A Toolbox for Fish Passage Engineering

Contemporary Design Approaches to Address Aquatic Organism Passage at Stream Crossings

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Hydrologic Solutions

FishPAC Webinar Series

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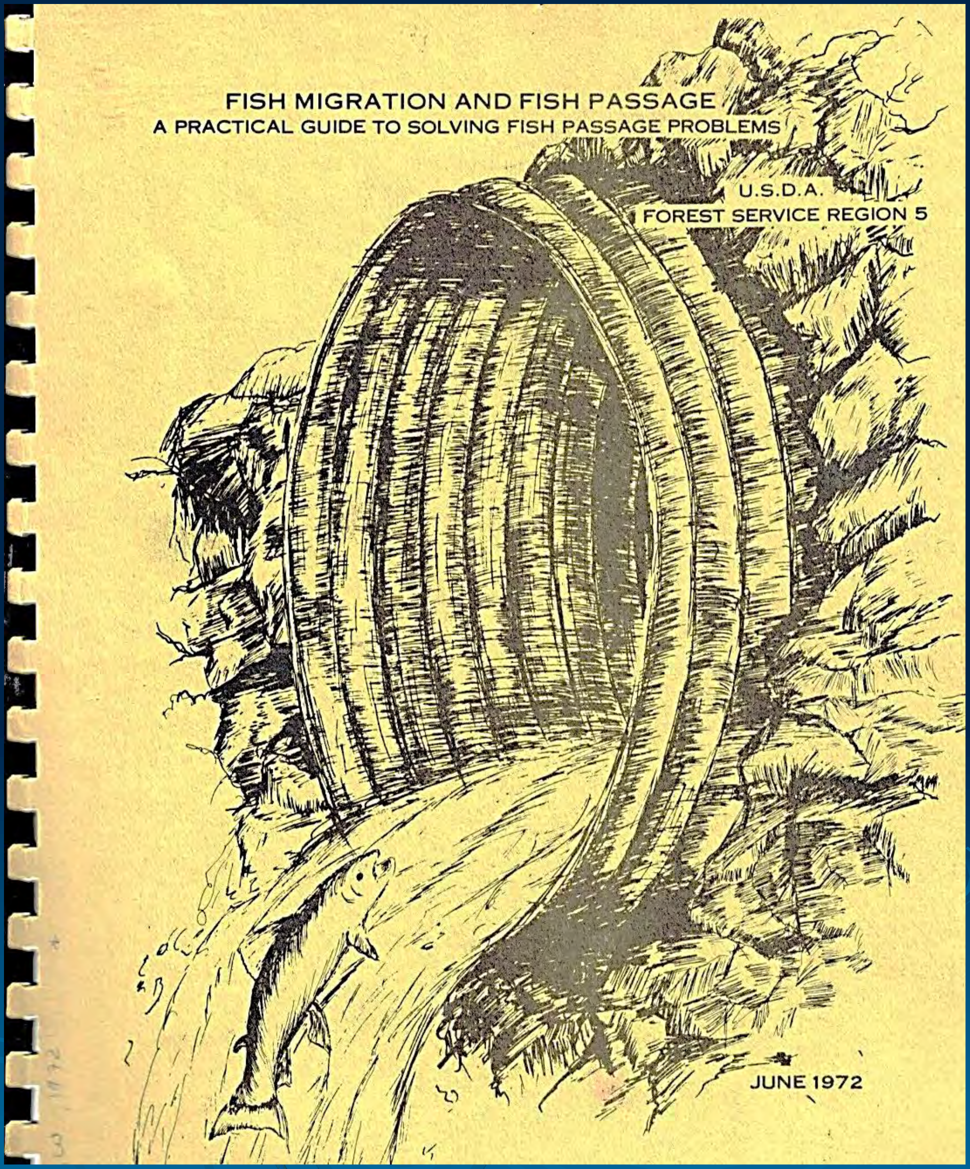
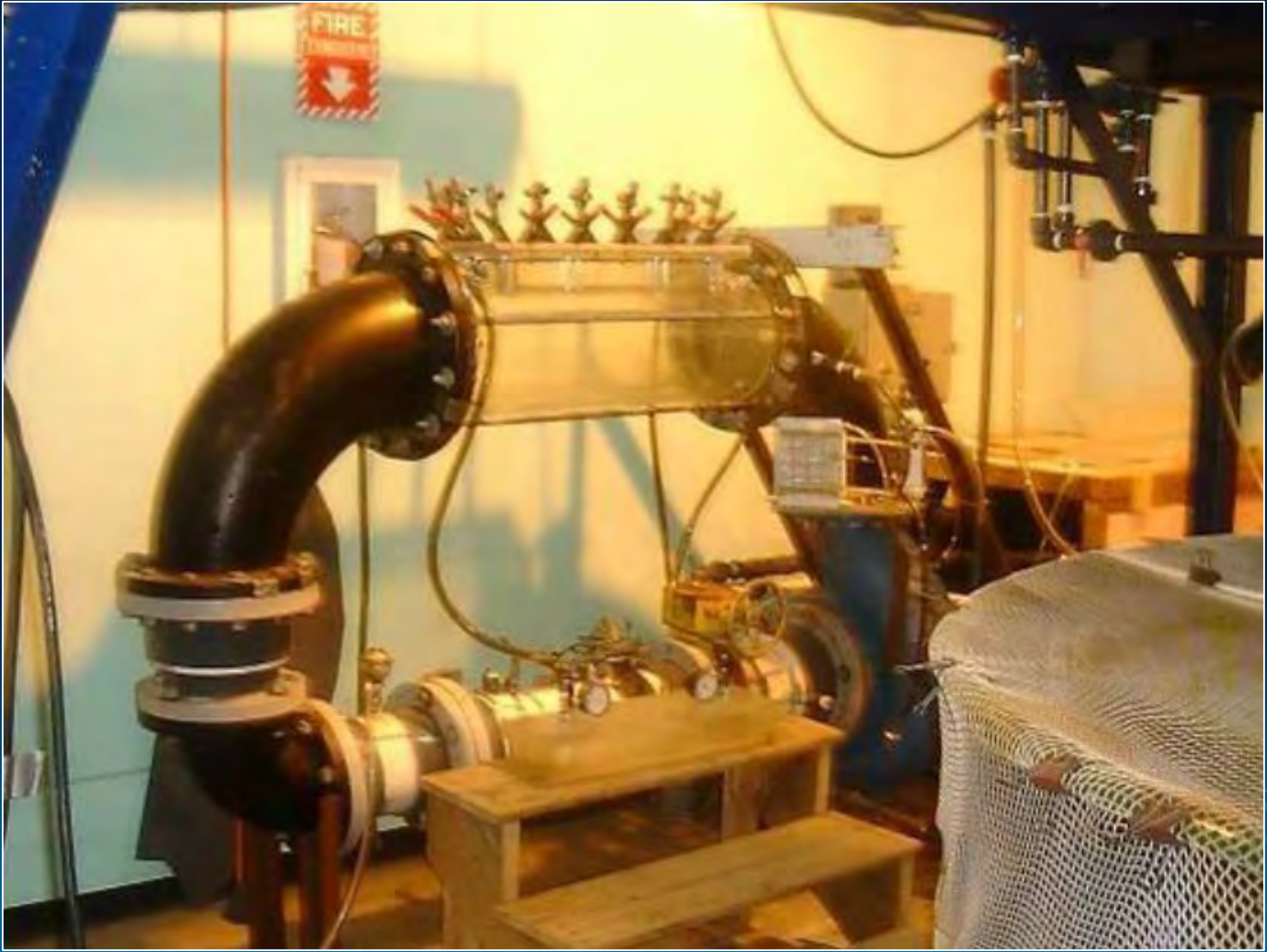
Fish Passage at Road-Stream Crossings Not a New Issue

- Clay (1961) “Design of Fishways & Other Fish Passage Facilities”
- USFS (1970’s & 1980’s) “Operation Swim-Up”
- FHWA (1970) “Fish Passage Through Highway Culverts”
- Caltrans (1970) “Passage of Anadromous Fish through Highway Drainage Structures”
- Bell (1973) “Fisheries Handbook of Engineering Requirements and Biological Criteria.” USACE.



Hydraulic Design Approach

Adult Salmonid Swimming Endurance & Leaping Abilities



Swim Speed Test Chamber

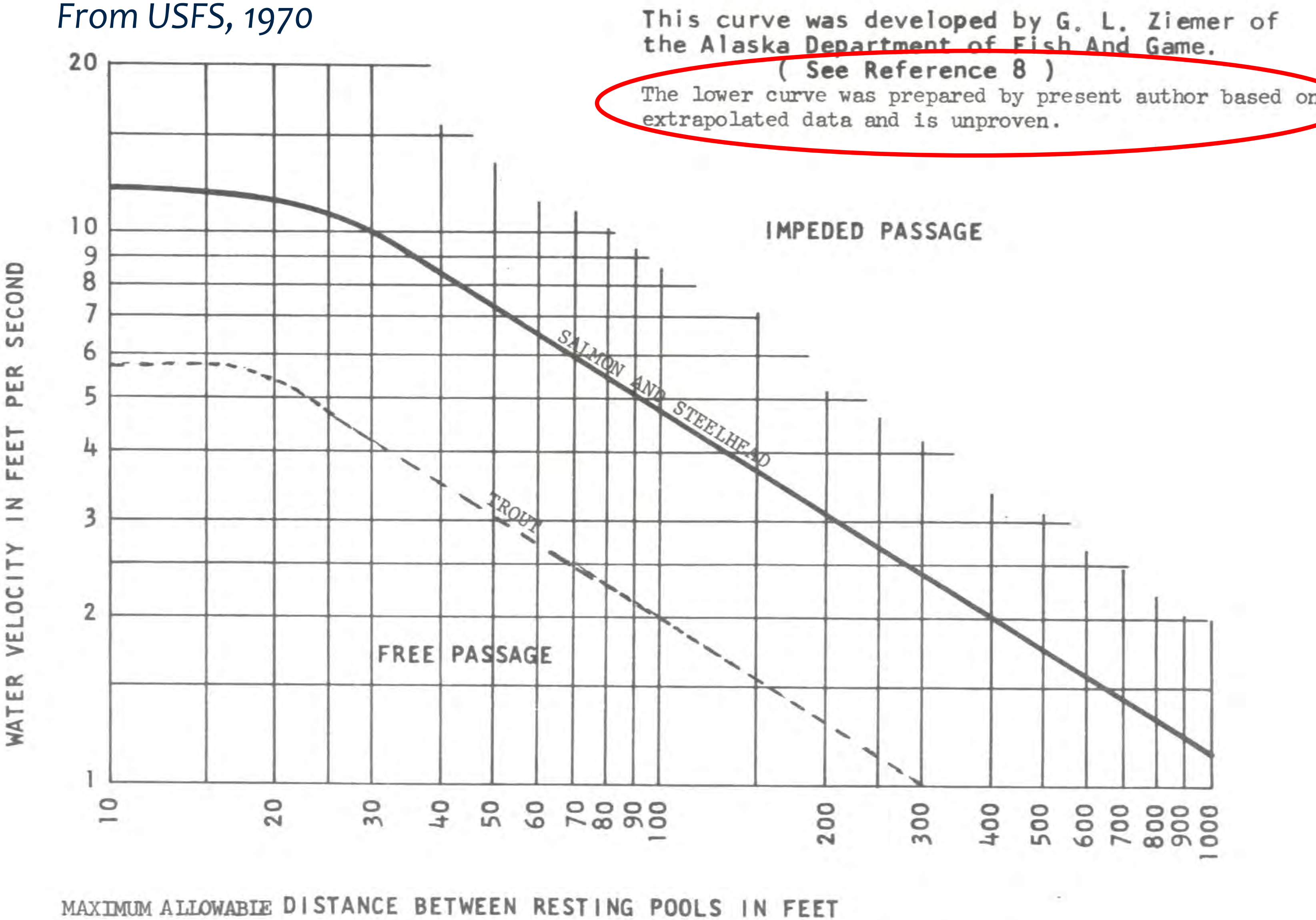
California Department of Fish & Game

Fish Passage Design Guidelines until 2002

- Focused only on Upstream Passage of **Adult** Salmonids
- No Criteria for Juvenile Salmonids or Non-Salmonids
- High Passage Flow originated from 1970 Group Consensus
- Based on Depth, Drop and Velocity
- Velocity Criteria based on the "Alaskan Curve"

The "Alaskan Curve"

From USFS, 1970



SWIMMING CAPABILITY OF MIGRATING SALMON

(ALASKAN CURVE)

Why Are there Still Barriers?

(a) Installed at-grade in 1979 for Fish Passage

(b) By 1988 High Velocities from Culvert Caused Downstream Scour Pool and Outlet Drop

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

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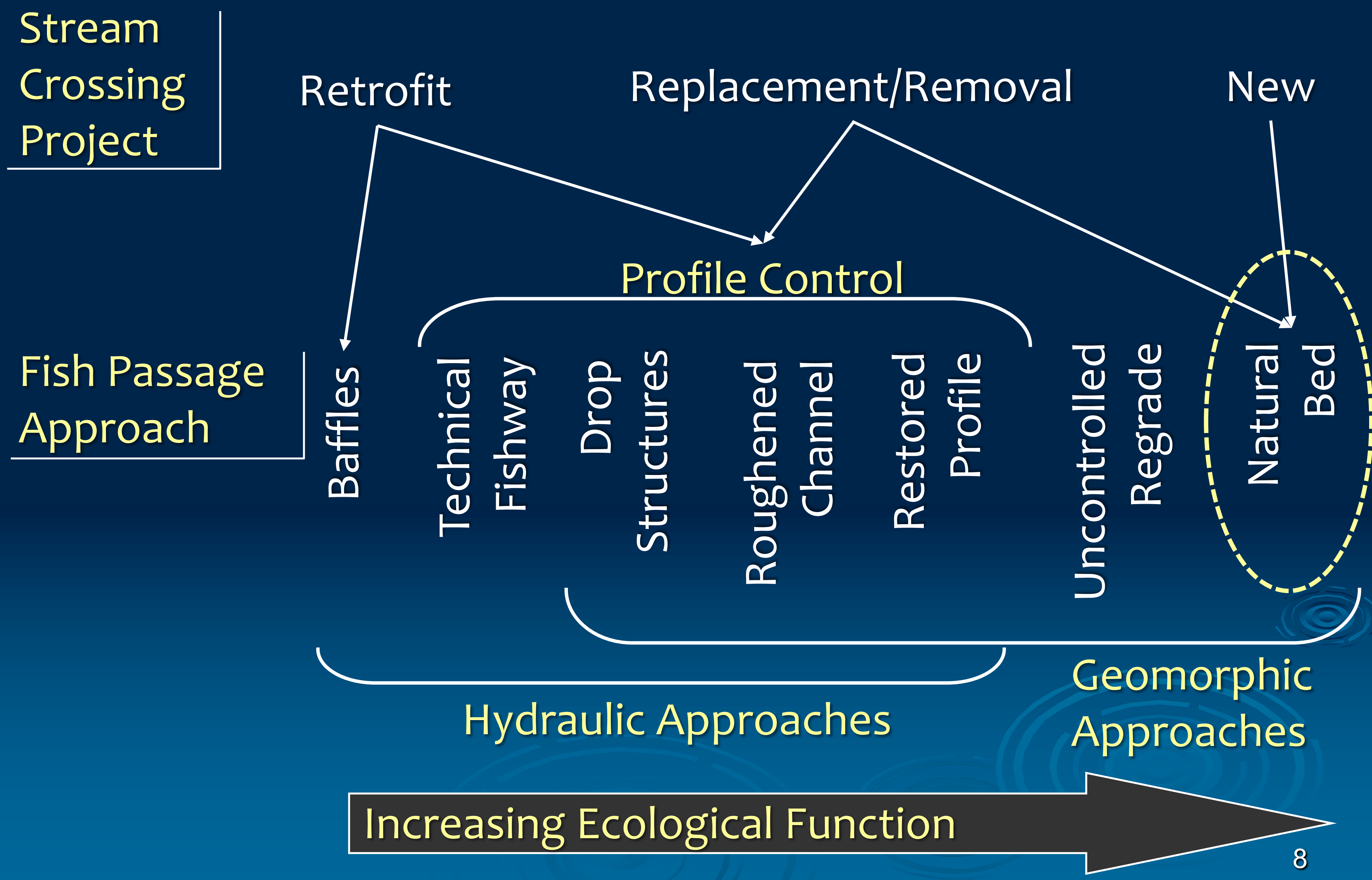
Olympia, WA

Design Approaches for Aquatic Organism Passage



Stream Simulation Design Approach for Passage of Aquatic Organisms

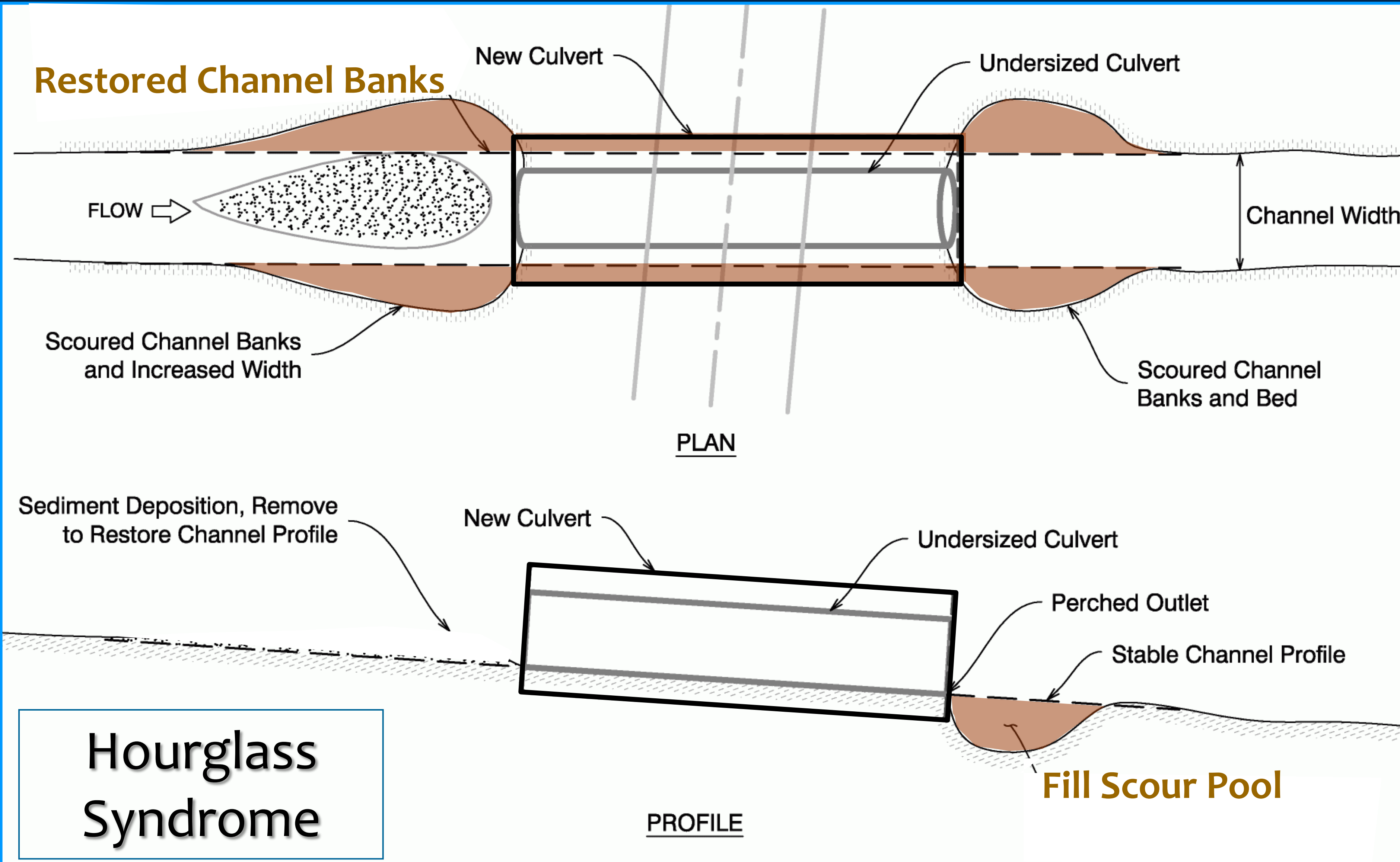
"A channel that simulates characteristics of the natural channel will present no more of a challenge to movement of organisms than the natural channel."

