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Slip Lined Culvert Retrofit and Fish Passage

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SLIP LINED CULVERT RETROFIT AND FISH PASSAGE

by

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of a thesis submitted by

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ABSTRACT

SLIP LINED CULVERT RETROFIT AND FISH PASSAGE

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Master of Science

Culverts throughout the country are approaching or are past their original design lives. These 'baby boomer' culverts will need to be repaired, rehabilitated, or replaced. Because entire culvert replacement is so expensive and intrusive, alternate measures to extend the culvert project life are growing increasingly popular. One such method is slip lining, where a 'sleeve' is installed within an existing culvert barrel and stabilized. Plastic pipe sleeves are very popular for slip lining primarily because the plastic material's lower Manning's roughness values allow for the culvert capacity to be maintained despite a reduction in culvert size. Unfortunately, the reduced friction within the barrel can create a barrier to fish passage due to increased water velocities. The increased velocities also cause greater outlet scour which can result in further obstacles to fish passage. These new fish barriers can greatly affect aquatic ecosystems by limiting

the access that fish have to smaller tributaries used for spawning and rearing—access that is critical to the life cycles of many fish.

It is suggested that mitigation of the increased velocities should go hand-in-hand with slip lined culvert design projects where fish passage (present or future) is to be considered. Can the demand for hydraulic capacity as well as the demand for fish passage be satisfied?

Careful design and installation, coupled with post-project monitoring can result in slip lined culvert retrofits which successfully pass fish. Investigation of federal and state laws and various agency guidelines has informed the creation of a list of culvert conditions which should prompt consideration of slip lined culvert retrofit among other design alternatives. Additionally, a literature review and survey of all U.S. state Departments of Transportation as well as state Fish and Wildlife Departments has shown that there has been very limited experience in providing for fish passage through slip lined culverts. Literature and practice has pointed to the use of baffles and tailwater control weirs for velocity mitigation. Site visits have been made to the few states with this experience to assess developing technologies and record successful and unsuccessful installations. Additional hydraulic analysis using current software suggests general trends in the effects slip lined culvert retrofits on flow type, headwater, velocity as well as the effects of tailwater control weirs. Issues of sustainability, constructability and maintenance, as well as monitoring are addressed.

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1 Introduction

The vast majority of pipe culverts in the United States were built over 40 years ago, during a massive transportation infrastructure upgrade; our culverts are reaching a kind of middle age. A Transportation Research Board Research Needs Statement explains that the highway infrastructure is characterized by a huge inventory of damaged and decaying culverts. Because entire culvert replacement is so expensive and intrusive, alternate measures to extend ‘baby boomer’ culvert life are growing increasingly popular. One such method is slip lining, where a ‘sleeve’—usually plastic—is installed, or slipped, within the existing culvert barrel and stabilized. The sleeve’s lower roughness value allows for the smaller pipe to convey the same capacity. This slip lining method is attractive because it does not require any excavation of the existing pipe and roadway fill, providing an opportunity for culvert replacement without the undesired disruption to highway traffic, not to mention the advantage of rehabilitating the culvert without less right of way concerns. Culvert and pipe fabricators have begun to design and manufacture product conducive to this new technology (TRB 2007).

The huge inventory of aging culverts was likely designed solely on the basis of peak design flows, and did not take into account fish passage. Many of these culverts have turned out to be significant barriers to fish movement. In 1973 the United States Government signed into law the Endangered Species Act (ESA). Once a species is listed as threatened or endangered, the ESA requires that ‘critical habitat’ be designated for that species, including areas necessary to recover the species. Federal agencies are forbidden from “authorizing, funding, or carrying out any action which destroys or adversely modifies" critical habitat (USC 1973). Unfortunately, the increased velocities due to slip lined culvert retrofit can result in further obstacles to fish passage. These new fish barriers can greatly affect aquatic ecosystems by limiting the access that fish have to smaller tributaries used for spawning and rearing—access that is critical to the life cycles of many fish.

It is suggested that mitigation of the increased velocities should go hand-in-hand with slip lined culvert design projects where fish passage (present or future) is to be considered. Can the demand for hydraulic capacity as well as the demand for fish passage be satisfied? To this point, there has been very limited experience in providing for fish passage through slip lined culverts. The objective of this paper is to introduce slip lining as an option for culvert retrofit and discuss fish passage implications associated with this method. Additionally, this paper contains a review of the currently available literature on mitigation techniques, a survey of transportation and fisheries agencies who have utilized mitigation techniques, and reports on visits to various project locations to identify successful implementation of slip lined culvert retrofits. Finally, this report includes recommendations for conditions where slip lined retrofits should be considered, as well as suggested methods for providing for fish passage in slip lined culverts.

