDFW – Restoration Manual

Part IX – Fish Passage Evaluation at Stream Crossings.

Part XII – Fish Passage Design and Implementation.

http://www.dfg.ca.gov/fish/

California Department of Fish and Wildlife

Fish Passage Resources

NOAA FISHERIES | West Coast Region

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Construction and development activities affect aquatic habitats. They impact the hydraulic conditions of a natural waterway and can block fish from migrating to and from the ocean. We work to minimize these impacts by implementing innovative engineering designs that facilitate safe, timely, and effective fish passage in estuaries and inland watersheds.

http://www.westcoast.fisheries.noaa.gov/fish_passage/solutions/

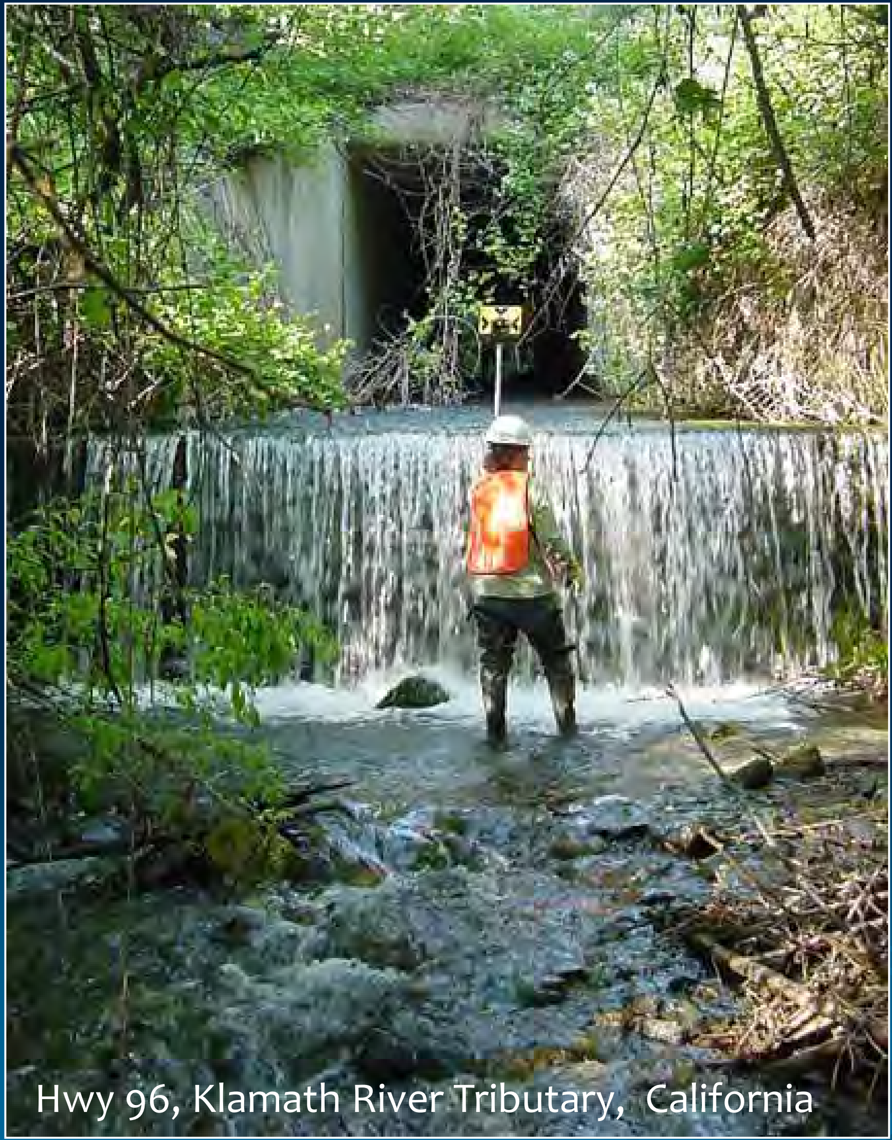
Fish Passage Resources

FishXing Download:

www.fs.fed.us/biology/nsaec/products-tools.html

Assessing Geomorphic Risk for Stream Crossing Projects

Humboldt State University



Hwy 96, Klamath River Tributary, California

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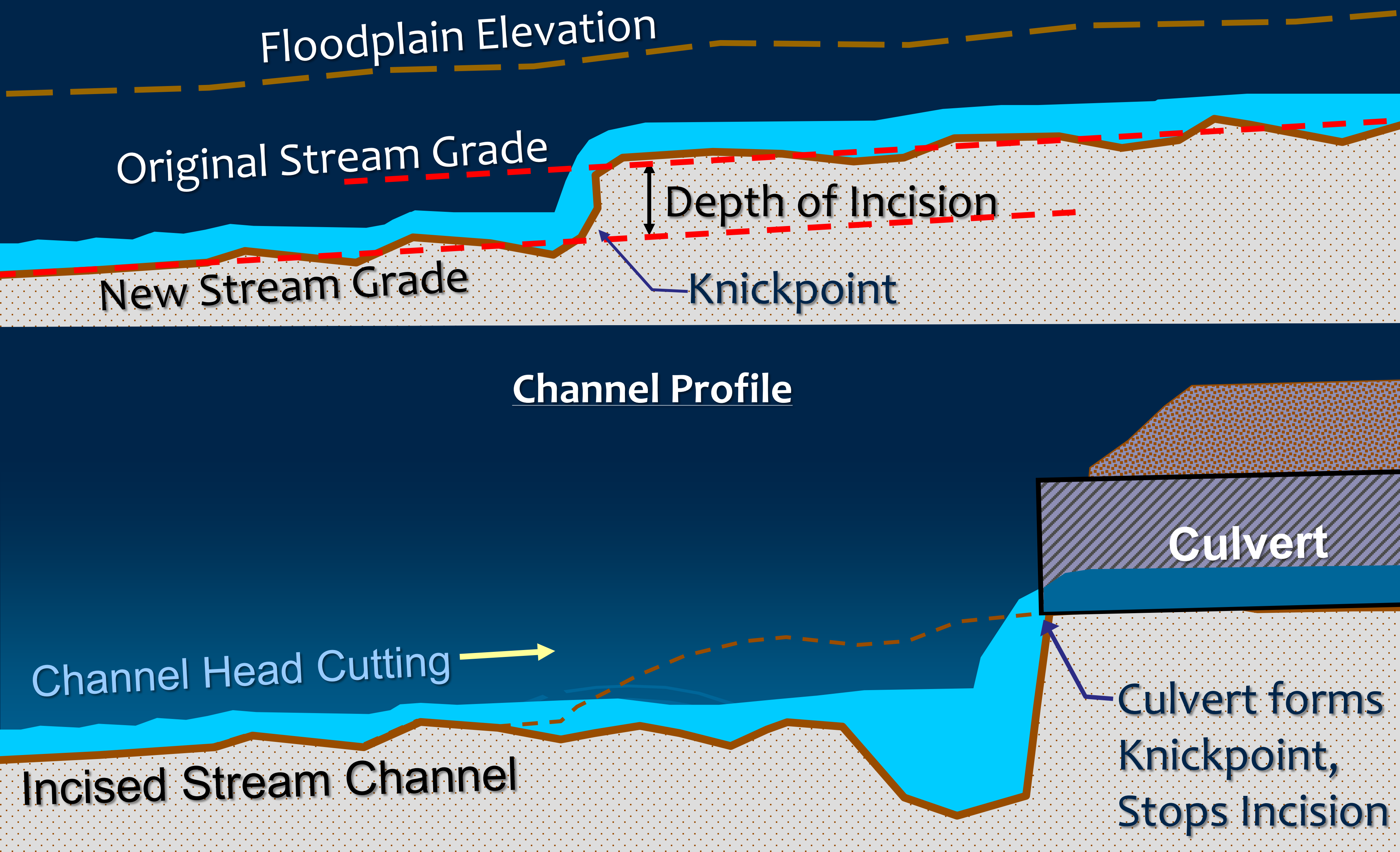
Michael Love & Associates
Hydrologic Solutions

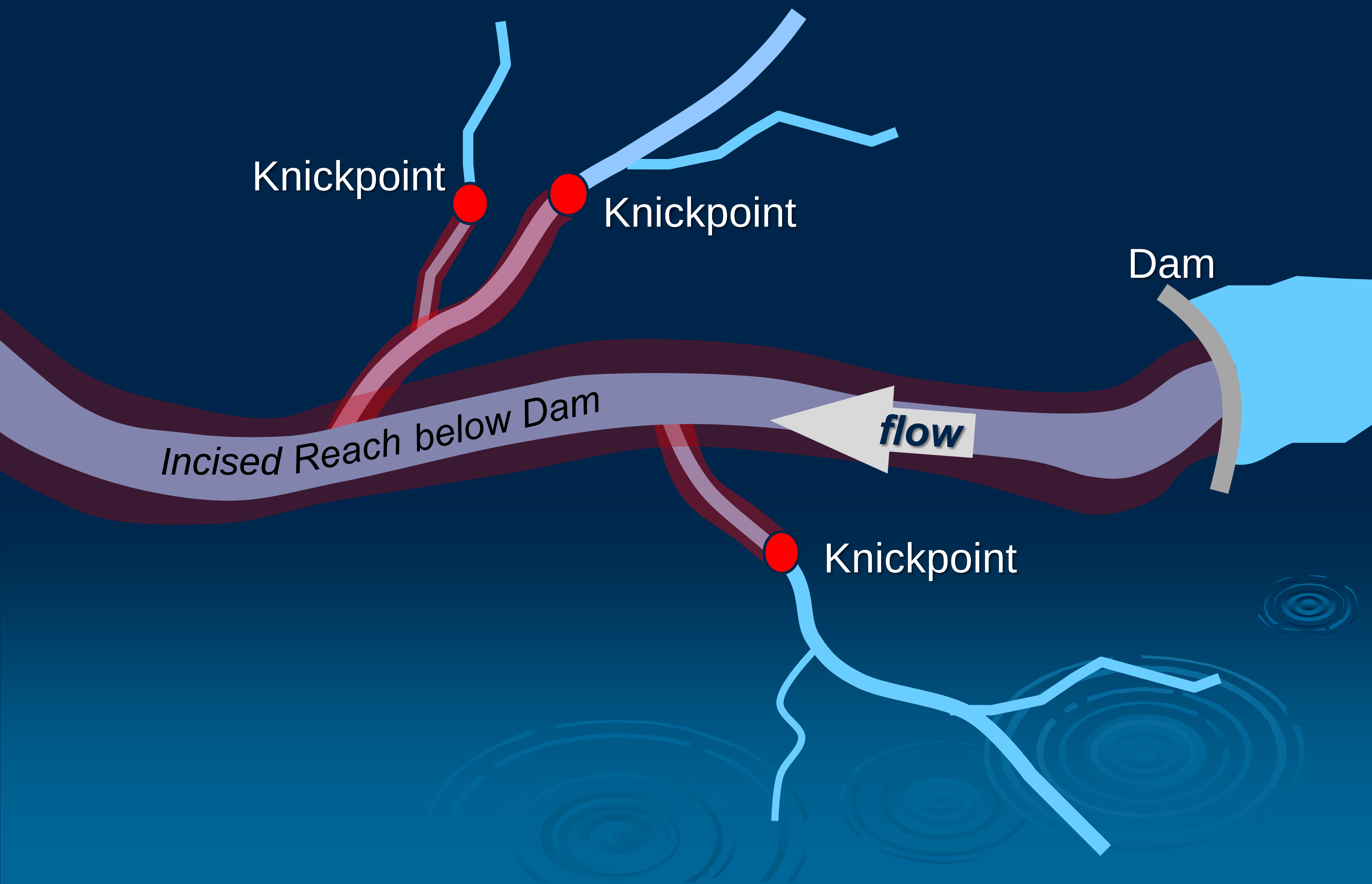
Process of Incision: Headwater Migration



Channel Incision is a Natural Process, but…

We Initiate of the Incision More often then Not

Incision Often Moves Headward into Tributaries



Knickpoints that Stop Incision but Create Fish Barriers

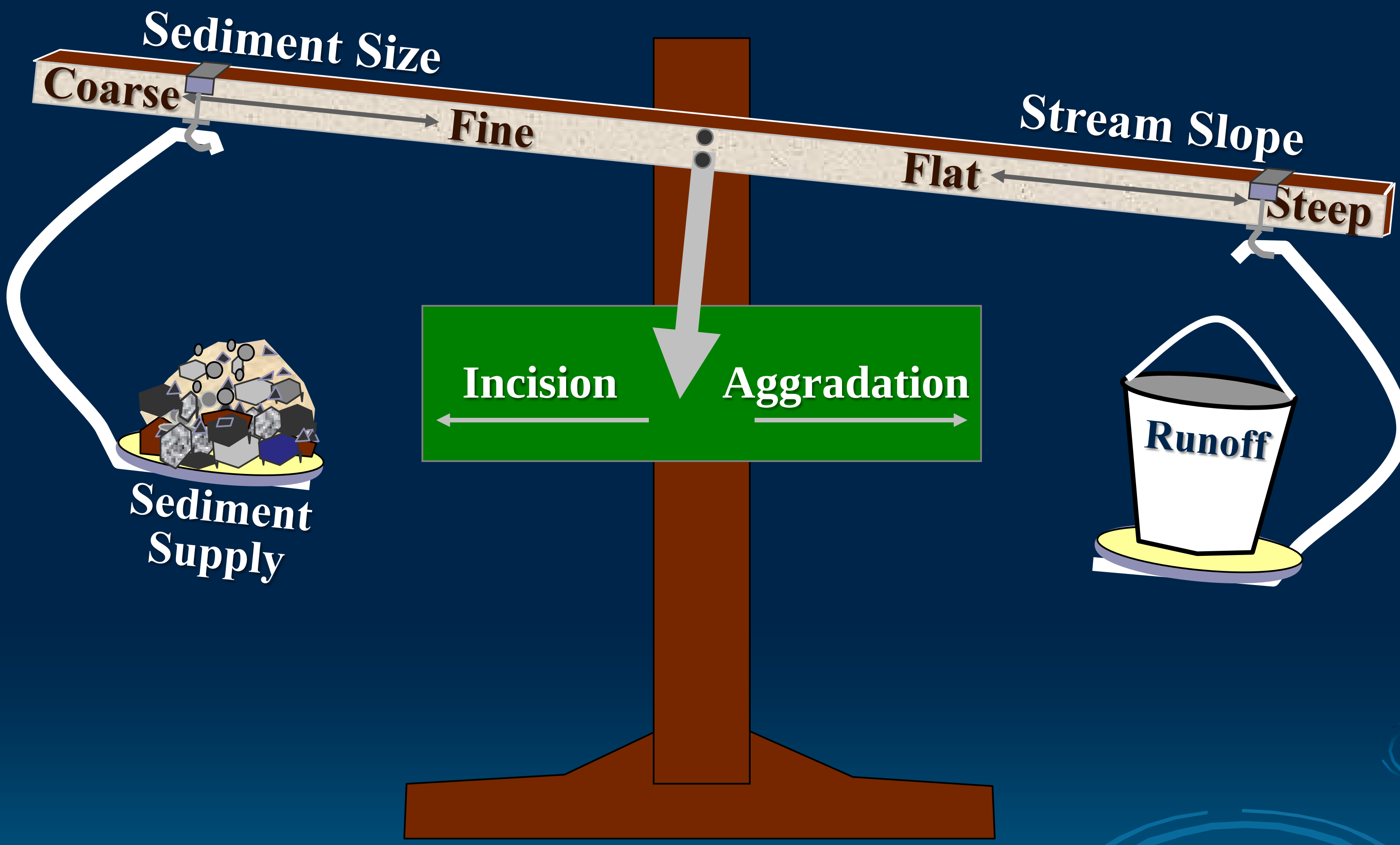
Perched Culverts

Armored Utility Crossings

Perched Bridge Aprons

Perched Fishway Entrances

Dynamic Equilibrium and Causes of Incision

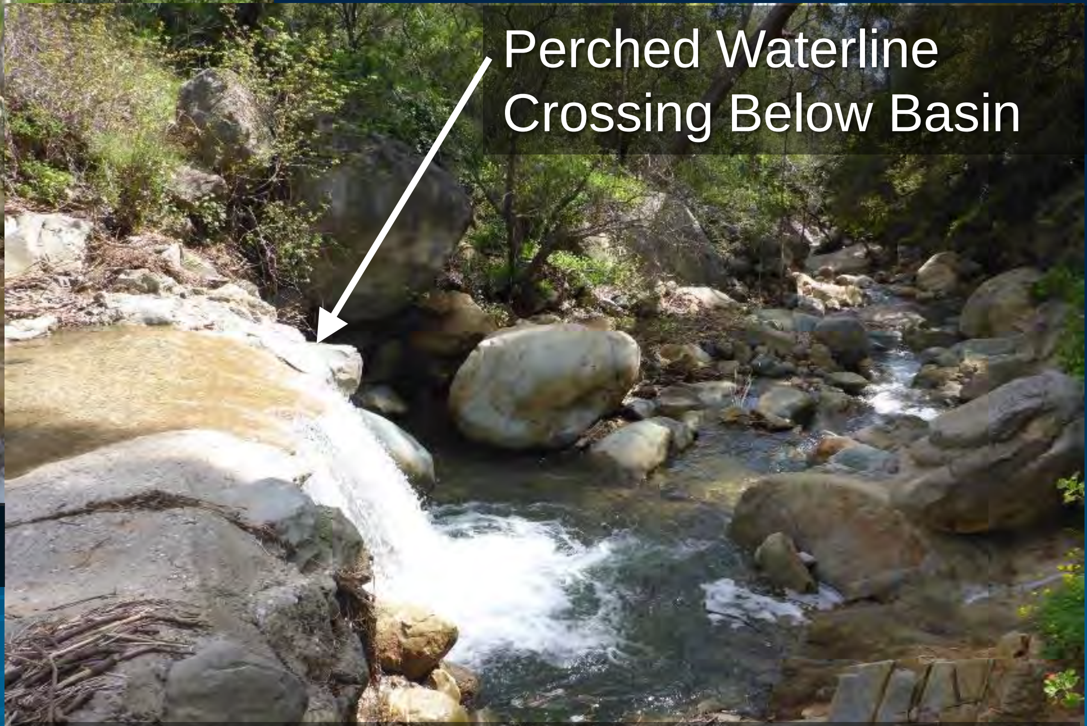


The Lane Relationship (from Lane, 1955)

Causes of Channel Incision

Dams and Debris Basins

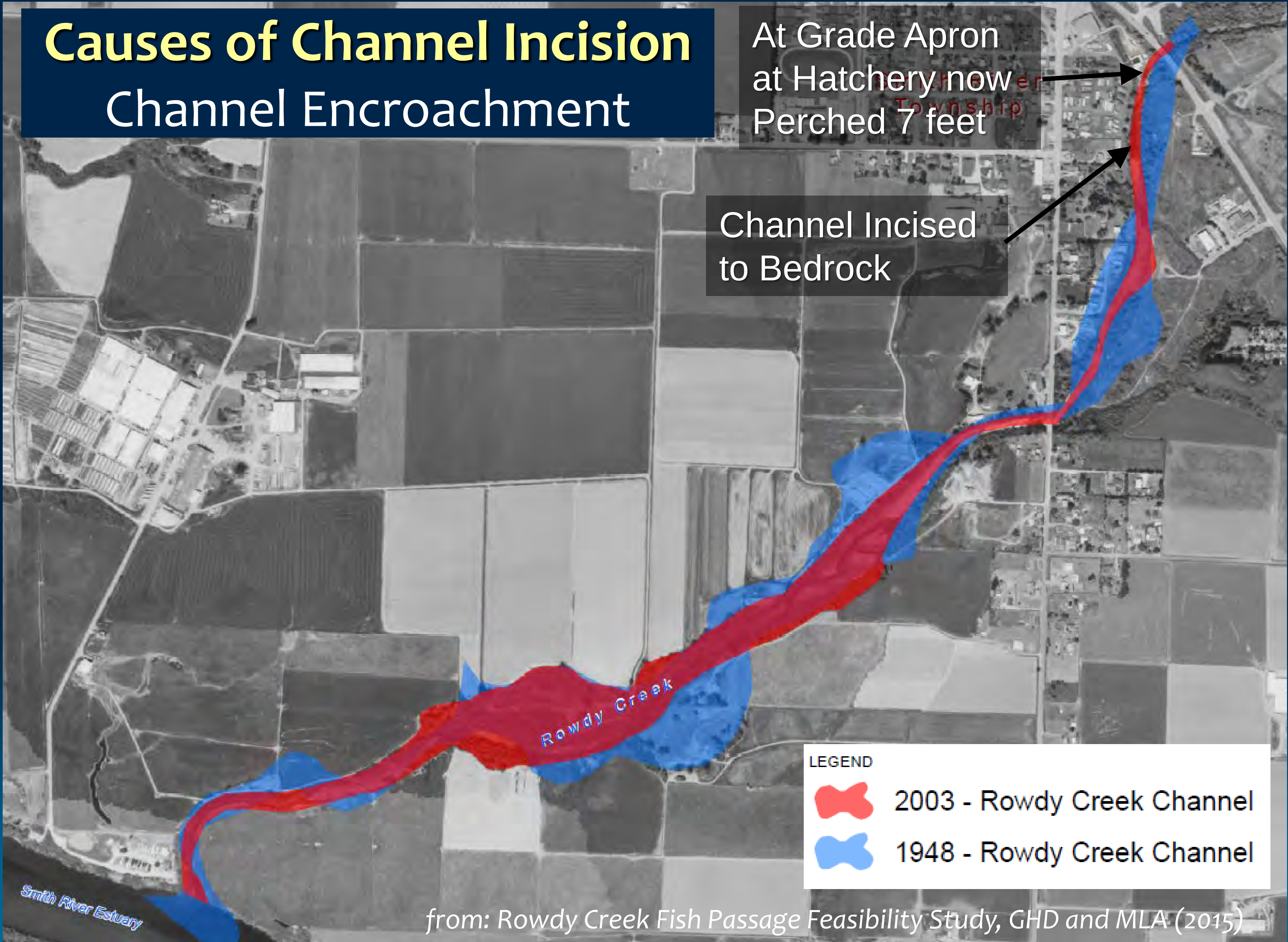
Debris Basin Catches all Sediment



Downstream Channel Incised 8 feet

Causes of Channel Incision

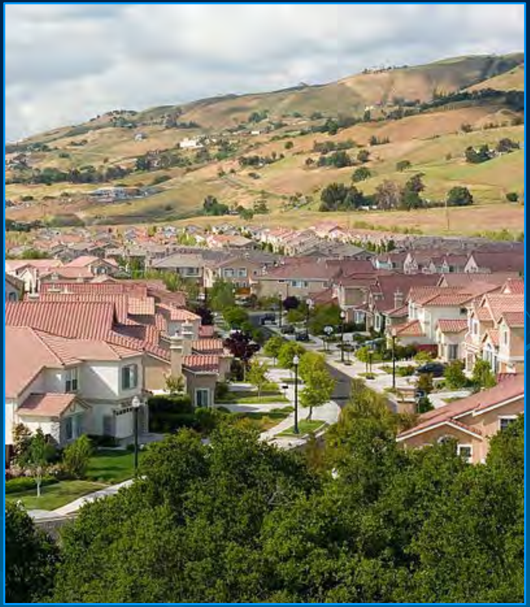
Channel Encroachment



from: Rowdy Creek Fish Passage Feasibility Study, GHD and MLA (2015)

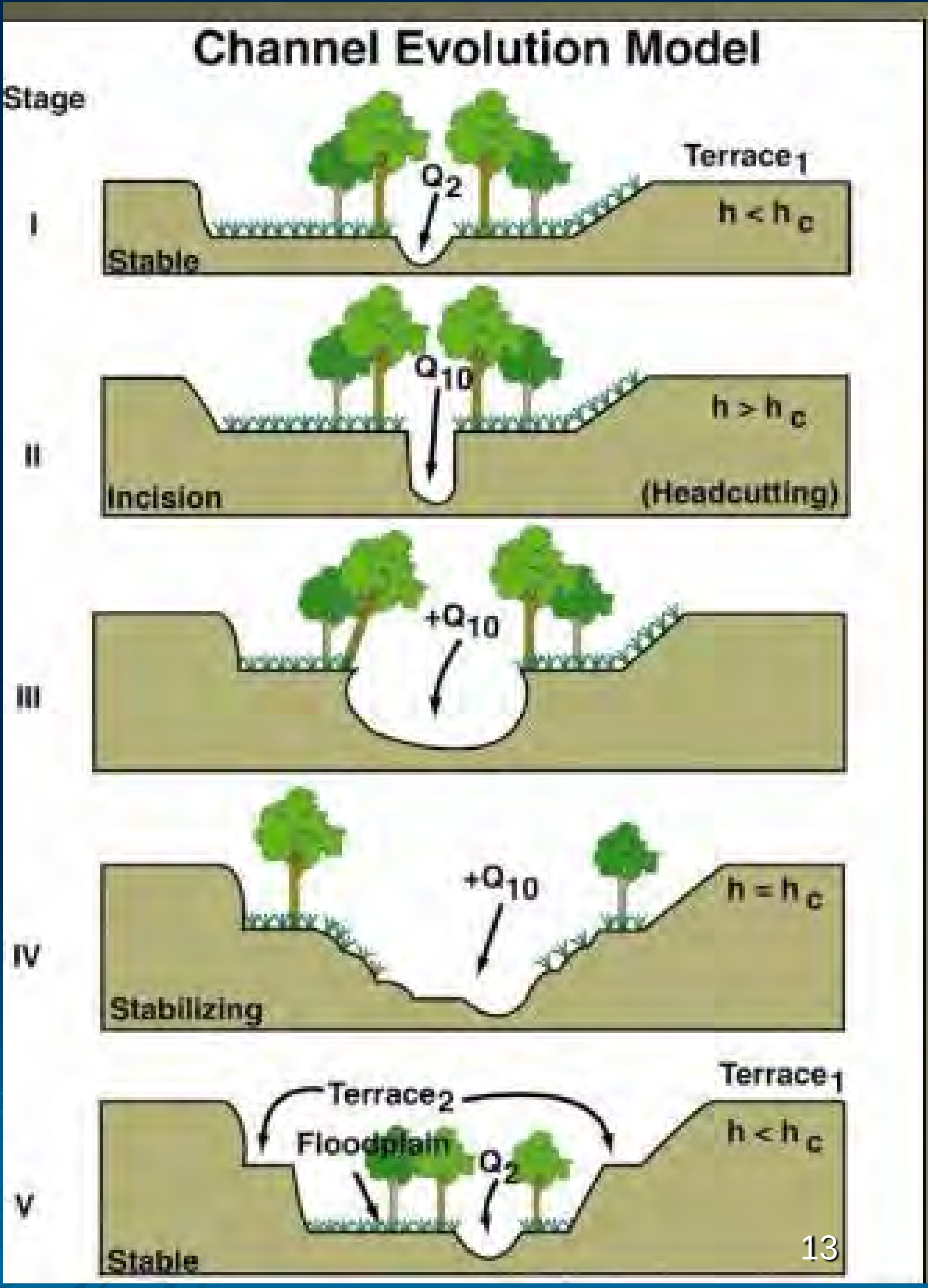
Causes of Channel Incision

- ✓ Decrease in sediment supply
  (dams, gravel extraction, urbanization)
- ✓ Channel encroachment
  (Increase depth of flow, bed & bank shear)
- ✓ Channelization
  (shortening/steepening the channel)
- ✓ Increase in runoff
  (urbanization, agriculture, road density)
- ✓ Loss of wood in streams
  (removal of large wood, beaver dams)
- ✓ Climate change/extreme weather



Channel Evolution Model (CEM)

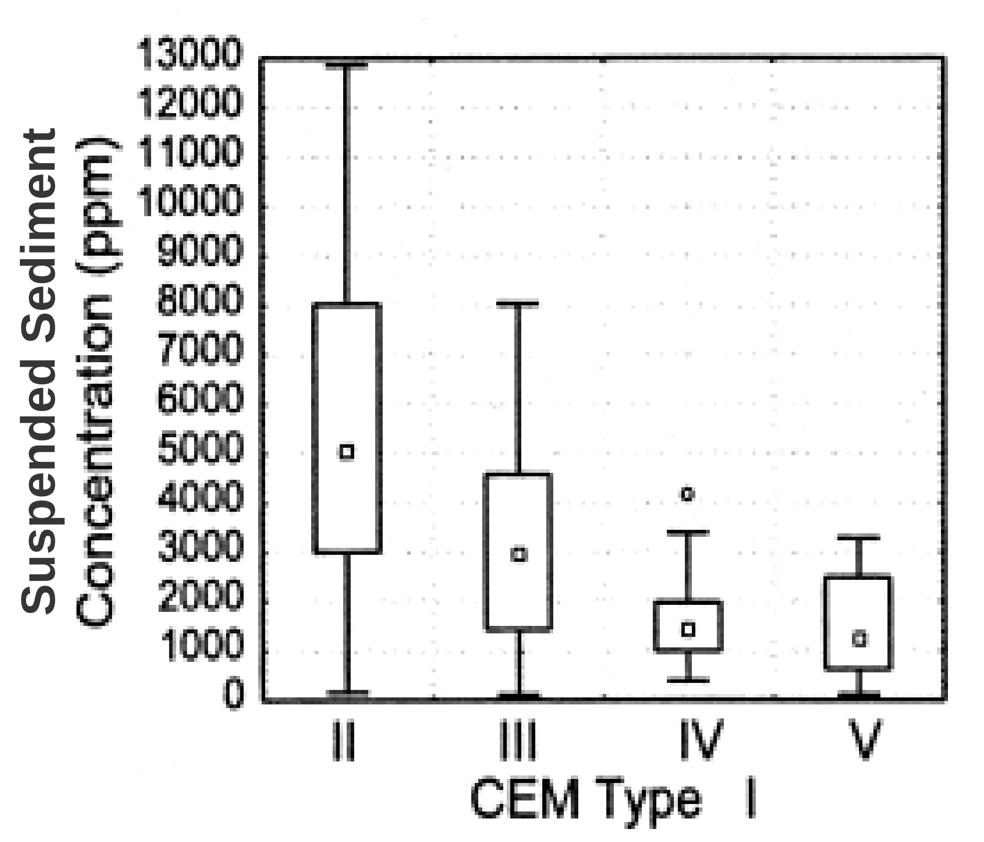
Stage II Incision

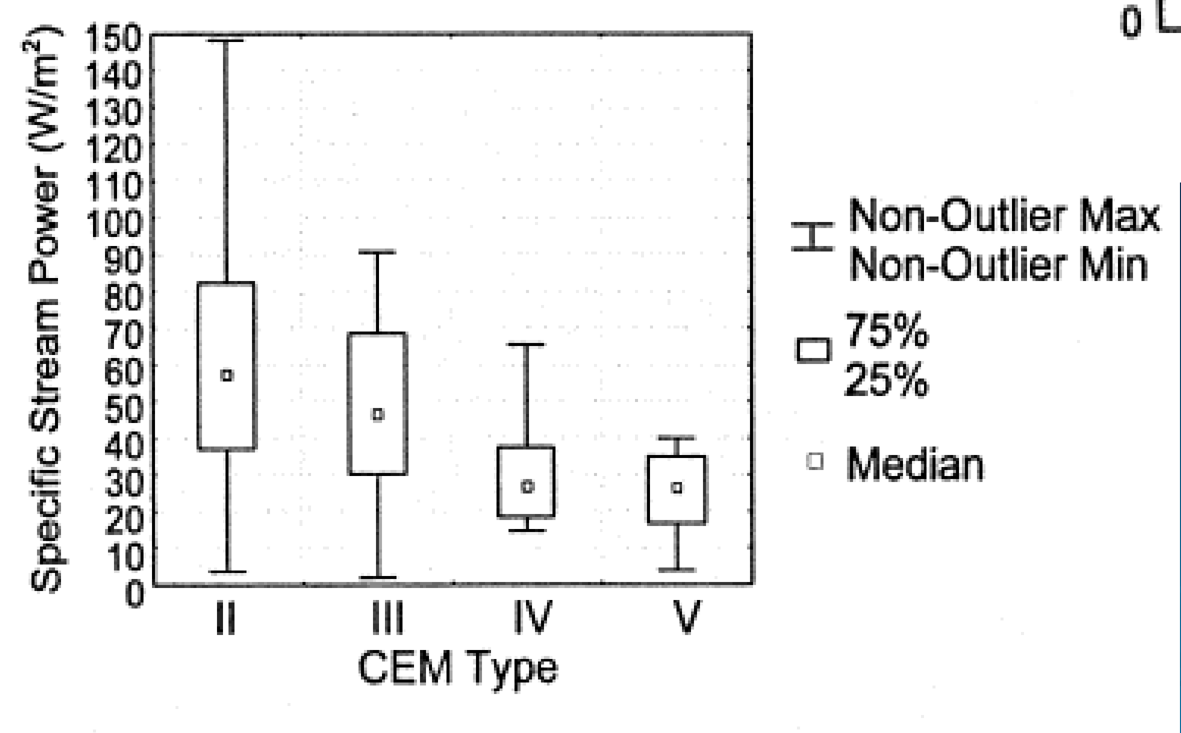


from Schumm, Harvey, and Watson. 1984.

Incising Channel, Toby Tubby Creek Watershed, Mississippi

Water Quality and Stream Power vs. CEM Channel Type

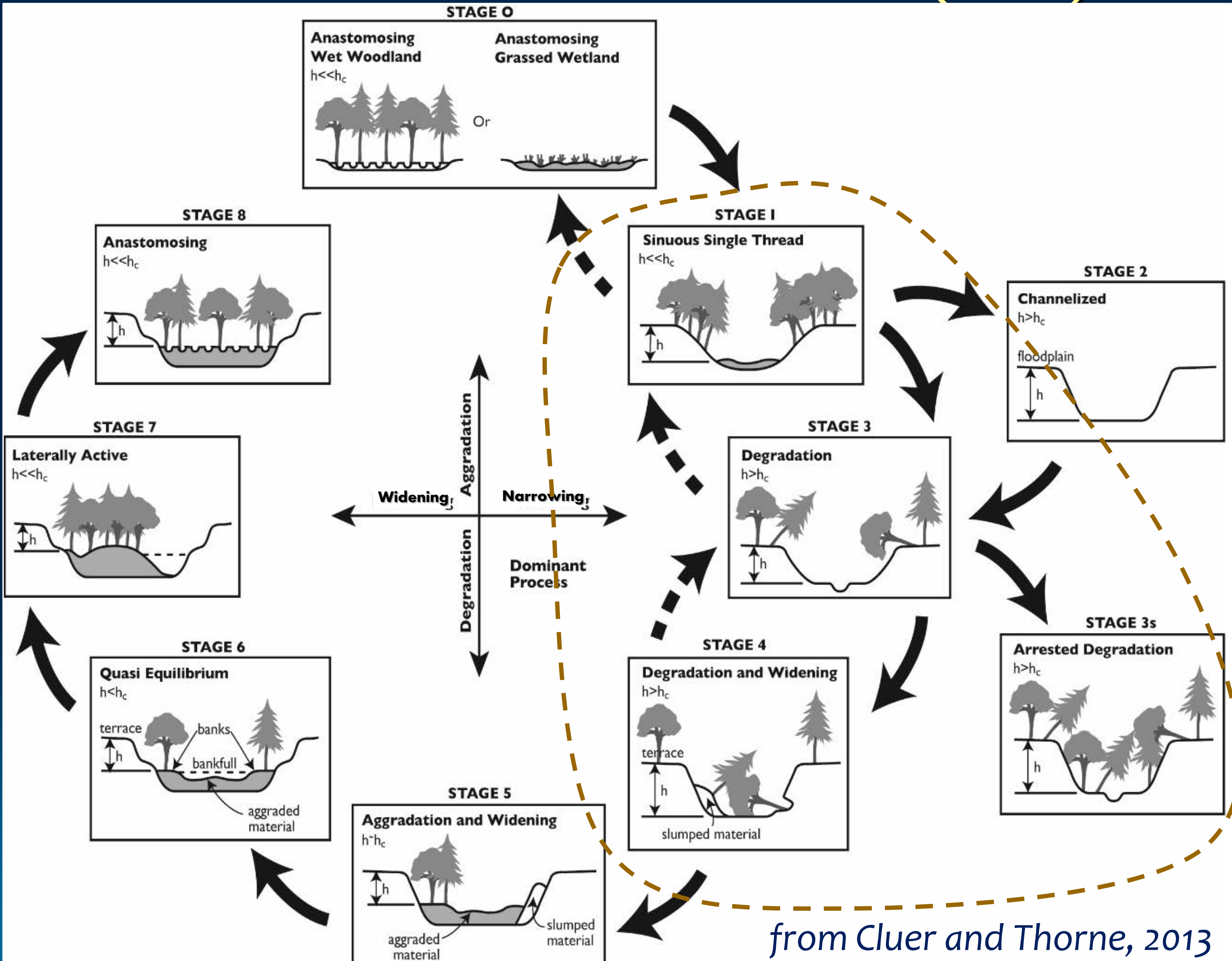




II	Incising
III	Widening
IV	Stabilizing
V	Stable

from: Bledsoe et al., 2002

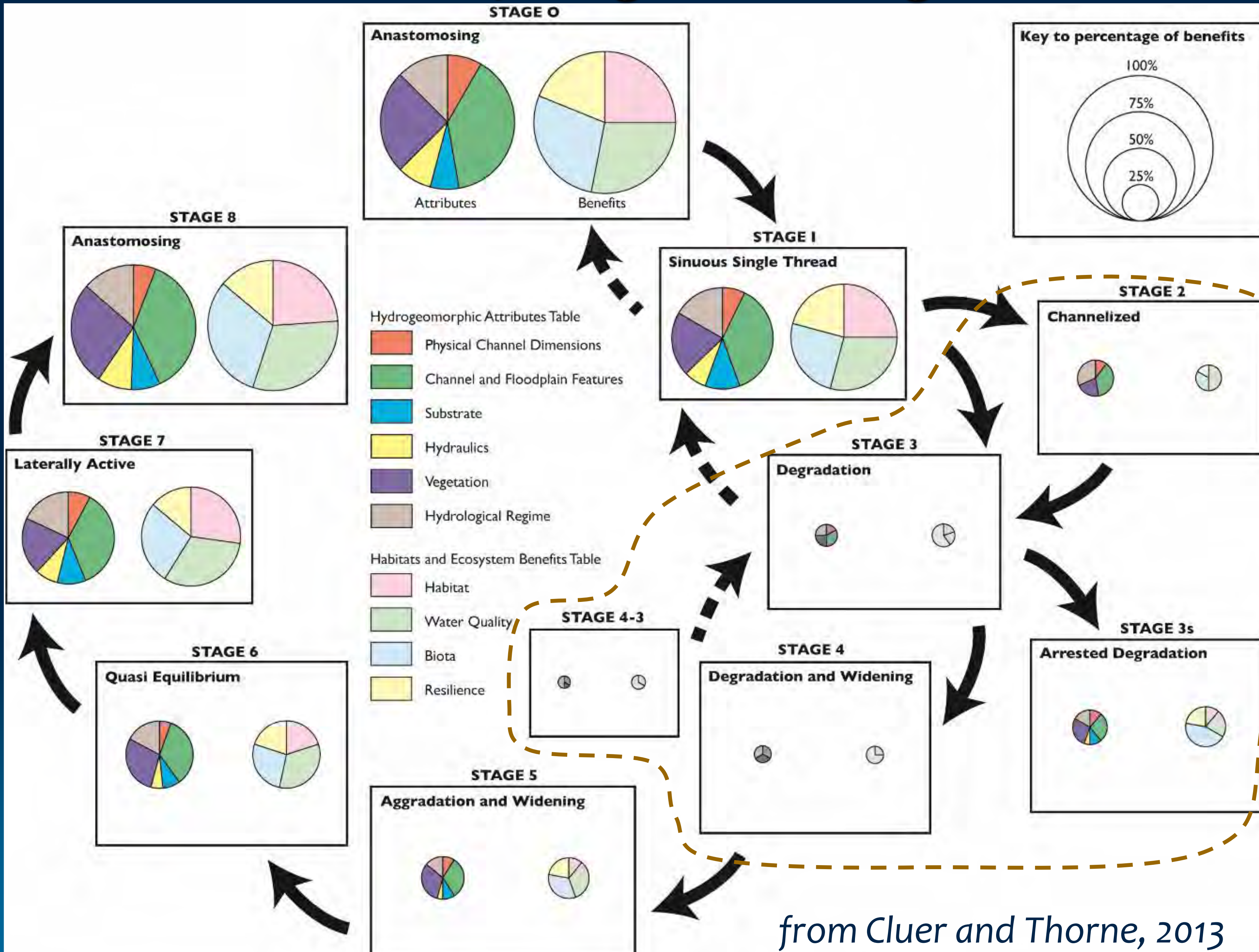
Stream Evolution Model (SEM)



Multiple Paths
Dead Ends

from Cluer and Thorne, 2013

Stream Evolutionary Stage vs. Ecological Benefits



from Cluer and Thorne, 2013

The Stream Channel Incision Syndrome
Loss of Habitat and Ecosystem Benefits

"We conclude channel incision presents a syndrome that is characterized by perturbed hydrology, degraded physical habitat, elevated nonpoint source pollution, and depleted fish species richness and that is extremely deleterious to instream ecosystem services."

Shields et al. 2010. *The stream channel incision syndrome and water quality.* Journal of Ecological Engineering

Allowing Incision to Migrate Upstream without Considering Risk


Before


After


Upstream Incision

Jordan Creek at Parkway Drive

Incorporating Incision Risk Assessments into Passage Projects

Recognize

↓

Characterize

↓

Assess Risk

↓

Mitigate Hazard

Resource: Castro, Janine. 2003. *Geomorphic Impacts of Culvert Replacement and Removal: Avoiding Channel Incision*. USFWS

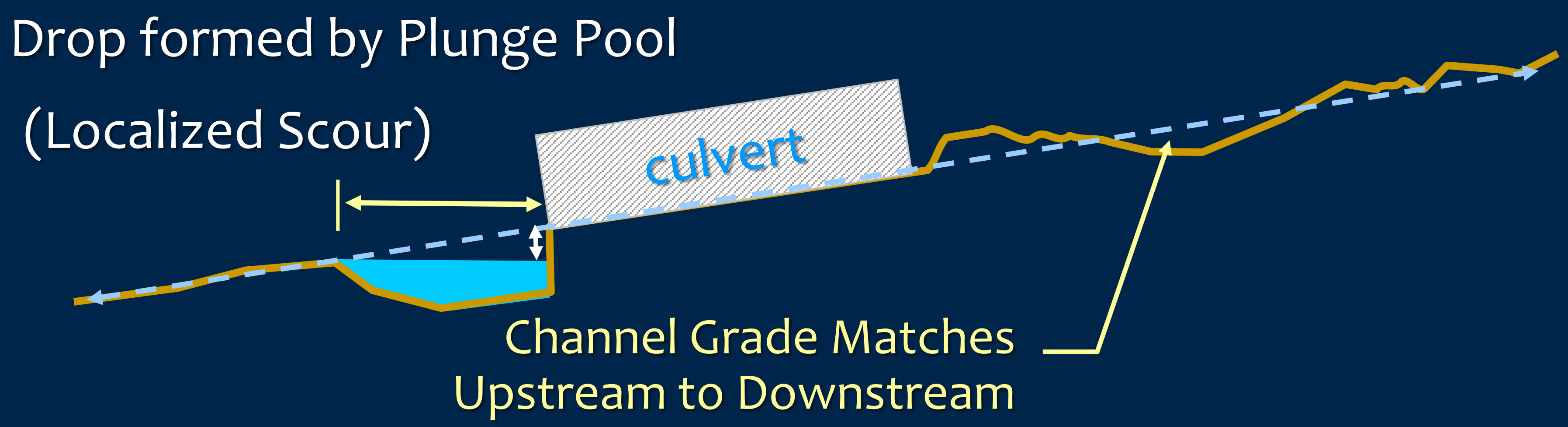
Step 1 - Recognition: Incision or Local Scour?

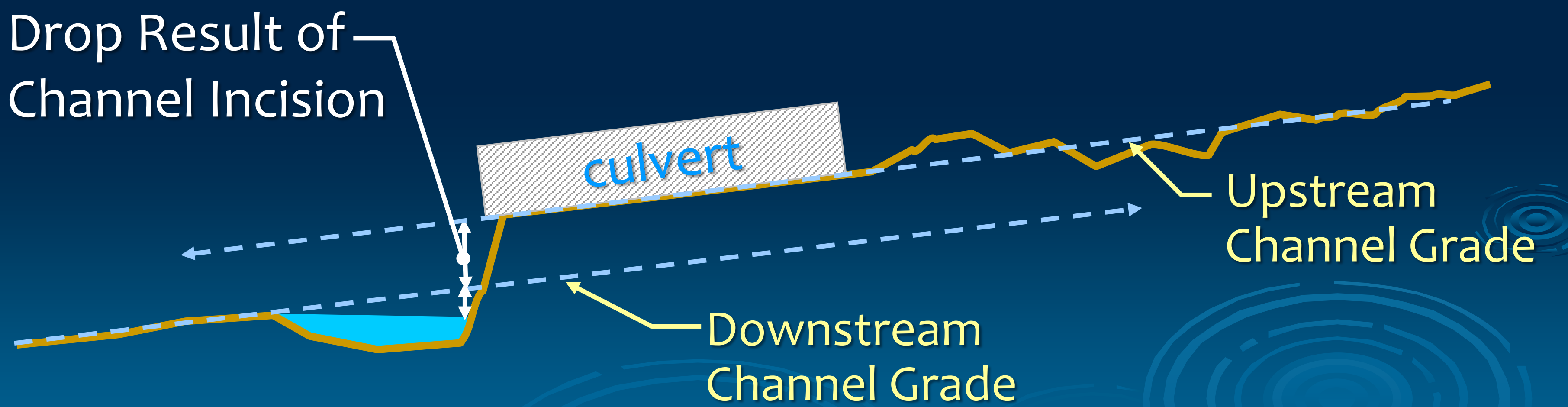
photo: Kozmo Bates

From further downstream – Pipe at Stream Grade

photo: Kozmo Bates

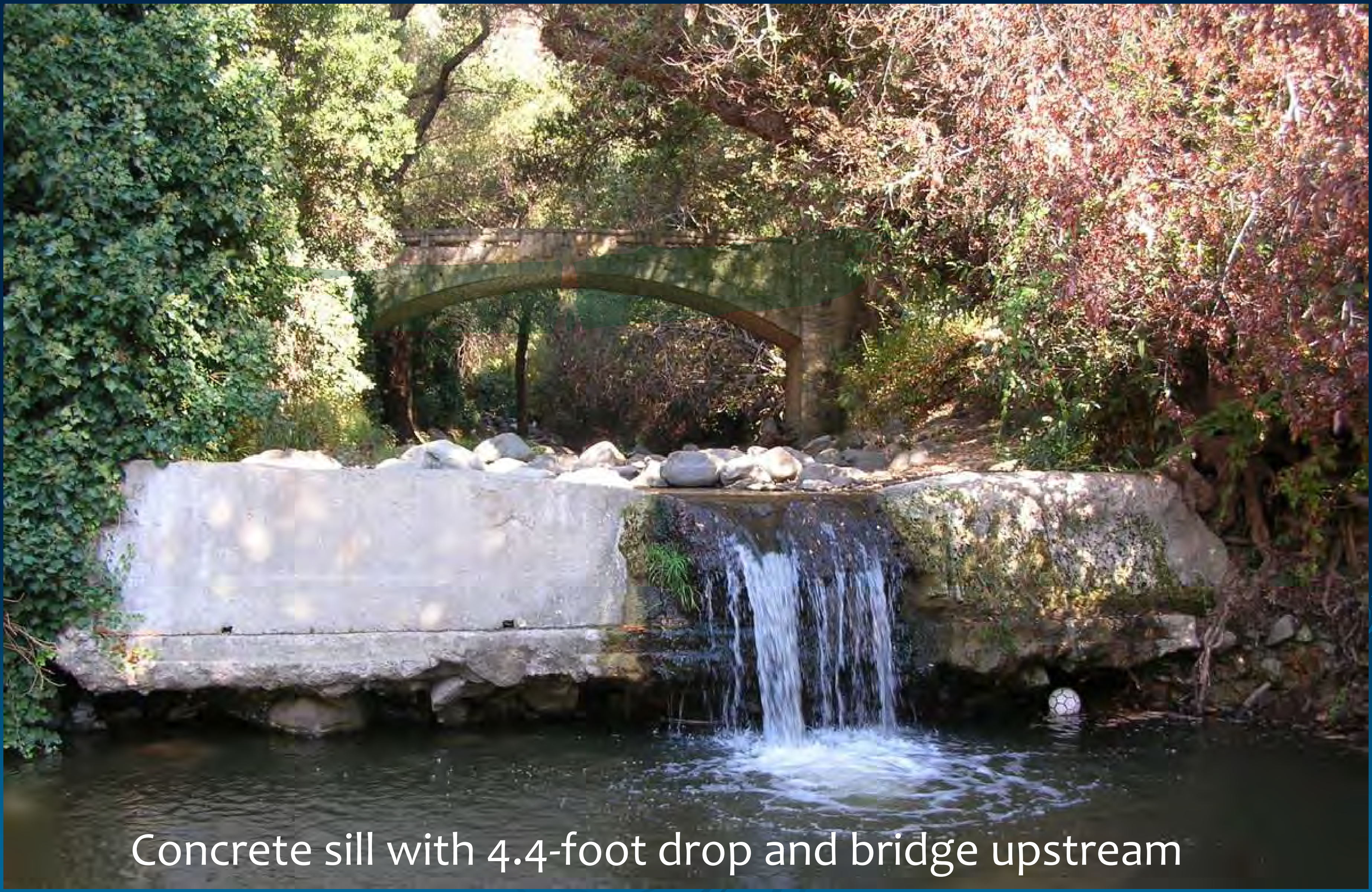
Recognize Local Scour vs. Incision



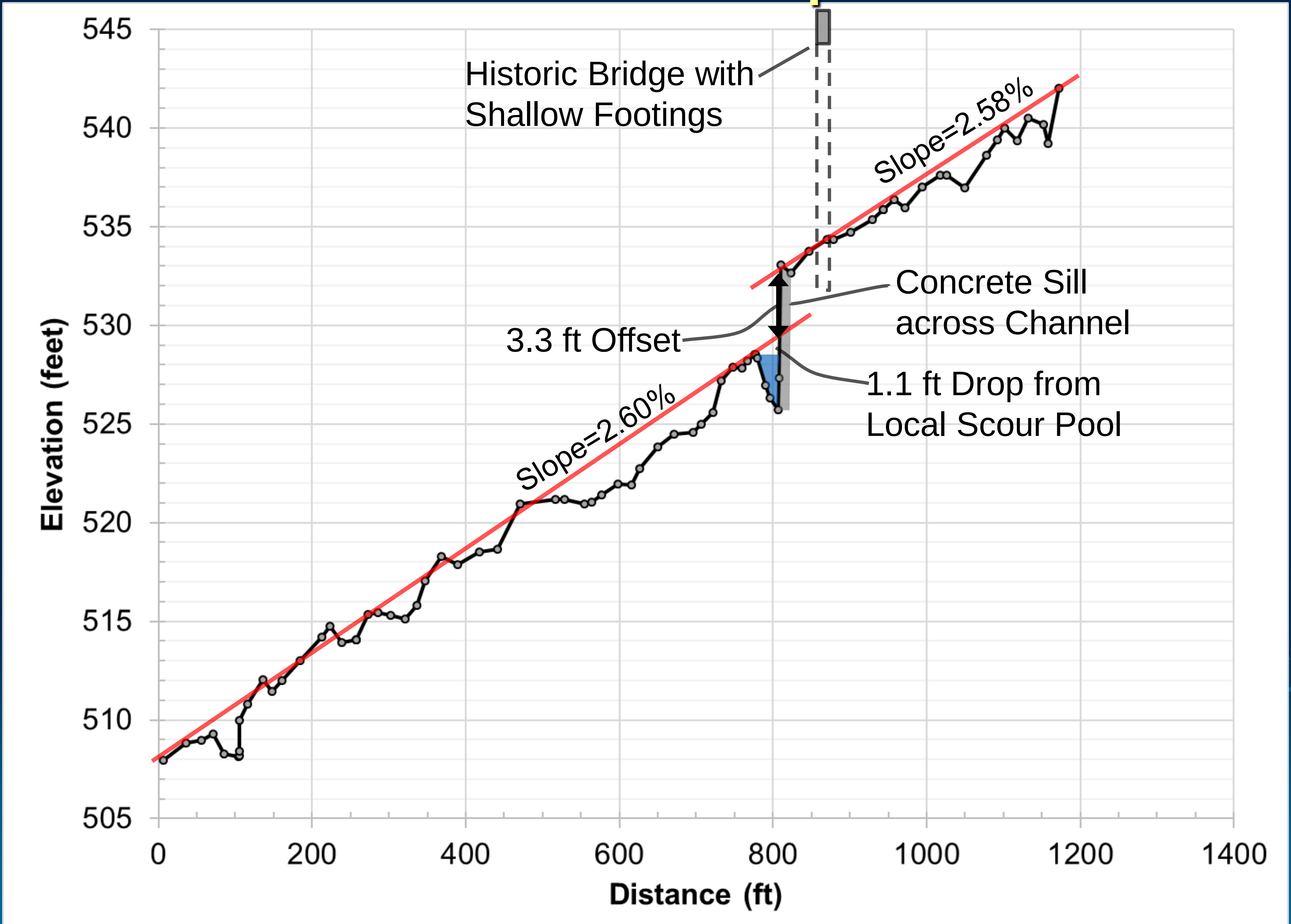


Channel Profile Interpretation

Incision Knickpoint or Not?



Channel Profile Interpretation

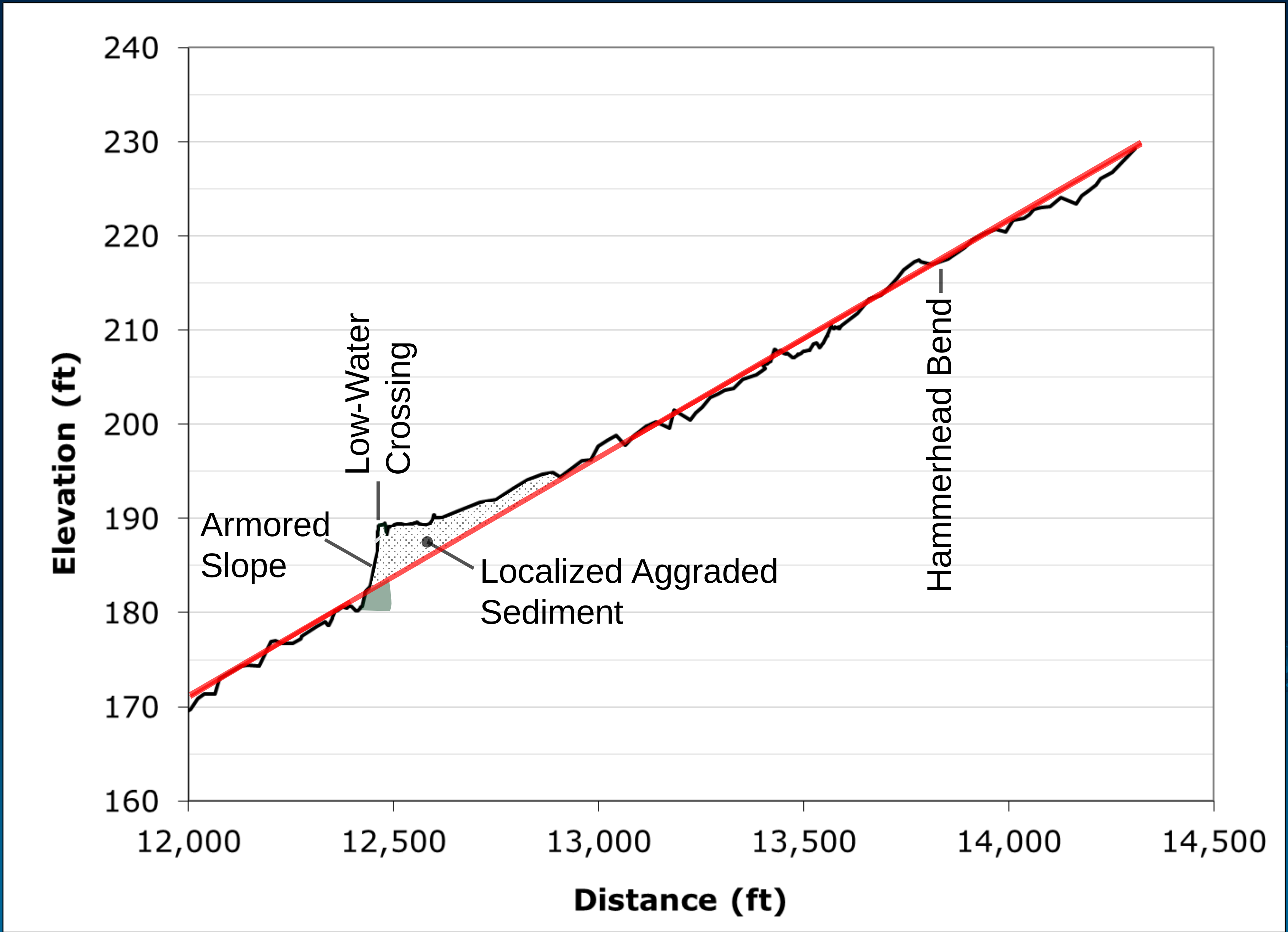


Channel Profile Interpretation

Incision Knickpoint or Not?

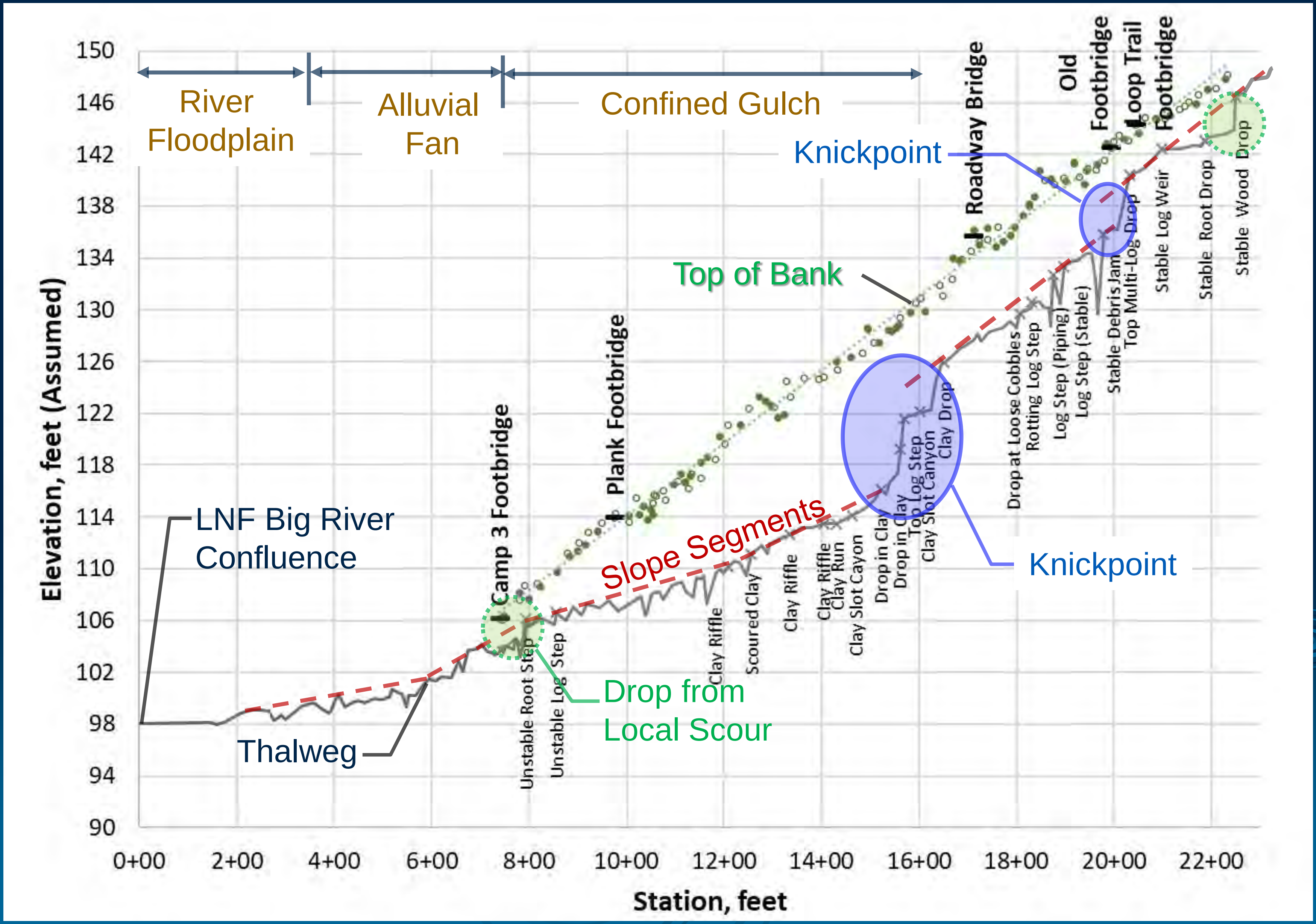
Vented low-water crossing (ford) with 8.7 feet of drop.

