Stream Simulation Design

Principles and Applications in the U.S.A.

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Acknowledgements
Images and Content
Dan Cenderelli – NSAEC
Mark Weinhold – NSAEC
Nat Gillespie – WO BPR

Topics

- Definitions
- Why stream Simulation
- Stream Simulation Design Methods and requirements

Normal Flow

Elevated Flow
Close to Bankfull

Stream Simulation Installed 2002

Definitions:

Stream Simulation Design Method: A channel that simulates characteristics of the adjacent natural channel (reference reach = gradient, dimensions, and instream structure), will present no more of a challenge to movement of organisms than the natural channel. It also can adjust vertically as the stream does thru time

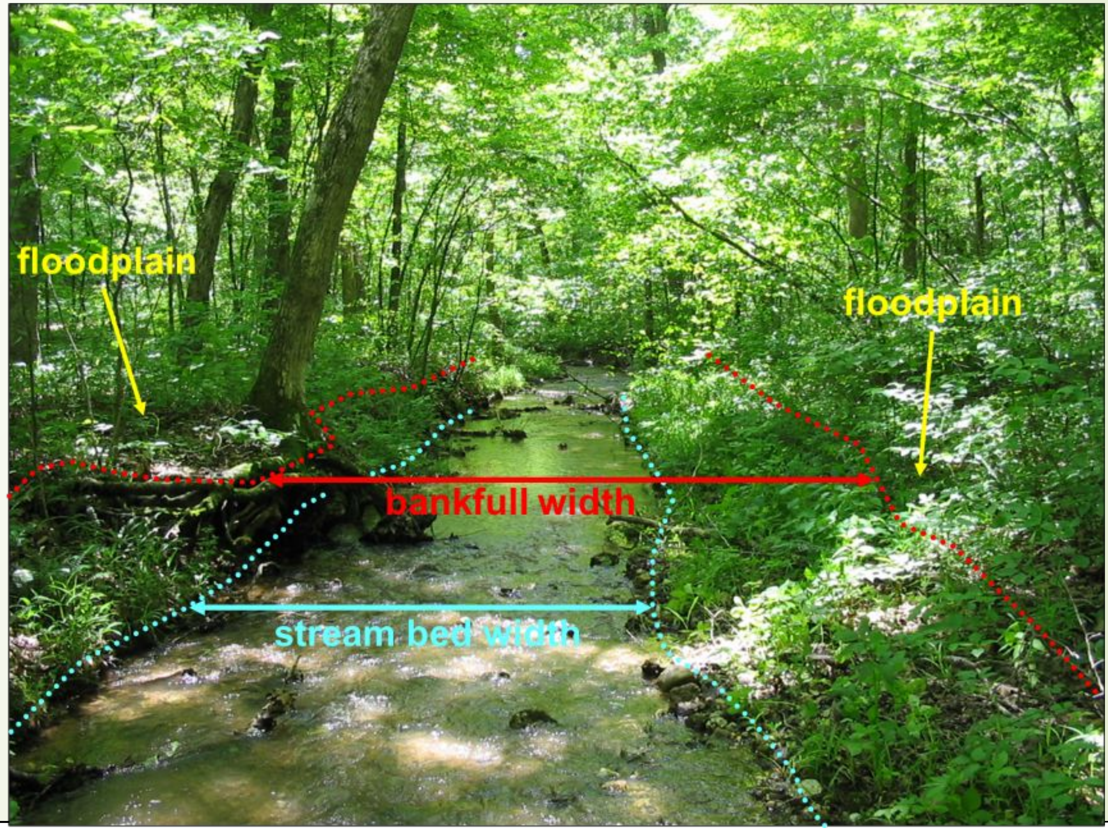
Simulated high gradient channel
Mitkof Island, AK.Tongass NF

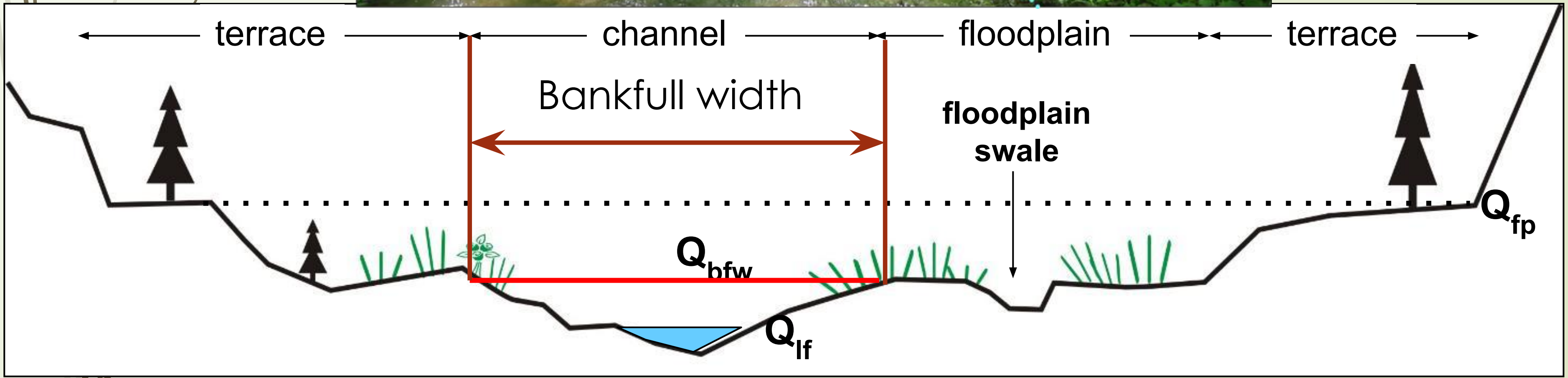
Reference reach
Mitkof Island, AK.
Tongass NF

Definitions:

- **Reference reach** – the stream segment that is copied /emulated to develop our channel dimensions & configuration that we wrap our structure around during design

Definitions





- **Bankfull width** – the width at the location where the channel spills onto the floodplain.

Definitions

- **Flood Resiliency** – A road crossing structure that can survive a flow greater than the design flood with minimal maintenance (if any) required

EVOLUTION OF AOP DESIGN METHODOLOGY

Stream Simulation Design Culvert

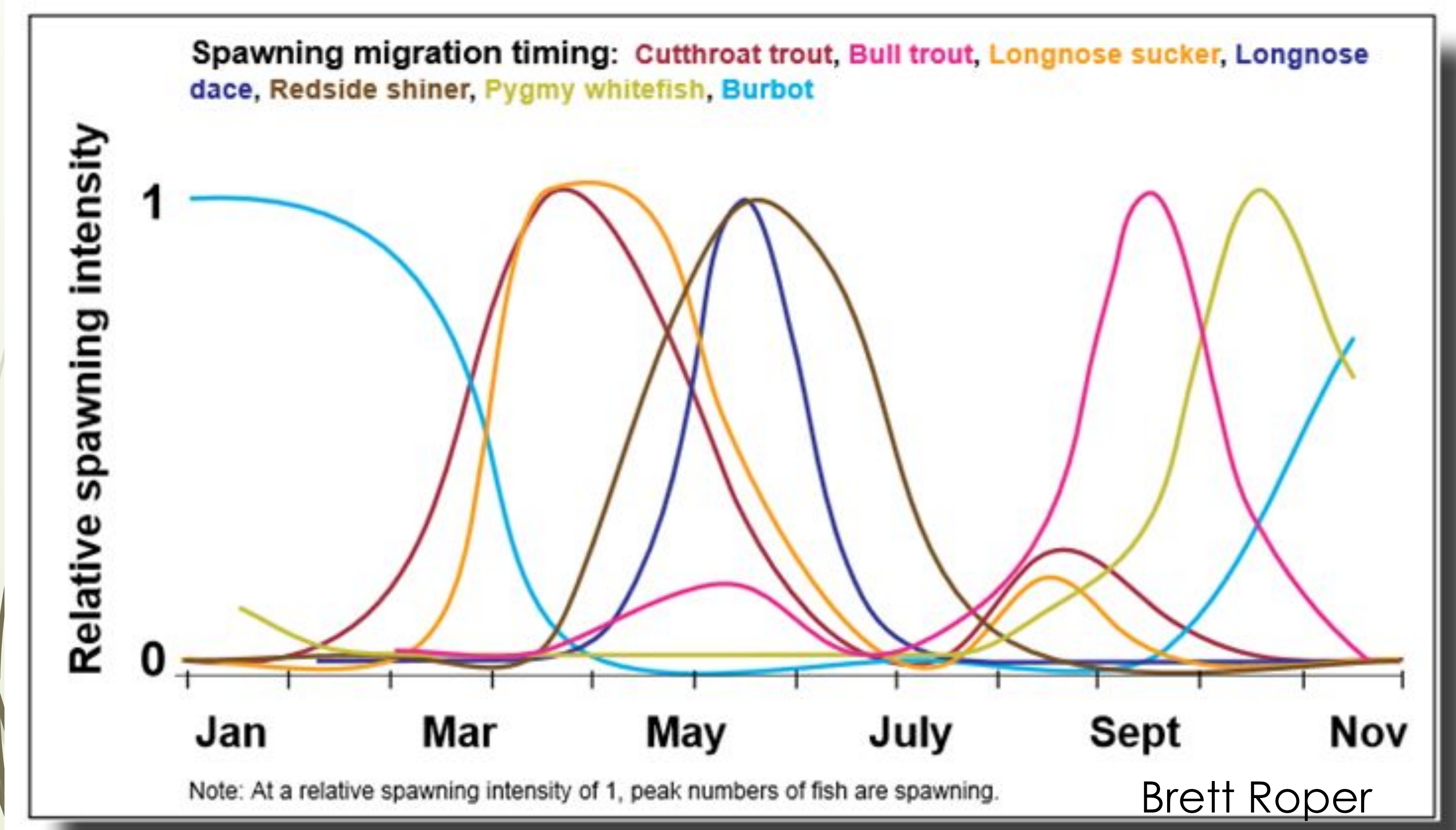
Hydraulic designed weirs in culvert

NATIONAL STREAM & AQUATIC ECOLOGY CENTER

Why did we select Stream Simulation as our Principal Design Method?