Primary Source:
USFS (2008). *Stream simulation: an ecological approach to road stream crossings*
Available at the FishXing website: **FishXing.org**

What is Stream Simulation?

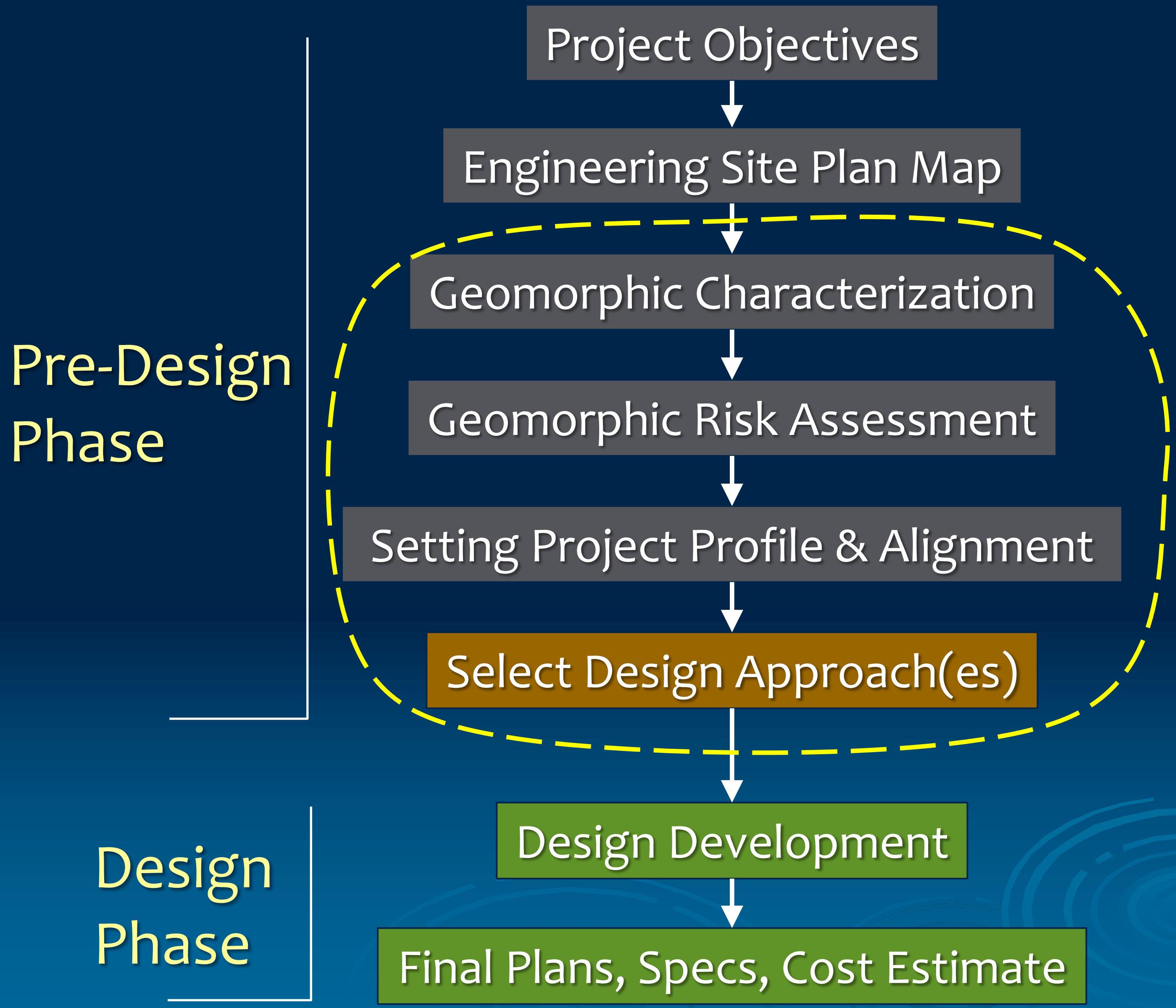
- A Geomorphic Approach to Designing Stream Crossings
- Design Profile Seamlessly Connects Downstream & Upstream Channel Profiles
- Simulate a Natural Channel Reference Reach
  - Channel Slope
  - Bankfull Cross Section Dimensions
  - Channel Structure
    - Channel Bedforms
    - Mobility/Stability
  - Forcing Features
  - Continuous Banks

Restoring Channel Geometry

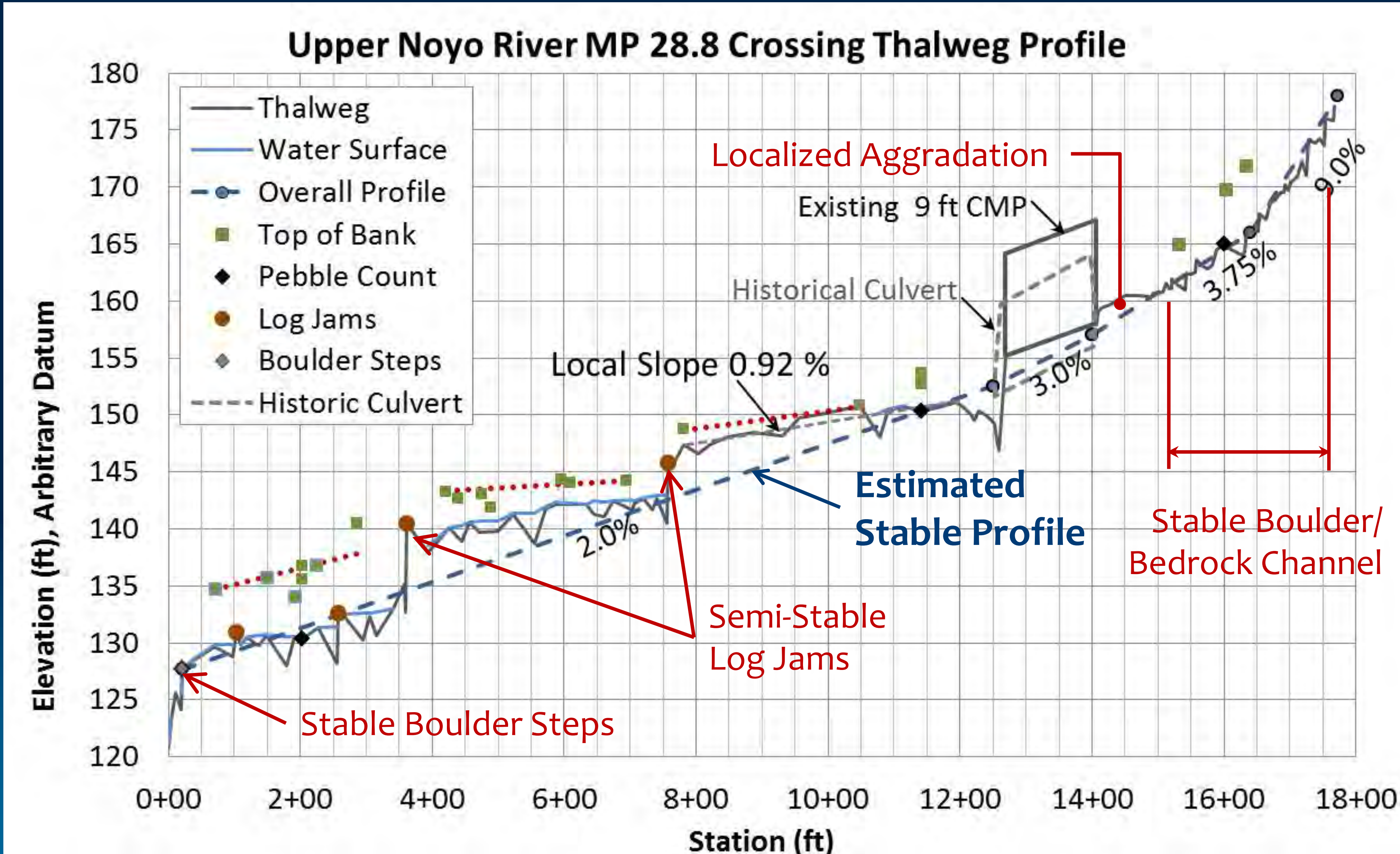


Hourglass Syndrome

Passage Design Process

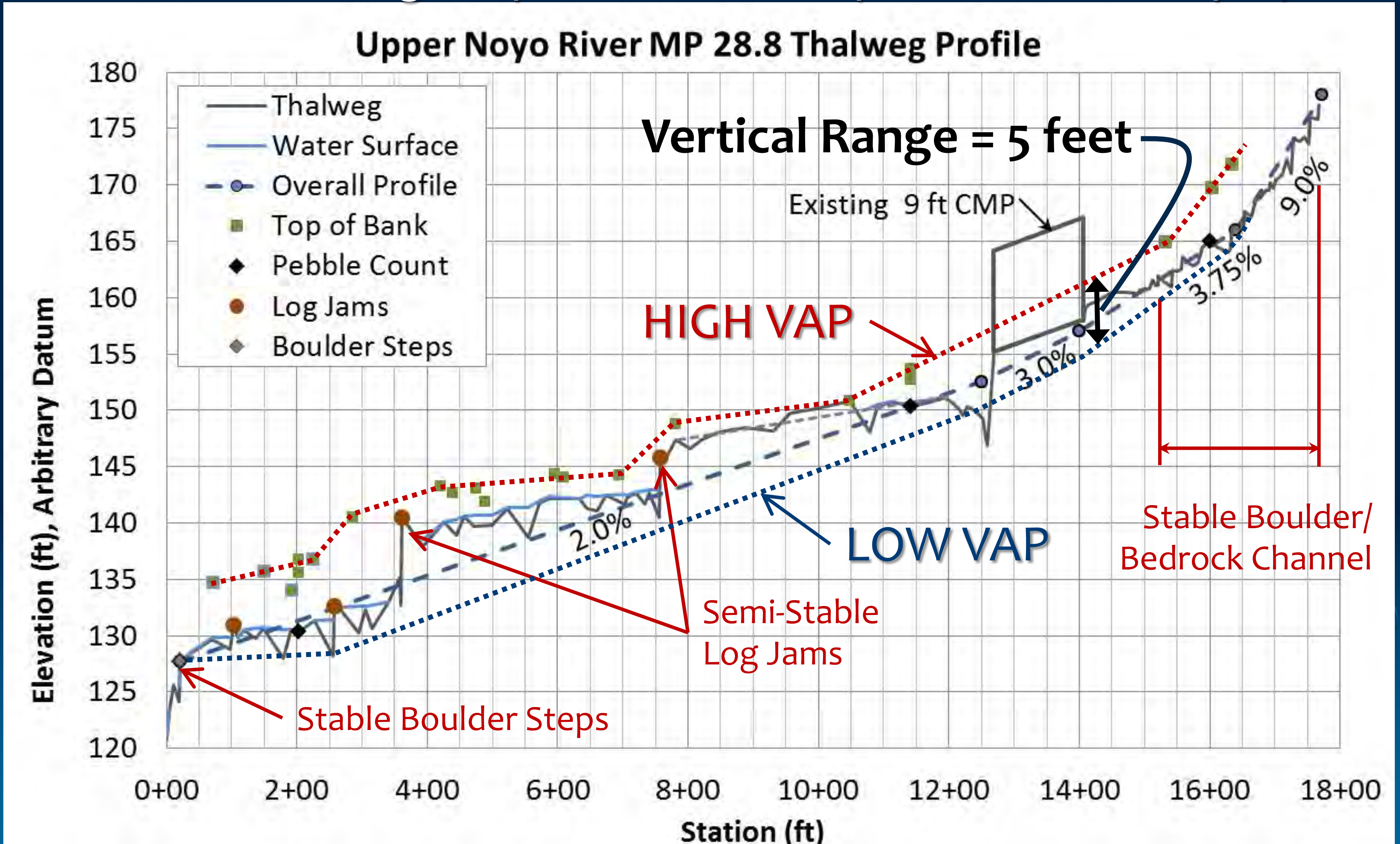


Channel Profile Analysis



Vertical Adjustment Potential (VAP) Profiles

Estimates the range of possible channel profiles for life of project

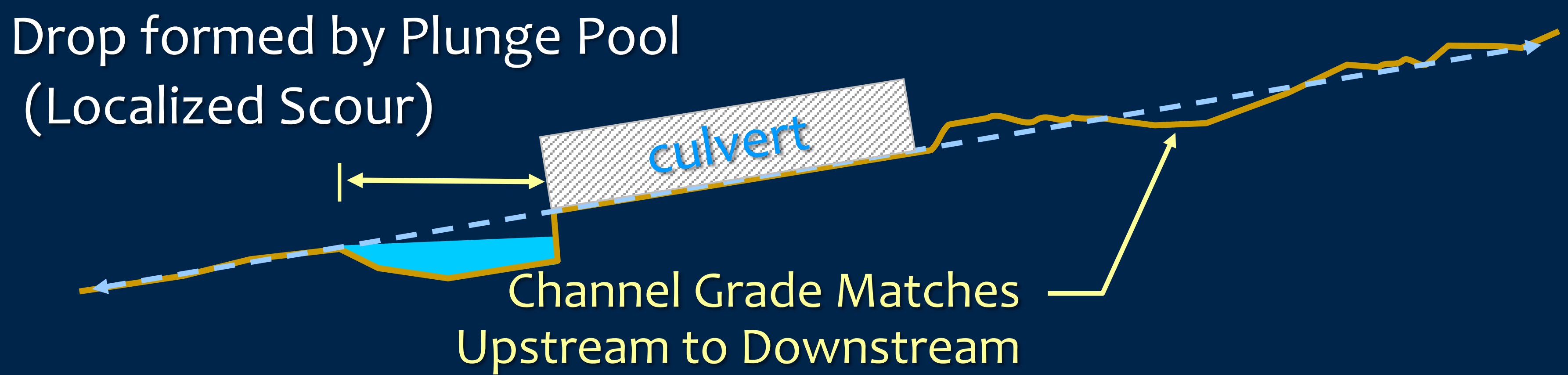


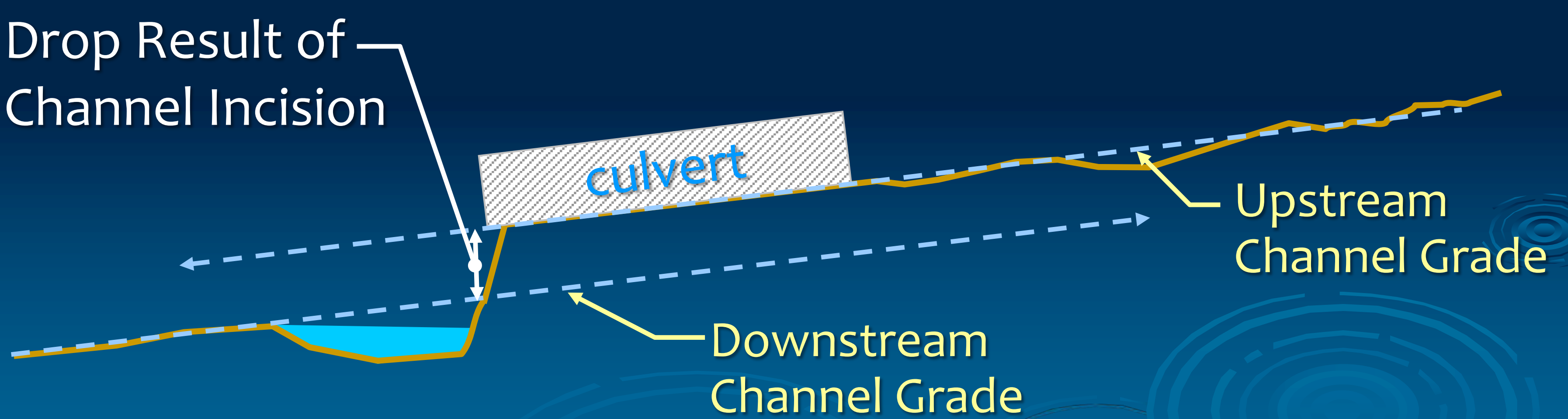
Vertical Adjustment Potential (VAP)

Develop VAP with long profile and field investigations:

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

Local Scour vs. Incision





Incision or Local Scour?

photo: Kozmo Bates

From further downstream

photo: Kozmo Bates

What Happened Here?