Channel Profile Interpretation



Channel Profile Interpretation

Slope Segments and Multiplie Knickpoints



Other Channel Incision Indicators

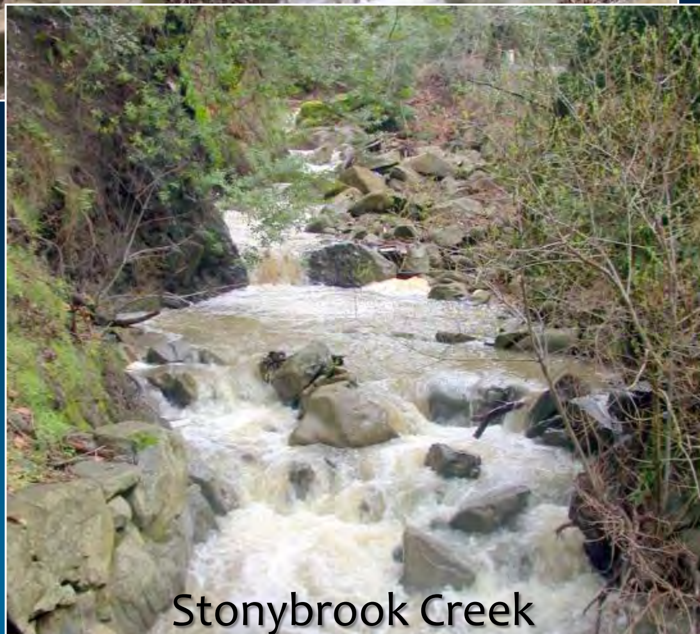
- **Toe of Bank is Vertical**
  Exposed roots, lack of sediment layering at streambed-banks interface
- **Actively Widening (Stage III)**
  Active bank failures, low depositional bars
- **Cultural Features Exposed**
  Perched culverts or exposed bridge footings, aprons, and pipelines
- **Lack of Sediment Deposition**
  Erosion of channel bed down to bedrock or other resistant soil layers
- **Lack of Pools**
  Long reaches of riffles/runs without pools

List adapted from J. Castro, 2003

Risk Assessment - Rate of Headward Incision

More mobile the bed material, more rapid the channel regrades.

Boulder Channel



Stonybrook Creek

Fine Grain Bed and Banks

Auburn Ravine

Risk Assessment - Extend of Regrade

McCready Gulch

Upstream of perched culvert, prior to removal

Morrison Gulch

Channel upstream of culvert replacement and regrade

Risk Assessment for Removing Knickpoints in Incised Channels

- **Anticipated magnitude and extent**
  Depth of incision and length of channel at risk
- **Risk to upstream property and infrastructure**
- **Impact to existing riparian/wetland vegetation**
  Will water table lower with incision and rootzone become dry?
- **Change in connectivity to side-channels and floodplain**
- **Rate of incision, bank widening, and sediment release**
  Mobility of bed, erosivity if banks, wood controls, bedrock
- **Ability of channel to recover**
  Will bank material and land-use permit channel evolution (widening)?

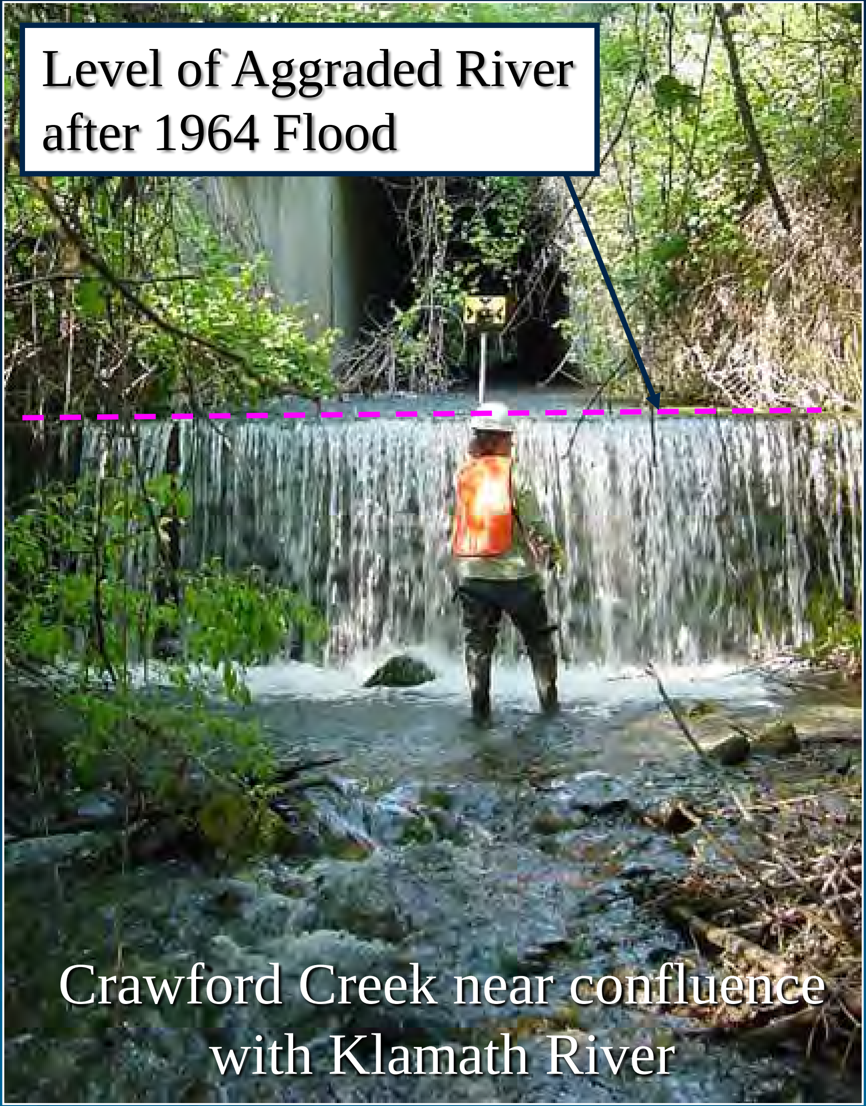
Channel Aggradation

Increased sediment loads combined with large flood can cause entire streams and rivers to aggrade.

Channel Aggradation and Culverts

Culvert replacements after flood events have added complexity and risk:

- ❑ Anticipating future regrade.
- ❑ Determining vertical placement of culvert invert or arch-footings.
- ❑ Providing enough flood capacity in aggraded state.

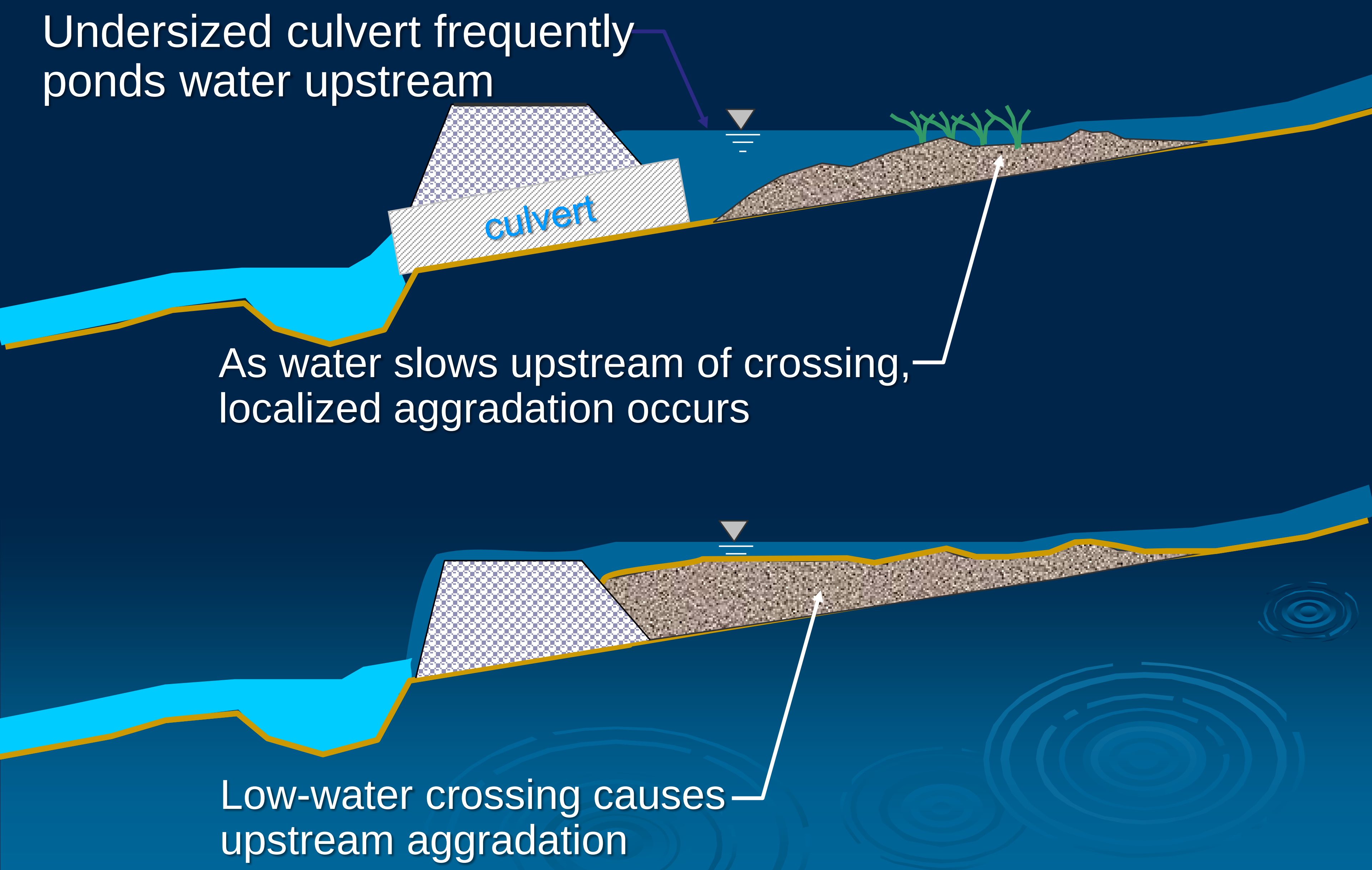


Backwater Influences

Sultan Creek Bridge
Influenced by Debris Jamming from High Flow Backwatering by Smith River

Little Mill Creek Bridge
Depositional Bar from River Backwatering

Crossings and Localized Aggradation



Fluctuating Levels of Beaches and Coastal Lagoons

Solstice Creek Outlet Discharging onto Beach

Arroyo Hondo Lagoon Breaching

The Pre-Design Phase

Geomorphic Based Stream Crossing Projects

Duffy Gulch, Noyo River, California

Michael Love P.E.
Arcata, California
mlove@h2odesigns.com
707-822-2411

Michael Love & Associates
Hydrologic Solutions

California Department of Fish & Wildlife

California Salmonid Stream Habitat Restoration Manual

Part XII: Fish Passage Design and Implementation (2009)

Available at:

http://www.dfg.ca.gov/fish/resources/habitatmanual.asp

Primary Authors:

Michael Love P.E.
Michael Love & Associates, Inc.

Kozmo Bates P.E.
Olympia, WA

Other Primary Sources for Fish Passage Design

US Forest Service, 2008

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

https://www.fs.fed.us/eng/pubs/pdf/StreamSimulation/

Washington Department of Fish and Wildlife, 2013

Water Crossing Design Guidelines

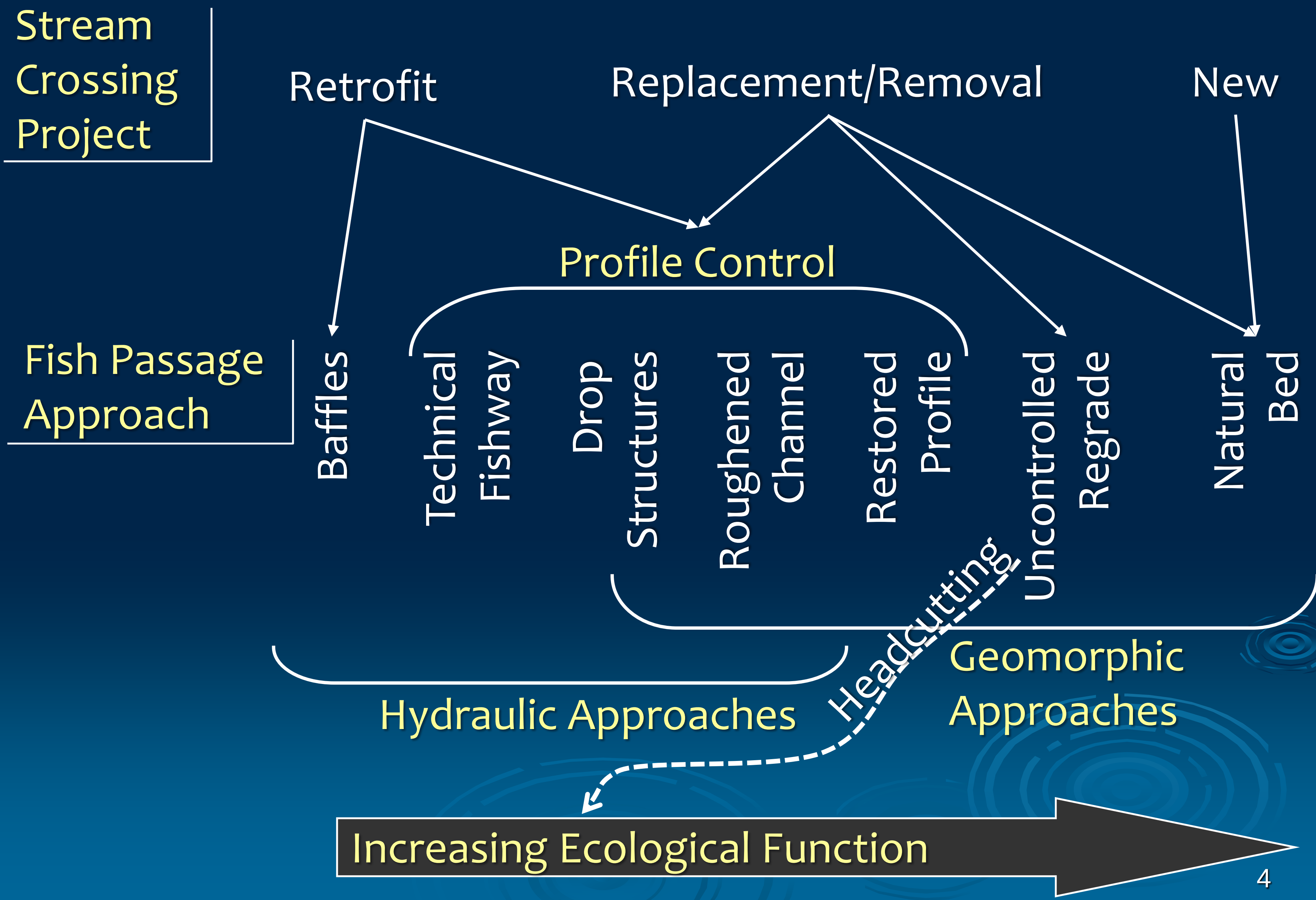
http://wdfw.wa.gov/publications/01501/

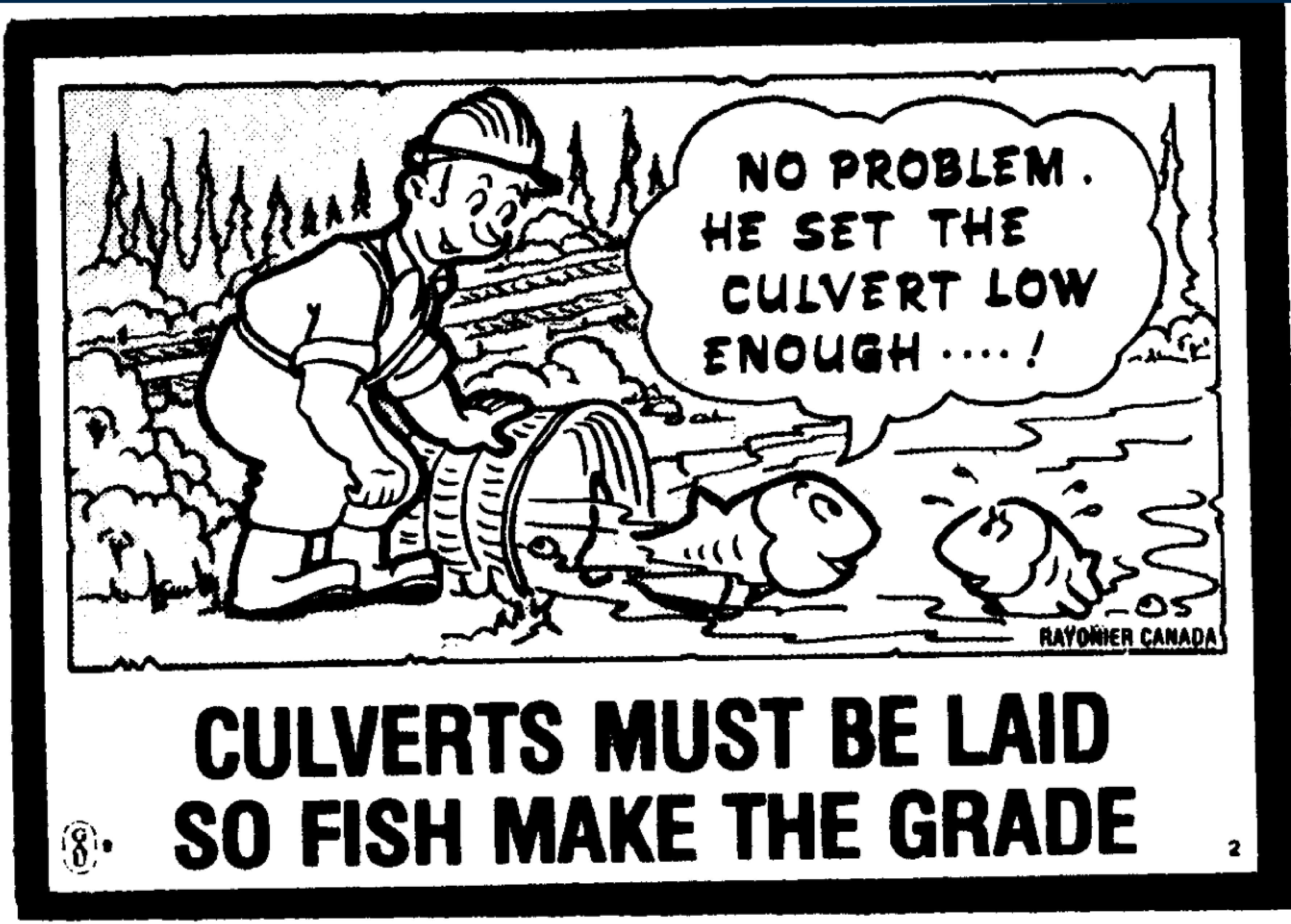
FishXing Software & Learning Systems (US Forest Service)

Passage Software, Case Studies, Reference Library

http://fishxing.org

Design Approaches for Aquatic Organism Passage





This isn't the first time we tried to get fish passage right…

Replaced 1979 – At Grade

1998 – Culvert outlet scour creates large pool, resulting in 1-foot outlet drop

This isn't the first time we tried to get fish passage right…

From: USFS 2008 Stream Simulation Design Manual

Passage Design Process

Pre-Design Phase

Project Objectives

↓

Engineering Site Plan Map

↓

Geomorphic Site Assessment

↓

Geomorphic Risk Assessment and Design Objectives

↓

Setting Project Alignment & Profile

↓

Select Suitable Design Approach(es)

↓

Design Phase

Design Development

↓

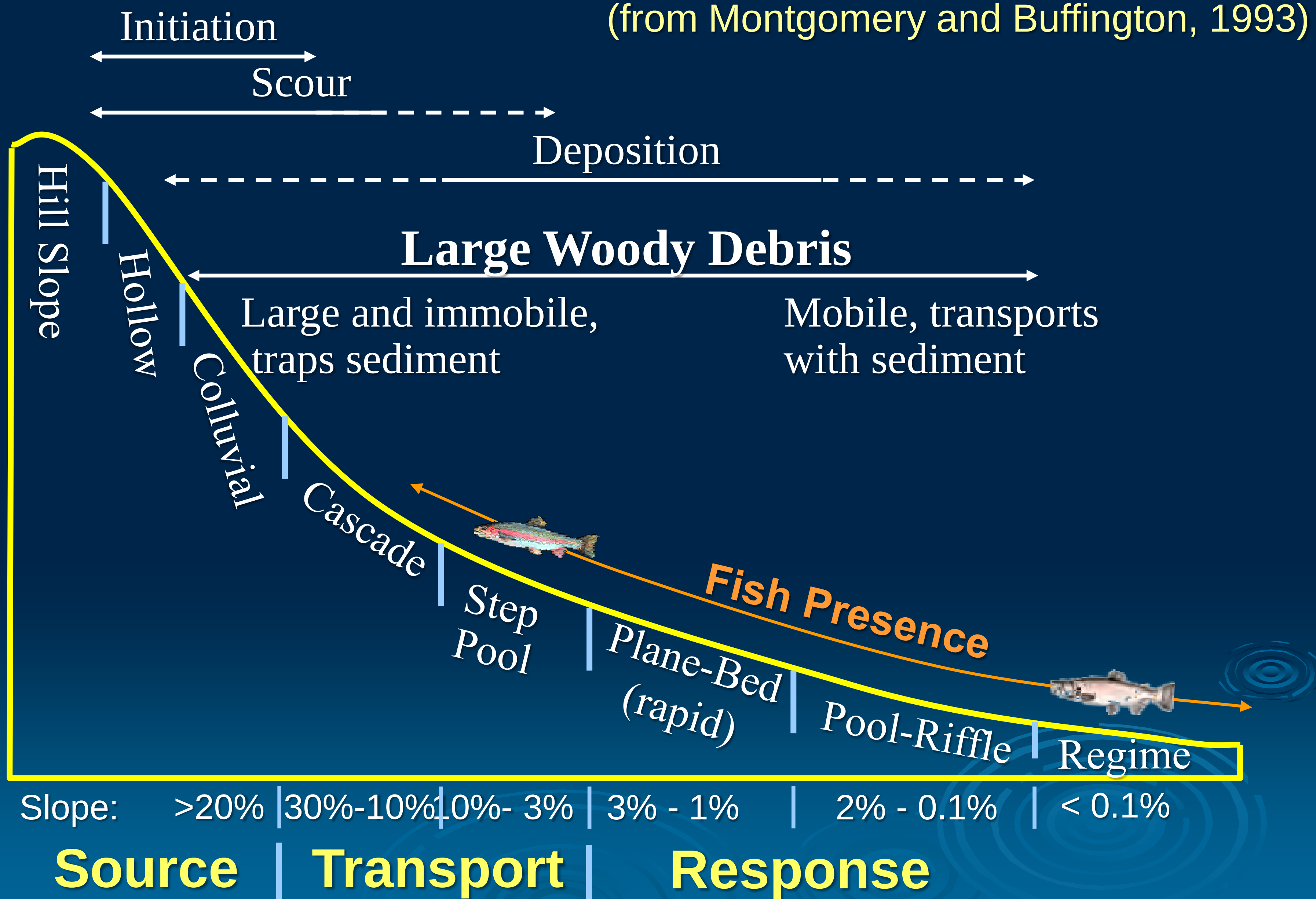
Final Plans, Specs, Cost Estimate

Site Assessment Objectives

- Gain an understanding of **channel history, stability**, and **adjustment potential:**
  - Channel type (transport vs. response)
  - Floodplain conveyance
  - Historic channel alternations
  - Bed variability (pool depths)
  - Headcut potential
  - Bank stability
- Develop a **channel template:**
  - Shape
  - Approach Alignment
  - Bed Controls (embedded wood, large rock, “ledge”)
  - Profile
  - Substrate Composition
  - Floodplain Connectivity

Generalized Stream Classification

(from Montgomery and Buffington, 1993)



Longitudinal Profile

- Survey profile along channel thalweg

- Extend survey well past culvert influence
  Recommend Min Profile Length = 20 channel widths

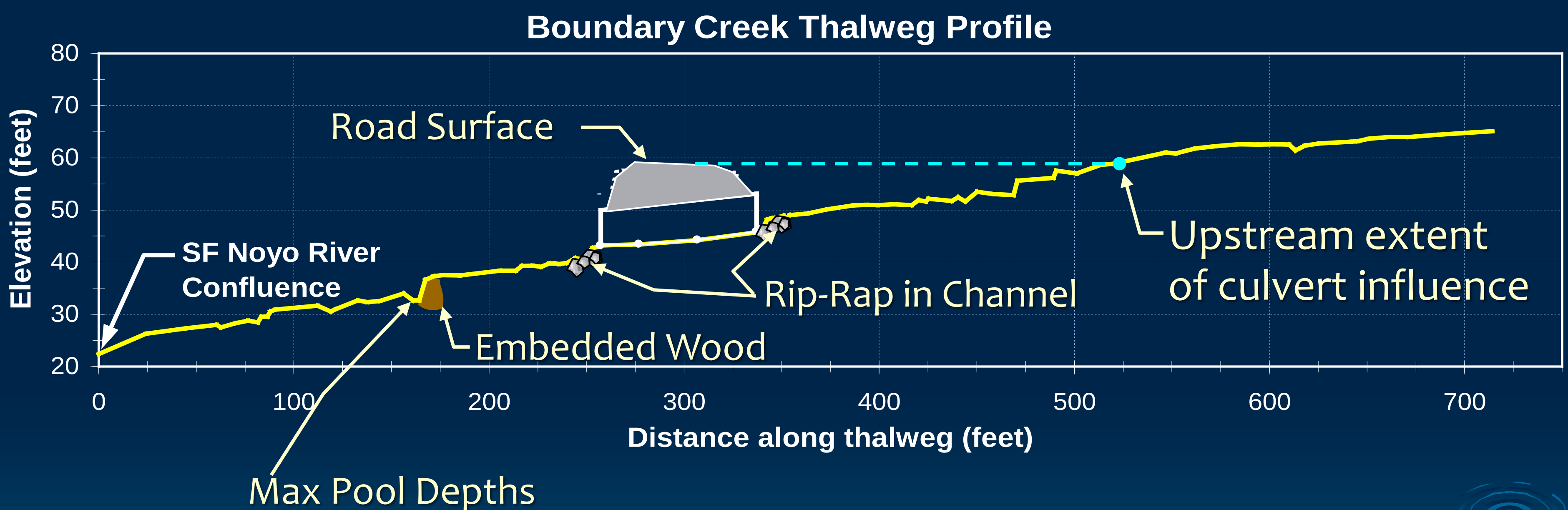
- Survey captures pool depths, riffles,

- Survey "forcing features" controlling grade
  Note long-term stability of each forcing feature

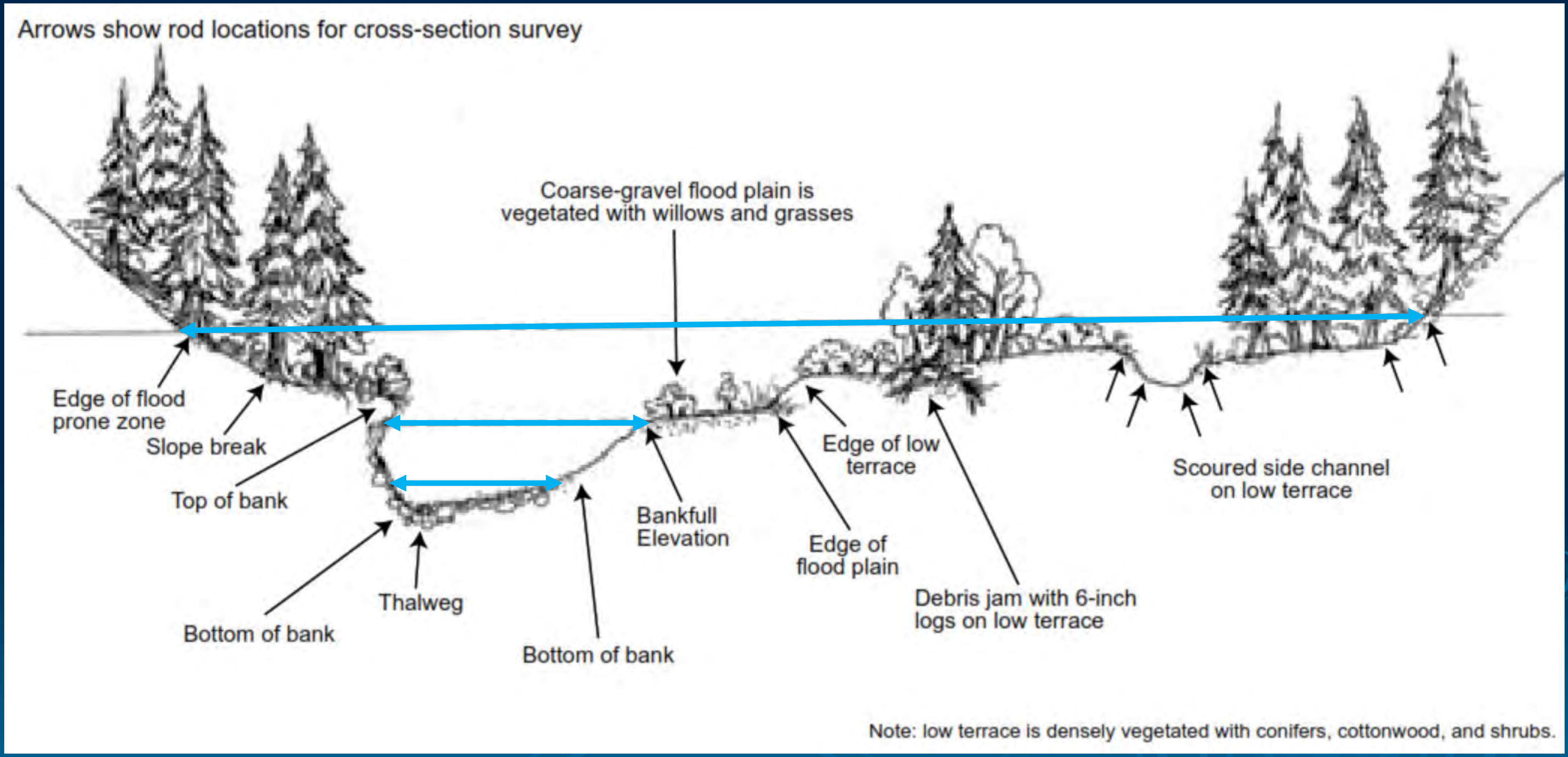
- Survey base and top of features controlling grade
  Bedrock, large colluvium, embedded wood, debris jams, check-dams, culvert inverts, stream confluence…

Longitudinal Profile

Min 20 Channel Widths Upstream and Downstream of Culvert Influence

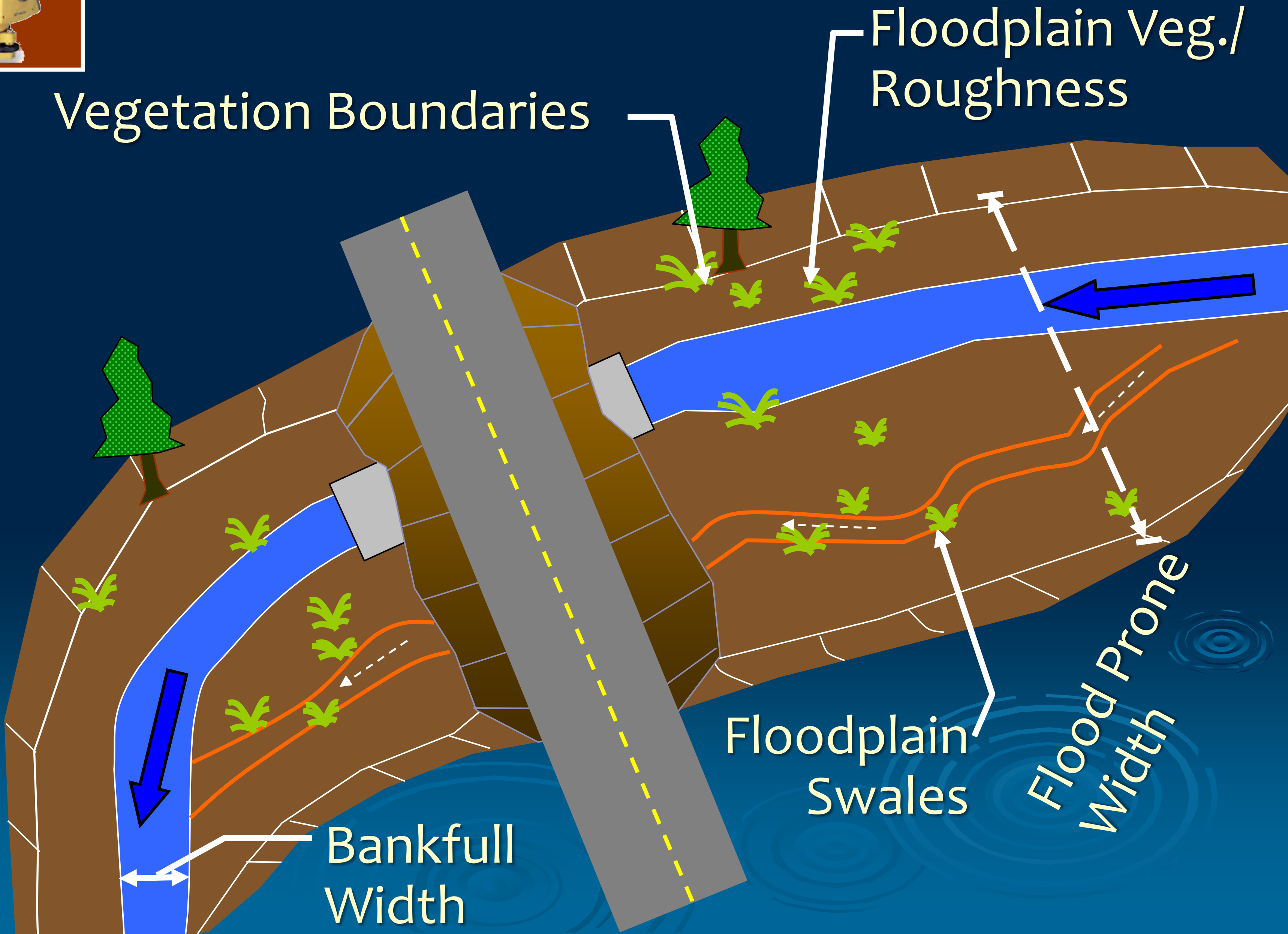


Surveying Channel and Floodplain Features



From: USFS 2008 Stream Simulation Design Manual

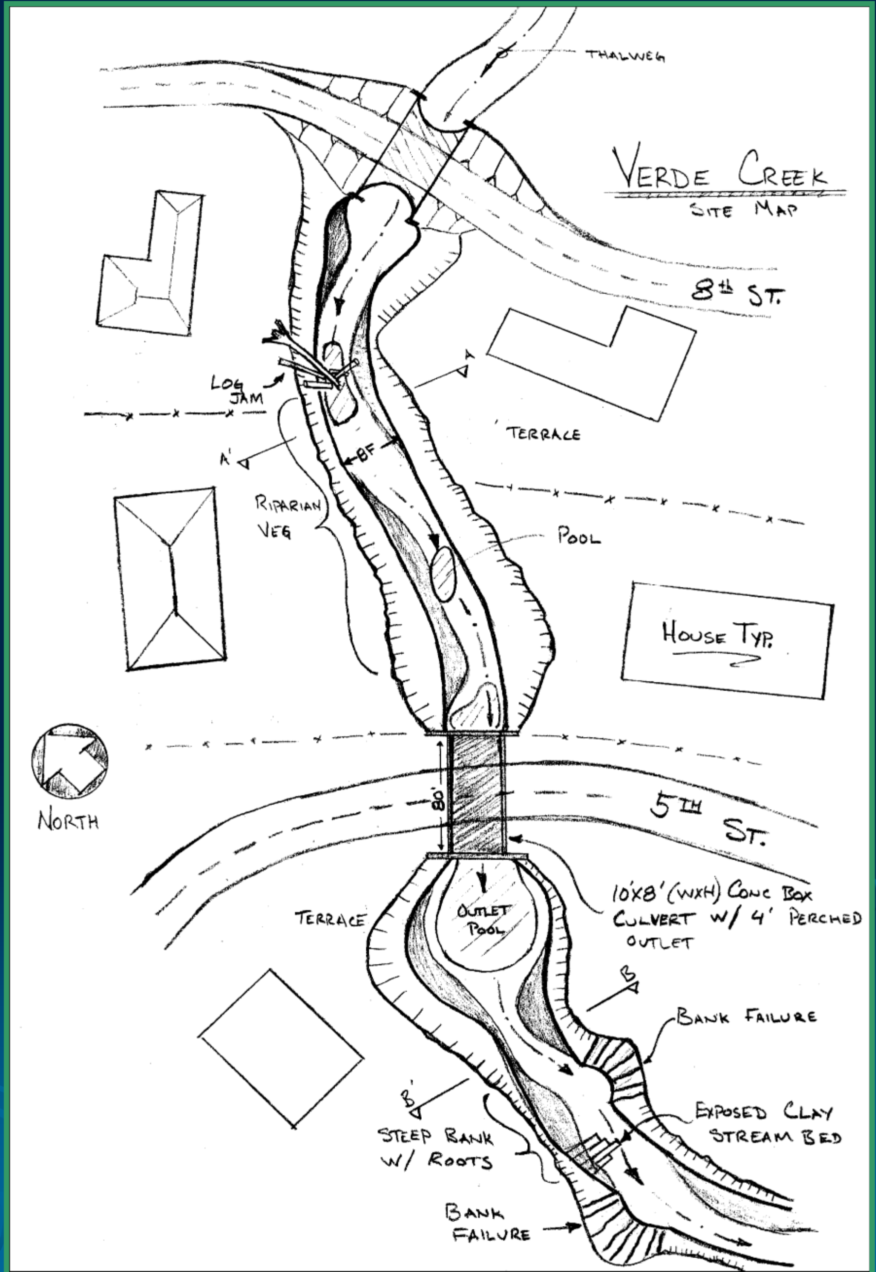
Surveying Floodplain Features



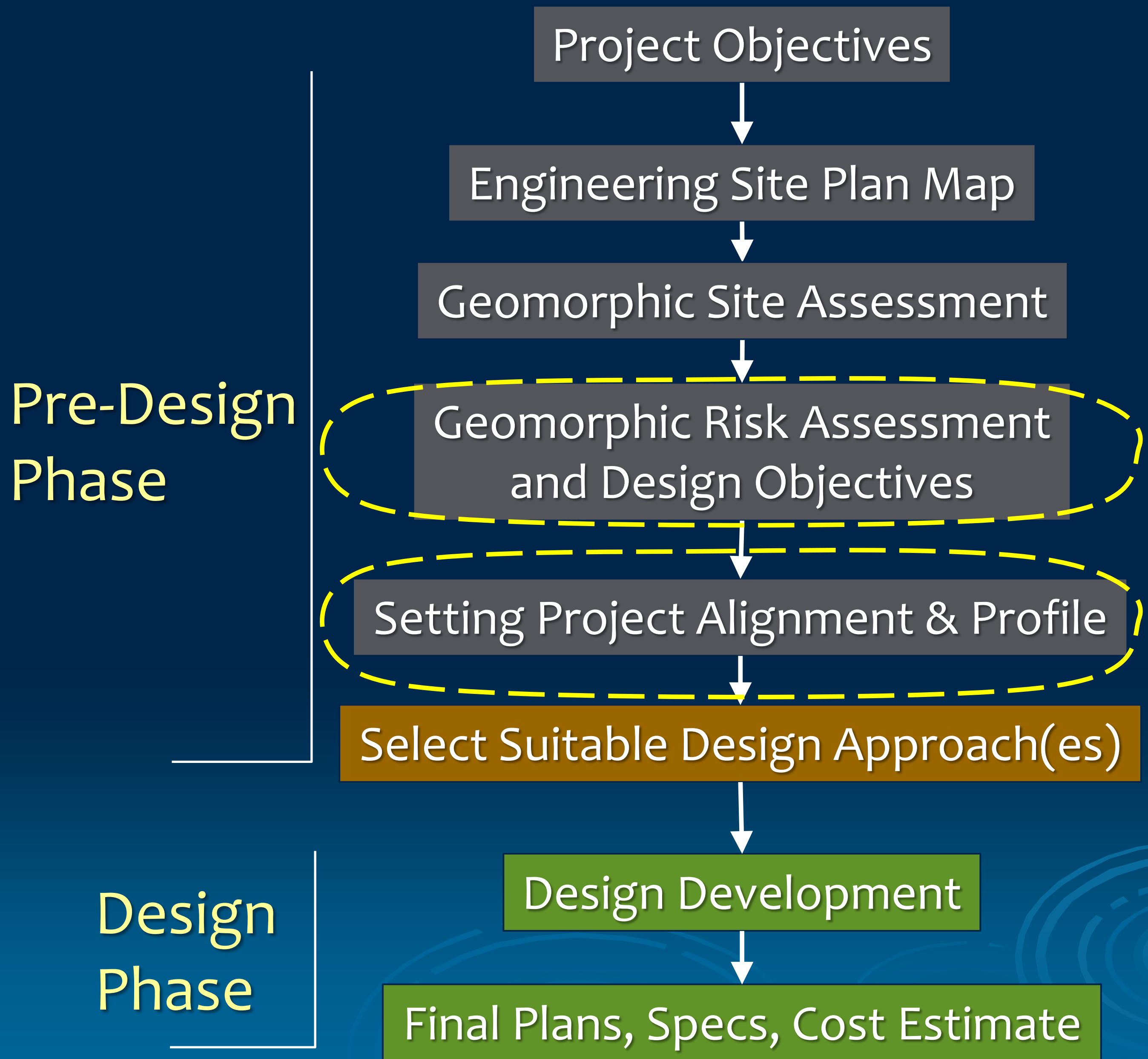
Making a Site Sketch of Stream Reach

Site Sketch should identify:

- Channel Bends
- Exposed Roots
- Overhanging Banks
- Bank Irregularities
- Woody Debris
- Bank Erosion
- Sediment Storage
- Sediment Inputs



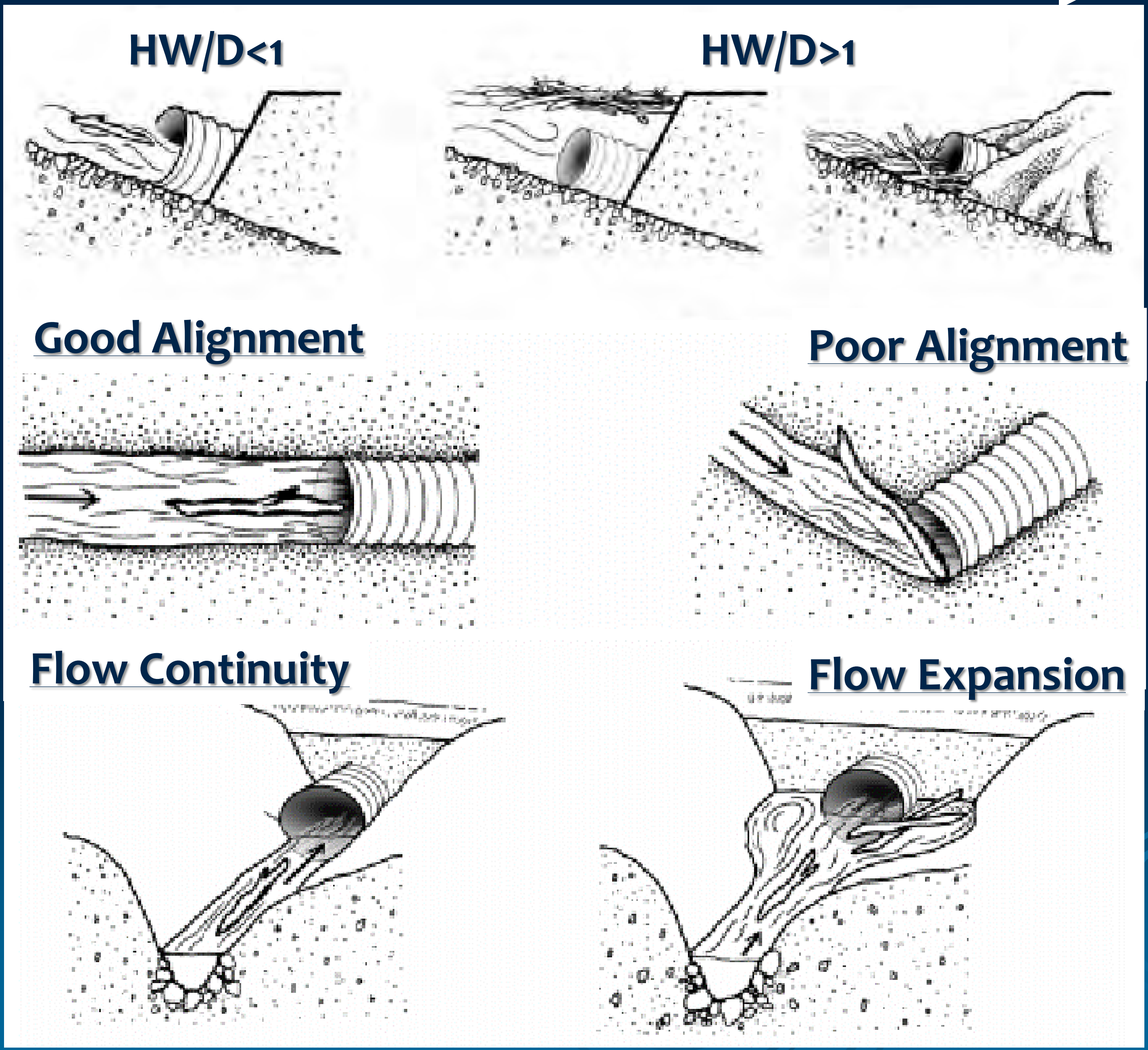
Passage Design Process



Alignment

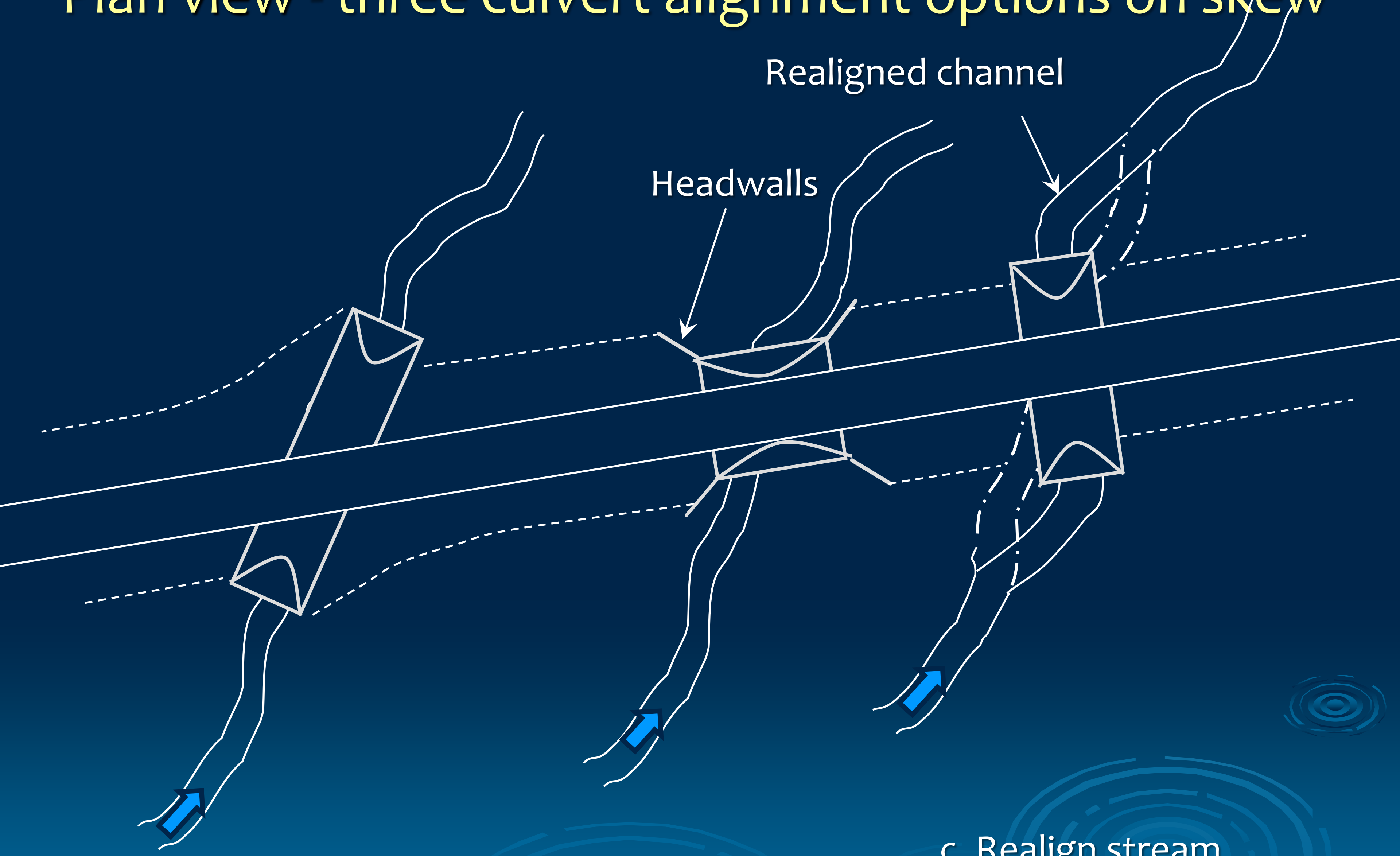
- Concurrent with profile design
- Important factor for debris blockage and failure
- Consider existing and future stream channel

Increasing Plugging Hazard



From:
Furniss et al. 1998

Plan view - three culvert alignment options on skew



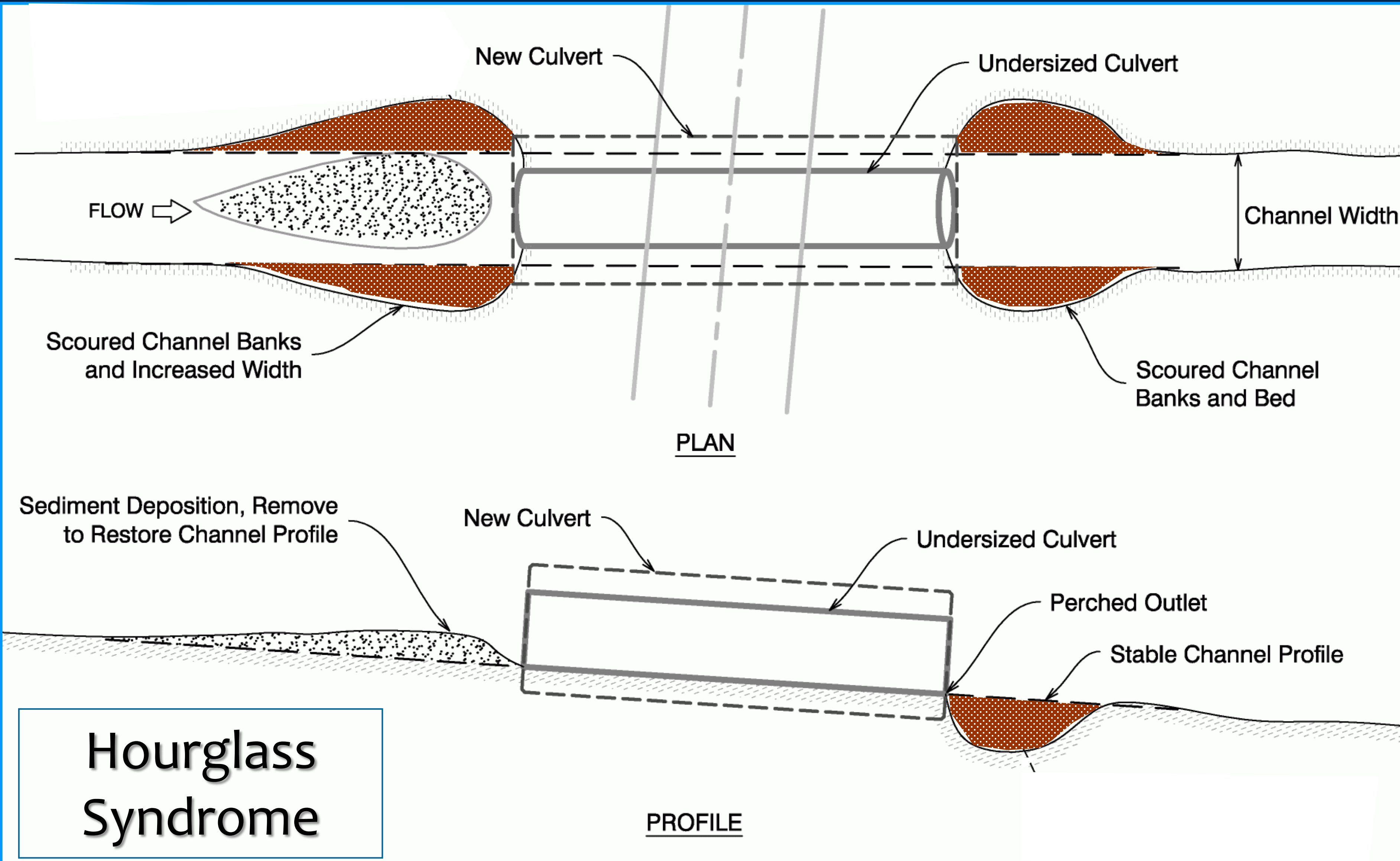
a. Culvert on stream alignment

b. Widen and/or shorten culvert

c. Realign stream to minimize culvert length

Flow Expansion at Inlet Transitions Turns Debris and Leads to Plugging

Restoring Channel Geometry at Transitions



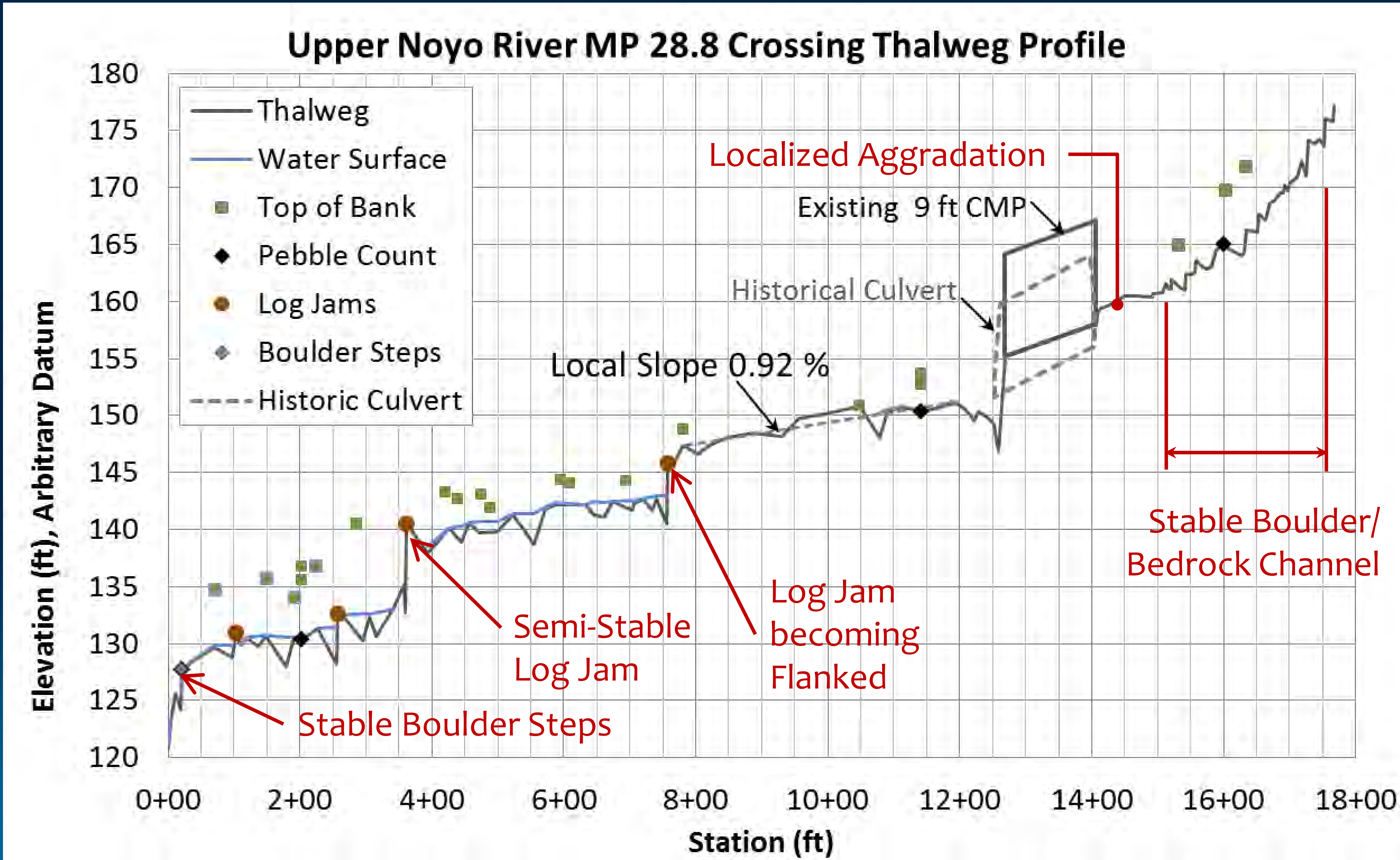
Hourglass Syndrome

Examples of Restored Channel Geometry at Inlets

Wood and Rootwads

Encapsulated Soil Lifts

Channel Profile Analysis

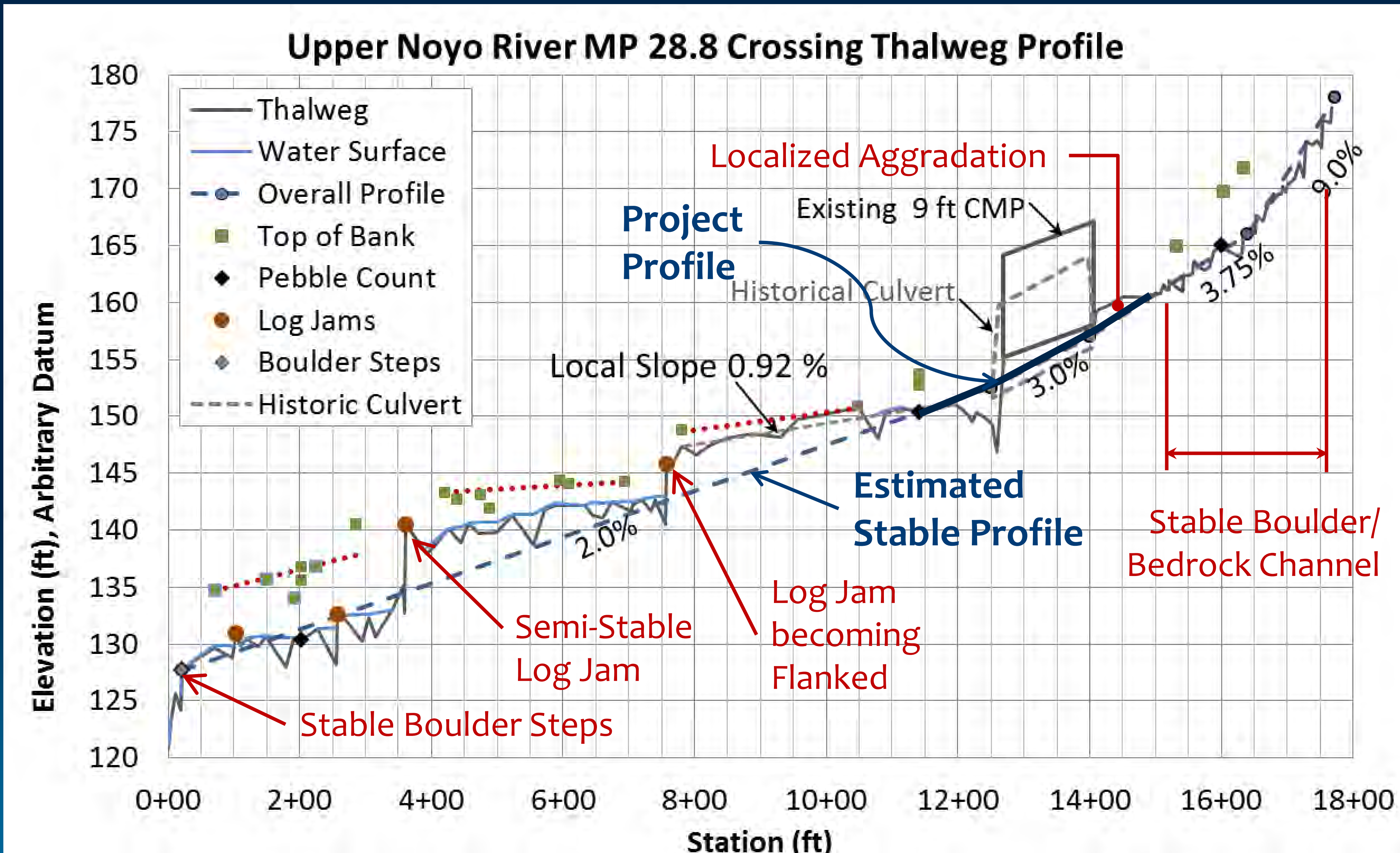


Estimating Channel Bed Structure Stability

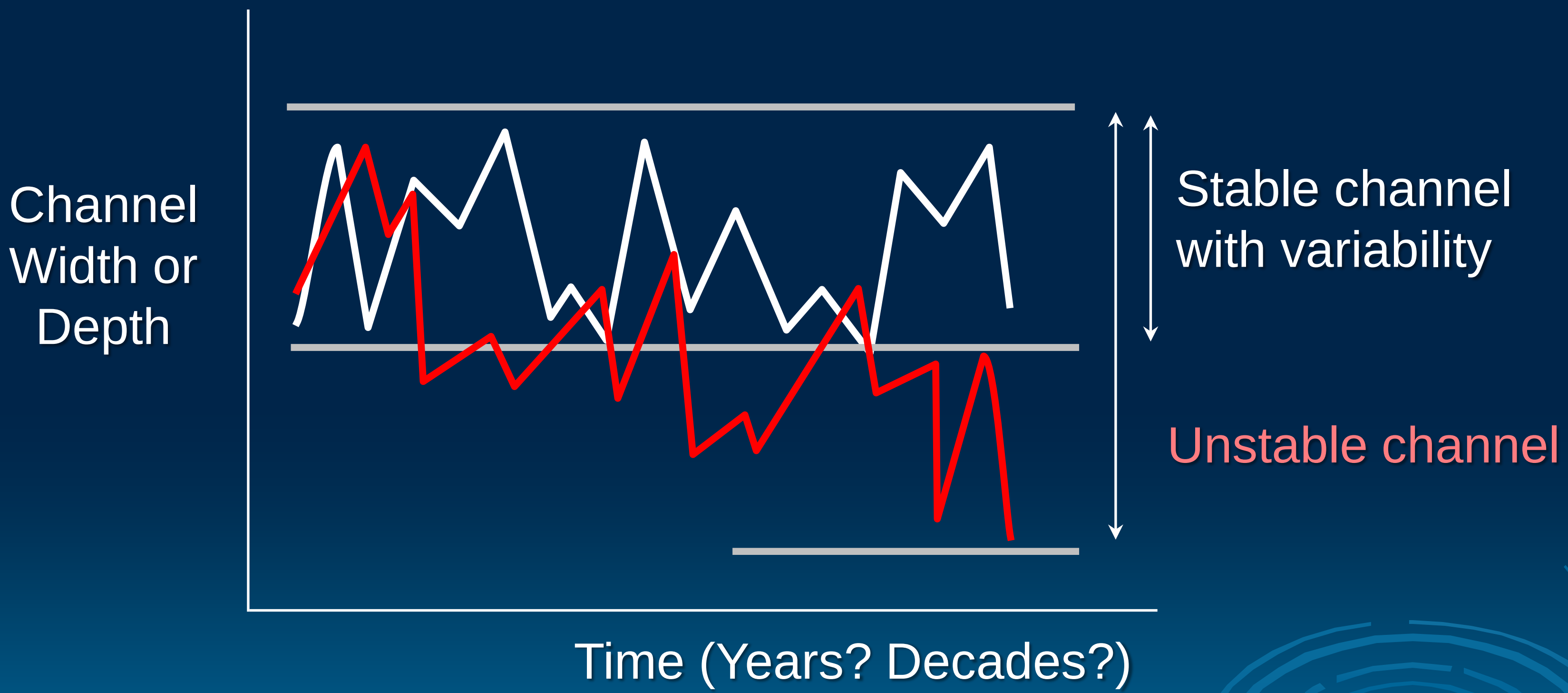
Table 5.3—A qualitative method for determining channel-bed structure stability. (USFS Stream Simulation Manual)