Original Reason

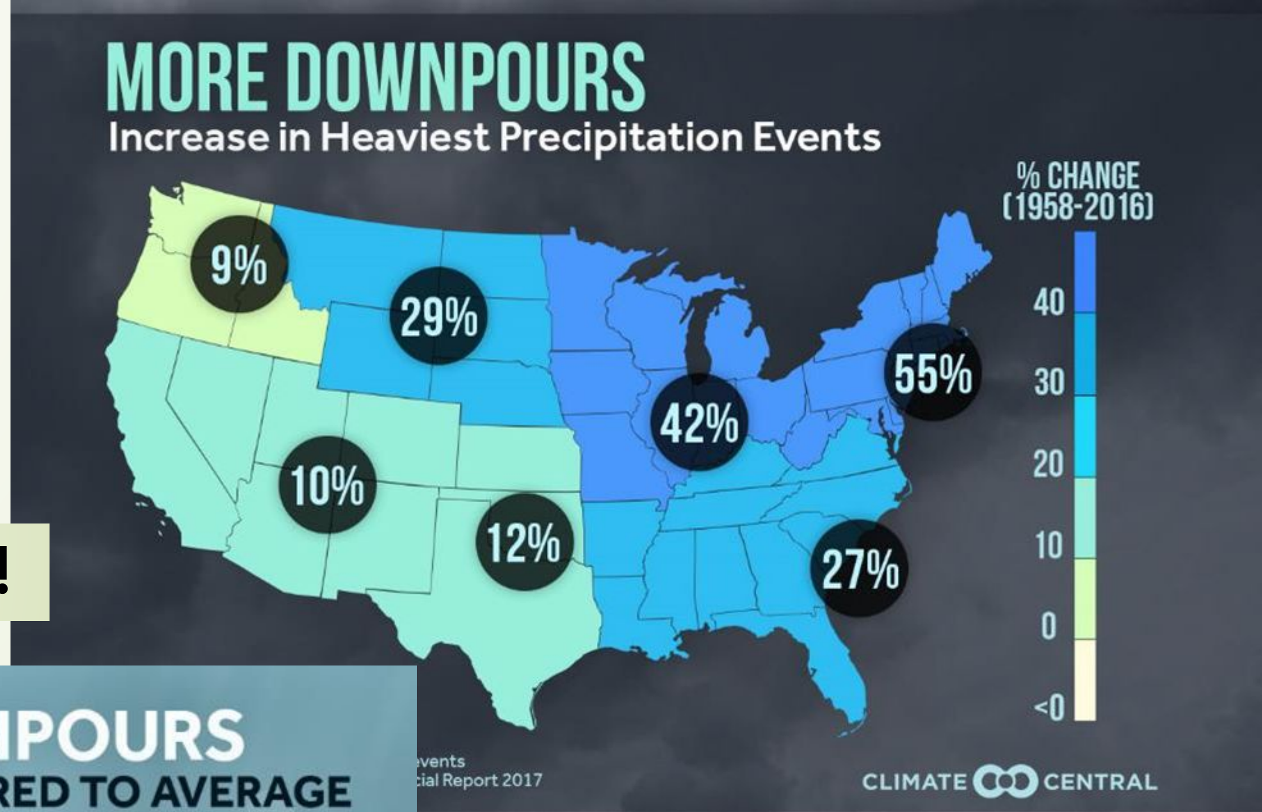
Hydraulic design methods do not provide passage for the entire aquatic assemblage (all species and life stages)

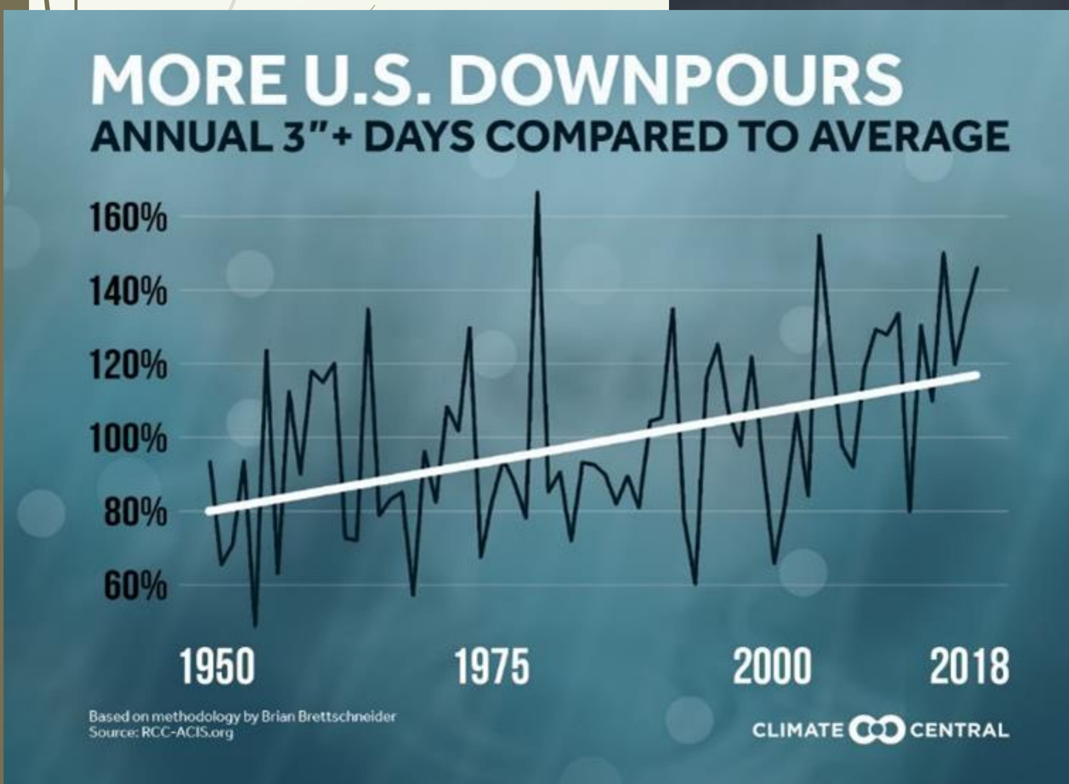


Brett Roper

Why did we select Stream Simulation as our Principal Design Method?

“CLIMATE CHANGE”!



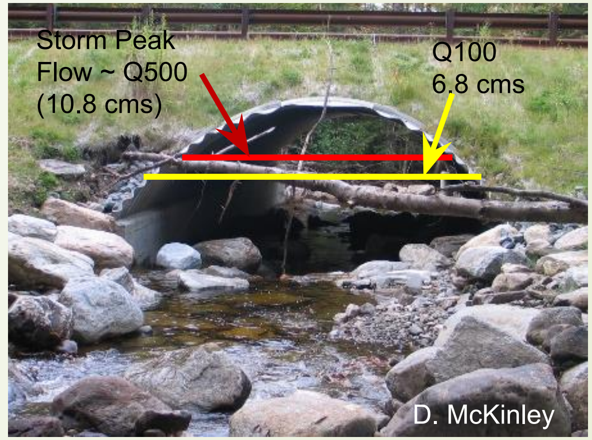


https://www.climatecentral.org/gallery/maps/more-downpours-increase-in-heaviest-precip-events?utm_medium=email&utm_campaign=News%20%20Heavy%20Downpours&utm_content=News%20%20Heavy%20Downpours+CID_eb9956627527859564f2e79a2e3c04e7&utm_source=Climate%20Central%20

https://nca2014.globalchange.gov/highlights/report-findings/extreme-weather/content/floods

Why did we select Stream Simulation as our Principal Design Method?