2 Slip Lined Culvert Retrofit and Fish Passage

This section describes the slip lined culvert retrofit process and the advantages of this method when compared to conventional culvert replacement. Additionally, this section outlines concerns that this method is counterproductive to fish passage, including exploring the affects that this method has on overall culvert hydraulics. Finally, this section describes conditions where slip lined culvert retrofit may be considered, as well as a review of mitigation measures promoted in available literature.

2.1 Slip Lined Culvert Retrofit

Slip lining involves three major steps. First, the existing culvert must be inspected and prepared for lining. This process includes flushing or cleaning the existing culvert to eliminate obstructions. Second, a smooth plastic (generally) pipe end is placed into the culvert and pushed through the culvert. Finally, the culvert ends are capped and the annular spaces between the existing culvert and the new liner are grouted to fix the liner in place and provide additional structural support (Campbell 1995). These culvert lining techniques often reduce construction costs by 50-75% (DeMarco and Muenchmeyer 1993, Campbell 1995). Additionally, slip lined retrofits often take half the time of regular culvert replacement, often with only very minor to no traffic impedance (DeMarco and Muenchmeyer 1993). Recent Utah Department of Transportation (UDOT) literature estimates a savings of $35,000 per culvert and a reduction in traffic costs and gives specific strategies for slip lined retrofits given various conditions. The same report states that “Rehabilitating, rather than replacing culverts, will become more common in Utah because existing aging culvert are failing and population growth makes traffic control more difficult.” (UDOT 2008)

Public Works Monthly (Campbell 1995) describes the rehabilitation of two stream crossings using a slip lining technique at the Kennedy Space Center. The first crossing involved twin corrugated metal culverts. These culverts were "severely rusted out and on one culvert the bands had pulled apart, creating a severe washout on the downstream side that caused the headwall to drop. Both shoulders...had experienced severe erosion caused by migration of soil into the deteriorated culvert. The road itself was in danger of collapse." EG & G Florida, Inc., the company which maintains the grounds at the Kennedy Space Center, chose to replace the 54-in. (1.37-m) corrugated metal culverts with liners whose interior dimensions are 42-in. (1.07-m). The branch manager for EG & G explained, "Relining culverts rather than replacing them has several advantages. Cost savings average about 65 percent versus replacement…It is also important not to have to disrupt traffic on the heavily traveled roads...This problem is solved by relining rather than replacing the culverts…In many cases flow capacity remains the same as the original culvert and often flows can be increased by the lining procedure." Once the liners had been inserted, the annular space between the original culverts and the retrofitted liners were grouted to prevent any road collapse due to soil migration.

Kustom Construction Co. was given charge to rehabilitate culverts in 13.3 miles (21.4 kilometers) of the Tri-State Toll Road north of Chicago's O'Hare International Airport. A total of 136 15-in. (38-cm) corrugated steel culverts had rusted through over their 35 years. Kustom Construction selected Ace Pipe Cleaning, Inc. and slip-lining. The liner's "…walls, ½-in. (1.27-cm), high-strength black polyethylene, resistant to acids and corrosion, last indefinitely" (Anon. 1994). The entire process of assembly and positioning averaged two liners per 6-hour day and in many cases, a three-man sub-contractor team installed up to seven liners per 6-hour day. Though the chosen liners were only 13-in. (33-cm) in diameter, their low coefficients of friction allowed even greater flows than the previous culvert. "Their purchase, assembly, and placement costs totaled only a fraction of excavating and other methods considered and . . . traffic was never impeded" (Anon. 1994). It is estimated that the project took one quarter of the man-hours and as little as 1/3 of the total time necessary for a conventional culvert replacement.

UDOT has recommended slip lined culvert retrofits be considered when (UDOT 2008):

1. Daily traffic exceeds 1000 vehicles.
2. Maximum cover over a culvert is more than 4 ft (1.22-m). This requires benching or shouldering when excavating, which increases the potential for workplace hazards.
3. The detour route for the work area is greater than 20 minutes. Conventional dig and replace projects require costly pavement repairs and complex traffic control.

2.2 Fish Passage

The 1973 ESA requires that critical habitat be designated for all listed species and that federal agencies are forbidden from authorizing, funding, or carrying out any action which "destroys or adversely modifies" this critical habitat. Therefore, all listed aquatic organisms are a concern when considering culvert design and culvert retrofit, though this report focuses solely on fish passage. Although slip lined culvert retrofits may be extremely appealing when considering cost, time, and culvert discharge capacity, this method is fraught with fish passage issues, and therefore, basic slip lined retrofits can be at odds with ESA requirements. The same hydraulic characteristic that makes slip line retrofit possible—increased velocities due to low roughness—can be a barrier to fish passage, and exacerbate several other barrier processes. The decreased roughness can cause increased scouring at the outlet of the culvert, causing it to be perched. There are several reasons that a culvert may represent a fish passage barrier. These barriers and possible impacts are found in the recent Federal Highway Administration document “Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report” (Hotchkiss and Frei 2007) and shown in Table 2-1.

