Washington Office Virtual AOP Design Assistance Team

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Assessment of a Simplified Design Method for Aquatic Organism Passage on the Tongass National Forest

Final Report

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Prepared for the Tongass National Forest
and Region 10.

ACKNOWLEDGEMENTS

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Executive Summary

Assessment Purpose, Background & Objectives

In 2011 the Tongass National Forest and Alaska Region 10 submitted a Process Improvement Proposal (PIP) which suggested a modified design method aquatic organism passage (AOP) at road-stream crossings. In essence, the premise for the proposal is that the standard Stream Simulation design is too costly for small streams with limited or marginal habitat, or where anadromous fish are absent. The Tongass, like so many other Forests, is struggling to fund aquatic organism passage structures while trying to address the cost/benefit ratio on these smaller streams. The Regional office is also interested is exploring alternative methods to meet AOP requirements in order to be fiscally responsible and provide some level of aquatic orgainism passage at more crossings sooner than current funding levels allow.

The Forest and Region were selected for multiple-year funding to develop and test a design method that reduced costs by minimizing assessment and design, and by simplifying construction. This simplified stream simulation approach seeks to achieve design savings by reducing the amount and level of data collection and analysis required for the USFS Stream Simulation Method. Savings in construction would be achieved by staging 'surcharge' materials (typically gravel and sand) upstream of the inlet allowing the stream to move materials into the embedded structure as opposed to placing material within the crossing to simulate stream bed and bank characteristics.

The Assessment Process

The assessment process consisted of a series of site visits with an interdisciplinary group of Forest Service specialists, as well as representatives for the Alaska Department of Fish and Game and the US Fish and Wildlife Service.

The first series of sites visited were historic AOP structures on Kuiu and Mitkof islands. The intent was to target historic Stream Simulation installations, as well as less rigorous methods of aquatic organism passage, to evaluate the long-term efficacy of different efforts.

The second series of site visits were to recent Minimally Engineered Aquatic Organism Passage (MEAOP) sites on Prince of Wales (POW) Island. The intent was to look at how well the structures were performing after a couple of runoff seasons, and gain insight on how subsequent installations might be modified in the following years funded by the PIP proposal.

Recommendations

In brief the following key recommendations are provided for the Region and Forest's consideration and are further expanded upon in later report sections

- Because communication is so critical find ways to enhance communication and cooperation between engineering, hydrology, and fisheries.
- Consider developing a Forest interdisciplinary design team(s) to provide the range of skills required for AOP crossing design, and share them among the districts. This should also be done for site prioritization and project planning.

- Consider increasing skill levels in geomorphology. Most of the design errors observed in the field stemmed from lack of sufficient field data, a lack of understanding of stream processes, and not enough analyses to identify risks associated with the site.
- MEAOP is an experiment to determine the feasibility and applicability of a simplified design and construction process for aquatic organism passage. See Section III C. for recommended locations and site conditions where MEAOP may be suitable.
- Consistent detailed monitoring on a longer timeframe is necessary to determine MEAOP efficacy. This should primarily consist of measuring physical attributes at the road-stream crossing and comparing them to adjacent stream reaches. Biological monitoring will also be a necessary component at some sites. Success cannot be claimed by simply having gravel in the pipe for a short period of time; the structures must work longer term. From our experience it may take up to 7 years for problems to manifest themselves due to temporal distribution of large events.
- Hire a shared services design engineer with partners like the nature conservancy that could focus on AOP and restoration projects.

Recommendations are also provided on suitable and unsuitable locations for the application of the MEAOP method, as well as suggestions for assessment, design and construction of MEAOP sites to improve their success.

Finally, the cost analyses on which the original PIP was justified should be revisited since it does not appear to reflect actual differences between alternative design/construction methods.

The WO Virtual AOP Design Team can offer hands-on assistance to the Forest on an actual design or monitoring plan, along with emphasis on geomorphic assessment, to help increase the team members' skill levels. A training is in the process of being scheduled for the week of July 13.

Section I. Introduction and Purpose

A. Background

In 2011 the Tongass National Forest and Alaska Region 10 submitted a Process Improvement Proposal (PIP), as outlined in the Engineering Transformation for the Forest Service, which suggested a modified design method aquatic organism passage (AOP) at road-stream crossings. The Forest and Region were selected for multiple-year funding to develop and test a design method that reduced costs by minimizing assessment, design, and analysis and by simplifying construction, primarily by not designing and constructing a stable streambed through the design reach. The proposed design methodology was originally called Simplified Stream Simulation, but was eventually referred to as Minimally Engineered Aquatic Organism Passage (MEAOP), and is described in more detail in Section B below.

Part of the proposal was a commitment to monitor the installations to "test the theories and verify the applicability of simplified stream simulation on a range of gradients and stream types". The first round of this monitoring and evaluation occurred during the week of June 22, 2014. The agenda for the June review included revisiting historic AOP crossings (1980 through 2005), as well as site visits to the PIP sites from the last 2 years. The intent was to provide a context for to the simplified method, compared to the current Stream Simulation design methodology used throughout the Forest Service.

This report summarizes the findings of this interdisciplinary review by revisiting historic and current methods in a semi-quantitative method based on field observations and limited field data collected during the week. Additional data will be collected by Tongass staff later in 2014 and 2015 to support further analysis, such as hydraulic modeling (if required) and longitudinal profile analysis on a subset of designated sites. This modeling would provide quantitative back up for some of the observations and interpretations made in the field.

B. The Proposal: Minimally Engineered AOP Design (Simple Stream Simulation)

The following italicized text is excerpted from the original Process Improvement Proposal:

Problem Statement: *National Forests across the country struggle with the costs associated with providing aquatic passage at stream crossings in compliance with the Clean Water Act. Existing culverts that do not meet Aquatic Organism Passage (AOP) requirements are being replaced as funding allows, but the high costs associated with the current stream simulation AOP projects is slowing progress. Historically the Tongass has spent an average of $70,000 to $110,000 for survey, design, and construction on small to moderately sized stream simulation AOP structures. During the AOP planning process, the environmental benefits are calculated by stream and only the culverts with the most environmental benefit within a given area are replaced - leaving the rest until additional funding becomes available.*

As the highest priority culverts that restrict the design fish during certain flows (red pipes) are replaced, diminishing environmental returns for red pipe replacement projects are being seen. We are investing the same amount of money per site with diminishing environmental returns.

During a recent highway construction project fish passage designers and fisheries biologists, working together, determined that a group of streams may not warrant the increased costs associated a normal engineered solution for fish passage. The culverts all had more than one of the following:

- ***significant (gradient 25-35%) bedrock cascades within a short distance downstream,***
- ***very limited upstream habitat,***
- ***small stream sizes,***
- ***non-anadromous fish, and***
- ***conflicting habitat calls (no upstream habitat) on the same stream by different biologists.***

A value analysis on the project questioned the survey, design, and construction costs compared to environmental benefits of engineering solutions at fish stream sites with limited habitat.

Empirical Solution: *At a number of sites on the forest we have observed a potential solution. In some locations, culverts have been installed slightly below grade and at a gradient similar to the natural stream. Later observations have shown that stream sediments washed down by storms partially fill the culvert and the culvert functions very similar to a stream simulation design but at a fraction of the cost. In talks with other road owners, some have developed stream simulation methods that are substantially less intensive than our current method. These methods seem to be suitable for fish streams with low to moderate environmental risk. (See photos on page 3.)*

Project Description: *This project will consist of working with an interdisciplinary team to establish criteria for simplified AOP. The team will examine culverts that could serve as models. (i.e. the empirical solutions described above). The team will also work with the Alaska Department of Transportation and Public Facilities, as well as private land owners, who have been engaged successfully in a simplified stream simulation process. Our goal is to refine the process and set up parameters that will provide a high probability of success for low to moderate risk sites. Culvert structures will be installed to test our theories and verify applicability of simplified stream simulation on a range of gradients and stream types. After installation, monitoring and refinements of our criteria and design will take place.*

Cost and Benefits: *A recent Tongass NF project incorporating the typical stream simulation fish passage was evaluated by a value analysis team. The team questioned the high cost of providing stream simulation fish passage for the small amount of habitat provided. A subsequent evaluation of costs associated with the typical stream simulation design shows the we could save an average of about $25,000 in survey, design, and administrative costs and $27,000 in construction costs per structure (A rough total of $52,000 per structure) if we were to utilize simplified stream simulation as proposed herein.*

There will be a small initial cost for developing a protocol to determine which sites are appropriate and setting up the monitoring criteria but most of the funding will go immediately into alleviating red pipe problems on culverts that meet the criteria. The cost to fund this pilot project is estimated at $70,000 matched with $70,000 in funding from the Tongass per year over period of five years. This will give us adequate time to evaluate the success and failures of the trials and fine tune the criteria and designs. The monitoring results, show and shine reports, and project accounting will be submitted annually as required.

The anticipated cost/benefit ratio ranges from 2:1 to 5:1 with the largest cost/benefit savings being seen on the smaller streams. The environmental benefit of providing fish passage at additional sites was not included in the calculation.