Flood Resiliency Example



Pre-Flood Stream sim, Vermont 2010

Post-Flood Stream sim, Vermont 2012

Large bottomless structure survived a Q500 flood with no maintenance required. Minor scour at the inlet and stream bed configuration changed, however AOP is not impeded

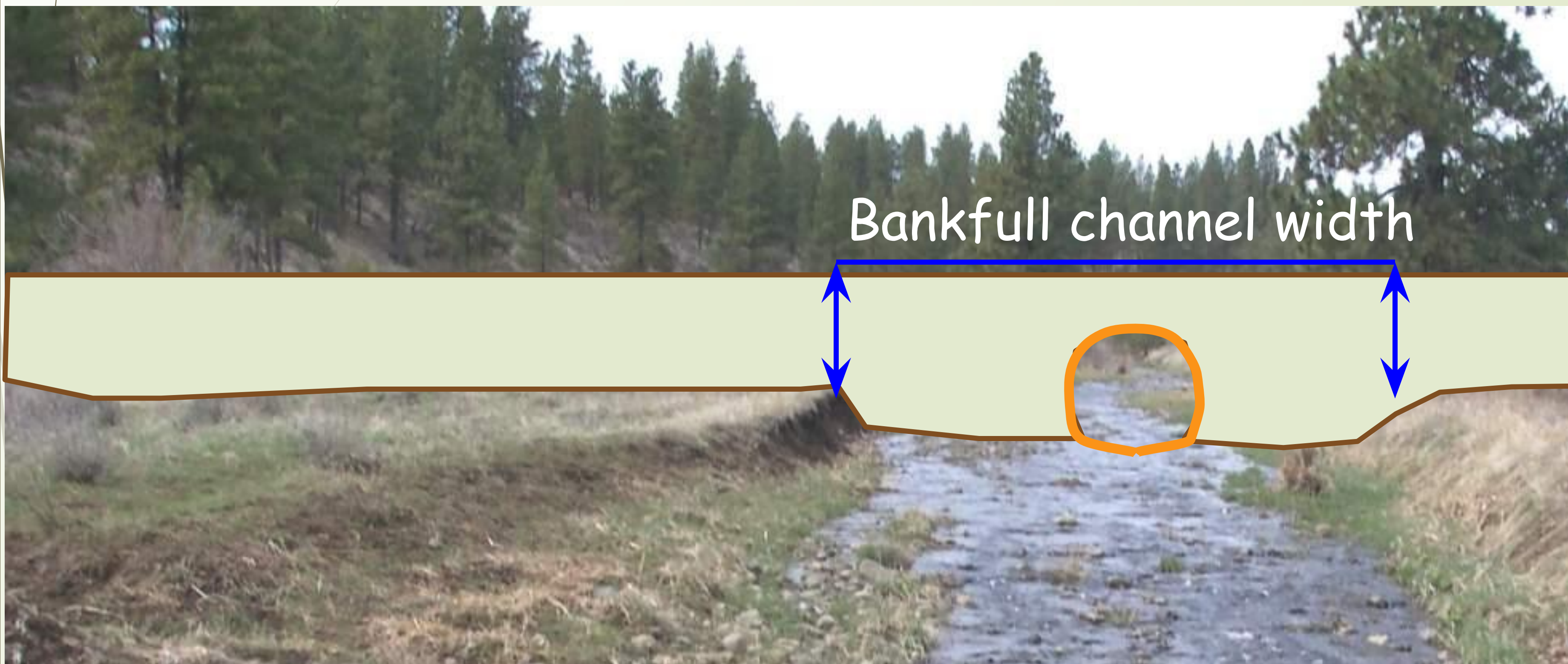
Why did we select Stream Simulation as our Principal Design Method?

Life cycle cost reduction
Low or No Maintenance and Repair Costs after Large Flood

Stream sim upfront costs are slightly greater (9 to 22%) but real life-cycle costs are less (Gillespie et al 2014.

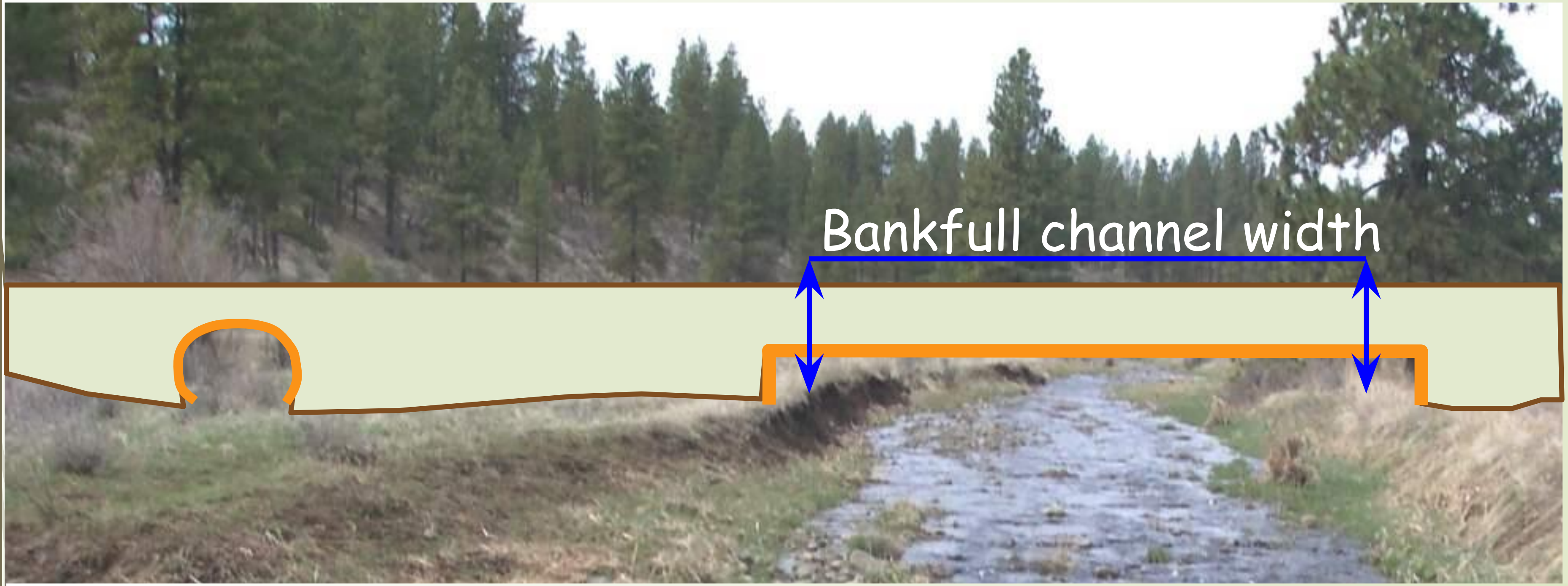
Nathaniel Gillespie, Amy Unthank, Lauren Campbell, Paul Anderson, Robert Gubernick, Mark Weinhold, Daniel Cenderelli, Brian Austin, Daniel McKinley, Susan Wells, Janice Rowan, Curt Orvis, Mark Hudy, Alison Bowden, Amy Singler, Eileen Fretz, Jessica Levine & Richard Kirn Flood Effects on Road-Stream Crossing Infrastructure: Economic and Ecological Benefits of Stream Simulation Designs. Fisheries.Vol. 39 No. 2 Feburary 2014