Table 2-1: Description of Barriers to Fish Passage and Possible Impacts (Hotchkiss and Frei 2007)

Barrier Type	*Description*	*Impact*
Drop	Drop at outlet exceeds fish jumping ability, or jump pool is insufficient to generate sufficient thrust.	Fish cannot enter structure, can be injured, or will expend too much energy entering the structure to traverse other obstacles.
Velocity	High velocity exceeds fish swimming	Fish tire before passing the crossing.
Turbulence	Turbulence within culvert prevents fish from entering, or confuses sense of	Fish do not enter culvert, or are unable to successfully navigate the waterway.
Length		Fish may not enter structure due to darkness. Fish may fatigue before traversing the structure.
Depth	Low flow depth causes fish not to be fully submerged.	Fish will be unable to swim efficiently or unable pass the structure.
Debris	Caught within a culvert, debris can block flow, or portions of flow.	Fish may not be able to pass by debris, or constricted flow may create a velocity or turbulence barrier within the culvert.
Cumulative	Series of culverts, each of which stresses fish during passage.	Group of culverts, each marginally passable, may be a combined barrier.

2.3 Culvert Hydraulics Software Analysis

This section focuses on the methods and results of software based hydraulic analysis which was done in an attempt to determine ranges of flow characteristics which would make fish passage possible in slip lined culverts. It was desired to determine ranges of specific gradients, culvert diameters, and discharges that, when used in combination, would make slip lining untenable for fish passage. Specifically, this analysis asked the following questions: When will a slip lined retrofit change culvert flow types from outlet to inlet control? How will a slip lined culvert retrofit change culvert headwater? How will a slip lined retrofit change culvert velocities? What recommendations can be made when analyzing these effects in combination? To answer these questions, over 3,000 computer simulations were run on the Federal Highway Administration (FHWA) culvert hydraulics software program Win HY-8 (FHWA 2008).

The parameters used for possible culvert and liner diameters are shown in the table below. Culvert liner sizes below 7-ft (2.14-m) in diameter are taken from a UDOT/Utah State University Report (UDOT 2008) and are shown in Table 2-2.

Table 2-2: Range of Original and Retrofit Culvert Sizes, and Discharges Used in HY-8 Simulations

Original Culvert Inner Diameter (ft)	*Liner Outer Diameter (ft)*	*Space Between Liner and Culvert (in.)*	*Range of Discharges Simulated (cfs)*
2	1.67	4	0 - 20
2.25	1.83	5	
2.5	2	6	
3	2.67	4	
3.5	3	6	
4	3.50	6	
4.5	4	6	
5	4.50	6	
6	5.25	9	
7	6	21	
8	7	12	0 - 30
9	8	12	
10	9	12	
11	10	12	
12	11	12	
13	12	12	
14	13	12	
15	14	12	0 - 60
16	15	12	
17	16	12	
18	17	12	
19	18	12	
20	19	12	

The material used for original culverts was corrugated steel pipe (CSP) (n=0.024), while the liner material used is smooth high density polyethylene (HDPE) (n=0.012). All culverts were 100-ft (30.5-m) long. Instead of slightly perching the liner inlet invert, as would be the case immediately after construction, the liner in these simulations are placed flush with streambed level, anticipating that deposition at the culvert inlet would create the condition simulated, and that this condition would be in effect during the vast majority of the culvert retrofit's design life.

The discharges shown in the above table were used to analyze flow type and velocity changes due to slip lined culvert retrofit, and were chosen to simulate expected fish passage velocities. Headwater analysis was done using fish passage discharges as well as discharges that would better represent design discharges. The highest velocities used in existing culverts for the simulations are 8-ft/s (2.44-m/s). Literature has shown the burst speed for Utah species is not expected to be higher than 6-ft/s (1.83-m) (Aedo et al. 2008, Bell 1991), while strong swimming fishes not found in Utah, such as adult steelhead, may have burst speeds of as much as 16-ft/s (4.88-m) (Bell 1991). Two tailwater conditions were: first no tailwater, simulating a perched culvert outlet; and second, tailwater produced is a rectangular channel with a bottom depth much greater than the culvert diameter and a slope equal to that of the culvert slope with a Manning's "*n*" of 0.03. This number corresponds with an average excavated or dredged channel, a fairly clean natural channel, or a channel constructed from concrete poured on irregular excavated rock (Chow 1959).

2.3.1 Flow Type

The first question answered by these simulation is related to flow type, specifically whether slip lining culvert retrofits would change a culvert from inlet control to outlet control or vice versa. A culvert which exhibits inlet control has free supercritical surface flow throughout the barrel and the type of barrel does not influence headwater. Only the inlet makes a difference. On the other hand, several factors influence headwater elevation in outlet control. These are entrance type, and because flow is subcritical, barrel roughness, culvert length and tailwater elevation. In cases where outlet control exists, changing barrel roughness will have a more significant effect on culvert velocities than will cases where inlet control exists.