Structure composition	Stability Rating	Structure Characteristics
Bedrock	*High*	*Bedrock ledges or falls span entire stream width*
Boulder-cobble steps	*High*	*Boulder-cobble steps span entire width of stream. Rocks are tightly keyed in place, and keyed-in material extends below base of scour pool below step.*
Cobble-boulder or cobble-gravel pool tail crests or riffle crests	*High*	*Cobble-boulder or cobble-gravel pool tail crests or riffle crests span the entire width of stream. Particles are tightly packed, embedded into the channel bed, and coarser than the remainder of the channel bed.*
Log	*High*	*Wood is sound and well anchored, spanning entire stream width.*
Composite log and rock	*High*	*Wood is sound and well anchored, may or may not span entire stream width. Rock pieces are well keyed in place and bridge gaps so that composite structure controls width from bank to bank.*
Boulder-cobble steps, cobble-gravel steps	*Moderate*	*Steps do not span entire width of stream or are loosely keyed in place. Keyed-in rocks may not extend below base of scour pool below step. Alternatively, step key pieces are not in contact with each other.*
Cobble-boulder or cobble-gravel pool tail crests or riffle crests	*Moderate*	*Pool tail crests span entire width of stream, but the largest particles are similar in size to those elsewhere observed along the channel bed. Alternatively, particles are moderately packed and/or moderately embedded into the channel bed.*
Log	*Moderate*	*Wood is rotten and punky. It may span entire stream width, but anchoring is susceptible to bank scour and movement during high flood events.*
Cobble-gravel steps or pool tail crests	*Low*	*Steps do not span entire width of stream, and/or are composed of loosely packed materials. Pool tail crests are constructed of material no coarser than rest of stream bed.*
Log	*Low*	*Wood is very rotten and punky, may or may not span entire stream width, and anchoring is poor and susceptible to bank scour and movement during bankful flood events. Indications of movement are visible where pieces are anchored into the bank.*
Composite log and rock, beaver dams	*Low*	*Wood is very rotten and punky, or structure is made of loosely packed pieces that are poorly anchored. Structure does not span entire stream width. Rock is small in size and subject to movement at bankfull flood events. Beaver dams are poorly constructed or old and inactive. Large key logs are not present.*

Channel Profile Analysis

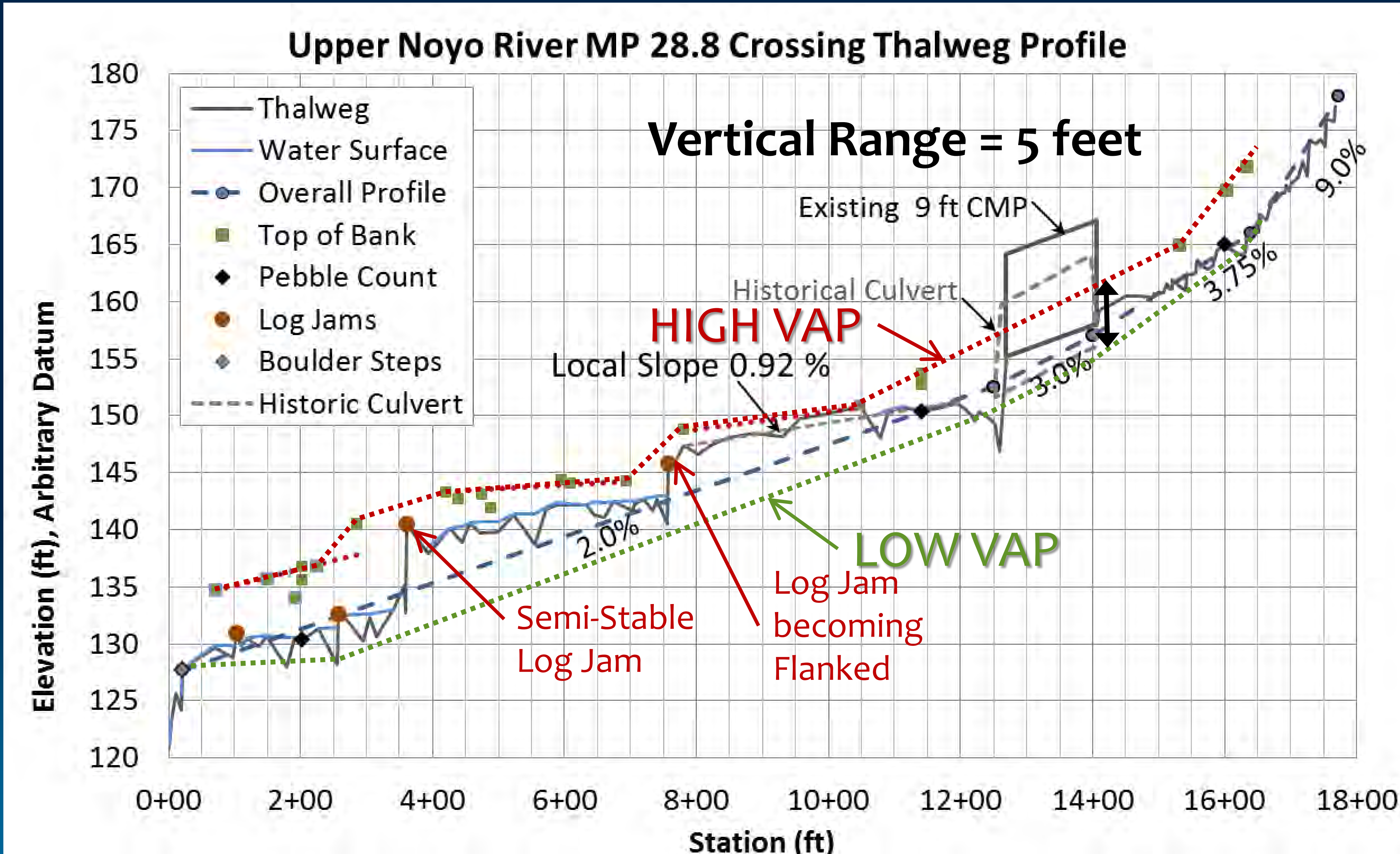


Estimate Channel Adjustments for Life of Project



Vertical Adjustment Potential (VAP) Profiles

Estimates the range of possible channel profiles for life of project

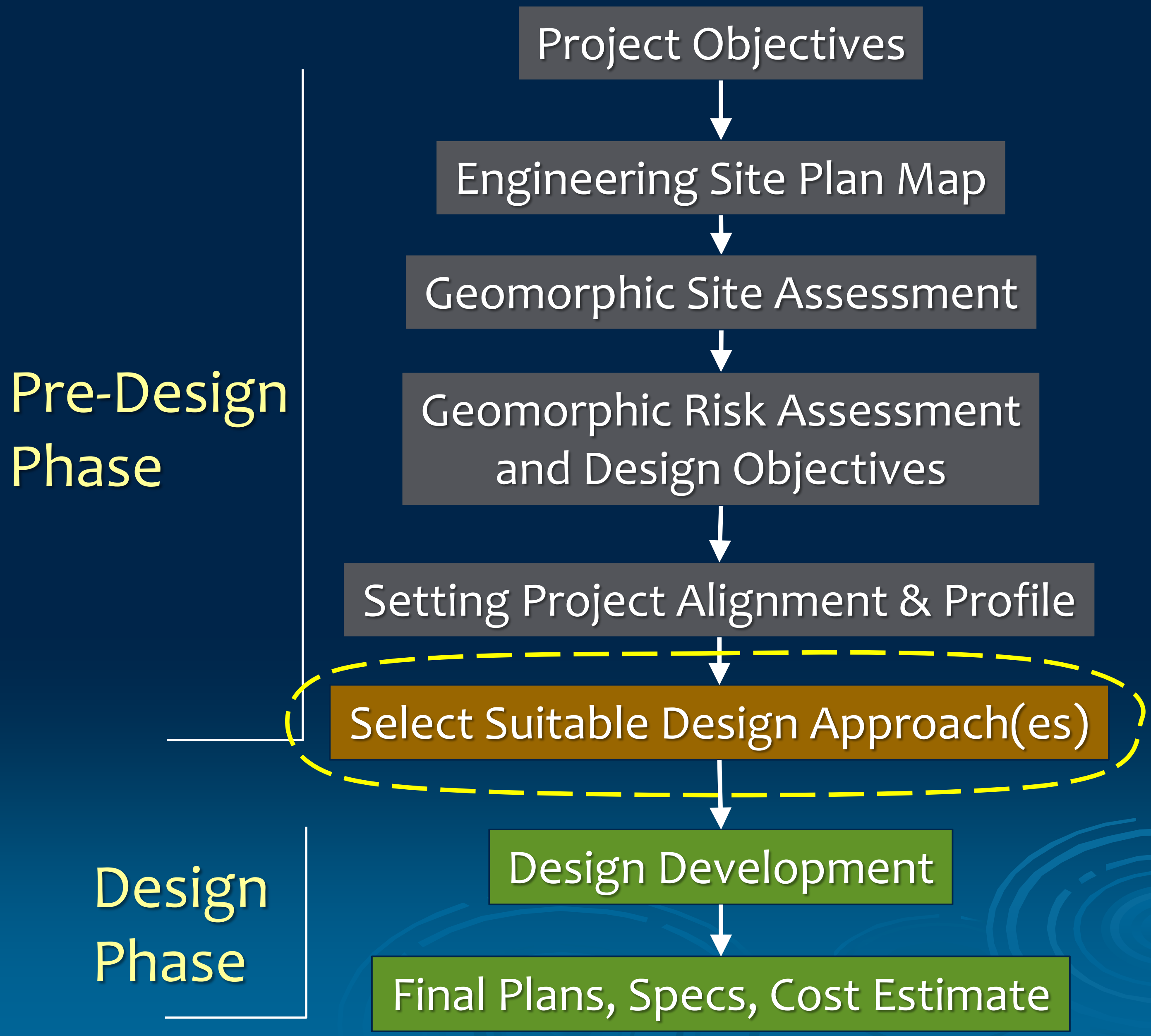


Vertical Adjustment Potential (VAP)

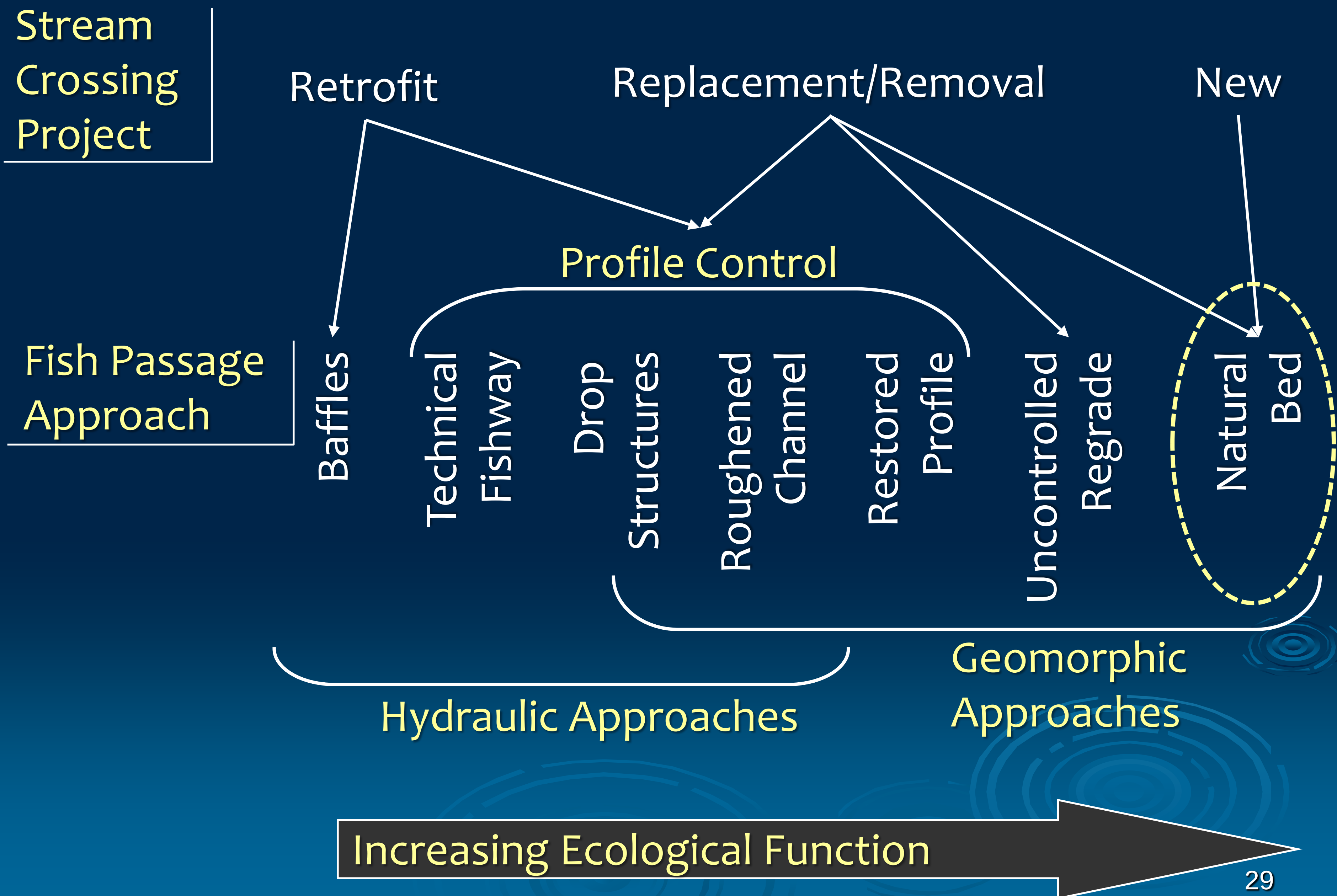
Develop VAP with long profile and field investigations:

- ✓ Channel slopes
- ✓ Stability/mobility of channel type/material
- ✓ Channel controls and anticipated longevity
  [bedrock, large wood, colluvium, hard infrastructure]
- ✓ Knickpoints, evidence of active incision (downcutting) or aggradation
- ✓ Pool scour depths (low VAP)
- ✓ Bankfull and floodplain elevations (high VAP)
- ✓ Historical information (existing invert elev. and slope)

Passage Design Process

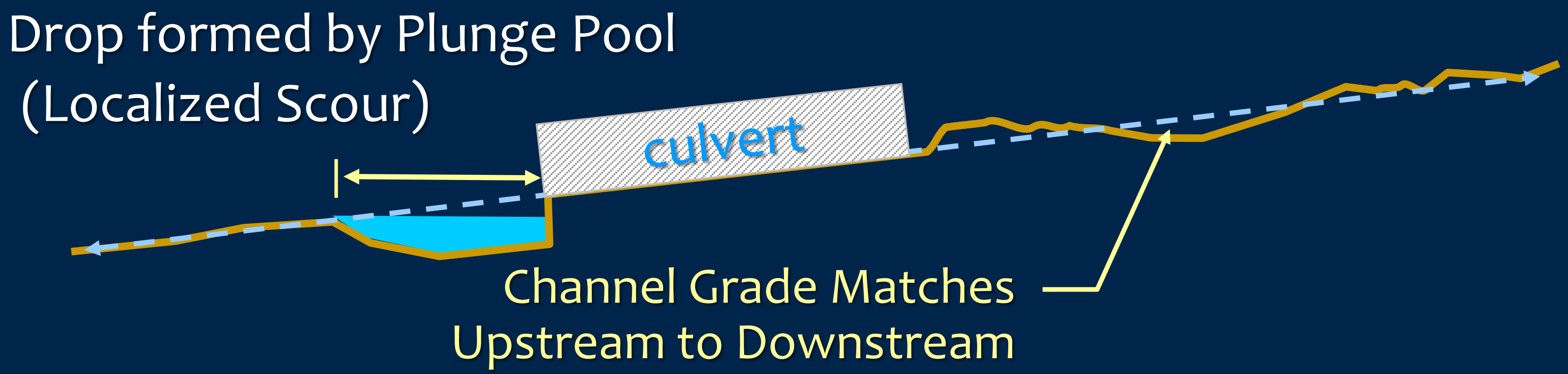


Design Approaches for Aquatic Organism Passage

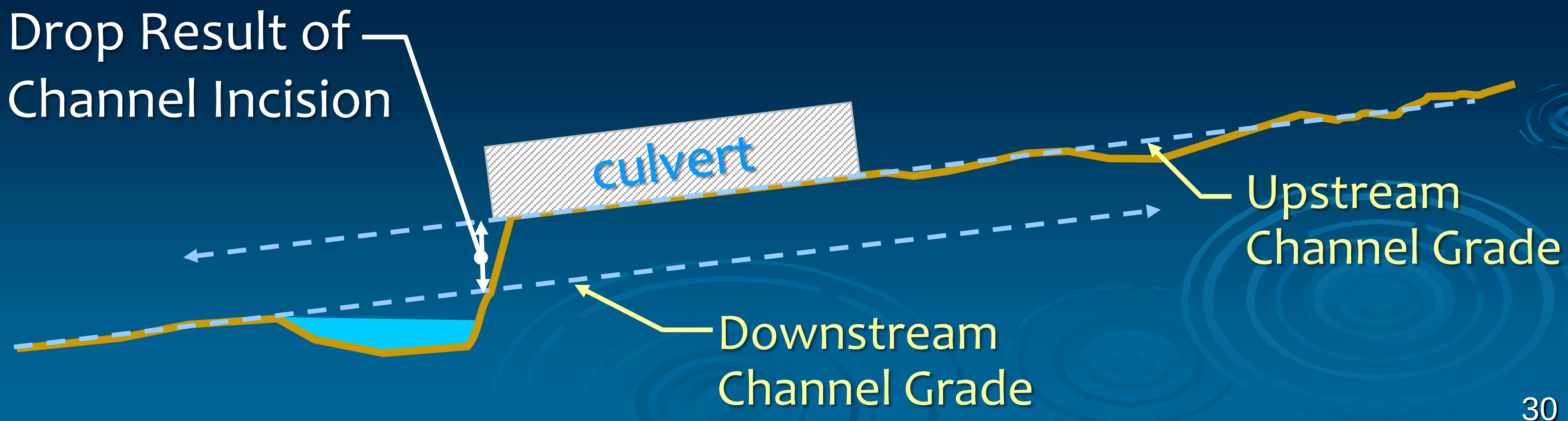


Is Stream Simulation Appropriate?

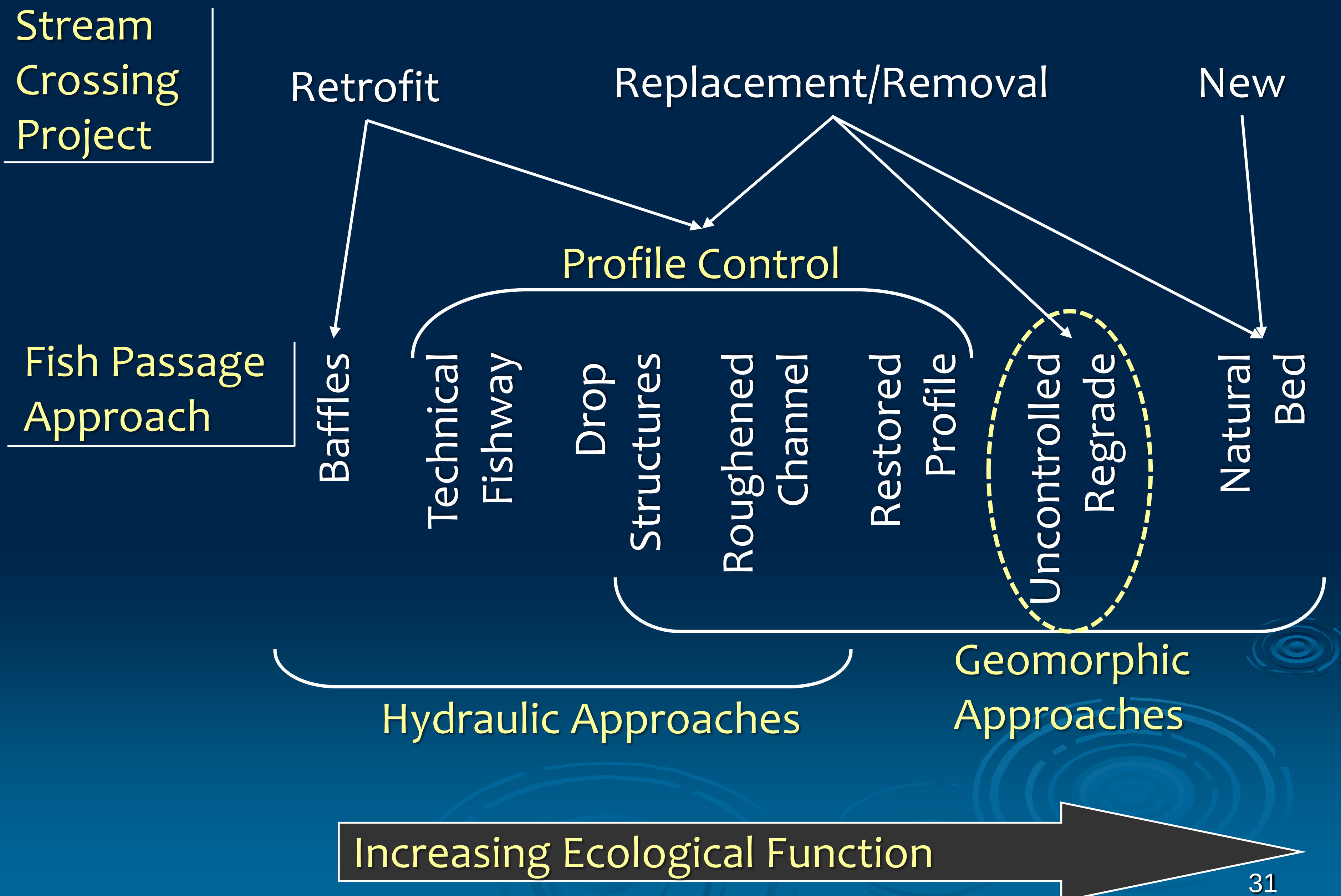
Appropriate



Not Appropriate



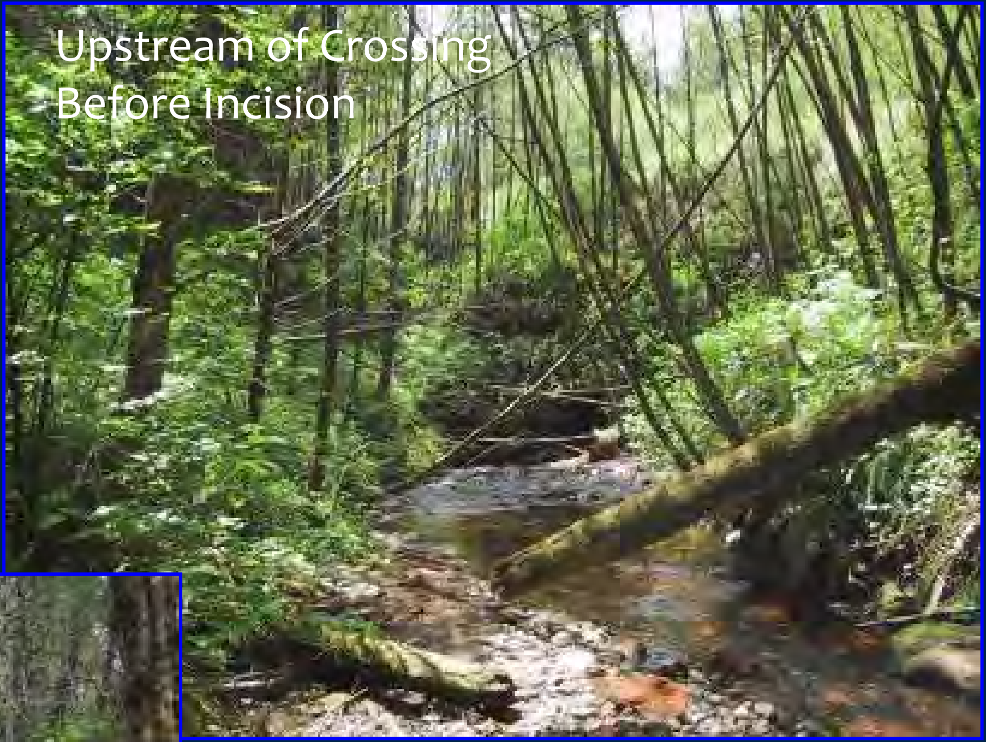
Design Approaches for Aquatic Organism Passage



Uncontrol Regrade

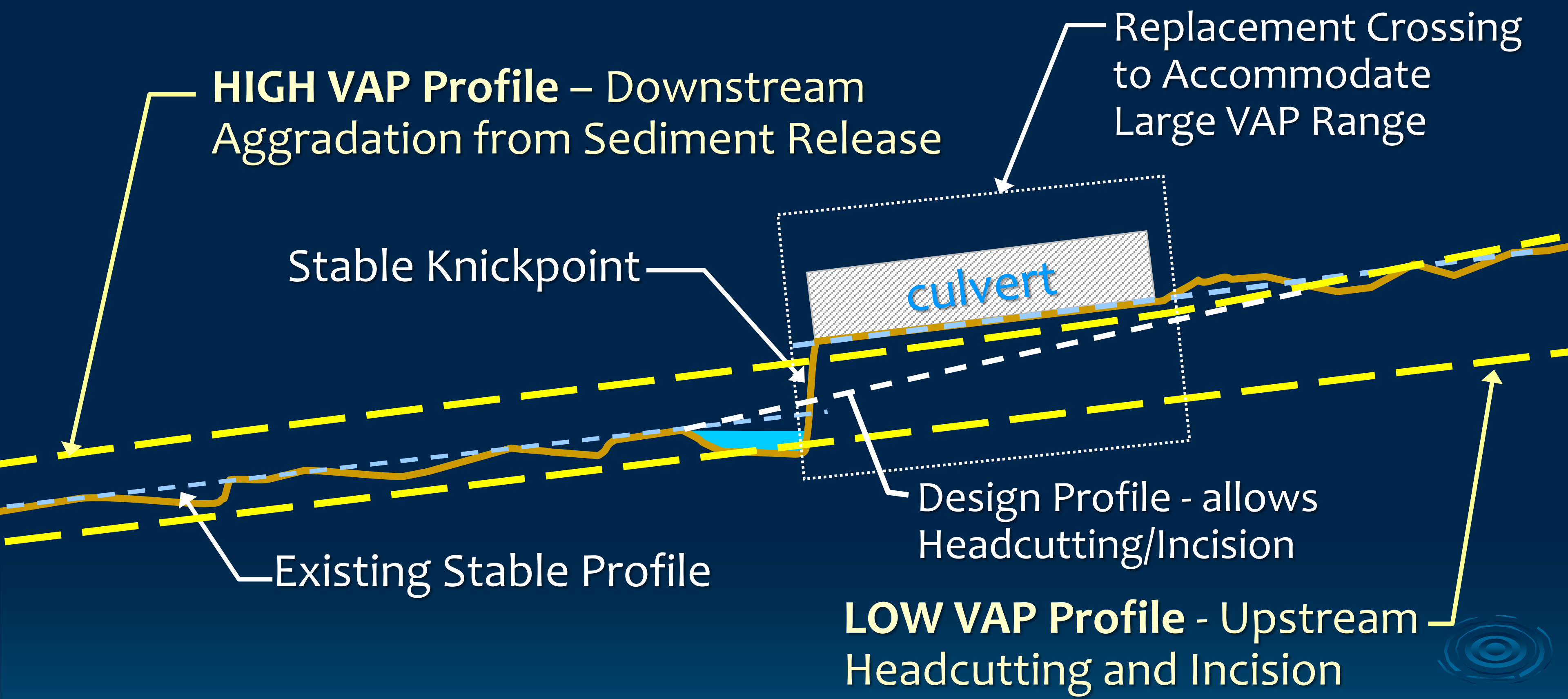
Wynoochee trib – 2002

Channel regraded to bedrock



Example from Kozmo Bates

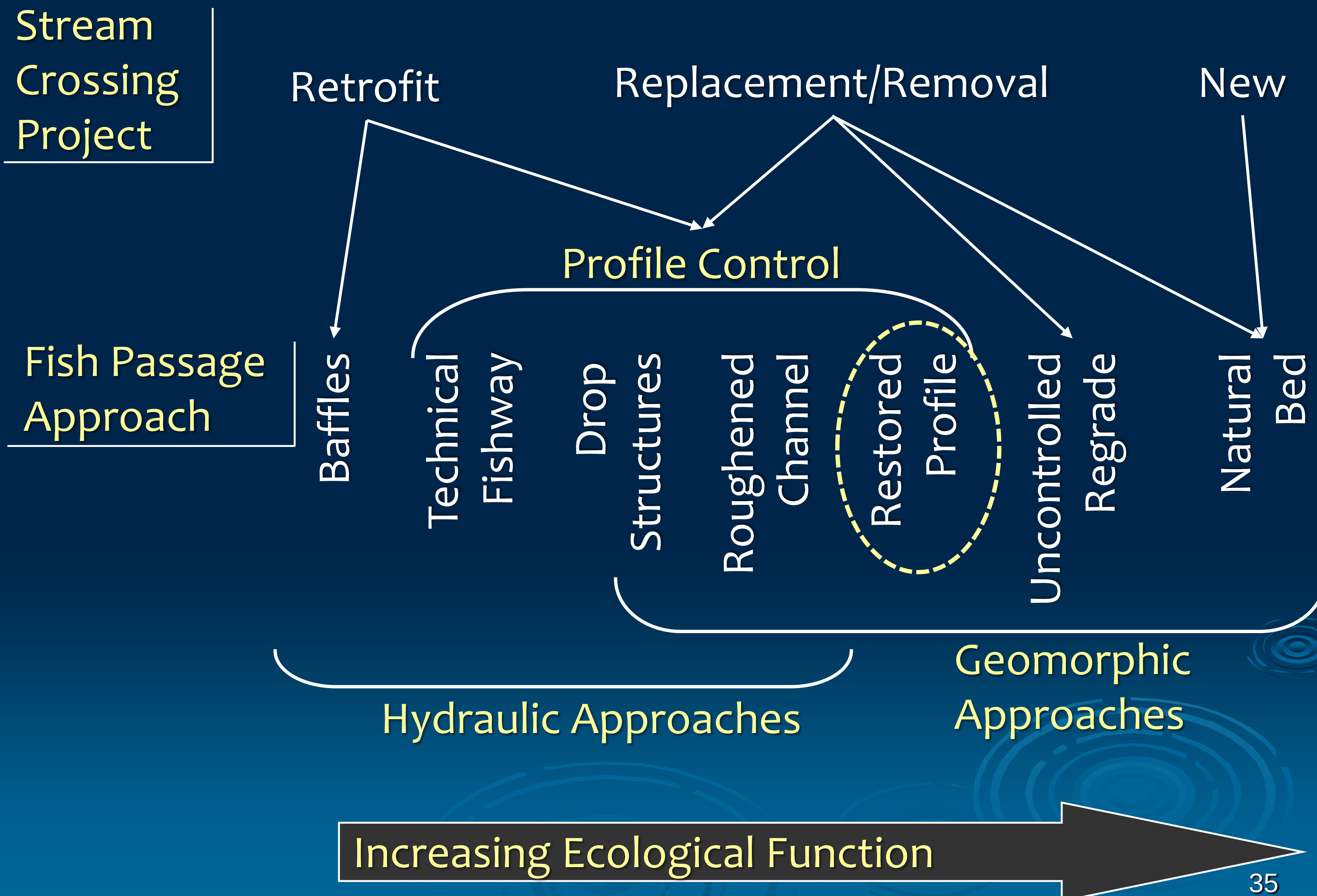
VAP Profiles for Incised Channels
(no grade control – "Uncontrolled Regrade")



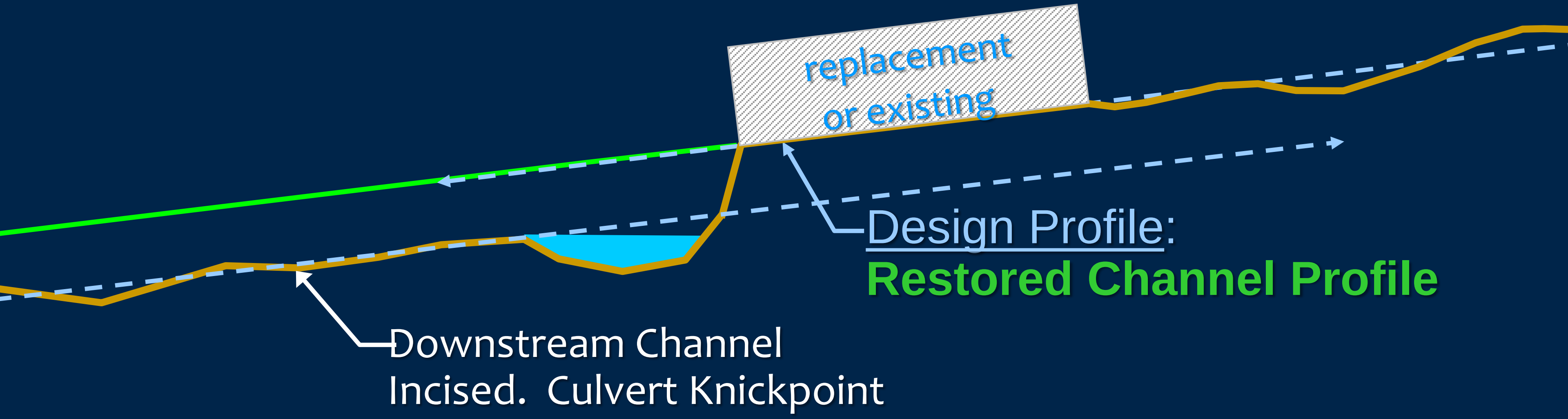
Uncontrolled Regrade – Sediment Slug

Downstream channel overwhelmed by sediment slug from headcut

Design Approaches for Aquatic Organism Passage



Restored Profile Option



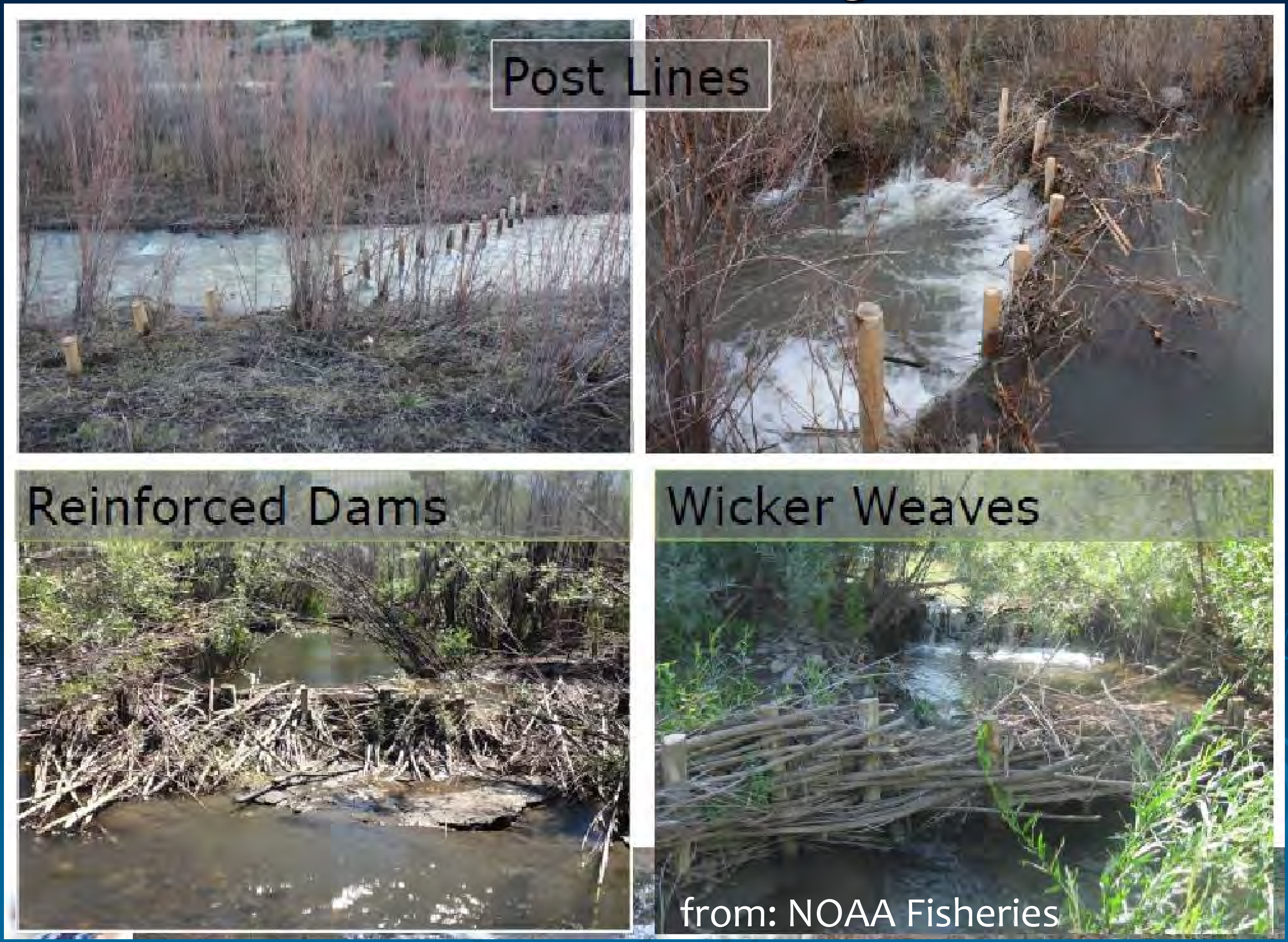
Restoring Incised Channels and Connectivity

Placing Wood - Profile Restoration

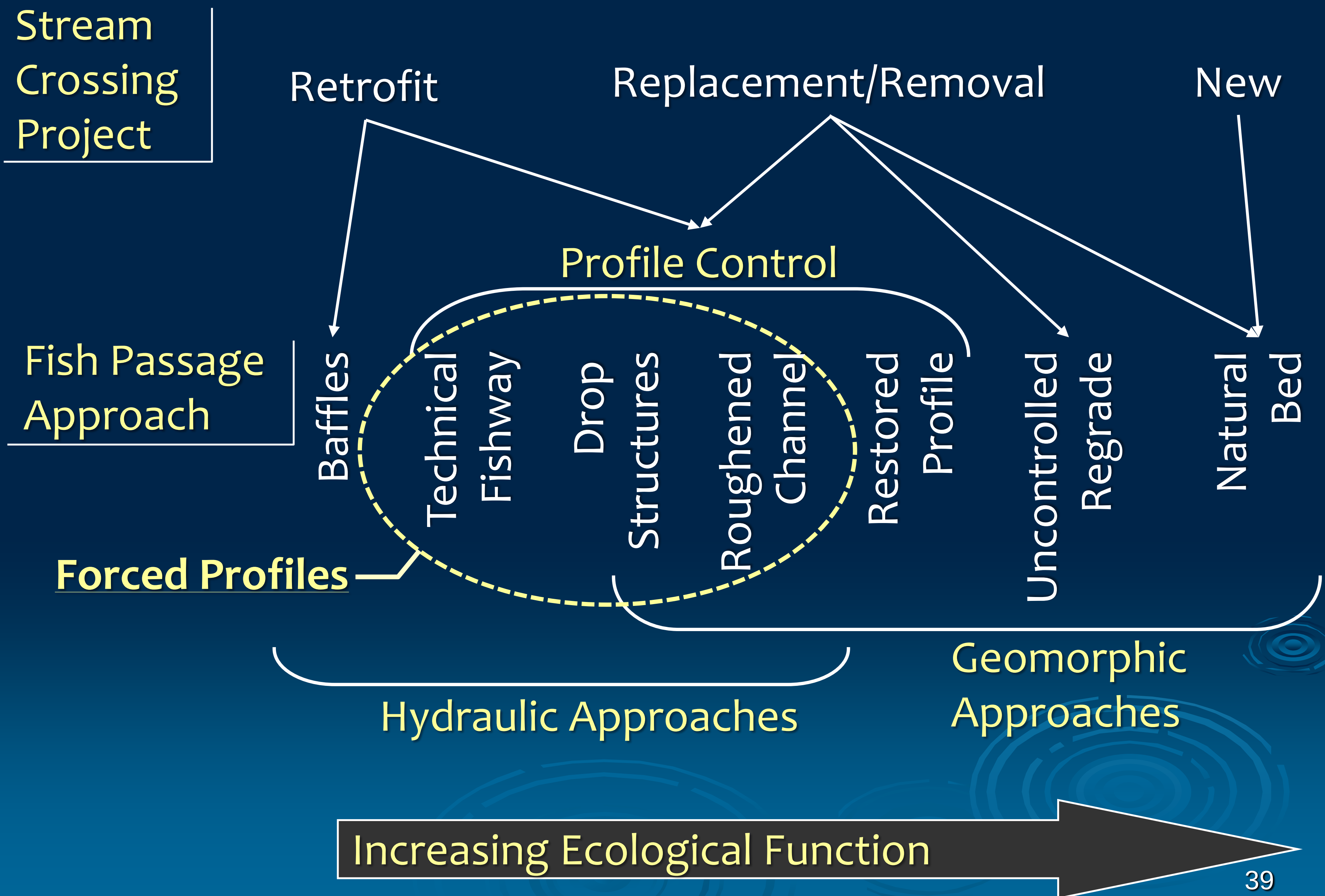
Baker Creek
photos: Sam Flanagan, BLM

Restoring Incised Channels and Connectivity

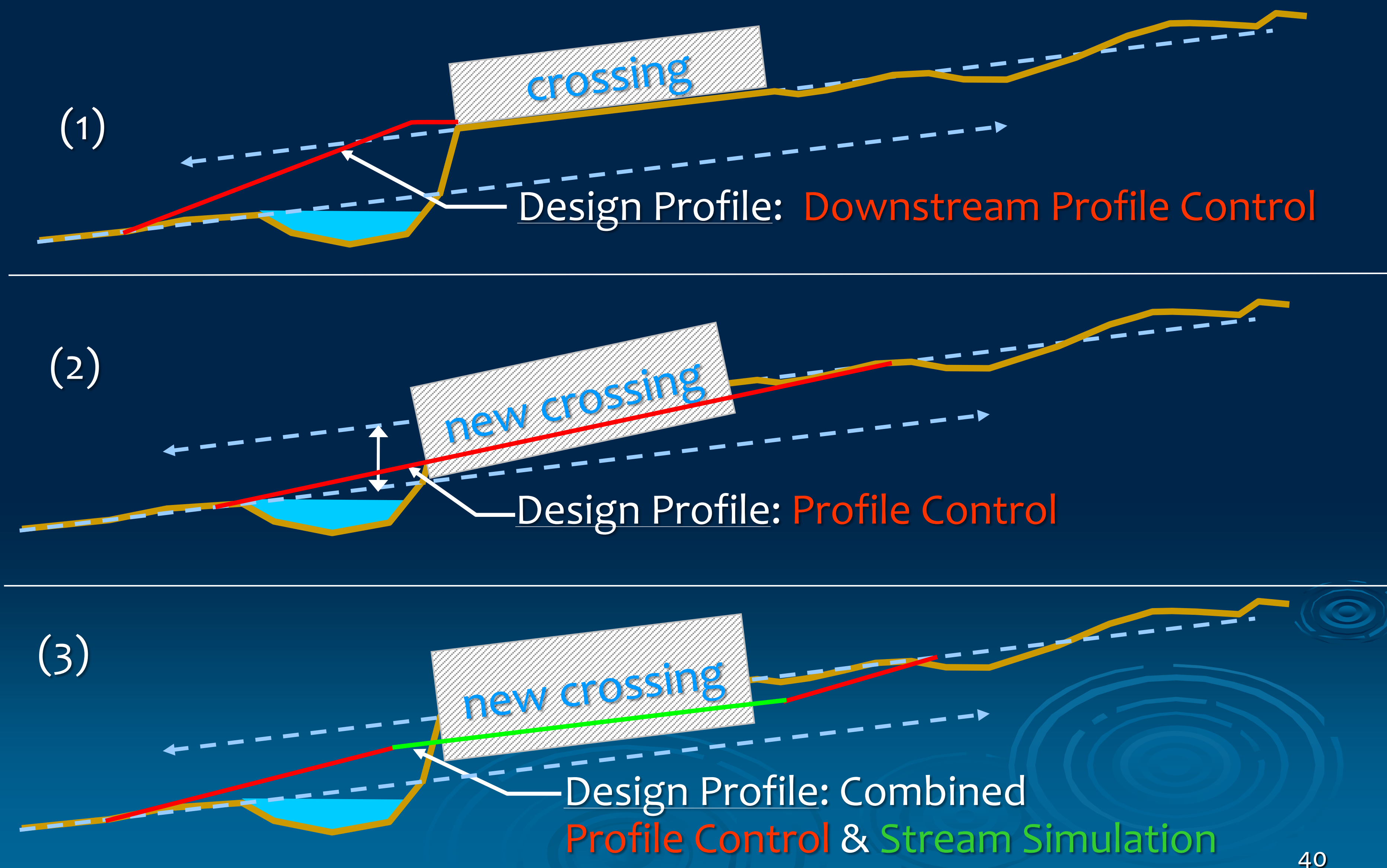
Beaver Dam Analogs



Design Approaches for Aquatic Organism Passage



Forced Profiles



An Uplifting Situation

Stream Simulation Design

A Geomorphic-Based Approach for Aquatic Organism Passage at Road-Stream Crossings

Trib to Big Creek, Tongass National Forest

Michael Love P.E.
Arcata, California
mlove@h2odesigns.com
707-822-2411

Co-developer of course material:

Kozmo Bates P.E.
Olympia, WA

Passage of Aquatic Organisms

Steelhead Trout

Three-Spined Stickleback

Western Pearlshell Mussels

Coastal Cutthroat Trout

Western Pond Turtle

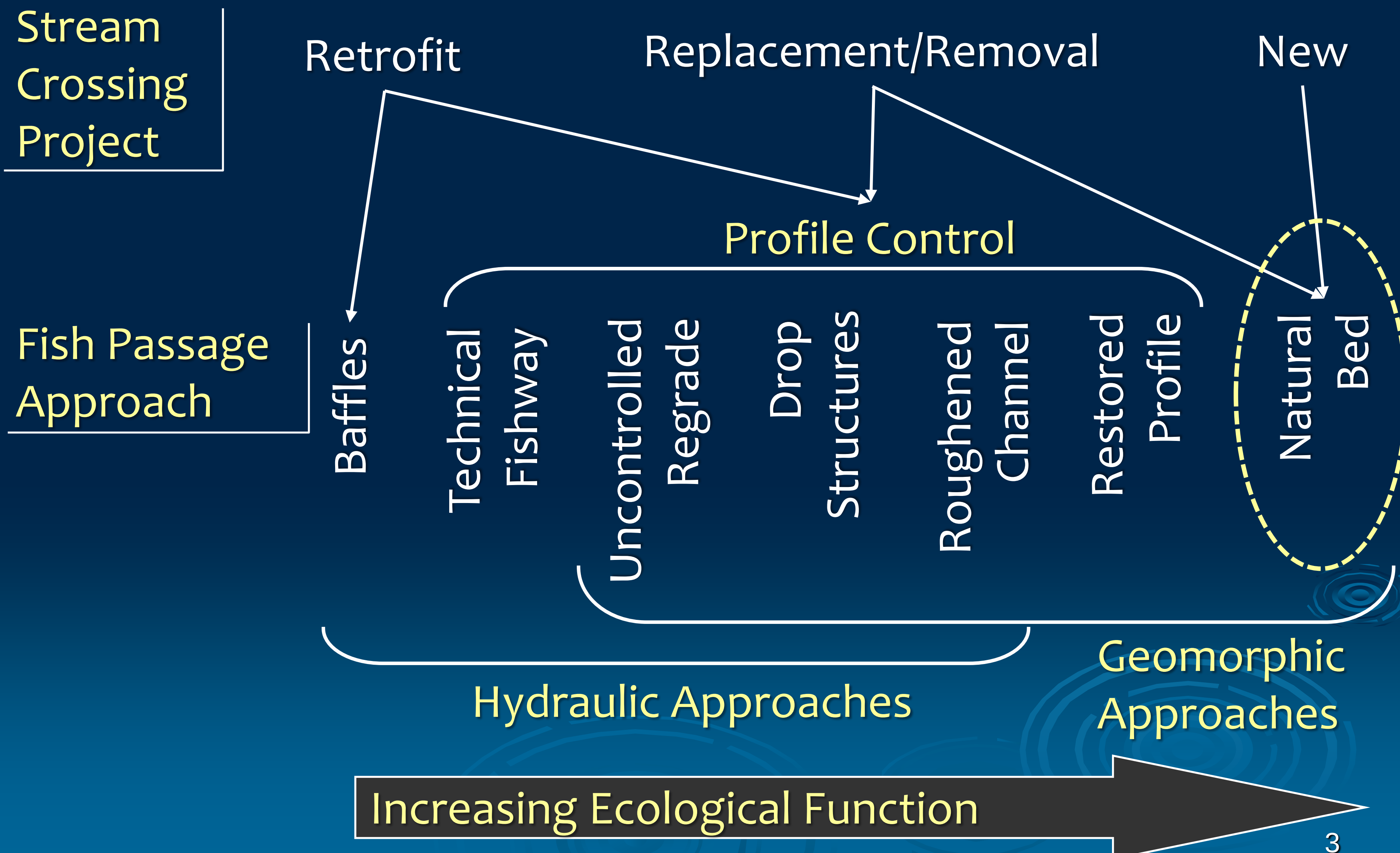
Arroyo Chub

Pacific Lamprey

Prickly Sculpin

Coho Salmon

Design Approaches for Aquatic Organism Passage



Stream Simulation Design Approach for Passage of Aquatic Organisms

"A channel that simulates characteristics of the natural channel will present no more of a challenge to movement of organisms than the natural channel."

Primary Source:

USFS (2008). *Stream simulation: an ecological approach to road stream crossings*

Available at the FishXing website: **FishXing.org**

What is Stream Simulation?

- A Geomorphic Approach to Designing Stream Crossings
- Design Profile Seamlessly Connects Downstream & Upstream Channel Profiles
- Simulate A Natural Channel Reference Reach

- Channel Slope
- Bankfull Cross Section Dimensions
- Channel Structure
    - Channel Bedforms
    - Mobility/Stability
- Grade Forcing Features
- Continuous Banks

Things Stream Simulation does not do within the culvert

- Light (although "sky lights" are included in some long culverts)
- Riparian function
  - Natural bankline – cohesive soil, root structure
  - Food production
  - Flood refuge
  - Passage of larger terrestrial species?
- Lateral channel migration and floodplain processes

Stream Simulation Design Process

Site Characterization

Assess
Stream Simulation Feasibility

Establish Project Profile
and Alignment

Select/Verify reference reach

Bed shape
and material

Structure width,
elevation, details

Mobility / stability

Final design

Site Assessment, Suitability

Suitability for a stream crossing?

- Channel stability
  - aggrading, alluvial fan, incising
- Debris flows
- Size of channel

~~Stream Simulation~~

Wetland Crossings Unsuitable for Stream Simulation

Yontocket Slough

- Large culvert embedded below slough bottom
- Hydraulic Design (maintain low velocities for juvenile salmon)
- Encourage fine-grain material to deposit along bottom of culvert

Suitable for Stream Simulation

- Rock, sediment dominated
- Channel is in equilibrium

Stream Simulation Design Process

Site Characterization

↓

Assessment
Stream simulation feasibility

↓

Establish Project Profile

↓

Select/Verify reference reach

↓

Bed shape
and material

↓

Structure width,
elevation, details

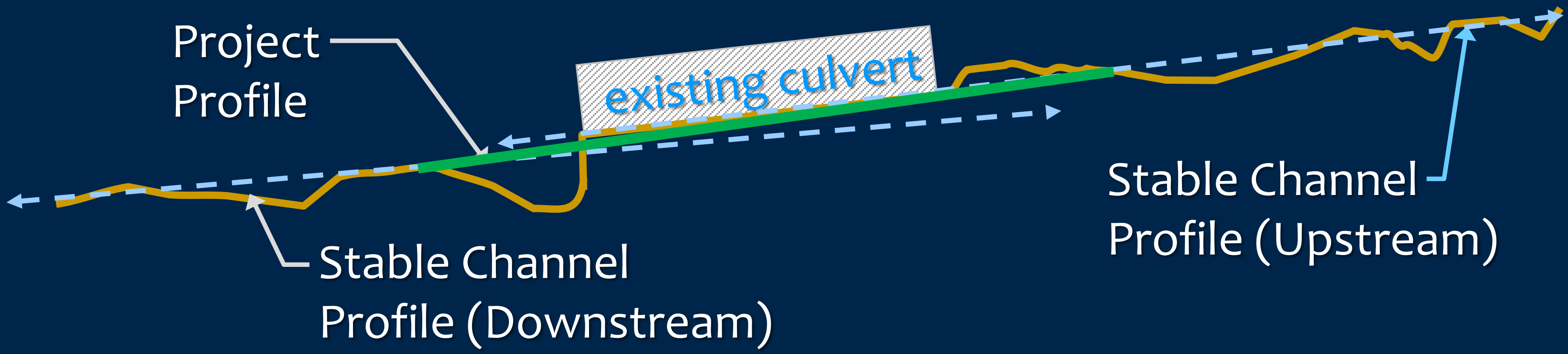
↓

Mobility / stability

↓

Final design

Stream Simulation Project Profile within 25% of Stable Channel Slope

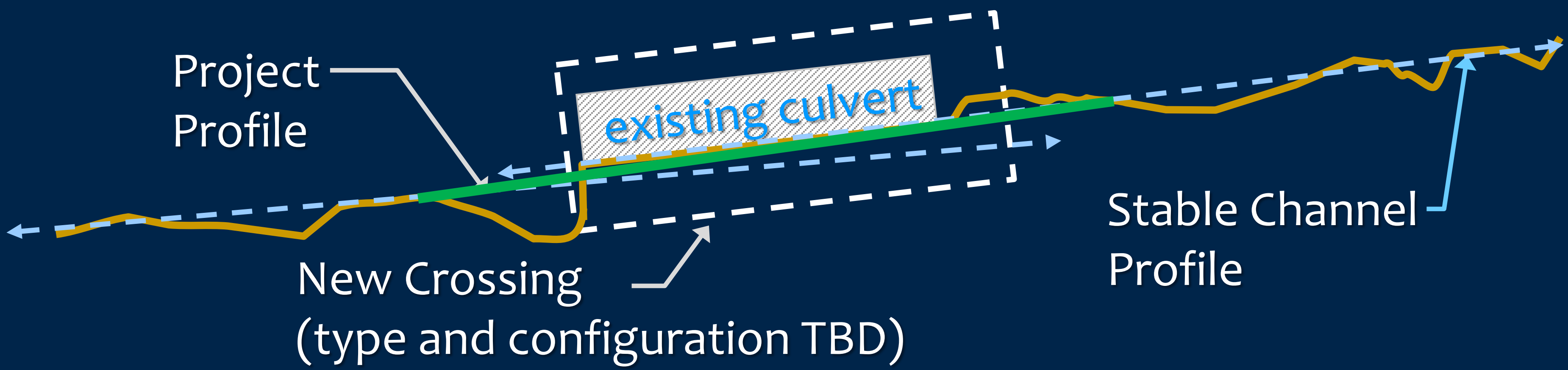


Stream Simulation Guidance:

Project Profile should not exceed 1.25*Stable Channel Profile

If steeper, will need to use profile control

Selecting a Reference Reach based on the Project Profile



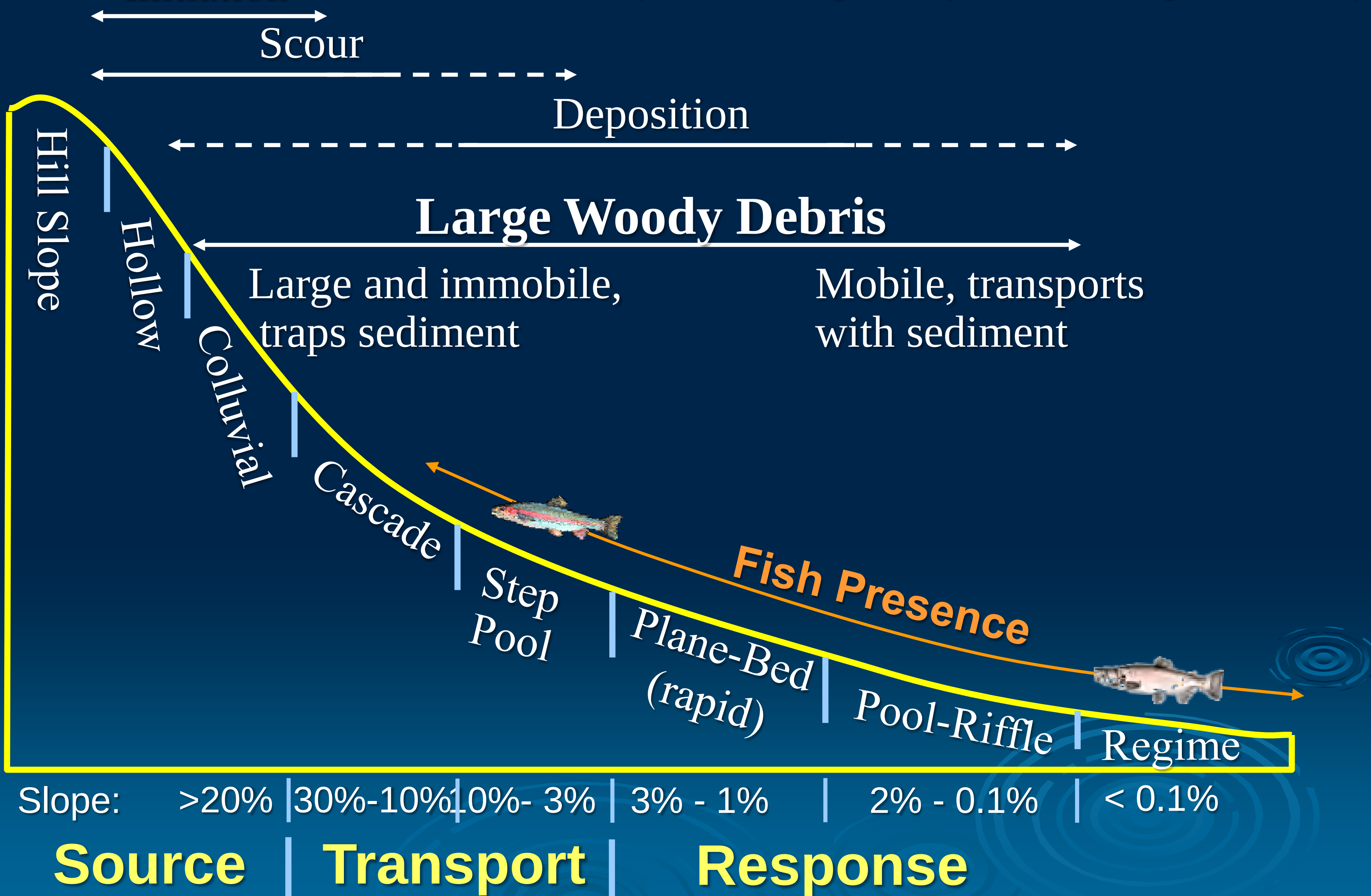
- **Reference Reach Slope within 25% of Project Design Slope**
  Project Profile = 2%, select Reference Reach with Slope between 1.5% and 2.5%
- **Reference reach beyond existing crossing influence**
- **Upstream of crossing typically best**
  - Represents what's delivered to crossing
  - Avoid going upstream of tributary inputs
  - Should be similar channel type as found adjacent to crossing

Characterizing the Reference Reach

- **Thalweg Profile** through reach, elevations tied to project site.
- **Cross-Sections** located through features (riffles, pools, cascades…).
- **Pebble Count**(s) to characterize bed composition.
- **Site Map** identifying roughness elements, bed and bank features, and locations of cross-sections/ pebble counts.