Hydraulic Design Method
Perspective View on a Road Crossing Site



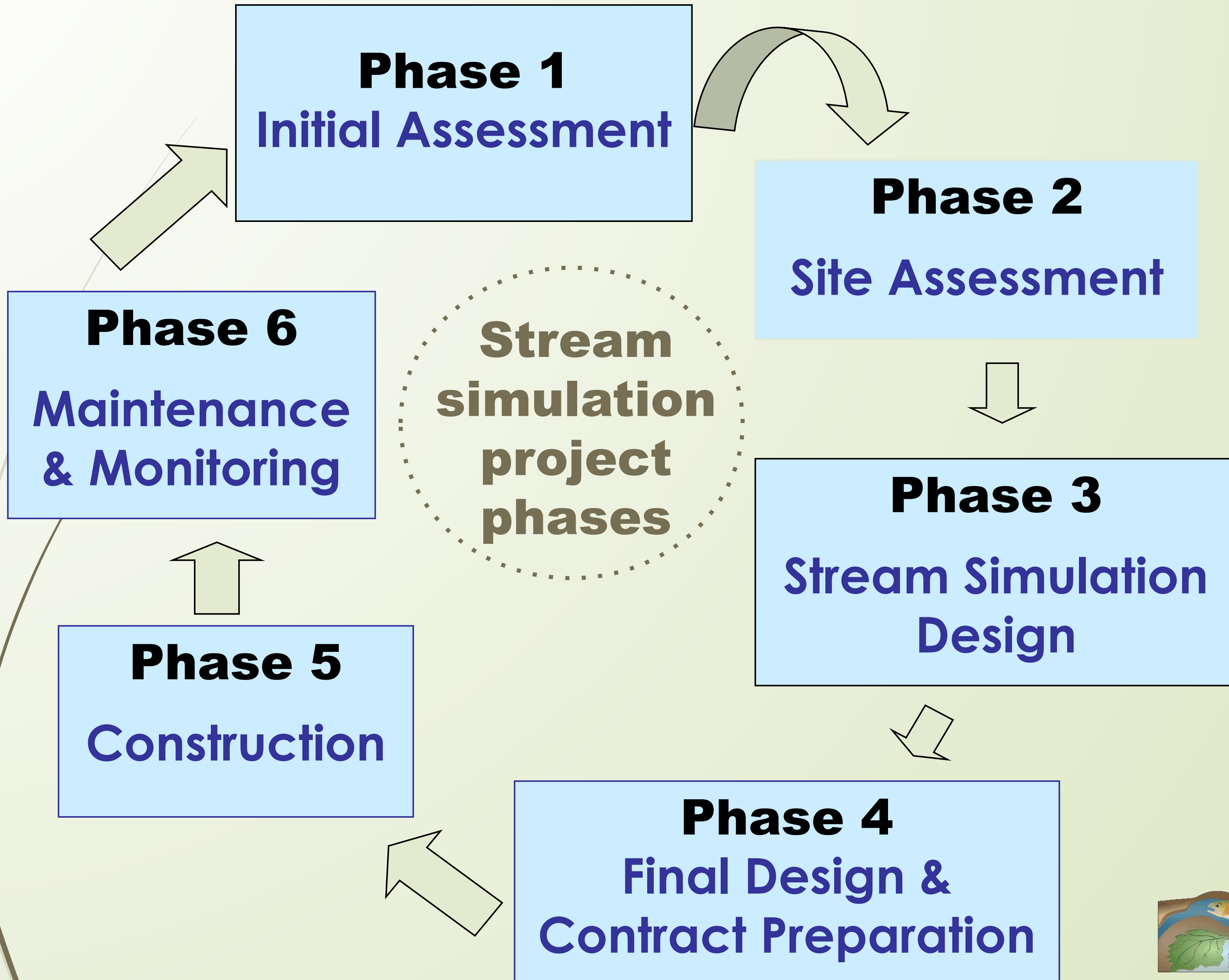
- Typically constrict the natural channel
- Rigid structure in dynamic environment and is not flexible to stream changes

Stream Simulation Design Method
Perspective View on a Road Crossing Site



- No constriction of the natural channel bankfull width
- Accounts for floodplain conveyance, most geomorphic processes, and all aquatic passage needs
- Flexible design to account for long term changes in bed elevations and flood discharges
- Maintains most ecological processes

Stream Simulation Design Process



Phase 1 - Initial Assessment

- Large scale view of the watershed and geologic hazards
- Helps determine overall project objectives
- Helps determine initial applicability of the method

Stream sim is NOT applicable in the following situations

Prone to frequent debris flows

Unstable streams

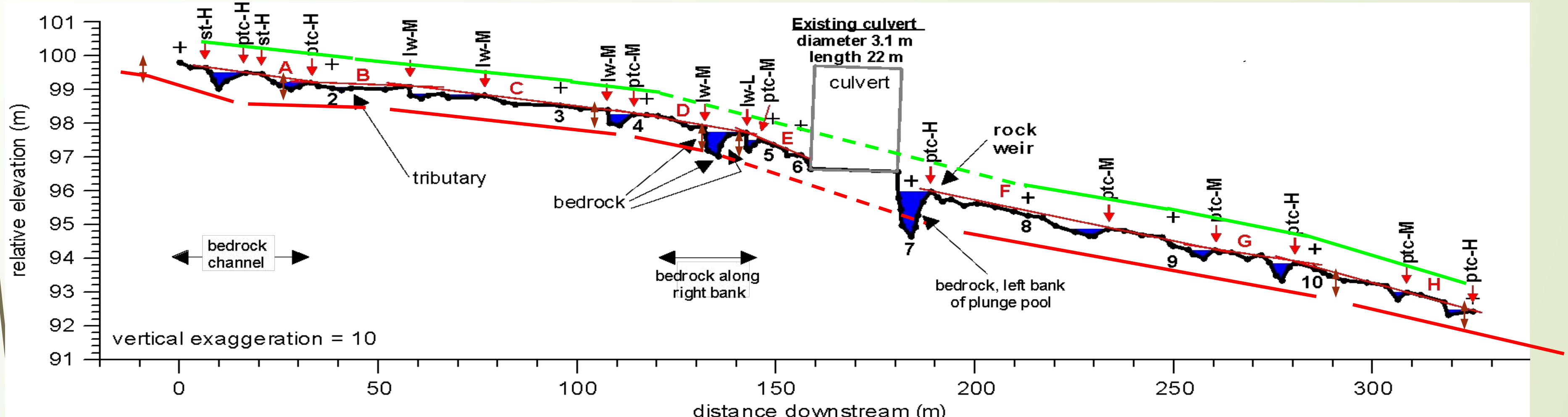
Road impounded wetlands

Phase 2 - Site Assessment

Purpose:

- Understand the stream conditions and stream dimensionality
- Breaks the channel into unique reaches based on grade
- One of the "unique Reaches" is what we will be our **"reference reach"** or the section we copy into our design

Phase 2 - Site Assessment
Longitudinal Profile Analysis



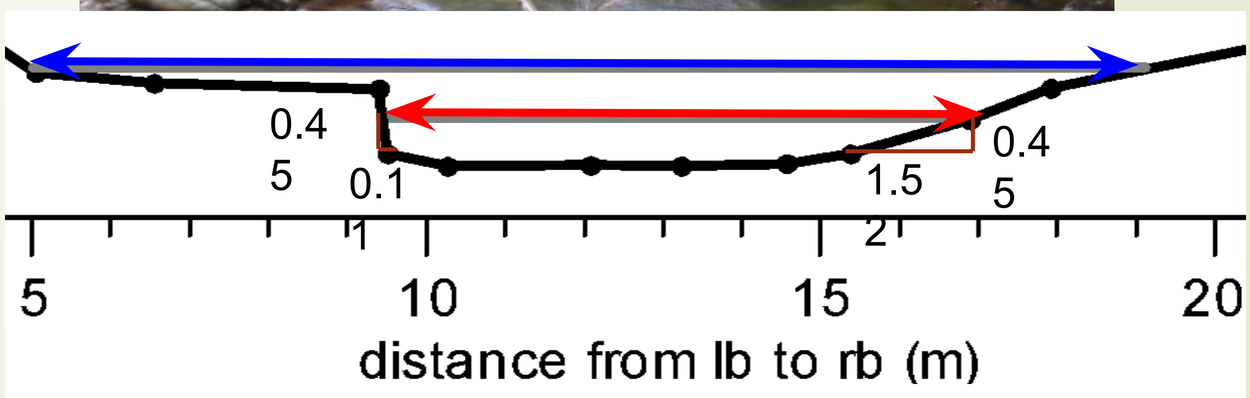
Longitudinal Profile Survey and Analysis

Site Assessment Metrics (what's measured in the field)

- Longitudinal channel features – riffles, pools, grade controls (steps, ribs, etc).
- Channel unit location, lengths, and slope
- Grade control stability

Long profile provides the location of **"reference reaches"** to select depending on The design profile gradient

Phase 2 - Site Assessment
Lateral/Cross Section Analysis



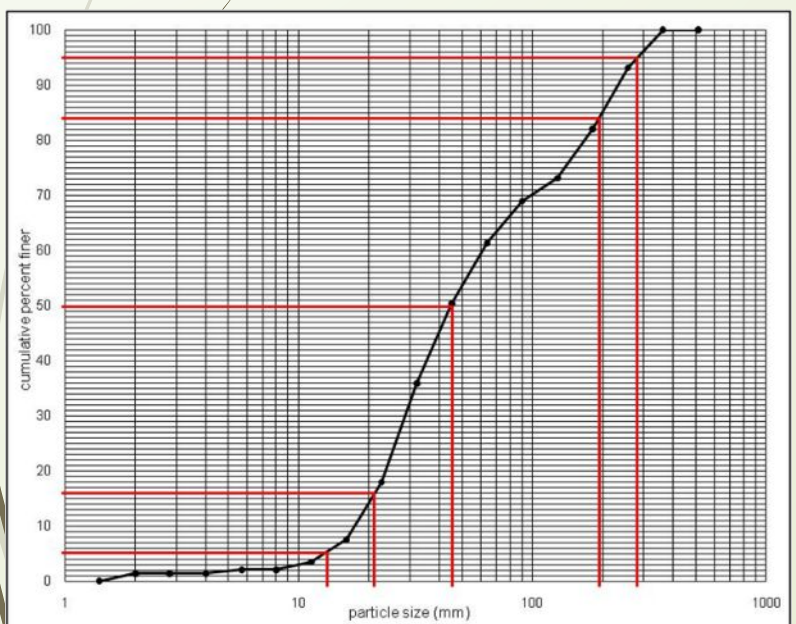
Site Assessment Metrics (what's measured in the field)