Although flow through a culvert barrel can be complex, two dominant profiles were exhibited in those simulations, a 1-S2n drawdown curve and a 2-M2c drawdown curve. The 1-S2n drawdown curve is shown within a culvert in Figure 2-1.

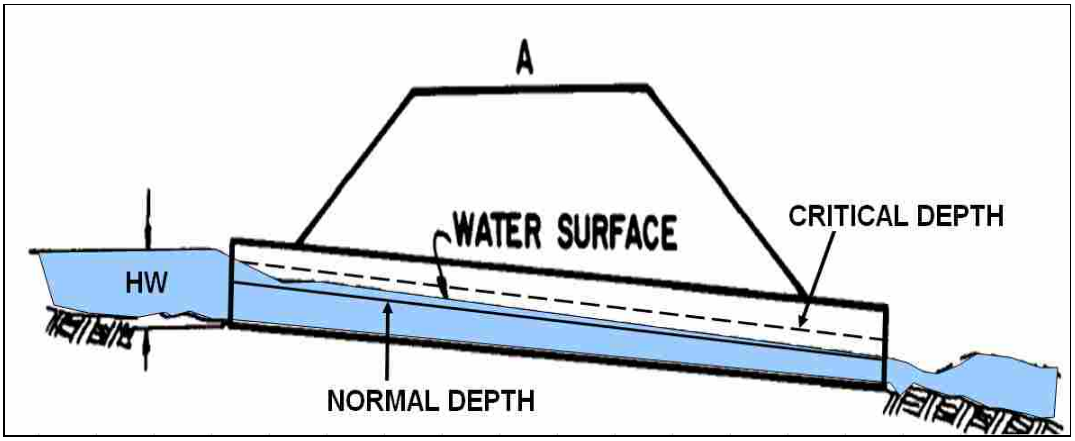

Figure 2-1: A 1-S2n drawdown curve in culvert on steep slope (Normann et al. 2005, adapted).

In the 1-S2n condition, "neither the inlet nor the outlet end of the culvert is submerged. The flow passes through critical depth just downstream of the culvert entrance and the flow in the barrel is supercritical. The barrel flows partly full over its length and the flow approaches normal depth at the outlet end." (Normann et al. 2005) The other common flow type is 2-M2c, which is shown in Figure 2-2.

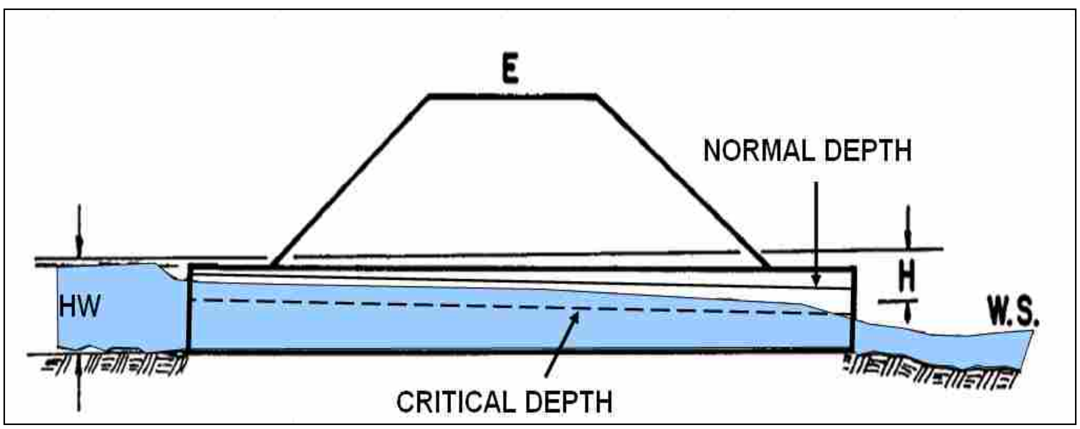

Figure 2-2: A 2-M2c drawdown curve in culvert on mild slope (Normann et al. 2005, adapted).

The flow in this culvert condition is entirely subcritical, with neither the inlet nor outlet submerged. This is an attractive condition for fish passage. Full descriptions of other flow types may be found in HDS-5 (Normann et al. 2005).