In essence, the premise of the proposal is that the standard Stream Simulation design is too costly for small streams with limited or marginal habitat, or where anadromous fish are absent. The Tongass, like so many other Forests, is struggling to fund aquatic organism passage structures while trying to address the cost/benefit ratio on these smaller streams. The Regional office is also interested is exploring alternative methods to meet AOP requirements in order to be fiscally responsible and provide some level of fish passage at more crossings sooner than current funding levels allow.

The purpose of the project is to provide a low cost alternative to Stream Simulation that provide AOP for a specific set of site conditions (see bullet list above). These are logical situations where we could see cost savings if there are no special attributes upstream of the crossings such as critical habitat (high quality spawning area, overwintering habitat, etc.) or the presence of T&E species.

The design concept was to save money on design and construction. Design savings were to be achieved by reducing the amount and level of analysis and data collection required for USFS Stream Simulation Method. The construction would save funds by staging 'surcharge' materials (typically gravel and sand) upstream of the inlet in the channel and the along the banks and let the stream move materials into the embedded structure.

Over the course of the last 3 years the Tongass N.F. has received joint funding from the WO and the Region 10 RO as part of the Process Improvement concept outlined in the Engineering Transformation. Installations of the proposed design methodology have been implemented in the previous 2 field seasons and have seen overbank flows occur at each site.

C. Objectives of MEAOP Program Review

The principal objectives for the review were to:

- Review all elements of the MEAOP design method
- Evaluate the method's limitations and applicability in the field, particularly in relation to historic AOP designs on the Forest
- Establish monitoring protocols to evaluate the installations and designs over the next 3 to 5 years
- Review and validate the economic analysis relative to actual costs and benefits
- Provide recommendations to the Forest and Region on the items above
- Assist in further development of the design method for national distribution if the MEAOP is considered successful in the long-term

D. Participating Staff

Staff from the Tongass National Forest, USFS Region 10 office, State of Alaska Department of Fish and Game, US Fish and Wildlife Service, and Washington Office Virtual AOP Design Team participated in the review. Not all of the Tongass engineering/design staff were present in the field; they were interviewed by phone after the review to help address methodology questions. The following people attended the design review:

Robert Gubernick R.G. – Watershed Restoration Geologist - WO Virtual AOP Design Team
Mark Weinhold P.E. – Forest Hydrologist - WO Virtual AOP Design Team

Julianne Thompson – Forest Hydrologist - Tongass N.F.
Ashely Hom – Hydrologist – Tongass N.F.
John McDonell – Assistant Forest Fish Biologist – Tongass N.F.
Sarah Brandy – Fish Biologist – Tongass N.F.
Mark Fox - Fish Biologist – Tongass N.F.
Quentin Smith – Roads Program Manager – Tongass N.F.
Molly Williams – Civil Engineer – Tongass N.F.
Jason Powell* – Civil Engineer – Tongass N.F.
Don Martin* – Acting Fish, Water, Wildlife, and Air Staff Officer – Tongass N.F.
Marie Messing – Regional Transportation Engineer – Region 10
Mark Minnillo – Habitat Biologist – Alaska Department of Fish and Game
Neil Stichert – Fisheries Biologist / AOP Program manager – US Fish and Wildlife Service

*Staff that were either interviewed or were only present during the closeout meeting.

E. Historical Perspective

History of AOP on the Tongass

In order to put the current MEAOP proposal in context, it is worth reviewing the evolution of fish and aquatic organism passage designs on the Forest. The Tongass National Forest has been a leader in Aquatic Organism Passage (AOP) for more than 30 years. Design methods began to evolve away from bare culverts in response to the Clean Water Act requirements and findings that a large portion of the existing road-stream crossing structures were not passing juvenile anadromous fish. In the late 1980's the Tongass began installing embedded culverts designed as hydraulic structures. These designs compared velocities in the structure during the accepted windows of fish migration against published swimming abilities for a given fish species. Since these designs were species and timing based, they were designed and constructed quite differently than current standards such as Stream Simulation.

The Forest experimented with different design and streambed infill methods (e.g. dam and wash substrate in the structure, place material inside structure by pushing in with excavator and logs, or allow bed to infill naturally) from 1986 to the mid-1990's. A primary assumption of the placement of materials within these structures was that sediment transport was continuous and would replace material being moved out by storms. These initial structures had varying levels of success over the years. Many crossing are completely functional and pass fish and aquatic organisms as designed; others have lost continuous substrate coverage and no longer meet the original design intent.

During that time the gradient of installed pipes was relatively flat, generally not exceeding 3.5 percent. This was a restriction of the design method since hydraulic analyses suggested that juvenile fish could never pass at gradients greater than 3.5 percent, and adults could only pass over a limited range of flows because of velocity or depth restrictions. Culverts slopes were blended with natural stream grades outside of the culvert, with grade controls placed downstream and upstream. Culverts installed were normally less than bankfull width. These sites were periodically monitored with varying levels of success observed. No dewatering was done during this timeframe, except for bottomless structures or bridge abutments, and all instream work was done in the wet.

After the mid 1990's, the designs became more interdisciplinary by including a geomorphic assessment to better understand the reach and watershed scale context of the road-stream crossing. Through 2000, the designs improved by incorporation of geomorphic principles such as adding roughness elements and grade controls, increasing structure width, increasing embedment depth, and trying to improve gradient transitions. The focus was still mainly on adult fish until a report from Alaska Department of Fish and Game documented a large portion of the drainage structures across the forest did not meet juvenile passage standards (Flanders and Cariello 2000). The Forest responded to this finding by dedicating over two million dollars annually for the next 6 years to address the problem.

After reviewing the previous work in the field, the Tongass methods were revised based on what was learned over the previous 20 years on Forest and from colleagues in other states. The Tongass began using its version of Stream Simulation design, which is a major part of the current USFS Stream Simulation design methodology.

Structures were matched to bankfull channel width, structure gradients were improved to more closely match reference conditions, embedment depth increased, variations in bed elevation were taken into consideration, and transitions to stream banks were improved. Several differences exist from those structures (2000 to 2005 designs) and current Stream Simulation methodology:

1) Banks were not consistently used; mostly margins of coarse rock were used along the edge of the structure
2) When steps were constructed, the step height was based on juvenile leap height versus natural step heights found in the stream
3) Sediment incipient motion analyses were not as extensive or accurate as current methods
4) Bed design mix was a mixture of key pieces (riprap size rock) and natural stream substrate. The current procedures are different for bed mix (mobile portion) and the key piece/grade controls (stable to Q100)
5) Embedment was based on a minimum depth or percentage of the rise of the structure. The current procedure uses maximum scour measured from current pool depths, which are then increased based on estimates of storm scour (a factor of safety based on substrate size).
6) Average cross section dimensions were used for the entire length of the design channel, versus dimensions based on the unique channel units (pool, step, riffle, etc.) and their location in the bed design.

In short, much more consideration for geomorphic risk and context is conducted now than was historically done.

Previous Attempts to Minimize Design and Construction Costs

Attempts at MEAOP are not new. Within the National Forest System several forests have tried allowing culverts to infill, but with no real success. Personal communications from Anne Connor (Clearwater NF) and John Kattell (Region 1 RO), along with previous work on the Tongass, have shown poor to limited long-term success. Unfortunately, none of this previous work has been formally documented and published.

Recent research in Ohio on letting embedded culverts fill naturally concluded that *"The results of the survey indicate that, at the 90% confidence interval, sediments are being washed through culverts with a slope 1% or greater"* (Tumeo and Pavlick 2011). They also concluded that higher outlet velocities, due to minimal barrel roughness in bare pipes, can cause localized scour and create an outlet perch in minimally embedded culverts. In this study all of the structures were embedded less than two feet, and most were embedded less than 1.5 feet.

The national AOP team is involved with ongoing research at the University of Minnesota looking at this very issue (Kozarek and Mielke 2014). The flume tests have been completed with the research report currently in review. Preliminary conclusions and recommendations include:

- *Very different sediment dynamics exist in different geomorphic settings (slope and grain size combinations). Site specific analysis of flow, shear stress estimates and mobility of the range of sediments is recommended to predict sediment movement into the culvert.*
- *Filling the culvert generally protects against upstream and downstream scour or head cuts provided the culvert is of a similar width to the stream.*
- *For high gradient streams, structures should be installed within the culvert to maintain sediment stability in culverts and to prevent headcuts upstream.*
- *In a high gradient stream, structures made up of larger interlocking pieces are critical for stream stability. Culverts may not fill with material representative of the stream until a flood flow that is large enough to displace this material from upstream. When this happens, significant scour can occur.*
- *Armoring can play a major role in stunting the movement of material into a culvert. The degree of armoring in the stream should be evaluated if sediment transport into the culvert is expected.*

Flume results of the study are included in Appendix A

Field Observations of Historic AOP Structures

Since the MEAOP procedure is essentially repeating some of the design elements that have already been tried on the Tongass, the decision was made to revisit early AOP crossing sites. These included sites on Kuiu Island (installed from 1985 to 2003) and Mitkof Island Installed in 2002 and 2003).