Generalized Stream Classification

(from Montgomery and Buffington, 1993)



Stream Simulation Design Process

Site Characterization

↓

Assessment
Stream simulation feasibility

↓

Establish Project Profile

↓

Select/Verify reference reach

↓

Bed shape
and material

↓

Structure width,
elevation, details

↓

Mobility / stability

↓

Final design

Bed Design Objectives

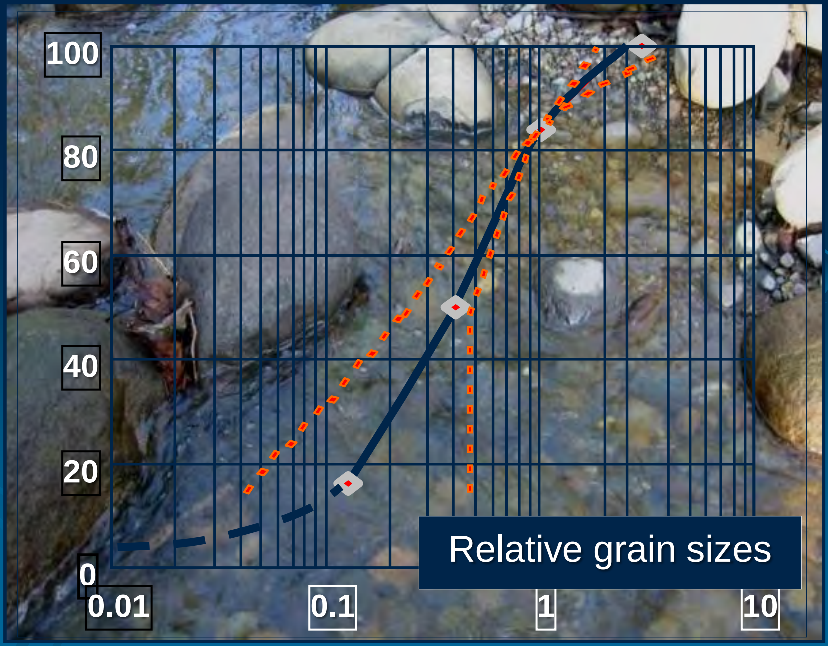
Simulate natural bed

- Bed shapes
- Diversity & Roughness
- Mobility/Stability
- Forcing features
- Control of permeability

Bed Material Design – Alluvial

Based on Reference reach Gradation:

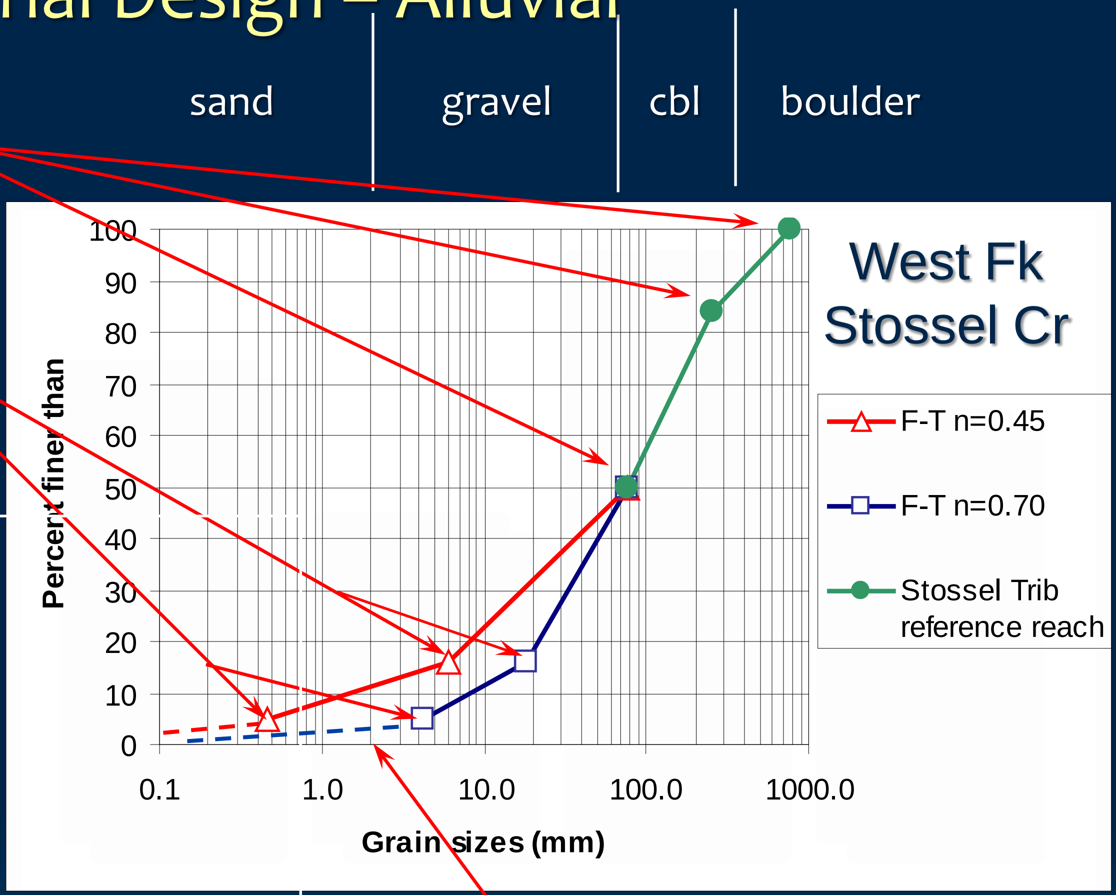
- Pebble count of reference channel for D_{100}, D_{84} and D_{50}
- Include dense gradation based on D50 for smaller material and impermeability.
- Fine-grained beds are special cases.
- Compensate for stability of initial disturbed condition.
- Account for large roughness and forcing features.



Bed Material Design – Alluvial

Larger particles sized directly from reference channel

Small grains derived by Fuller-Thompson (1907) curve based on D_{50}



Verify 5% to 10% are fines (<2mm)

Fuller-Thompson Equation:

$$P = \left[\frac{d}{D_{Max}} \right]^n$$

P = percent finer

d = diameter of particle

n = Fuller-Thompson density; varies 0.45 to 0.70

Modified to: **$D30 = 0.60^{1/n} \times D50$**

$D16 = 0.32^{1/n} \times D50$

$D5 = 0.10^{1/n} \times D50$

Bed Material Example

W Fk Stossel Cr

	Reference	Strm Sim	Fuller-Thompson n=0.64	
D100	30”	30”		
D84	10”	10”		
D50	3”	3”	3”	
D30			1.4”	$= 0.6^{1/n} \times D50$
D16			0.5”	$= 0.32^{1/n} \times D50$
D5			0.08”	$= 0.10^{1/n} \times D50$

Which is: 50% cobble and boulder

45% gravel

5% fines less than 2 mm (sands/slits/clays)

Bed Material Example

W Fk Stossel Cr – 6.4% slope

- 1 scoop bank run fines
- 4 scoops 4" minus river run
- 4 scoops 8" minus cobbles (or quarry spalls)
- 2 scoops 1.5' minus rock
- 1.5 to 2.5 foot rock added during installation

Stream Bank Diversity

Ore Creek, Oregon
From USFS, 2006

Bed Design by M&B* Channel Types

Based on channel type of reference reach

Increasing slope
Decreasing mobility

- Dune-ripple;
  construct or recruit
- Pool-riffle / Plane-bed;
  construct and let form develop
- Step-pool, forced channels;
  construct steps
- Cascades;
  construct cascades
- Bedrock
- Clay

* Montgomery and Buffington, 1997

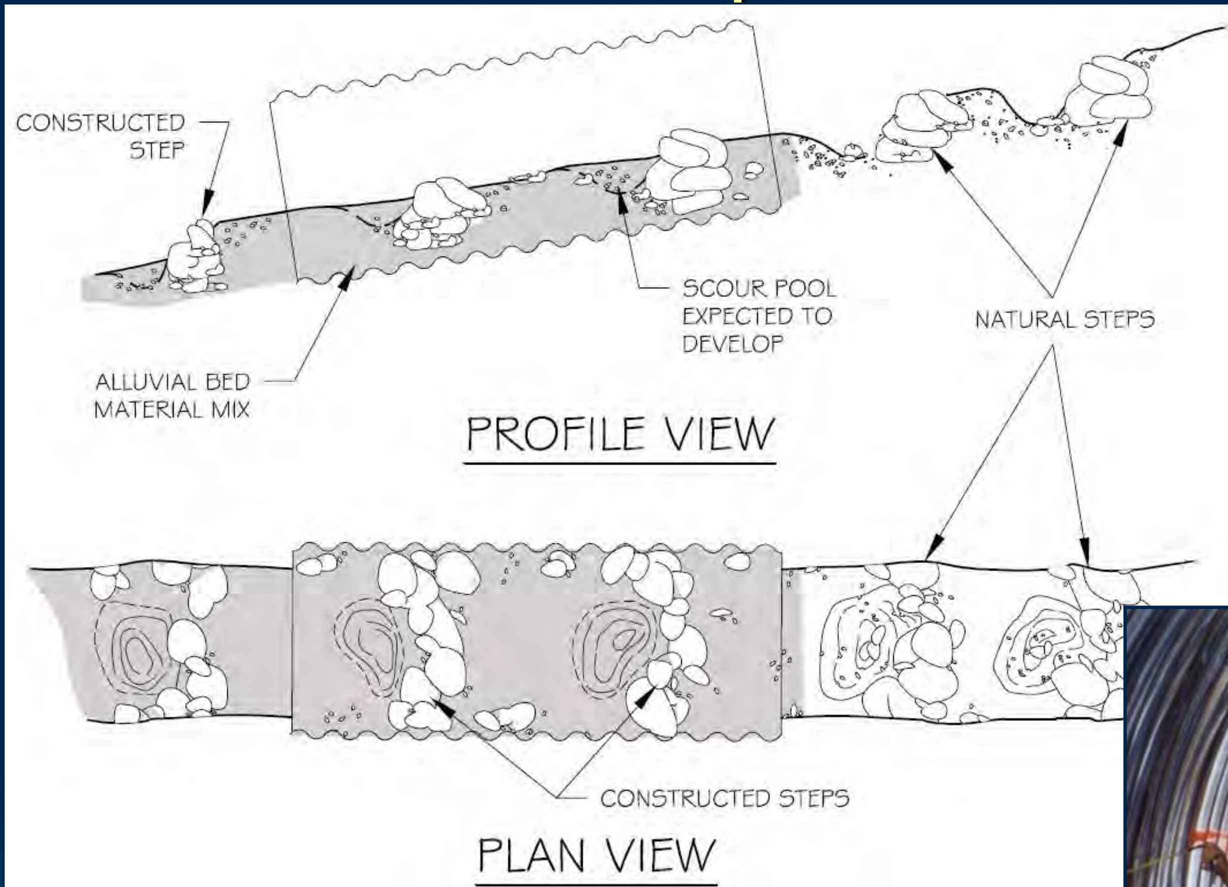
Boulder Plain-Bed Channel

< Reference Reach

Stream Simulation
Channel and Bridge
Crossing

Fort Goff Creek
Highway 96

Step Pool Channels



- Simulate boulder step-pools
- Simulate wood-forced step pools
- Generally considered a "stable" bed form

- Rock in steps sized to be immobile at design event (i.e. Q100)
- Design process becomes similar to roughened channel

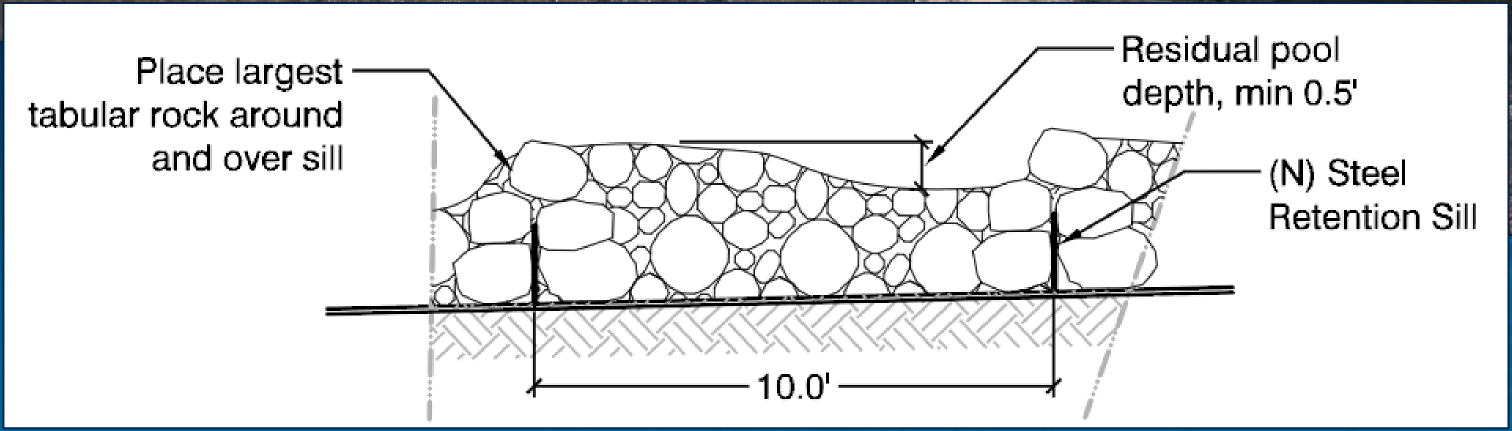
Bed Retention Sills

- Purpose: Retain bed material
- They are not baffles or weirs
- Recommended top of sill set below Low VAP Profile
- Debatable value:
  - Anchors bed; keeps bed from sliding out of culvert
  - Anchors bed steps
  - Helps limit subsurface flow
  - Safety factor for steep slopes
  - May conflict with stream processes
  - NOT FOR LOW-GRADIENT CHANNELS

Step Pool Channels

Gulch 7 Step-Pool Channel

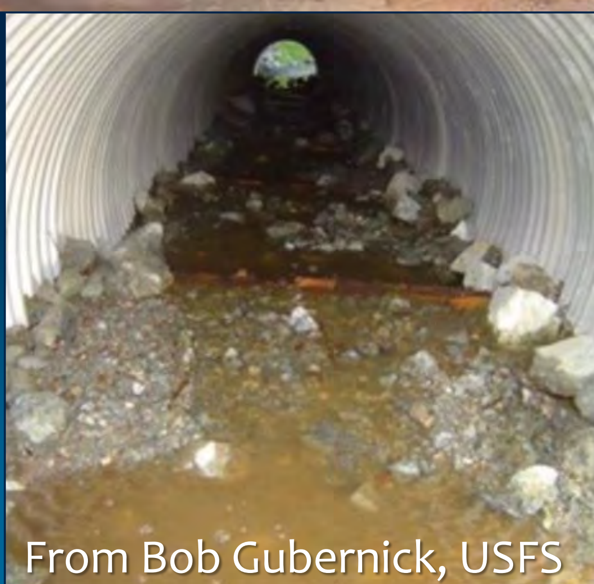
- Slope = 6%
- Step Spacing = 10 feet
- Bed Retention Sills



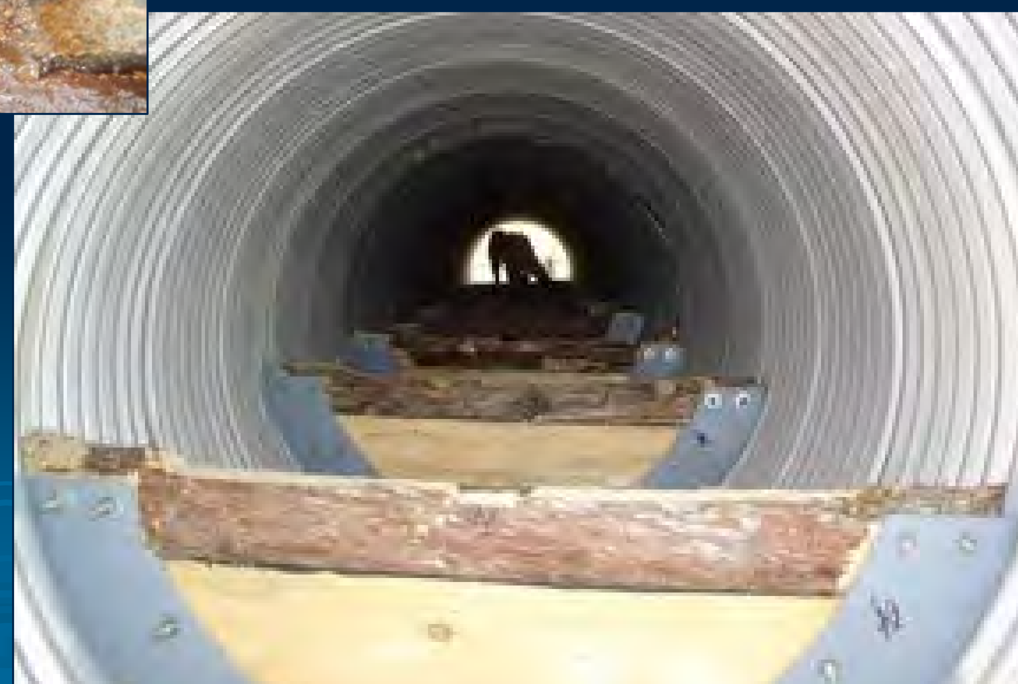
Wood Steps-Pool Channels

Tongass NF, AK

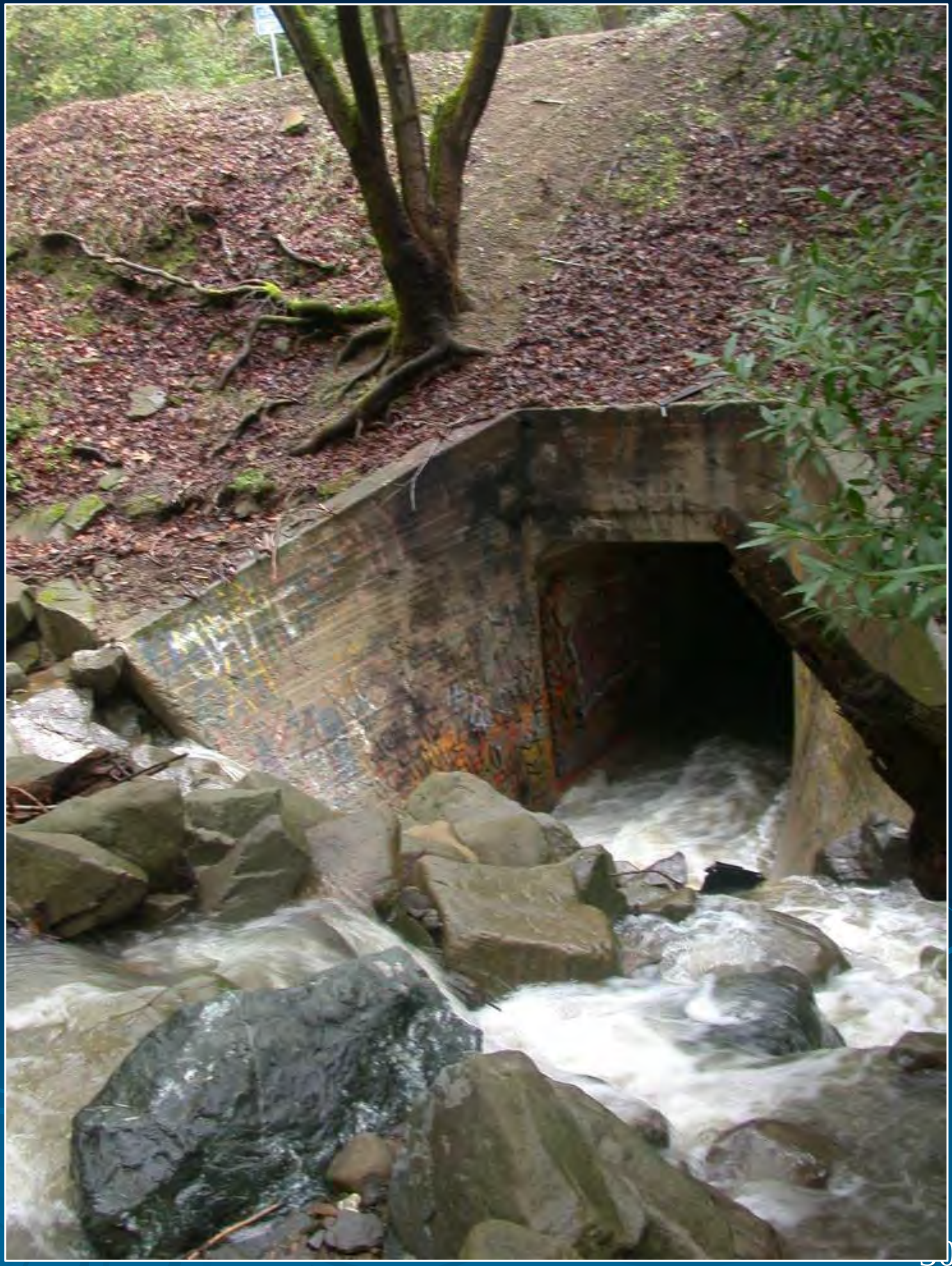
- Slope = 11%
- Used Cedar planks and "brow" logs for crests
- Filled with bed material to for sediment transport continuity
- Still functioning after 14-years



From Bob Gubernick, USFS



Stonybrook Canyon Cascade-Step-Pool



Boulder Channel Aggraded ~10 feet Upstream of Plugged Culvert.

Stonybrook Canyon Cascade-Step-Pool

Existing Cascade (Reference Reach)

Constructed Cascade

Constructed Cascade

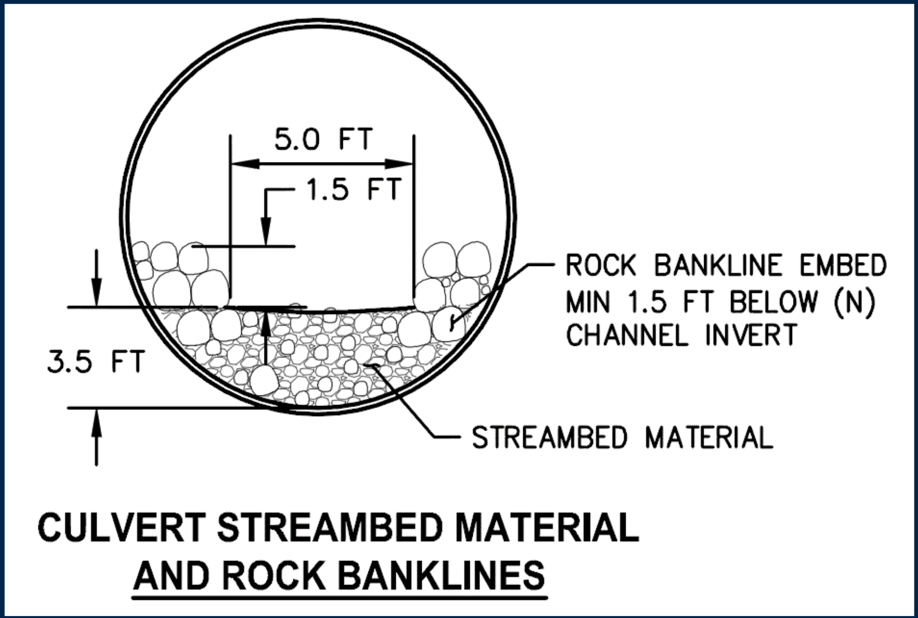
Restoration of Aggraded Channel Upstream of Plugged Box Culvert

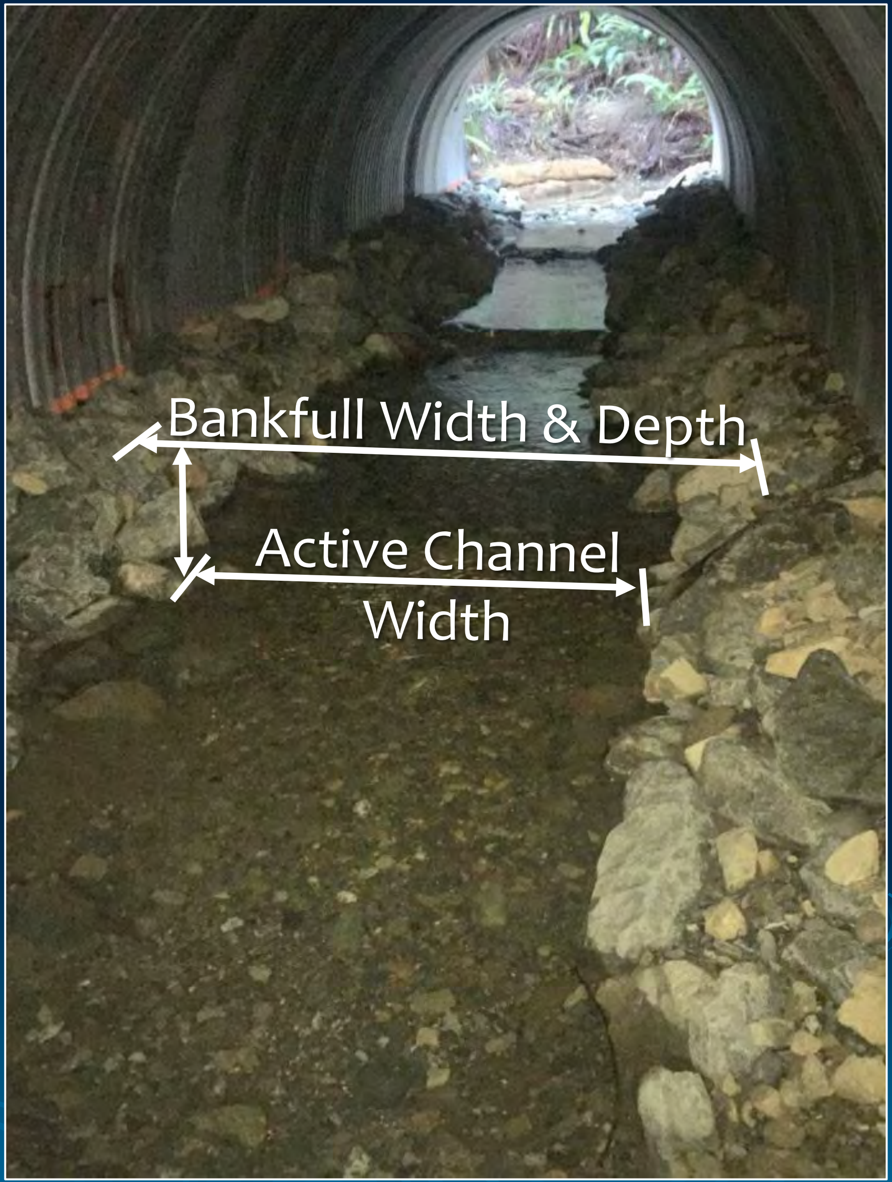
Stream Simulation without Banks

Thalweg Trenching against Culvert Wall

Wetted Channel
Over-widened and Shallow

Continuous Banklines



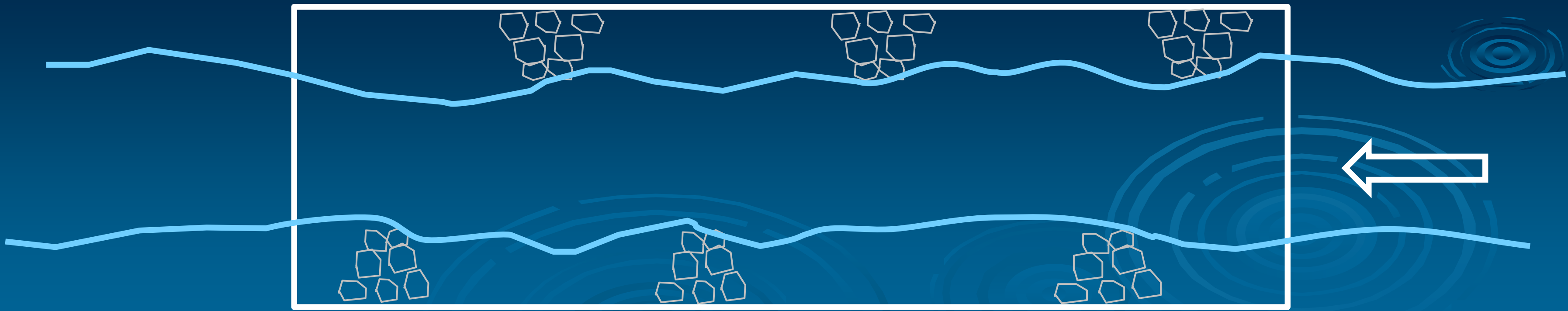


- Defines channel shape
- Edge diversity
- Terrestrial pathway
- Rock sized for stability (ie Q100)
- Fill voids with smaller material

Rock Clusters for Channel Margins

Rock Clusters

- Add bed diversity
- Prevents trenching
- Simulates bank irregularities in ref. reach (woody debris, rootwads, bedrock outcrops)
- Sized to be stable (i.e. 100-year flow)
- Often sized using riprap sizing equations
- **May better accommodates downcutting (low VAP) than continuous banklines**



Last thoughts on bed material

- Mobility is a key to design of bed
- Carefully select and supervise source, mixing, and placement
- May mitigate the “mess” by placing washed gravel over top
- Round vs angular rock?
- Does it meet project objective?

Stream Simulation Design Process

Site Characterization

↓

Assessment

Stream simulation feasibility

↓

Establish Project Profile

↓

Select/Verify reference reach

↓

Bed shape

and material

↓

Structure width,

elevation, details

↓

Mobility / stability

↓

Final design

Crossing Elevation and Height

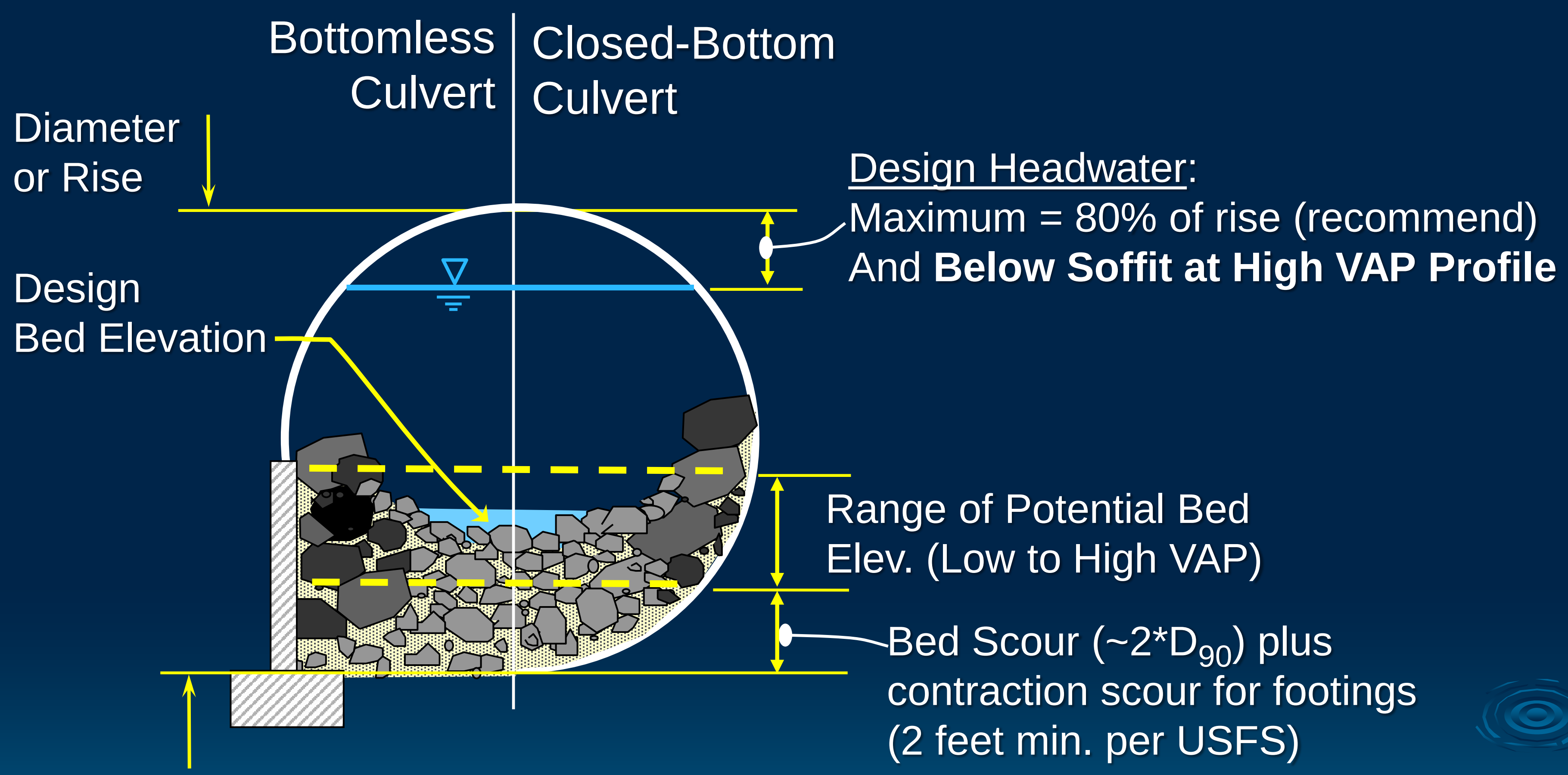
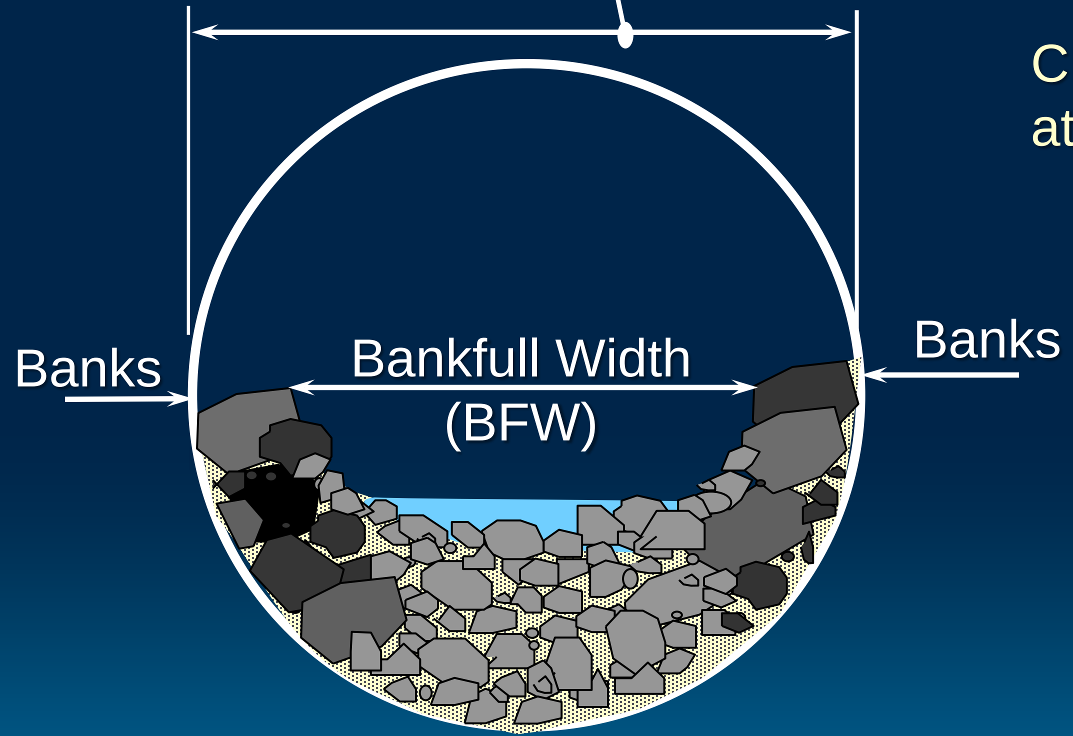


Photo: Kozmo Bates

Stream Simulation
First Estimate of Crossing Width

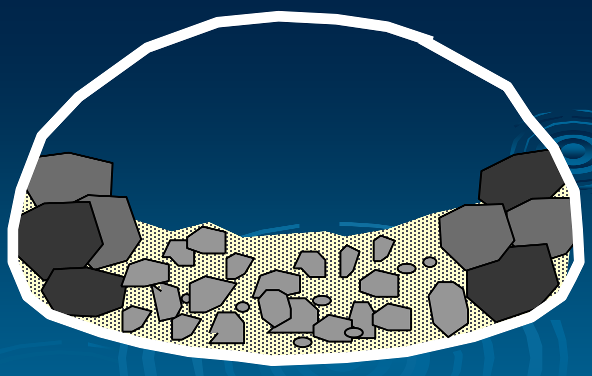
First estimate:
Culvert width to fit over channel banks/margins



Often Applied Criteria:

Min. Crossing Width = 1.2*BFW

Chanel Width must be provided at Bankfull Depth



Stream Simulation Culvert Sizing

1. Based on Project Objectives:

- Passage of aquatic, non-aquatic species
- Bed sustainability and stability
- Hydraulic capacity of the culvert
- Risk of blockage by floating debris or beaver activity
- Construction, repair, and maintenance needs
- Meandering channel pattern part of project objectives
- Protection of floodplain habitats

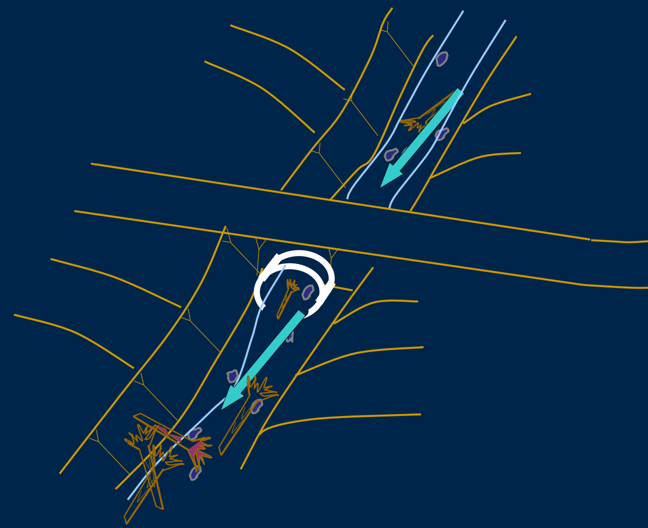
Stream Simulation Crossing Sizing

2. Based on Site Conditions:

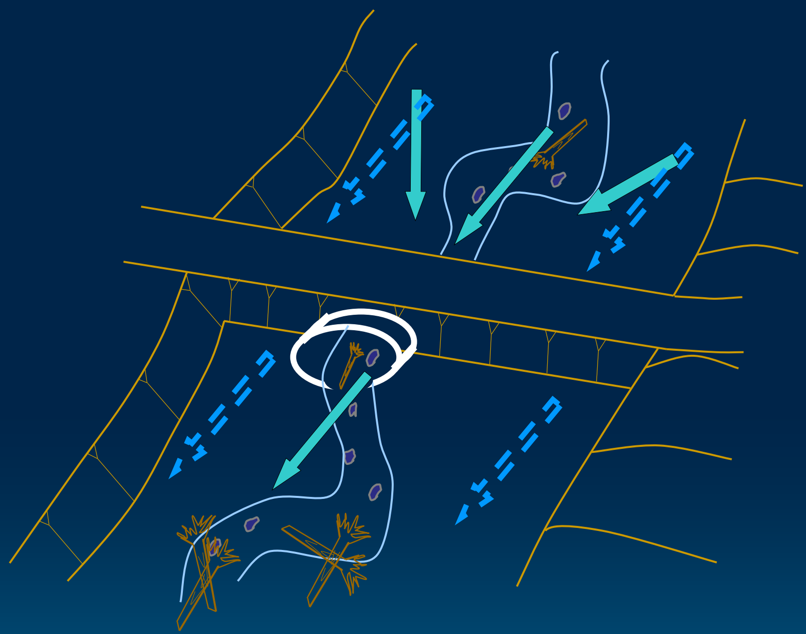
- Expected future channel width (incised channel widening)
- Channel skew with road crossing
- Large bed material relative to culvert width (D100$\leq$0.33*Width)

"Widening streams make for ugly bridges"

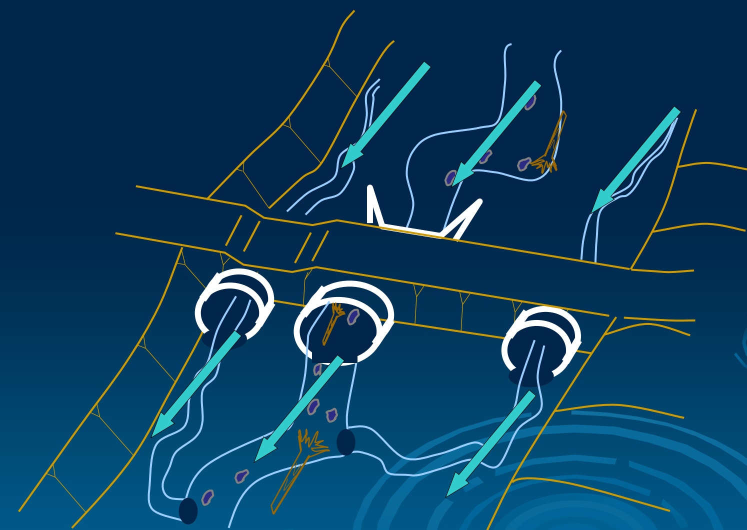
Stream Simulation
Culvert Width



a. Confined



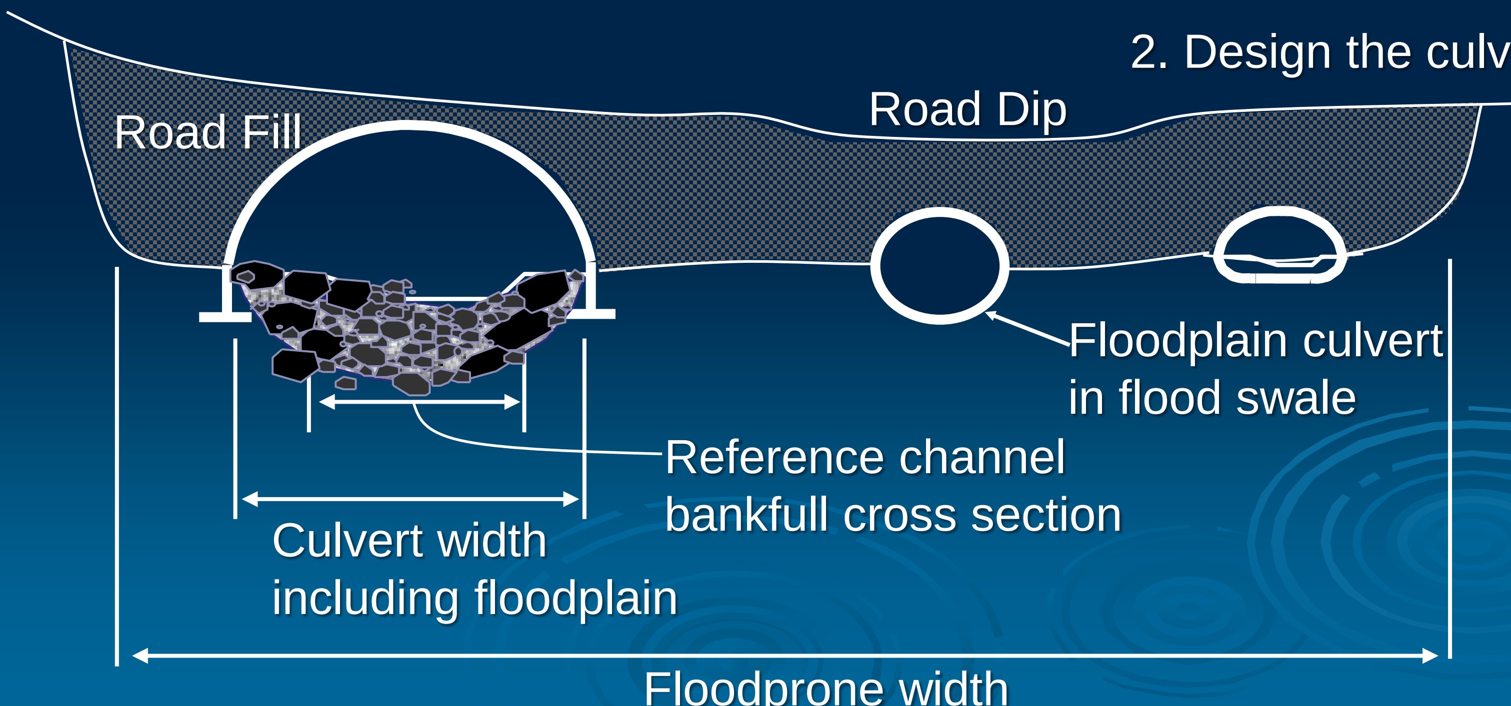
b. Unconfined
with wider culvert



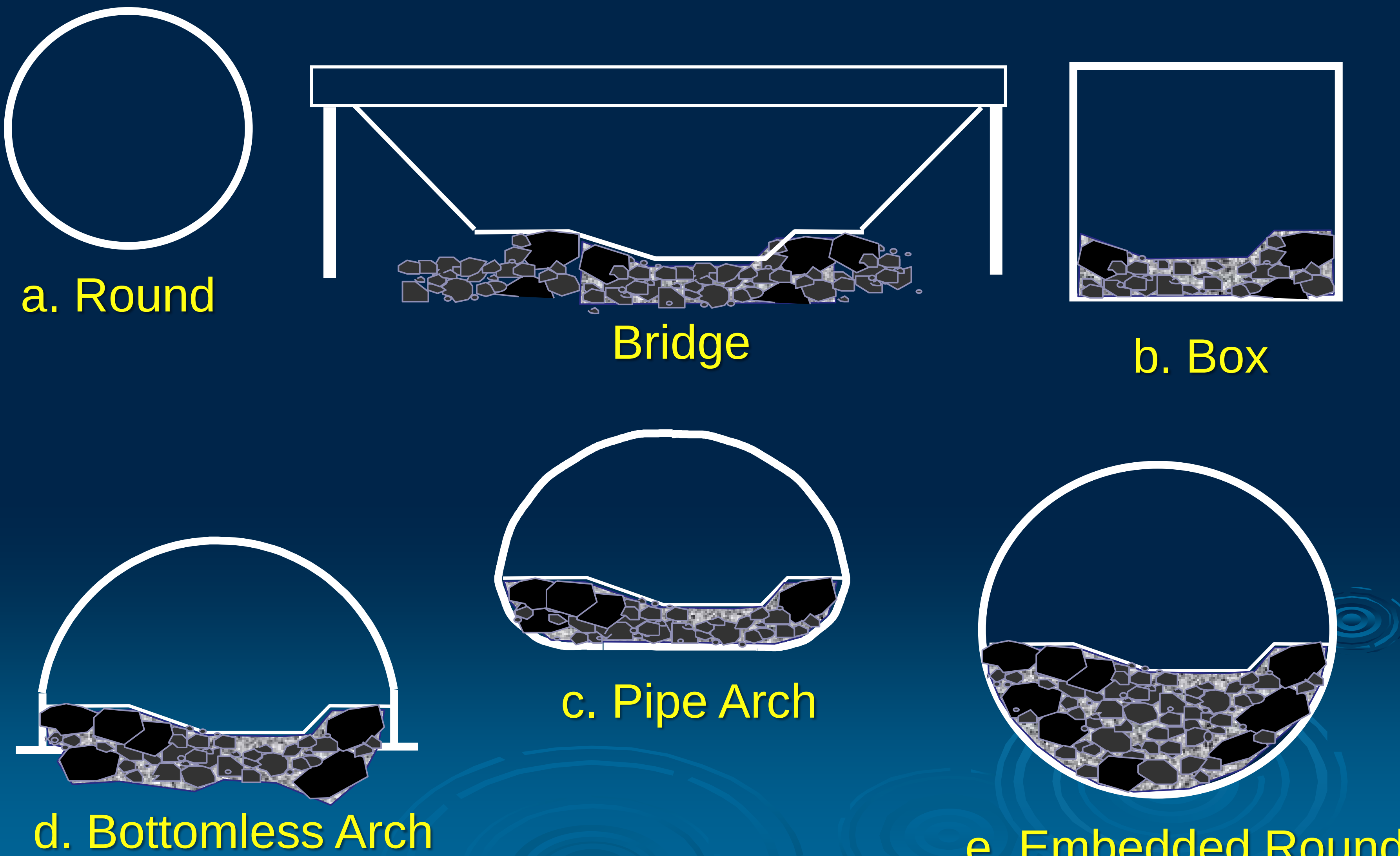
c. Unconfined
with floodplain culverts

1. Design the channel and floodplain

2. Design the culvert to fit



Crossing Types



Bottomless Crossing

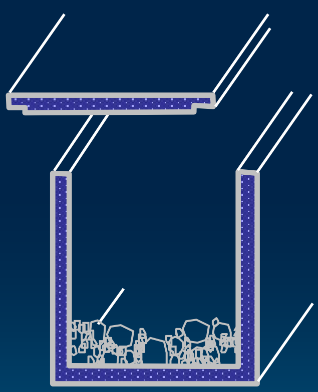
Compared to Closed Bottom Culverts

- Can be placed over existing streambed or top loaded
- Can be placed over bedrock channels
- Footings can be shaped to bedrock.
- Concrete stemwall/abutment provides durability against abrasion and corrosion
- High shear strength of bed reduces risk of bed failure (no bare metal/concrete beneath)

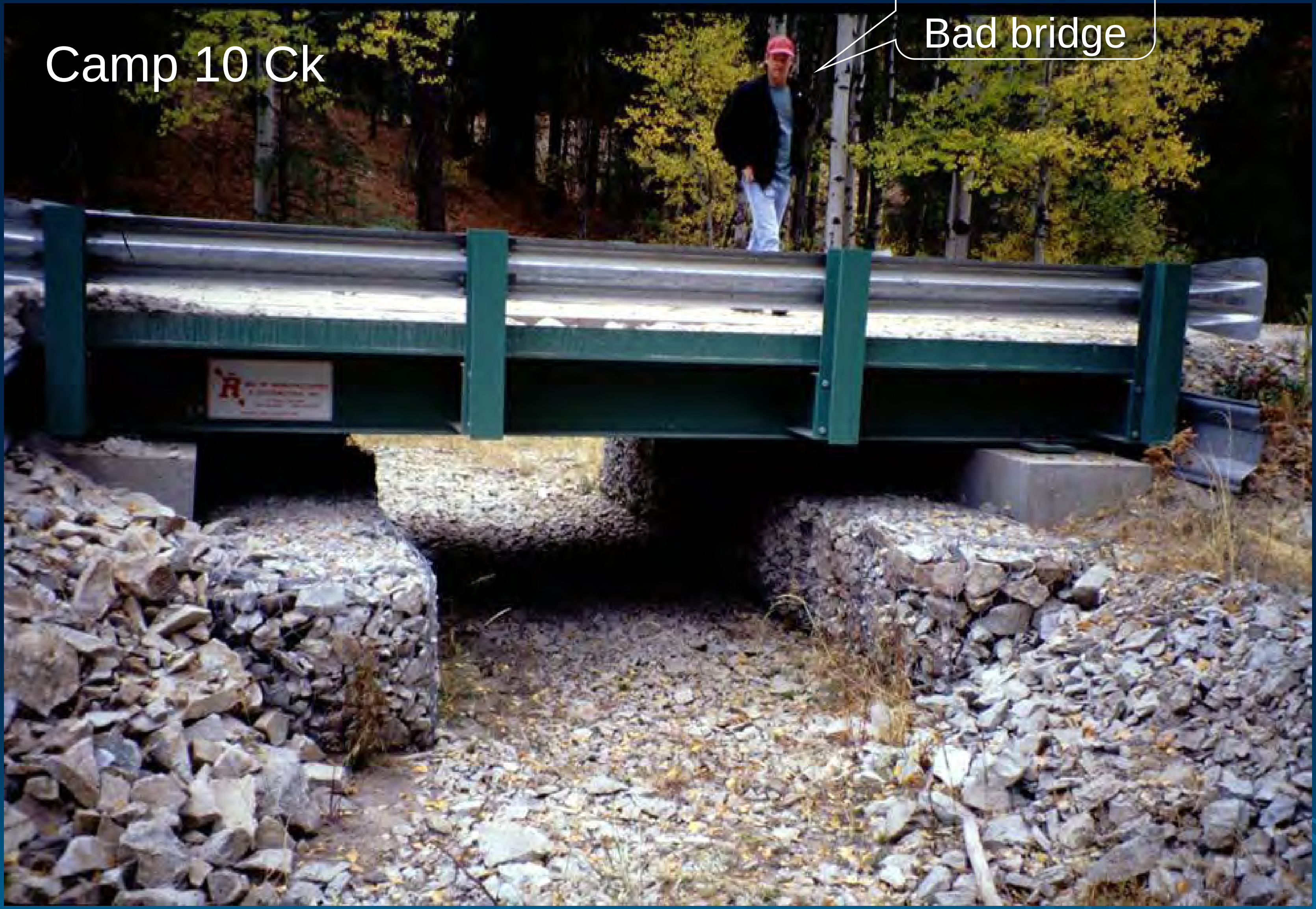
- Bed material placement/compaction easier without rounded shape
- Construction duration increased by cast-in-place concrete

Closed Bottom Culverts

Compared to Bottomless



- Pre-assembled pipe greatly reduces time for construction
- Structure not vulnerable to scour and headcut
- No measures needed to protect stream from fresh concrete
- Less costly and complex construction and less risk of error because no concrete footing
- Higher load capacity in poor foundation soils
- **Box culverts maintain channel width if bed degrades**



Not necessarily better just because it’s a bridge.

Stream Simulation Design Process

Site Characterization

↓

Assessment
Stream simulation feasibility

↓

Establish Project Profile

↓

Select/Verify reference reach

↓

Bed shape
and material

↓

Structure width,
elevation, details

↓

Mobility / stability

↓

Final design

Bed Failure

Stimson Creek
Culvert to BF Width Ratio = 1.0
Slope = design 5%; current 2.2%

Note upstream regrade

Original profile

Resulting profile

Culvert too narrow, bed material too small. Bed slope flattens.