The simulations show that culverts 20-ft in diameter and smaller do not typically exhibit outlet control in discharges that produce velocities where fish passage is a possibility. The simulations show that outlet control is exhibited in culverts with a diameter of 11-ft (3.35-m) or smaller when at a slope of 1% or less, as well as small culverts on a 2% slope. This is shown in Table 2-3:

Table 2-3: Flow Types of Original Culverts at Various Slopes

Original Culvert Diameter (ft)	*Flow Types*				
	S = 0.01	*S = 0.02*	*S = 0.03*	*S = 0.04*	*S = 0.05*
2	2-M2c, 7-M2c	1-S2n, 2-M2c, 7-M2c	1-S2n, 5-S2n	1-S2n, 5-S2n	1-S2n, 5-S2n
3	2-M2c	1-S2n, 5-S2n, 2-M2c	1-S2n	1-S2n	1-S2n
4	2-M2c	1-S2n			
5	2-M2c				
6	2-M2c				
7	2-M2c				
8	2-M2c				
9	2-M2c				
10	2-M2c				
11	2-M2c, 1-S2n				
12	1-S2n	1-S2n	1-S2n	1-S2n	1-S2n

The preceding table shows that variable flow types are produced in culverts of small diameter. The flow type of 2-ft (0.61-m) culverts is generally inlet controlled (1-S2n, 5-S2n) for discharges under 15-cfs (0.0566-cms) and changes to outlet control (7-M2c, 2-M2c) for slopes of 1% or 2% and discharges over 15-cfs (0.057-cms). All culvert simulations done on 1% slope and under 11-ft (3.35-m) in diameter exhibited outlet control at each discharge simulated. Each corrugated steel pipe culvert which exhibited outlet control initially shows a change from outlet to inlet control when retrofitted. Other than these cases, all cases studied exhibited inlet control before and after retrofit.

Subcritical flows are more beneficial to fish passage. Because of this, it is helpful to know the limit slope, or smallest critical slope, for a given channel shape and roughness. This is the slope, that for a given channel shape and material, produces subcritical flow no matter what the discharge. The limit slope for circular channels has been derived (Rao and Sridharan 1970) as:

$$S_L = 33.06 \frac{n^2}{d^{\frac{1}{3}}} \qquad \textbf{(2-1)}$$

where:

n = Manning's Roughness Value
d = Culvert diameter (ft)

The limit slope curves for various materials and diameters are shown on Figure 2-3.

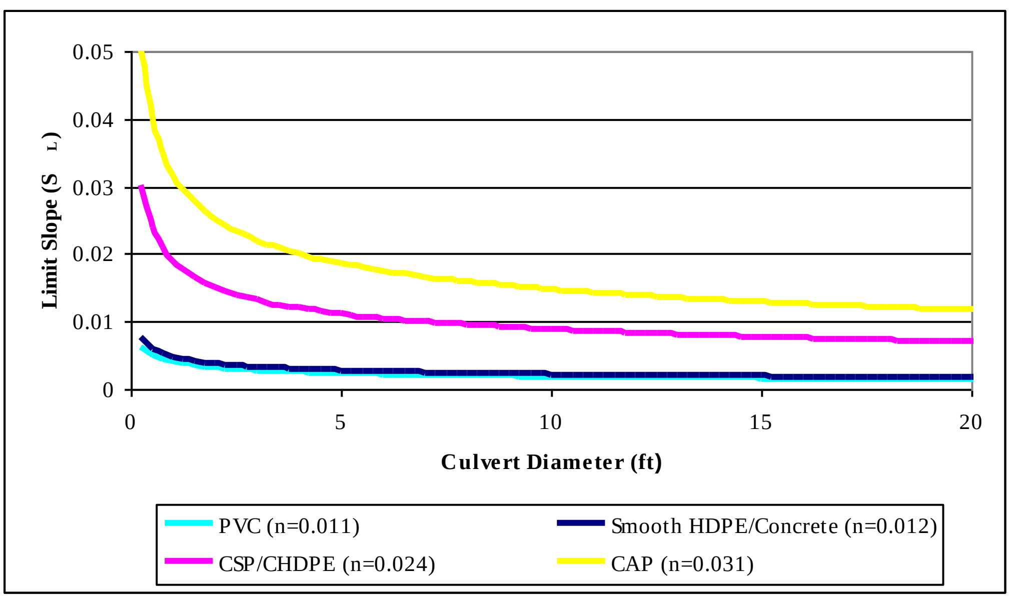

Figure 2-3: Limit slope for various culvert materials. PVC (n=0.011), CSP/CHDPE (n=0.024), Smooth HDPE/Concrete (n=0.012), CAP (n=0.031)

All combinations of slope and culvert diameter which fall above the lines produce supercritical flow, while subcritical flow would be found below the lines. Only the limit slope curves for liner materials are shown enlarged in Figure 2-4.

