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Session A9: To Fill or Not to Fill: Stream Simulation and Embedded Aquatic Organism Passage Structures

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To Fill or Not to Fill

stream simulation and embedded aquatic organism passage structures

Self filled AOP structure
Tongass NF, Alaska

Stream Simulation Placed material
AOP structure   Tongass NF, Alaska

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Washington Office AOP Design Team

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Stream Simulation AOP
Tongass N.F.

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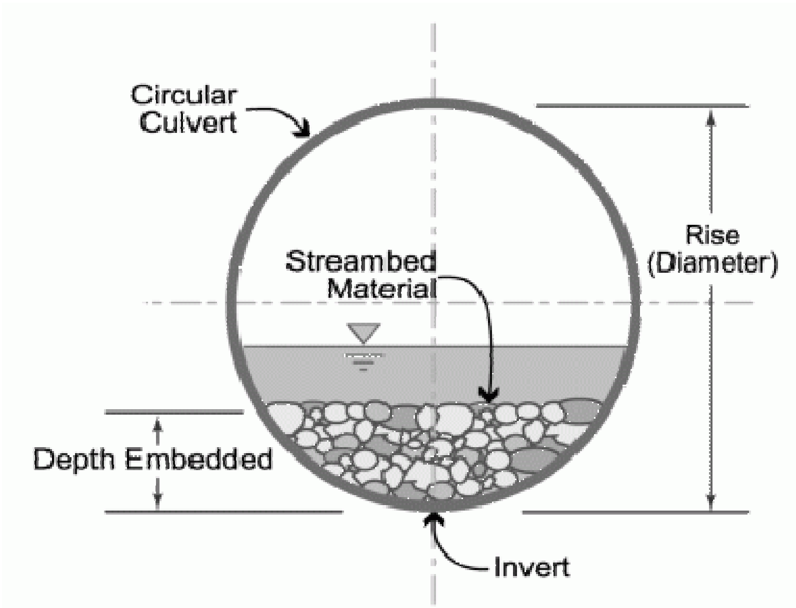
Embedded (Recessed) Culverts

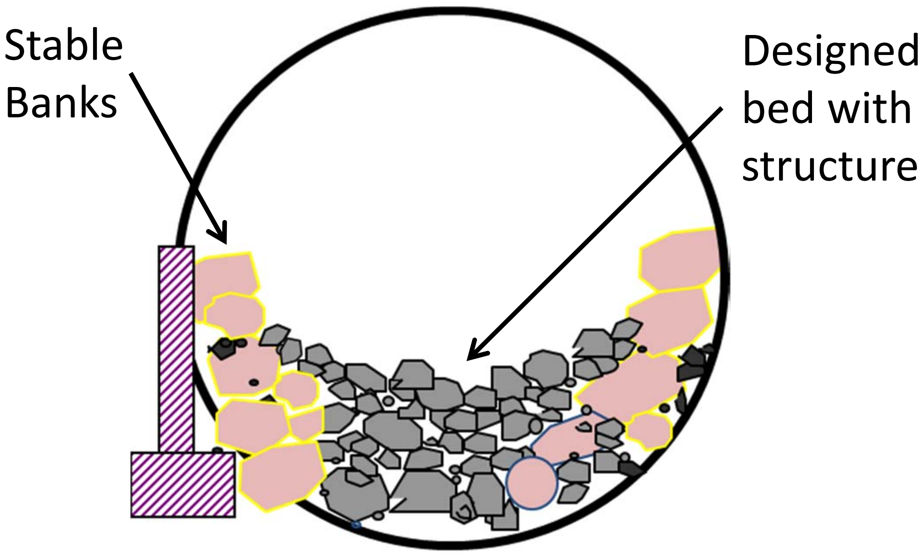


Embedded Schematic

Embedded Structure
Tongass N.F.

- Usually left to infill naturally or are seeded with some material
- Design guidelines (width & embedment depth & slope) vary from State to State
- No streambed structure or banks are constructed

Stream Simulation Culverts



Stream Simulation Schematic

Stream Sim Structure
Chequamegon-Nicolet N.F.

- Bankfull plus in width and embedded by a factor of safety plus max residual pool depth from the reference reach
- Culverts are infilled with a streambed substrate and structural and roughness elements (ribs, steps, boulder clusters, etc.)

Problem Statement 1 – Performance and Limitations:

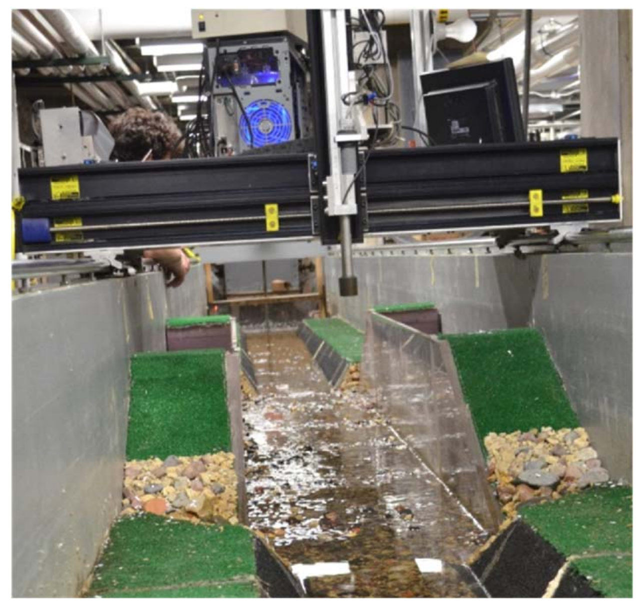
- Does allowing natural infilling of embedded culverts perform as well as those that are filled during construction?
- Are there stream impacts, aquatic passage concerns, or site limitations for allowing embedded culverts to "self fill"?