Kuiu Island Lessons Learned.

1) Bed within the structure was generally flat with not much diversity (very simplified) for early structures. Later designs had much more bed diversity and complexity.
2) Older structures were narrower than bankfull but had downstream grade controls. This helped maintain sediment in the structure and partially backwatered the structure, yielding deeper flow depths during low water conditions. (See Figure 1).
3) Where key pieces were not incorporated in the bed mix, some structures had lost their bed material or had sporadic substrate cover. (See Figure 2).
4) Where structures did not have good bank transitions from the stream bank to the structure, channel widths change rapidly and aggradation has occurred. This can result in minimal water depths and migration issues during low flow. (See Figure 3).

Figure 1. Kuiu Island 6407 road - log and boulder grade controls backwatering the structure and maintaining gravel/cobbles in a structure that is narrower than bankfull width. An additional small cmp was added as a lateral structure to handle flood flows.

Figure 2. No key pieces present in narrower than bankfull width structure. The wedge of streambed material is at the inlet of the structure, while the remainder of the culvert retained very little of the originally placed stream substrate. Downstream of the outlet the channel may have degraded or the grade control failed.

Figure 3. Stream bed aggradation has occured due to lack of proper inlet and outlet transitions from the culvert to stable stream banks. Leaving over-wide channel from previous undersized structures causes rapid width expansion, which results in sediment deposition. (6415 Road)

Mitkof Island Lessons Learned

1) Later designs have more complex stream beds, and represented characteristics similar to reference conditions. (See Figures 4 & 5).
2) Pools from steps were variable in depth, some reflect pool depths in the reference reaches, and some were shallower. The use of a single cross section dimension versus unique dimensions associated with a channel unit (steps, riffles, and pools) caused accumulation of cobbles in pools; channel width contractions were not constructed to maintain pool scour. Step height was also limited during this time period by biological concerns for juvenile fish versus, as opposed to using step heights from reference conditions (which is the current practice in Stream Simulation).
3) Margins (rough rock along the structure walls) were discontinuous. This was likely a result of a combination of inadequate inspection during construction and an imprecise analytical method to estimate bank material stability during flood flows.
4) Sites with very poor hydraulic geometry have the thalweg of the stream pushed up against the culvert wall or are accumulating stream bed material. No sites are currently at risk.

Figure 4. Bed complexity in 2004, similar to that observed in the natural channel. (40000 rd, 3.337mp)

Figure 5 - Bed complexity in 2014, ten years later at same site as Figure 4. (40000 rd - 3.337mp)

Section II. Findings from Site Visits

A. Overview

MEAOP sites were visited from two different contracts on Thorne Bay Ranger District, Prince of Wales Island.

A road-stream crossing that is expected to be stable in the long-term, providing a safe transportation network and meeting all the required ecological standards, requires interdisciplinary input. In particular, some understanding of how the road-stream crossing fits into the larger stream reach (geomorphic setting) is critical to understanding certain design assumptions and the long-term viability of the structure. Understanding the long-term risks from potential changes in the stream should be fully understood, no matter which design methodology is used.

The Forest Service is a first cost agency, so we usually don't consider long-term maintenance and repair costs in our initial economic analyses. However, given our agency's limited funding and staffing, primary objectives for road-stream crossings should include having structures that require zero or minimal maintenance, cause no stream problems (erosion, head cuts, aggradation or degradation), and pass aquatic organism <u>for the full service life of the</u>

structures. If the design requires recurring maintenance, or creates a barrier upstream or downstream movement, we have not met our objectives.

There are a number of design considerations and site risks that were not recognized or analyzed during the MEAOP design process that will likely require additional maintenance in the field. These are discussed below.

B. Vertical Alignment (Profile) Considerations

Vertical Adjustment Potential

Vertical adjustment potential is the range of upper and lower potential channel bed surfaces the stream may experience during the service life of the structure. Risks from channel bed increases (aggradation) at the crossing are due to both natural and human causes:

- Large wood falling in the channel downstream of the structure (see Figure 6)
- Placing the structure flatter than the upstream channel gradient
- Initiating a headcut upstream
- Large pulses of sediment coming downstream from local slope failures
- Failure of an existing natural grade control upstream of the crossing
- Flood flows depositing mobilized streambed materials at gradient breaks
- Poor horizontal and vertical continuity designed through the crossing

Conversely channel bed lowering (degradation) can be caused by:

- Loss of a downstream grade control (natural or constructed) and subsequent headcut (Figure 7)
- Initiating a headcut by leaving a vertical excavated face at a countersunk pipe with no infill
- Bed scour during high flows
- Loss of sediment continuity from logs falling upstream
- Poor vertical alignment and tie with the existing channel (steeper structure grade than reference conditions in the channel)
- Insufficient structure width (causing greater bed shear within the structure)
- Insufficient roughness within the barrel of the structure

Figure 6 - 20rd-102.907 mp - Note logs in channel immediately downstream of outlet. Wood is excellent habitat for aquatic organisms however its proximity to the outlet pose a risk of future aggradation reducing hydraulic capacity. Shifting the pieces along the margin of the channel would have reduced risk and still provide the habitat component

Figure 7 - 20rd-125.242 mp - Natural log grade control immediately downstream of MEAOP design. Logs are in poor structural condition. These rotten and broken logs can easily be lost in future high flows causing loss of substrate within the structure or perching the structure from the tailcrest elevation differential.

The structure needs to be sized and placed with these potential variations in mind. The ability of a design to accommodate unavoidable adjustments in the streambed is a primary key to long-term success.

Headcut Potential

Headcut risk is a function of the substrate size and gradient in the stream, and how the design profile (structure) fits within the adjacent channel vertical profile. Headcuts flatten and lower the stream profile, while potentially moving large quantities of sediment from the bed. Allowing a headcut to progress upstream should be carefully considered since they can easily cause detrimental effects to the upstream channel and can potentially move an AOP barrier from the culvert to an upstream location. Headcuts were observed at sites 27rd-0.71mp, 20rd-125.242mp, 2008600rd-0.659mp, 2085rd-0.944mp, 3015rd-8.743mp.

The causes of the headcuts are combination of:

1. A rapid increase in stream gradient immediately upstream of the crossing from leaving a free erodible face in the streambed from embedding the pipe 2+ feet without infilling the culvert bed.
2. A reduction in channel width and cross sectional area upstream of the culvert from placement of surcharge material, which caused shear stress to locally increase.
3. Failing to tie the design profile to existing stable grade controls (upstream and downstream) or constructing a new grade control.
4. Not evaluating the size and mobility of the substrate in the channel.

The observed headcuts varied in degree of severity. The 27rd-0.71mp has undermined existing grade controls and hit a bedrock ledge, causing a barrier to AOP upstream of the now passable culvert (see Figure 8). The natural woody debris grade control on the bedrock ledge barrier holds back a shallow veneer of gravel upstream. It is anticipated the this low stability grade control will fail in future high flows and the upstream reach will be turned into a bedrock stream section with little habitat diversity, high velocities, shallower water depths and no real pools.

20rd-0.944mp has a 1.5-foot headcut migrating upstream (see Figure 9) that will undermine upstream wood controlled steps, which may increase the height of the free face of the headcut as it continues to move upstream. The height and configurations of the headcut can be a barrier for juvenile fish and some adult fish depending on flow.

The other three sites with identified headcuts have not developed any significant issues.

Figure 8. Exposed bedrock face from headcut at 27rd-0.71mp. Headcut will continue once woody debris atop of the bedrock is washed out during high flows.

Figure 9. 1.5-foot high headcut moving upstream at 20rd - 0.944mp. Head cut will continue to move upstream until it hits a stable grade control or bedrock.

Design Profile Gradient

According to Jason Powell (Civil Engineer), one of the lead designers of the MEAOP project on Prince of Wales Island, the design method used to determine the profile design (structure invert) was to estimate a reach-averaged gradient from both upstream and downstream survey points, and then use a best fit line to try and predict uniform profile. While this methodology may work in some instances, it is not universally applicable in streams with typical profile variability because:

1. A best fit uniform slope does not recognize distinct slope segments between stable grade controls, which are critical for long-term bed stability.
2. No consistency can be applied between designers to determine the 'average' slope.
3. The design profile is not tied to existing stable grade controls and no consideration is given to likely changes in bed elevation from unavoidable channel adjustments following construction.
4. Installation of embedded structures with no streambed infill leads to headcuts and destabilization of existing in-stream grade controls on which the survey was based.
5. Headcuts are typically a lower gradient than the existing channel gradients, increasing the likelihood of aggradation, particularly when coupled with no cross section definition within the structure.

The longitudinal surveys contained relatively few survey points, which did not capture the existing grade controls nor the pool scour observed in the stream. Had the longitudinal profile been surveyed and analyzed in a more comprehensive manner (see the 2008 Stream Simulation Technical Guide for details), most of the design consequences could have been identified and avoided. Improved survey and analysis of the longitudinal profile would help identify the headcut risks and vertical adjustment potential at each site. It would also provide a measured baseline for subsequent effectiveness monitoring.