- Cross section shape and dimensions in the channel units
- Bankfull width & depth, bed width, floodplain extents, floodprone width, degree of confinement

Phase 2 - Site Assessment
Channel Bed Analysis

Key pieces and grade controls

Key pieces – small boulder roughness



Gradation of Channel bed materials

Subsurface material

Phase 2 - Risk Considerations - Channel Stability:

Phase 2 - Risk Considerations - Vertical Adjustment Potential (VAP): Aggradation or Degradation

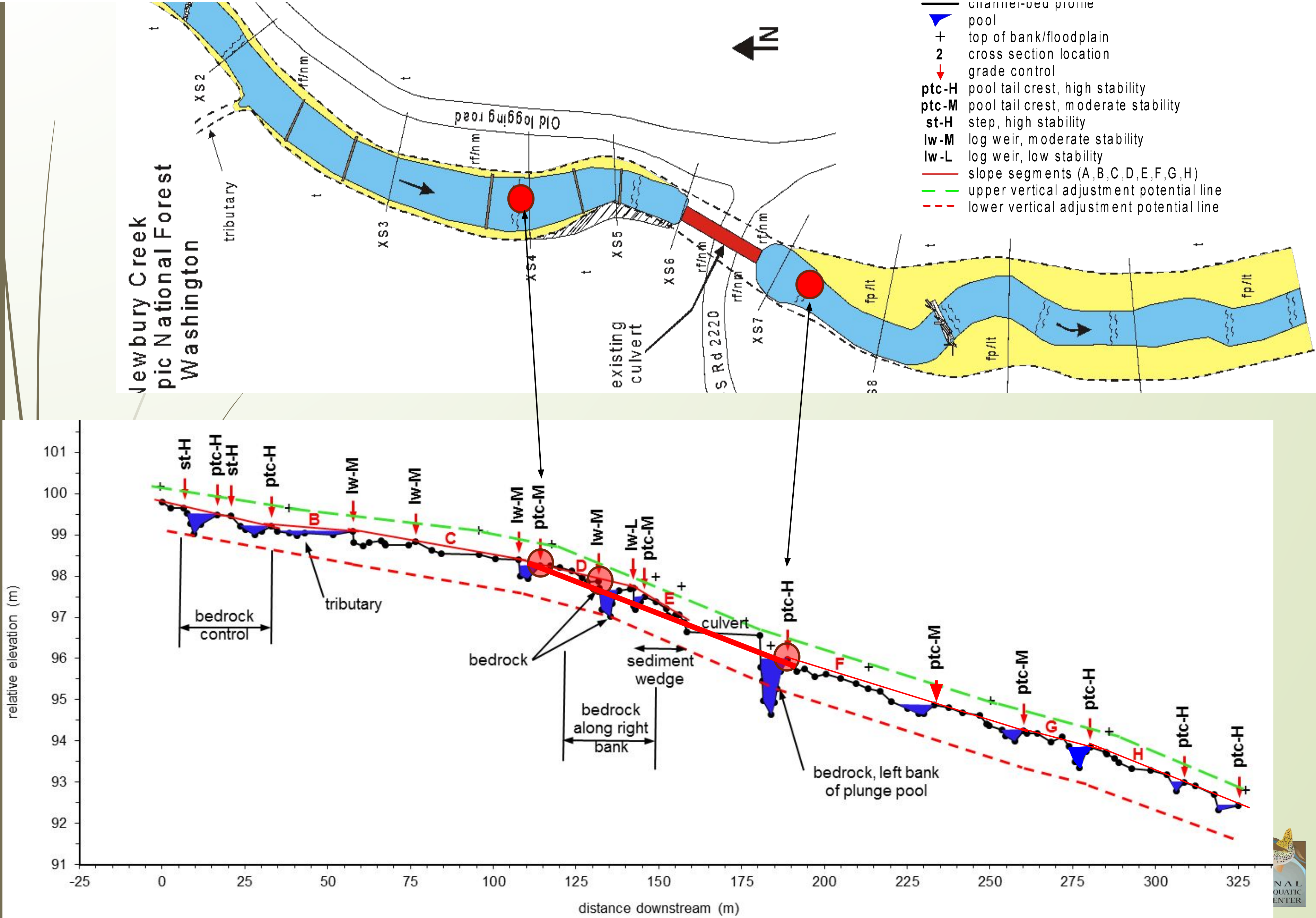
Phase 2 - Risk Consideration - Headcut Potential

Photo courtesy of Bill Dickson

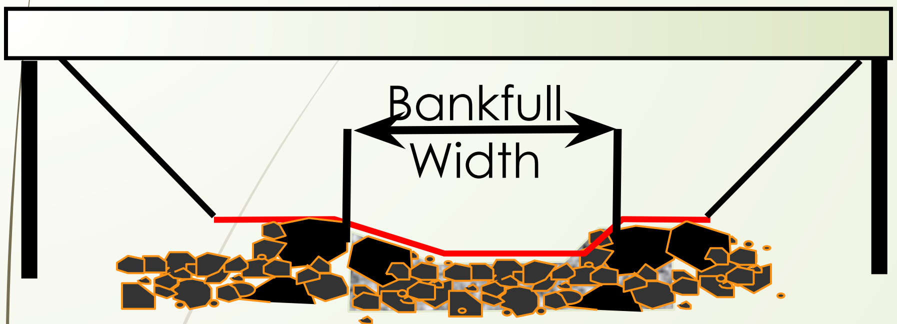
Phase 2 - Risk Consideration
Lateral Adjustment Potential:

Phase 2 - Risk Consideration – Floodplain conveyance/connectivity:

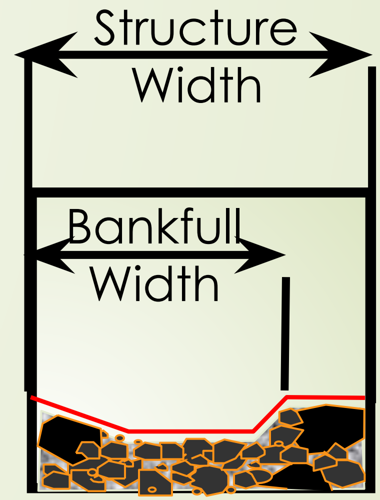
Phase 3 - Design Profile (Vertical and horizontal Alignment)