Problem Statement 2 - Economics:

Can we rely on natural sediment transport processes to provide stable substrate for AOP and save money by not infilling?

- USFS simulation culverts survived 2011 Hurricane Irene in Vermont (Gillespie et al. 2014)
  - ~9-22% more expensive than hydraulic design
- Cost analysis in MN (Hansen, 2009)
  - ~10% increase for recessed culverts
  - ~10% increase for roughness
  - ~15% increase for weirs
- Cost Analysis in Alaska (Gubernick, 2006 USFS analysis)
  - -5% to 38% more expensive than hydraulic design
  - Stream simulation was less or equal to hydraulic design in high gradient applications

Univ. of Minnesota Flume Experiments:



Study objectives:

- What is the impact of filling and self filling a embedded culvert on streambed stability/roughness in the culvert?
- How does this change with flow rate/slope/grain size?

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Channel Types and Slopes Used In Flume Study

Pool Riffle channel
0.002 to 0.02 Low slope gradient
Flume slope = 0.002

Step Pool channel
0.03 to 0.10 High slope gradient
Flume slope = 0.03

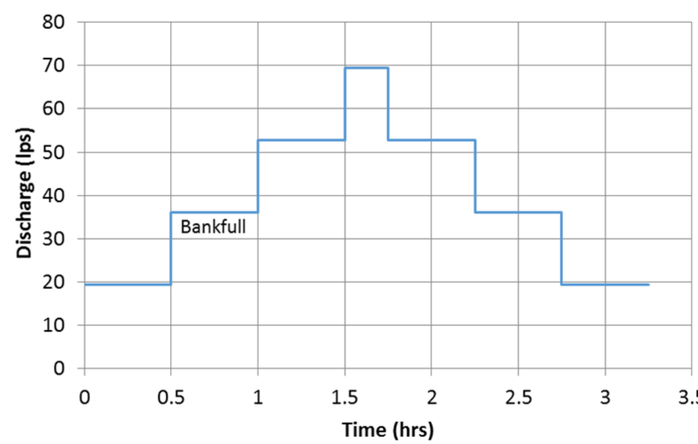
Plane bed channel
.01 to .03% Moderate slope gradient
Flume slope = 0.015

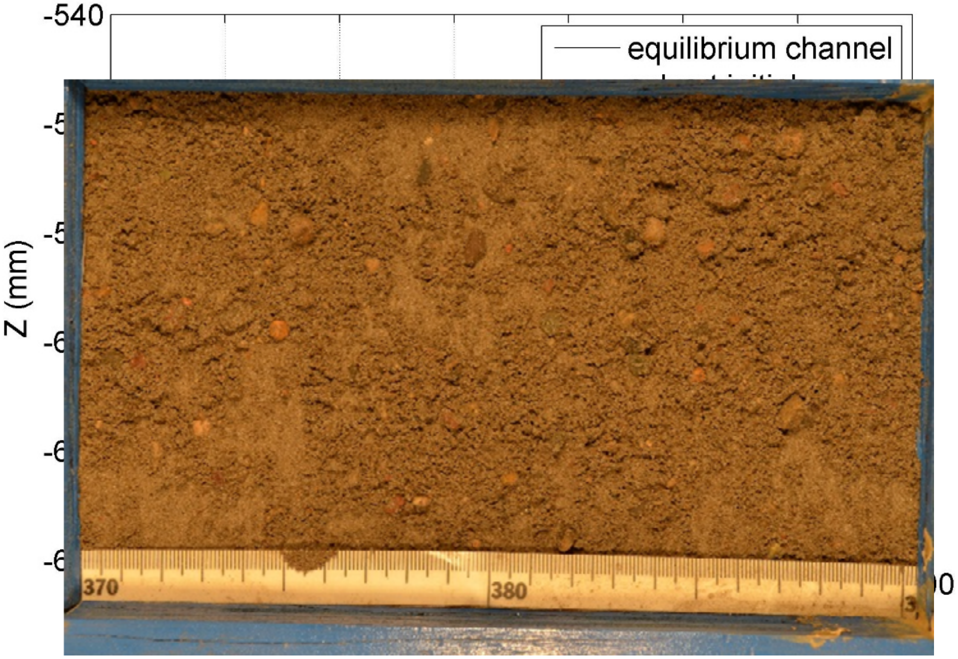
Experimental Setup

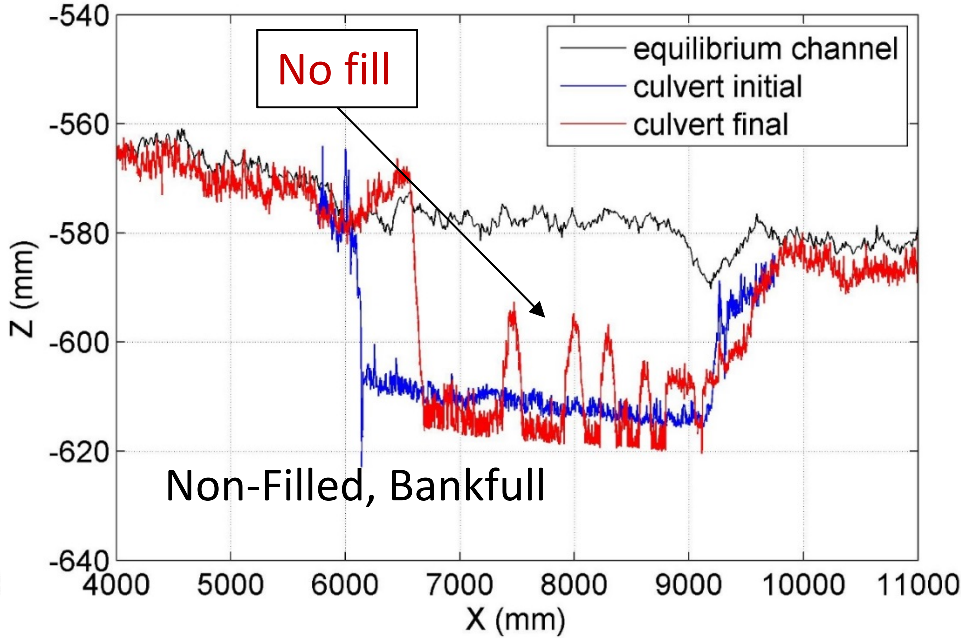
1. The equilibrium slope was developed at bankfull flow with banks along entire flume