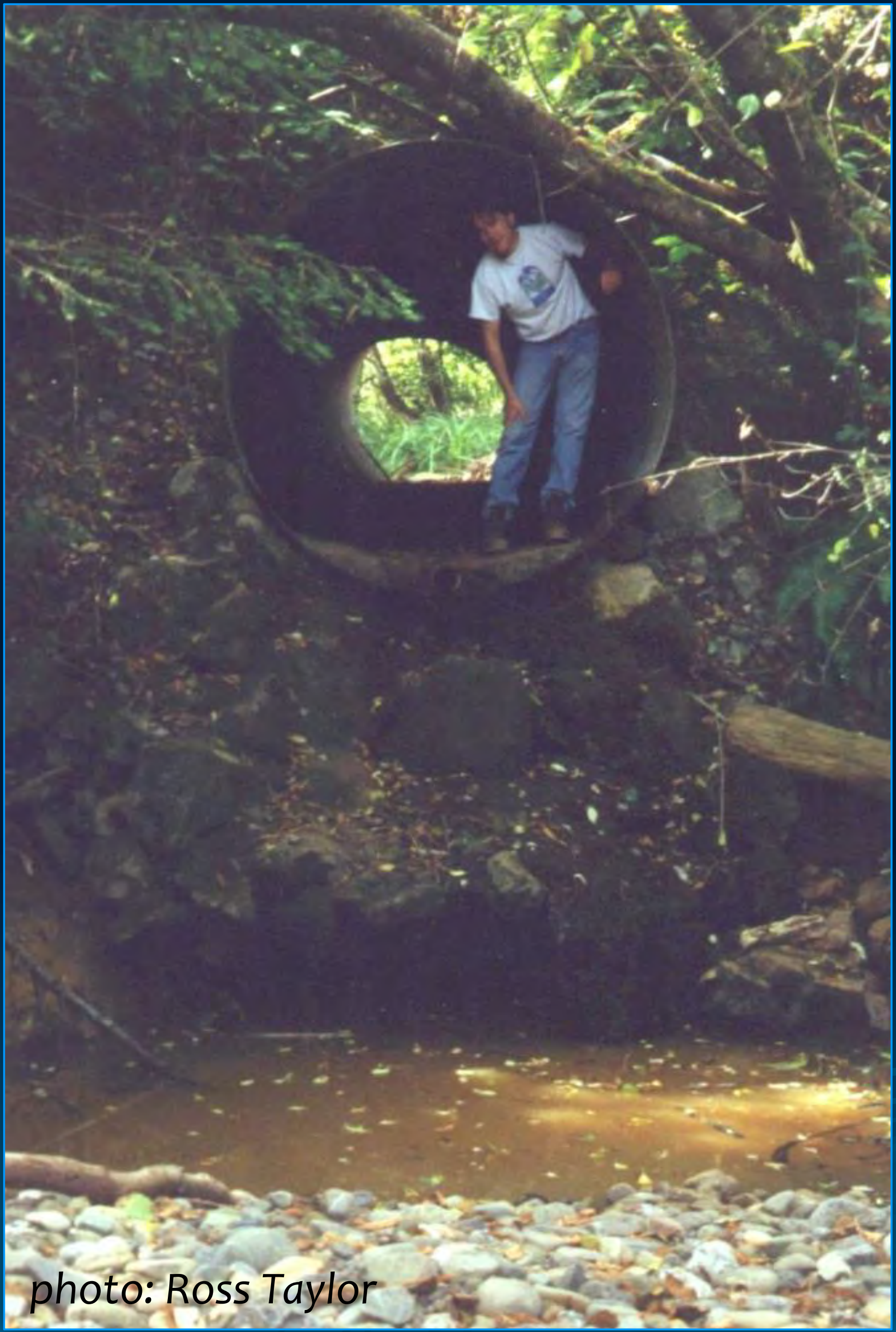
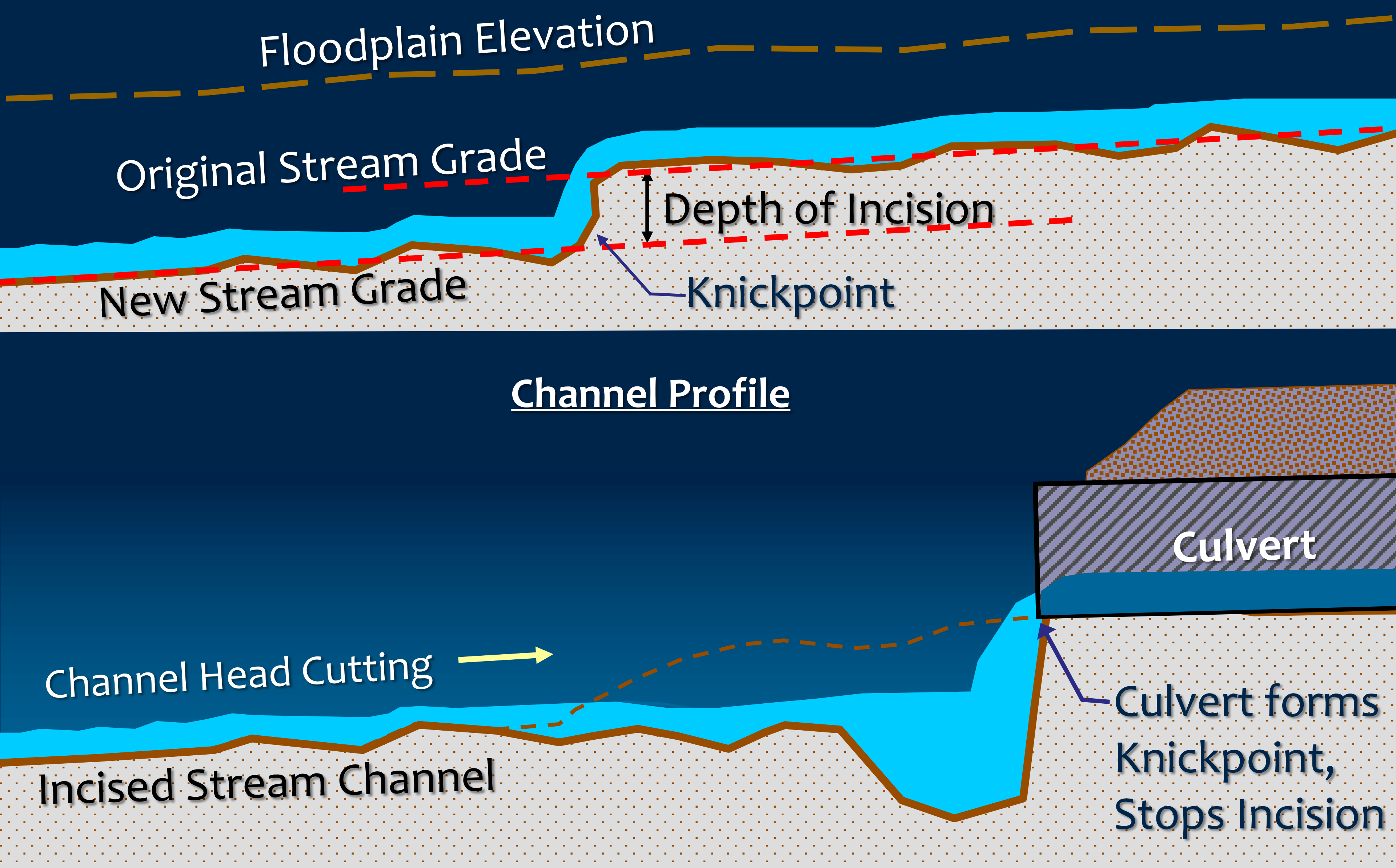


photo: Ross Taylor

Process of Incision: Headwater Migration



Knickpoints that Stop Incision but Create Fish Barriers

Perched Culverts

Bridge/Utility Scour Protection

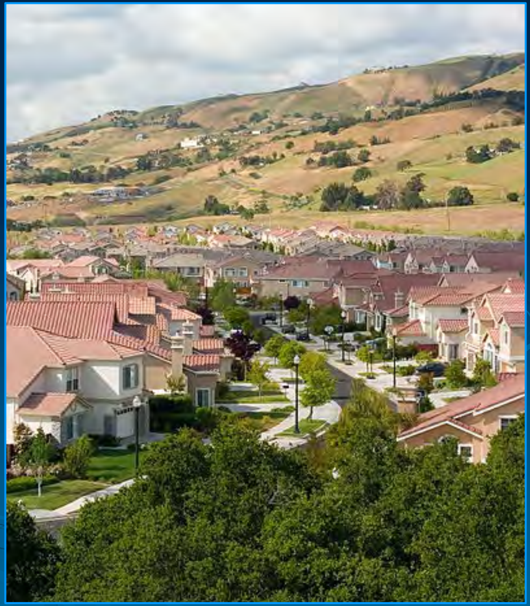
Perched Fishway Entrances

Channel Incision is a Natural Process, but…

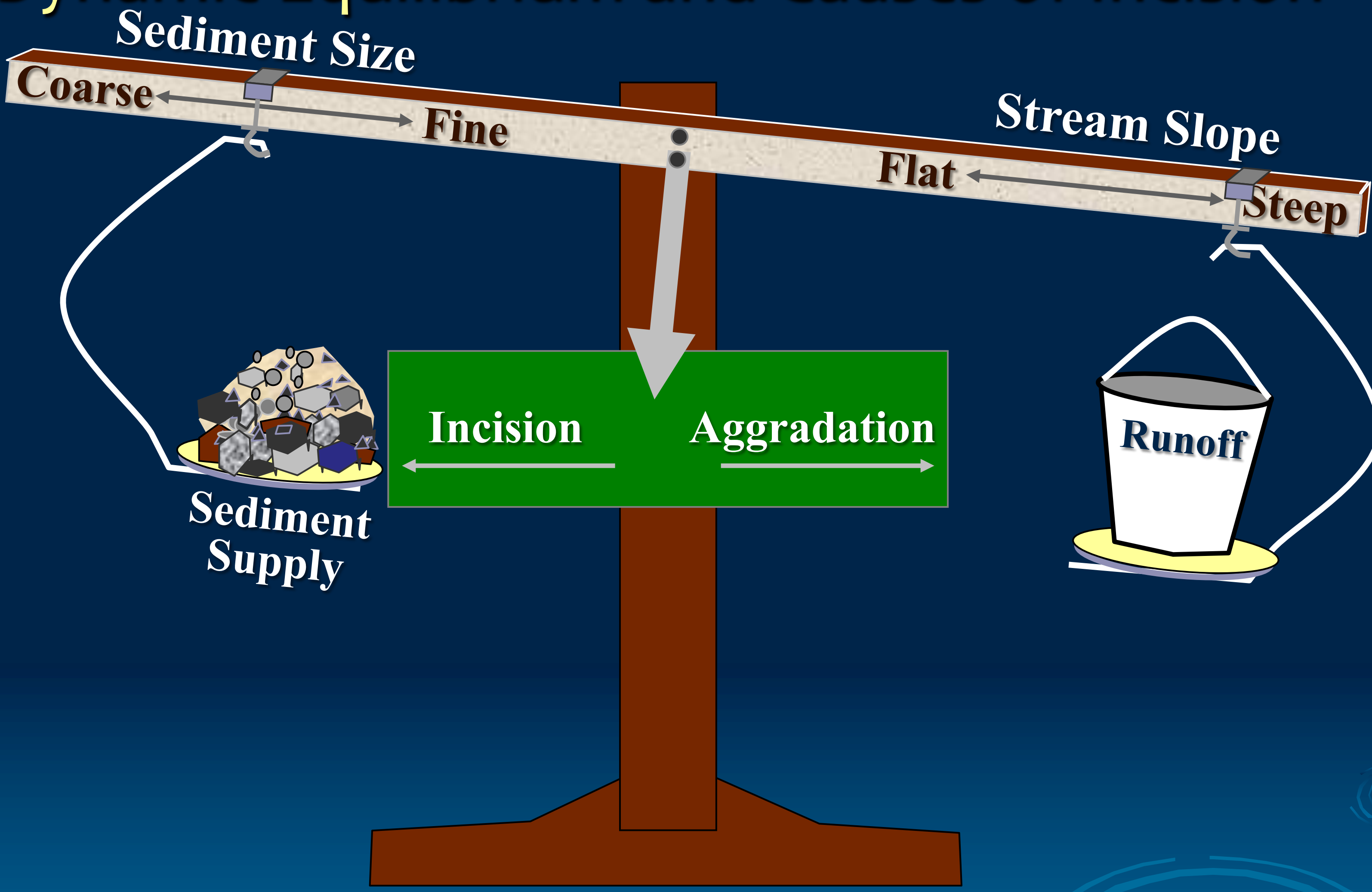
We Initiate the Incision More often then Not

Causes of Channel Incision

- ✓ Channelization
  (shortening/steepening the channel)
- ✓ Increase in runoff
  (urbanization, agriculture, road density)
- ✓ Decrease in sediment supply
  (dams, gravel extraction, urbanization)
- ✓ Stream cleaning
  (removal of large wood jams, beaver dams)
- ✓ Climate change/extreme weather

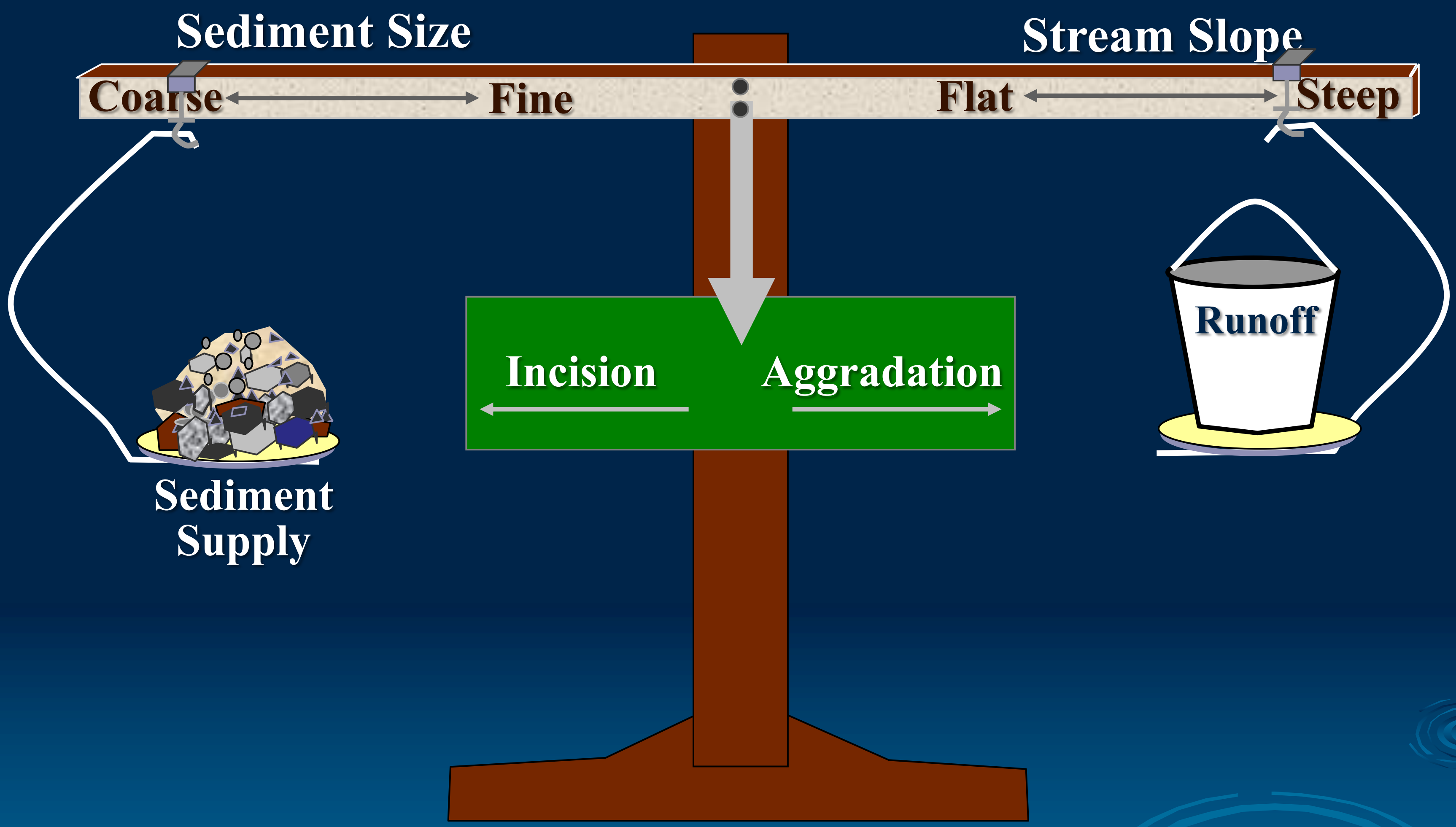


Dynamic Equilibrium and Causes of Incision



The Lane Relationship (from Lane, 1955)

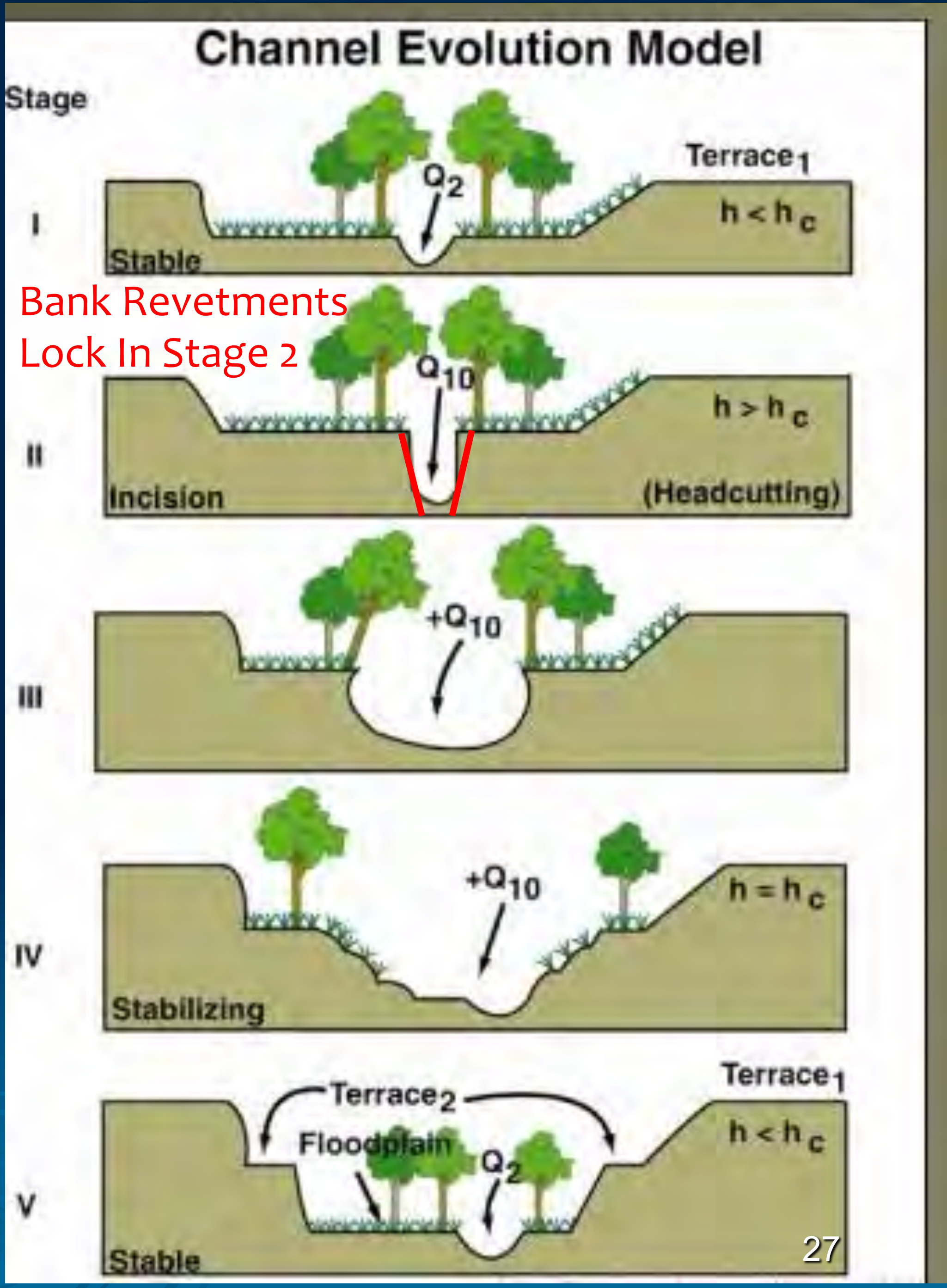
Dynamic Equilibrium and Causes of Incision