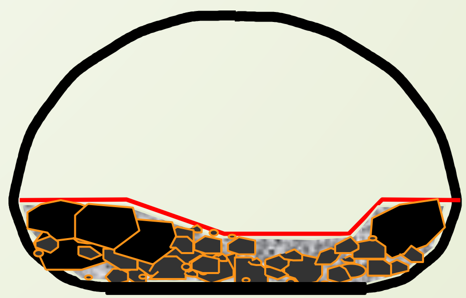
Structure Width and Cross Section Area



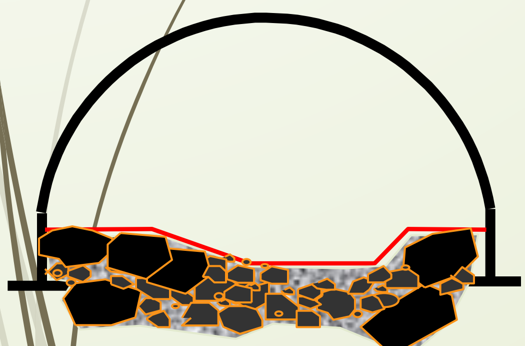
a. Bridge



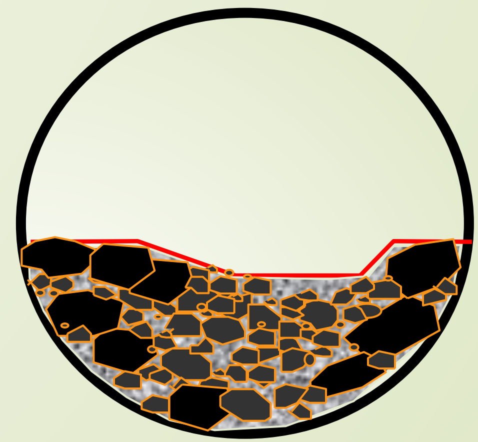
b. Box



c. Pipe Arch



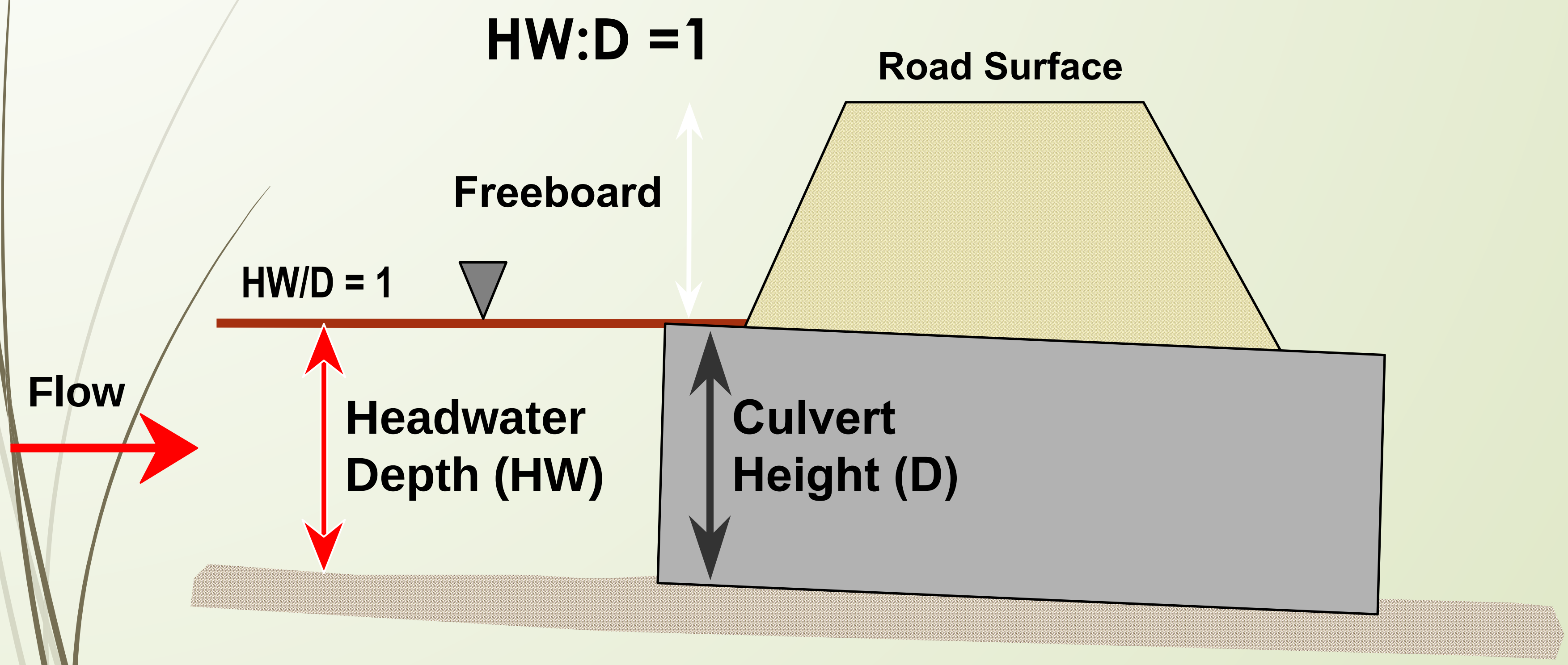
d. Bottomless Arch



e. Embedded Round

Banks or margins are recommended

Culvert Anatomy:
Hydraulic Capacity and Debris Passage



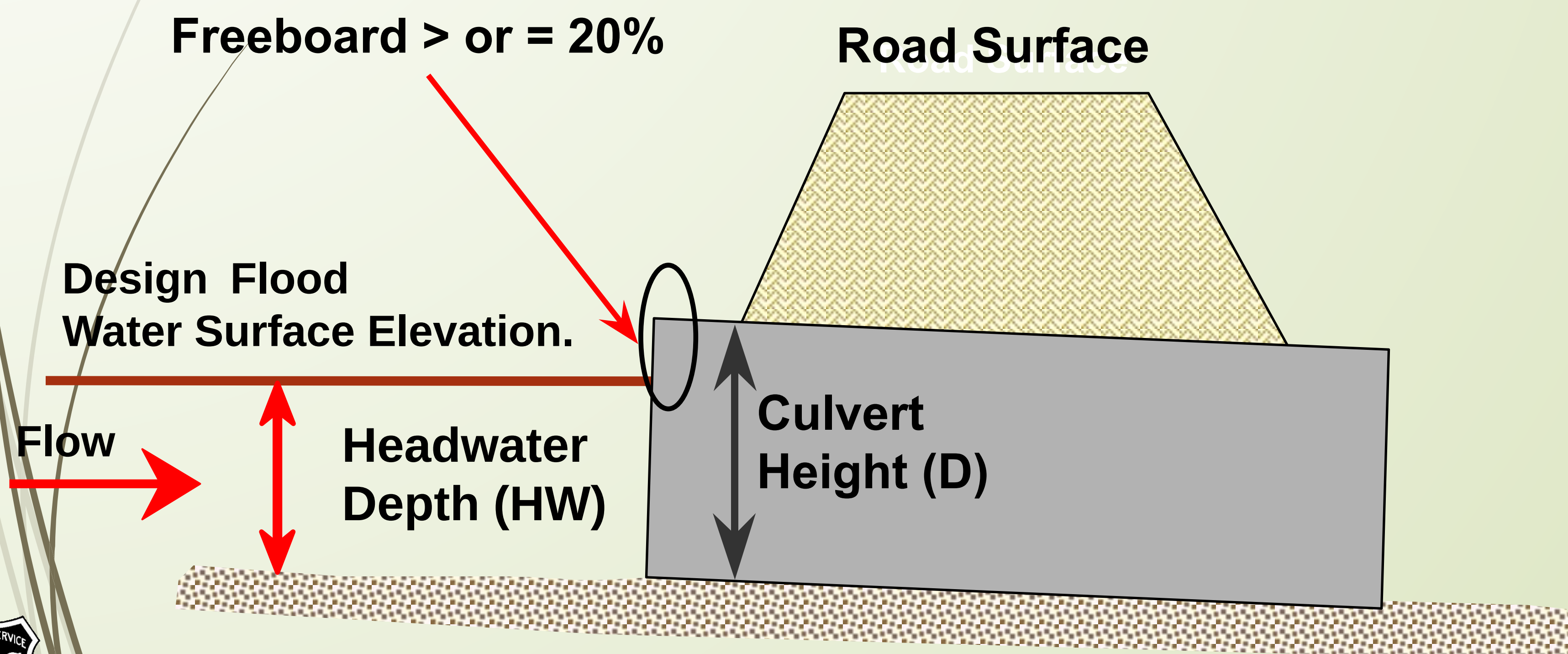
Good Practice (Stream Sim Requirement)