From: Kozmo Bates

Bed Mobility and Stability Analysis

1. Stream Simulation Objective:

   Similar sized bed particles become mobile at similar flows in Reference Reach and Stream Simulation Reach

2. Mobility Analysis Compares

   Critical Entrainment Flows (Qc) and Shear Strees (τc):

$$Qc_{\mathbf{culvert}} = Qc_{\mathbf{reference\_reach}}$$

$$\tau c_{\mathbf{culvert}} = \tau c_{\mathbf{reference\_reach}}$$

3. Mobility analysis typically used on higher risk sites:

   - Floodplain constrictions
   - Project Profile steeper than reference reach

4. Don’t let the analysis drive the design

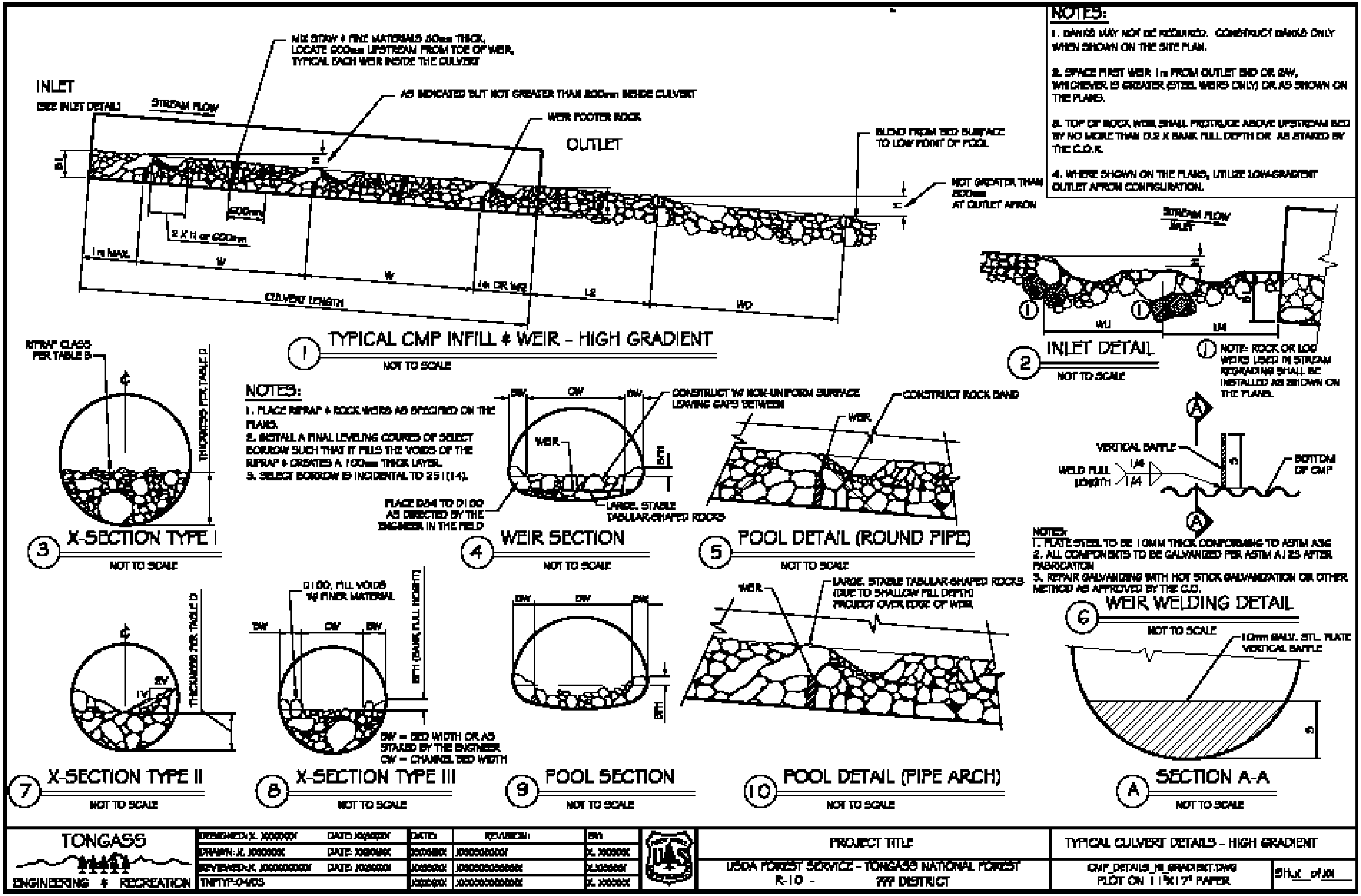
Key Pieces - Stability Analysis

- Key pieces include banklines, clusters, steps, and others
- Key pieces are permanent (up to stability design flow)
- What is stability design flow?
- Stability models - analytical
  - Bathurst (1987)
  - USACE bank riprap (1994)
  - USACE rock chute (1994)

USACE. 1994. Hydraulic Design of Flood Control Channels 1110-2-1601. U.S. Army Corps of Engineers,


Bankfull Width Structure
after 16 years
Width ratio: 1.0, slope 4.5%
Johansen

Developing Standard Details



Bob Gubernick, USFS

Bed Material Placement

- Requires vigilante on-site inspection
- Consider building the bed from downstream to upstream rather than in lifts
- Plans should indicate specific locations of Key Pieces/Forcing Features
- Pebble counts serve to check bed gradation
- Make sure the bed is compacted
  - Use flooding or jetting
  - May use vibratory means

Stream Simulation Construction

Placing Bed Material with Standard Construction Equipment

Premixed

Kim Johansen, USFS

Stream Simulation Construction

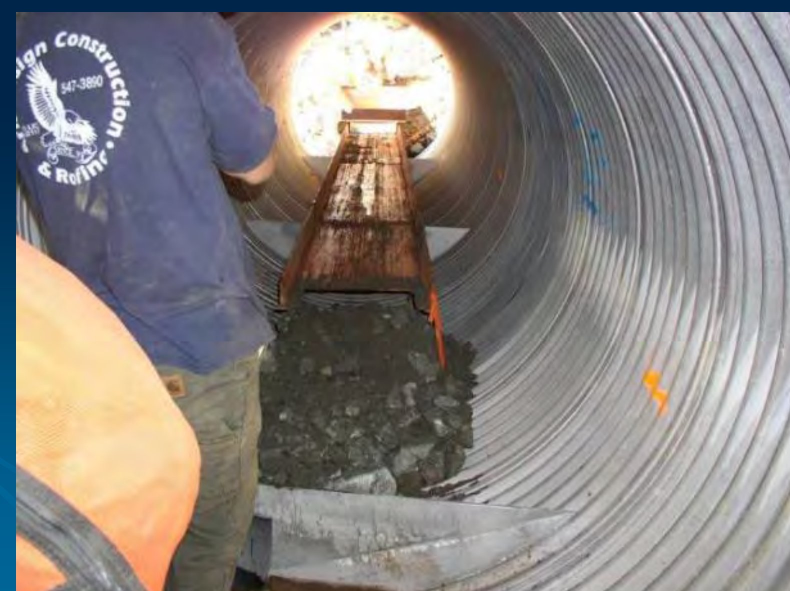
Standard Construction Equipment

Premixed

Bed Material Placement

- Dingo Loaders
- Manually
- Trail Equipment

Bed Material Placement
Special Equipment

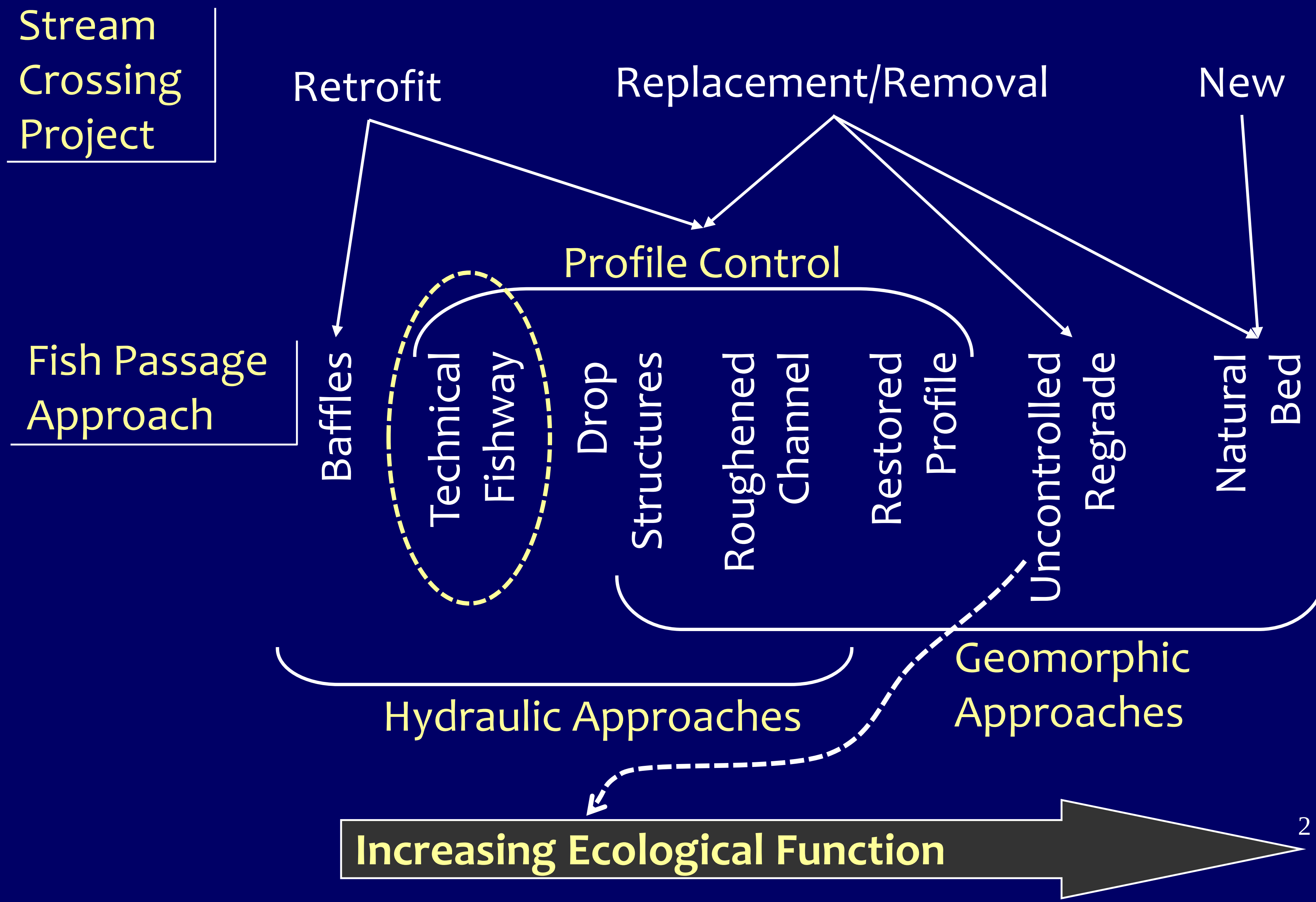



ROADWORK
CHEEP
$100 HR

Traditional Hydraulic Designs for Fish Passage at Stream Crossings

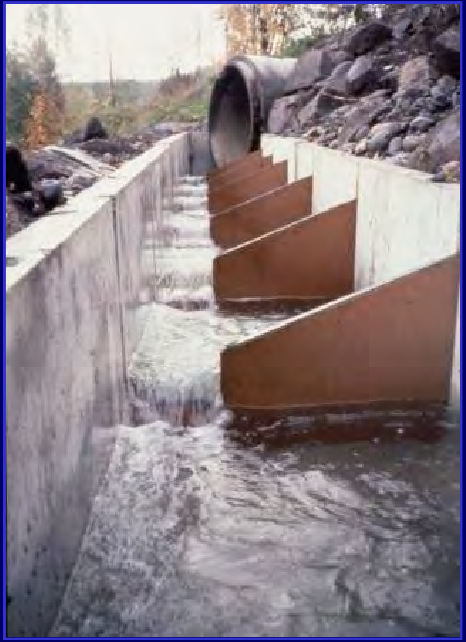
Michael Love P.E.
Michael Love & Associates
Arcata, California
mlove@h2odesigns.com

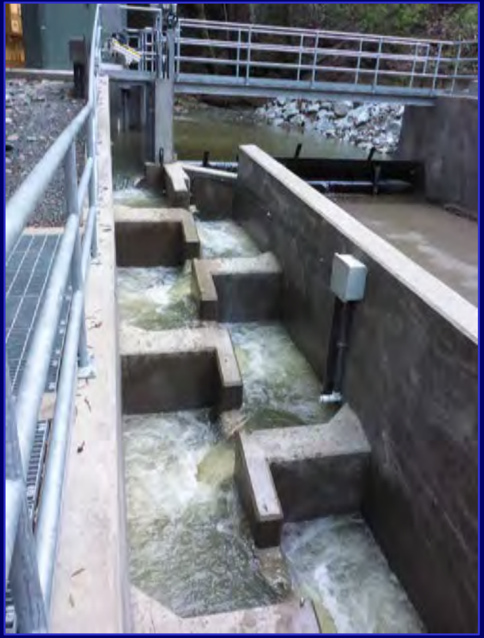
Design Approaches for Aquatic Organism Passage



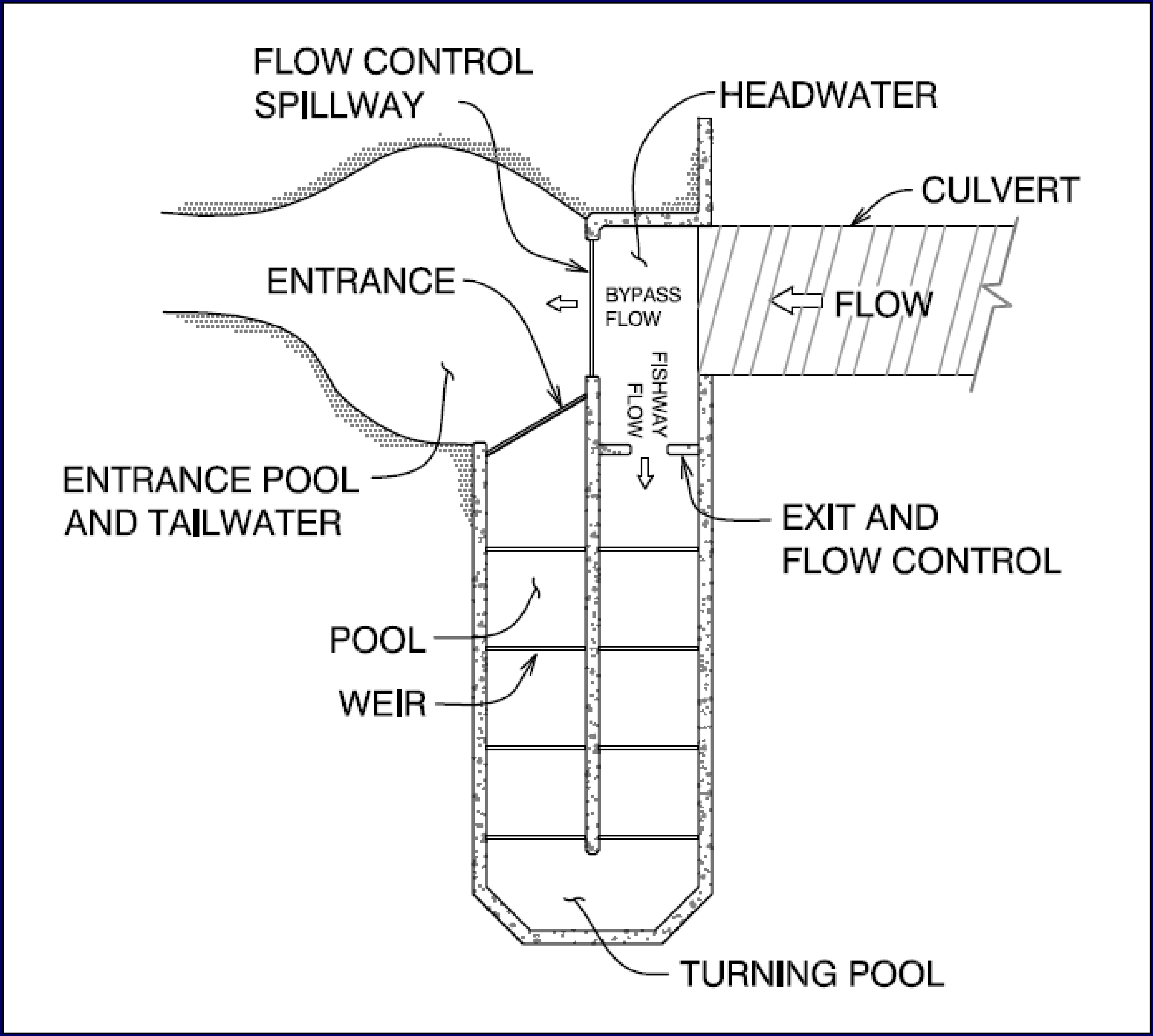
Technical Fishways

- Rigid permanent bed control (typically concrete or sheetpile)
- Passage typically optimized for target species
- Can be constructed steeper than most geomorphic based profile controls
- Minimum footprint
- Narrow flow range for passage
- High construction, operation, maintenance cost

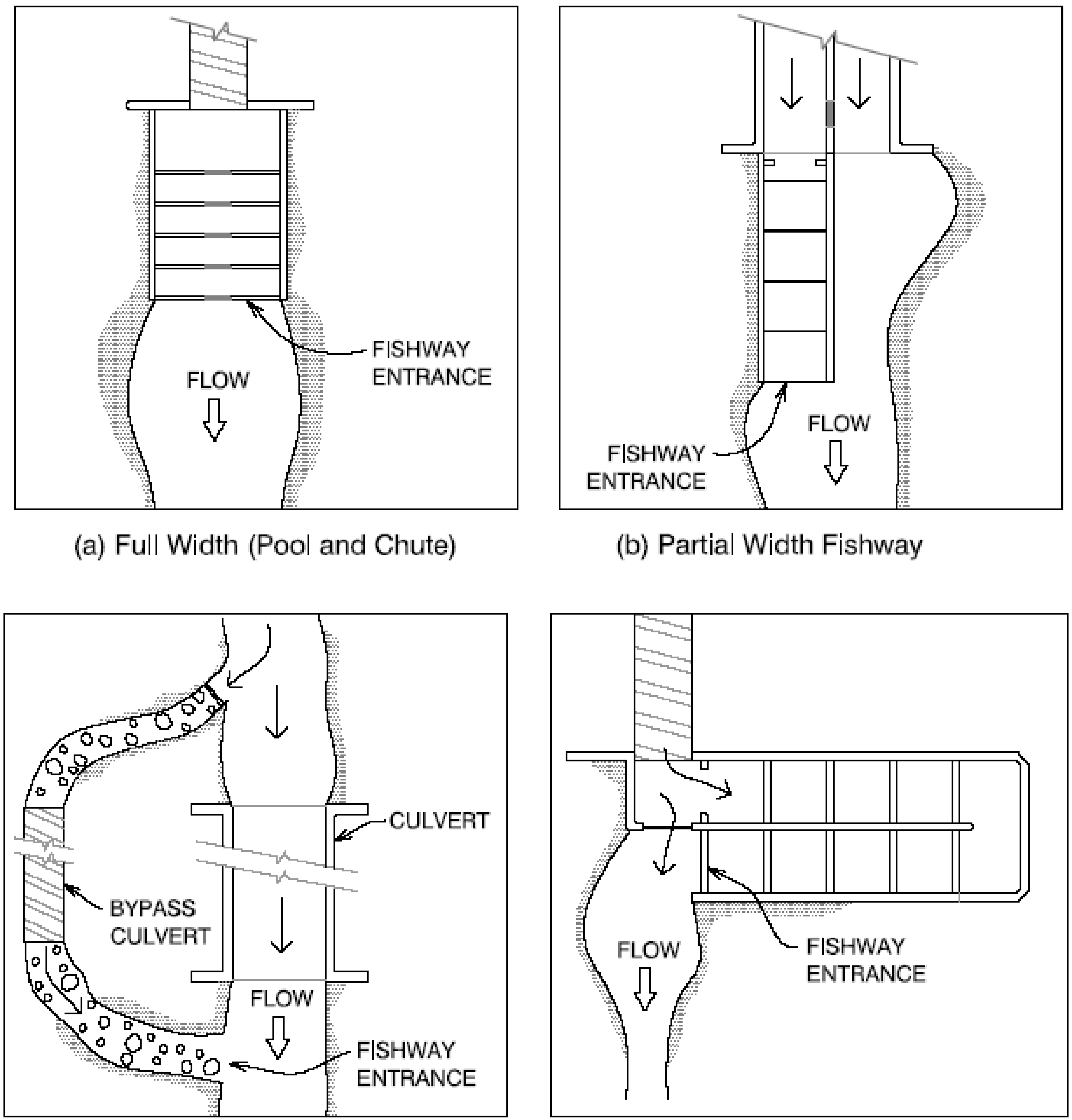




Fishway Nomenclature



Fishway Layouts



(a) Full Width (Pool and Chute)

(b) Partial Width Fishway

(c) Bypass Roughened Channel

(d) Bypass Pool and Weir

Roughened Chute Fishways
Denil and Alaskan Steeppass

- Uses roughness to control velocities
- Placed at steep slopes
- Passes adult salmonids and alewives (but not weaker swimming fish)
- Tend to clog quickly with debris
- Operates over narrow flow-range
- Convey small portion of total flow (poor fish attraction in some cases)

CDFW/NMFS do not allow these types of fishways for permanent installations and are actively removing them

Technical Fishways for Stream Crossings

Partial Width Pool-and-Chute Fishway

Bypass Pool-and-Weir Fishway

Full Width “Vortex” Pool-and-Chute Fishway

Bypass “Serpentine” Pool-and-Weir

Fishway Types: Pool & Weir

Sloping Weir Crest (V-weir) Creates Good Passage Conditions along Edge

$$Q_{v-weir} = \frac{8}{15} C_{dt} \sqrt{2g} \tan\left(\frac{\theta}{2}\right) H_{v-weir}^{2.5}$$

Where:

$$C_d = 0.6072 - 0.000874\theta + 6.1 \times 10^{-6} \theta^2$$

Fishways using “zero” stream length

Little Park Cr

Photos: Kozmo Bates

Plunging Flow & Turbulence

- Energy is Dissipated in Receiving Pool Through Turbulence (heat)
- Excessive Turbulence and Air Entrainment can Block Fish Passage

Example of Energy Dissipation Factor (EDF) in Pool and Weir Fishway

$$EDF = \frac{\gamma Q h}{V}$$

Calculate EDF in a fishway pool:

Q = 7.5 cfs
H = 1.0 ft
Pool; L=6', w=5', d=4'

$$EDF = \frac{62.4\ lb/ft^3 \times 7.5\ ft^3/s \times 1.0\ ft}{6\ ft \times 5\ ft \times 4\ ft}$$

$= 3.9$ ft-lb/sec/ft^3
< 4.0 ft-lb/sec/ft^3

Adult Resident Trout
Max EDF = 3 ft-lb/sec/ft3

Hybrid Fishway Type: Pool & Chute Fishway

Plunging at Low Flow

Streaming & Plunging at High Passage Flow

Photos: Kozmo Bates

Hybrid Fishway Type: Pool & Chute Fishway

Low Passage Design Flow

Big Sulphur Creek Retrofit

High Passage Design Flow

Pool and Chute Fishways:

- Can be built at slopes up to 10%
- At this slope, avoid overall drop greater than approximately 7 feet
- Lower slopes, may increase overall drop

Vortex Pool & Chute Fishway

Fishway Slope = 7%
8” Drops
Overall Fall = 7 feet

Plunging at Low Passage Flow

Maintains Plunging along Shoulders & Dry Shoulder for “Passage Corridor”

Streaming down Center at High Passage Flow

Pool & Chute Fishway Limitations

- Applicable to low head dams and some culvert retrofits
  - At fishway slope of 10%, observed undesirable hydraulics with total drop across fishway greater than <u>6 to 7 feet.</u>
  - At slopes of 7% to 8% and drops up to 12 feet, undesirable hydraulics not observed
- Must be relatively straight due to streaming flow (no switchbacks)
- Fishway velocities at downstream end are <u>High</u>, and can cause downstream channel scour.

Substrate in Fishways

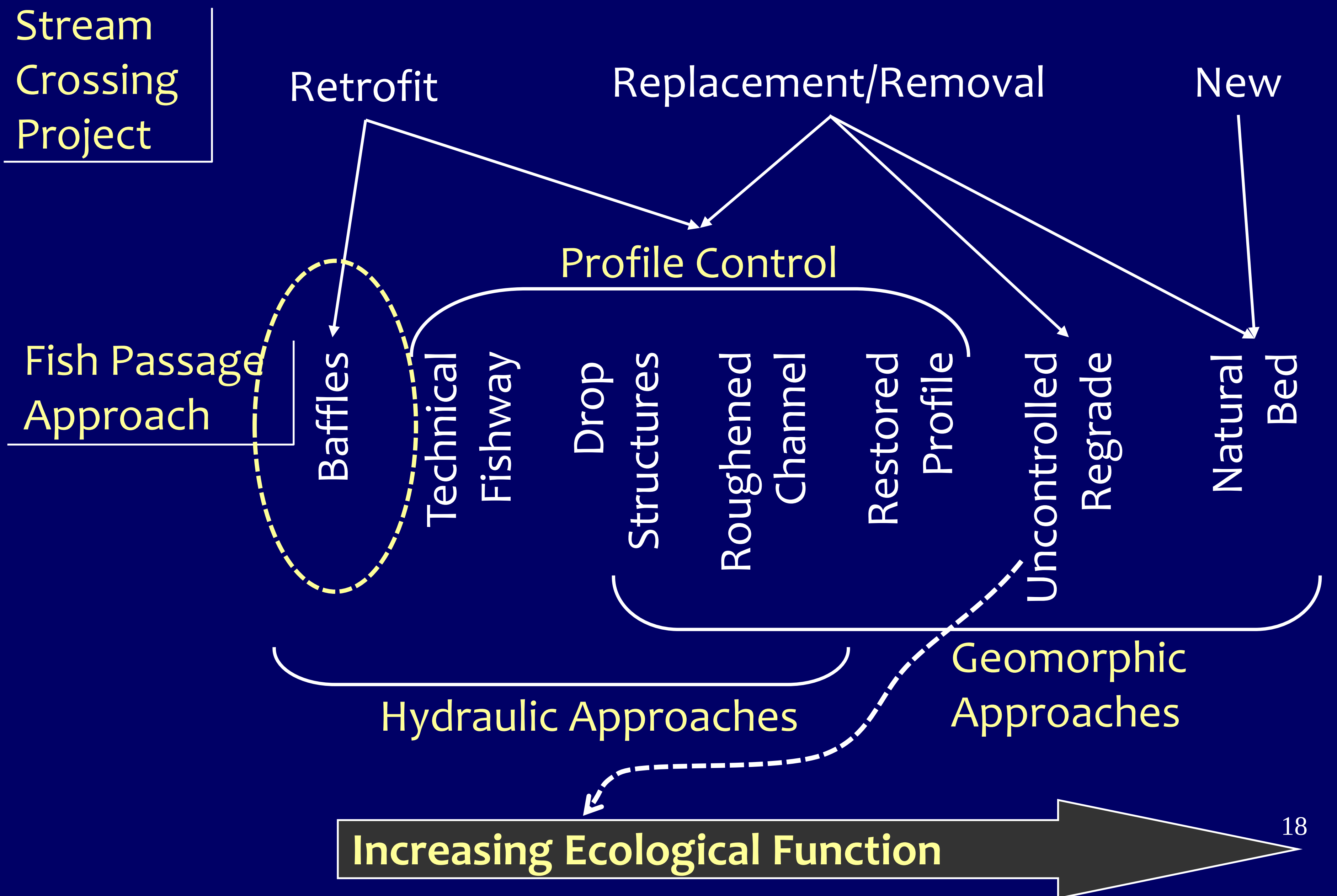
- Some coarse substrate good
- Dissipates energy
- Creates velocity shadows for fish
- Excess substrate can fill fishway pools, making for poor passage

Photos: Zack Larson

Inspection and Maintenance of Technical Fishways

- Develop and Inspection and Maintenance Plan
- Plan inspections after every large flow event and annually to ensure timely clearing of debris/sediment
- Maintenance may include repairs to damaged concrete and steel
- A biological monitoring may be needed at project start-up to ensure project objectives are satisfied

Design Approaches for Aquatic Organism Passage



Hydraulic Retrofits of Culverts for Fish Passage using Baffles

Concrete Angled Baffle Retrofit

Slip-lined CMP with Corner Baffles

Baffles for Fish Passage

Culvert Retrofit Improves Fish Passage

- Increases Hydraulic Roughness
- Decreases Velocity
- Increases Depth

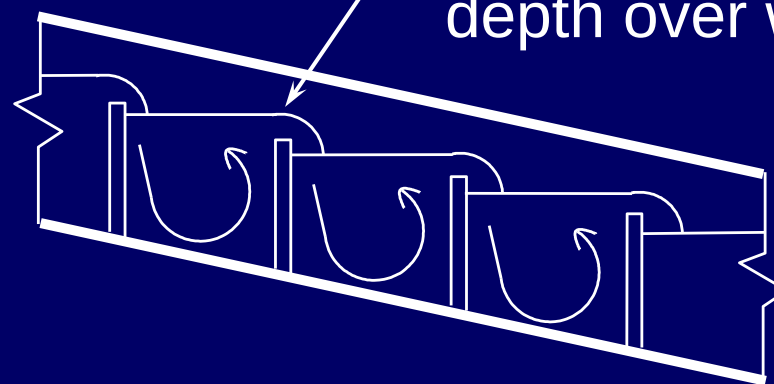
Baffles for Fish Passage

Two Hydraulic Regimes

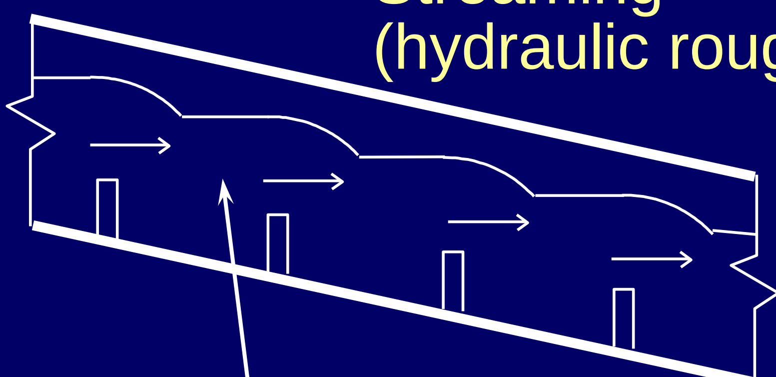
- **Plunging Weir Flow (Low Flow)**
  - sharp crested weirs
  - turbulence dissipated in pool below baffle
  - excess turbulence generally not an issue
- **Streaming Flow (High Flow)**
  - hydraulic roughness
  - uniform turbulence

Plunging (weir flow)

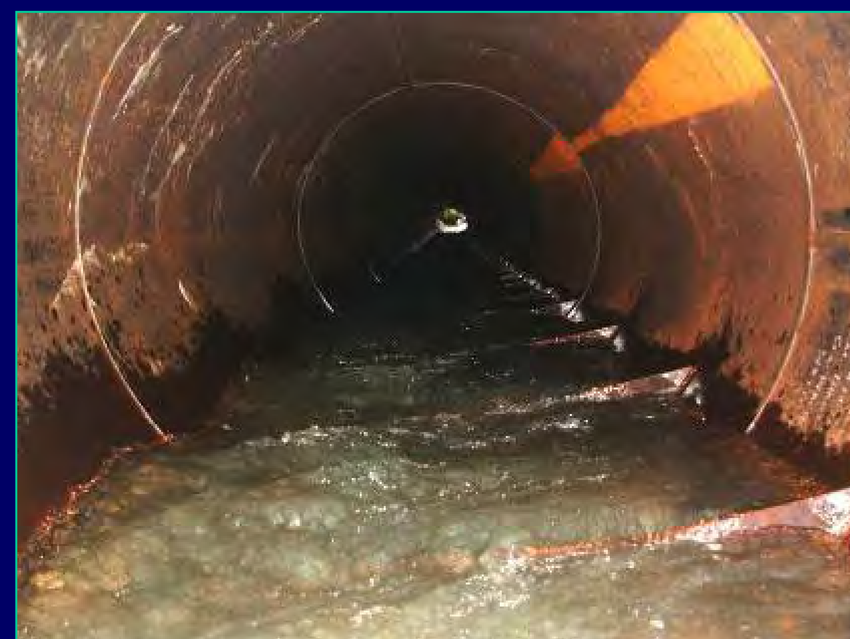
Shallow relative depth over weir



Streaming (hydraulic roughness)

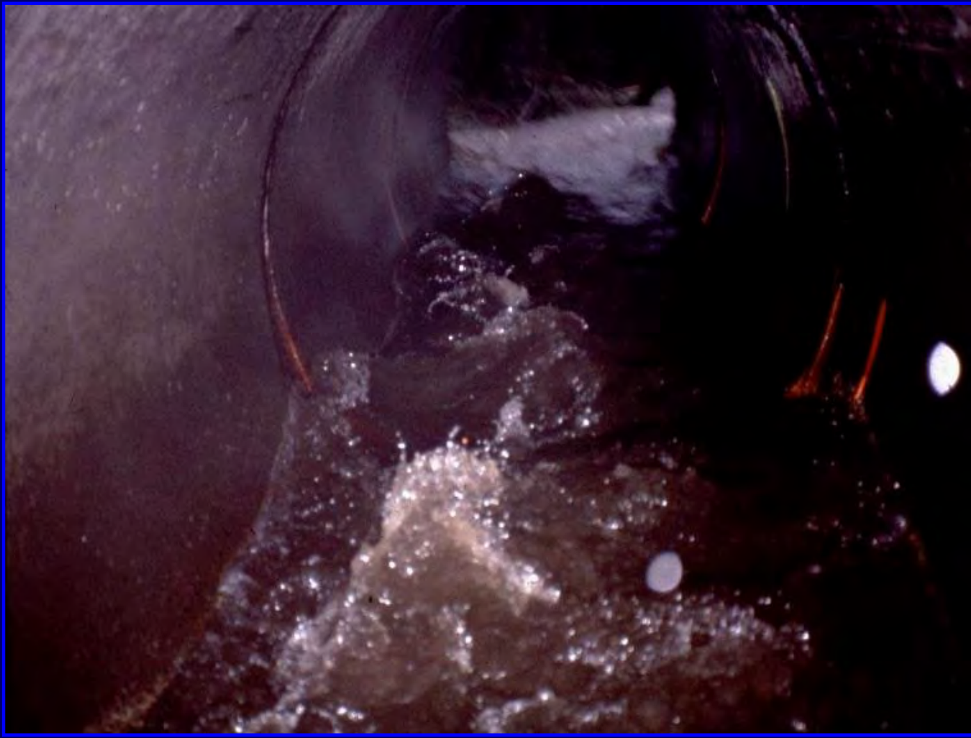


Increased relative depth over baffle



Turbulence in Streaming Flow

Moderate Flow – Transition from weir to roughness



- Energy is Dissipated in Receiving Water Column Through Turbulence (heat)
- Excessive Turbulence Creates can Block Fish Passage

Hydraulic Roughness & Turbulence

EDF in Baffled Culverts
with Streaming Flows:

$$EDF = \frac{\gamma Q S}{A}$$

S = Channel/Culvert Slope (ft/ft)
Q = Flow (cfs)
A = Wetted Area (sf)
γ = Unit Weight of Water (62.4 lb/cf)

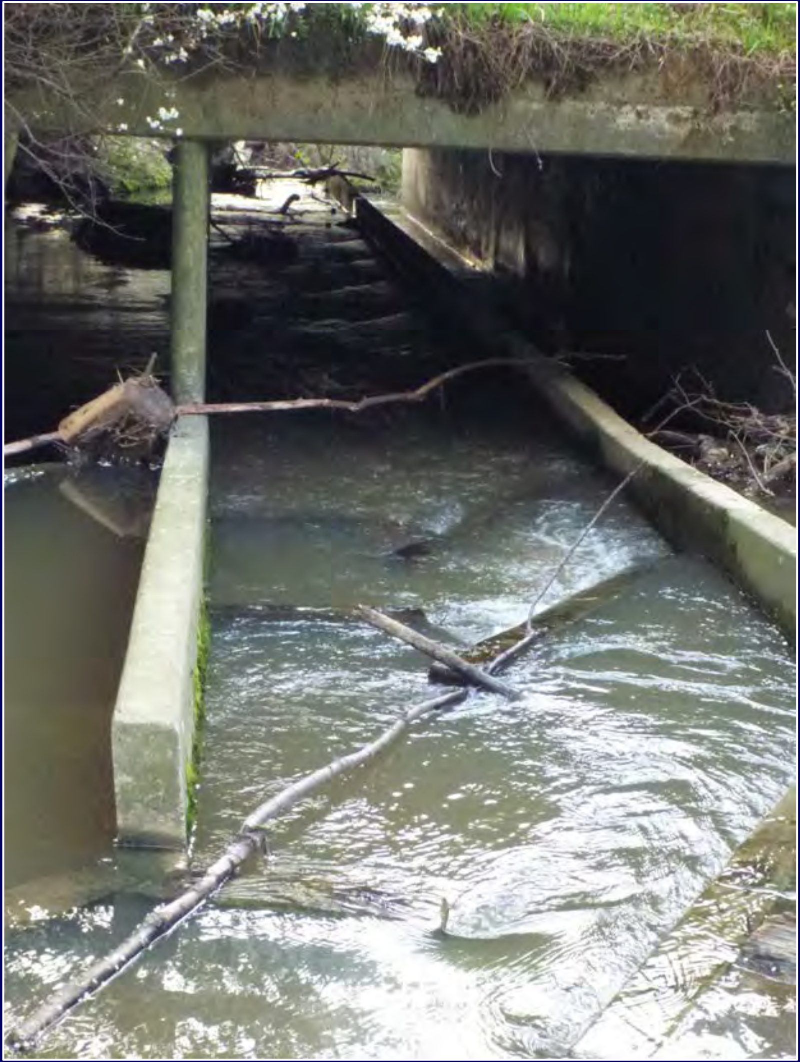
Thresholds (rule-of-thumb for Baffles):
Adult Salmon: EDF > 5 ft-lb/s/ft^3

Baffles from Yesteryear

Ramp Baffles

Lack of Depth at Low Flows
Functional over Narrow Flow Range

Off-Set Baffles

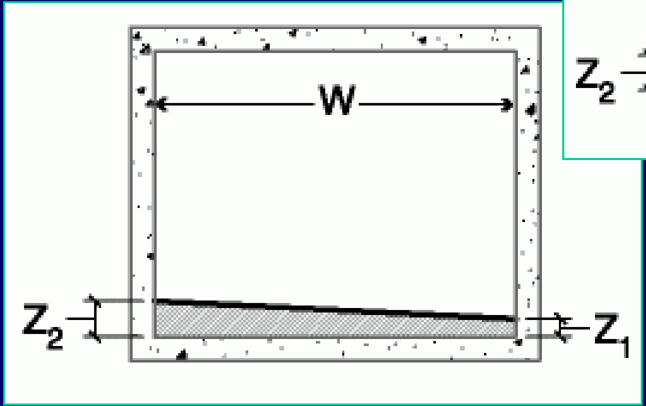


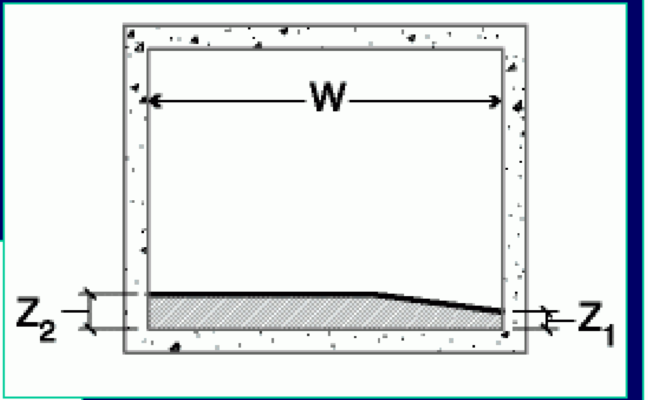
Tend to Catch Debris!!!
Slot Velocities too Fast for Small Fish

Angled Baffles for Flat-Bottom Culverts

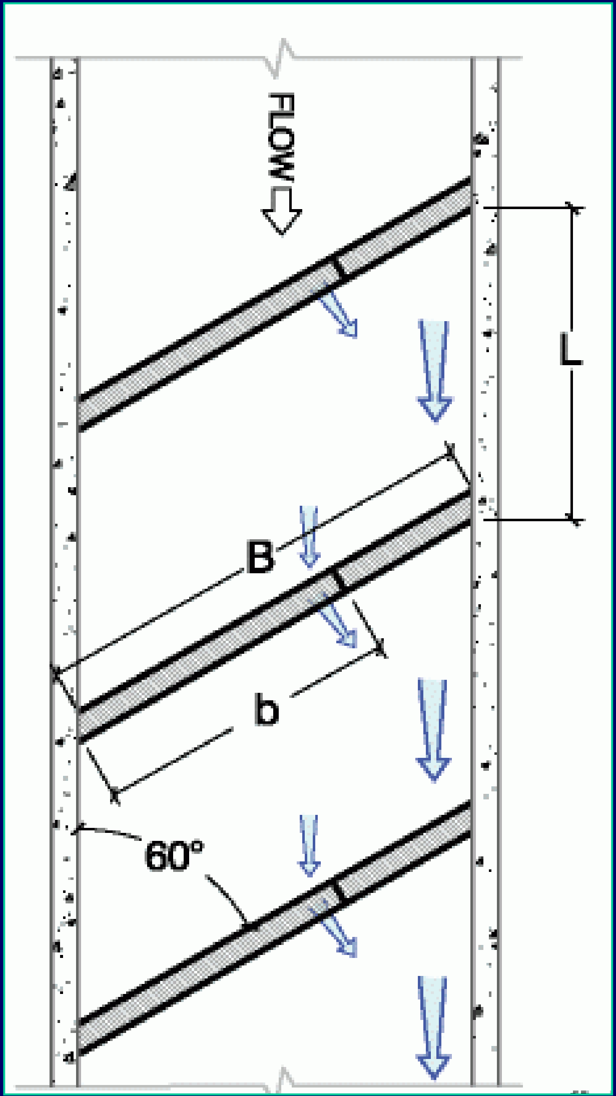
Angled Baffles

- Skew shunts flow and debris to one side
- Fish passage corridor on high side





Section



Plan

Angled Baffles for Flat-Bottom Culverts

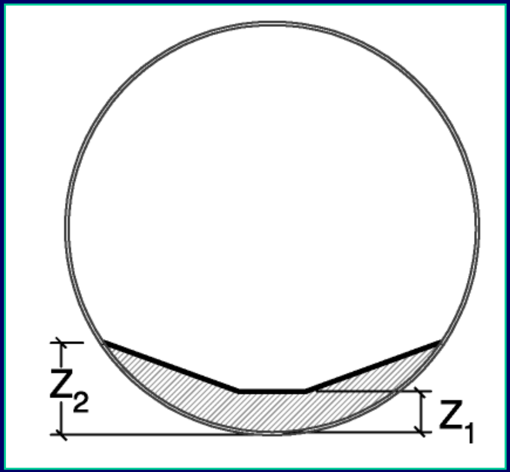
Wooden Angle Baffle
(looking downstream)

Double Angle Baffles for Wide Culvert ("Vortex Baffle")
(looking upstream)

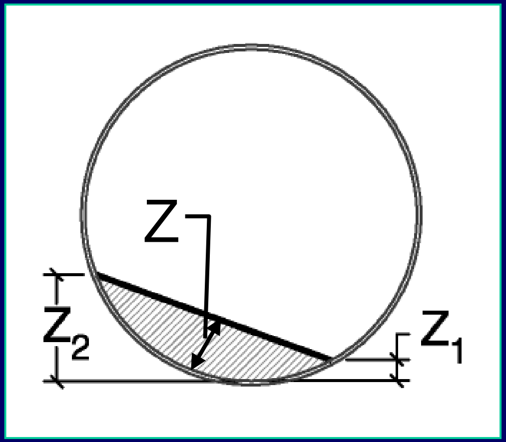
Corner & Weir Baffles

Weir Baffles

- For circular or pipe-arch culverts
- For larger culverts (W>8')
- Convey flow & debris in center
- Passage along sides



Corner Baffles



- For circular culverts
- Smaller culverts
- Convey flow & debris along low side
- Passage along high side

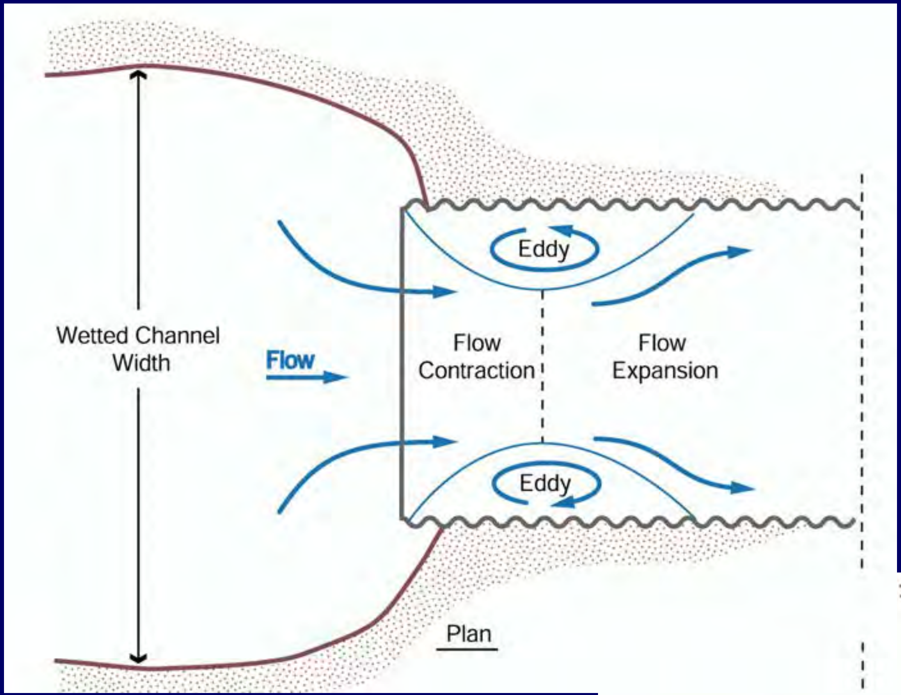
Outlet Transition

Low Flow

High Fish Passage Flow (excessive hydraulic drop)

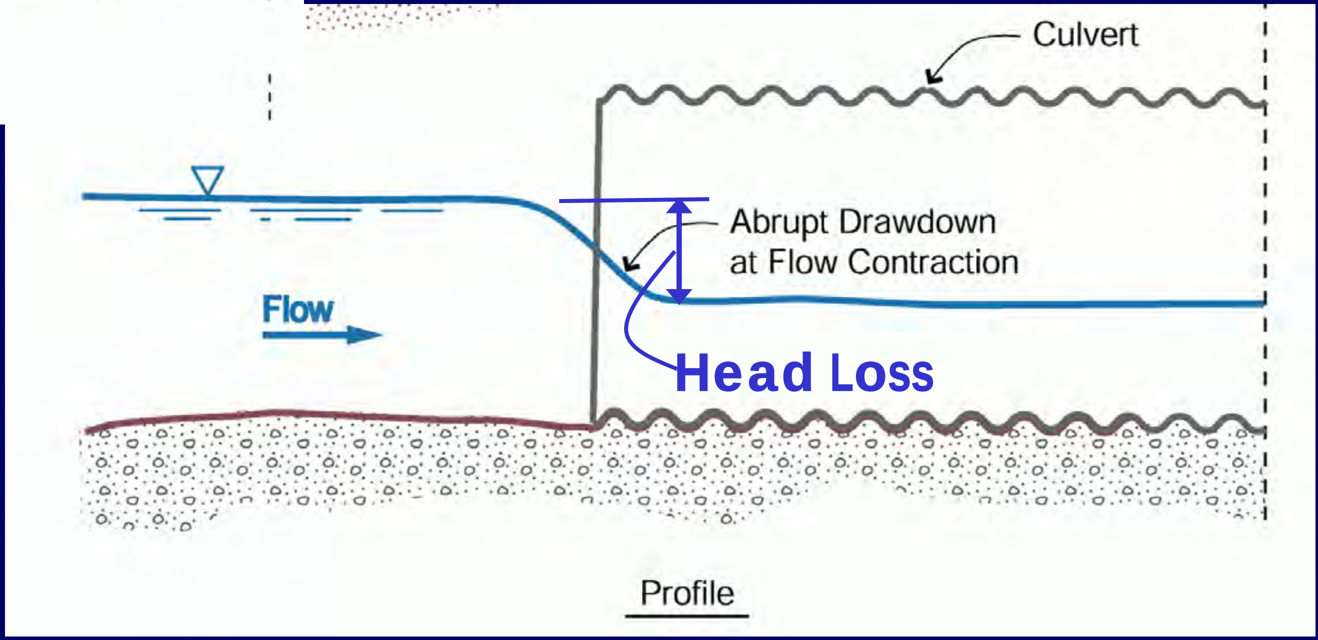
- Evaluate the Outlet Transition with FishXing
- Avoid Excessive Hydraulic Drop at Outlet
- Match Normal Depth to Tailwater

Inlet Transition



Max Inlet Head Loss for Fish <u>Passage (Rule of Thumb)</u>

- 0.5 feet for Adult Salmonids
- 0.2 feet for Juvenile Salmonids



Baffling Thoughts

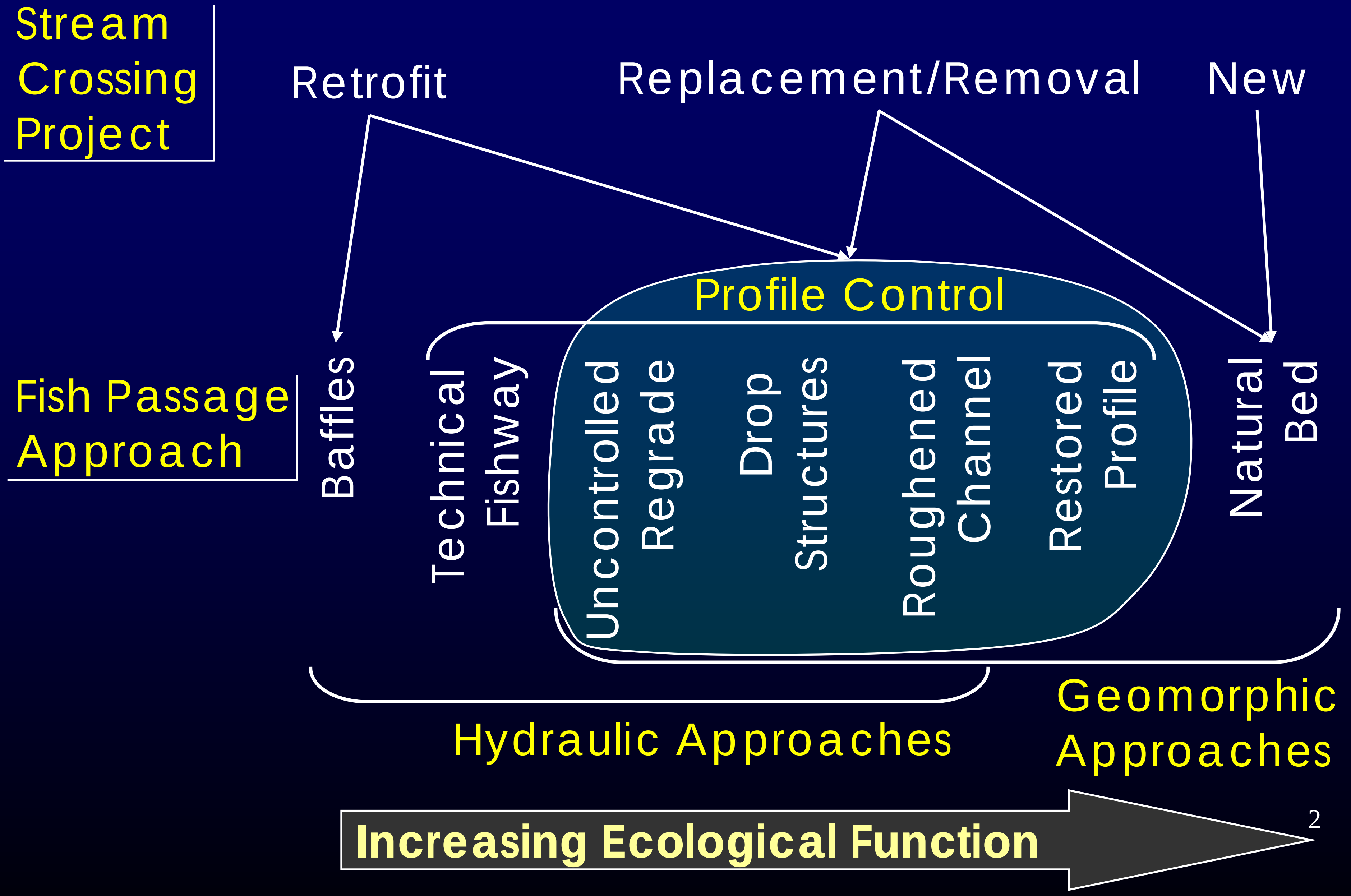
- ONLY for Retrofits
- Requires Maintenance/Debris Cleaning
- Frequently Reduces Capacity
- Turbulence blocks fish
- Match normal depth to tailwater

For More on Design of Baffles:
Refer to the California Department of Fish and Wildlife Fish Passage Design Manual (Love & Bates, 2009)

Profile Control

Michael Love, P.E.
mlove@h2odesigns.com

Tools for Aquatic Organism Passage



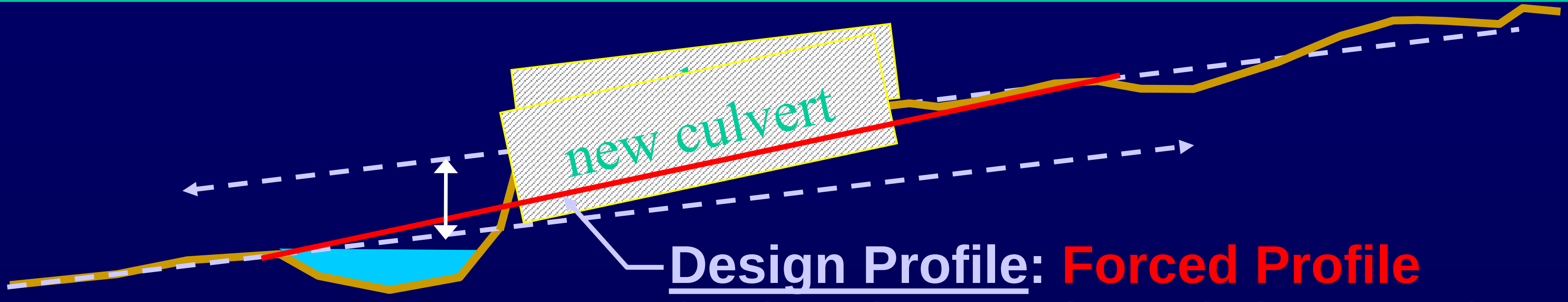
Profile Control Options





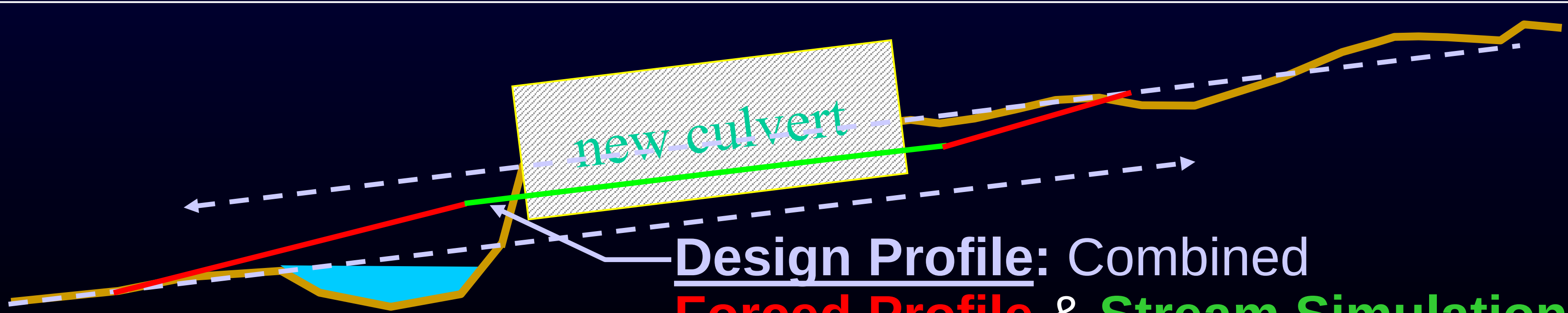
	Slope	Pros / Cons
Restored Profile	Limited by channel type	+ Passage diversity, Habitat - Scale/cost
Roughened Channel	Durability, bedload limit	+ Passage diversity - Species, failure risk
Boulder Weirs	≤5%	+ Passage diversity, Habitat - Failure risk
Rigid Weirs (log, concrete)	≤5%	+ Rigid, durable - Species, habitat
Technical Fishway	10% or "vertical"	+ Small footprint - Species specific, flow, sediment, debris

Design Profiles for Incised Channels: Replacement



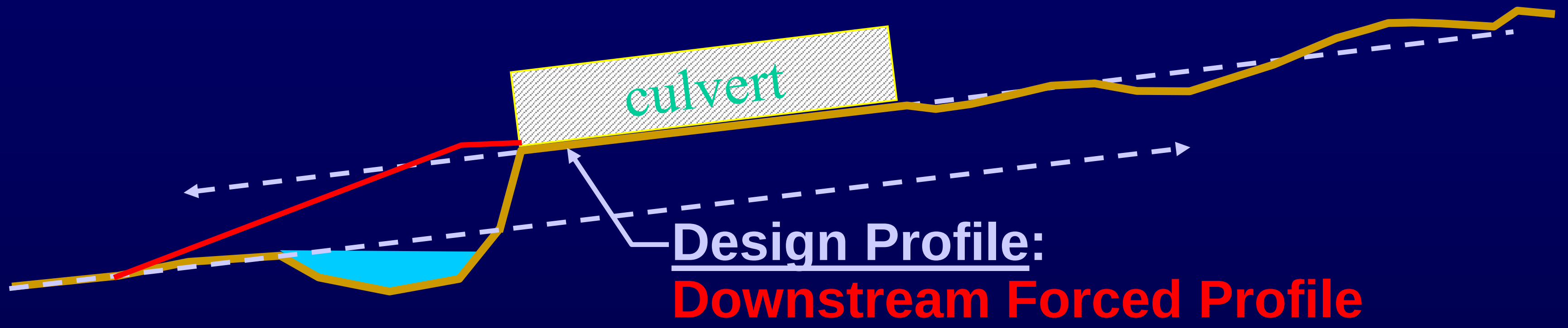
Design Profile: **Forced Profile**
(rock weirs, roughened channel…)

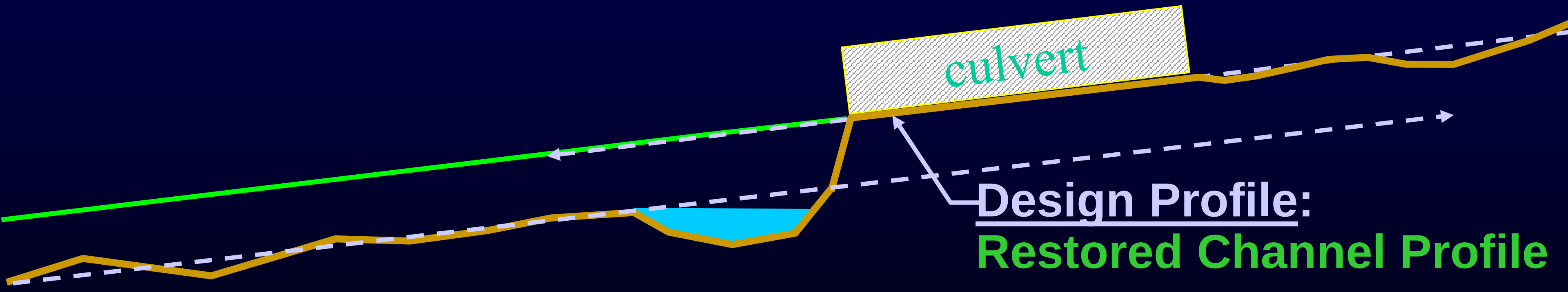
Design Profile: **Stream Simulation** with **Uncontrolled Regarde** (headcutting)



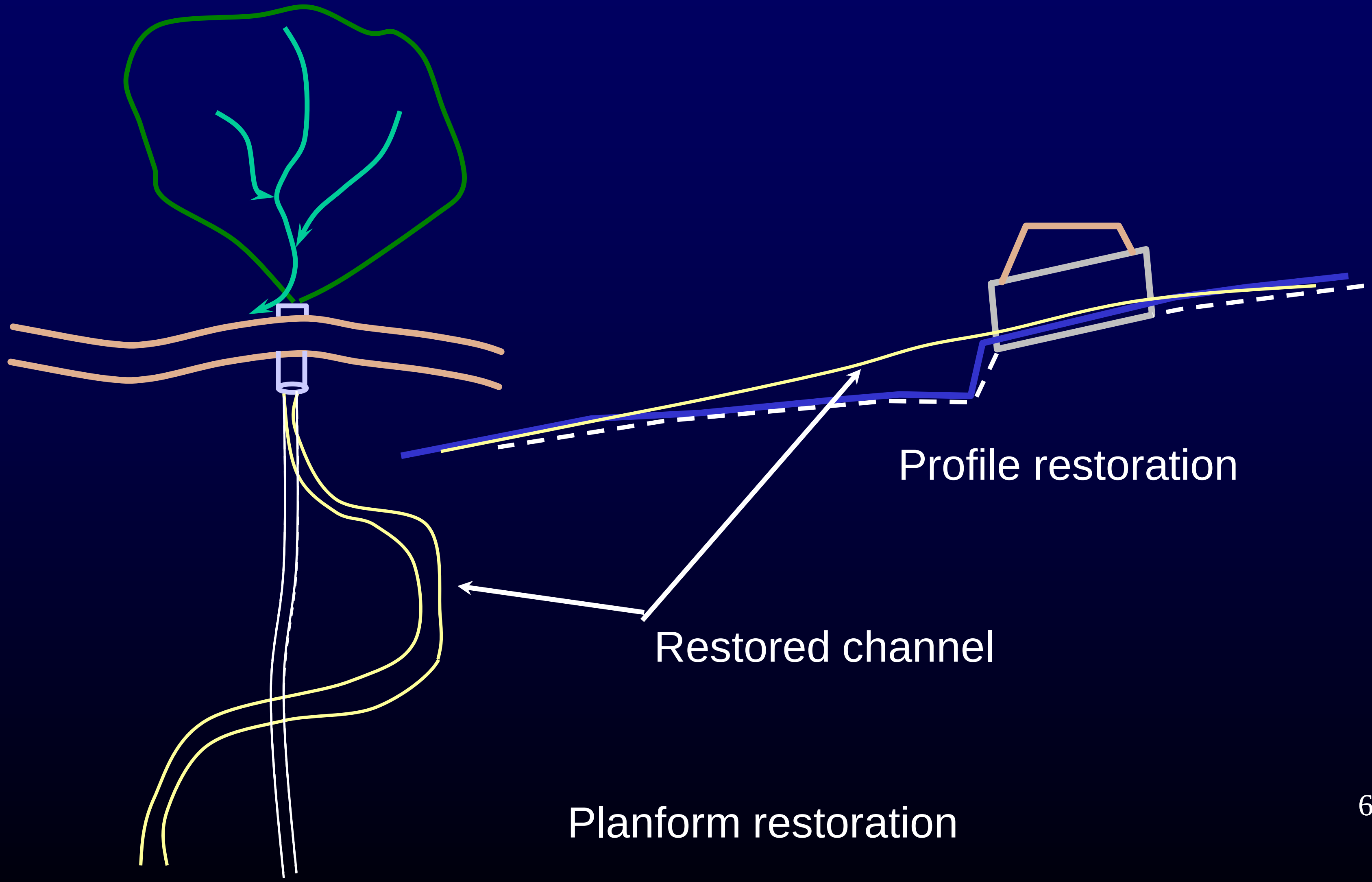
Design Profile: Combined
Forced Profile & **Stream Simulation**

Design Profiles for Incised Channels
- Retrofit or Replacement -





Channel Restoration for Passage of Aquatic Organisms



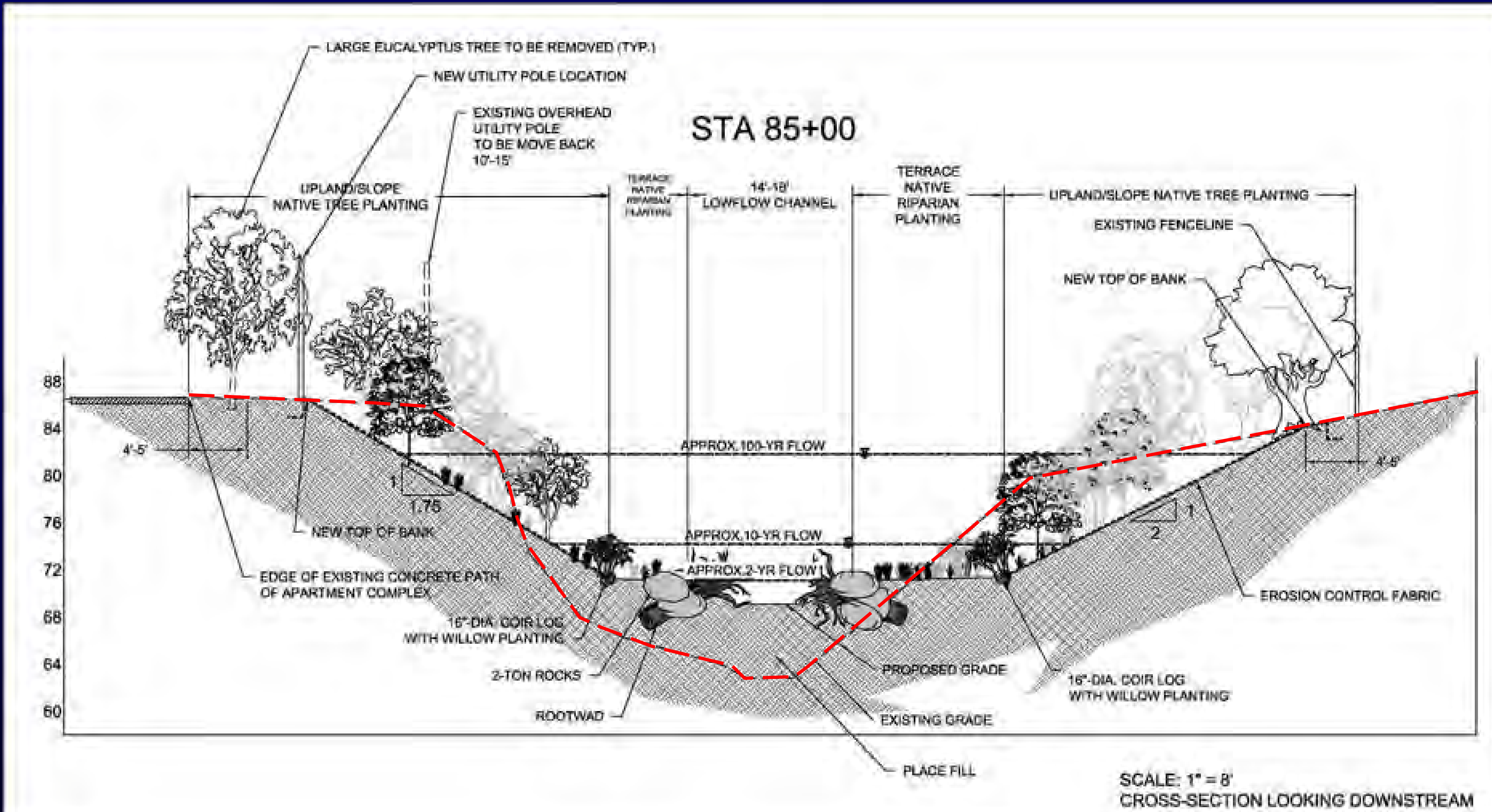
Profile Restoration

From Christine Chann,
San Pedro Creek
Watershed Coalition

Restored 1,300 feet of incised channel:

- **Stabilized Banks**
- **Created Instream and Riparian Habitat**
- **Eliminated a Culvert Barrier**

Profile Restoration



From Christine Chann, San Pedro Creek Watershed Coalition

Profile Restoration

- Sloped-back banks to reduced entrenchment
- Raised channel bed as much as 8 feet using native and imported fill
- Increase bankfull width by 20% and built floodplains
- Installed profile control to force riffles and pool

Profile Restoration
Outlet Creek

Upstream of Culvert
No Incision Experienced

Downstream of Project
Channel Remains Incised

Photos from Kozmo Bates

Profile Restoration
Outlet Creek

Channel restoration
for fish passage correction

Constructed 2000
Photos from 2005

Photos from Kozmo Bates

Site 10 was constructed as a spanner racked additional wood. Looking downstream and aggradation is along right bank.