The Lane Relationship (from Lane, 1955)

Channel Evolution Model (CEM)

Stage **II Incision**



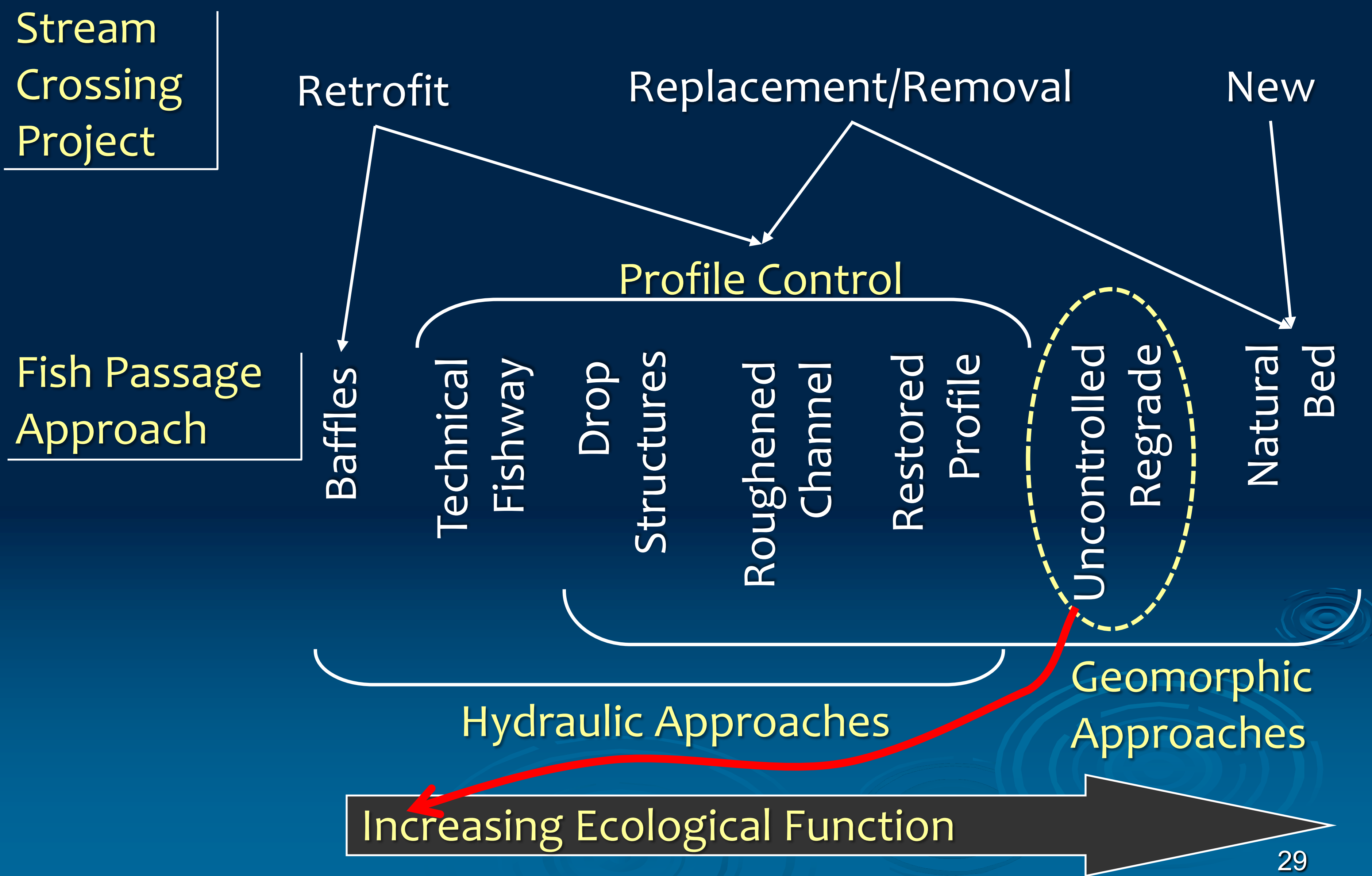
from Schumm, Harvey, and Watson. 1984.

The Stream Channel Incision Syndrome
Loss of Habitat and Ecosystem Benefits

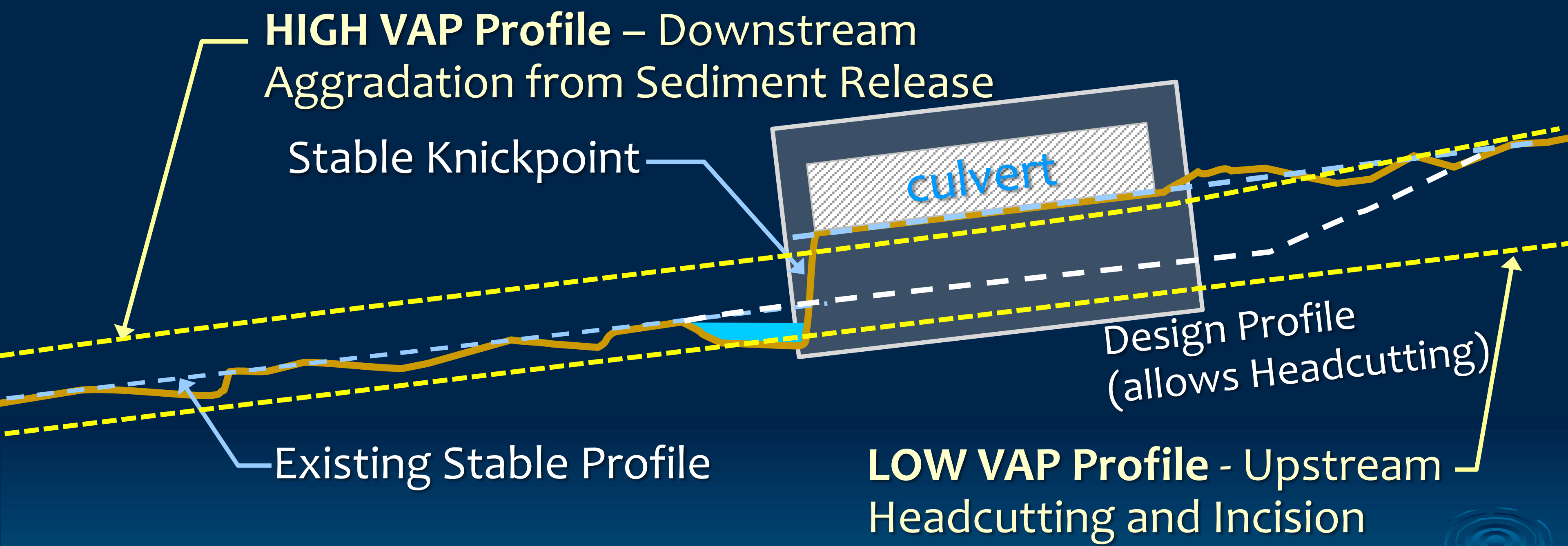
"We conclude channel incision presents a syndrome that is characterized by perturbed hydrology, degraded physical habitat, elevated nonpoint source pollution, and depleted fish species richness and that is extremely deleterious to instream ecosystem services."

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

Design Approaches for Aquatic Organism Passage



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



Uncontrolled Regrade without Evaluating Associated Risks

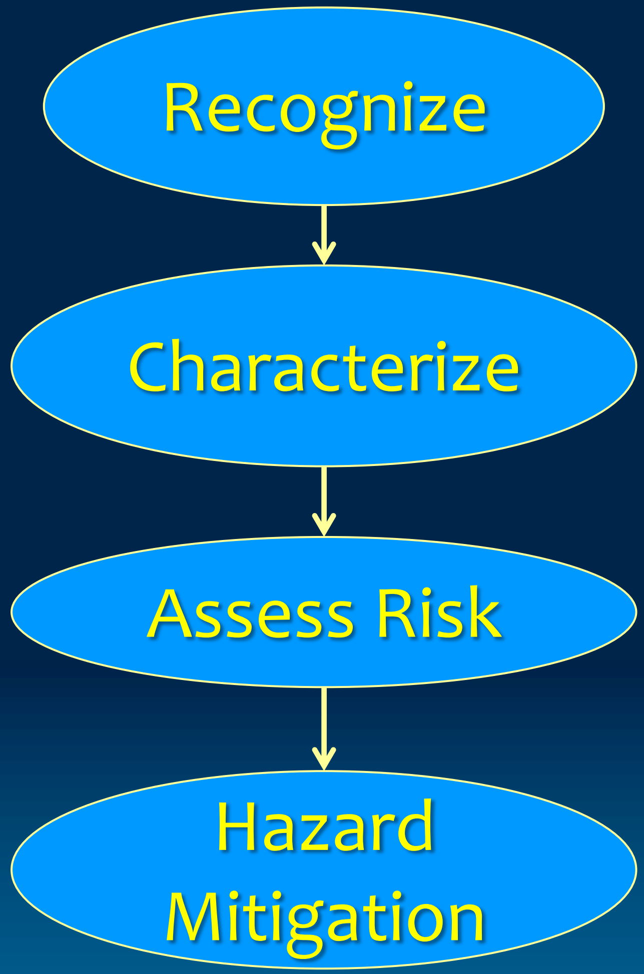
Jordan Creek at Parkway Drive

Before

New Crossing

Upstream Incision after Crossing Replacement

Incorporating Incision Risk Assessments into Passage Projects

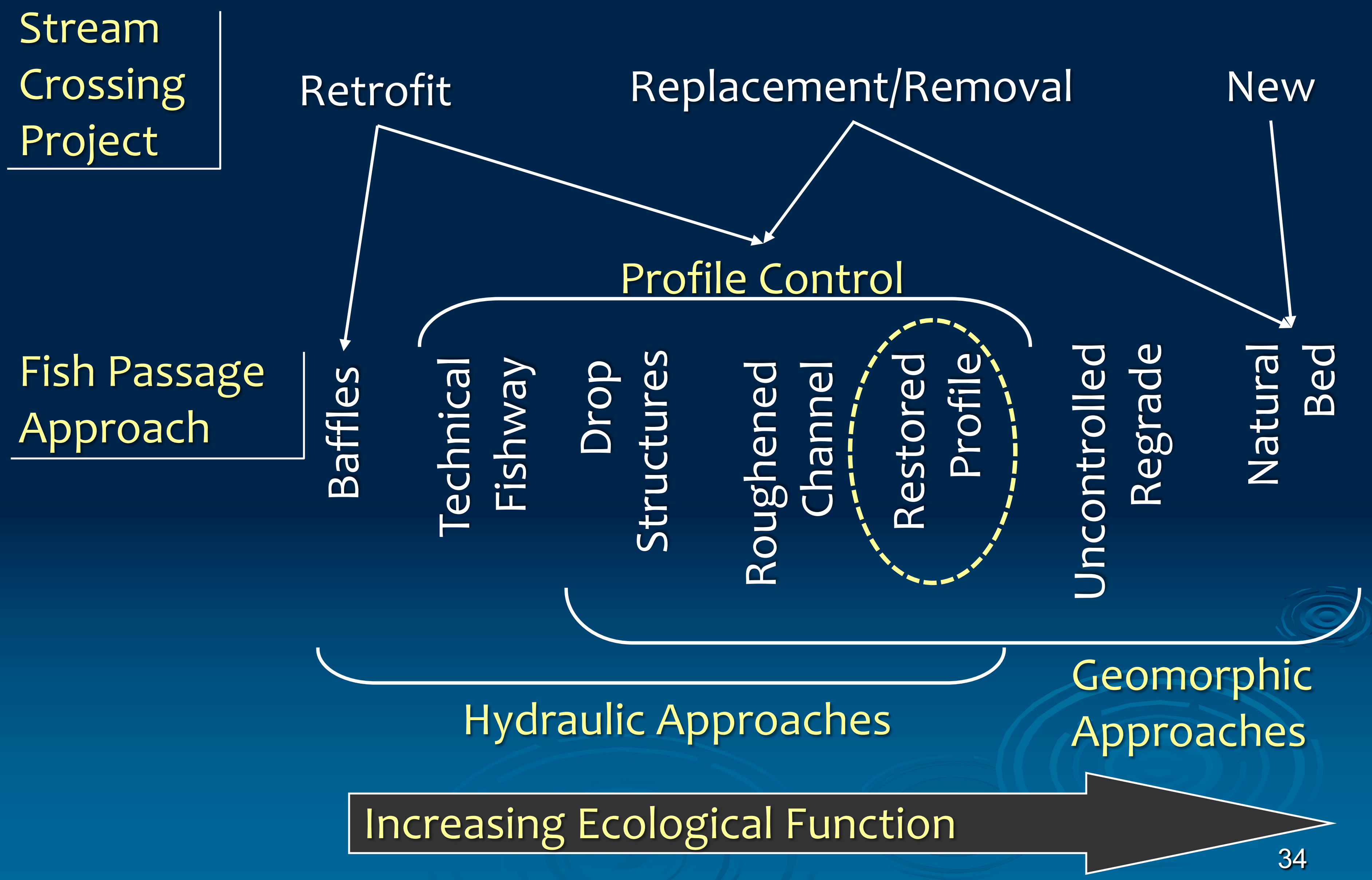


Resource: Castro, Janine. 2003. *Geomorphic Impacts of Culvert Replacement and Removal: Avoiding Channel Incision*. USFWS

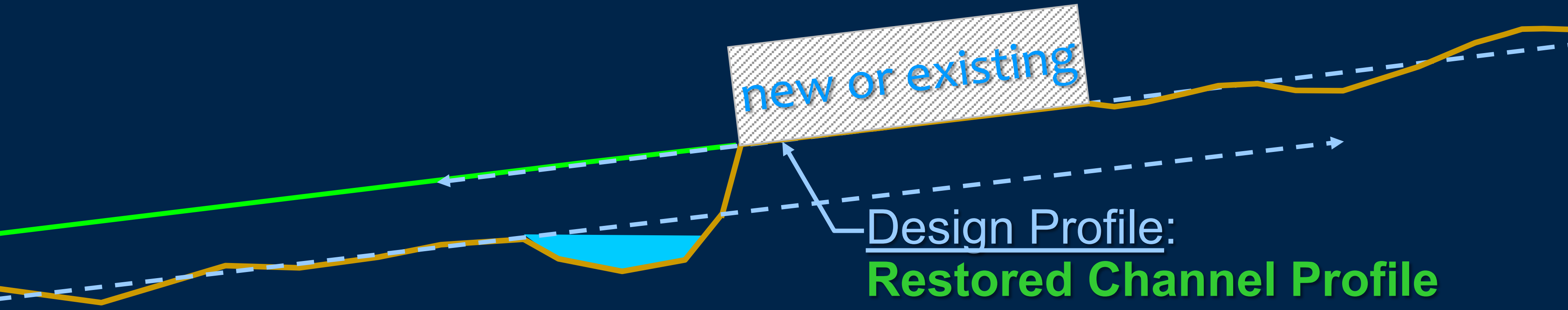
Risk Assessment for Removing Knickpoints in Incised Channels

- **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)?

Design Approaches for Aquatic Organism Passage



Restored Profile Option



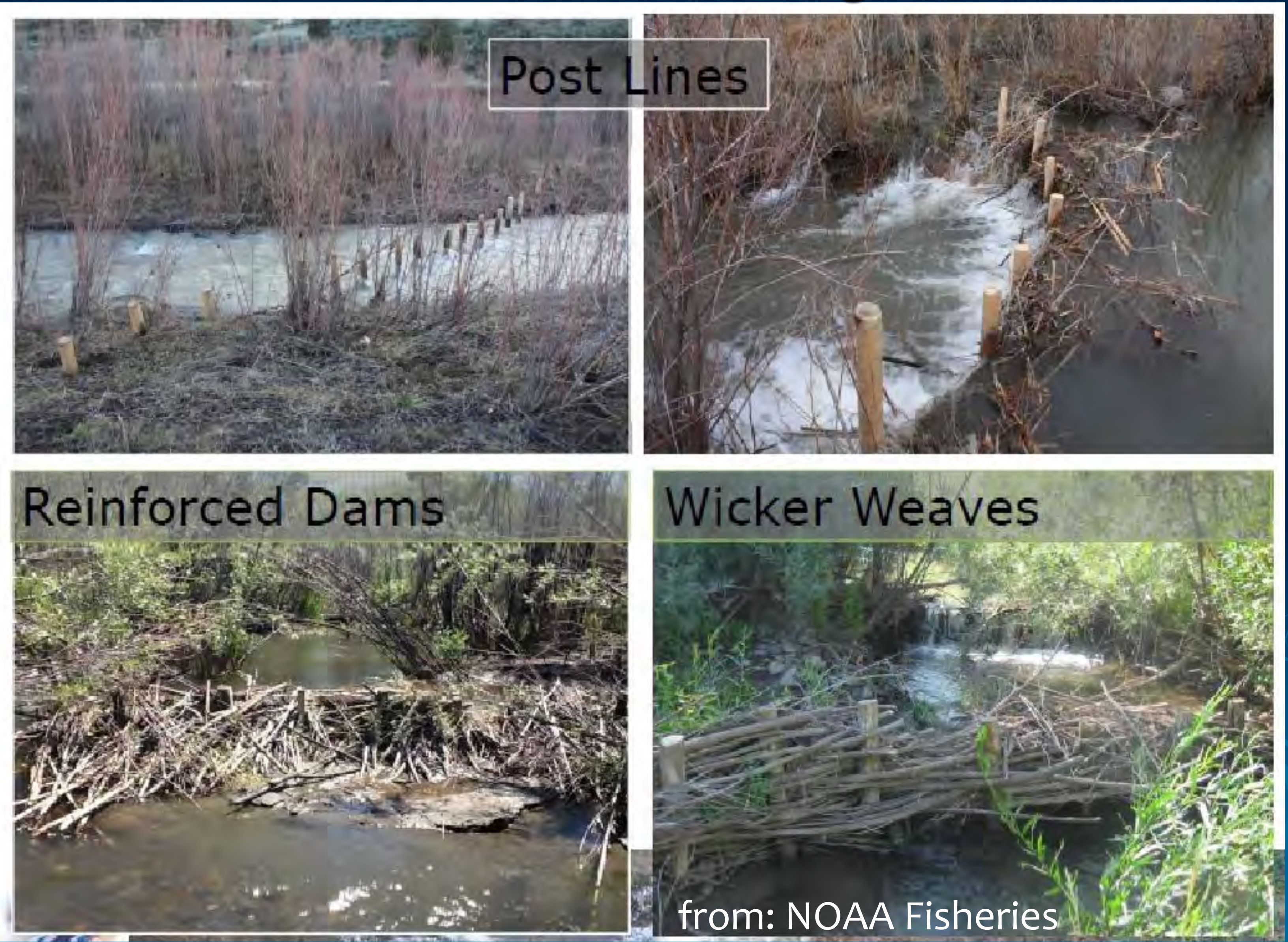
Restoring Incised Channels and Connectivity