It should be noted that surveying a stream profile is not the same as surveying a road. To obtain meaningful data to inform the design, a person knowledgeable in stream/habitat surveying should be involved.

Placement and Design of Grade Controls and Key Roughness Elements

The use of grade controls varied from site to site. When used, grade control structures were installed at both the inlet and outlet. Although not always visible in the field, the plans called for placement of grade controls (steps) to be placed within ½ bankfull width of the inlet. This location tends to be problematic in the long-term because of the proximity to the zone of contraction at the culvert inlet, where water is funneled into a narrower cross section at high flows.

The plans indicate a Class 3 rip rap for the grade controls; although a review of the design documents showed no stability analysis performed to support the sizing. The riprap was to be placed in small bands of loose rock. This is usually problematic for long-term stability, especially in high gradient streams. Using the natural channel as a template, stable step grade controls consist of large key pieces that are interlocked and stable in floods ranging from a Q30 to Q80 event. In higher gradient streams, designing these features to be stable up to a Q100 flood event (Stream Simulation design standard) is critical for stability of the stream profile.

Proper construction and design techniques are necessary to ensure stability of key features such as steps. One of the problems in the MEAOP design is that the upstream grade control has no downstream burden to buttress the feature. With no infill, the upstream grade control has a much larger step height than what would be found in most of the streams observed, which increases the potential for detrimental scour or even creating a passage challenge to some organisms.

No grade controls are designed or placed inside of these MEAOP structures. The length of these structures is typically much longer than the natural grade control spacing found in the stream. This adds to long term failure potential for MEAOP structures in high gradient stream where stream beds are relatively static moving only small bedload over the surface.

Stability of Existing Natural Grade Controls and Risks to the Road Crossing

The ability to maintain streambed material within a road-stream crossing structure is dependent on maintaining a stable profile through the design reach. This requires a detailed assessment of the location and stability of grade controls upstream and downstream of the crossing. This type of analysis was not completed as part of the MEAOP design, so long term risks to the installation were not identified.

Loss of an upstream grade control is less problematic than a downstream one. Risk from the loss of an upstream grade controls is sediment input to the crossing, particularly if it is large and holds back a lot of sediment. Aggradation causes a loss of hydraulic capacity by decreasing the cross sectional area available in the structure.

Conversely, the loss of a nearby downstream grade control can cause incision and degradation to the stream bed via migration of a headcut. Small headcuts are typically arrested or dampened at the next upstream grade control. But since MEAOP do not include roughness elements and other grade control features within the structure, erosion of the streambed material is likely to result.

Given that the MEAOP designs are new, this mechanism has not developed. However there is a good example of a low stability downstream grade control that will fail and affect the structure by leaving a perch at the culvert outlet. This site is 20RD – 125.242MP (see Figure 10). The 2-foot step height of the downstream grade control is maintaining streambed material in the culvert. It is composed of both rock and rotting and broken logs, but has a relatively low stability rating and is not expected to persist long-term.

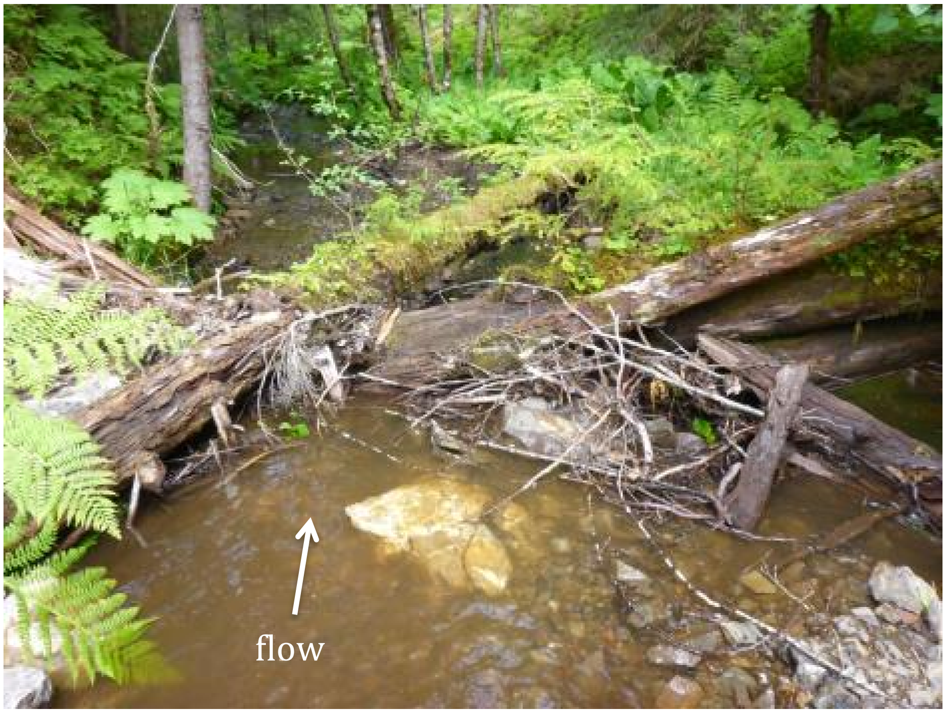


Figure 10. Downstream low stability grade control buttressing upstream sediments within the culvert on 20rd-125.242mp. Loss of this structure would cause a 1 to 2-foot perch at the culvert outlet and remove sediment from inside the structure.

Embedment Depth of the Structure

According to the Tongass engineering staff, the embedment depth was determined by reviewing the deepest pool and multiplying by a factor of safety, which was checked against general guidelines of a percent of maximum rise of the structure. Road fill height was also taken into consideration. This is similar to guidelines for Stream Simulation. However, the design profile, long profile shape, structure to stream orientation, subsurface geology, and stream bed material composition should also be considered when determining embedment depth.

C. Horizontal Alignment Considerations

Inlet Skew and Lateral Adjustment Potential

Lateral adjustment potential is defined as the potential for the stream to change planform positions over time, thereby affecting inlet and outlet geometry and hydraulic efficiency. In most cases where MEAOP was used (confined channels), lateral long-term shifting of the stream was not a significant issue. In cases where floodplain channels exist, lateral adjustment should be evaluated. Since MEAOP is intended to be utilized in small streams with limited habitat, risk should be low due to limited or small floodplain near the crossing.

An example of lateral adjustment is at 20rd-102.907mp which has room for lateral movement in its floodplain (see Figure 11). A vegetated island upstream, likely the aggraded sediment wedge from the previous undersized structure, has allowed the channel to switch flow paths after recent high flows. Now the main channel follows the original flood swale on river right. This site has poor hydraulic alignment (approach angle between the stream and the structure) no matter which flow path the stream occupies. Poor hydraulic alignment inevitably results in higher potential for debris and sediment accumulation, loss of hydraulic capacity, and increased likelihood of road-fill scour at the pipe inlet

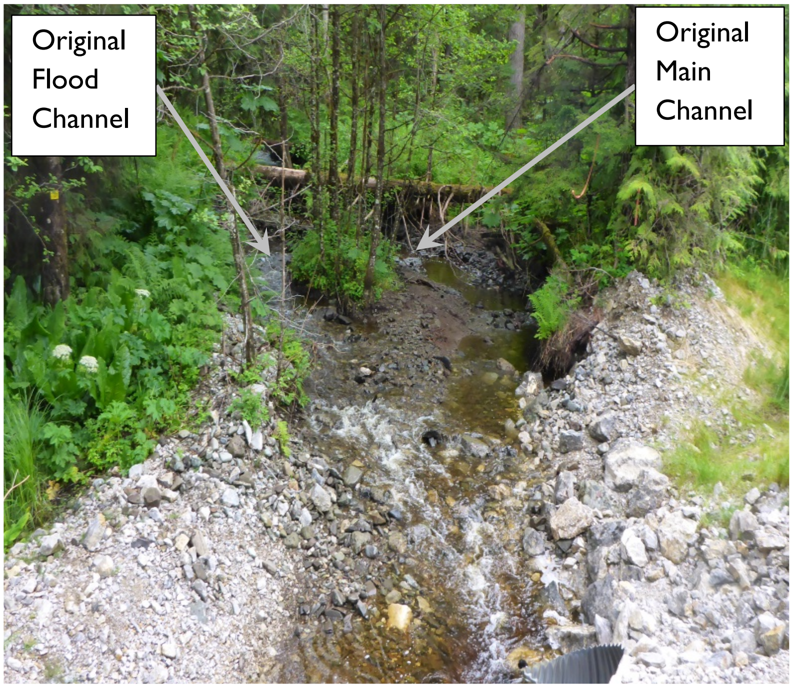


Figure 11. Stream has primary flow in flood channel after large storm at 20rd-102.907mp. The crossing has very poor stream to structure geometry.

Inlet and Outlet Transition from Culvert to Natural Stream Banks

Transitions from natural stream banks to banklines (or culvert walls) in wide structures are necessary for hydraulic continuity, which maintains sediment and debris transport through the structure. Most historic undersized culverts have substantial scour and widening at both the inlet and the outlet. If left untreated, the rapid width expansion at the inlet and outlet typically causes sediment deposition and aggradation (see Figure 12). This leads to a reduction in hydraulic capacity as the bed level increases, a very simplified stream bed, and shallow water depths, especially during low flows.