Wood Count: 93 total wood fractions (Volume: 60.9 cubic meters)
17 large trees with rootwads,
69 large logs,
3 medium logs,
4 bunches of "small wood debris" (aka slash)

From Joe'l Benegar & Rocco Fiori

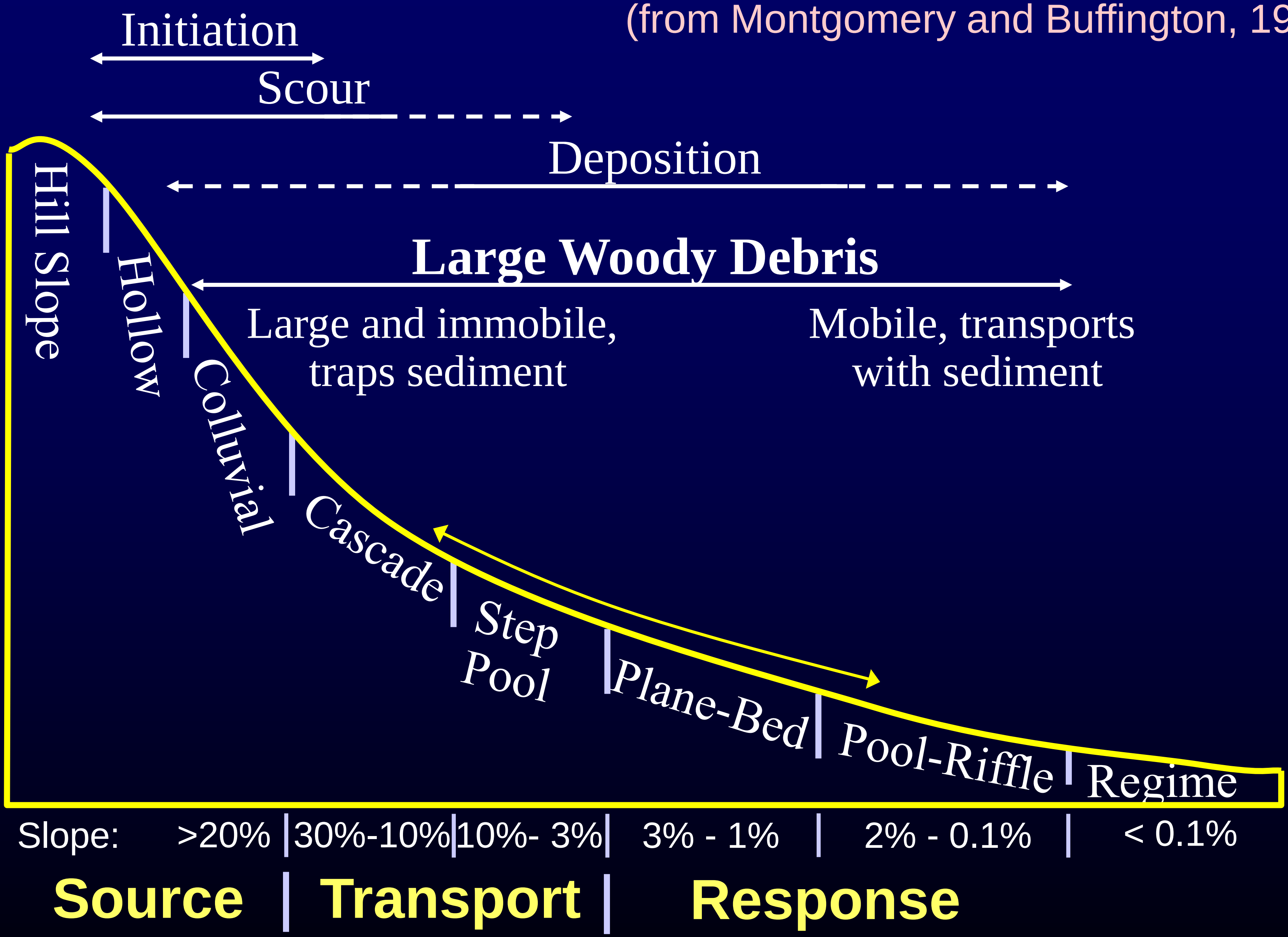
Geomorphically-Based Roughened Channels

- Channel constructed **steeper** than the adjacent channel (profile control)
- Based on morphology of steeper stream channel
- Stable *engineered streambed material (ESM)* forms channel bed & banks
- Quazi-hydraulic design for target species/lifestages (velocity, depth, drop, EDF)

Examples of a Roughened Channel in Europe

Generalized Stream Classification

(from Montgomery and Buffington, 1993)



Natural Steep Stream Morphology

Steep Boulder-Cobble Stream Channels

Natural Step Pool Stream Morphology

Geomorphically-Based Roughened Channels

Common Channel Types

Increasing Slope

- ❖ Roughened Riffles
- ❖ Plane Bed Channel (rock ramps)
- ❖ Rapids or Chutes & Pools
- ❖ Step-Pools
- ❖ Cascades & Pool

Caution:

- ➢ Only use channel types & slopes that the target species/lifestage are known to ascend
- ➢ Risk increases further the roughened channel characteristics deviates from the natural channel (i.e. slope, bed material, entrenchment)

Plane-Bed (Rock Ramp) Roughened Channels

Slope & Length Thresholds:

- Slope Range: $\leq$ 4%
- Max Head Diff.: 5 feet
- Use chutes and Pools for Larger Head Differentials

Bed Morphology:

- Random placement of rock
- D100 < Channel Depth

Grub Creek "Rock Ramp"

Pinole Creek Rock Ramp at I-80 Culvert Outlet

- 3.5 feet of drop over 60 feet
- 4% slope
- Target Species:
  - Adult Anadromous Steelhead
  - Adult Rainbow Trout
  - Juvenile Trout

Low Flow Hydraulic Diversity (~2 cfs)

High Passage flow for Juvenile Trout (~20 cfs)

Pinole Creek Rock Ramp at I-80 Culvert Outlet

High Passage flow for adult Salmon and Steelhead Trout

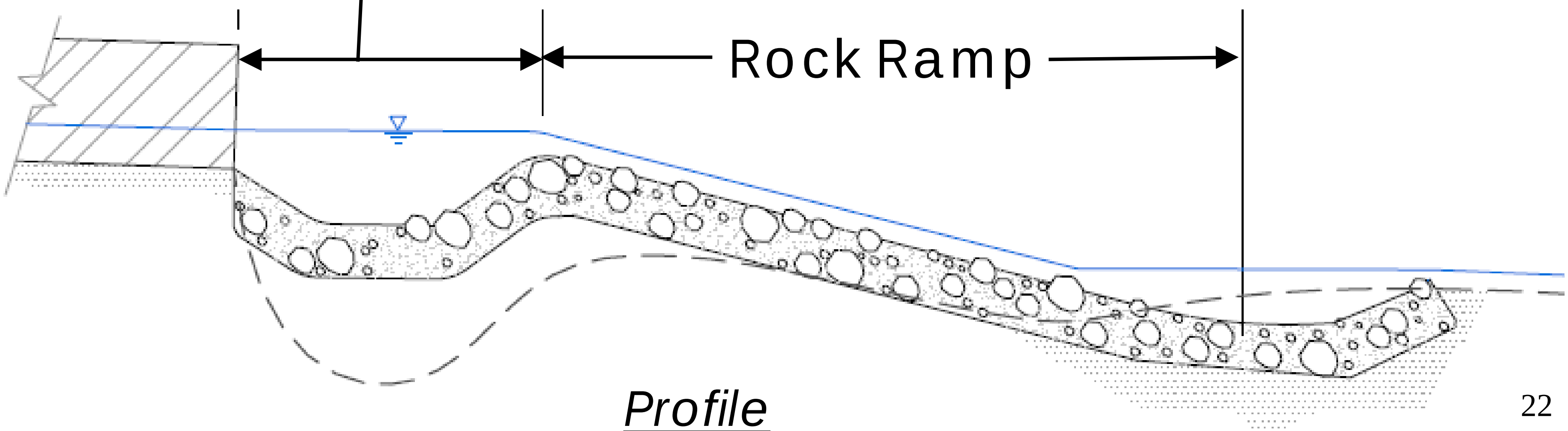
Plane-Bed (Rock Ramp) Roughened Channels

Fish Passage Pros:

- Doesn't rely on leaping abilities
- Large amount of hydraulic diversity at all flows

Cons:

- Shallow depths at low flows
- High flow passage often limited by turbulence



Profile

Chutes & Pools Roughened Channels

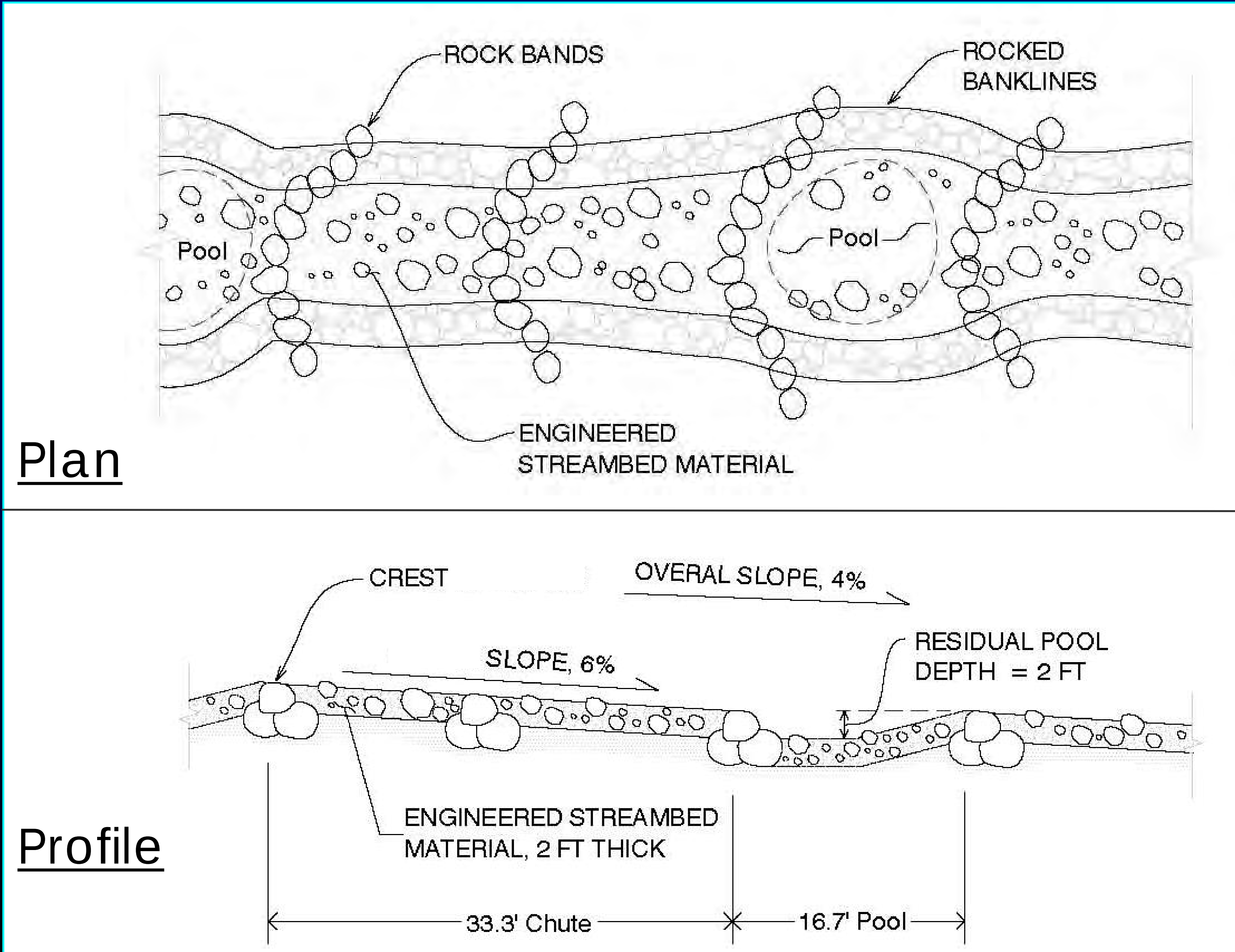
Slope & Length Thresholds (for armored pools):

- Slope Range: $\leq$ 8% across a chute
  $\leq$ 4% overall
- Max Head Diff.: 2 feet per chute

Bed Morphology:

- Chutes (Rapids) with Random Rock Placement
- D100 < Channel Depth
- Pools Armored with Coarse Bed Material

Typical Chutes & Pools Roughened Channel



Chutes & Pools Roughened Channel

Penitencia Creek, Alum Rock Park

Chutes & Pools Roughened Channel

Profile

Penitencia Creek, Alum Rock Park

Chutes & Pools Roughened Channels

Fish Passage Pros:

- No leaping required
- Large amount of hydraulic diversity
- Pools provide resting/ holding habitat and dissipate energy

Cons:

- Shallow depths at low flows, especially on steep chutes
- High flow passage often limited by turbulence

NID Measurement Weir

Concrete sills provide added
stability & control subsurface flow

Step-Pool Roughened Channels

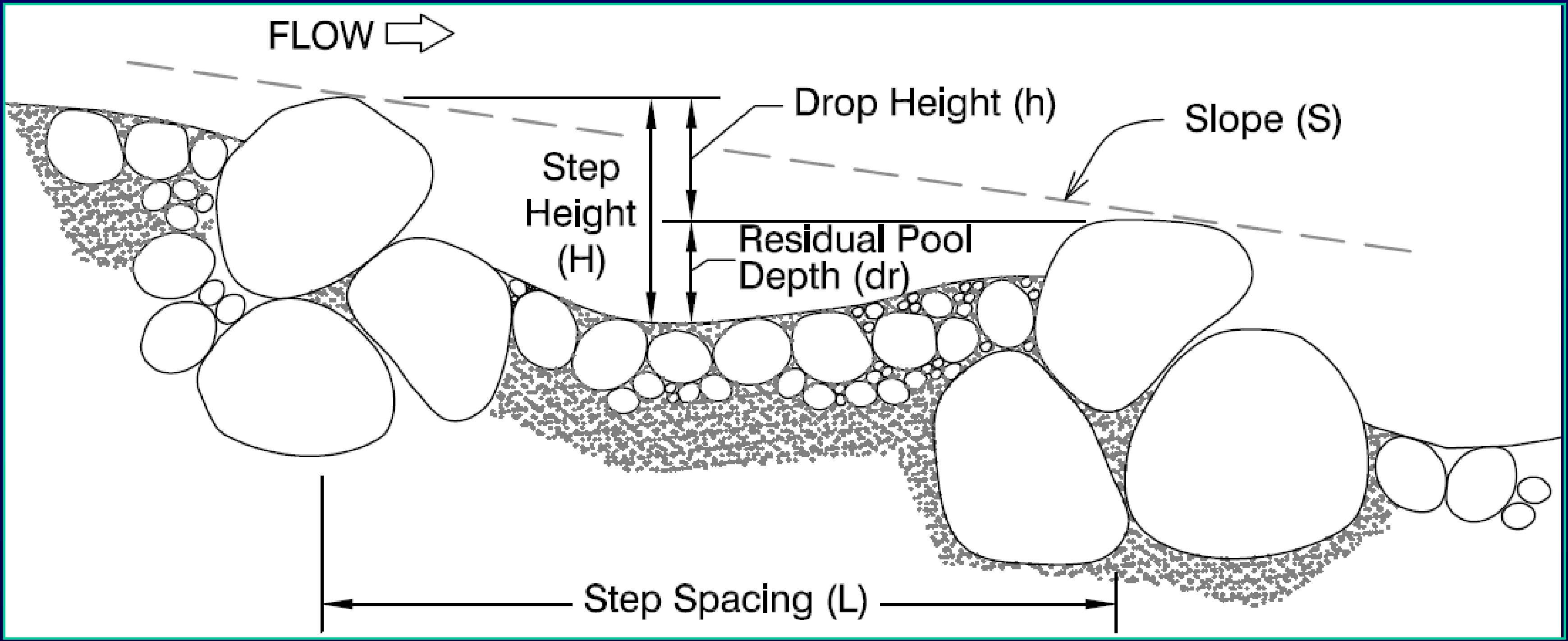
Slope & Length Thresholds:

- Slope Range: 3% to 6.5% overall

Bed Morphology:

- Rhythmic Pattern of Boulder Steps/Weirs
- Larger Rocks in Step 0.5 to 1.0 Bankfull Depth
- Oversized Pool every 3 to 5 feet of drop
- Pools Armored with Coarse Bed Material

Step-Pool Roughened Channels



Morphology of Steps (general guidance):

- Step-pool channel slopes $\leq$4%:
  2 $\leq$ H / L / S $\leq$ 5 (Chin 1998)

- D50 of Rocks forming Step ≈ Step Height (H)
  (Chin 1999; Chartrand & Whiting, 2000)

- Drop Height (h) & Pool Depth (dr)
  should satisfy fish passage criteria

Step-Pool Roughened Channels

Fish Passage Pros:

- Good low-flow passage
- Pools provide resting/ holding habitat and dissipate energy

Cons:

- May require fish to leap
- Challenging to construct complex steps
- Not suited for large, wide or unconfined streams
- Steeper slopes with small drops (i.e. 6 inch) result in small pools
  - Less holding/energy dissipation
  - Channel instability (streaming flows)

Rohner Creek Step-Pool Roughened Channel

Gulch 7 Step Pool
Roughened Channel-Stream Simulation Hybrid

2006

Gulch 7 Step Pool
Roughened Channel-Stream Simulation Hybrid

2013

Cascade & Pool Roughened Channels

Slope & Length Thresholds:

- Slope Range: > 5% cascade
  $\geq$ 4% overall

Bed Morphology:

- Complex series of small drops and pools
- Largest keystone boulders $\geq$ bankfull depth
- Drops and constructions form jet & wake hydraulics
- Armored pool every 3 to 5 feet of drop to dissipate energy

Stonybrook Canyon Step-Pool-Cascade

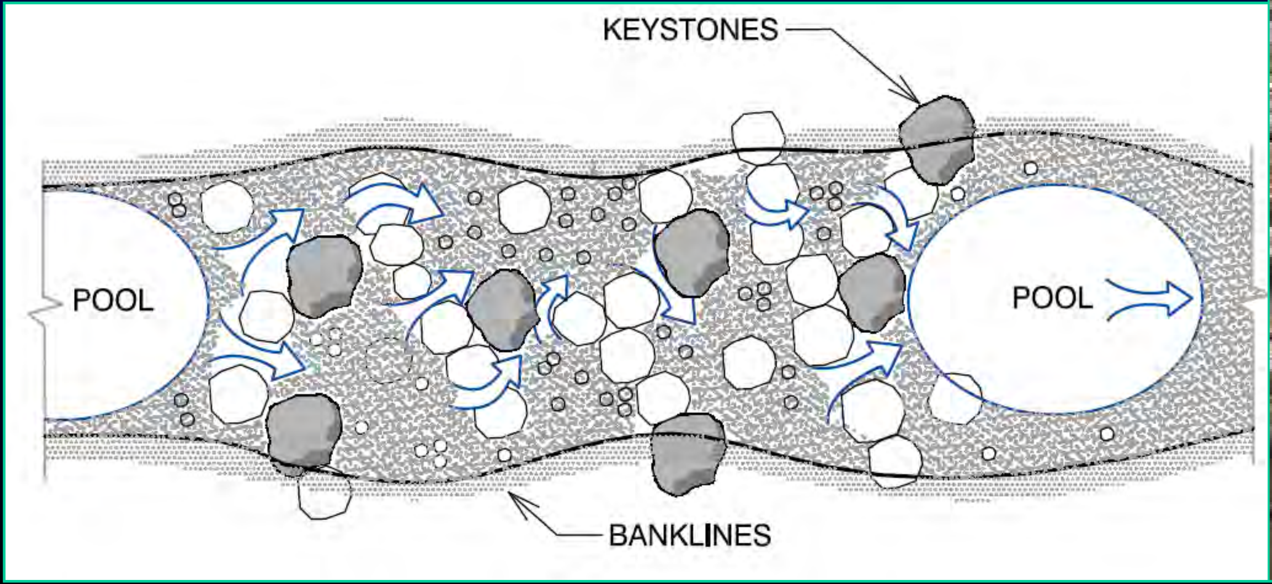
Cascade & Pool Roughened Channels

Fish Passage Pros:

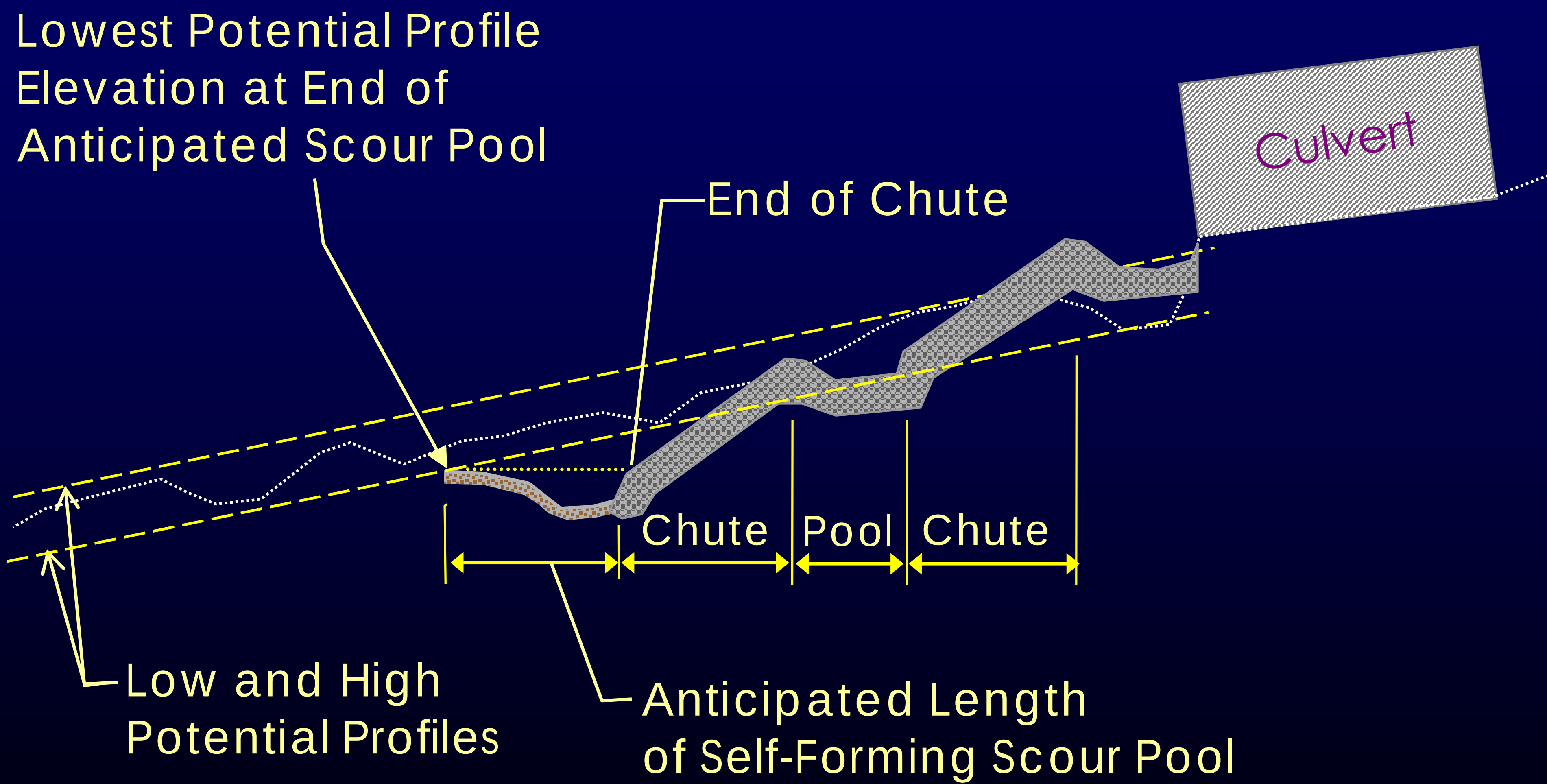
- Passage of non-leaping fish
- Diverse high-flow hydraulics for passage
- Pools provide resting/ holding habitat and dissipate energy

Cons:

- Poor low-flow passage
- Requires straight & entrenched channel reach
- Considered experimental for juvenile passage, May require monitoring



Profile Control Transitions
Chutes & Pools Roughened Channel



The Roughened Channel Design Concept

Limitation - Lack of Sediment Continuity

<u>Engineered Bed Material is</u>:

- Larger than bedload transported into roughened channel
- No replacement by natural bedload material
- Sized to be stable to a <u>*bed design flow*</u> (Q100yr)

Developing the Channel Design and Bed Mixture

The **Iterative** Design Process

1. Calculate Qbed & Qfish
2. Develop initial channel shape & slope to fit site
3. Calculate Stable D84 rock size at Qbed:
   - Initial guess for D84
   - Use hydraulic roughness relationships dependent on flow & substrate size
   - Calculate Unit Discharge for channel
   - Calculate a stable D84

Iterate

5. Evaluate fish passage conditions

If unsuitable, change channel shape/slope and repeat no. 2-5

Estimating Hydraulic Roughness

Flow resistance for steep mountain streams:

$$n = \frac{0.0926R^{1/6}}{1.16+2\log(R/D_{84})}$$ (Limerinos, 1970)

Manning's roughness

Hydraulic Radius

Water Depth

$$\sqrt{\frac{8}{f}} = 5.62 \bullet \log_{10}\left(\frac{h}{D_{84}}\right) + 4$$ (Bathurst, 1985)

Darcy Friction Factor

84% of bed material finer than D_{84}

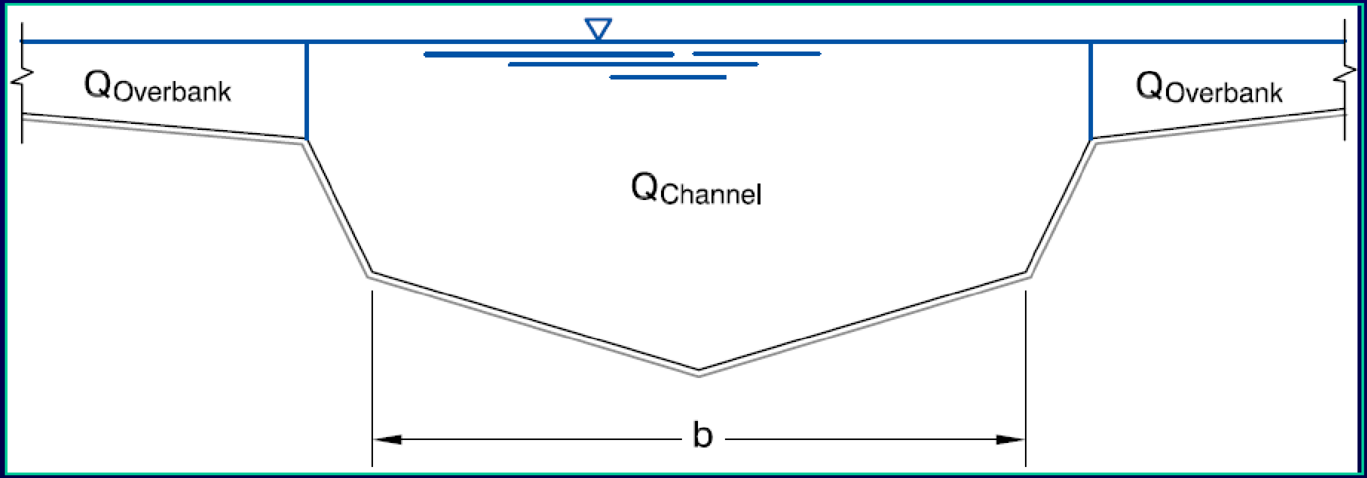
Numerous relationships developed with varying limitations.

See Appendix B in CDFG Part XII for more relationships.

Designing a Stable Bed Using Unit Discharge Method

Unit Discharge:

$$q = \frac{Q_{channel}}{b}$$



Water surface slope (ft/ft)

Unit discharge (cfs/ft) at *stable bed design flow* (i.e. Q100)

$$D_{30-ACOE} = \frac{1.95S^{0.555}1.25q^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$

from USACE EM 1110-2-1601 based on Abt et al, 1988

Developing Gradation of Bed Material

USACE (1994) produces **porous uniform gradation** for bed material:

D84/D15 = 1.7 to 2.7

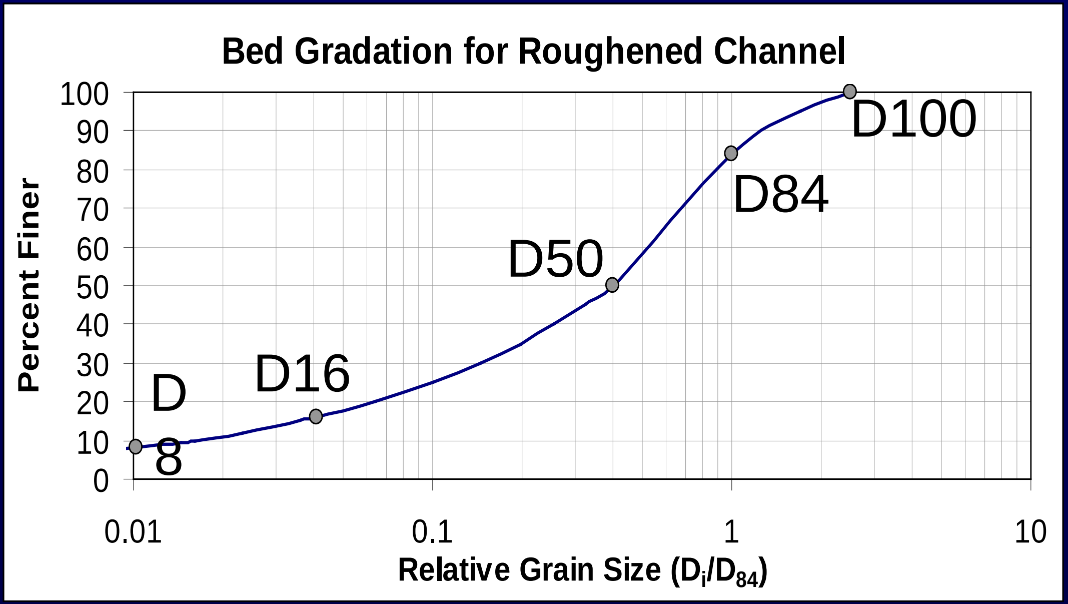
Natural channel streambed material has wide gradation:

D84/D15 = 8 to 14 (typical in steeper streams)

- Larger Material (≥D50) is framework for stability
- Smaller material (<D50) fills voids to control porosity

Porous Riffle-Pool Rock Chute

Developing Engineered Streambed Material (ESM)



Gradation Shift for ESM:

$D84_{ESM} = 1.5\ (D30_{ACOE})$

(from WDFW, 2013)

For $D_i \geq D50_{ESM}$ use **Ratios Relative to D84**:

$D100_{ESM} = 2.5(D84_{ESM})$

$D50_{ESM} = 0.4(D84_{ESM})$

(from WDFW, 2003)

Sometimes produces oversized rock, may be reduce to 1.5D84

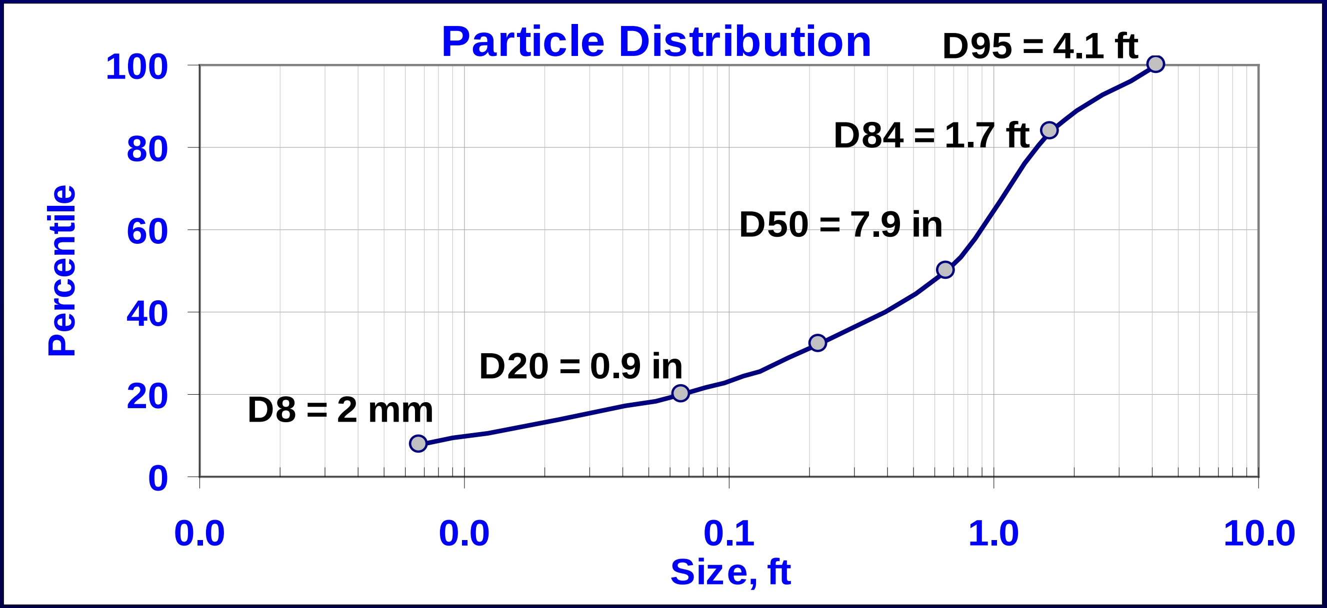
For $D_i < D50_{ESM}$ use **Fuller-Thompson Equation**:

$$D_i = (2 \cdot i)^{1/n} D_{50}$$

n ranged from 0.45 to 0.70

Set n to achieve D8 $\simeq$ 2mm

Sizing and Specifying Material Gradations

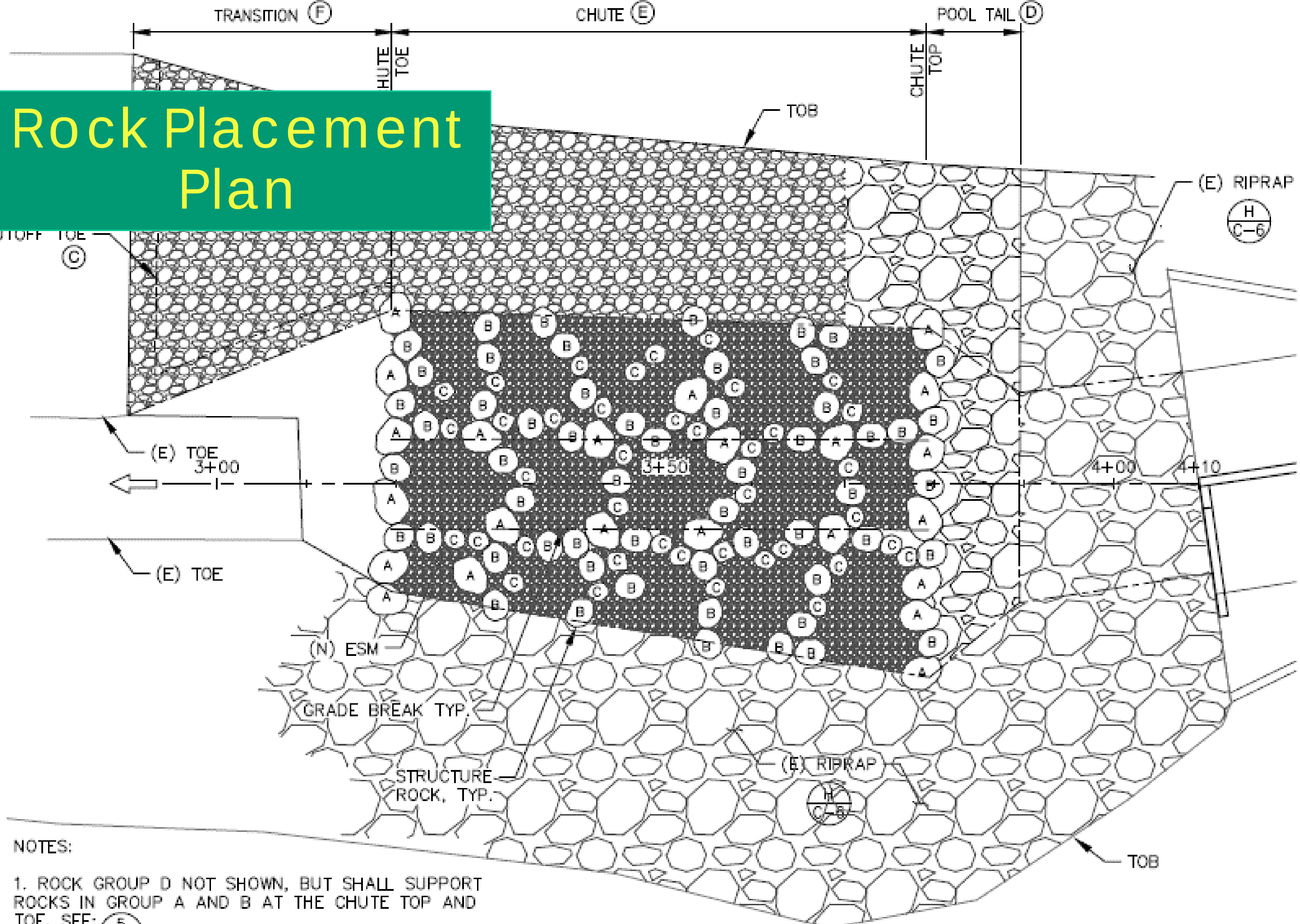


Example Specifications for Gradation of ESM

Percent of Mix	Range of Size (Intermediate Axis)	
16	20 in	48 in
34	8 in	20 in
18	3 in	8.0 in
12	¼ in	1.0 in
8	Passes Sieve #10 **(2 mm)**	

Use largest size class to form structures (steps, keystones)

Rock Placement Plan



NOTES:

1. ROCK GROUP D NOT SHOWN, BUT SHALL SUPPORT ROCKS IN GROUP A AND B AT THE CHUTE TOP AND TOE, SEE: 5 / C-5

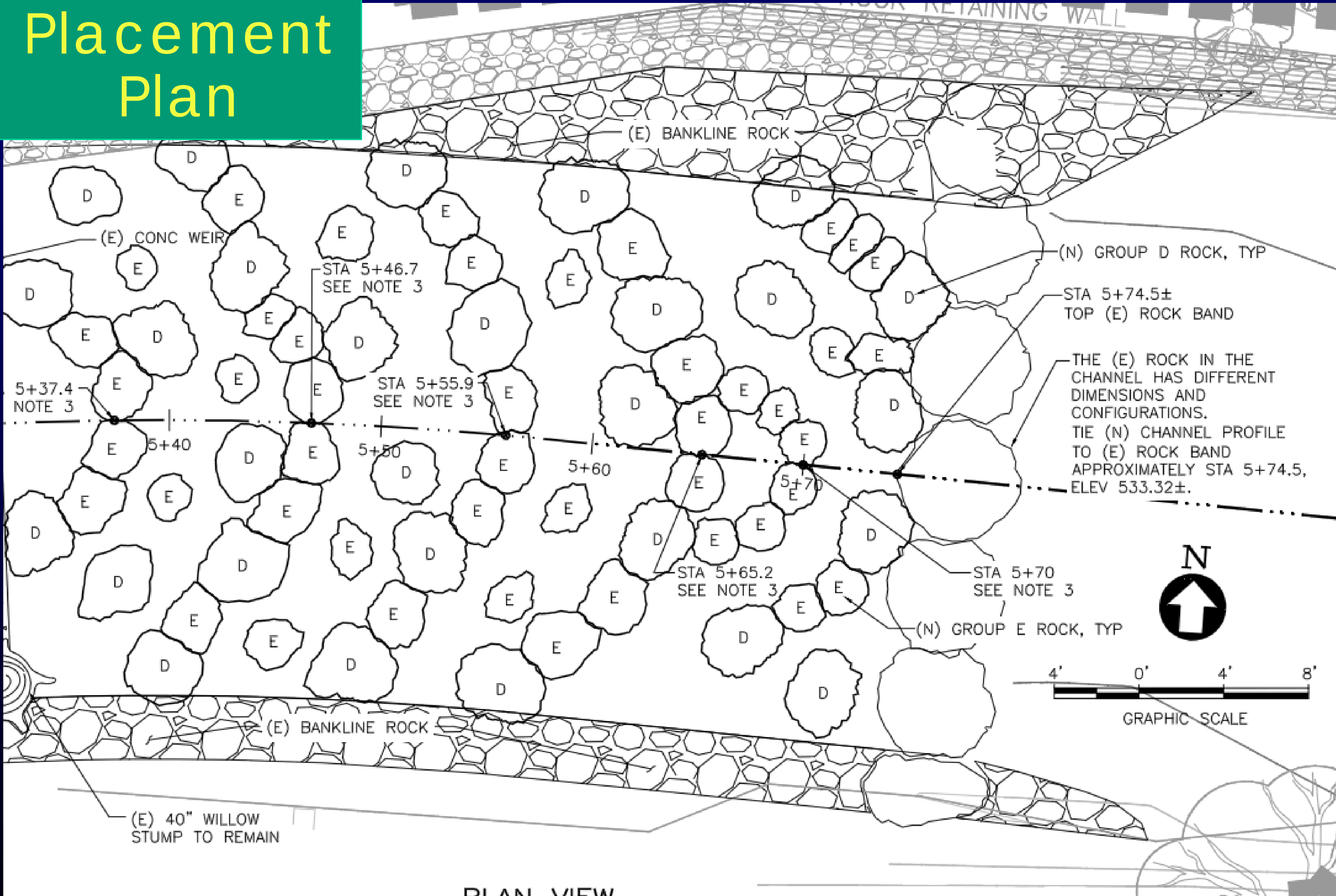
2. FOR DETAIL SECTIONS SEE: 7 / C-6

6 / C-4 **ROCK CHUTE AND POOL**
DETAIL PLAN

Graphic Scale
0 10' 20'

Rock Placement Plan

Rock Placement Plan



Rock Placement Plan

Evaluating Fish Passage Conditions in Roughened Channels

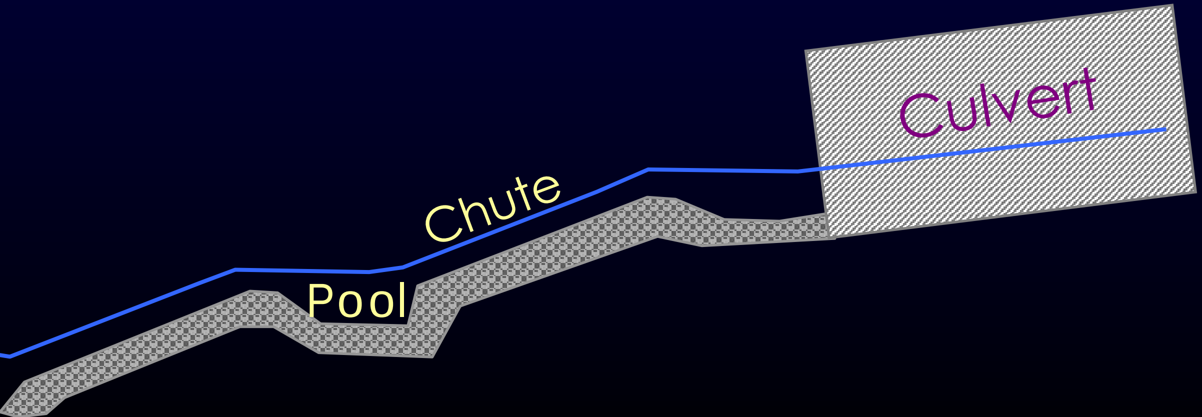
Applied Passage Criteria

In Ramps, Chutes & Cascades

1. Ave. Cross Section Water Velocity (*U*)
2. Max Water Depth in Cross Section
3. Turbulence (EDF)

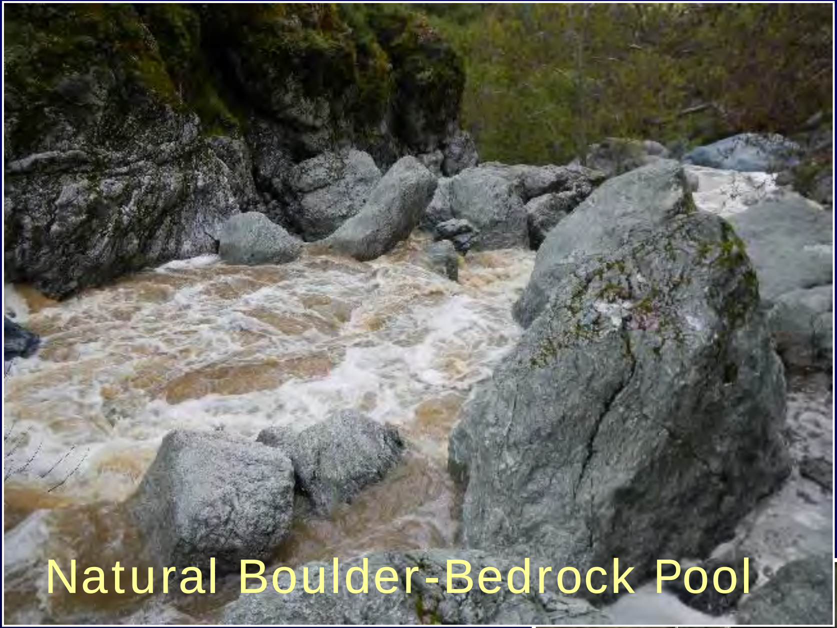
In Rock Armored Pools

1. Water Surface Drop
2. Pool Depth
3. Turbulence (EDF)



Plunging Flow & Turbulence

- Energy is dissipated in receiving pool through turbulence (heat)
- Pools with adjustable beds will scour and enlarge to dissipate energy
- Armored pools will not adjust – can become extremely turbulent
- Excessive Turbulence Creates can Block Fish Passage


Natural Boulder-Bedrock Pool


Grouted Rock Pool


Concrete Fishway

Turbulence in Pools

Energy Dissipation Factor (EDF)

Measure of Power Dissipation per Volume of Water:

$$EDF = \frac{\gamma Q h}{V}$$

h = Drop into Pool, change in EGL (ft)

Q = Flow (cfs)

V = Pool Volume (cf)

γ = Unit Weight of Water (62.4 lb/cf)

For a pool dissipating energy from a chutes or cascade:

$$h = \frac{U_{chute}^2 - U_{pool}^2}{2g}$$

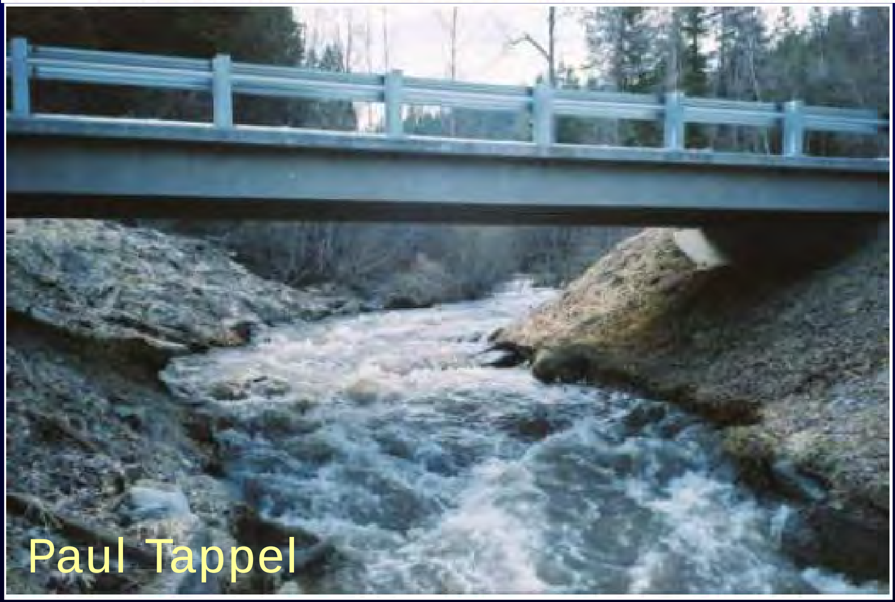
U = Water Velocity (ft/s)

Thresholds for Pools :

Adult Salmon:
EDF > 4 ft-lb/s/ft^3

Adult Resident Trout:
EDF > 3 ft-lb/s/ft^3

Turbulence in Rock Ramps/Chutes and Cascades



In Ramps, Chutes & Cascades

Turbulence:

$$EDF = \gamma QS/A$$

γ = Unit Weight of Water (62.4 lb/cf)

Q = Flow (cfs)

S = Slope of the Water Surface or EGL (ft/ft)

A = Wetted area (sf)

Turbulence in Rock Ramps/Chutes and Cascades

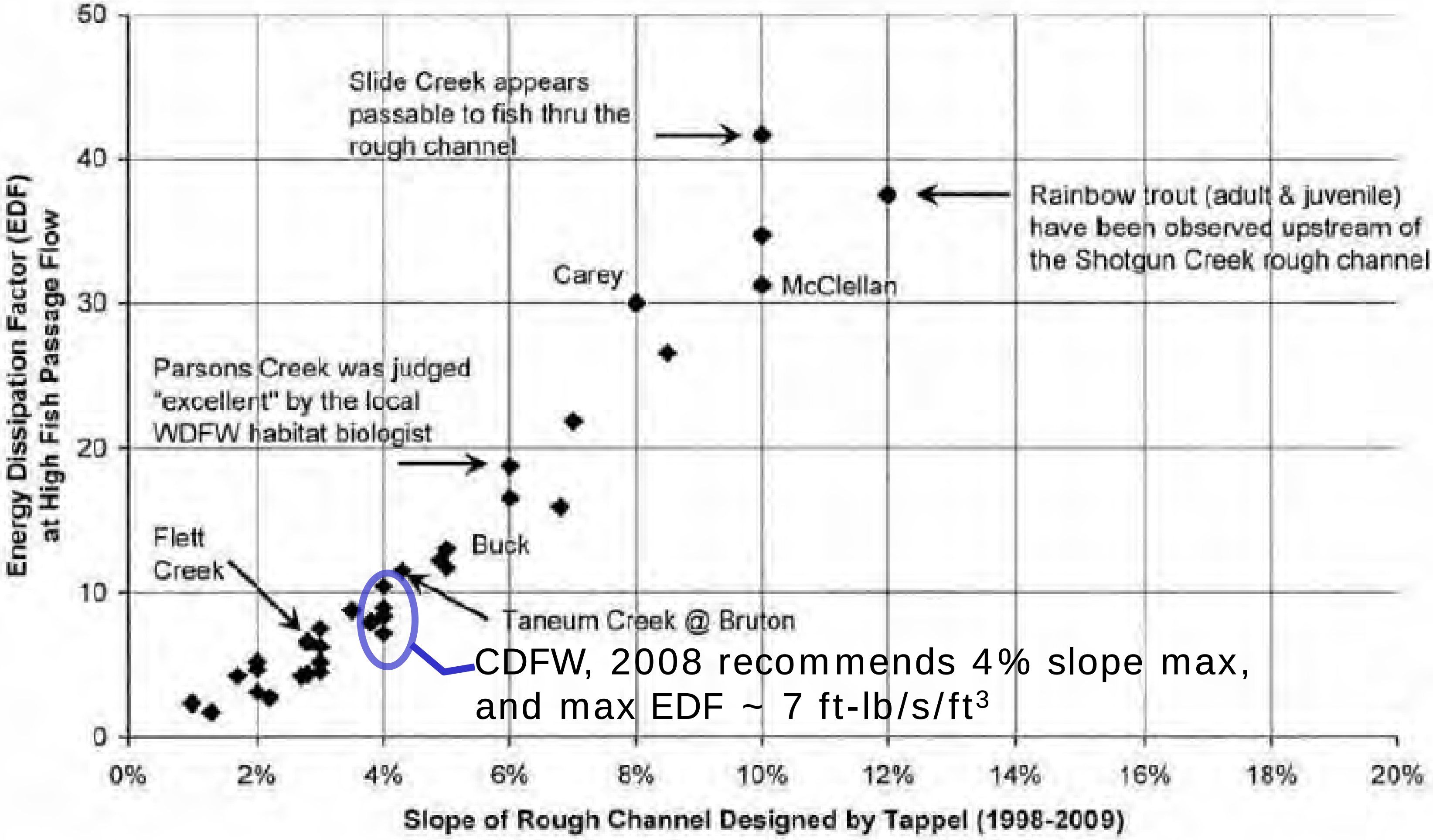
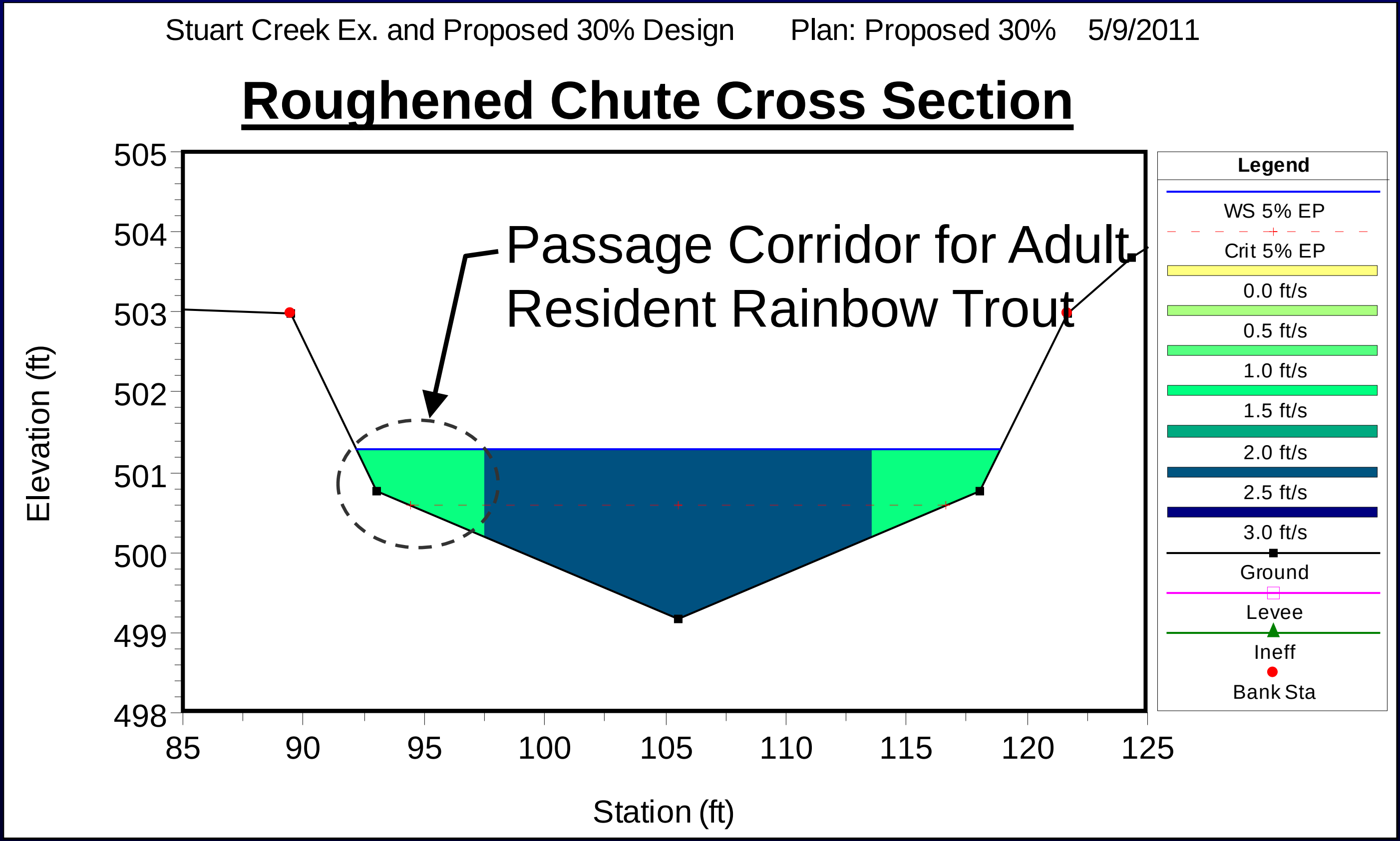


Figure 6.9: Energy dissipation factor for selected roughened channels (Tappel 2010).

Dividing Channel into Subsections
Rock Ramps/Chutes/Cascades

High Passage Flow
Adult Resident
Rainbow Trout

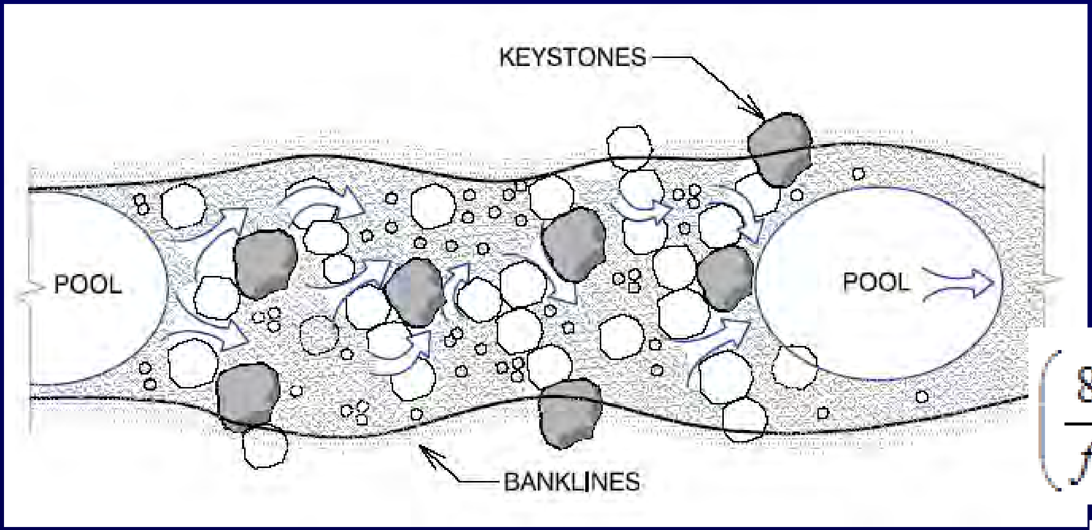


Passage Conditions in Subsection

Mean Width = 4.5 ft (DFG min = 4 ft)
Ave. Depth = 0.76 ft
Ave. Velocity =1.45 ft/s

Flow in Section = 5.0 cfs
Water Surface Slope = 0.03 ft/ft
EDF = 2.7 ft-lb/s/ft^3

Cascade and Pool Roughened Channel



Relative Roughness is Key to Fishway Performance

Friction Factor

Depth

$$\left(\frac{8}{f}\right)^{0.5} = 1.11\left(\frac{d}{D_{84}}\right)^{0.46}\left(\frac{D_{84}}{D_{50}}\right)^{-0.85} S_0^{-0.39}$$

Mussetter (1989)

1:6 Model of Trabuco Cascade & Pool Roughened Channel

Construction Sequencing and Methods

1. Grading and Compact
2. Placing Rock Structures

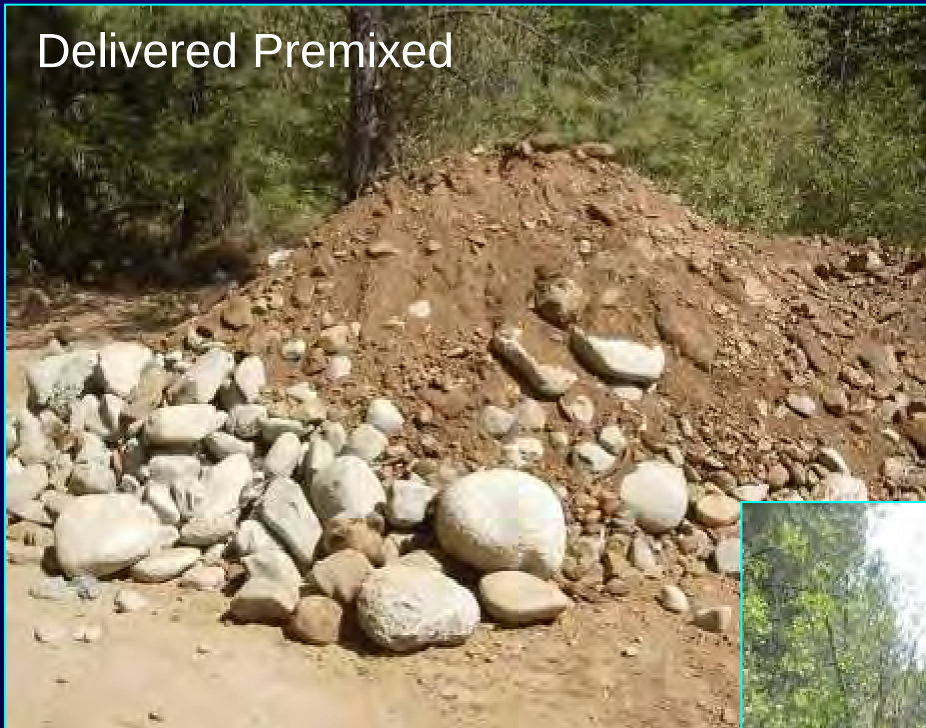
Construction Sequencing and Methods

3. Keystones and Bankline Rock

Construction Sequencing and Methods

4. Stockpile Engineered Streambed Material onsite. Within a small section of channel, place material in correct proportions and mix with excavator bucket …

Construction Sequencing and Methods



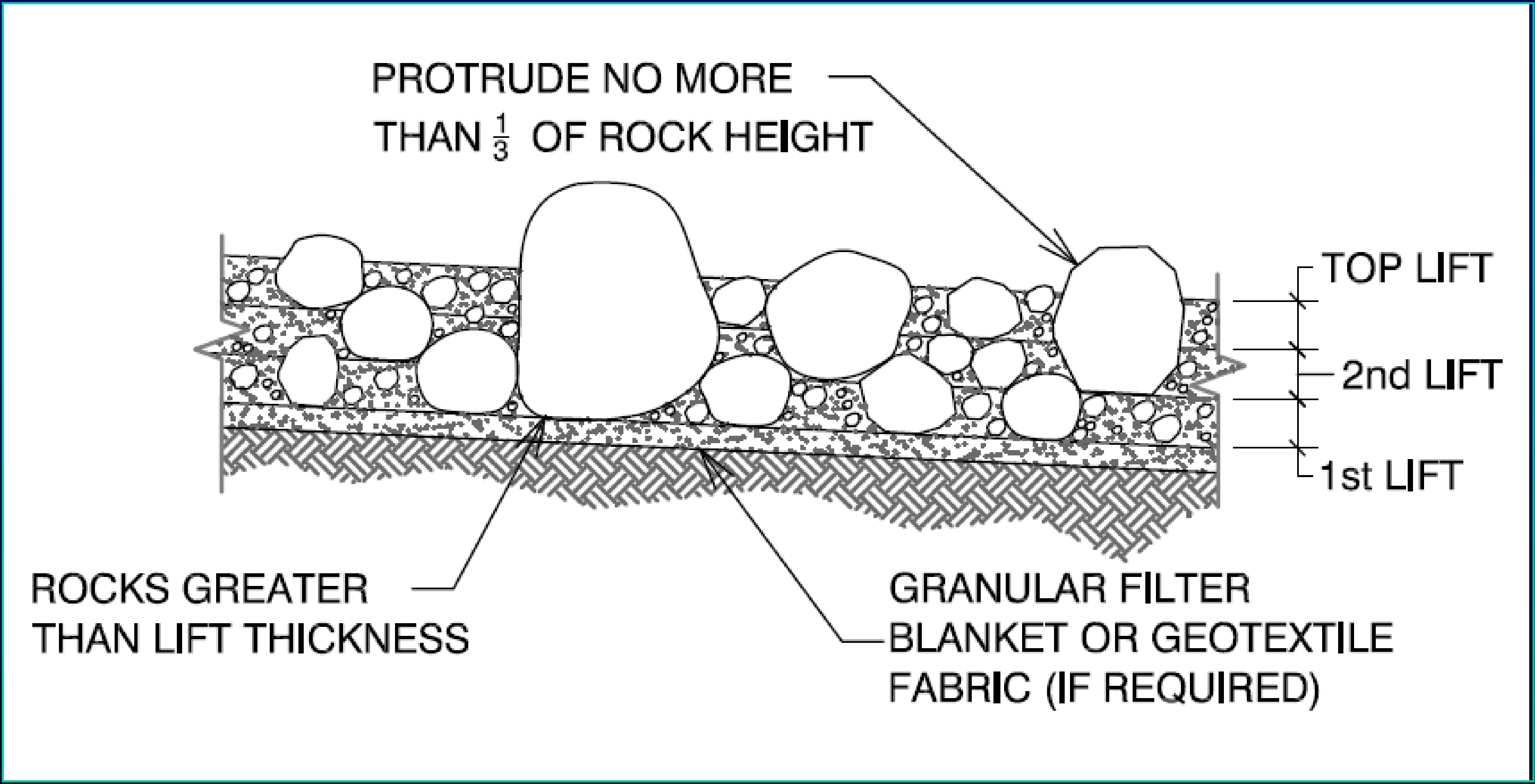
4. …If delivered premixed to site, must be remixed in channel due to settling in truck.