Placing Wood - Profile Restoration

Baker Creek
photos: Sam Flanagan, BLM

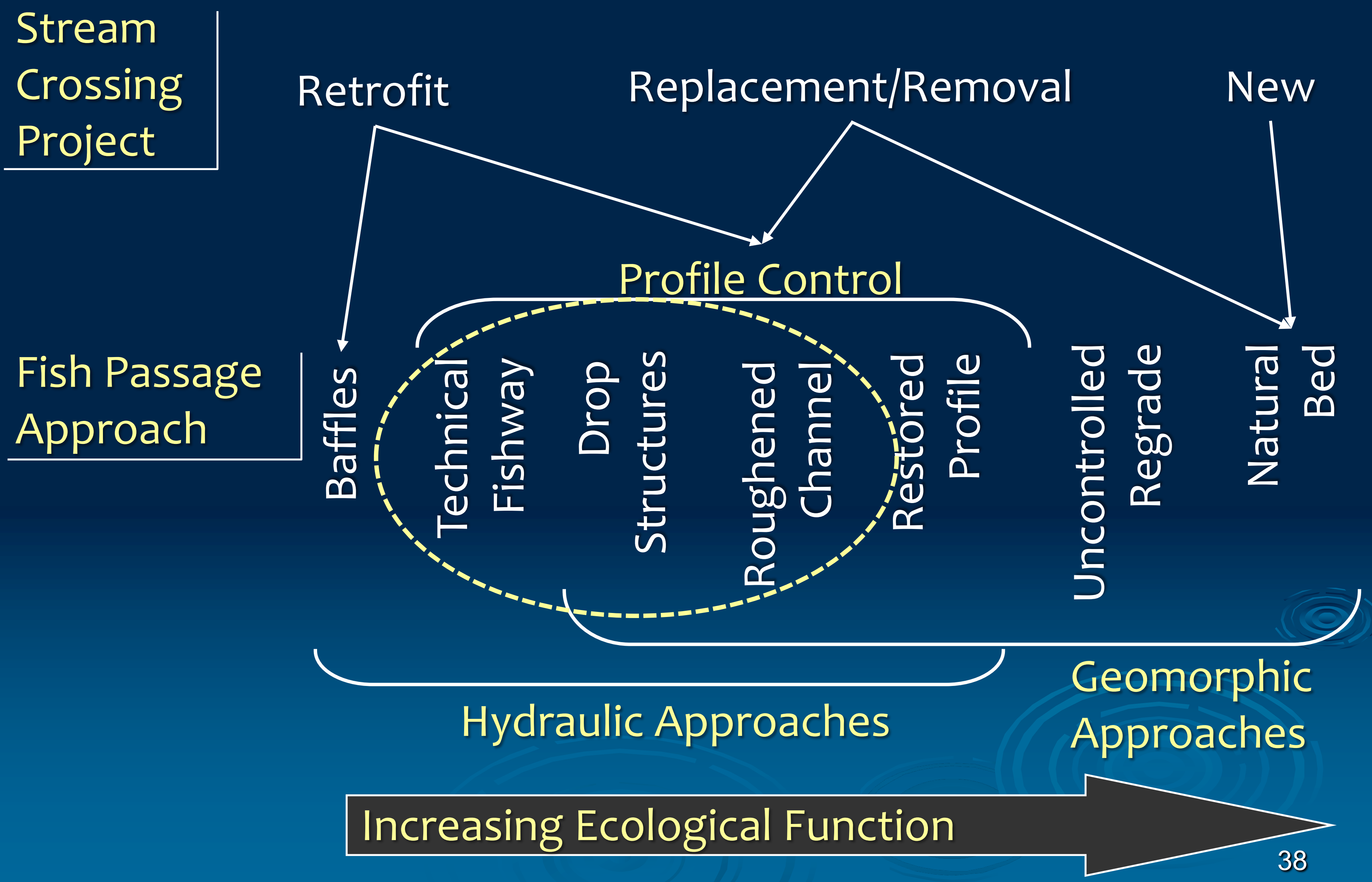
Restoring Incised Channels and Connectivity

Beaver Dam Analogs



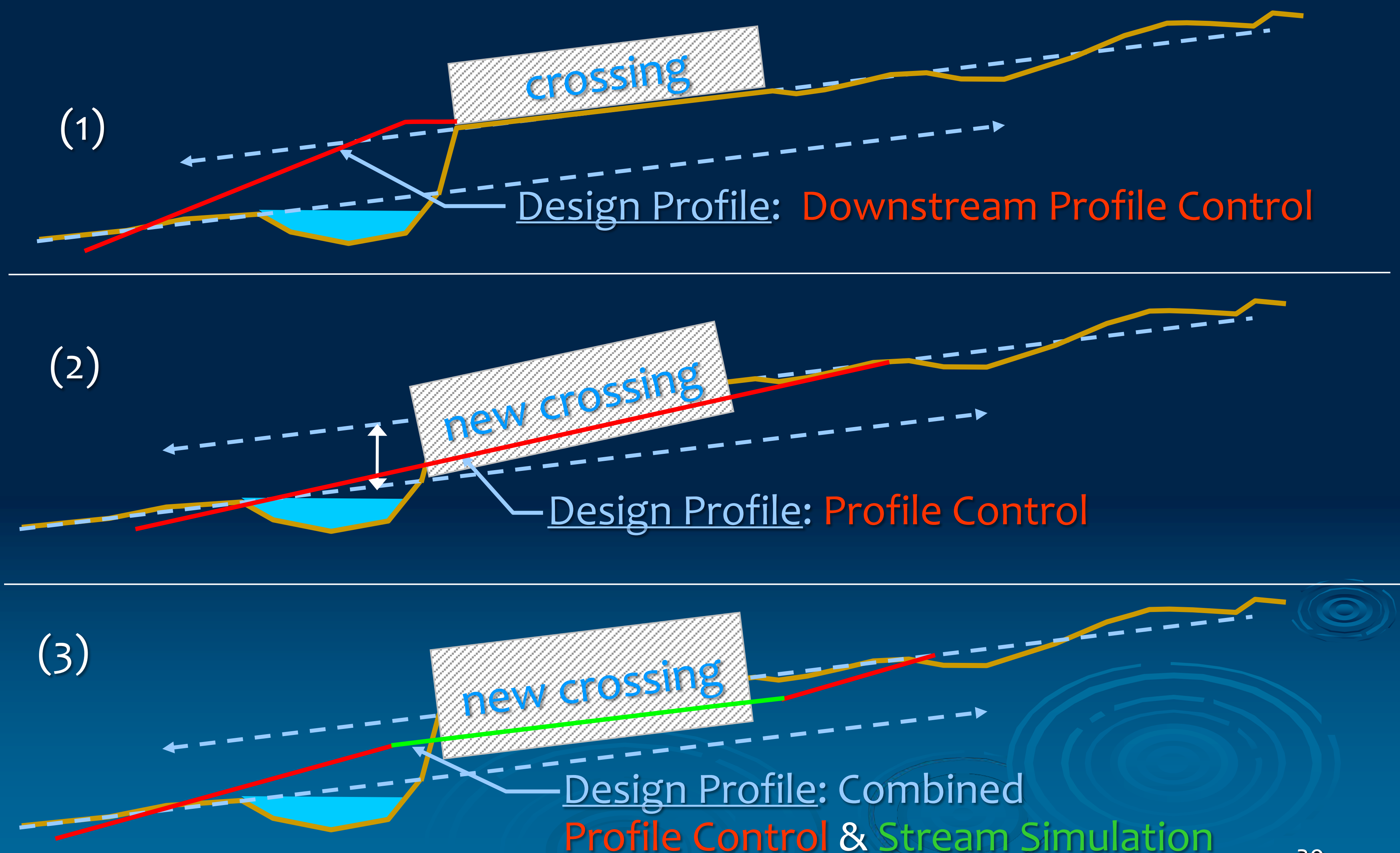
from: NOAA Fisheries

Design Approaches for Aquatic Organism Passage



Forced Profiles for Incised Channels

Use of Profile Control

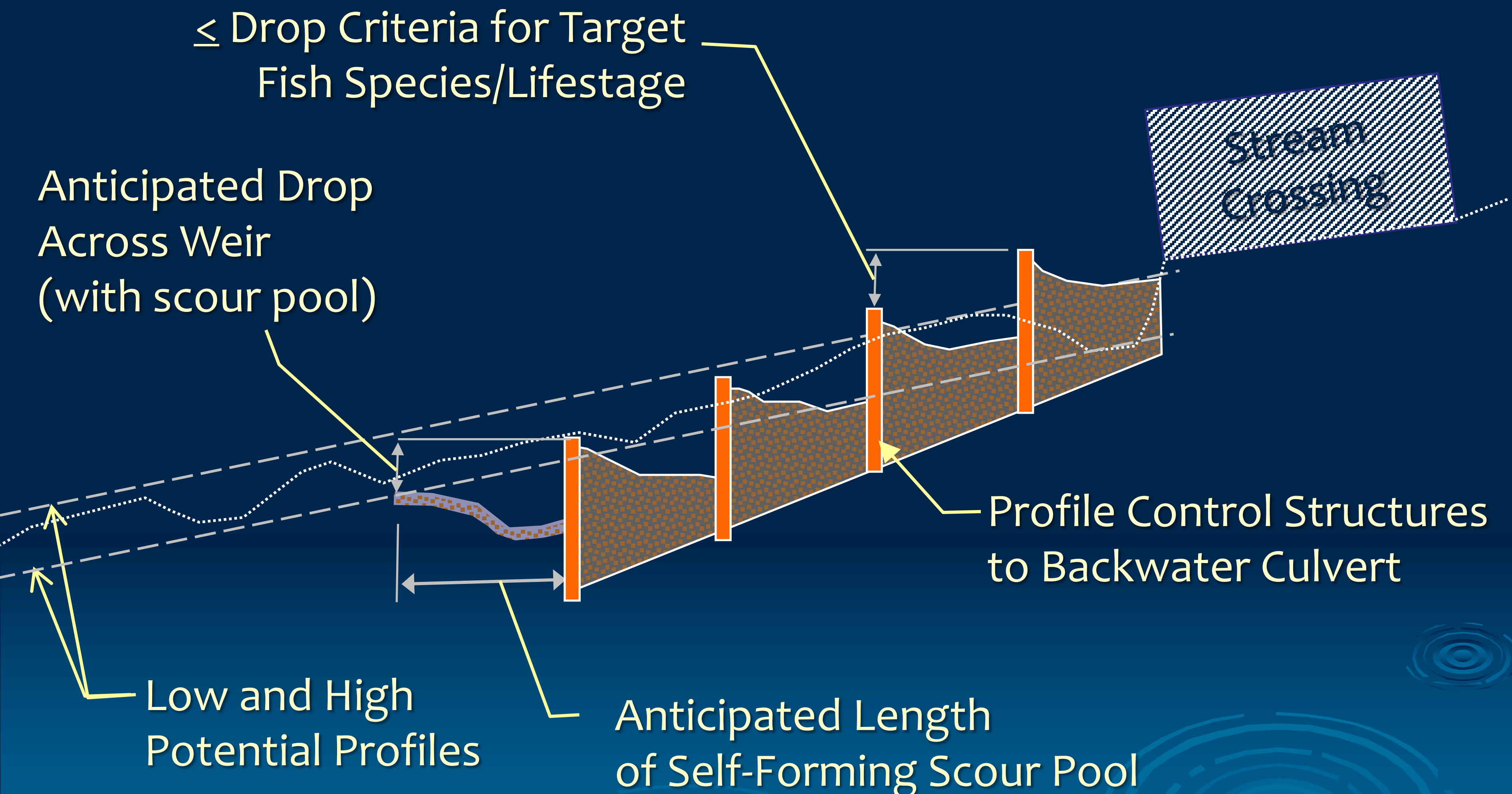


Profile Control - Downstream Transitions

Drop at Fishway Entrance from Downstream Scour

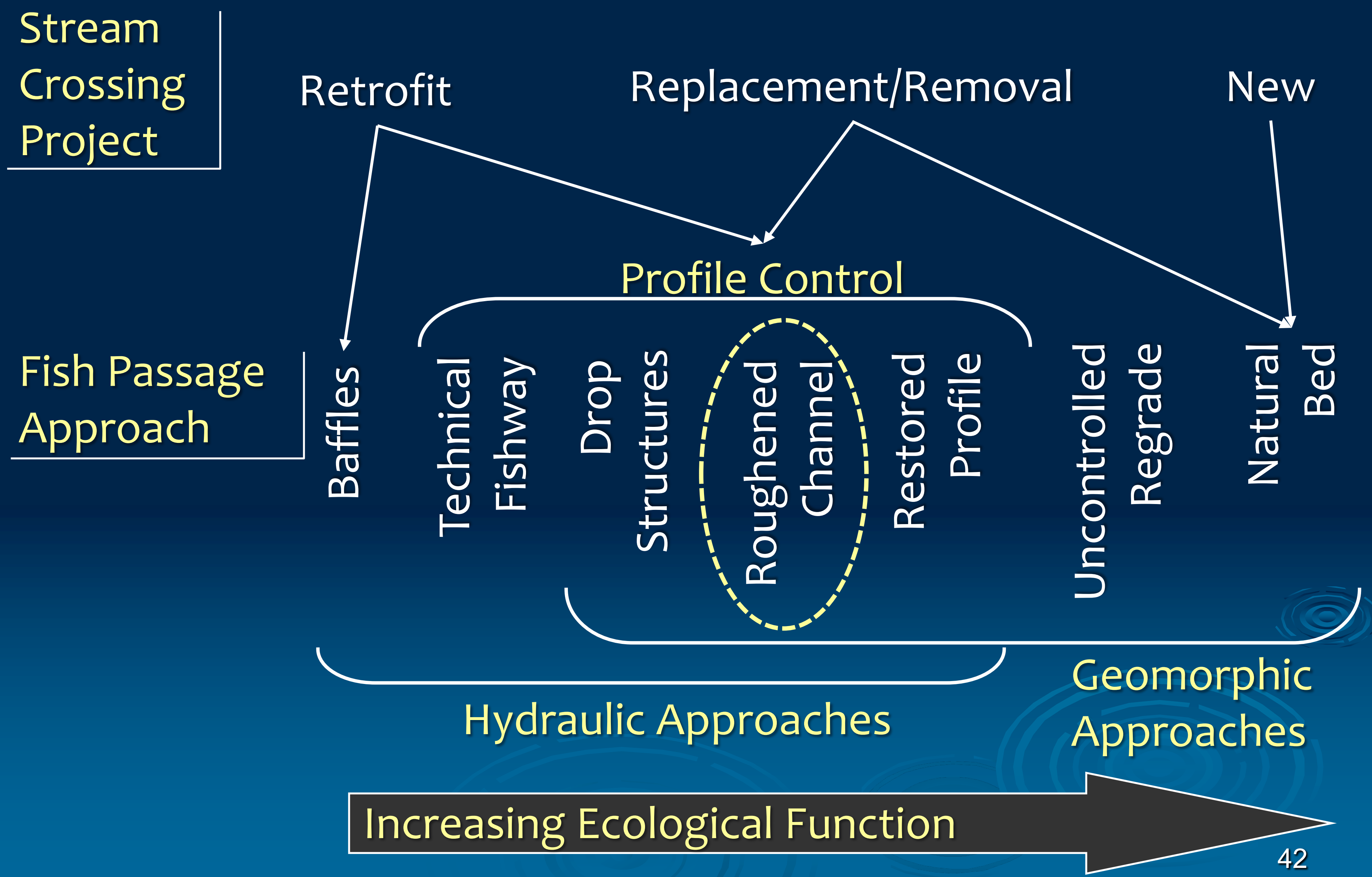
Rock Weir Excess Drop from Downstream Scour

Using Low VAP to Set Profile Control Transition



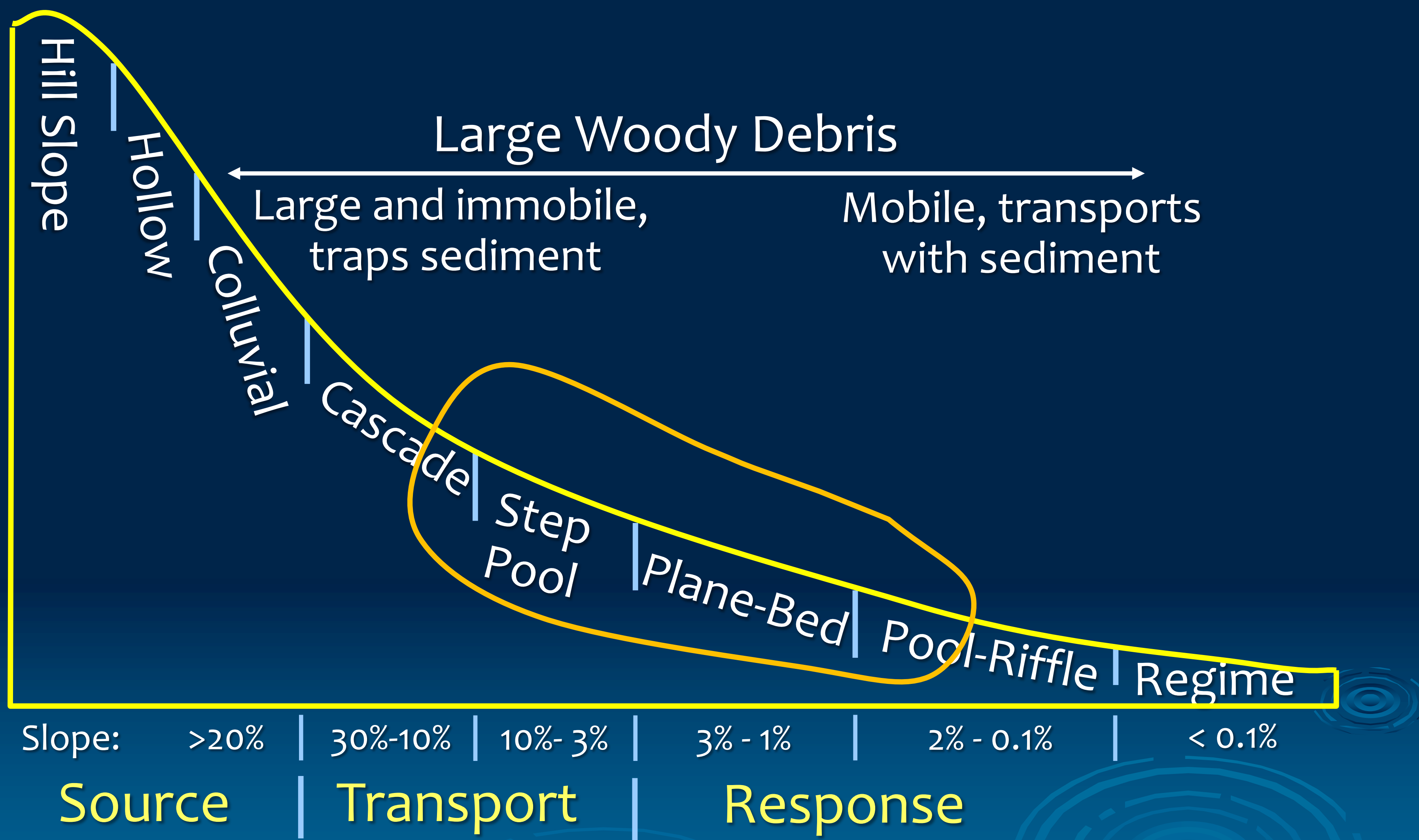
- ✓ Place Downstream End of Profile Control based on Anticipated Scour Pool Length at Low VAP Profile