2. An armor layer was developed with sediment recirculation

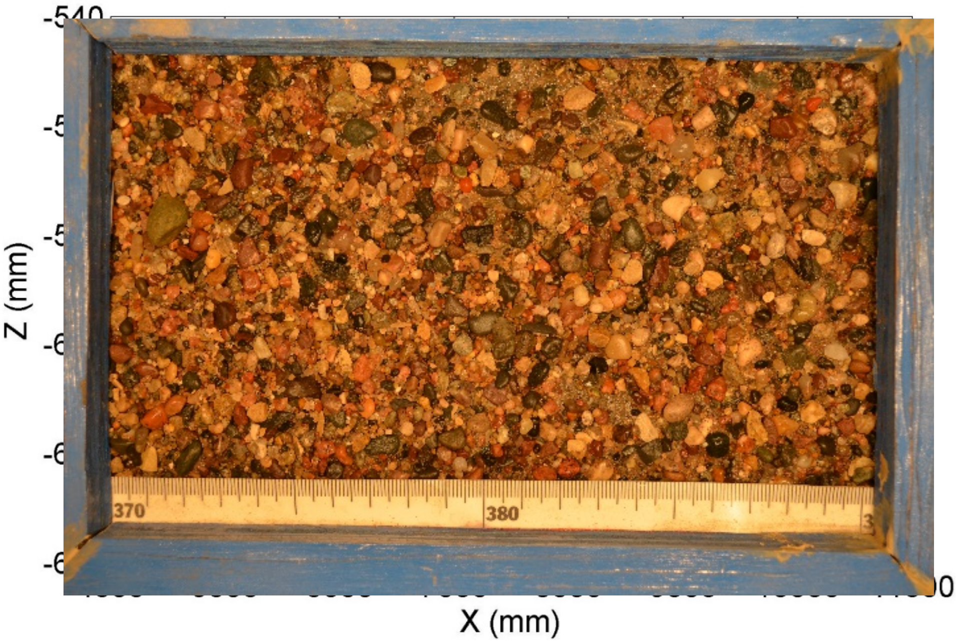
3. Culvert was set at 300 mm (scaled) below grade. Bankfull and overbank hydrograph experiments were conducted. “Filled” experiments with the equilibrium bed and “non filled” with material in culvert removed