5. Install Engineered Streambed Material (ESM)…

Construction Sequencing and Methods

5. ...Place Structure Rocks into Lifts.

Construction Sequencing and Methods



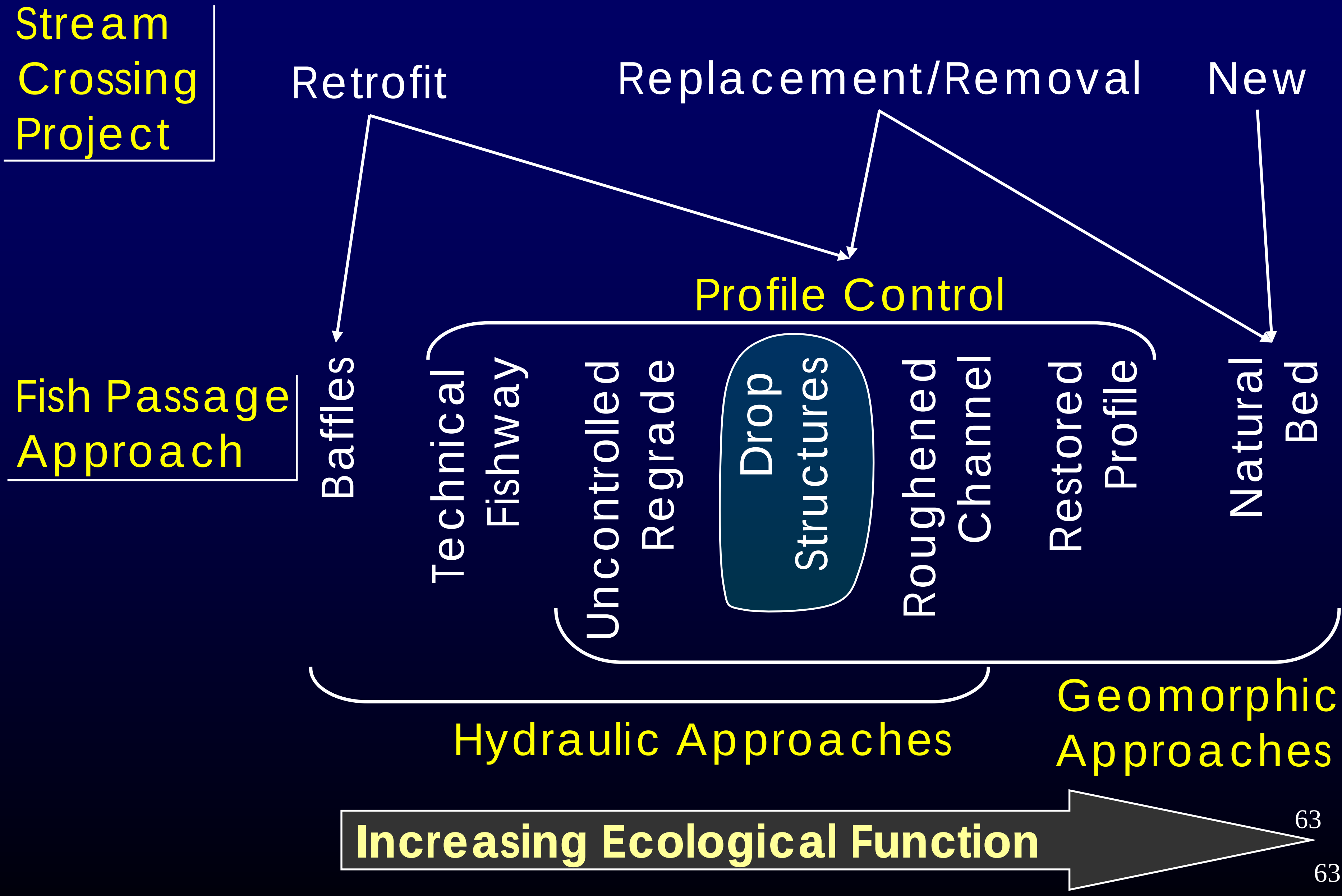
5. ..Construct channel bed in lifts. Compact each lift...

Construction Sequencing and Methods

<u>For best results</u>: Flood each lift and use a plate compactor

6. Flood channel bed and banklines to fill voids, compact bed, and wash fines off surface. Collect and remove fines from bottom of reach.

Tools for Aquatic Organism Passage



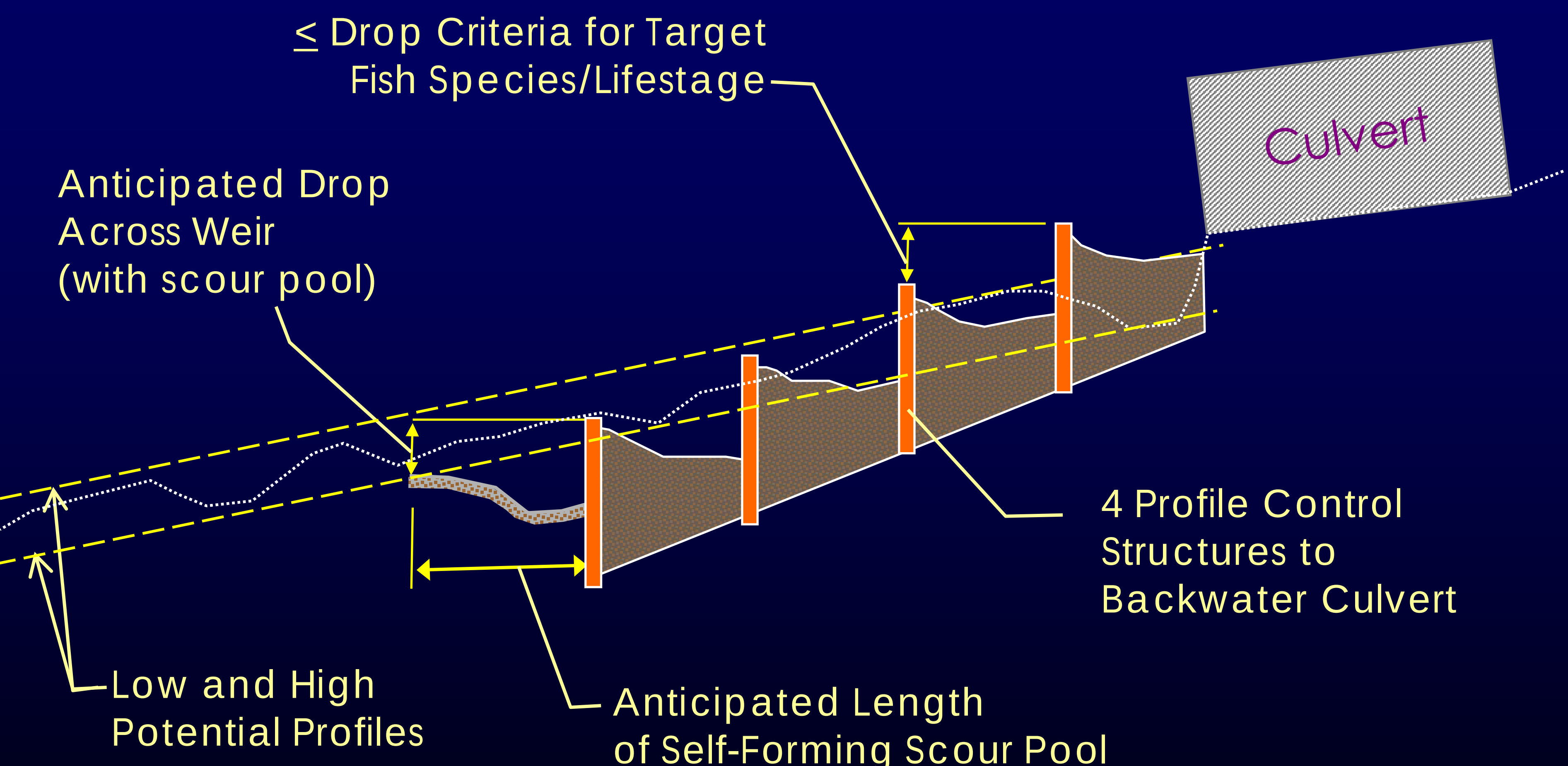
63

Forced Profiles with Drop Structures

Drop Structures (weirs, sills, chutes):

- Discrete structures
- Distinct drops in the channel
- <u>Native streambed material between</u>
- Types: Flexible vs Rigid

Profile Control Transitions (Steps or Drop Structures)



- ❖ Place End of Profile Control based on Low Potential Profile with Anticipated Scour Pool

65

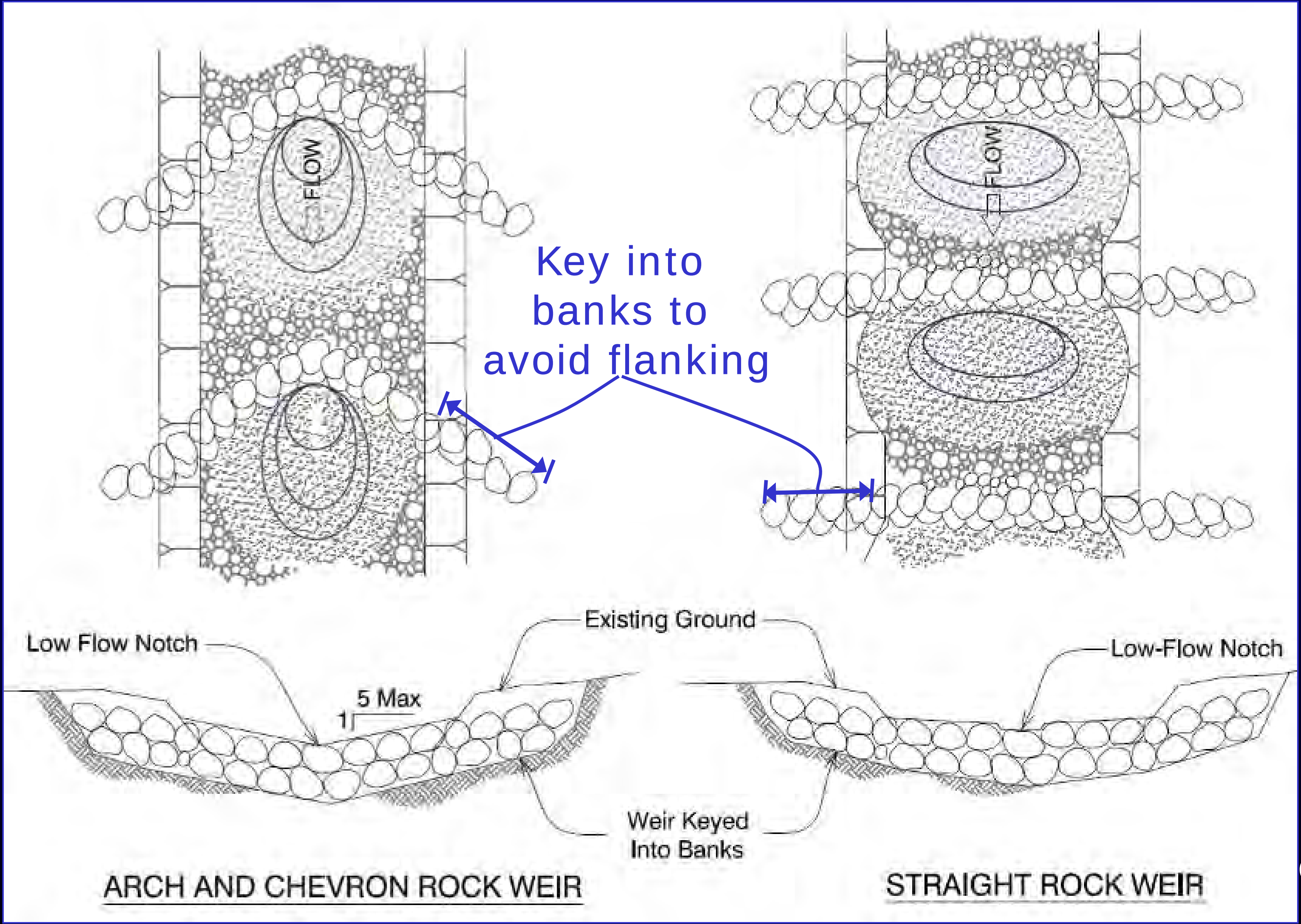
Rock Weirs & Chutes

- Irregular surface provide hydraulic diversity
- Withstands small shifts, and easy to field adjust
- Maintains channel shape
- Lower cost than roughened channel

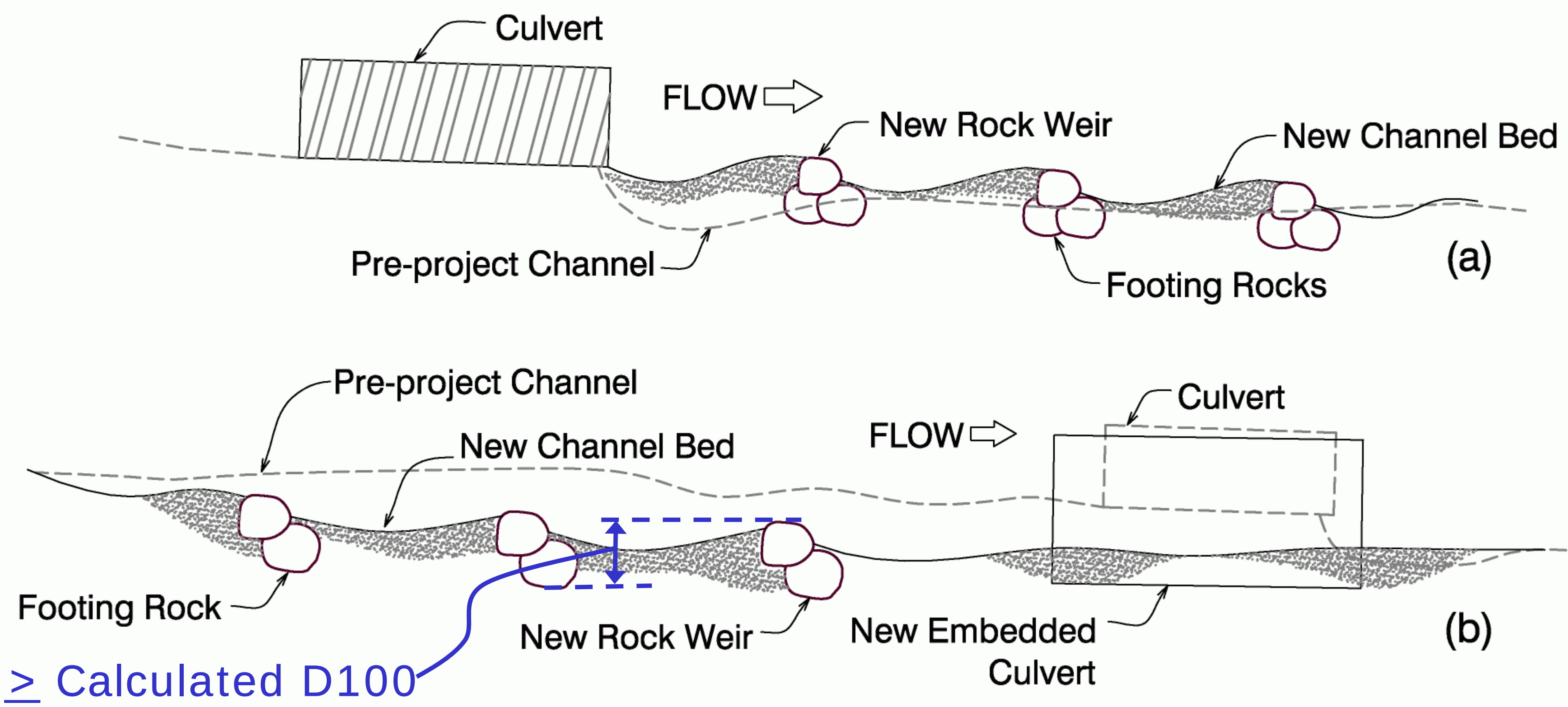
- Requires skilled operator
- Larger Vertical Tolerance
- Built at lower slopes than rigid weirs (max 4 to 5%)
- Cascading failure possible

Arch Shaped Rock Weirs

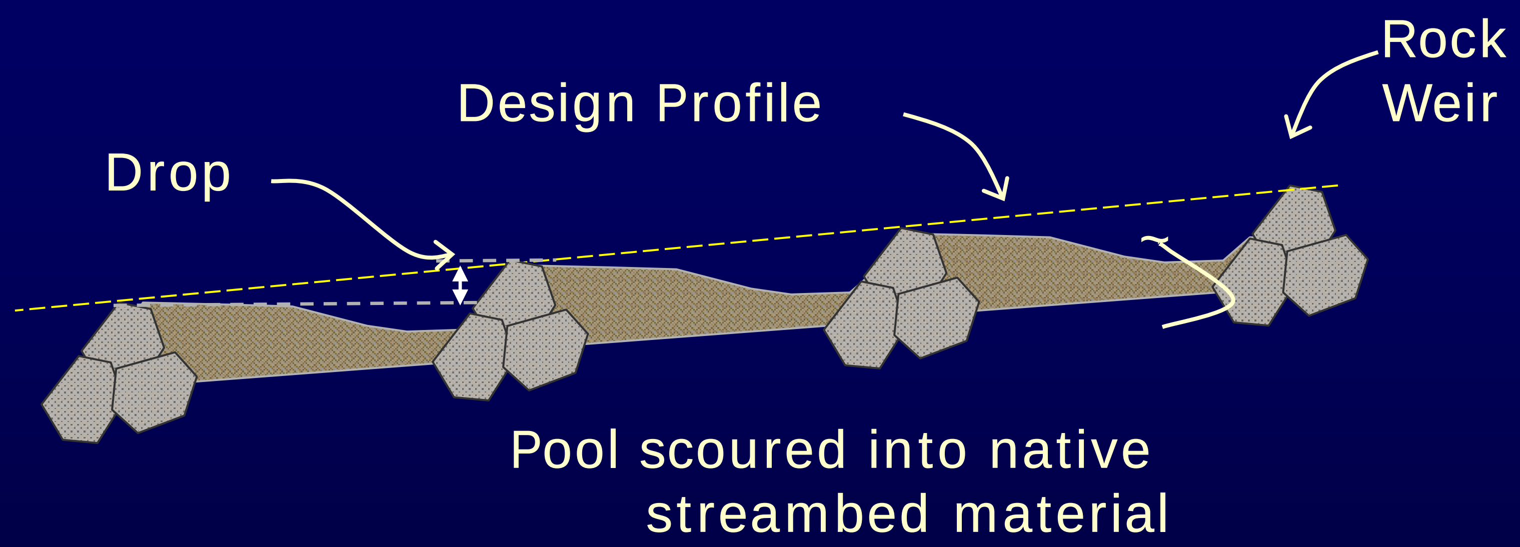
Shape of Rock Weirs

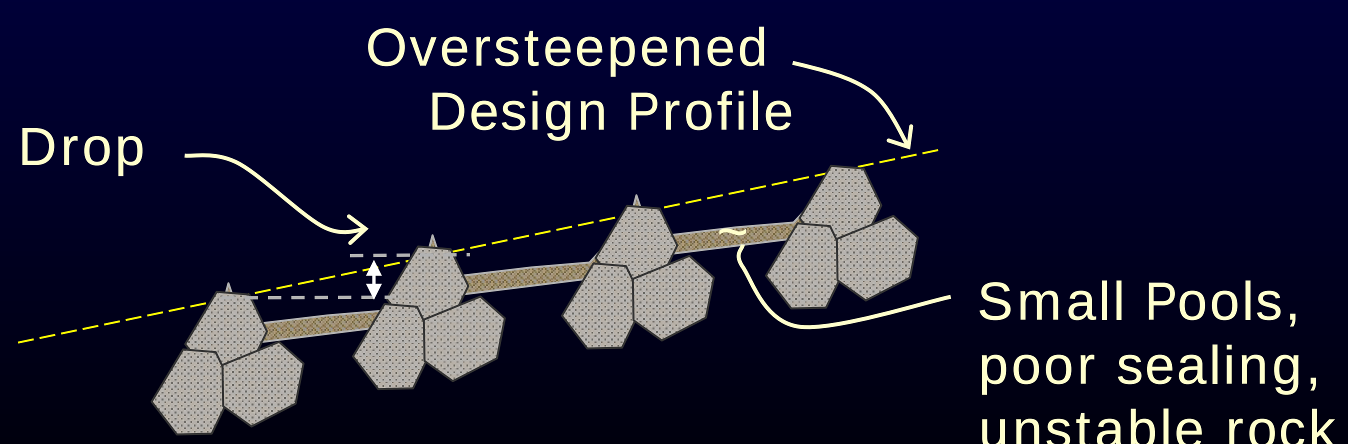


Footing of Rock Weirs



Spacing of Rock Weirs





Rock Sizing for Weirs

From Design of Rock Weirs (NRCS, 2000)

$$D_{50-riprap} = \frac{2.9wDS}{CK}$$

Far West States (FWS) Lane Method riprap sizing method (NRCS, 1996)

w = channel top width at the design flow (feet)

D = maximum depth of flow in channel (feet)

S = channel slope (feet/feet)

C = coefficient for channel curvature (1 for straight channels)

K = side slope coefficient. 0.53 for 1.5H:1V, 0.87 for 3H:1V,

Rock Weir Gradation

Dmin-Weir = 0.75 (D50-Riprap)

D50-Weir = 2 (D50-Riprap)

D100-Weir = 4(D50-Riprap)

Rock Riffles and Chutes as Drop Structures

<u>Individual Chutes</u>:

- Energy dissipation
- Diversity
- Slope from crest to crest typically $\leq$ 3%

<u>Shape of Chute</u>:

- Top width
- Head differential (typ. 2 ft max)
- Plan vee
- Cross section vee
- Low flow channel

Riffles and Chutes

Spring Prairie Cr
Cobble riffle

From Luther Aadland

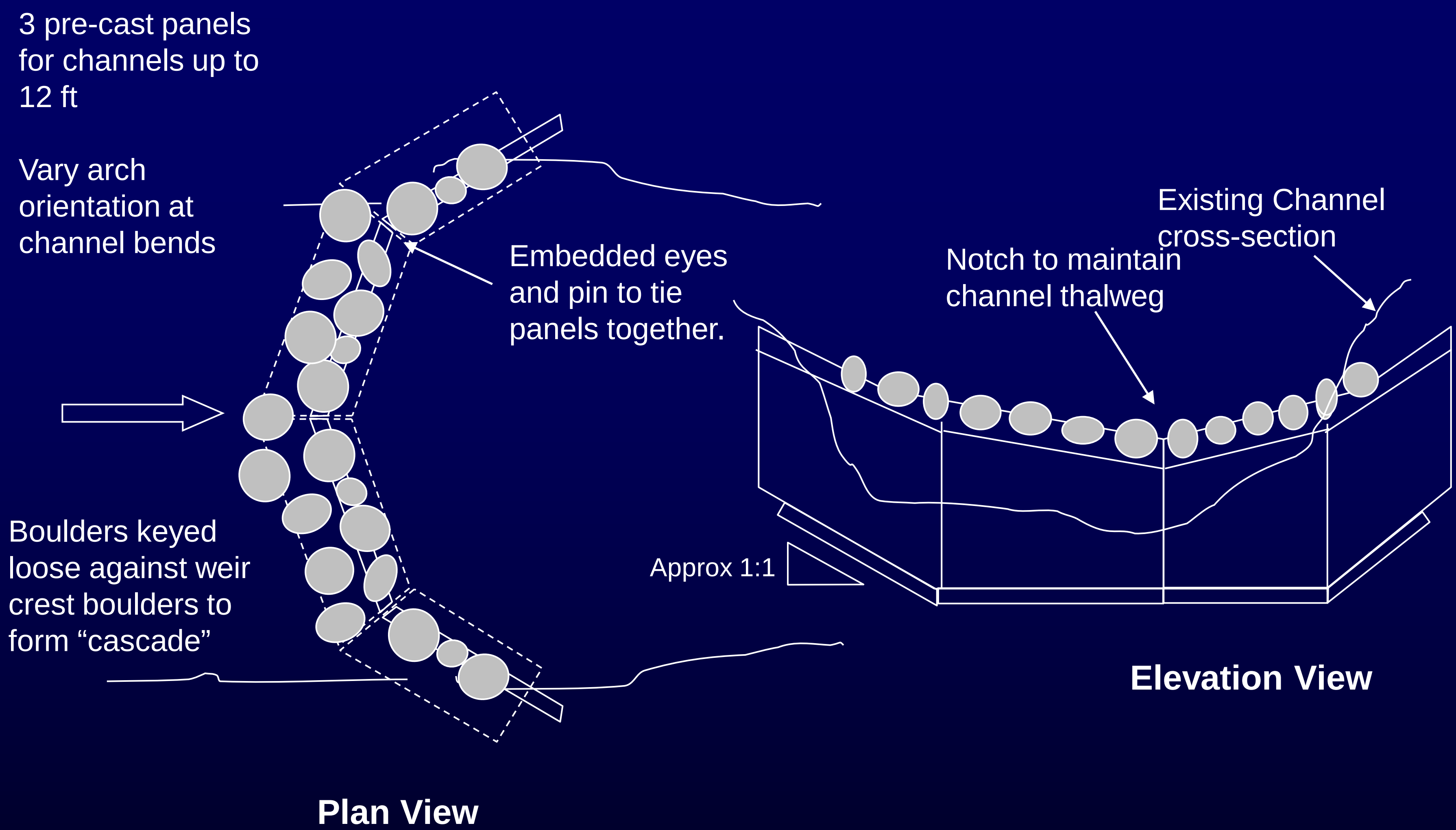
Rock Riffles and Chutes

Rigid Weirs: Concrete, sheet pile, ...

- Objectives:
  - Steepen grade (self sealing)
  - Rigid permanent bed control to maintain steep grade
- Max 5% grade in small streams
- Prefabricated; installation easy but demands care
- Deeper keys into bed and banks than rock weirs
- Shape to fit channel and control thalweg (v-shape)
- Can add hydraulic complexity along crest to improve passage

Prefabricated

From: Kozmo Bates



Modular Arch Drop Structure

From: Kozmo Bates

Log controls

Log Controls
Used to raise
incised channel

Passage optimized,
Habitat not

Log controls

Horizontal Double Log Sills

- Keeps log wetted to increases longevity
- Easy to construct
- Spreads out flow
  - Forms wide pools, rather than long
  - Anticipate bank erosion when keying
- Wide smooth surface/ low hydraulic complexity
  - May not be good for juvenile passage

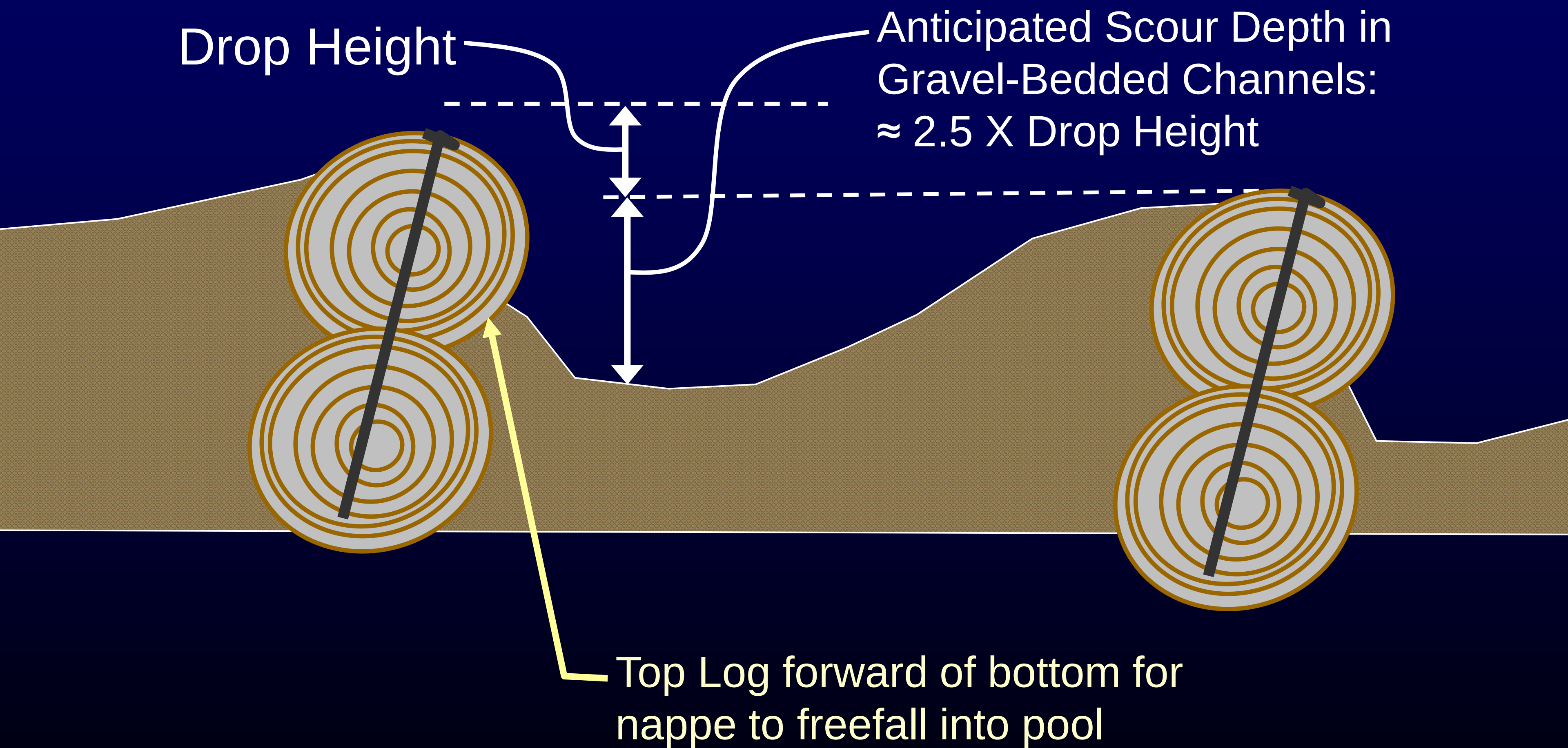
Three keys to stability

1. Double log, spiked
2. Ballast
   (concrete or rock)
3. Tiedown

Structure flanked

Log control remains structurally sound

Log controls: Rule of Thumb for Scour



Log controls

- Logs anchored to wood posts
- Rock added to protect banks

Complex Log Steps

Index Creek
Vee log weirs

Complex Log Steps

Physt R. trib

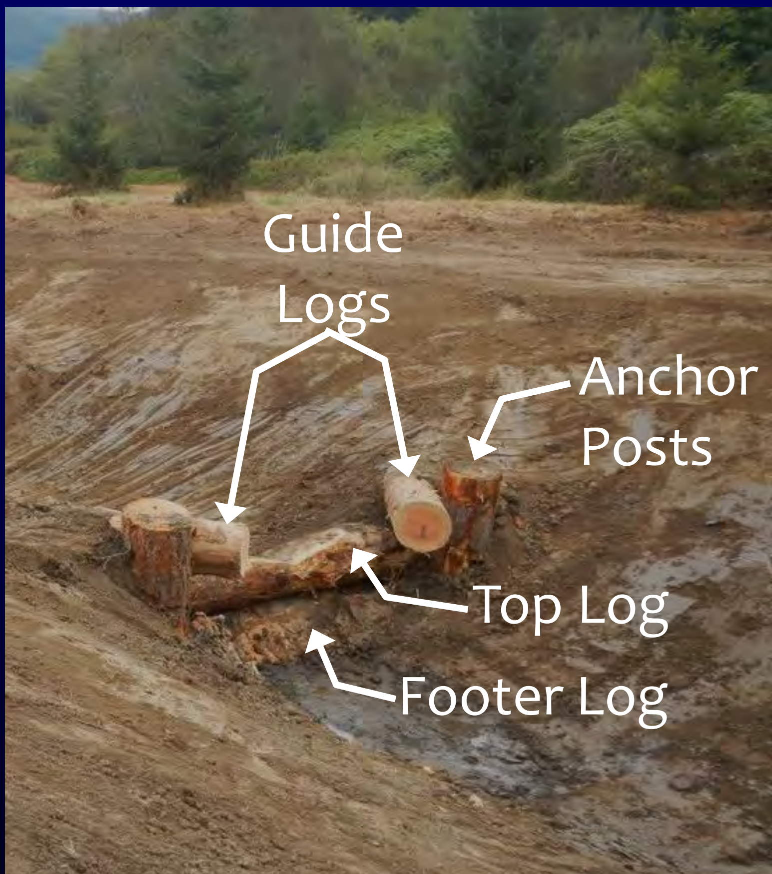
"X-weirs"

Natural Log Steps

Training logs along bank confine flow

Complex Log Steps

Notched Top Log



- Top Log and Guide Logs Thru-Bolted to Anchor Posts
- **Top Log Anchored to Footer Log**

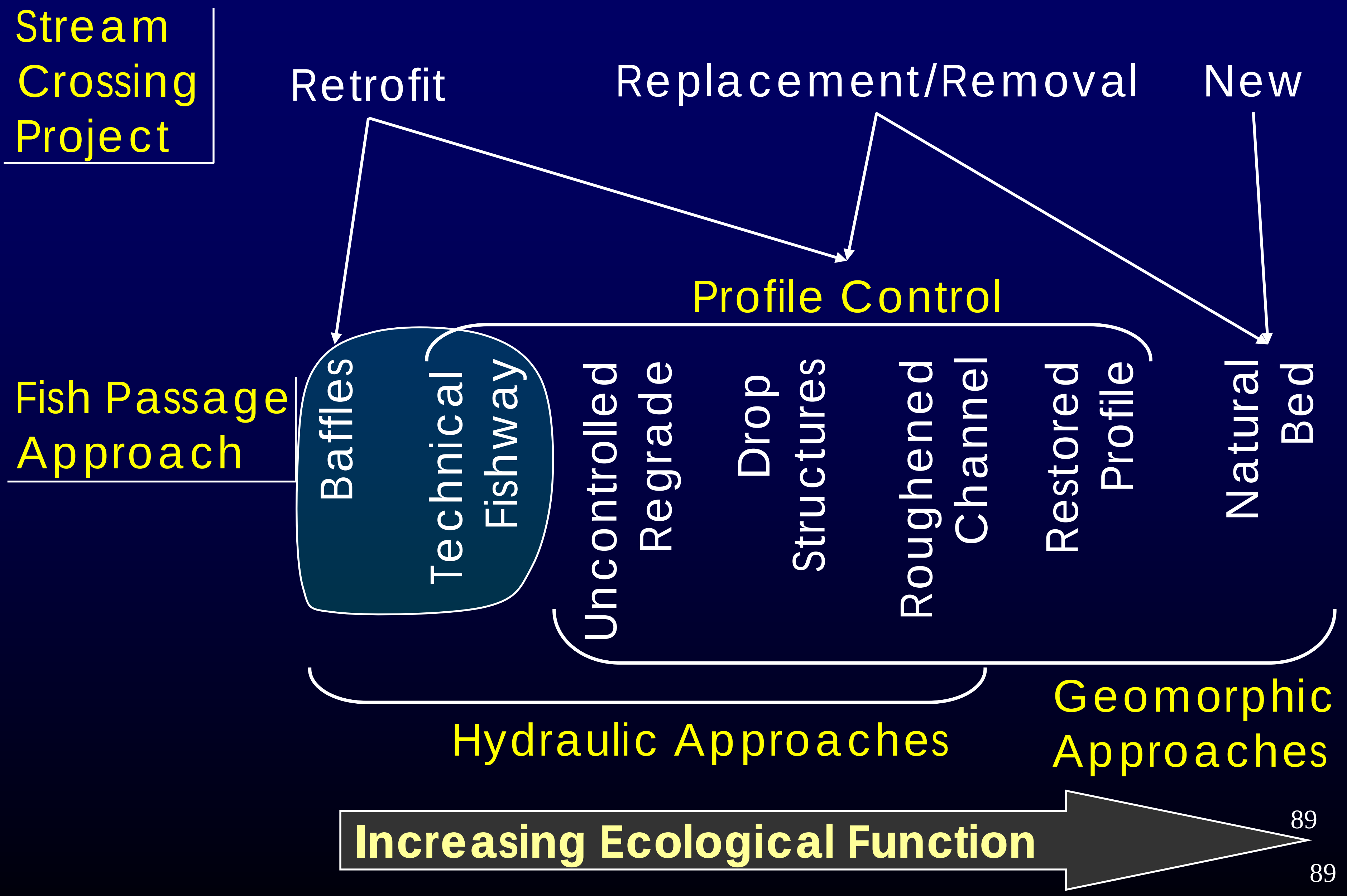
Complex Log Steps

No Rock Used

Log controls

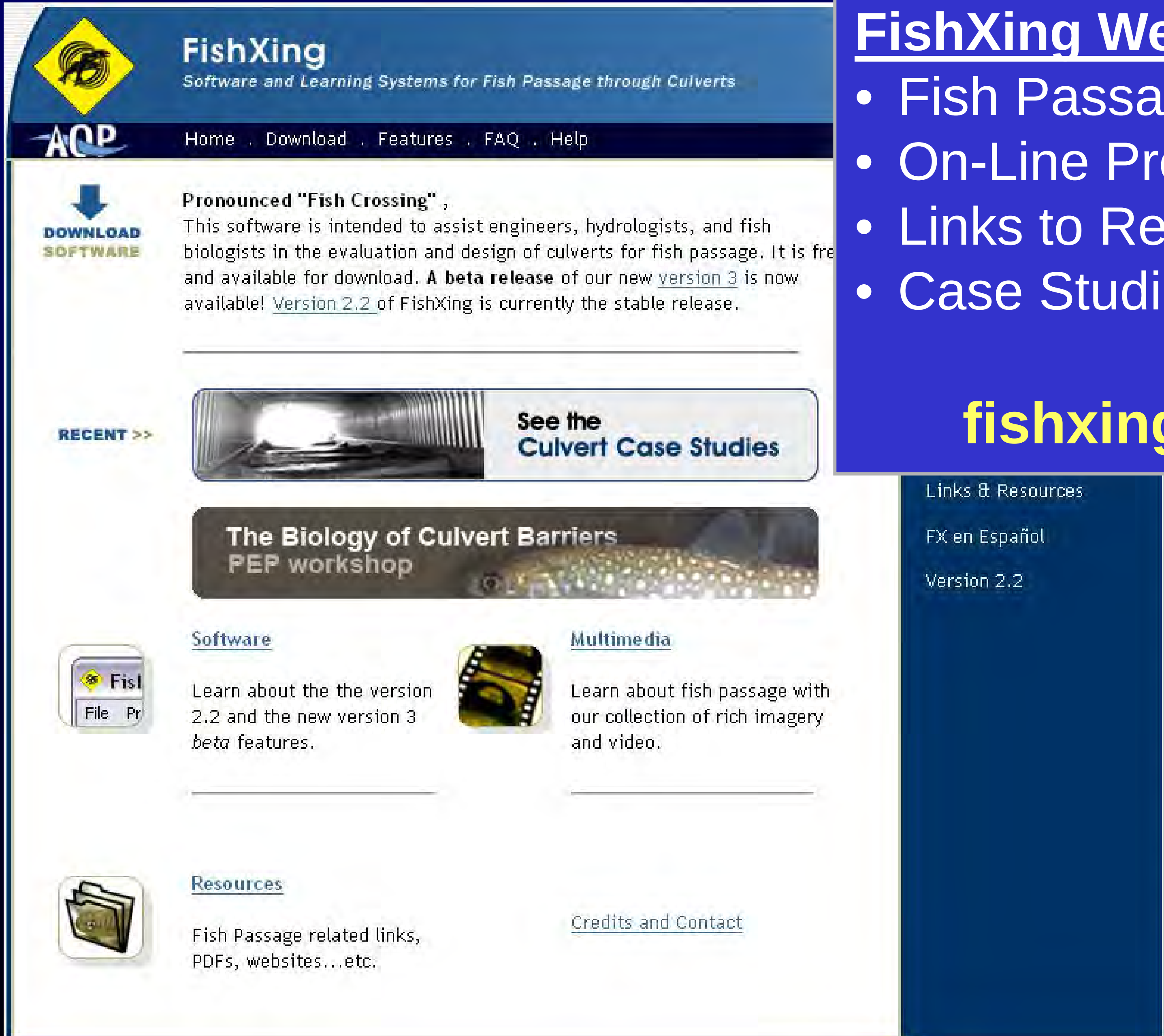
- **Straight**
  - Objective: Steepen grade, optimize select passage, minimize cost and length, secure elevation control
  - 5% grade max as bed retention
  - Uniform channel
  - Secure designs available
- **V- Shape**
  - Objective: Steepen grade, deepen thalweg, narrow channel, provide select passage
  - More diverse channel
- **Can be made complex**
- **Durable**

Tools for Aquatic Organism Passage



89

Fish Passage Resources



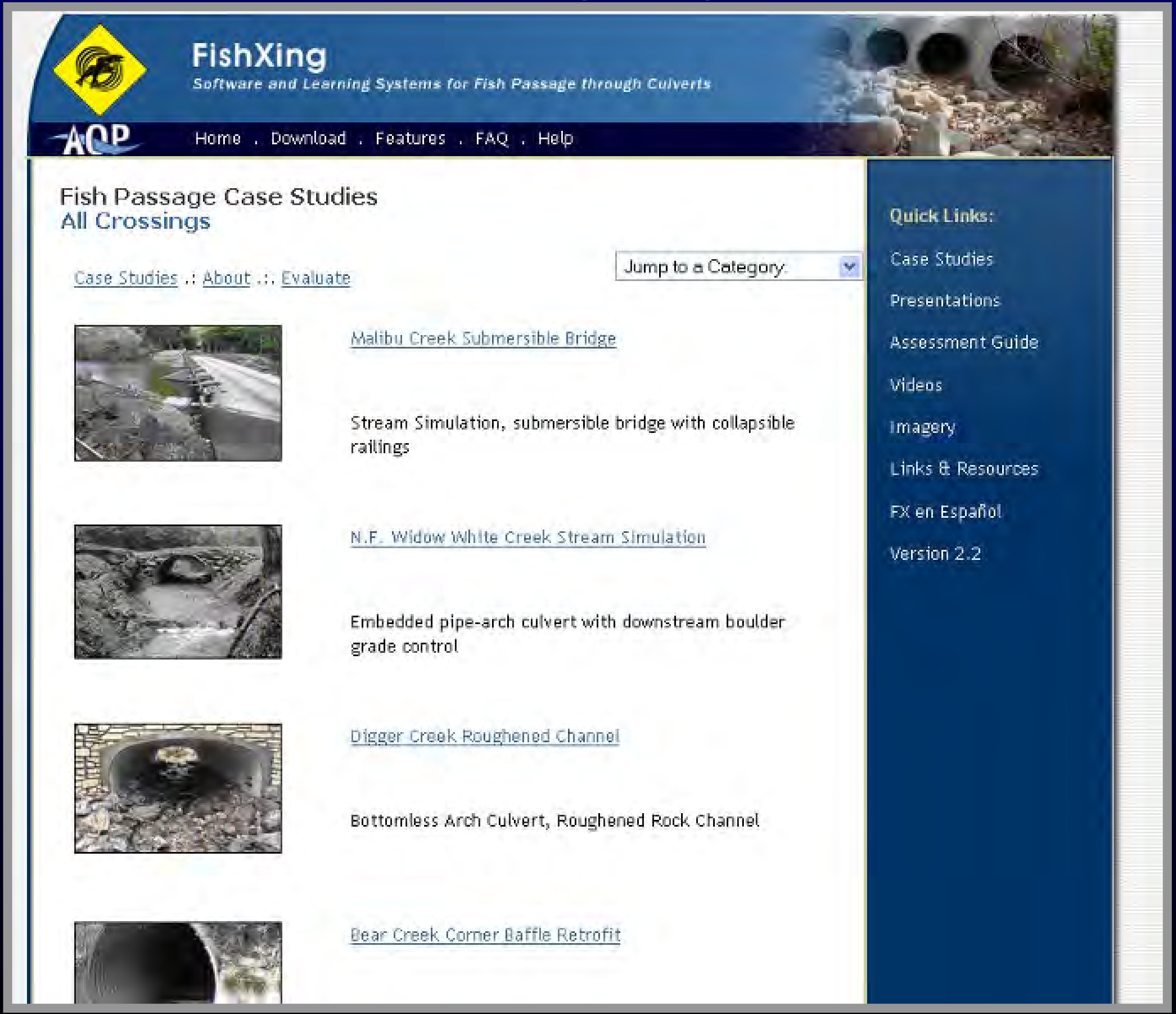
FishXing Website

- Fish Passage Software
- On-Line Presentations
- Links to Resources
- Case Studies

fishxing.org

Fish Passage Case Studies

fishxing.org



Post-project Monitoring

Ross N. Taylor
Ross Taylor and Associates

Michael Love
Michael Love & Associates

Michael J. Furniss
Pacific Northwest Research Station
Aquatic and Land Interactions

Dr. Margaret Lang, P.E.
Humboldt State University
Environmental Engineering

Fish Passage Design Workshop

Assume
Steady State

STREAMS CHANGE

Streams + Culverts = Channel
(dynamic) (static) Adjustment

1979

1998

Assessments Provide Baseline for Monitoring

- Assessment efforts are monitoring the performance of the existing infrastructure.
- Our baseline is drawn (almost).
- Passage Assessment Database (PAD). www.calfish.org

Five-Co. Assessments

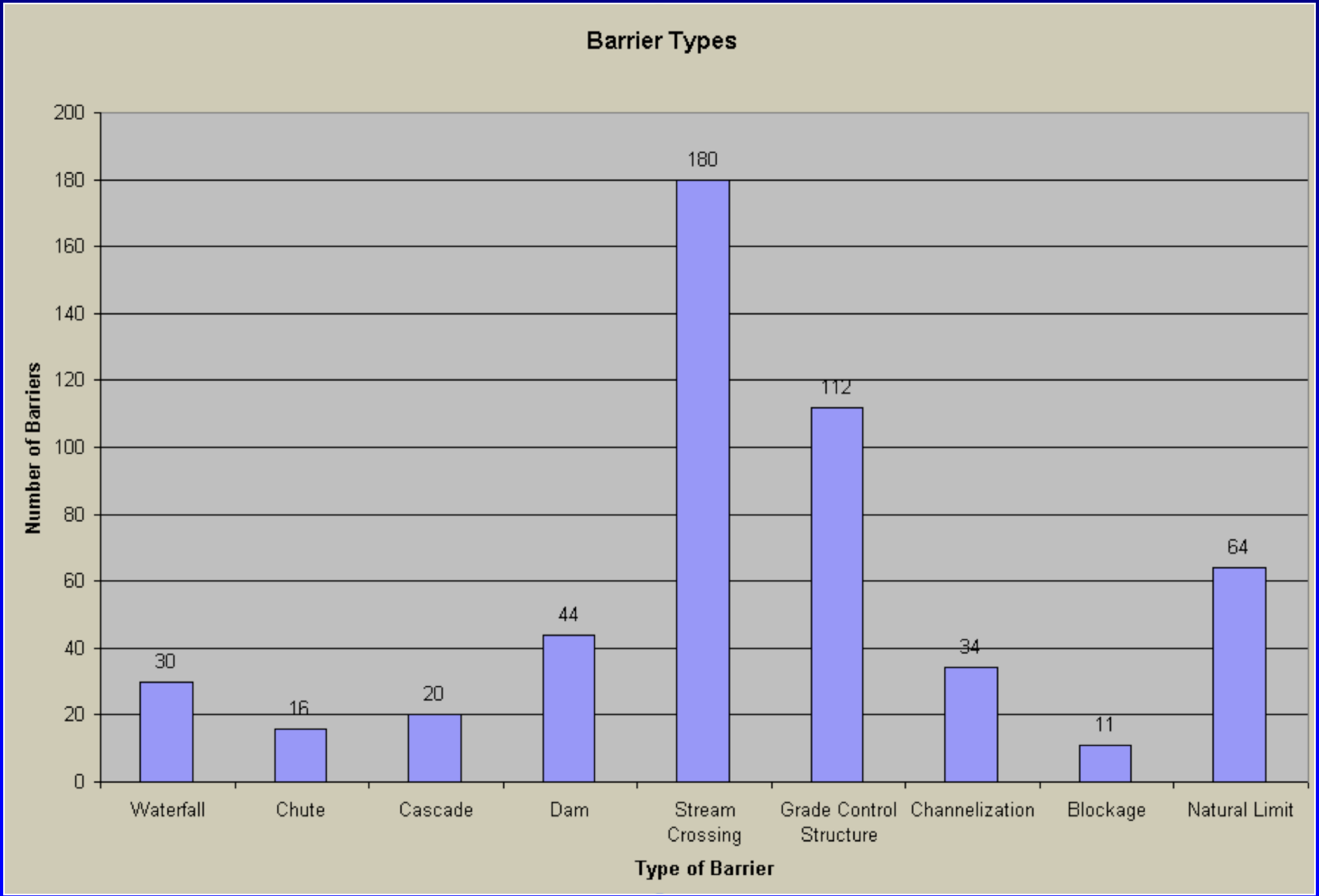
- Humboldt County – 160 crossings inventoried and 92 evaluated.
- Del Norte County – 67 crossings inventoried and 34 evaluated.
- Coastal Mendocino – 74 crossings inventoried and 34 evaluated.
- Siskiyou County – 118 crossings inventoried and 36 evaluated.
- Trinity County – 107 crossings inventoried and 51 evaluated.

COUNTY	Poor Condition	Undersized (<10 yr)	Passage Assessment	High-Priority Sites
Humboldt	28%	57%	Red = 14 Gray = 51 Green = 2	20 sites
Del Norte	21%	79%	Red = 9 Gray = 17 Green = 2	6 sites
Siskiyou	19%	53%	Red = 25 Gray = 10 Green = 1	10 sites
Coastal Mendocino	39%	36%	Red= 15 Gray = 10 Green = 3	5 sites
Trinity	14%	73%	Red = 41 Gray = 9 Green = 1	13 sites
Clean-up Assessment	42%	74%	Red = 30 Gray = 9 Green = 1	5 sites
AVERAGE or TOTAL	**23%**	**62%**	**RED = 134** **GRAY = 106** **GREEN = 10**	**59 sites**

Five-Co. Projects Completed: 1998-2012

County	Completed Projects	Miles Made Accessible	Percent High Priority Completed	Remaining High Priority Sites
Del Norte	6	11	75%	2
Humboldt	26	39	71%	6
Mendocino	11	20	100%	0
Trinity	12	25	67%	3
Siskiyou	10	51	40%	9
TOTAL	**65**	**146**	**71%**	**20**

Santa Barbara Co. Barriers Identified by Matt Stoecker



Three Monitoring Types

- Implementation "Did we build it as intended?" ODF Survey
- Effectiveness "Did it work?" Smith River PIT, Reba
- Validation "Are the assumptions correct?" Lang, Love & Trush

Two Types of Stream Crossing Monitoring

- **Qualitative**
  - All replaced or retrofit crossings, selected performance checks. Revisit should be scheduled (Implementation + Effectiveness).
- **Quantitative**
  - Just a few projects, but comprehensive (Effectiveness + Validation).

Define performance expectations (objectives); monitor against these.

Bed Stability
Sediment Distribution
Bank-Lines
Bank Stability
Water Depths
Velocities

Fish Migration/Delay
Population Densities
Habitat Utilization
Juvenile Passage

Implementation Monitoring

- Crucial elements to get right
  - Inadequate inspection
  - Unknowledgeable inspectors
- “As built” vs design
- Essential to evaluate and interpret effectiveness

Qualitative Monitoring:
Develop a Checklist

Bed adjustment and stability

- ✓ Is a channel setting up in the crossing?
- ✓ Aggradation and degradation?
- ✓ Permeability problems?

Channel adjustment and stability

- ✓ Bank stability
- ✓ Head-cutting
- ✓ Pool formation

Crossing condition

- ✓ Catching debris
- ✓ Accumulating sediment at inlet
- ✓ Structural issues

Photo Monitoring

Upstream Channel

Culvert Outlet

Culvert Inlet

Downstream Channel

Effective Use of Photos

- ✓ Careful selection of vantages.
- ✓ Reference points and scale in shots.
- ✓ Wide angle or panoramas.
- ✓ Take lots, find the keepers.
- ✓ Metadata! (captioning). Never skip this.
- ✓ Effective archiving.
- ✓ Re-shoot the same frames on revisit.

Photo Monitoring – reference points

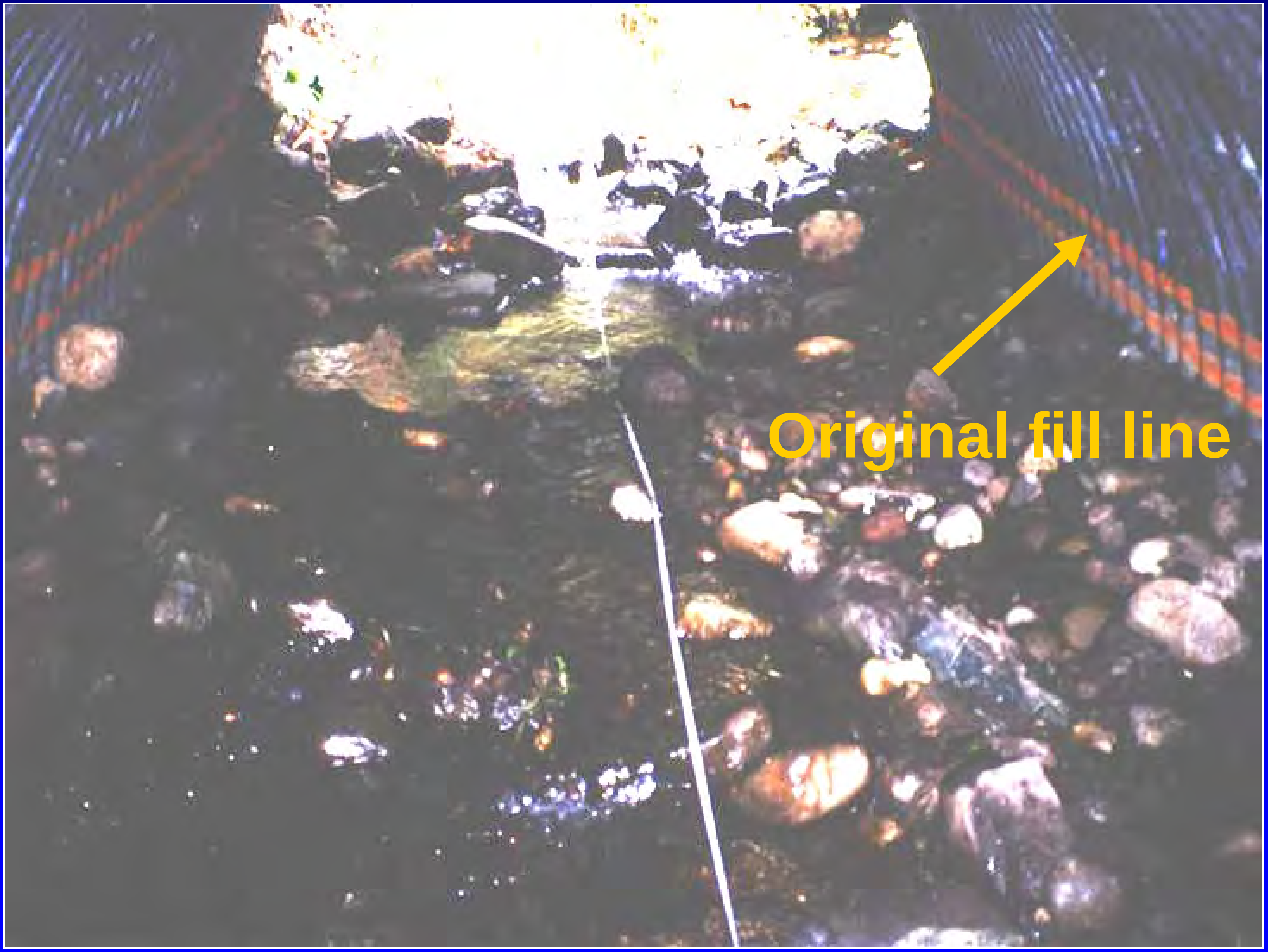


Photo Monitoring – McCready Gulch

Implementation

Photo Monitoring – McCready Gulch

Effectiveness

Quantitative Monitoring

Physical Monitoring

- **Longitudinal profiles**
- **Velocity distributions**
- **Substrate composition**
- **Bedload movement**

Detailed measurements needed over time

Quantitative Monitoring

Streambed Simulation Design Option:

- Slope w/in new crossing similar to natural channel?
- Velocities w/in new crossing similar to natural conditions?
- Minimum depths w/in new crossing similar to natural channel?

Quantitative Monitoring

Hydraulic Design Option:

- **Resurvey crossing, longitudinal profile and tailwater cross-section.**
- **Re-run new crossing with FishXing.**

Morrison Gulch – Case Study of Design versus As-built

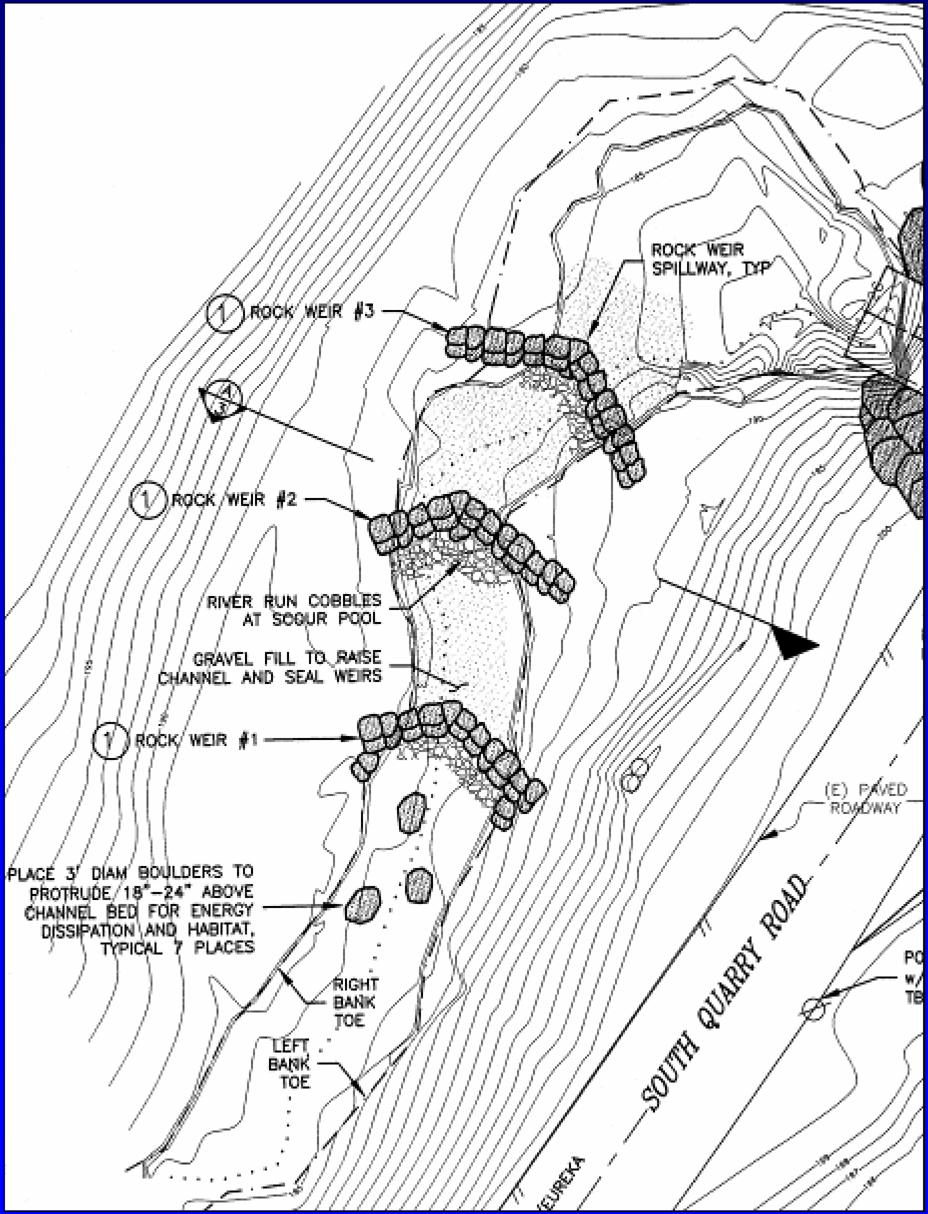
Morrison Gulch – Case Study

- High-priority – severity of barrier and fish presence.
- High likelihood of re-colonization raised site to #1 priority.
- Hydraulic design option selected.
- Grade-control structures utilized.