Design Approaches for Aquatic Organism Passage



Natural Steep-Stream Morphology

Generalized Stream Classification



(from Montgomery and Buffington, 1993)

Geomorphically-Based Roughened Channel Concept

Common Channel Types

Increasing Slope ↓

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

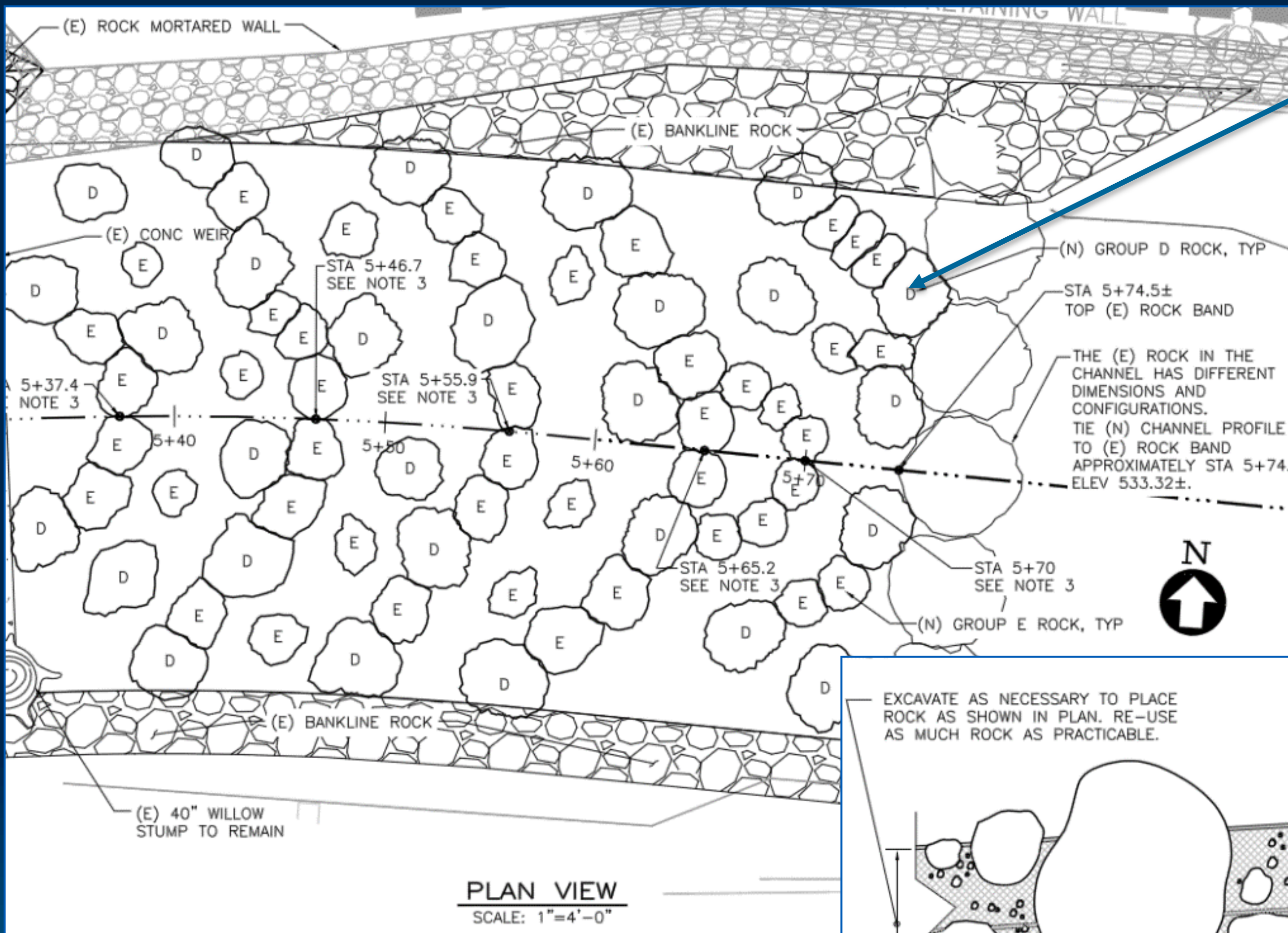
Caution:

- 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)

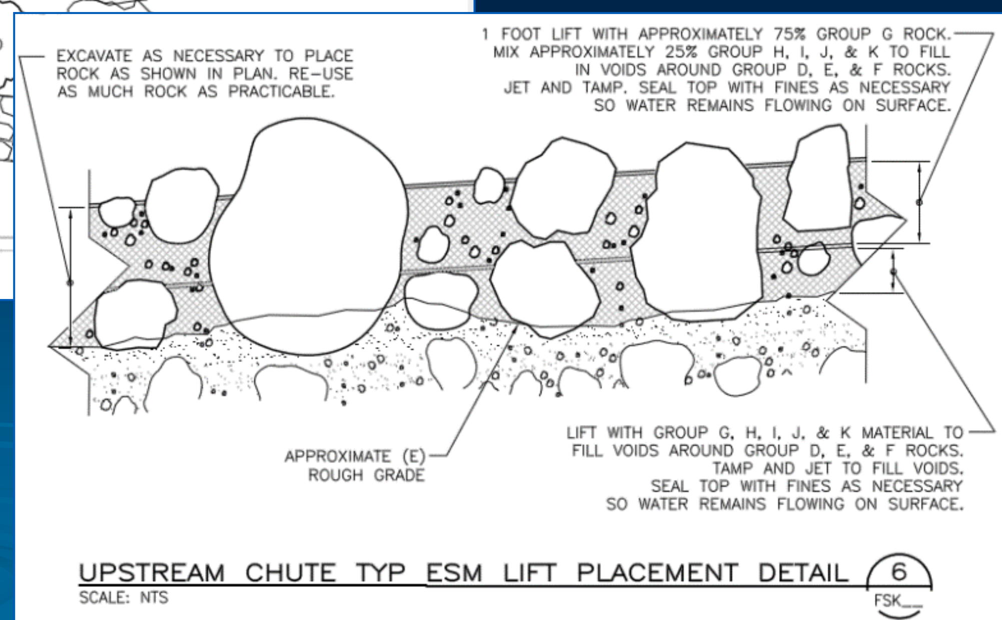
Geomorphically-Based Roughened Channels

- Constructed steeper than the adjacent channel (profile control)
- Based on morphology of steeper stream channel
- Stable *engineered streambed material (ESM)* forms channel bed & banks, with smaller material filling voids
- Quasi-hydraulic design for target species/lifestages [velocity, depth, drop, turbulence-EDF]

Roughened Channel Rock Placement Plan

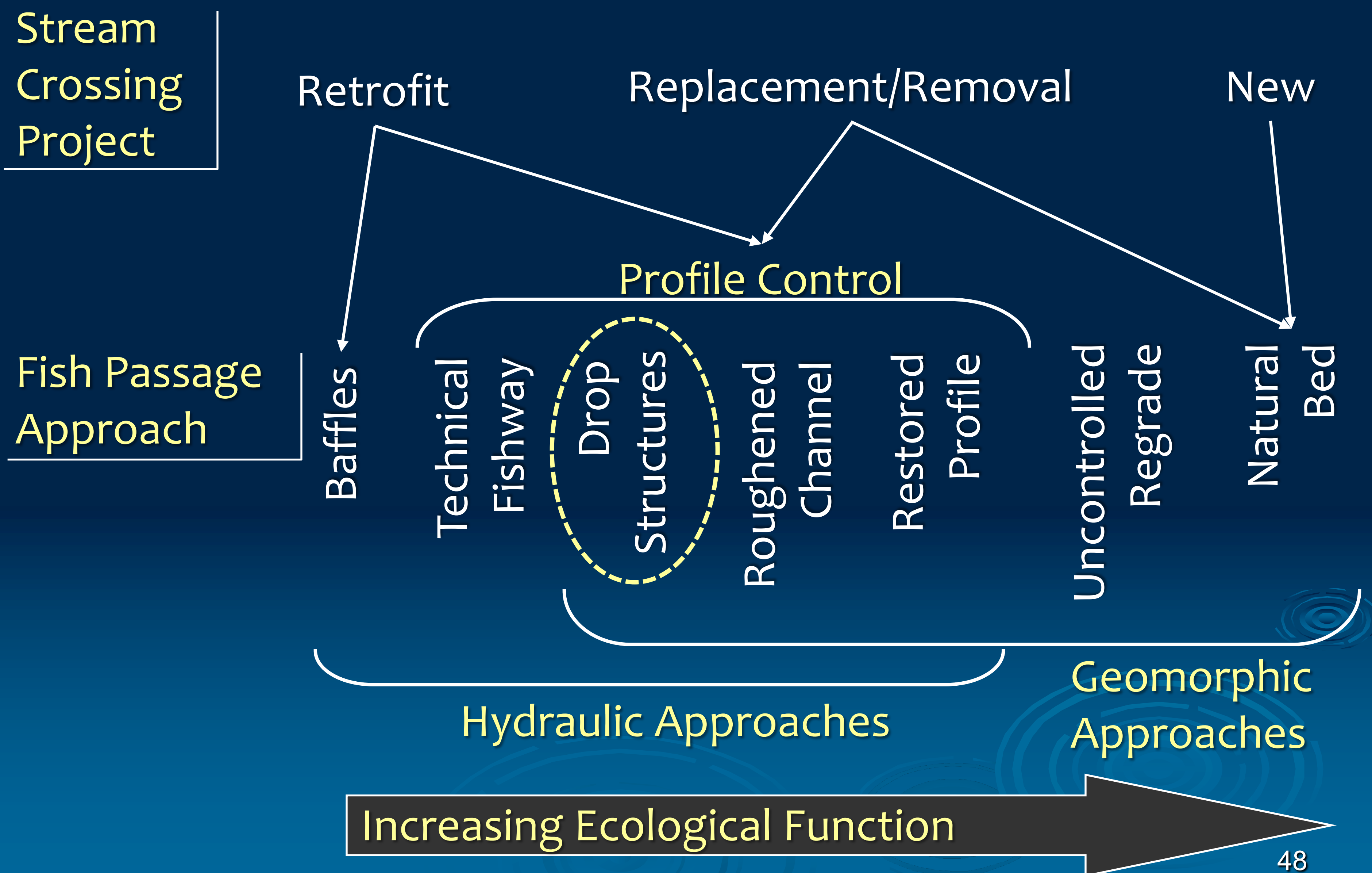


Placement Plan for Structure Rocks [D, E] within ESM



Material Placement in Lifts

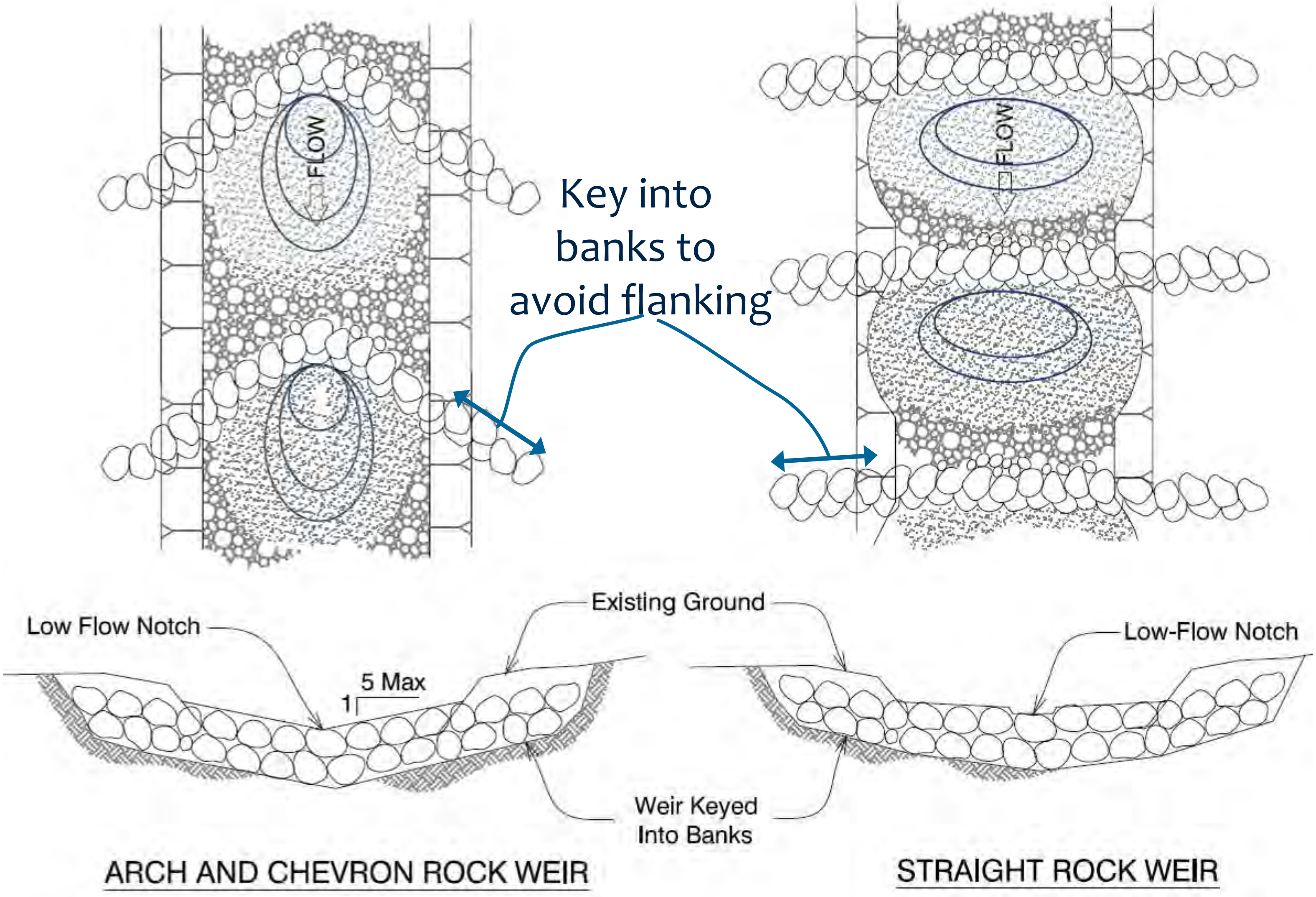
Design Approaches for Aquatic Organism Passage



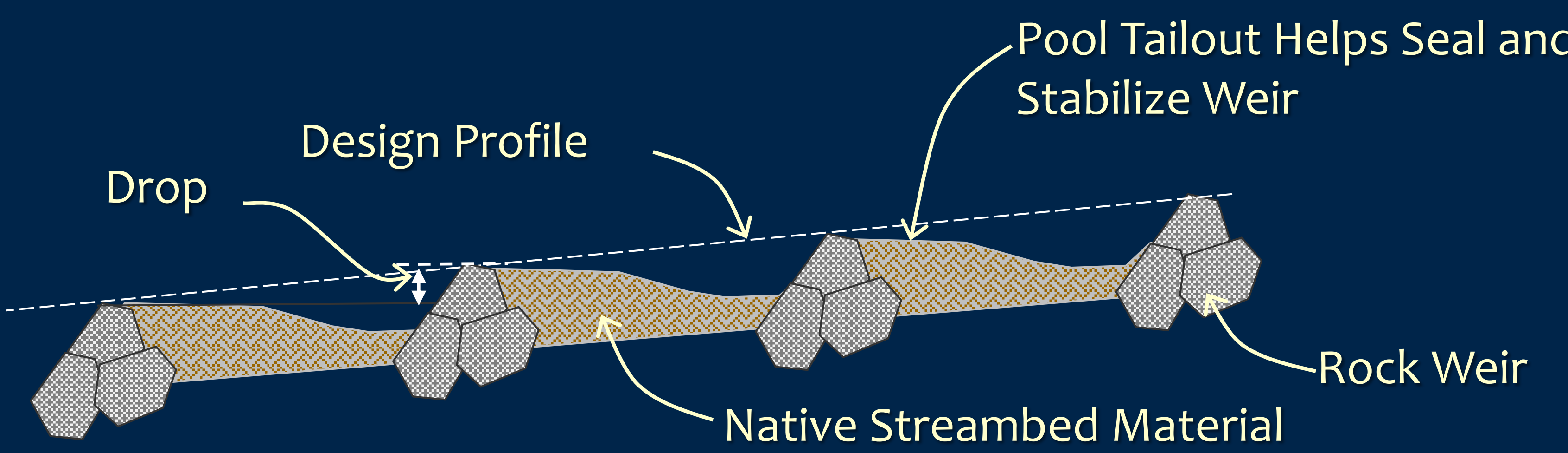
Shape of Rock Weirs
Controls Scour Pool Shape

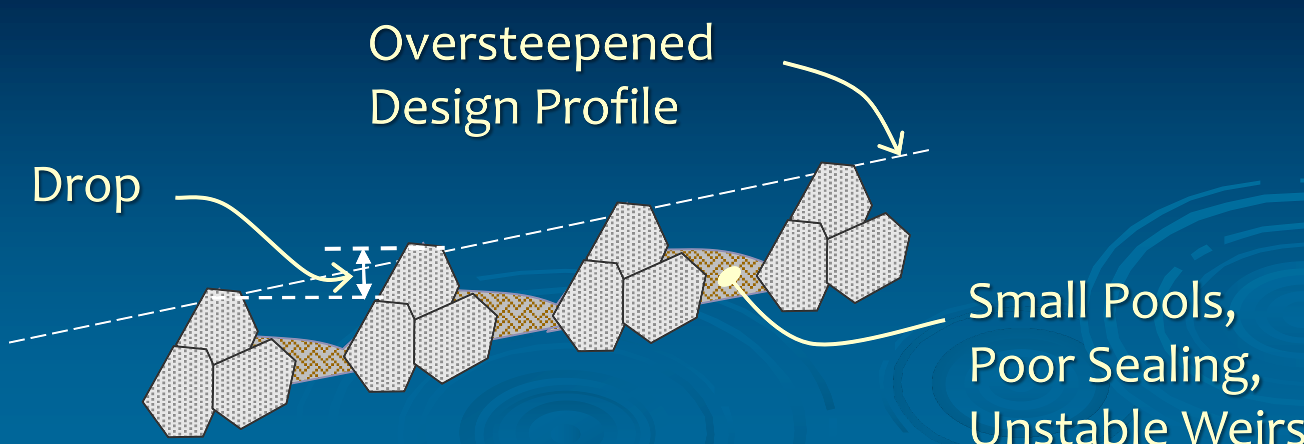
Arch Concentrates Scour
(Longer/Narrower Pools)