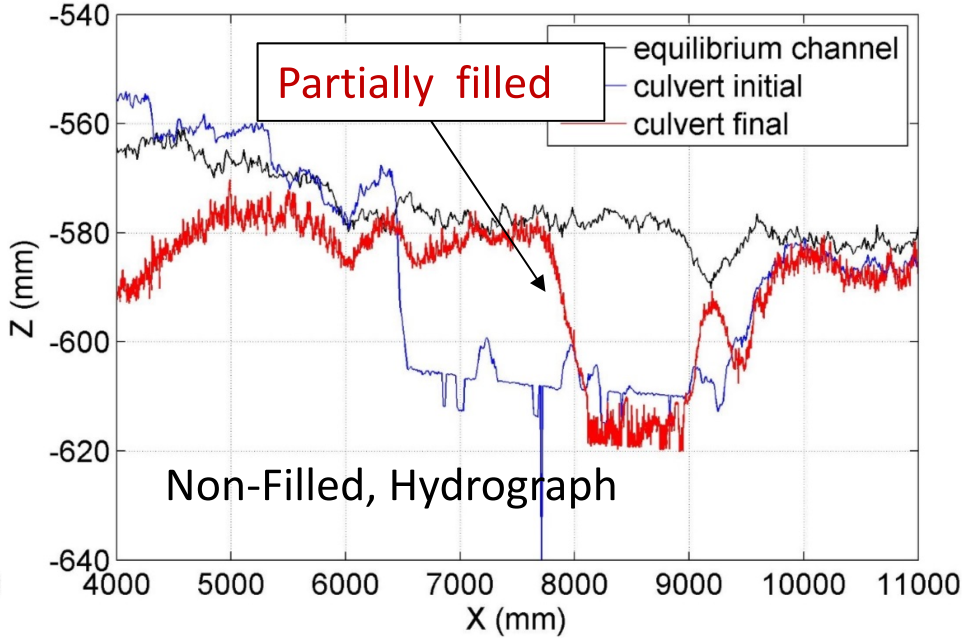


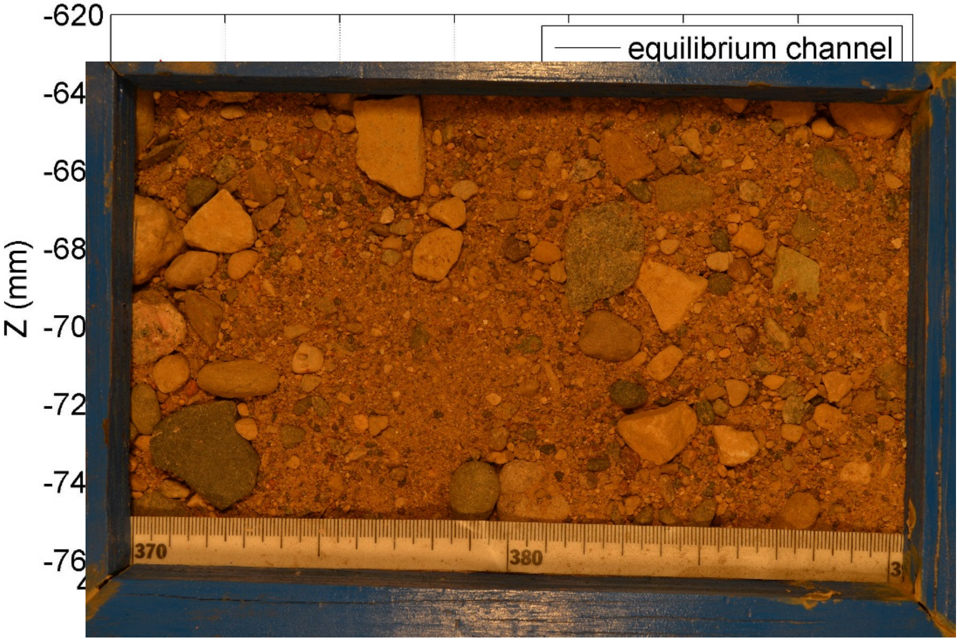


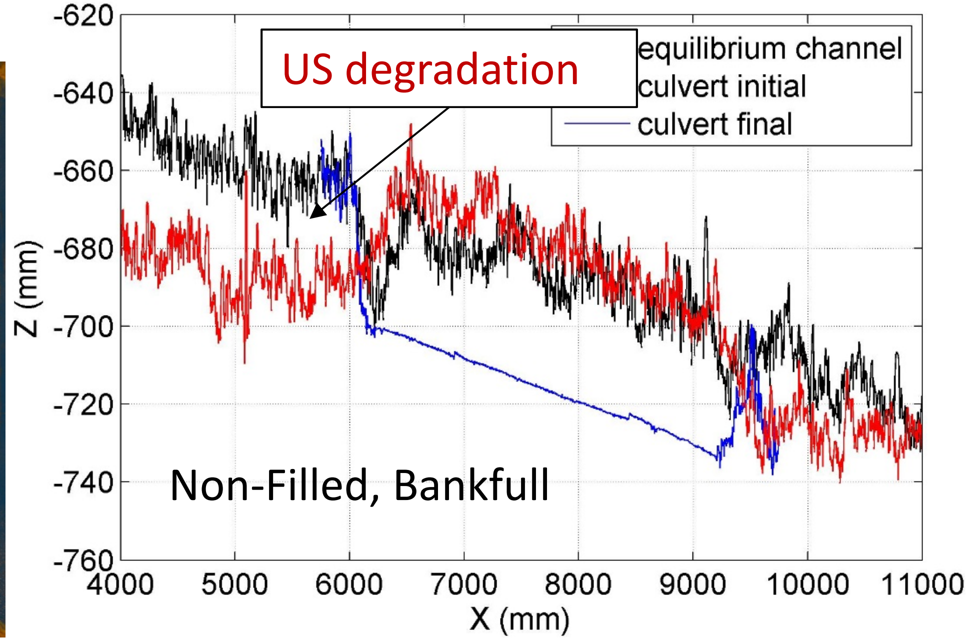


Low Gradient

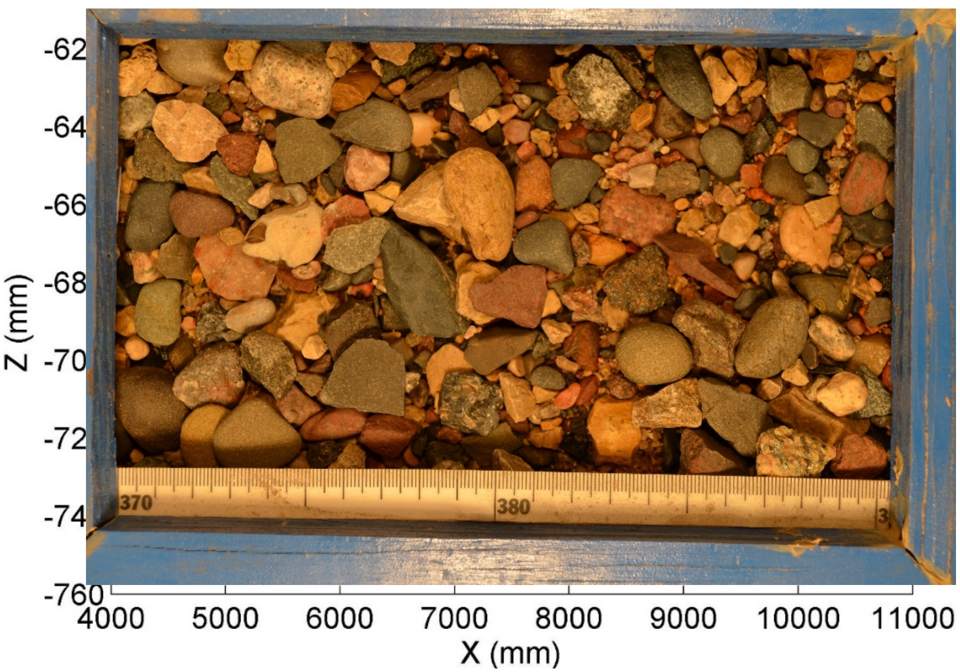


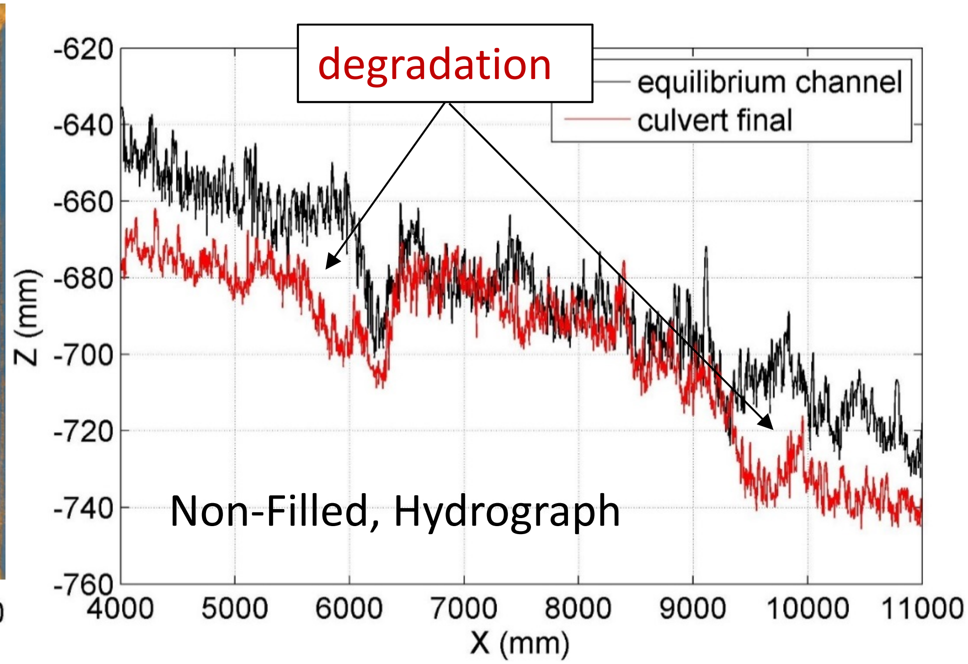






Moderate Gradient





Low and Moderate Gradient Summary

- Culvert width equal to bankfull width did not inhibit sedimentation in culvert
- Very different sediment dynamics in low slope and moderate slope experiments
- Site specific analysis of flow, shear stress estimates and mobility of sediments is needed to predict sediment movement into culvert
- Filling the culvert in general protected against upstream and downstream scour