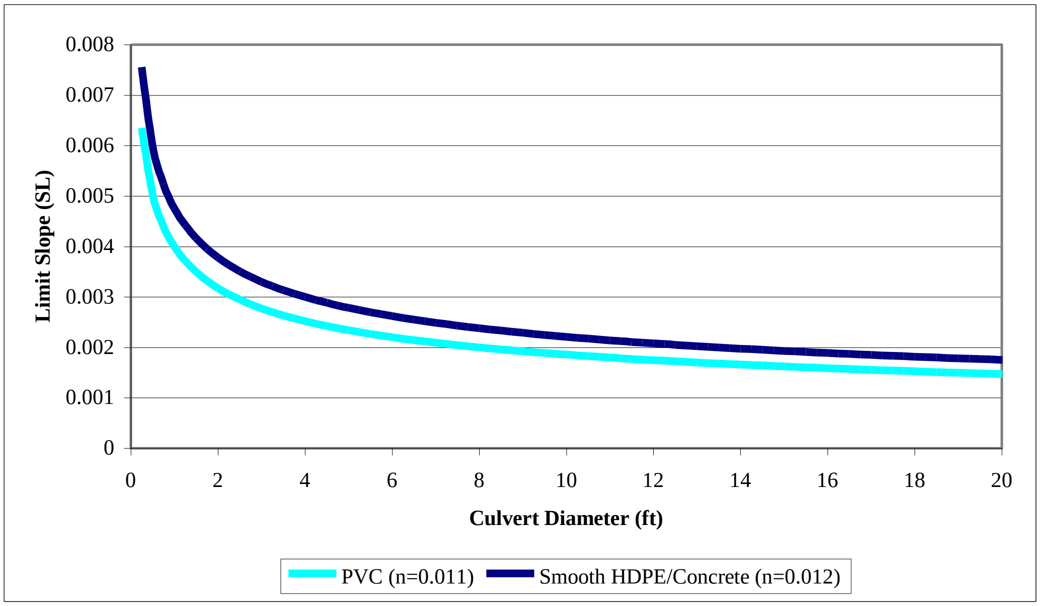

Figure 2-4: Limit slope for possible culvert liner materials.

This figure shows only the limit slopes for Smooth HDPE (n = 0.012) liners as well as PVC (n = 0.011) liners. A combination of slope and liner diameter above the respective lines will produce supercritical flow, while subcritical flow would be created by a combination of slopes and culvert diameters below the lines. Design engineers can use this relationship to identify whether a given liner and slope combination will naturally produce subcritical flow, or if mitigation measures would be necessary to produce such flows.

Although inlet control exists in most cases before and after retrofit within velocities conducive to fish passage, it should be noted that none of these simulations included any external or internal energy dissipaters, such as culvert baffles, or tailwater weirs. It is expected that these stream crossing accoutrements installed along with a slip lined retrofit would often cause a shift from inlet to outlet control, which may result in an unacceptable increase in headwater depth at the entrance for the flood design discharge.

Due to the number, sizes and sheer variety of energy dissipators available, in-depth hydraulic analysis with these structures is beyond the scope of this study. References to application and design of these structures may be found under the section heading Survey of Current Practices, as well as the references section of this document.

2.3.2 Headwater

The second question to be answered by the software analysis is regarding changes in headwater due to culvert slip lined retrofit. As is stated above, hydraulic theory states that the headwater is not influenced by barrel roughness in inlet control conditions. Because this culvert hydraulics analysis is constrained by fish swimming performance velocities, the vast majority of initial culvert conditions are tested at relatively low flows and exhibit inlet control. The headwater therefore, is not influenced by the change in barrel roughness, which is one of the two changes made in slip lined culvert retrofit, along with culvert diameter. However, headwater is affected by inlet conditions, which are changed due to the reduction in the culvert diameter. How sensitive is headwater to the change in inlet conditions? Figure 2-5 and Figure 2-6 show the percent change in headwater due to slip lined culvert retrofit at a range of original culvert diameters of 2-ft to 20-ft. Figure 2-7 and Figure 2-8 are commonly referred to as boxplots, or whisker-plots, which show the sample minimum, the sample median and sample maximum. The box is defined by the upper quartile and lower quartile of the data, meaning that 50% of the samples are contained within the box. The dash in the middle of the box represents the sample median. These figures show the percent change in headwater due to slip lined culvert retrofit at a range of slopes from 1% to 5%.