Straight Weirs Spread Scour
(Shorter Pools/Wider)

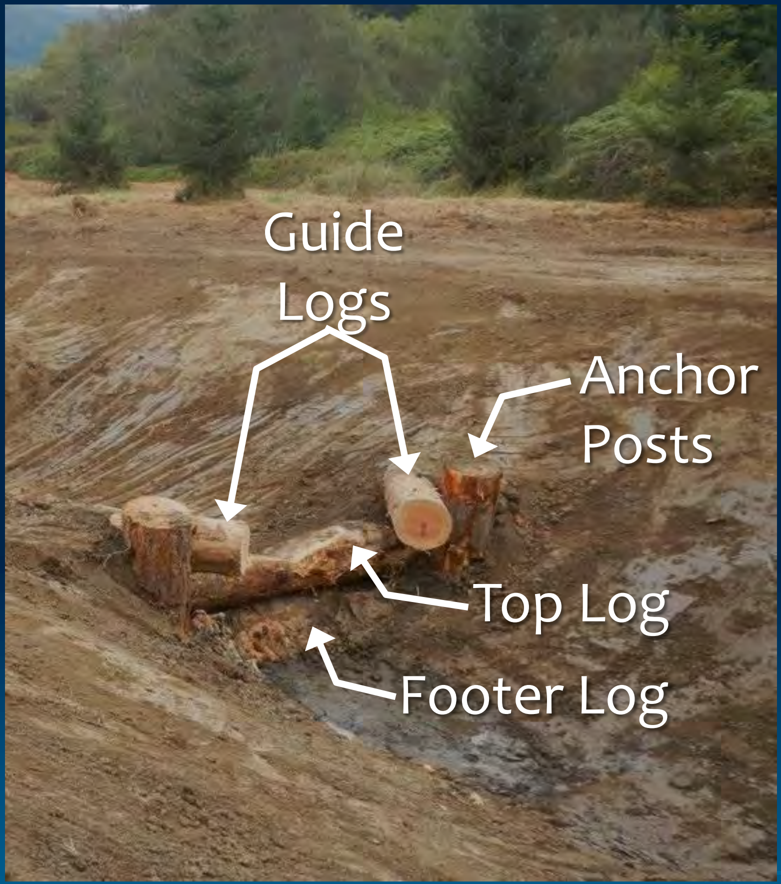


Spacing of Rock or Log Weirs



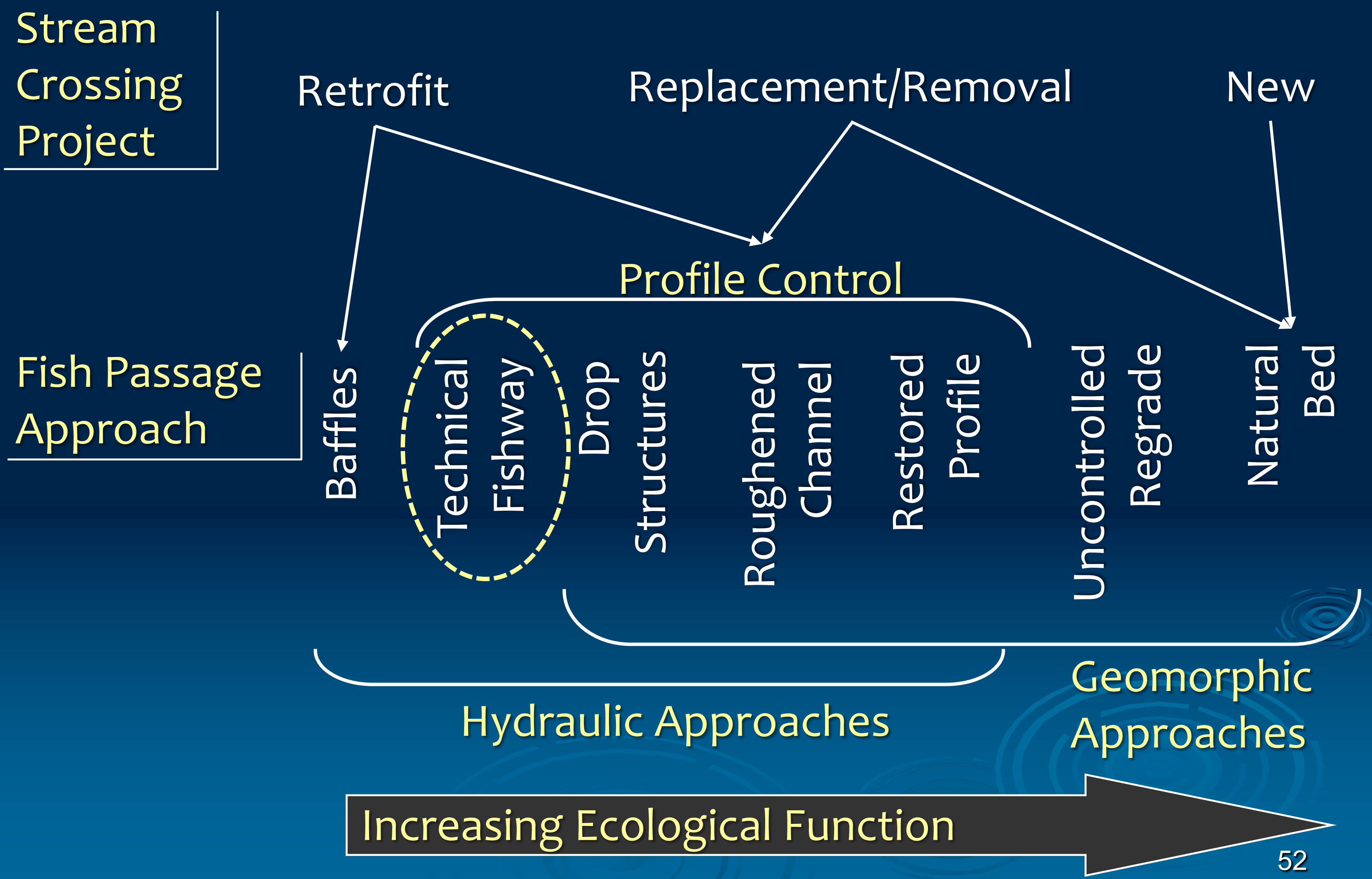


Log Weir Design

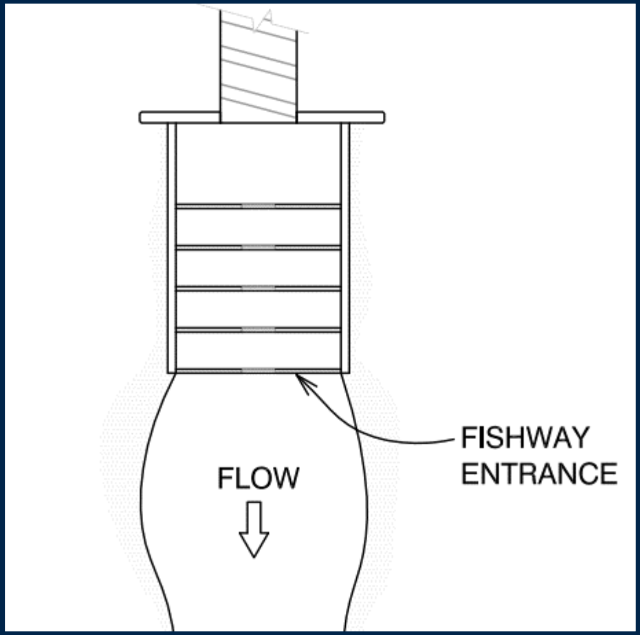


- Top Log and Guide Logs Thru-Bolted to Anchor Posts
- Top Log Anchored to Footer Log

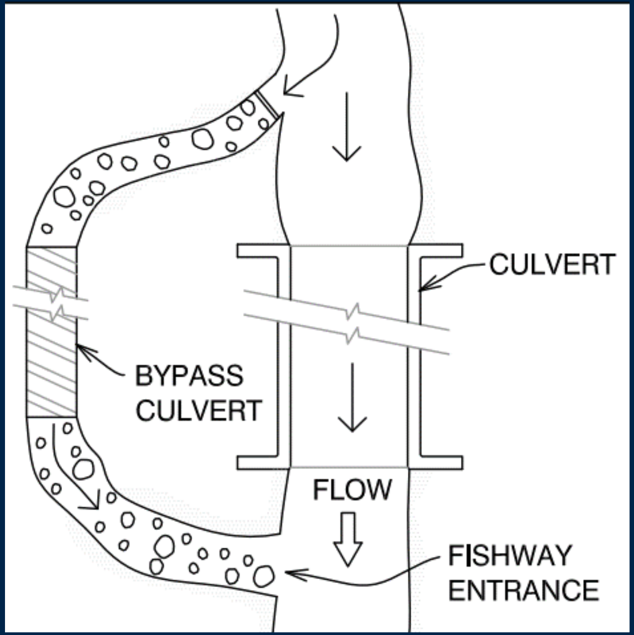
Design Approaches for Aquatic Organism Passage



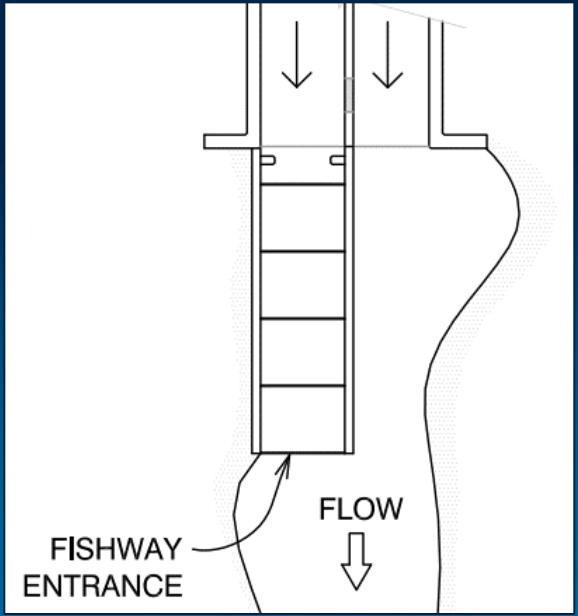
Technical Fishway Configurations



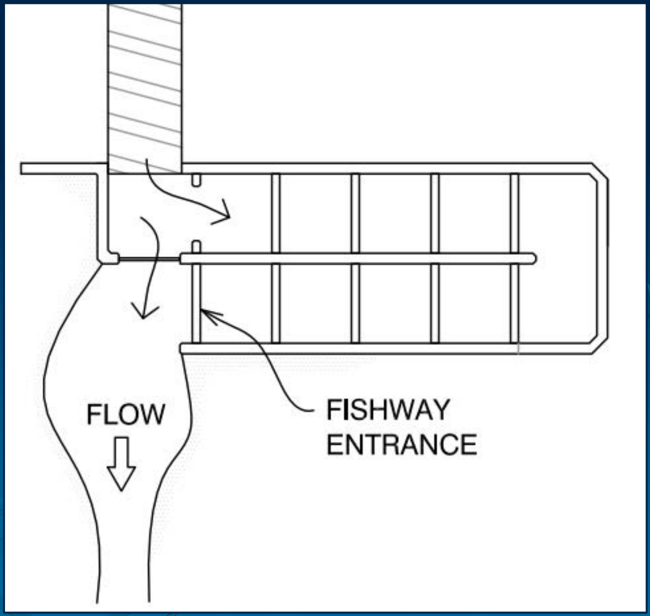
Full Width



Bypass Fishway



Partial Width Fishway



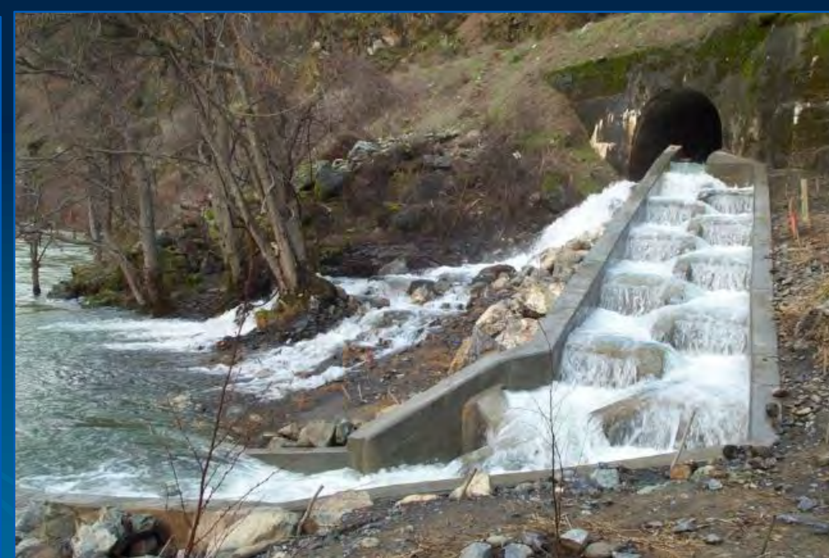
Bypass Fishway

Technical Fishways for Stream Crossings

Full Width "Vortex" Pool-and-Chute Fishway

Bypass Pool-and-Weir Fishway

Partial Width Pool-and-Chute Fishway



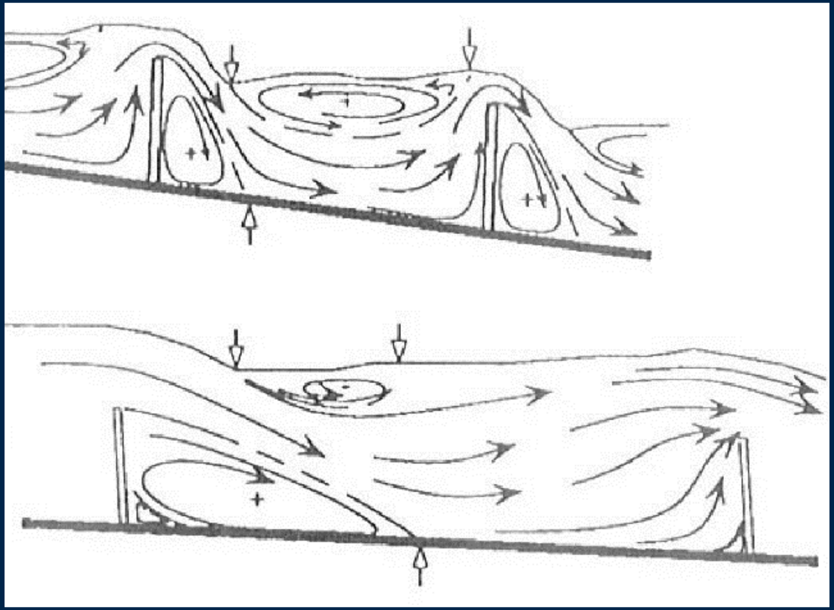
Bypass "Serpentine" Pool-and-Weir Fishway

Fishways & Turbulence

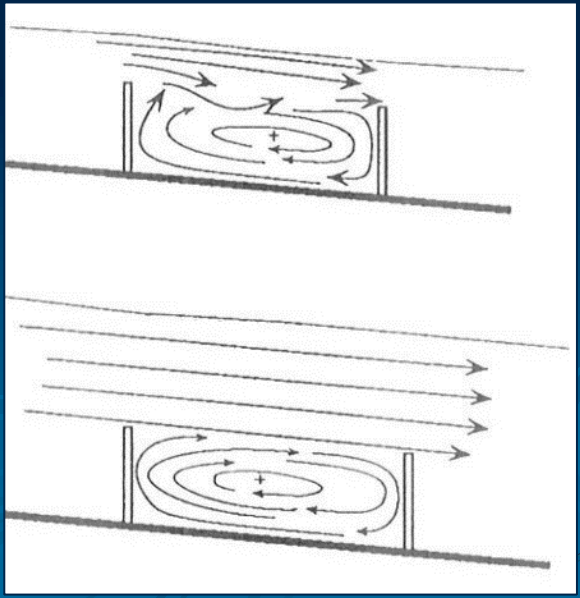
- Energy is Dissipated in Receiving Pool through Turbulence (heat)
- Excessive Turbulence can Block Fish
- The Energy Dissipation Factor (EDF) provides Rate Energy Dissipates per Volume of Water

Flow Regimes of Technical Fishways

Plunging (weir flow)