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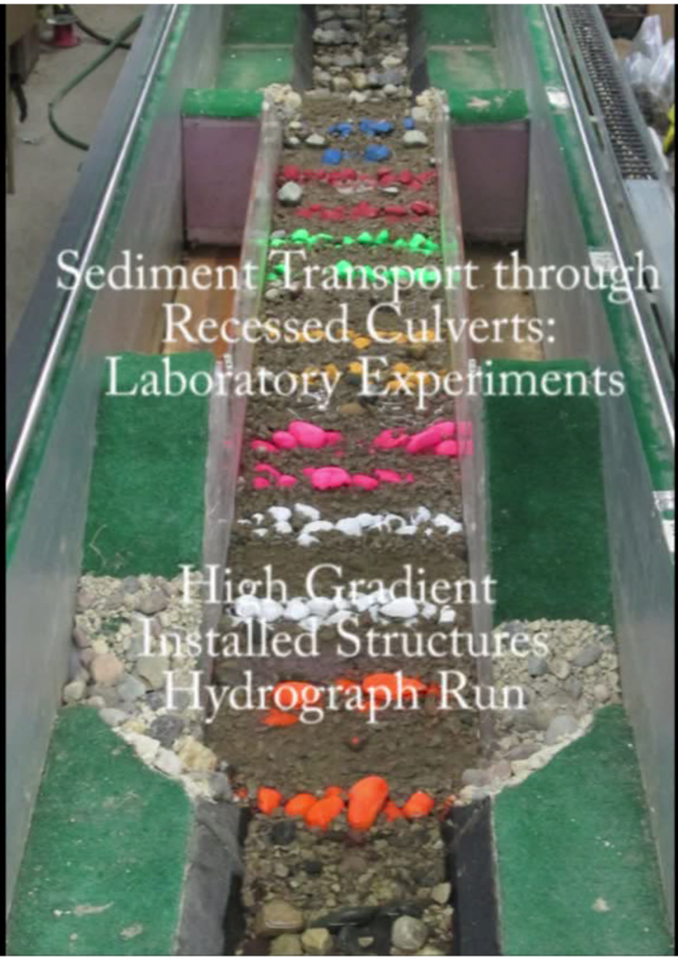
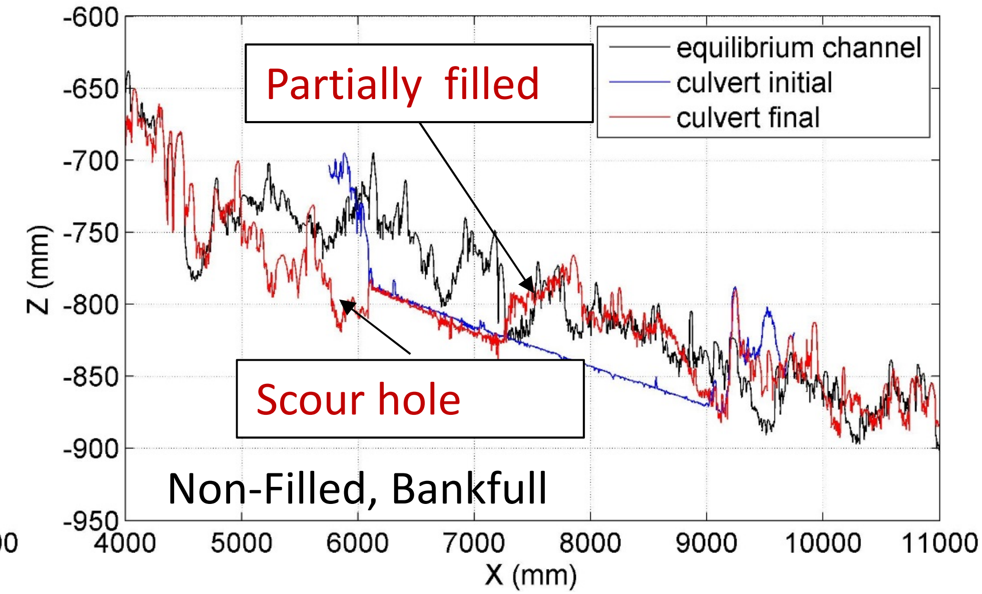
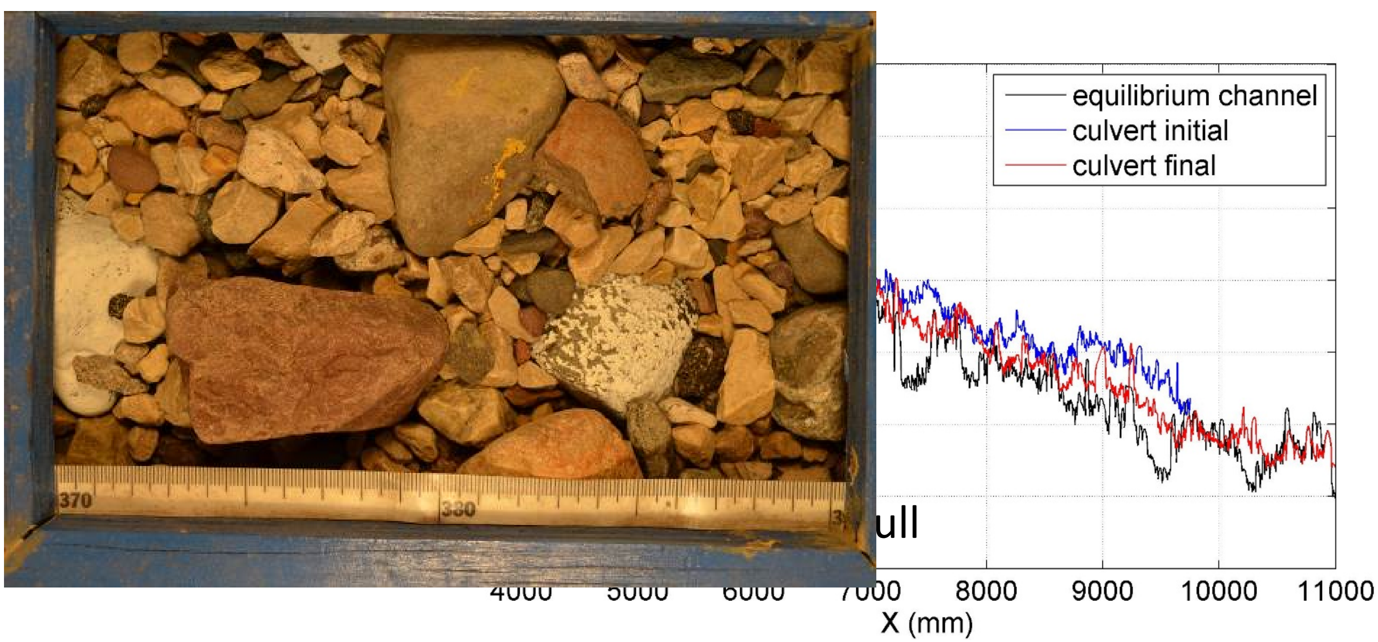
High Gradient – with Bed Structures