All MEAOP sites reviewed lacked smooth transitions at the inlet, the outlet, or at both ends of the structure. This design element was not part of the contract plans and specifications.

At some older Stream Simulation sites on Mitkof Island, the rock banks originally constructed have been removed by road maintenance ditching operations. It is important to teach and remind the road maintenance crews of the importance to not remove the rock banks at the edge of the ditch where AOP culverts are located to prevent aggradation at these sites (see Figure 13). Proposed MEAOP sites should construct rock banks to improve sediment transport and better transition the banks at any new installation. At previously constructed sites, the Forest should consider retrofitting banklines.

Figure 12. Scoured out banks from the original undersized structures were not reconfigured to tie culvert walls into the natural channel banks at 3015rd - 8.743mp. This overwide area causes deposition. In this case, development of a gravel-cobble bar that splits the channel at low flow.

Figure 13. Stream simulation culvert installed in 2002 at 40000rd-2.49mp. Note the removal the bankline on river left from reconstruction of the inboard ditch along the road in the current condition. The culvert is functioning fine, however destruction of bankline could lead to long-term aggradation, reducing culvert hydraulic capacity and decreasing low flow water depths at the inlet.

D. Other Design Considerations

Structure Width and Cross Section Shape

Stream width and gradient are intimately related; steeper stream reaches are typically narrower than low gradient reaches on the same stream. Consequently, selecting a structure width should be based on measurements in a reach that has a similar gradient to design reach.

Rather than using a representative reach, the MEAOP method takes width measurements along the channel over a mix of gradients and channel units (pools, riffles, steps, etc.). Those measurements are pooled together and a histogram is developed. The structure width is then based on the 66th percentile of the distribution. Because of the mix of gradients and channel units measured, the MEAOP structure width may be over or undersized for the design gradient. Over-wide structures can lead to shallower water depths at low flow and long-term aggradation, along with subsurface flow during low water periods. An example of subsurface flow was found at 20rd-125.242mp where the last 6 feet of the structure was dry. This is due to both the wide, flat cross section and the coarseness of the surcharge material used. The subsurface flow at this location may correct itself in time.

Conversely, narrow structures relative to the design gradient are more likely to experience scour at high flows and will be difficult to maintain a continuous layer of stream substrate inside.

A related issue with not building a streambed within a structure is the development of a flat, smooth streambed with no roughness elements and associated diversity. This is not an issue if the natural stream channel cross section is rectangular in shape with little roughness, but it can be problematic in wide pipes with small substrate sizes.

Sediment Supply

In order for the MEAOP structure to fill with streambed material, there must be available sediment supply for transport beyond what is placed as surcharge. Typically this is not a problem, except in some palustrine type channels with organics and silt substrate. In these cases, there are no suitable sized sediments available to be recruited into the structure. An example is at 20rd-122.678mp where the upstream channel is a wetland. Since there is essentially no coarse sediment supply through this reach, the only sediment retained in the MEAOP structure is the residual of the surcharge materials (Figure 14). Even a cursory site assessment would have brought this issue to light. In cases like this, some probing should be done to determine if the channel has a thin covering of silt and vegetation over gravel or if it is a palustrine type channel with a silt and sand bed controlled by vegetation.

Figure 14. Upper photo shows upstream channel at 20rd-122.678mp. Note sedges which allow the fine grained material to be maintained in the channel and stabilize the erodible material. The surcharge material can be seen at the inlet. Lower photo is looking downstream from the inlet. The upstream channel is not able to recruit enough sediment to fill this structure. Fortunately the culvert is backwatered through some of its length, which is important for AOP in these types of streams.

Subsurface Conditions

No design information was provided to demonstrate an understanding of the subsurface conditions relative to the design. On the Tongass, many of the high gradient streams are wood forced step pool morphology with shallow bedrock. In this type of channel, the failure of existing grade control features, by allowing uncontrolled headcut or by destabilizing existing grade controls during construction, can cause a migration barrier and produce bedrock bottom stream reaches with little habitat value. This was the case at site 27rd-0.71mp where the channel incision from an uncontrolled headcut undermined the upstream grade control and created a barrier to upstream AOP. A simple geomorphic assessment to identify (or probe for) bedrock exposures and to identify the stability of existing grade controls would have prevented this situation.

E. Review of Economics

The MEAOP Process Improvement Proposal was founded on perceived differences in cost with Stream Simulation design. The reported cost savings come from either assessment and design or implementation. These are both discussed below. At first glance, it appears that the cost differential is exaggerated based on extreme cases.

For example, design costs used in the Tongass MEAOP economic analysis for in-house design were reported as $2,000. We believe this is an understated cost. For a 3 person survey and data collection crew, $2,000 would be the majority of the cost for an on-island crew. If travel and per diem are involved, then we would expect costs to be much higher. Although site assessment and design costs for MEAOP are minimized, there are still non-trivial costs for the travel, site survey, AutoCAD drawings, and contract package.

In contrast, comparable costs for Stream Simulation were based on consulting firm designs, as opposed to costs for trained in-house designers. The economic analysis completed by Tongass engineering used design costs of $43,570 per site, which is taken from the last A&E contracts let in 2009 with Tetra Tech and R&M engineering. These costs are significantly higher than other A&E Stream Simulation designs performed on the Tongass during the 2000 to 2005 time period. Costs from Bratslavsky Consulting Engineers and USKH ranged from $13,000 to $15,000 per site during that time period.

National averages, reported in various personal communications, range between $15 and $80k for A&E designed sites depending on location, complexity, geotechnical needs, and the design submittal and documentation requirements. We pay a premium for A&E designs because of inferred liability, very high overhead, and the fact that many firms we use have very little design experience in USFS Stream Simulation design methodology. Most of these current costs are significantly higher than in-house USFS design costs. For example, the WO AOP team recently designed a **major** (large bottomless) Stream Simulation structure as turnkey designed project for less than $25k on the Allegheny N.F. This included field survey, data collection, geomorphic assessment, and full civil design and contract package. The $25k also included travel, per diem, and overhead charges (~ 25%) to the Enterprise Team that handles our agreements with Forests. Region 4 engineers (Justin Humble and Chad Porter) and Region 6 engineers (Holly Bentz) report similar costs for their in-house designs; costs vary between $10 and $20k per site, depending on the size and structure type.

Smaller sites have lower design costs because of limited survey requirements and less data to collect (~ 20 to 30 bankfull widths) and analyze, compared major crossings. We have been collecting design cost data from other NFS units; Holly Bentz from R6 regional AOP cadre stated their costs for producing Stream Simulation designs for small crossings are on the order $3,500 to $5,000 per site, depending on the size and site conditions. They reuse drawings and contract templates which save time on the contract preparation. In Region 4, RO Engineering staff Justin Humble and Chad Porter reported costs of approximately $10 k for in-house design. If geotechnical work is required, the design cost could increase by $8 to $15k.

In addition, the national AOP cadre just completed full field survey and geomorphic data collection for design on the Ottawa National Forest for approximately $4000 per site. Sites ranged in bankfull width from 6 to 15 feet. This includes travel and per diem for team members coming from different parts of the country. Information collected included the construction topo survey, longitudinal profile, cross sections, pebble and key piece counts and sizes, and all design and geomorphic data required for a Stream Simulation design. Complete in-house design (plans and specifications) is estimated at $10K per site, unless additional geotechnical investigation is required.

These figures suggest that development of an interdisciplinary team to do the AOP designs would be a major cost saving to the Tongass and Region 10 compared to A&E design costs. This idea is discussed further in the recommendations section.

Regarding actual construction of the structures, the MEAOP sites are built with bankfull width structures and embedded to depths similar to full Stream Simulation. Additionally, per Tongass Engineering staff, the sites were all dewatered for installation. Hence the only construction cost savings between MEAOP and Stream Simulation is placement of bed material and bank rocks/roughness elements within the design structure. Low bid numbers provided by Tongass contracting from the recent Forest Highway 43 project yielded in place costs of $100 per cubic yard (CY) for stream simulation bed material and $200 per CY for bank rock and roughness elements. These figures are used in Table 1 for three common pipe sizes to show volume and cost estimates for bed and bank material, if they were included in the design.

Table 1. Estimated cost increase for infilling MEAOP structures based on recent costs from Forest Highway 43.

Pipe Size	Embedment depth / burial percent of rise	Material volumes for 40ft long structures	Costs based on $100/ CY for bed material and $200/CY bank and roughness elements
72” round	2.4ft / 40% of rise	15 CY for bed 7CY for bank	+$2,900
81” x 59” Pipe arch	1.6ft / 30% of rise	12CY for bed 7CY for bank	+2,600
117” x 79” Pipe Arch	1.5ft / 20% of rise	15 CY for bed 12CY for bank	+$3,900
117” x 79” Pipe Arch	2ft / 28% of rise	22 CY for bed 12CY for bank	+$4,600

These figures represent minor increases in overall construction costs, particularly when viewed in the context risks to aquatic resources observed at some field sites. These small increases in cost, when viewed over the life span of these structures, are a minimal investment to help guarantee the long-term function of the pipes and the stability of the stream system.