HW/D < 0.8

(20 percent open space for debris and hydrologic uncertaint

By going to a minimum bankfull width + structure,

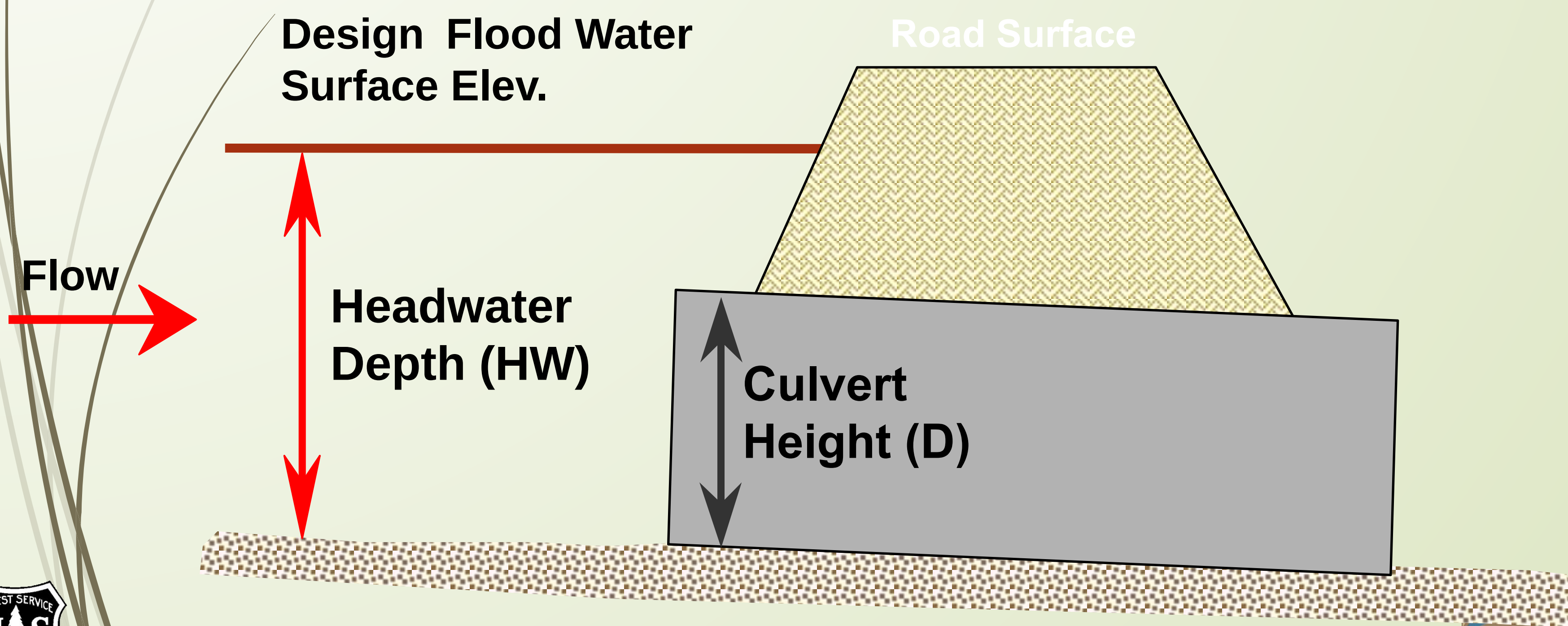
HW:D usually ranges from 0.6 to 0.7HW:D



Poor Practice

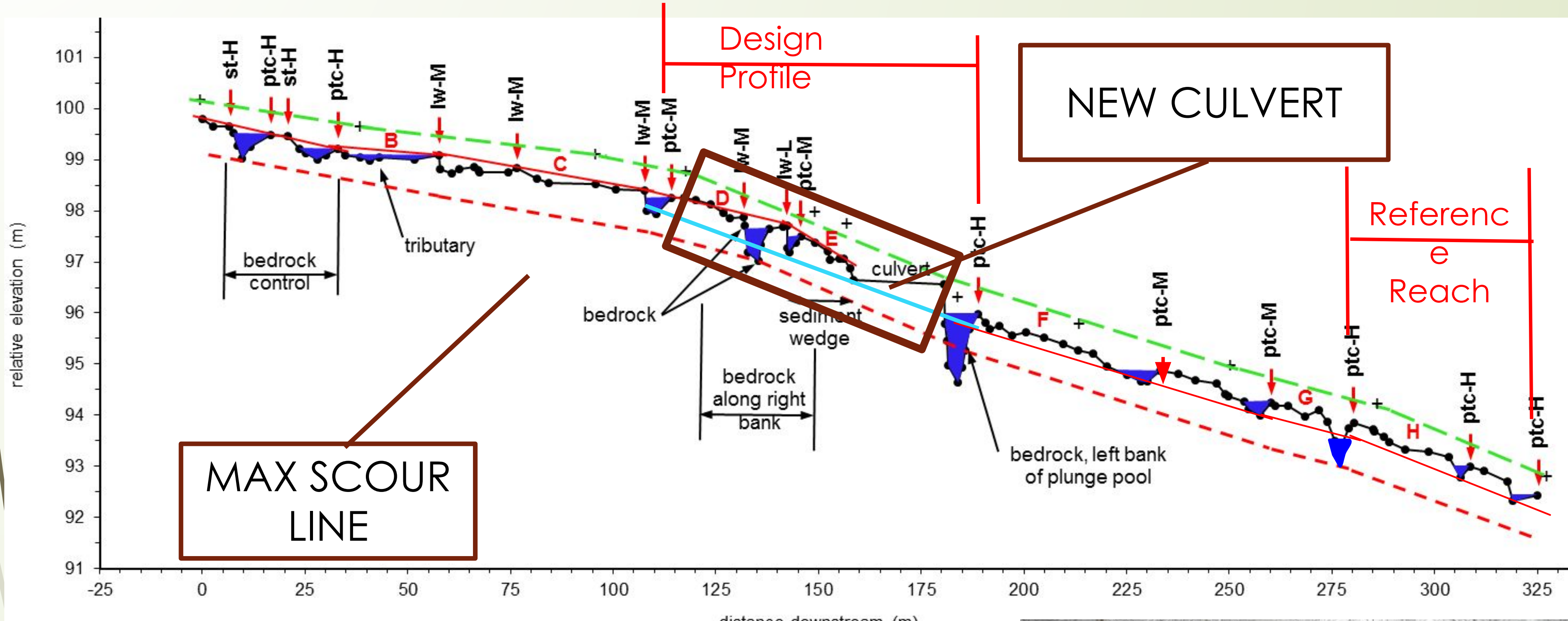
HW/D > 1

(pressurized flow
NO FREEBOARD DEBRIS CATCHER)



Vertical Adjustment Potential (VAP)

Embedment depth - Maximum anticipated scour



- 1.00 x Pool Max Depth (PMD): Step-pool channels, S > 5%, boulder-cobble boundaries.
- 1.25 x PMD: Step-pool channels with S < 5%, cobble-gravel boundaries.
- 1.50 x PMD: Steep riffles with ribs, cobble-gravel boundaries.
- 1.75 x PMD: Riffles, gravel-cobble boundaries.
- 2.00 x PMD: Riffles, sand-fine gravel boundaries.

Smooth Inlet and Outlet Transitions Don't Hang up Large Debris!

Phase 3 -
Bed and channel unit configurations:

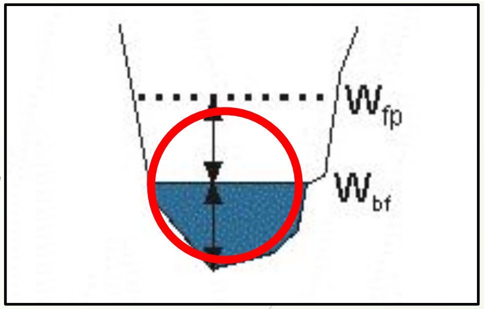
Need to be similar dimensions and spacing in the structure as in the reference reach

Goal is to have similar roughness to provide similar hydraulic properties

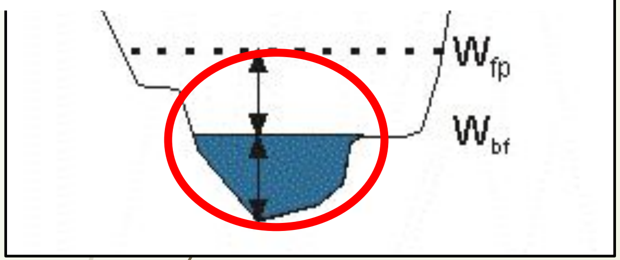
Phase 3 - Streambed Mobility and Stability:

Sediment transport in = sediment transport out

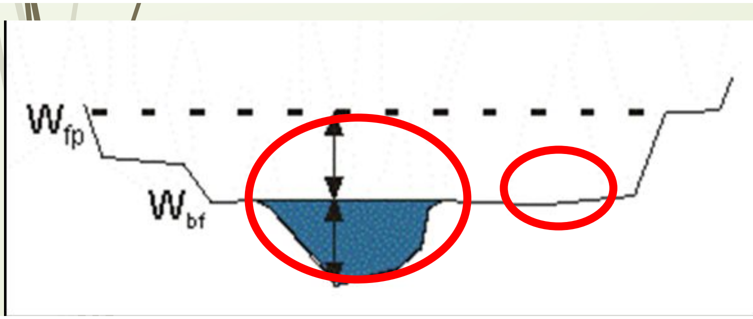
Design layout based on valley configuration