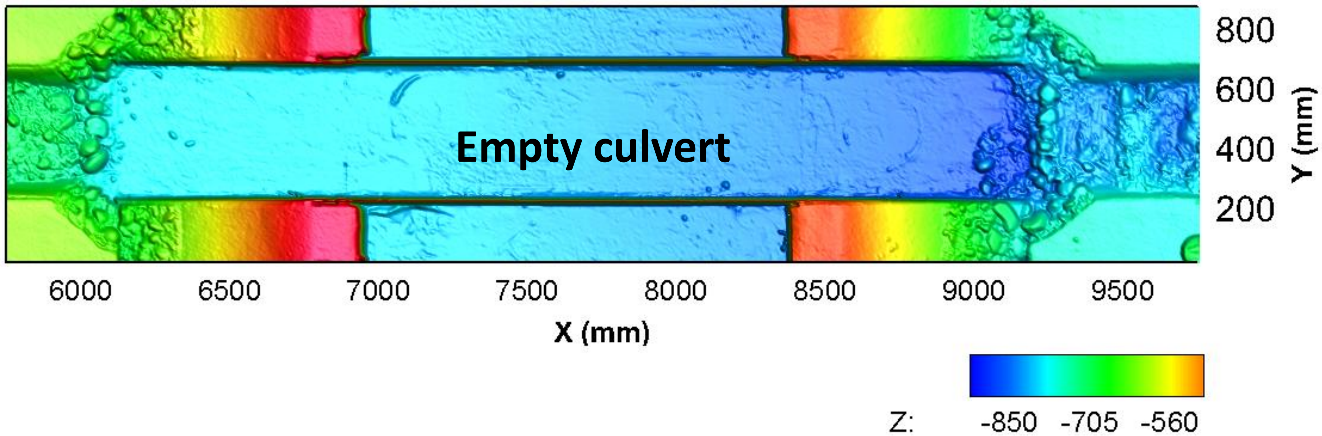




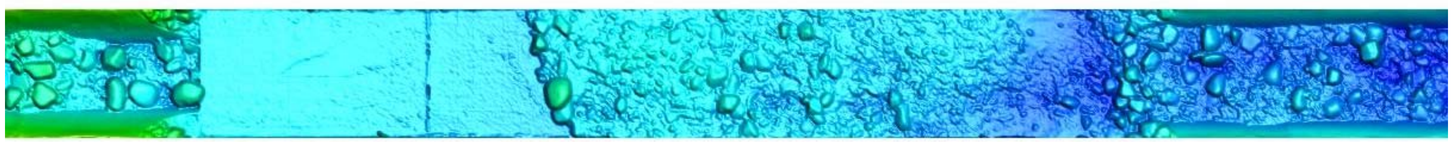
High Gradient



High Gradient, Non-filled



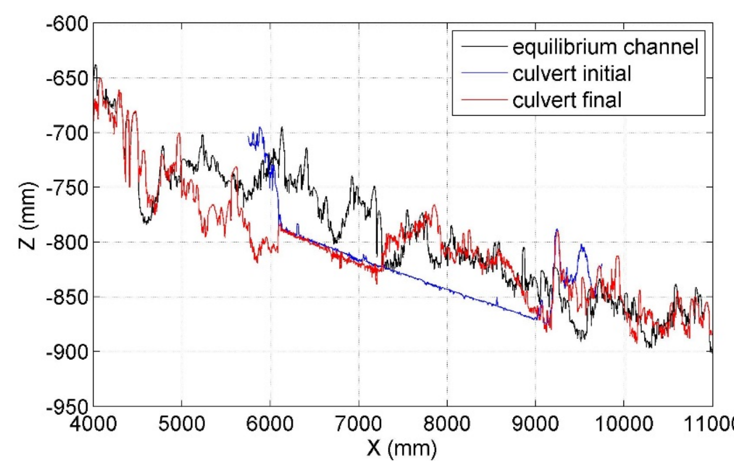
Flow



After Bankfull Flow

After 1 hour of run time, some sediment had moved into culvert, but culvert had not filled.

Significant scour occurred upstream of culvert up to the location of the last immobile structure.



Summary – High Gradient

- Structures are important to maintaining sediment stability in culverts and upstream for high gradient systems
- Placement of grade controls within ½ BFW can cause failure of other downstream control during high flows
- Sediment filled into empty culvert only when upstream structures failed (resulting in significant scour)

Field Experiments – Tongass N.F.

Objectives:

- Develop a low cost alternative to stream simulation design that saves money by minimizing design and avoiding infilling inside the culvert

- Site conditions – moderate to steep gradients (0.02 to 0.045 ft/ft). Pool riffle to step pool channels. Gravel to cobble bedded channels

Field Experiments – Tongass N.F.

Design:

- Minimal survey measurements used in design
- Best fit design profile used based on average stream grades
- Surcharge material (stream bed material) was placed along banks to assist in infilling the culvert

Bed material used to surcharge pipe with material

Field Experiments – Tongass N.F.

Results:

- Surcharge material caused rapid infilling and also initiated headcuts and destabilized grade controls
- Bed topography was flat and bankfull width and much wider than stream bed at low flows
- Head Cuts due to embedment and surcharge placement are causing significant channel modification in some cases

450 mm headcut moving upstream of embedded nonfilled pipe

Field Experiments – Tongass N.F.

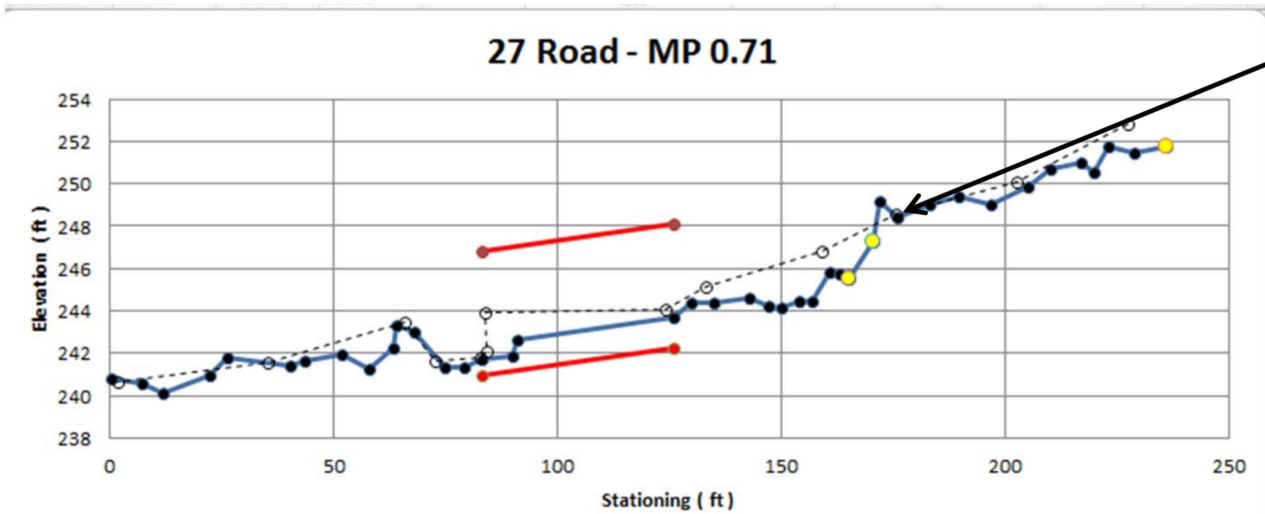
Results:

- Sediment covered the bottom of the majority of the structures after 2 years
- Surcharge material covered bank and over wide transitions. The material has moved out and aggradation potential is high at some sites due to lack of confinement
- Lack of design did not identify the geomorphic site risks

Overwide bank transition leads to long term aggradation

Field Experiments – Tongass N.F.