F. Communication

During the course of our field trip, and after interviews and conversations with various resource and engineering staff, it is apparent that there needs to be improved communications between the disciplines on the Tongass. This includes developing an understanding of everyone’s roles and responsibilities, and most importantly, reaching consensus on a logical rationale of when and where to provide aquatic organism passage.

The Tongass and Region 10 are in a very unique position compared to the rest of the National Forest system. The early recognition of the need for anadromous protection, recognition of critical crossings, the use of many bridges, and an aggressive AOP replacement program from the mid 90’s to now have all contributed to keeping most of the high value streams passable for aquatic organisms. Since commercial and sport fishing are the primary economic drivers in the region, it only makes sense to take the utmost care to ensure fish have access to available habitat, particularly in light of climate change.

The Clean Water Act requires us to provide aquatic organism passage, but no specific methodology is required. The public expects us to use tax dollars wisely and insure that whatever we construct works and isn't a money sink due to maintenance. The engineers are proactively attempting to develop lower cost methods to do more and be able to quickly respond to year end dollars and apply them to AOP projects. The resource staff are concerned that the engineer's methods are causing stream impacts and won't work in the long-term, and that this minimal design has now been adopted as the standard procedure.

A balance must be struck between the disciplines and the regulatory agencies and it is our belief that the Tongass can be a model for the rest of the country. As a beginning, the following are suggested:

1) Provide full stream simulation design / highest protection for all class 1 streams that have sufficient upstream habitat. This must be evaluated on a case by case basis. We need to insure that there is a cost benefit to what we do and that we pass the red face test with the public, our partners, and regulatory agencies. If there is minimal beneficial upstream habitat, either don't provide passage (the greatest cost savings) or use a lesser design standard as long as it works for site conditions. The biologists must decide what is the viable upstream length or area to require AOP for full protection (Stream Simulation) or lesser protection (MEAOP or hydraulic design methods). Considerations should include the quantity and quality of habitat, the degree of fragmentation or total cumulative loss of passage at the sub-watershed or watershed scale, the importance of the drainage to subsistence, commercial and sport users, and presence of anadromy.
2) For Class 2 crossings, provide a population viability assessment at the sub-watershed or watershed scale. A simple cut based on upstream habitat length and/or area would reduce the existing backlog of work. (See Hasting 2005, Whiteley A.R., Hastings K. et al 2010) Cumulative effects in a given watershed should be considered if many small crossings are located within the same watershed so the stream doesn't suffer death by a thousand cuts. Upstream gradient at the site can also be used as another decision point to avoid very small steep pipes (>15%) which are problematic, difficult to construct, and do not have the same efficacy as lower gradient sites.

Based on Tongass upstream habitat assessment and barrier analysis data provided by John McDonell, there are 1,107 road-stream crossing on the Tongass identified as "RED" barriers to fish passage. Table 2 shows the distribution between Class 1 and 2 streams, along with a threshold of available habitat length and area. While 100 meters (or 100 square meters) of available habitat may not be the preferred threshold, the data in Table 2 at least suggests that some limited criterion can be used to determine to whether full, partial, or no passage is required. The Tongass has already pioneered work in this arena. The Tongass developed a Biological significance model in ~2005. This model utilizes existing GIS, upstream assessment and fish passage assessment data and to our knowledge covers most of the Forest.

The recommendations of the "Test of a Process to Assign Fish Passage Remediation to Culverts in the North Thorne Watershed" 2006 provided positive incentive to pursue the combined GIS modeling and expert analysis decision making model work to determine what sites should and should be replaced and which should provide a lesser amount of passage. The report pointed out some data gaps which need to be filled to effectively run the model. Since our national effort is to do work in priority watersheds identified by the watershed condition framework. We recommend that the forest focus on priority watersheds and collect the necessary data to make informed decisions.

Table 2. Tongass AOP road-stream crossing barrier summary (red pipes based on Forest-wide passage assessment).

Stream Class	Number of Barrier crossings remaining	Number of sites with less than 100 Sq. Meters of upstream habitat area	Percent of total crossings	Number of sites with less than 100 meters of upstream habitat length	Percent of total crossings
Class 1 (anadromous)	162	29	18%	31	19%
Class 2 (resident)	945	221	23%	227	24%

Section III. Recommendations

Based on a review of available information, the Tongass engineering staff succeeded in the goal of reducing the engineering analysis and data collected for the MEAOP sites. However the lack of analysis, understanding of geomorphic process and underlying geology in the stream have caused stream issues and with risks for potential long term failure (i.e. aquatic organism passage will not be provided over the full design service life of the structure). The design of road stream crossings is an interdisciplinary project requiring input from biologists, hydrologists, geologists, and engineers. No single person or discipline has the training or background to complete all phases of an AOP design. The Tongass engineers have asked the biologists for site selections, but have not typically involved watershed staff or the biologists any further in the design process, with the exception of applying for the Title 16 Concurrence. This is to the detriment of the design process and has caused problems in the field that could have been alleviated if aquatic specialists were involved.

A. Staffing and Skill Development

- Consider developing a Forest interdisciplinary design team(s) to take advantage of the full gamut of skills required for AOP crossing design, and share them among the districts. Having a steady stream of assessment and design work would rapidly increase their skills. Suggested focus areas include:

  - Biologists - Assess existing sites for AOP, determine sites to fix, evaluate importance in the watershed, determine the level of passage required (adult fish to full AOP), and monitor the sites after replacement
  - Hydrologists/Geologists – Assist Engineers with stream survey (they should be the rod person for the longitudinal profile and ensure the necessary stream dimensional data are collected for design), collect reference reach data (bankfull dimensions , pebble counts, grade control assessments, roughness element inventory, etc), develop the channel cross section configuration(s) for hydraulic modeling (if needed), help determine the final design profile through the structure, provide initial sediment sizes (bed and key pieces), determine Q100 and dewatering (if applicable) discharges, design the bedform spacing and roughness elements, and assist with (or conduct) the hydraulic modeling and sediment mobility-stability analyses.
  - Engineers – Survey the road and construction area, assist hydrologist with longitudinal profile and cross section survey, perform the civil and structure design (roadway alignments, structure type and configuration, etc.), perform geotechnical investigation and evaluation, perform or assist in the hydraulic modeling and sediment mobility-stability analyses, develop plan sets and contract documents, and provide contract administration and construction oversight.
- Consider increasing skill levels in geomorphology. Most of the design errors observed in the field stemmed from lack of sufficient field data, a lack of understanding of stream processes, and not enough analyses to identify risks associated with the site. The WO Virtual AOP Design Team can offer hands-on assistance to the Forest on an actual design, along with emphasis on geomorphic assessment, to help increase the team members' skill levels.
- Team up with the Nature Conservancy and hire a shared services employee. A designer P.E. preferably could handle the entire design workload for the Tongass and staff costs are greatly reduced since the Forest would only be paying for part of the employee's cost.

B. Monitoring

MEAOP is an experiment to determine the feasibility and applicability of a simplified design and construction process for aquatic organism passage. Therefore, consistent detailed monitoring is necessary to determine its efficacy. This should primarily consist of measuring physical attributes at the road-stream crossing and comparing them to the adjacent stream, similar to the monitoring that was completed at one site during the site visits (see example file 27Road_MP0.71(27June2014).xlsx). Because the ultimate objective of stream simulation design is to provide for aquatic organism passage, biological monitoring is a necessary component to the analysis of whether MEAOP achieves this. Aquatic organism passage cannot solely be determined by the presence of gravel in the pipe given that sediment characteristics within the structure may be significantly different from reference stream conditions. A combination of physical monitoring corroborated with biological monitoring is recommended.

The monitoring study should be designed to help us understand:

- How long it takes for structures to infill
- What are the effects to the upstream and downstream reach
- In which of the recommended site conditions is MEAOP successful. Sites should be stratified and test cases developed for the different channel types and geologic settings. The Forest must understand that success in these types of structures is measured over the long-term. Success cannot be claimed by simply having gravel in the pipe for a short period of time.

The WO Virtual AOP Design Team would be available to assist with the development and initial implementation of a long-term monitoring plan.

C. Future MEAOP Projects

Because of the experimental nature of the MEAOP Process Improvement Proposal, we recommend limiting the number of structures, including a multidisciplinary site assessment on all future sites, and following the site screening/selection methodology outlined in the proposal. This method appears to be becoming the design standard on the Forest, even with the current lack of observable success.

Based on the number of sites, stream sizes and classes observed in the field, we recommend that any further MEAOP experimentation be done on Class 2 streams, with the exception of Class 1 stream crossings with very limited upstream habitat.