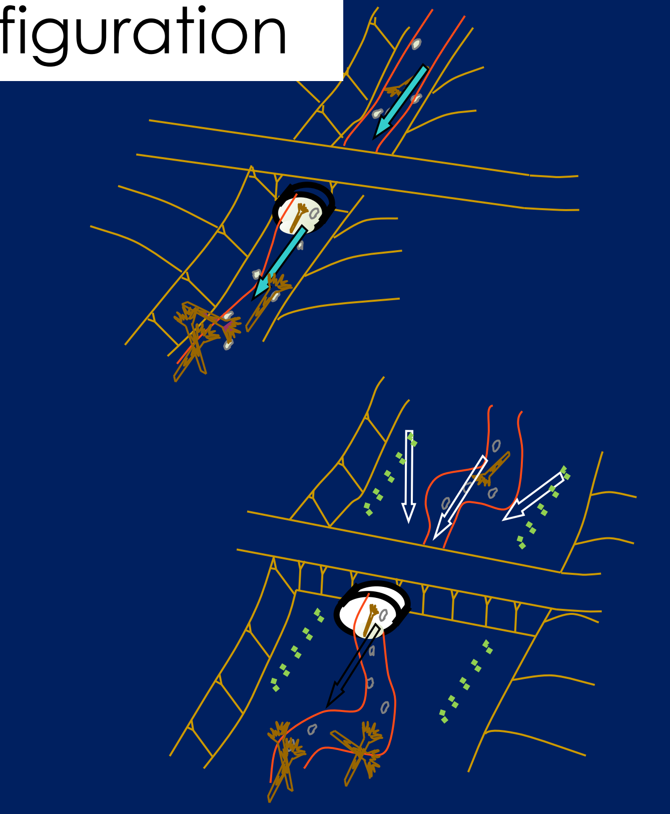
a. Confined / Incised channels



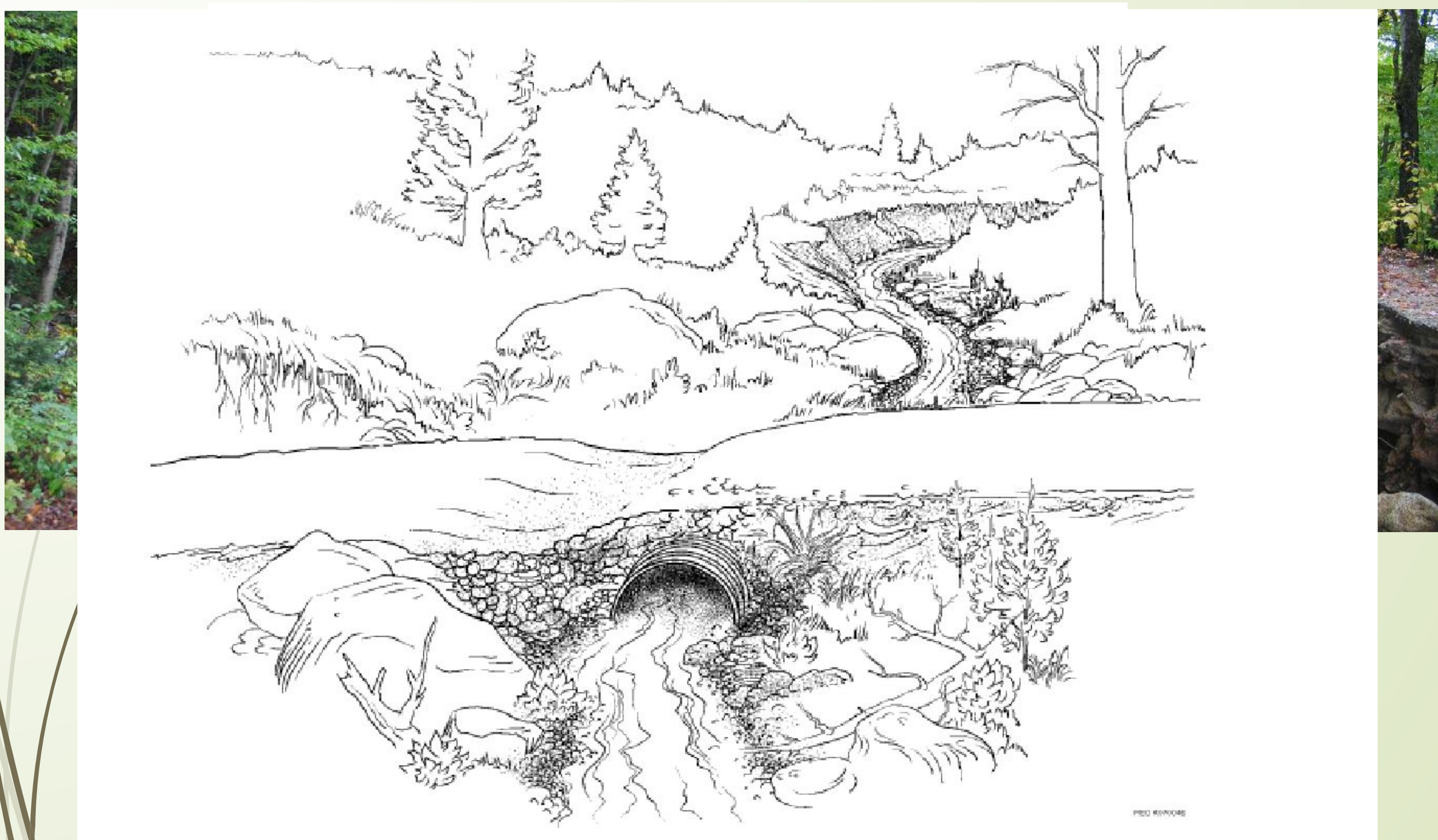
b. Unconfined – Small floodpain, low flow conveyance



c. Highly Unconfined – larger floodplain, high flow conveyance



Design for Failure and Diversion Potential



amount of road loss

- Construct substantial ditch blocks and provide a drivable dip

Stream Simulation Design Publications

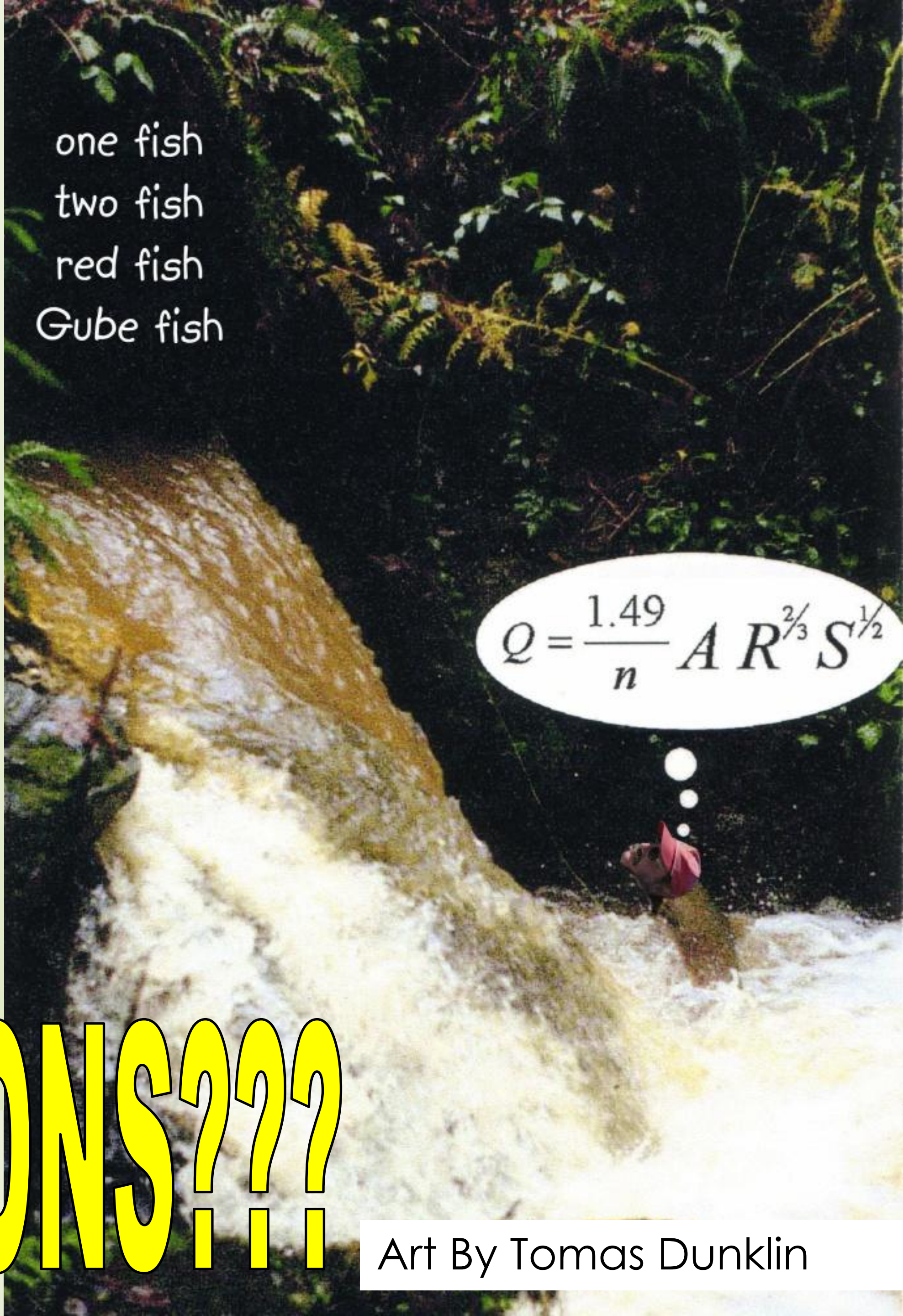
Cenderelli, D., Clarkin, K., Gubernick, R., Weinhold, M. Stream Simulation for Aquatic Organism Passage at Road-Stream Crossings. Transportation Research Record. Journal of the Transportation Research Board, 2011

Stream simulation: An ecological approach to designing road-stream crossings. Stream simulation working group. San Dimas Technology Development Center USDA Forest Service. May 2008

Gubernick. R, Bates. K, Designing culverts for Aquatic Organism Passage: Stream Simulation Culvert Design. International Conference of Ecology and Transportations Proceedings, Lake Placid, NY. 2003

Gubernick. R, Clarkin. K, and Furniss. M, Site Assessment and Geomorphic Considerations in Stream Simulation Culvert Design. International Conference of Ecology and Transportation Proceedings, Lake Placid, NY. 2003

???QUESTIONS???



Art By Tomas Dunklin

Why did we select Stream Simulation as our Principal Design Method?

Flood Resiliency Example

Flood occurred in 2015 - Q50 to Q100 flow

Pre-Flood Stream sim, Alaska 2006

Post-Flood Stream sim, Alaska 2019