Head cut that is now a barrier



Pre design (dashed line) and current (solid) longitudinal profiles

Results:

- Minimal survey data lead to not identifying critical geomorphic grad controls and not understanding the effect of head cuts on them
- Permeability (dry sections) was an issue at some sites

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Field Experiments – Tongass N.F.

Tentative Conclusions: (Monitoring is on going for 5 more years)

- Sediment transport does fill up recessed culverts
- Allowing natural infill produces a flat featureless stream bed in the culvert which may be a barrier in low flow conditions
- Headcut can produce barriers upstream of the culvert and impact habitat
- Don’t use unfilled structure over 3%
- install grade controls to prevent head migration
- Use in Marginal / minimal length habitat
- Economic savings were really only ~10% from full stream sim however long term maintenance and stream impacts may cancel out upfront savings

Field Experiments – Chequamegon - Nicolet N.F.

Site Conditions:

- Low gradient sand bedded channels (<0.002).
- Minimal offset from upstream to downstream channel
- Vegetation controlled banks

Design:

- Utilized USFS stream simulation design Methodology
- No infill placed
- Some sites no bed or bank structure placed. Some had bed structure placed

Embedded culvert with no bed structure placed. Sand bed is fairly flat and has full coverage. No head cut observed

Field Experiments – Chequamegon - Nicolet N.F.

Conclusions:

- Not infilling is appropriate for most sand bedded channel conditions
- Stream bed should not be offset by more than 0.5ft without a careful evaluation of a longitudinal profile. Some offsets are due to upstream aggradation some from downstream adjustments
- Utilize some bed structure to produce a thalweg and some bed complexity

Embedded culvert with no bed structure placed during construction. Sand bed has maintained a thalweg and bed has topographic relief

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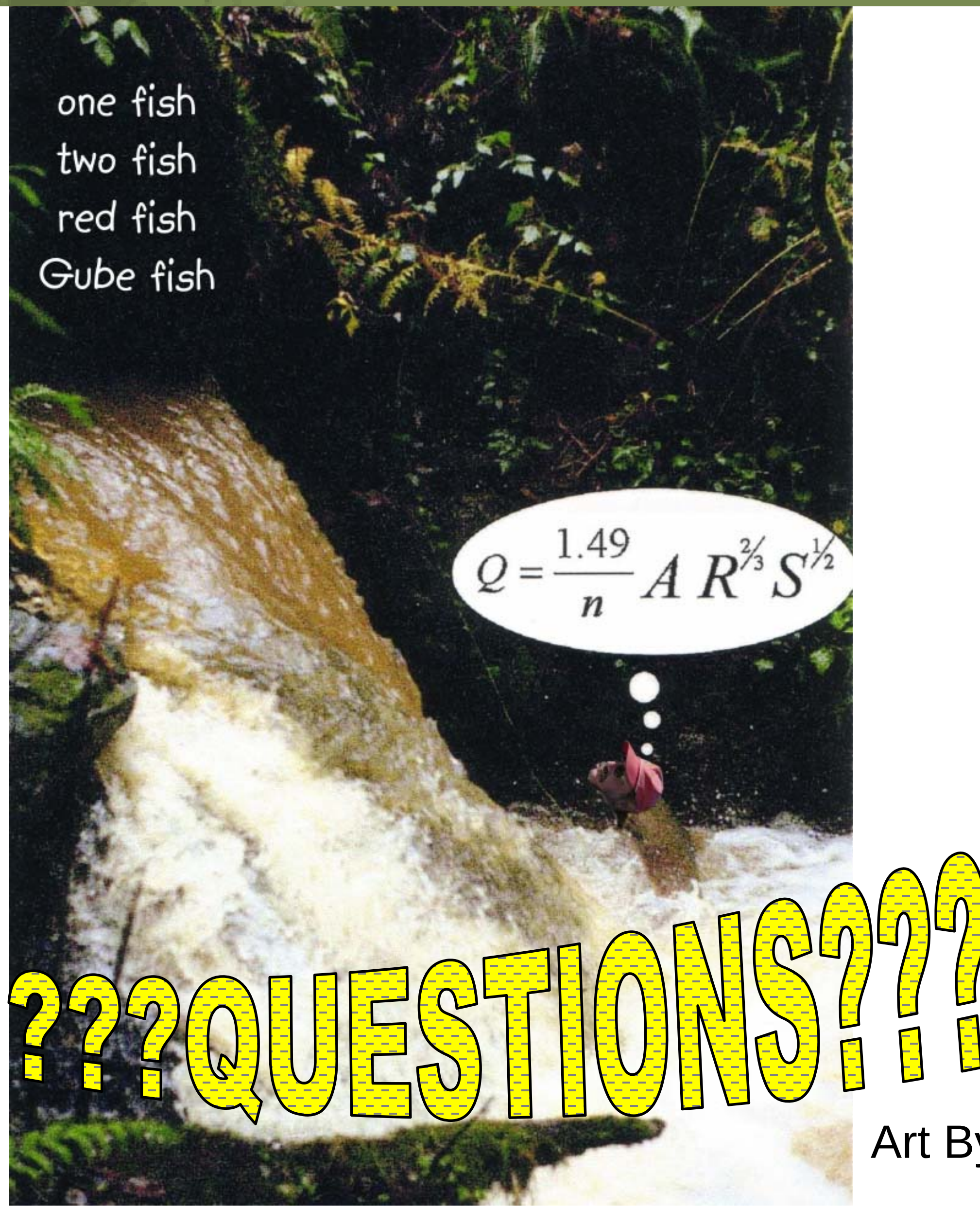

Art By Tomas Dunklin