Locations where MEAOP could be used

1) PA (palustrine) Channels – these sites are backwatered and the downstream water surface control should be far downstream (hundreds of feet). Culvert should be embedded a minimum of 2 feet and based on the estimated bed surface if the downstream control is lost.
2) Channel types less than 3 percent gradient with sand to cobble sized bed material in ample supply.
3) Sand bedded channels, no matter the length of the upstream habitat. Note that head cuts in in low gradient sand bedded channels can propagate upstream thousands of feet so the vertical offset from existing upstream to downstream channel needs to be considered.
4) Class 1& 2 streams with limited or marginal upstream habitat. This requirement would need to be validated by the biologists and regulatory agencies.
5) In watersheds or sub-watersheds where the amount of blocked habitat is a small fraction of the entire available upstream habitat.

6) When multiple channels exist, as in the case of a main channel and smaller side channels, MEAOP could be utilized in the side channels as long as the main channel crossing is stable and provides Stream Simulation.
7) At crossing locations where a stream enters a lake (depositional zones) and the crossing is adjacent to the lake or pond.

Locations where MEAOP should not be used

1) In stream channels steeper than 3 percent, since long-term stability relies on the presence of bedforms and roughness elements, neither of which are likely to be recruited from the upstream channel in the short-term.
2) Class 1 & 2 streams with large amounts or high quality upstream habitat, or where other important habitat types that may be limited downstream
3) In situations where there is a large vertical offset in channels less than 3% or in convex slope profile conditions.
4) Streams with shallow bedrock (less than 1-foot below the streambed).

D. Suggestions for Design and Construction for MEAOP Sites

- Perform a longitudinal profile analysis to identify geomorphic risks, stable tie points in the stream, and to establish a design profile (gradient) that is consistent with reference conditions in the stream. Utilize properly trained staff as the rod person during the survey to ensure risks are identified in the field and sufficient data are collected for design.
- Measure actual bankfull widths and make the connection to channel gradient when making decisions for structure width. Measure the pool widths or tailcrest width along the survey reach and base structure width on whichever is larger
- Construct bank transitions from structure inlet and outlet back to stable banks outside the influence of the existing structure.
- Place stable grade controls with footer rocks below the maximum scour depth. They should be placed ½ bankfull width upstream of the inlet or 3 feet, whichever is greater. Since the MEAOP experiment is to avoid placing infill, the upstream grade control must be more extensive (longer and larger rock) since it has no burden downstream to bear against. On the downstream end, reconstruct the plunge pool tailcrest or construct a new grade control downstream of the outlet. This will require a stability analysis unless pieces are large compared to those found in the stream.
- The Grade controls must extend into the banks (depending size of stream and bank composition, with a minimum of 3 feet or ½ bankfull, whichever is greater) to avoid flanking during flood flow. Large wood can also be used as long as they are sloped from side to side to concentrate flow during low water conditions. Any log grade control should have backing material placed to the anticipated scour depth behind and under the sill log; this can be larger boulders or additional wood to prevent scour undermining the grade control.

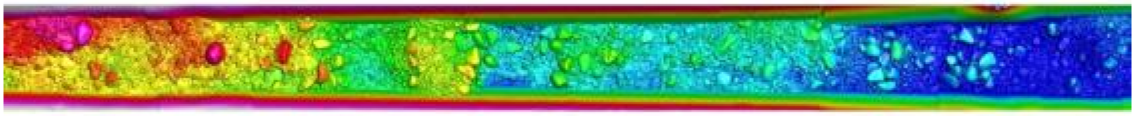
- Ensure culvert and grade controls/bedforms are inspected in the field during construction.
- Avoid allowing headcuts to migrate up stream, which cause incision and then widening to adjust to the loss of the floodplain. While headcuts do provide the material to infill the bare structures, they are detrimental to the upstream reach and can create upstream barriers when subsurface conditions are unknown.
- Utilize culvert made from aluminum or concrete for MEAOP structures. Most of the structure used are aluminized steel (versus galvanized) which is good choice to increase the lifespan of culvert. However, since no banks are constructed within MEAOP structure, the aluminized coating is subject to abrasion from bedload transport. This abrasion occurs along the sides of the culvert, which is a critical location for supporting the weight (deadload) and lateral forces from the road fill. Long term abrasion in this area will allow corrosion to begin, thus shortening the life cycle of the culvert. We have examples of this with galvanized pipe on Mitkof Island in structures installed between 2002 and 2003. Data from a study by the Federal Highway Administration (Ault and Ellor 2000) observed pitting in the moderate to high bedload transport streams, thus reducing the life cycle of the structure. Their study looked at normal corrosion patterns that occurred along the invert of structures, versus in embedded structures where it is along the walls of the structure.
- Identify shallow bedrock in the design reach and in the upstream reach.
- Conduct an as-built survey with permanent bench marks for long term monitoring.

Appendices:

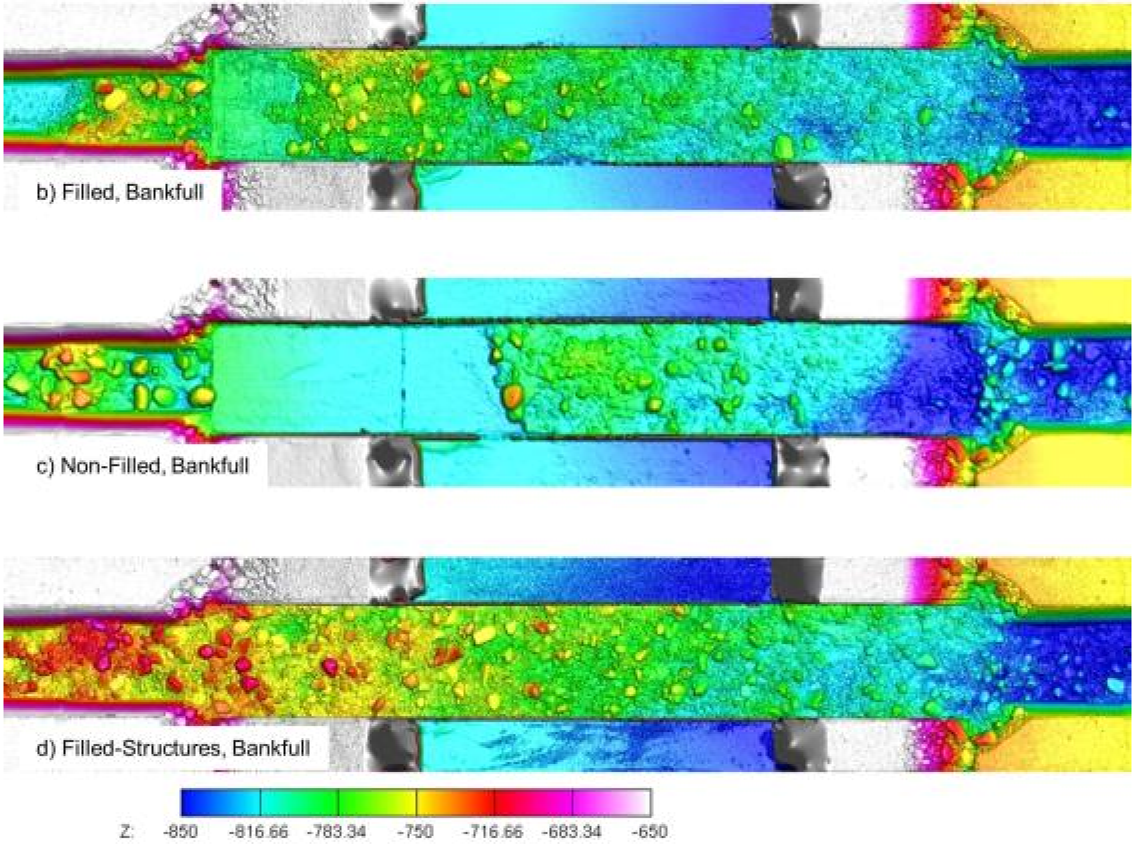
Culvert research results are courtesy of University of Minnesota, St. Anthony Falls Laboratory, University of Minnesota, 2 SE 3rd Ave, Minneapolis, MN 55414

"Sediment Transport through Recessed Culverts: Laboratory Experiments" report in press. (Kozarek and Meilke 2014)