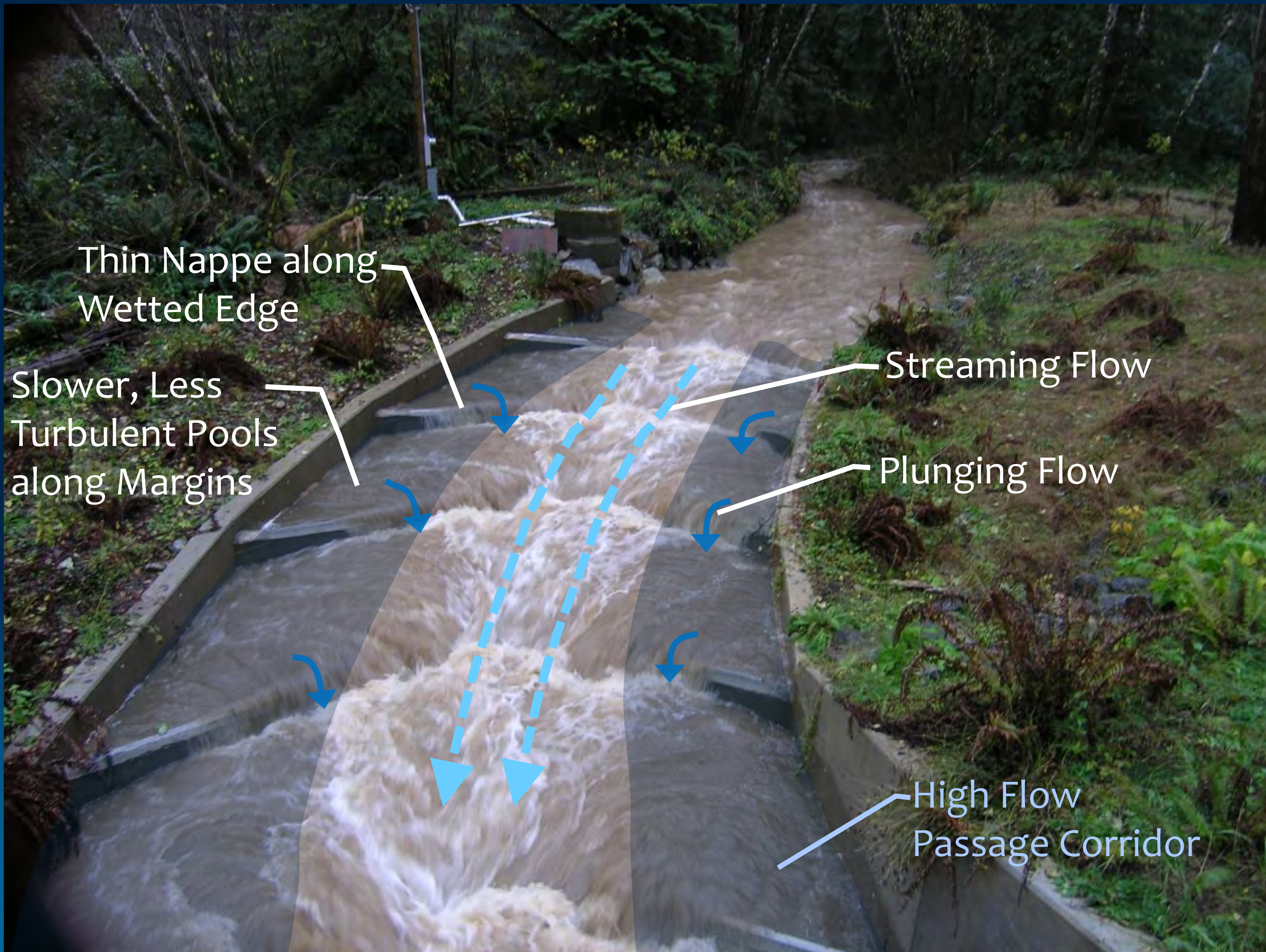


Streaming
(hydraulic roughness)

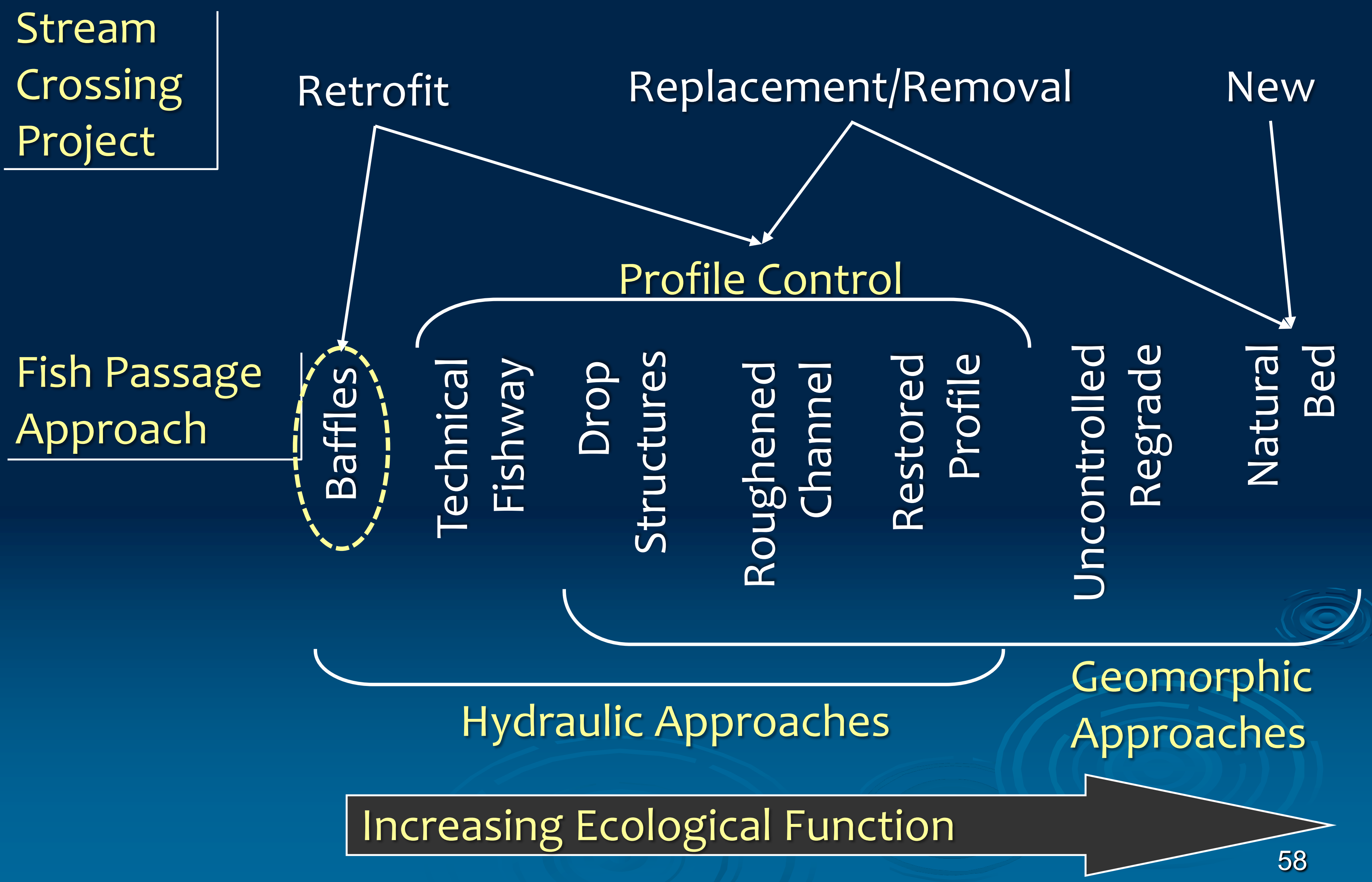


from Ead, 2004

Pool and Chute Fishway Hydraulics



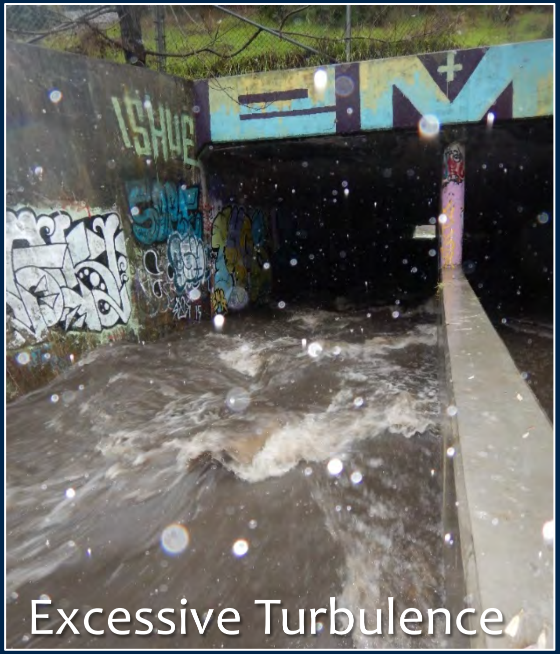
Design Approaches for Aquatic Organism Passage



Culvert Baffle Retrofits for Fish Passage

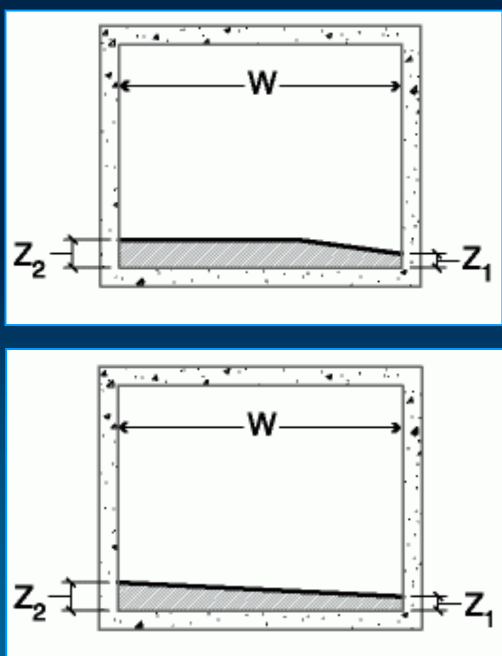
Baffles Improves Fish Passage

- Increases Hydraulic Roughness
- Decreases Velocity
- Increases Depth
- **Limited to Culvert Slopes Less than 3%** (excessive turbulence at higher slopes)
- **Turbulence limits range of passage flows**

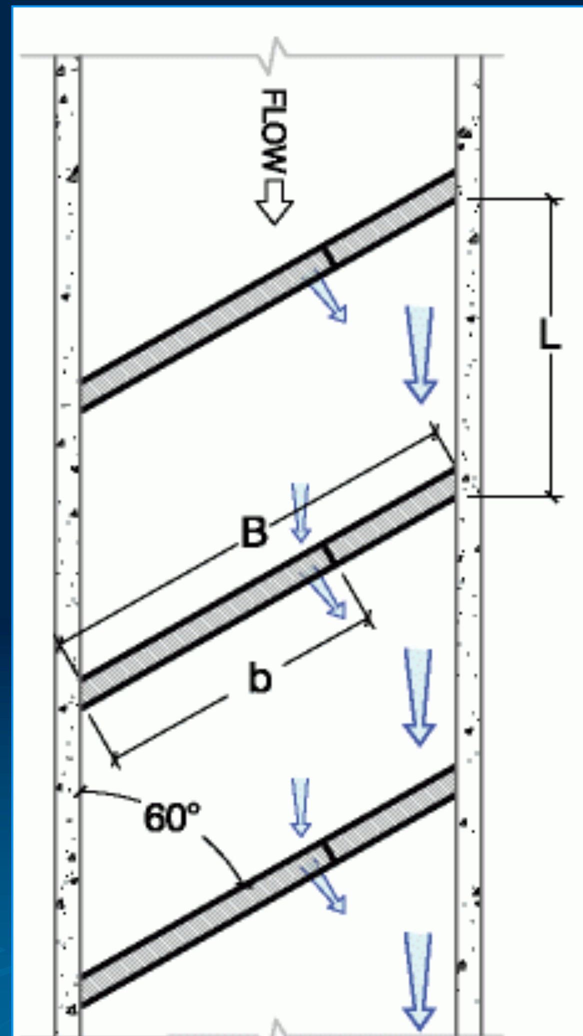


Angled Baffles for Retrofitting Flat-Bottom Culverts

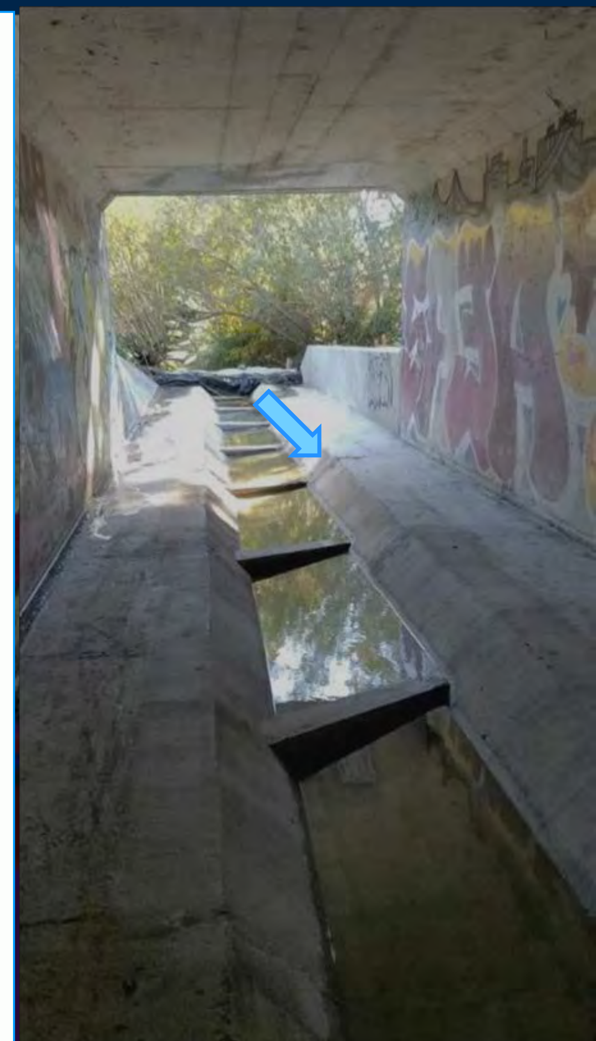
- Skew shunts flow and debris to low side
- Fish passage corridor on high side



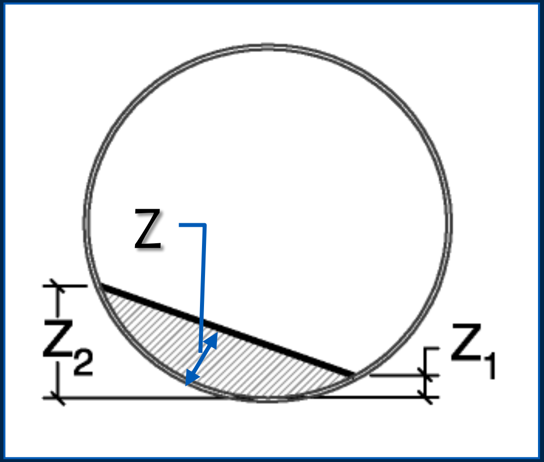
Section



Plan



Corner & Weir Baffles



Corner Baffles

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

Weir Baffles

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

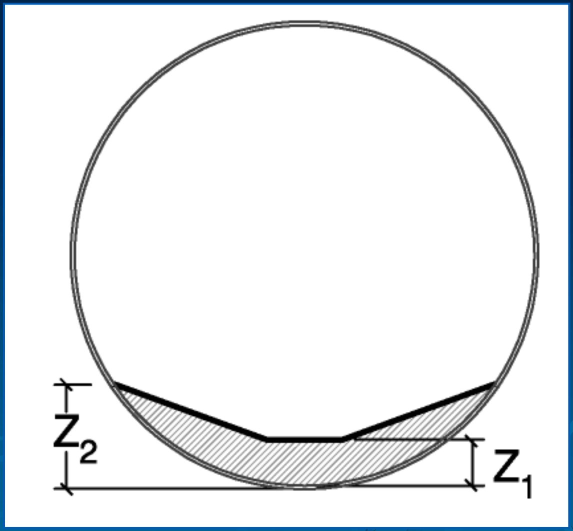


Photo: Kozmo Bates

Baffled Outlet Transition

Low Flow

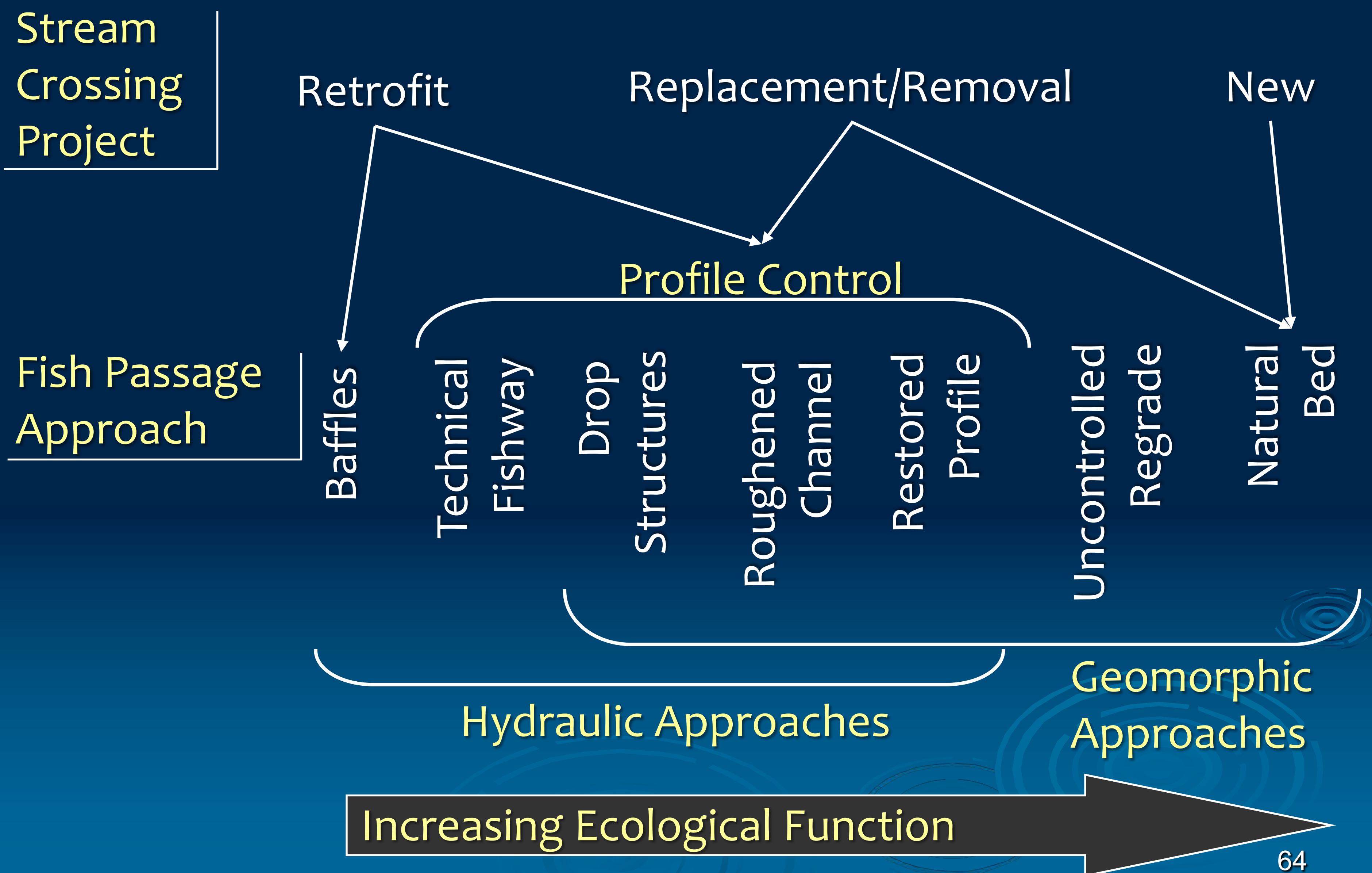
High Fish Passage Flow
(excessive hydraulic drop)

- ✓ Evaluate the Outlet Transition
- ✓ Avoid Excessive Hydraulic Drop at Outlet
- ✓ Tailwater should Meet or Exceed Depth in Baffled Culvert

Baffling Thoughts

- ✓ ONLY for Retrofits
- ✓ Requires regular inspection and debris clearing
- ✓ Passage effectiveness for smaller/weaker swimming fish is unknown
- ✓ Frequently reduces capacity
- ✓ Turbulence limits passage
- ✓ Give due attention to hydraulic transition at culvert outlet

Design Approaches for Aquatic Organism Passage



Questions?