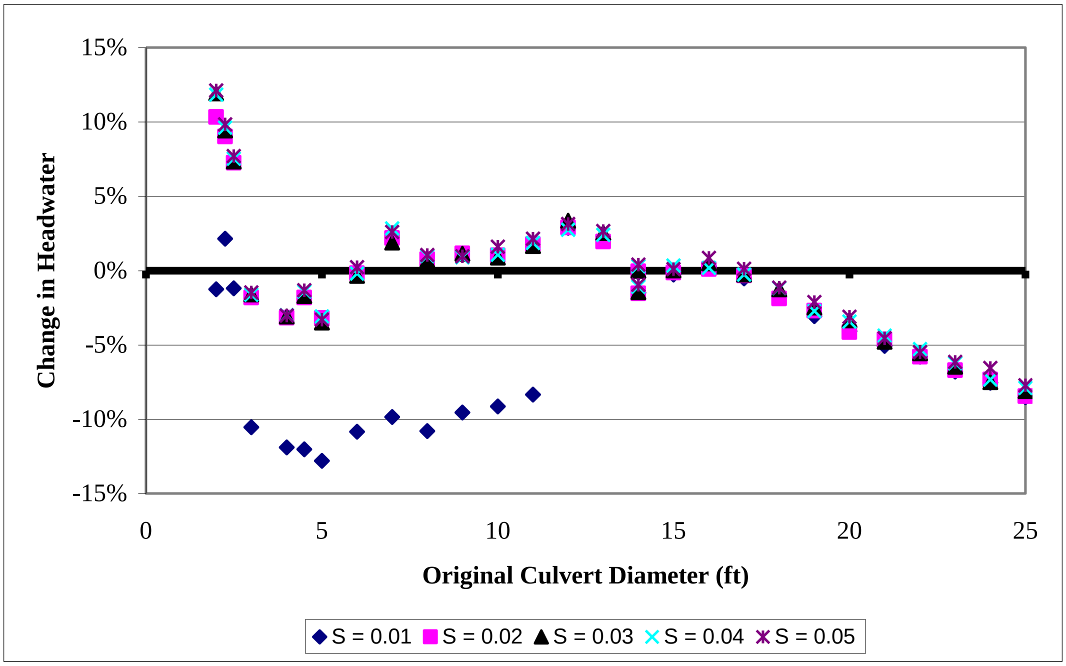

Figure 2-5: Change in headwater for various culvert sizes at various slopes with no tailwater channel.

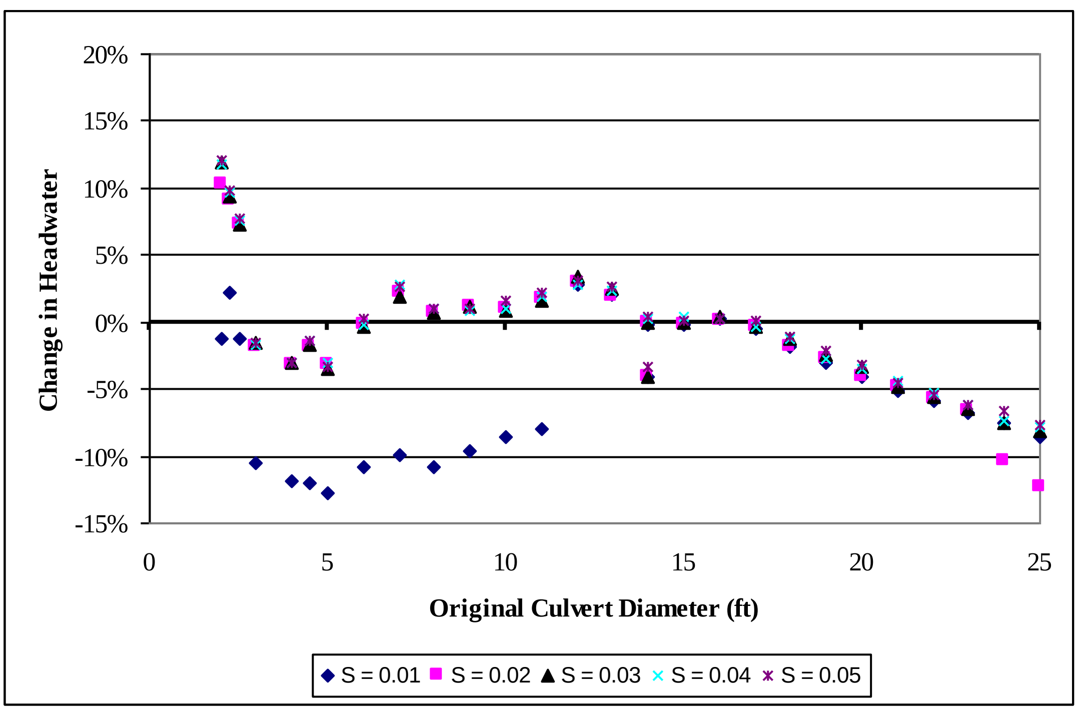

Figure 2-6: Change in headwater for various culvert sizes at various slopes with a tailwater channel of the same slope.