Morrison Gulch – Design Features

- **Slope through culvert = 0.0%.**
- **Elevation of downstream weir relative to culvert outlet = 0.5 feet higher.**
- **Design concept – install culvert, then construct grade-control weirs.**

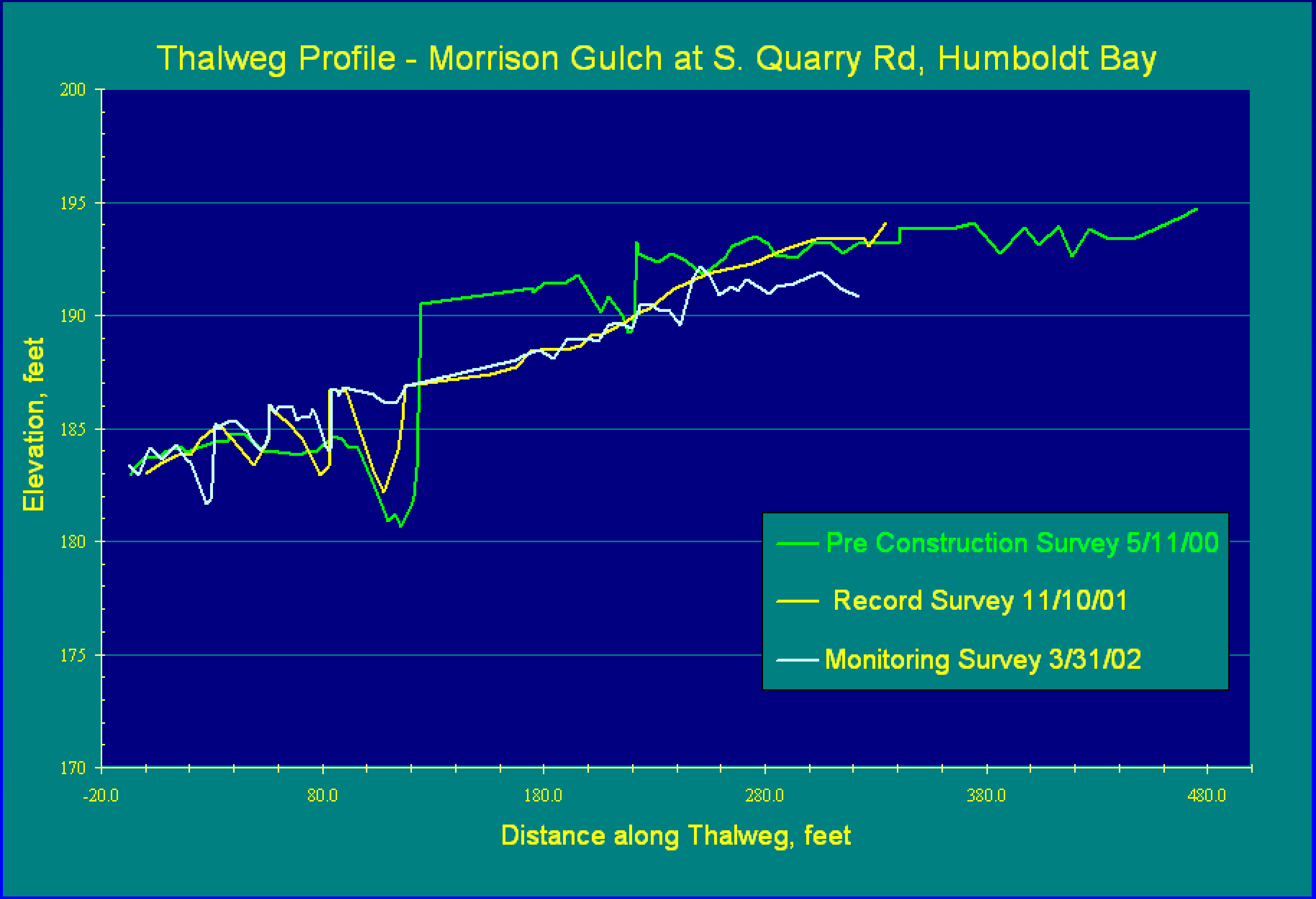
Morrison Gulch – Design Features



Morrison Gulch – As-Built Features

- Slope through culvert = 1.17%.
- Elevation of downstream weir relative to culvert outlet = set at same elevation.
- Grade-control weirs were constructed first - then culvert was installed.

Channel Bed Adjustment



Quantitative Monitoring – Passage Evaluation

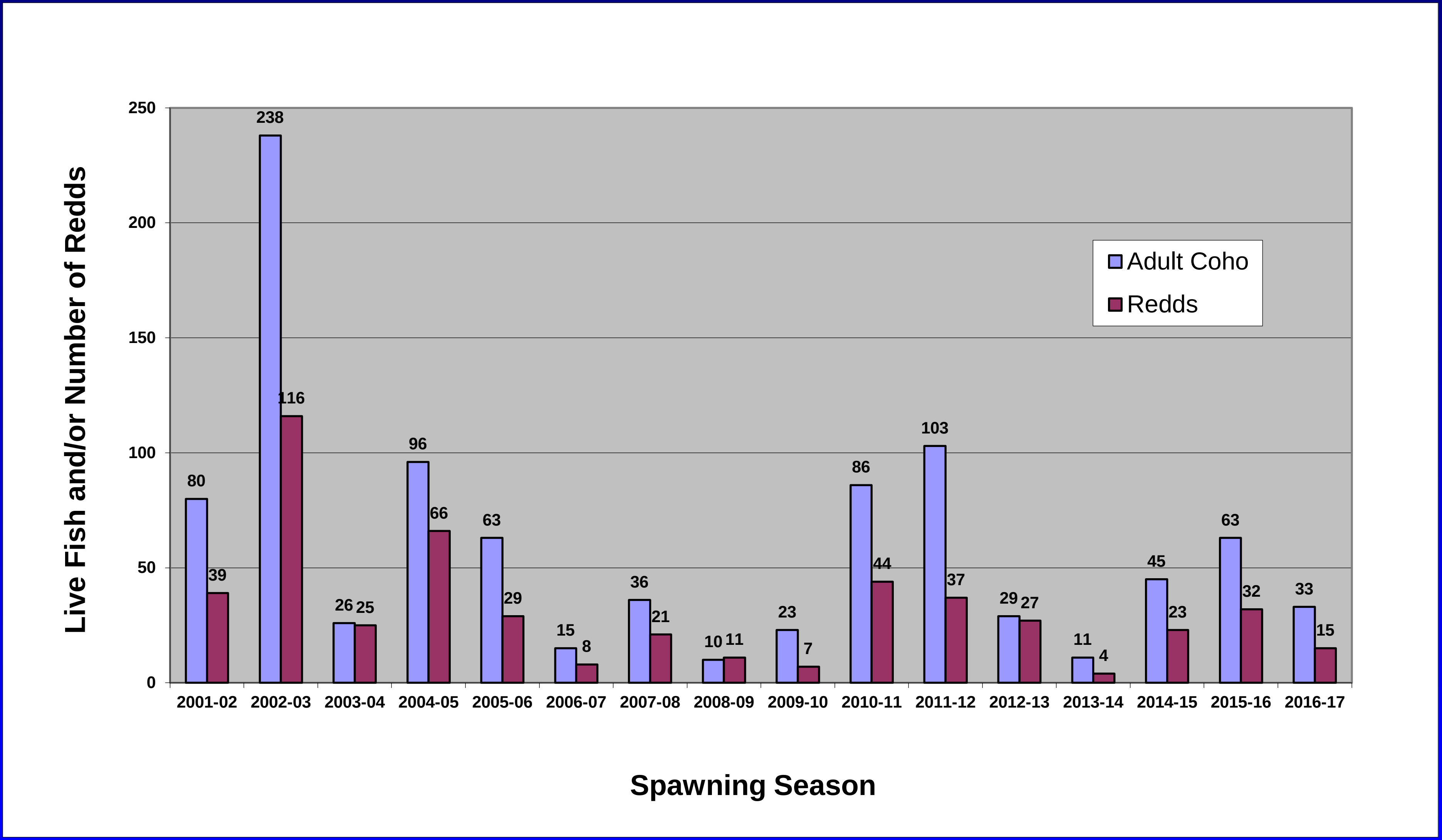
- Utilized 2002 re-survey data and new culvert specification.
- Assessed with FishXing.
- Adult passage = 90% - insufficient depth.
- Resident/2+ passage = 30% - excessive velocity.
- 1+/y-o-y passage = 0% - excessive velocity.

Quantitative Monitoring - Biological

Pre- and post-project:

- Visual observations
- Spawner or redd surveys
- Snorkel counts

Quantitative Monitoring –



Project Stability and Longevity

- **Resurveyed downstream weirs and culvert inlet and outlet on May 5, 2017.**
- **Slope through culvert = 1.31%.**
- **Elevation of 1st downstream weir relative to culvert outlet = 0.27 feet higher.**
- **Elevation between 1st and 2nd weirs = 0.78 feet.**
- **Elevation between 2nd and 3rd weirs = 0.79 feet.**

Qualitative Monitoring – Crossing Retrofits

- Baffles and weirs within crossing.
- Grade-control structures.
- Re-visit photo points over time.
- Assess hydraulics during migration flows.
- Assess performance in passing storm debris.
- Assess longevity of structures.

Qualitative Monitoring - Retrofits

Additional Types of Biological Monitoring

- View Ports
- PIT Tag Antenna Array
- Time-Lapse Camera

Additional Types of Biological Monitoring

Frykman Gulch 2010 pre-project electrofishing

Downstream of barrier: **juvenile steelhead, juvenile coho salmon, prickly sculpin and Pacific lamprey ammocetes.**

Upstream of barrier: **juvenile steelhead and prickly sculpin.**

Additional Types of Biological Monitoring

Frykman Gulch 2012 post-project electrofishing

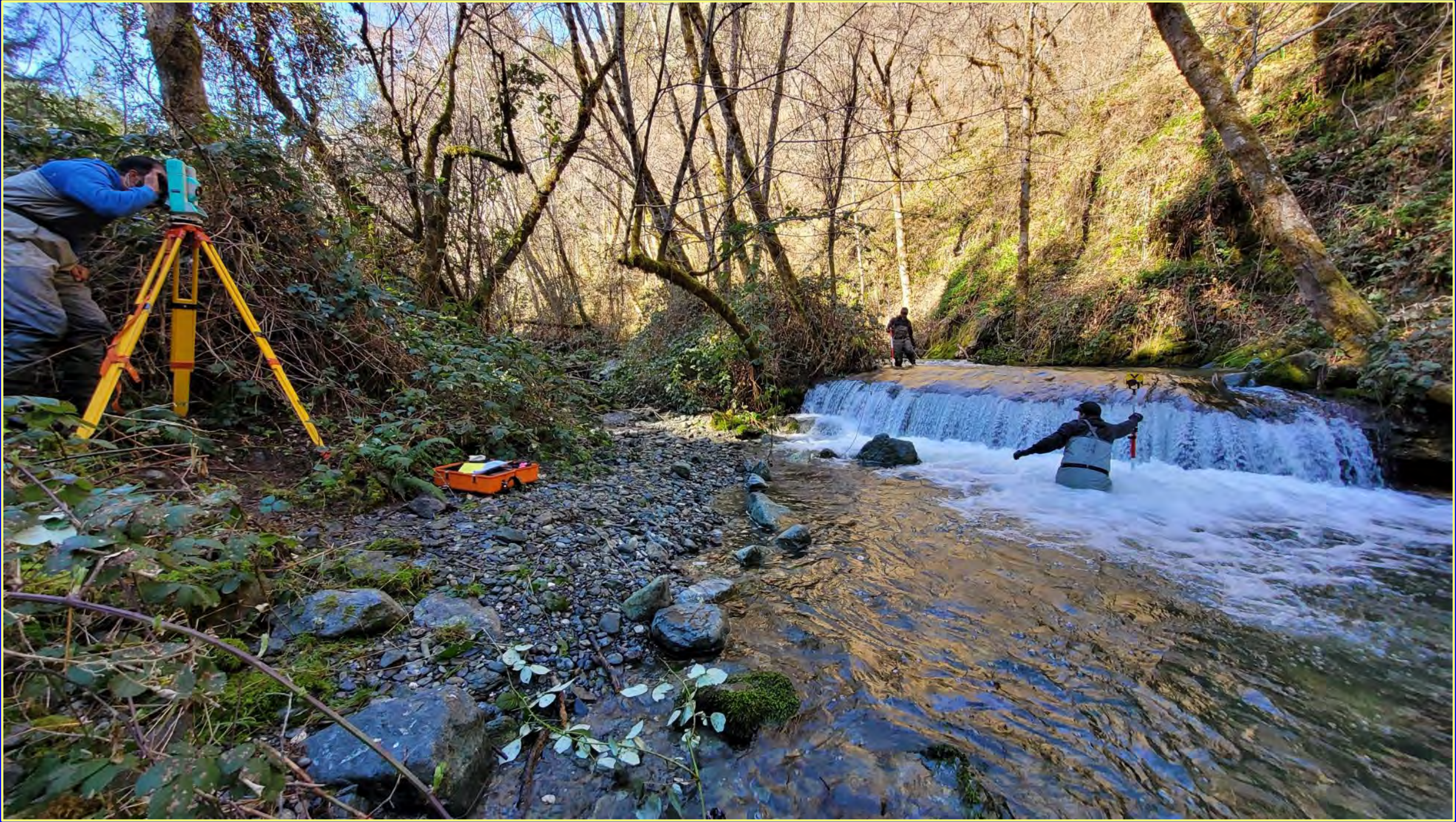
Downstream of Bridge: juvenile steelhead, juvenile coho salmon, prickly sculpin and Pacific lamprey ammocetes.

Upstream of Bridge: juvenile steelhead, juvenile coho salmon, and prickly sculpin.

Coho salmon – most likely non-natal. Juveniles often are initial colonizers of newly opened habitat (Pess et al. 2011).

Additional Types of Biological Monitoring

Soctish Creek – Pre-project eDNA Sampling



Additional Types of Physical Monitoring

Glenbrook Gulch/Albion River – Dam Removal Project

Secondary project objective: restore spawning habitat .

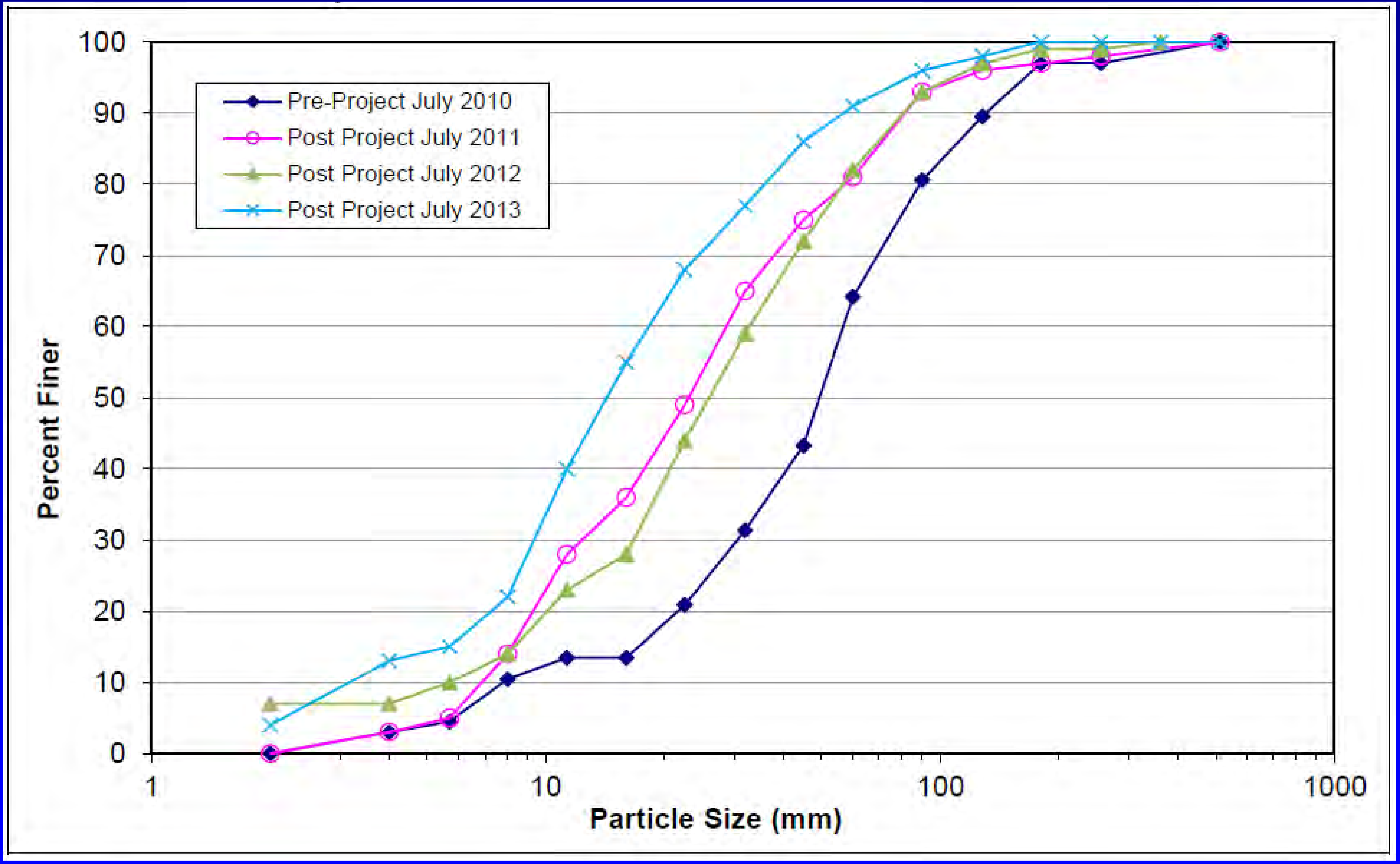
Downstream of Dam: channel scoured to bedrock with large angular substrate. No suitable spawning habitat.

Solution: install channel-spanning boulder and log structures to capture mobilized sediment. Minimal removal of stored sediment during dam removal.

Monitoring: photo points, longitudinal thalweg surveys and pebble counts (pre and post).

Additional Types of Physical Monitoring

Transect #2 – Pre and Post Particle Size Distribution



Additional Types of Physical Monitoring

Pre and Post Particle Size Distribution

Table 1. Comparisons of pre-project and post-project D50 particle sizes (mm) from five transects on Glenbrook Gulch, 2010 - 2013.

Transect Number	Pre-project 2010	Post-Project 2011	Post-Project 2012	Post-Project 2013
1	40	26	28	17
2	50	23	26	14
3	42	18	20	21
4	25	N/A	29	19
5	45	30*	46	33

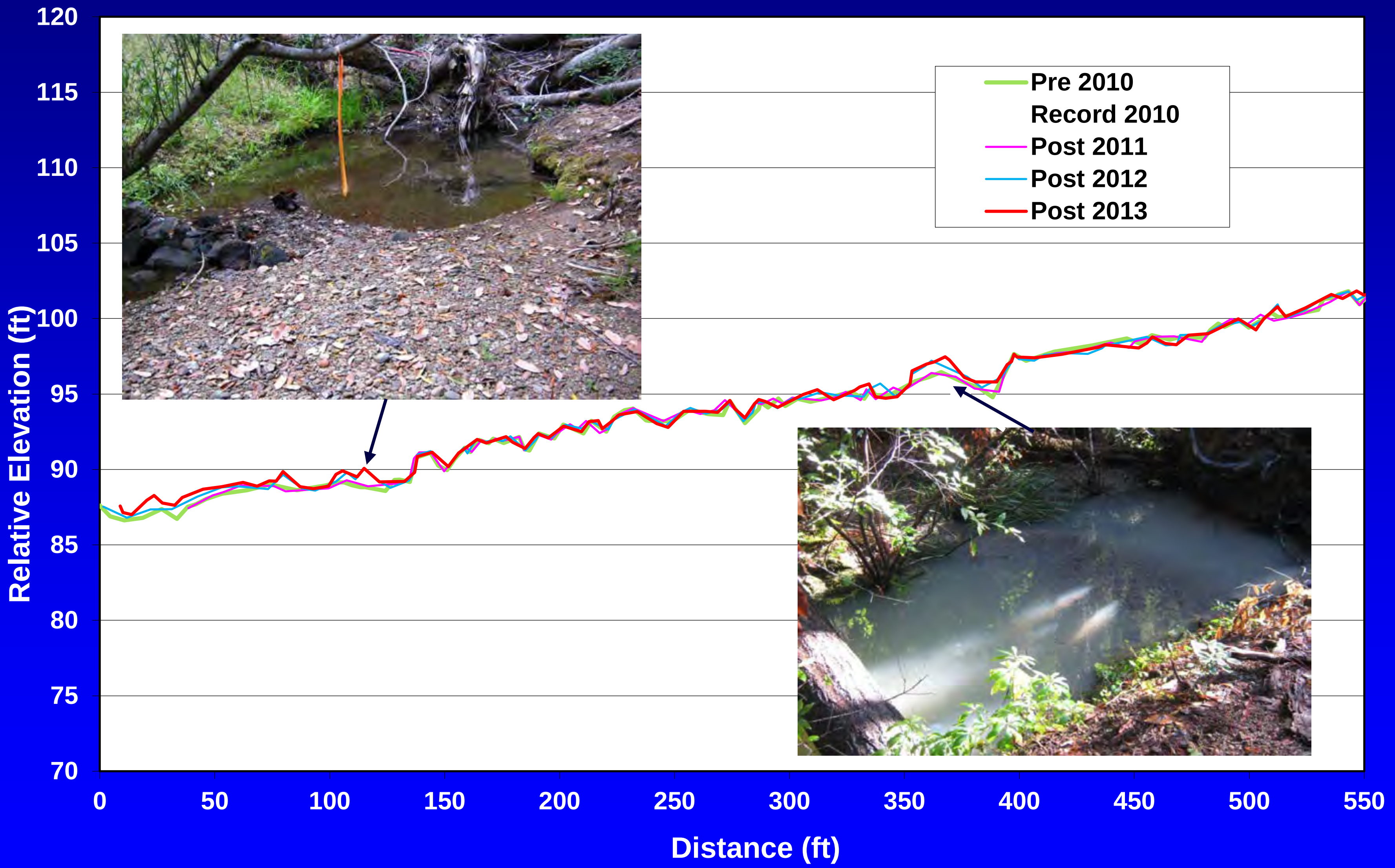
*Transects #4 and #5 were combined in 2011.

Table 2. Comparisons of pre-project and post-project D84 particle sizes (mm) from five transects on Glenbrook Gulch, 2010 - 2013.

Transect Number	Pre-project 2010	Post-Project 2011	Post-Project 2012	Post-Project 2013
1	82	100	78	43
2	104	68	65	42
3	108	64	66	43
4	48	N/A	49	35
5	86	65*	86	63

*Transects #4 and #5 were combined in 2011.

Sediment Retention Structures



Corralitos Fish Passage Projects

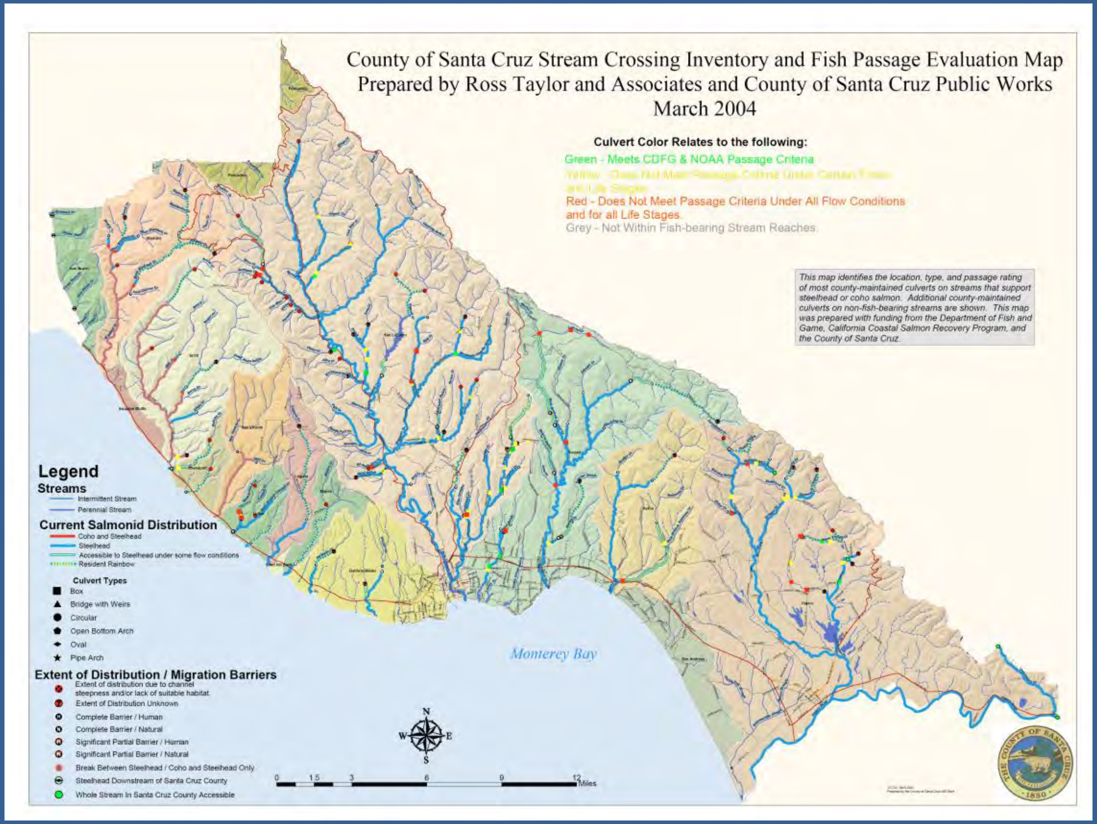
Kristen Kittleson
Fishery Resource Planner
County of Santa Cruz

Presentation Outline

- Overview: Fish Passage in Santa Cruz
- Corralitos and Pajaro
- Project Sites
- Tour logistics

County of Santa Cruz Fish Passage Program

- Grant from CDFW Fishery Restoration Grants Program 2002-2004
- Ross Taylor and Associates evaluated 80 stream road crossings – 65 within fish bearing stream sections



- 13 High Priority Sites
- 13 Medium Priority Sites
- 27 Low Priority Sites
- 12 Sites “GREEN” – meets fish passage criteria

IWRP

INTEGRATED WATERSHED RESTORATION PROGRAM FOR SANTA CRUZ COUNTY

Resource Conservation District of Santa Cruz County (RCD) and Coastal Conservancy

Integrated Watershed Restoration Program (IWRP)

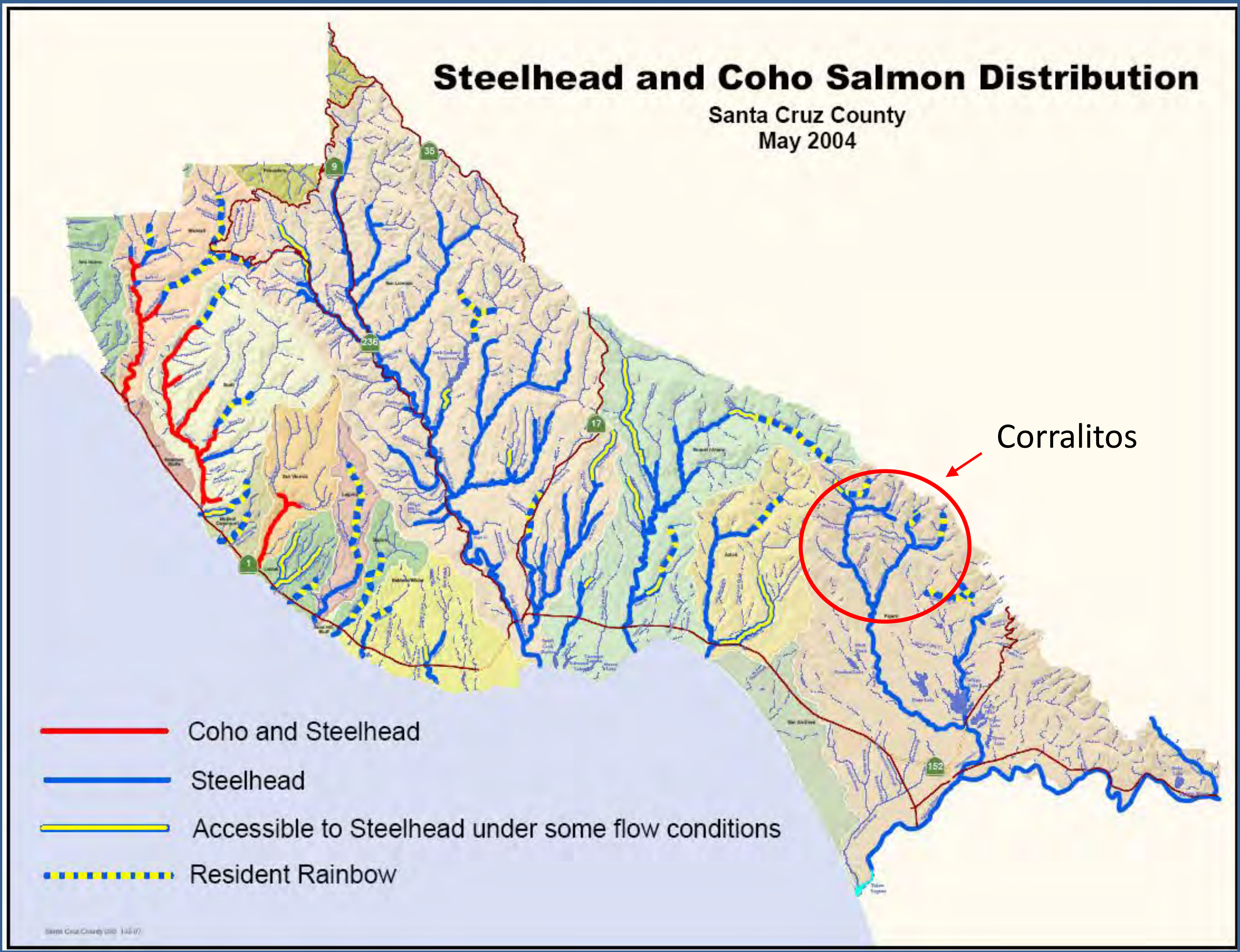
2004-2021
27 Fish Passage Projects!

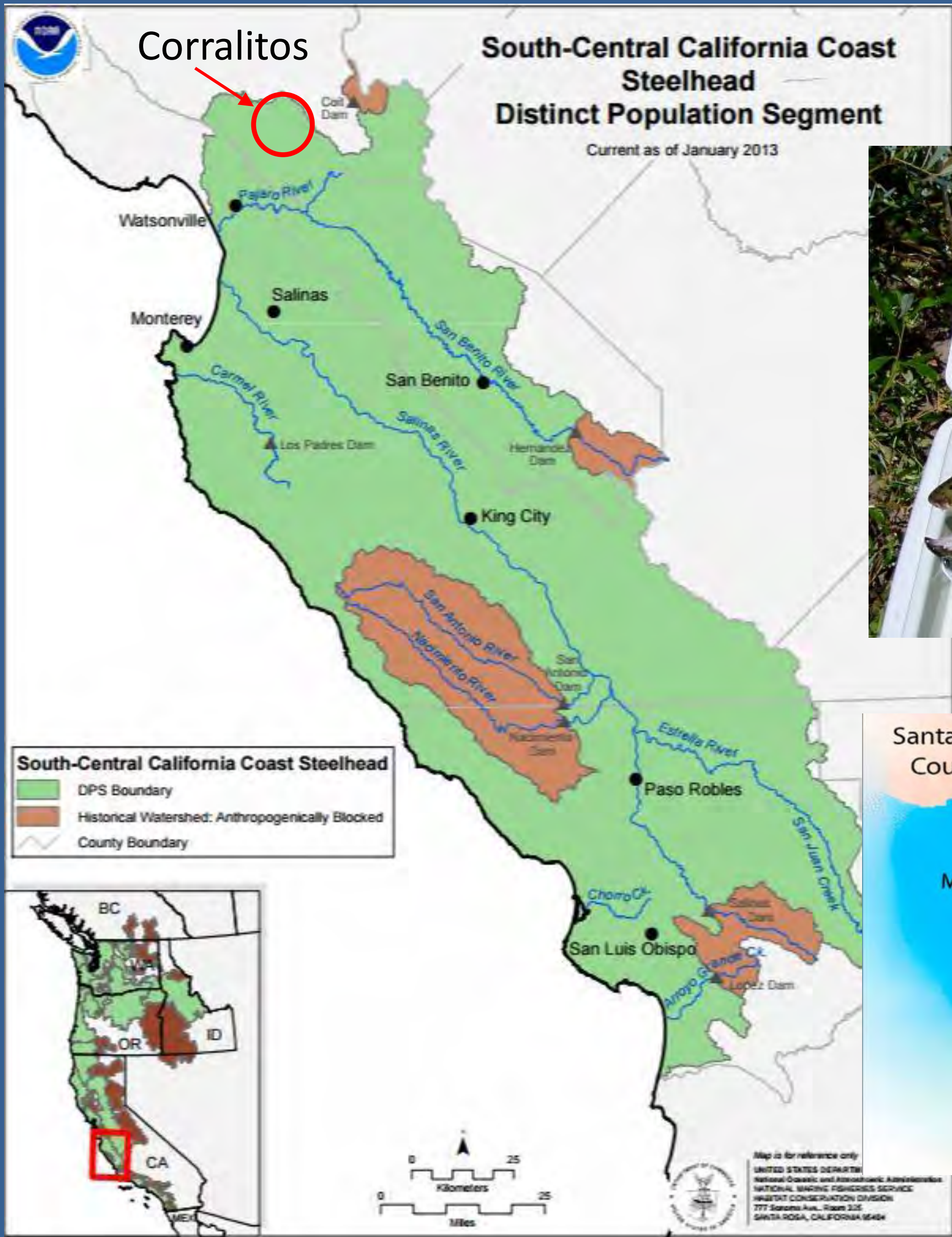
- County completed 14 fish passage projects, including 7 through IWRP
  - Corralitos Creek at Eureka Canyon PM 2.95
  - Shingle Mill Gulch at Eureka Canyon PM 4.8 and 5.24
  - Valencia Creek Fish Ladder and Valencia Road culvert retrofit
  - Gold Gulch Arch Culvert
  - Spreckels Weir Removal passage project

- Resource Conservation District
  - 6 road stream crossing projects (Corralitos, San Lorenzo, Soquel)
  - 3 Dam Removals (Branciforte)
  - 1 boulder cascade modified (San Lorenzo)

- City of Watsonville – fish ladder replacement
- CalPoly Swanton Pacific Ranch – Swanton Road at Quesaria
- Mill Creek Dam Removal, San Vicente Watershed

Corralitos and Pajaro River Watershed


Steelhead and Coho Salmon Distribution
Santa Cruz County
May 2004
Corralitos
Coho and Steelhead
Steelhead
Accessible to Steelhead under some flow conditions
Resident Rainbow
9
35
236
17
1
152


Corralitos
South-Central California Coast
Steelhead
Distinct Population Segment
Current as of January 2013
Watsonville
Pajaro River
Salinas
Monterey
San Benito River
San Benito
Carmel River
Los Padres Dam
Salinas River
Hernandez Dam
King City
San Antonio River
Nacimiento River
San Antonio Dam
Nacimiento Dam
Estrella River
Paso Robles
San Juan Creek
Chorro Ck.
San Luis Obispo
Salinas Dam
Arroyo Grande Ck.
Lopez Dam
South-Central California Coast Steelhead
DPS Boundary
Historical Watershed: Anthropogenically Blocked
County Boundary
BC
WA
OR
ID
CA
MEX
Kilometers
Miles


Santa Cruz County
Santa Clara County
San Benito County
Monterey Bay
Monterey County
Pajaro River Watershed

The Projects

Corralitos Fish Passage Projects

Project Name	Ownership	Project Type	Year completed
Corralitos Fish Ladder	City of Watsonville	Replace fish ladder	2008
Corralitos 2.95	County of Santa Cruz	Box culvert retrofit	2008
Shingle Mill 4.8	County of Santa Cruz	Arch culvert retrofit	2008 Rebuild 2011
Koinonia	Private Camp	Replace culvert with bridge	2009-2011
Shingle Mill 5.24	County of Santa Cruz	Replace culvert with new culvert	2010

City of Watsonville Corralitos Fish Ladder

City of Watsonville Corralitos Fish Ladder

Corralitos Fish Ladder – Construction

Corralitos Fish Ladder: migration flows

Corralitos Fish Ladder: downstream weirs

Corralitos Fish Ladder – ladder exit area

Original trash rack removed – woody material and sediment blocked the exit

Adult ladder blocked
Ladder sides switched 2x/year

Corralitos Fish Ladder – Site Summary

- Success? YES. Monitoring shows upstream and downstream adult and juvenile passage.
- Get the stream diversion right at first – expect 2X the effort and materials.
- Revised fish passage criteria will make it easier to meet both adult and juvenile passage criteria
- Maintenance and operation are future costs
- Practice adaptive management – change what's not working

Corralitos 2.95

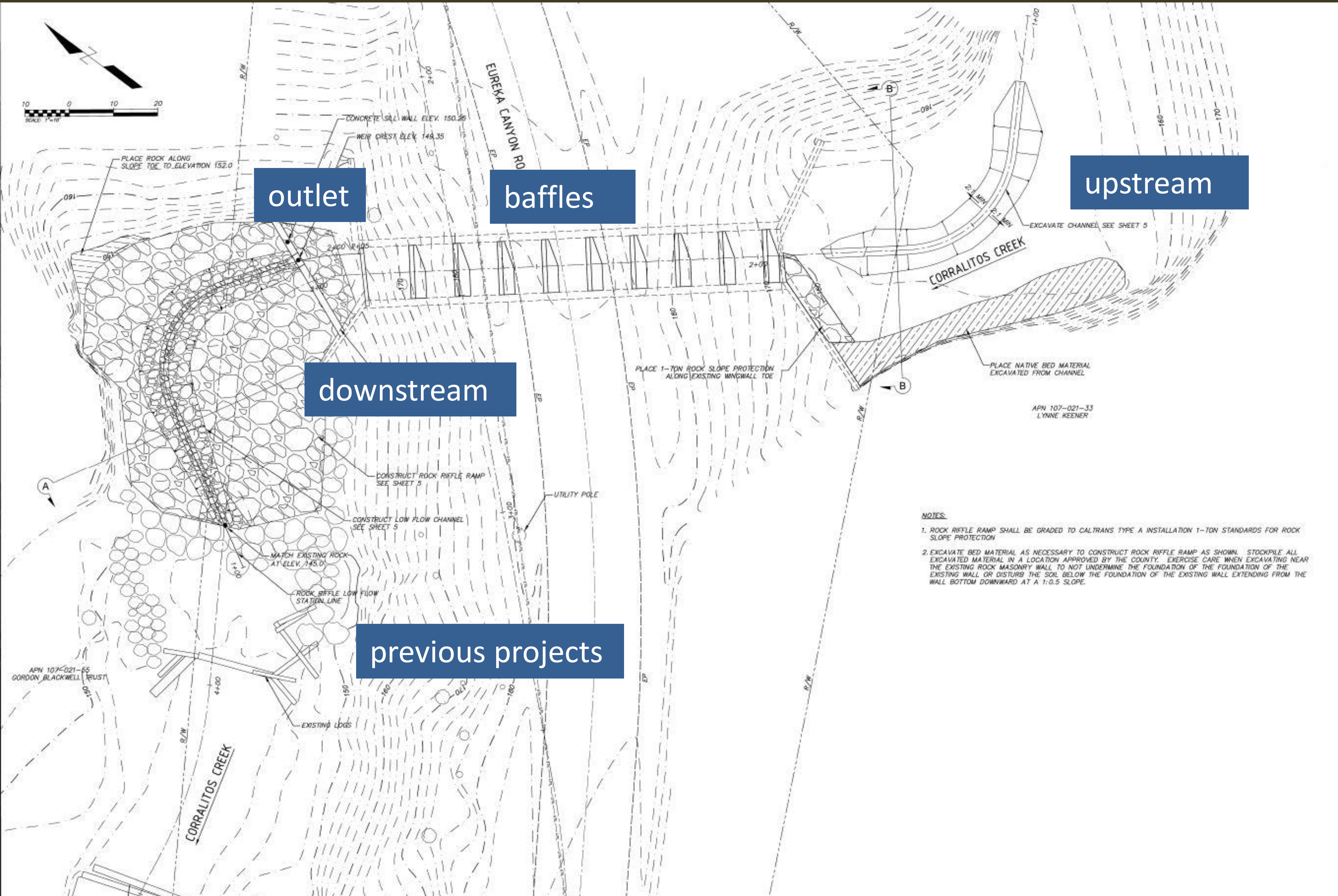
Corralitos Creek at
Eureka Canyon Road at Post-Mile 2.95

Corralitos 2.95: outlet pre-project

Corralitos 2.95: previous projects

1986 - log weirs and baffles
1997 - baffle repair and cabled boulder "necklace"

Corralitos 2.95 - Designs



Corralitos 2.95: Construction

Corralitos 2.95: baffle construction and completed

Corralitos 2.95: outlet post-project

Corralitos 2.95: high flows 2009

Corralitos 2.95: downstream post-project

Corralitos 2.95: Current Condition

Corralitos 2.95: Site Summary

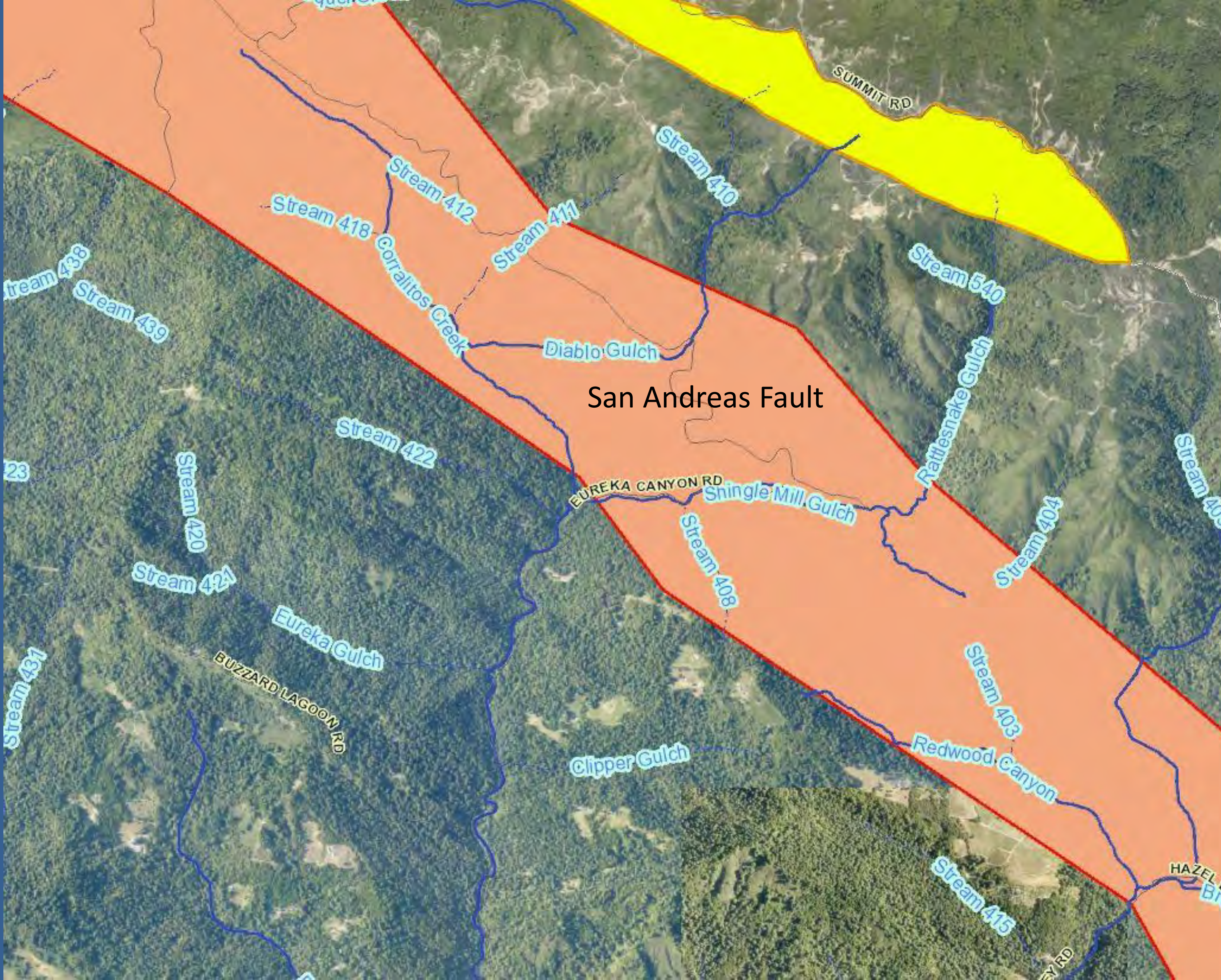
- Success? YES. Monitoring shows upstream and downstream adult and juvenile passage.

- Not sure. Creating better culvert exit conditions not successful.
- Need to monitor channel changes and drop/wood at old Boulder Necklace.

- Group brainstorming can improve the design

- Ramped baffles work great for moving sediment and woody material through a culvert

- A retrofit carries future maintenance and adjustment


San Andreas Fault
SUMMIT RD
Stream 410
Stream 412
Stream 418
Stream 411
Corralitos Creek
Stream 438
Stream 439
Stream 540
Diablo Gulch
Rattlesnake Gulch
Stream 422
Stream 420
Stream 421
EUREKA CANYON RD
Shingle Mill Gulch
Stream 408
Stream 404
Stream 405
Eureka Gulch
BUZZARD LAGOON RD
Stream 431
Stream 403
Clipper Gulch
Redwood Canyon
Stream 415
HAZEL DELL RD

Shingle Mill 4.8

Shingle Mill Gulch at Eureka Canyon Road
Post-Mile 4.8

Shingle Mill 4.8: 2002 assessment photos

Ranking: High priority with habitat assessment

Shingle Mill 4.8: Before

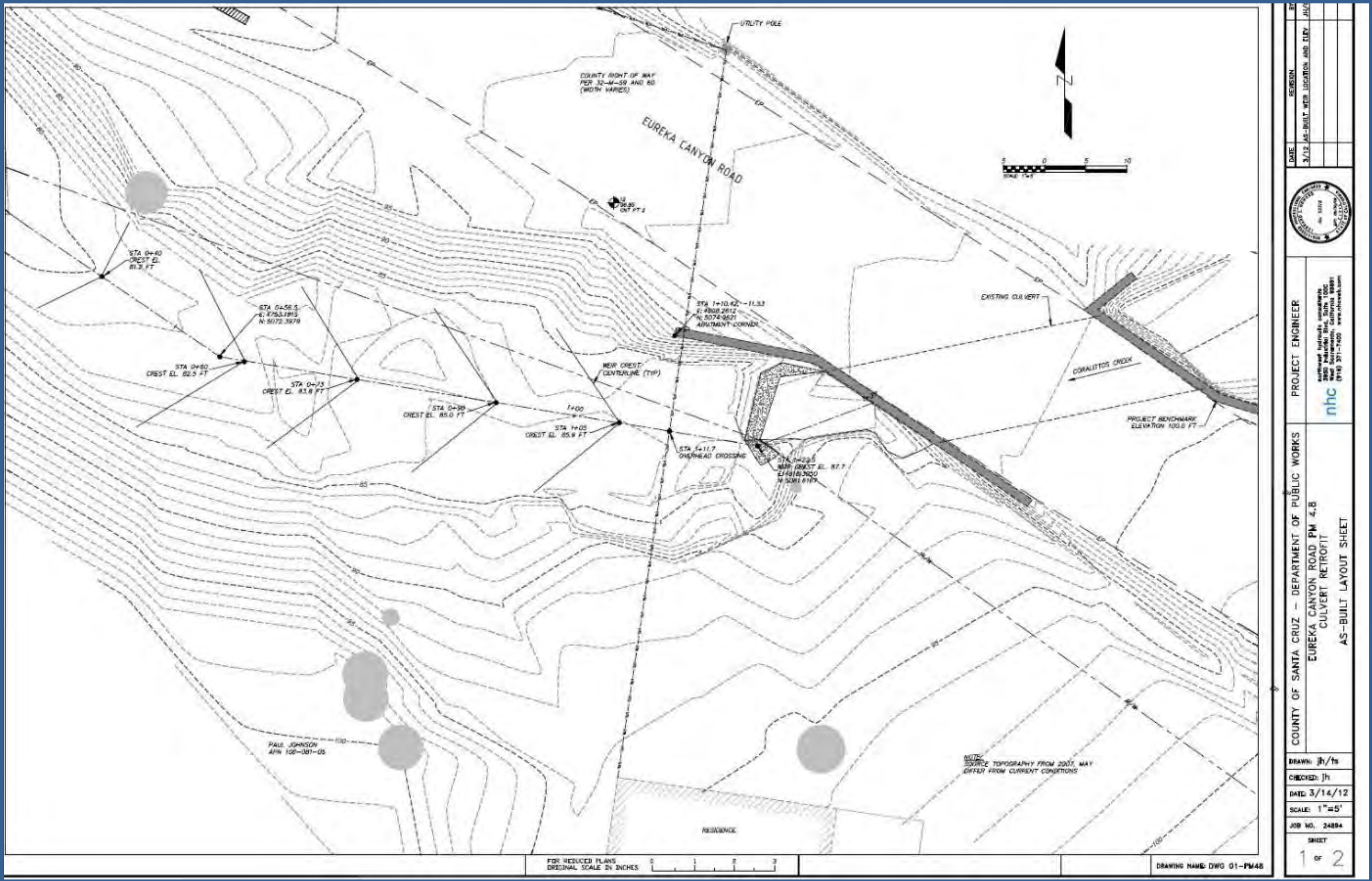
Shingle Mill 4.8: post-construction 2008

Shingle Mill 4.8: post-construction 2009

Shingle Mill 4.8: post-construction 2009

Shingle Mill 4.8: 2009 storms

Shingle Mill 4.8: 2011 Rebuild



Shingle Mill 4.8: checking the elevations

Shingle Mill 4.8: rock weir construction

Shingle Mill 4.8: post- reconstruction 2014

Shingle Mill 4.8: Site Summary

- Success? YES and NO.
  - YES Better constructed project
  - YES Meets passage criteria (almost)
  - NO. Created major changes to natural channel and bank conditions
- Using a low-bid, inexperienced contractor is a risky approach for specialized work, such as rock weirs
- If possible, use an experienced contractor by bidding as a Professional Services
- Always something unexpected, in this case, a dense clay layer

Koinonia Bridge

at Shingle Mill Gulch

Koinonia Culvert Crossing

Koinonia Culvert Crossing

Koinonia: Construction

Koinonia: downstream weirs and channel work

Koinonia: completed channel work

2009

Koinonia: completed revegetation

2012

Koinonia Bridge

2022

Koinonia Bridge Crossing

2022

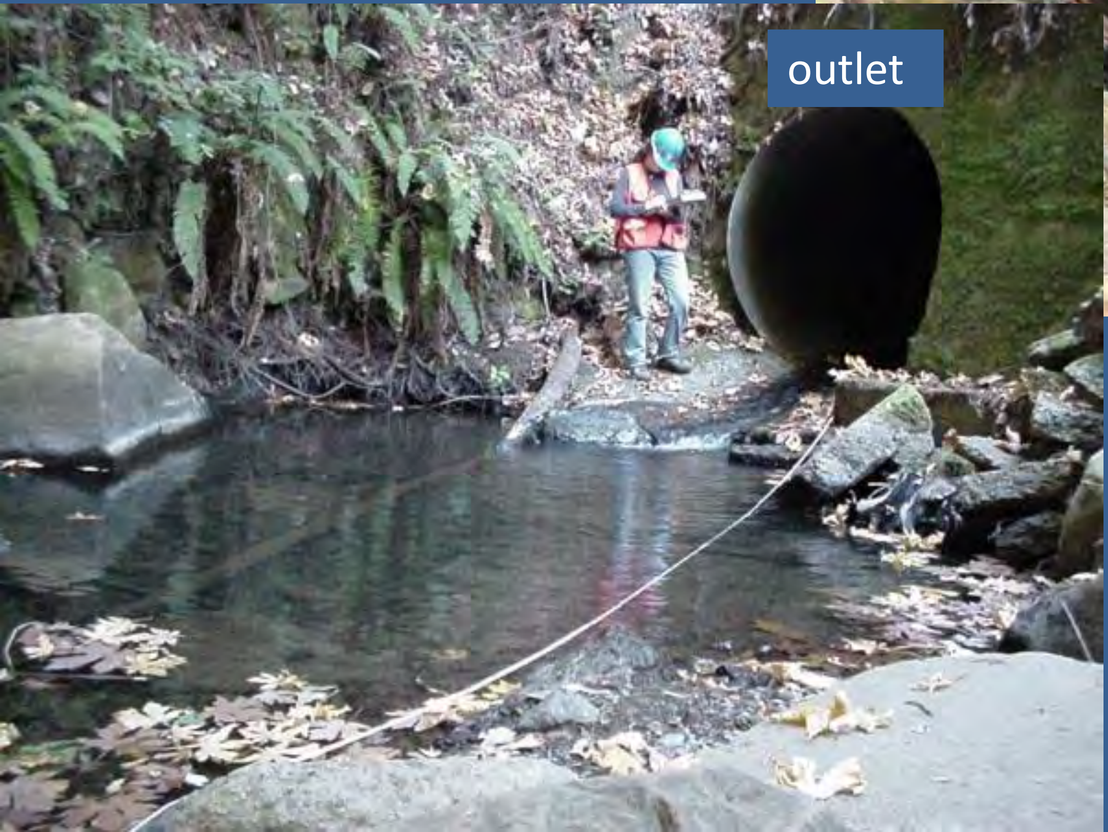
Koinonia Culvert Crossing

- Success? YES. Win-Win for fish passage and driveway safety.
- Stream habitat assessments pay off
- Stay open to opportunities
- Expect to need grade control when removing culvert crossings
- Always something unexpected…

Shingle Mill 5.24

Shingle Mill Gulch at Eureka Canyon Road
Post-Mile 5.24

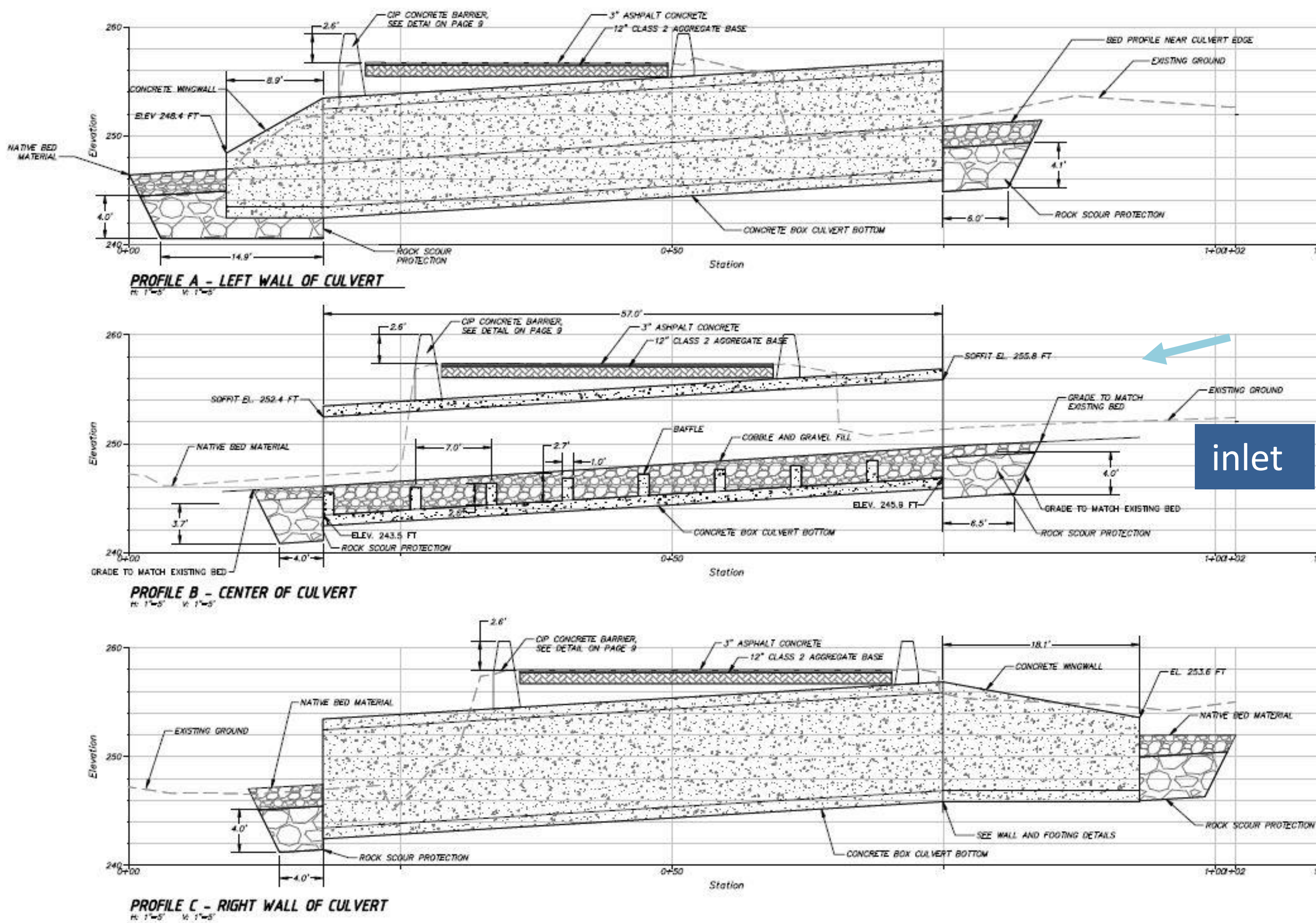
Shingle Mill 5.24: 2002 Passage Assessment



2004 Ranking: Moderate priority

Culvert undersized, poor condition; full replacement recommended

Shingle Mill 5.24: Designs



Shingle Mill 5.24: diversion and temporary bridge installed

Shingle Mill 5.24: rebar complete

Shingle Mill 5.24: baffles completed

Shingle Mill 5.24: Completed Project

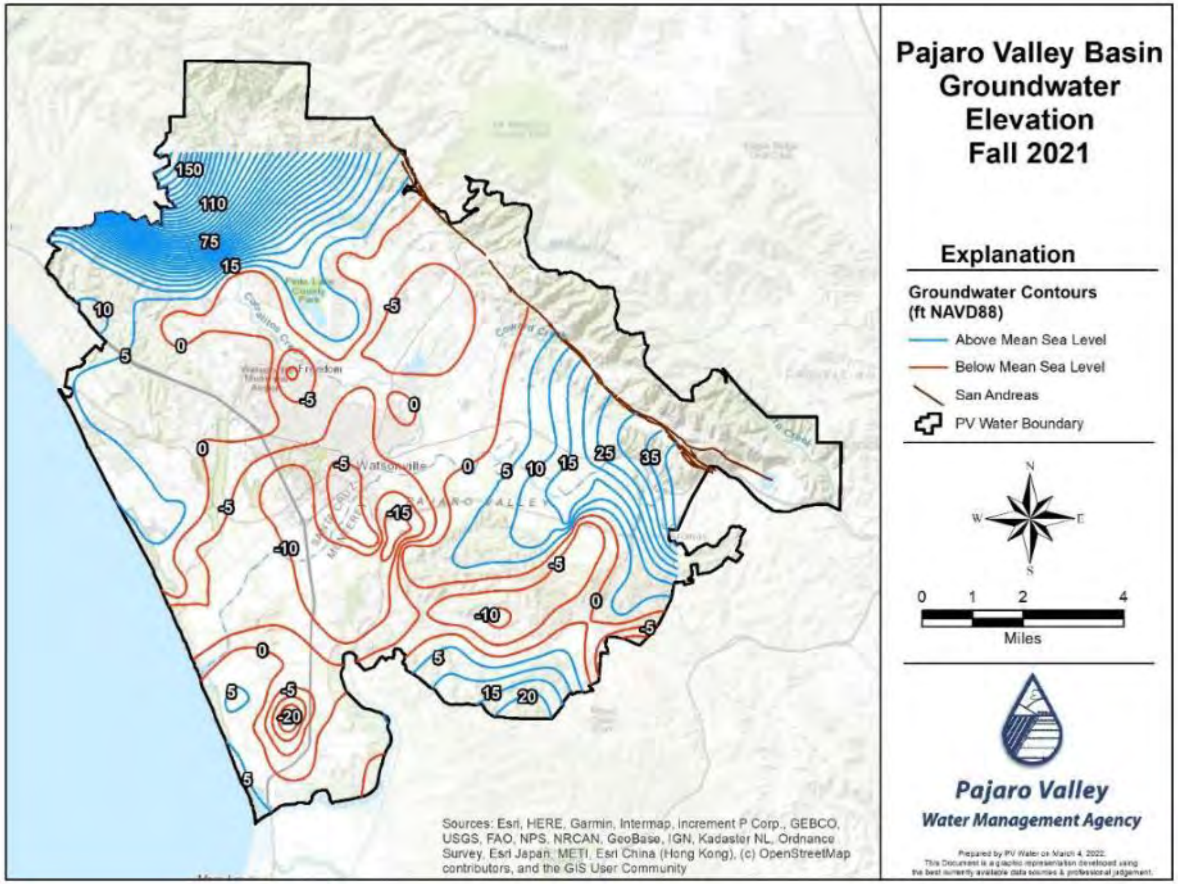
Shingle Mill 5.24: Completed Project

Shingle Mill 5.24: Site Summary

- Success? YES.
  - ✓ Replacement right approach
  - ✓ New alignment working to protect opposite bank
  - ✓ Baffles successful at retaining sediment
- Construction constraints can influence project design
- Your least favorite option may be the best solution
- Baffles work well to retain sediment, especially on steep streams

It's a long way from Corralitos to the Monterey Bay…

No flow, no passage



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