Appendix A. Culvert Infill Research High Gradient (3%) Flume Results

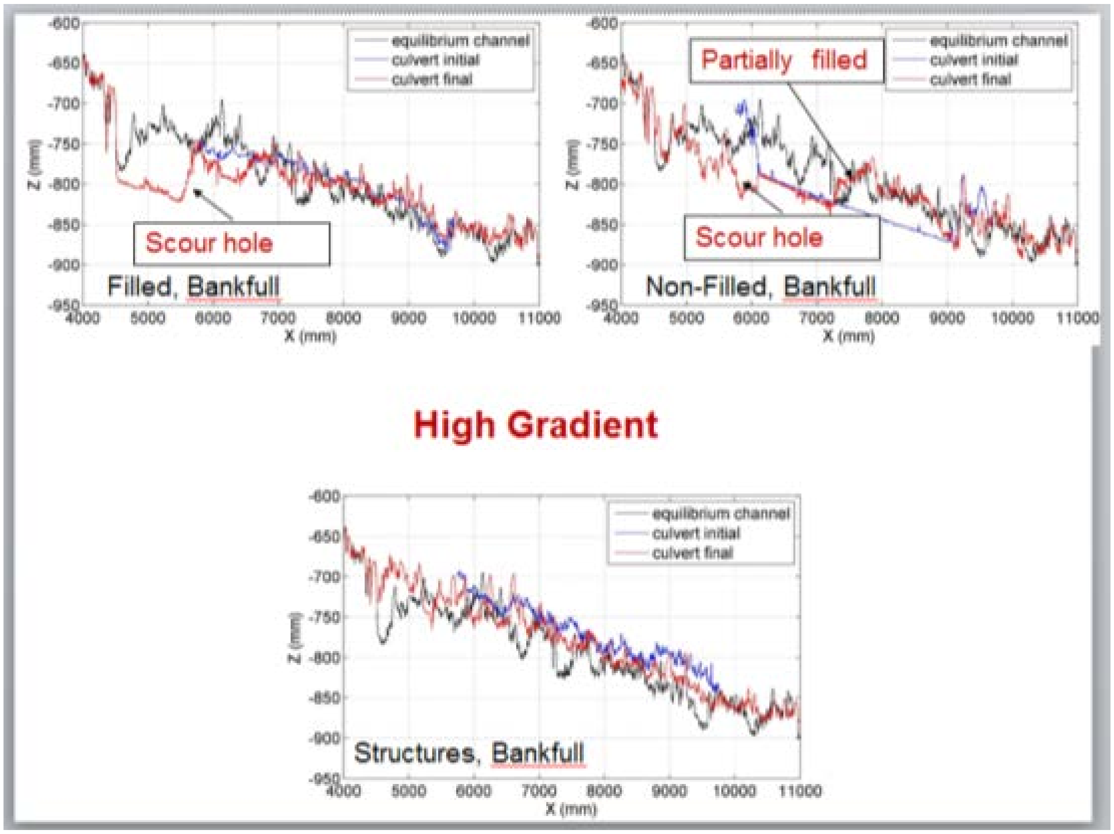


a) Equilibrium (no culvert)



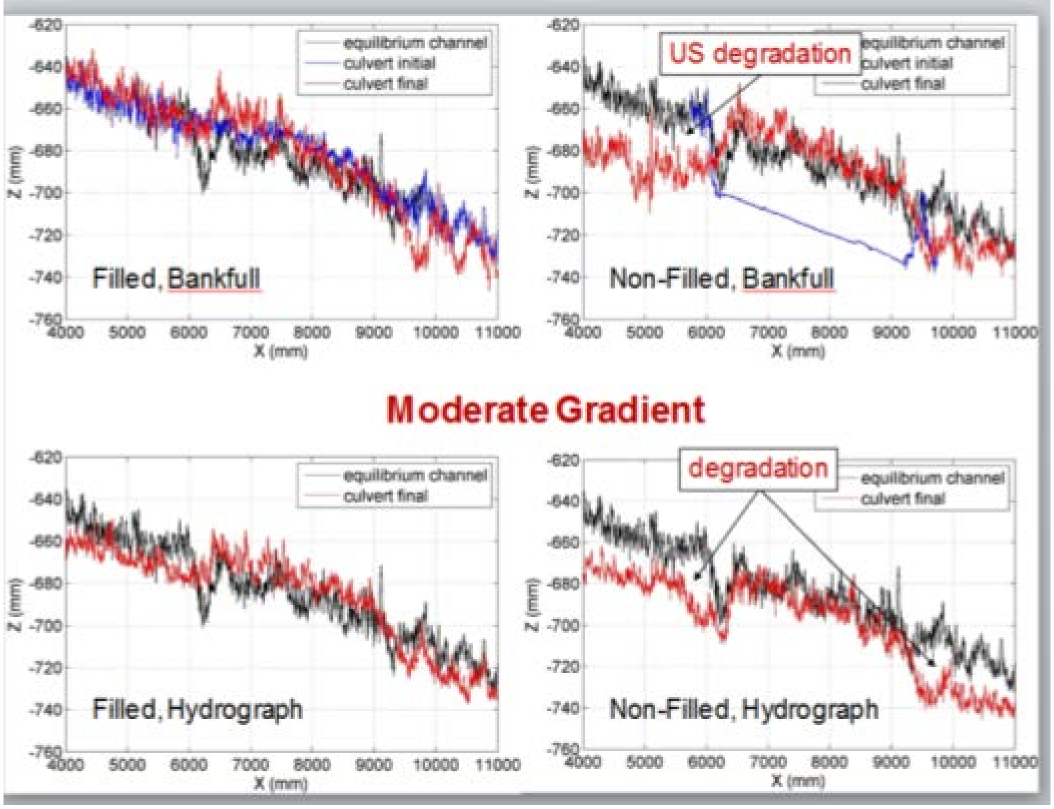
Final topography for equilibrium (no culvert), filled, non-filled, and filled with structures initial conditions for the high gradient experiment with bankfull flow. Note that only the filled culvert with constructed bed structures (grade controls) retained bed material thru out entire structure and resisted excessive scour.

Appendix B. Culvert Infill Research High Gradient (3%) Flume Results



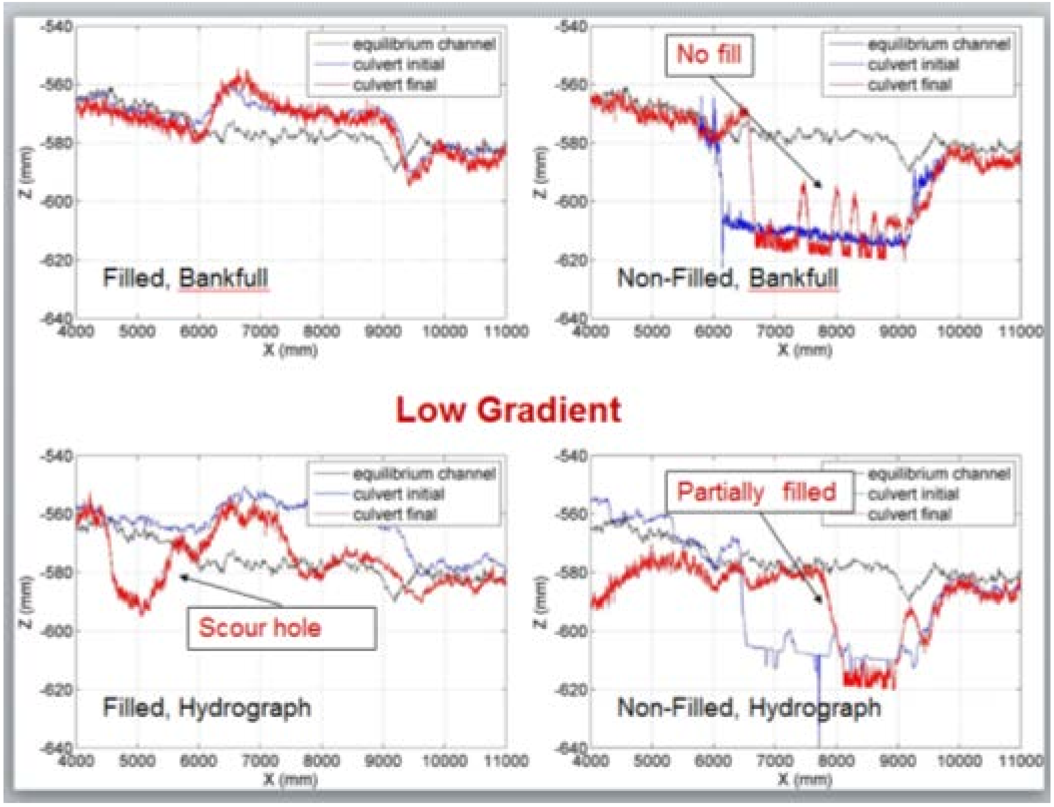
Comparison of centerline profiles of equilibrium (no culvert), initial, and final bed elevation along the channel midline for the high gradient experiment. Note that only the filled culvert with constructed bed structures (grade controls) thru out the culvert and along the stream bed retained bed material. Those runs with no bed structures caused significant scour at the inlet region and stream bed.

Appendix C. Culvert Infill Research Moderate Gradient (1.5%) Flume Results



Comparison of centerline profiles of equilibrium (no culvert), initial, and final bed elevation along the channel midline for the moderate gradient experiment. The non-filled culvert for both the bankfull flow and storm hydrograph flume runs show substantial bed degradation (scour and head cuts). Reinforcing the need for grade controls both up and downstream of the structure.

Appendix D. Culvert Infill Research Low Gradient (0.2%) Flume Results



Comparison of centerline profiles of equilibrium (no culvert), initial, and final bed elevation along the channel midline for the low gradient experiment. Results illustrate the effect of armoring, the length of time, and size of flow required to infill a non-filled structure. Based on the natural stream bed material size for the low gradient stream scaled down to the correct Froude scale, the bankfull flow did not fill in the non-filled structure in a single run time. During the storm flow hydrograph runs both filled and non-filled structures exhibited scour.

Appendix E. Bibliography

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Appendix C. Monitoring Example

See Excel spreadsheet file 27Road_MP0.71(27June2014).xlsx