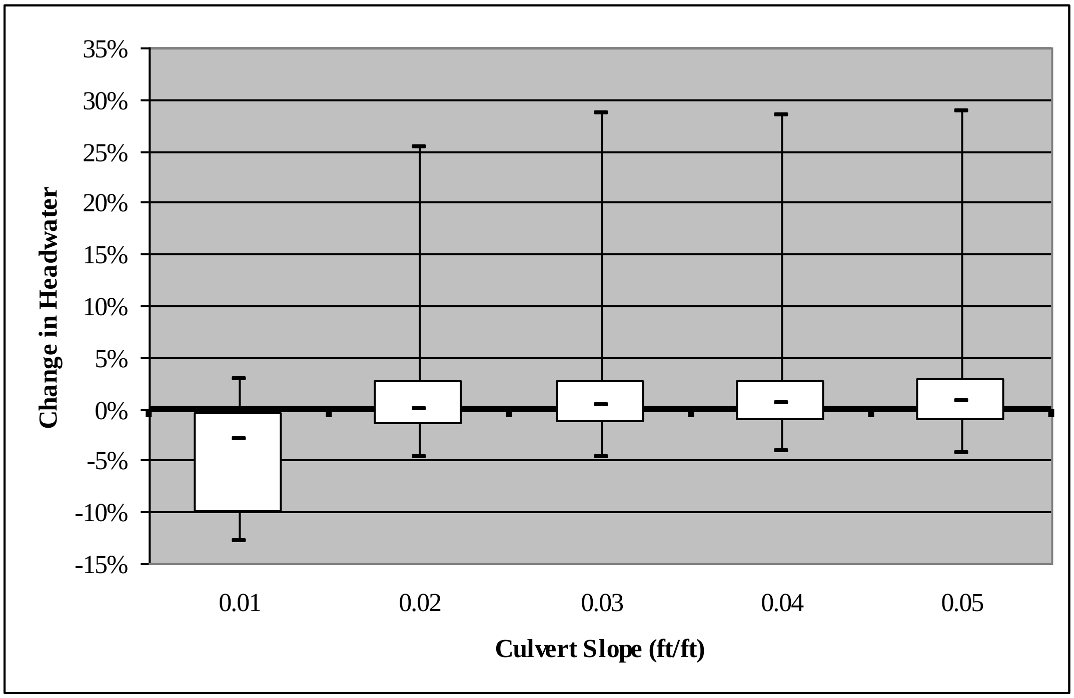

Figure 2-7: Boxplot of the percent change in headwater at various slopes due to slip lined culvert retrofit with no tailwater channel.

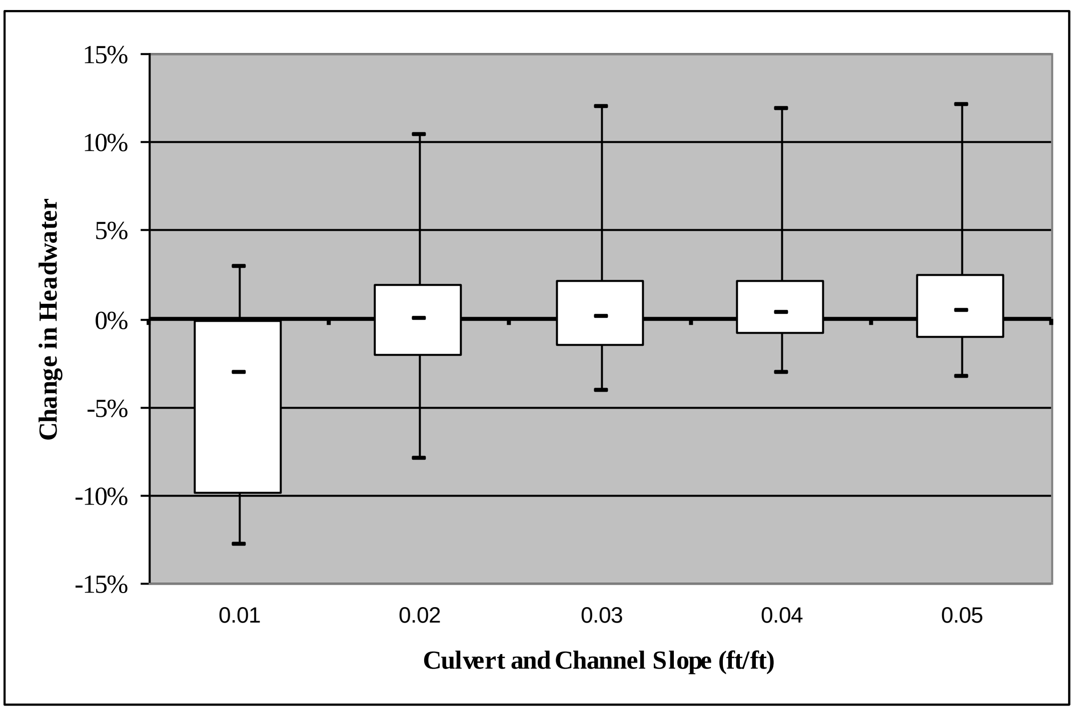

Figure 2-8: Boxplot of the percent change in headwater at various slopes due to slip lined culvert retrofit with a tailwater channel.

Given that the study comprises culverts which are almost exclusively exhibiting inlet control, it is not surprising that the simulation results show a minimal difference between the headwaters of the "No Tailwater" samples and the "with Tailwater" samples. Similarly, it is not surprising that that smaller culverts, as well as culverts that are on a shallower gradient channel experience greater changes in headwater. Indeed, culverts that are greater than 3-ft (0.91-m) in diameter and are on 2% or greater slopes experience almost no change in headwater due to slip lined retrofits until a culvert size of roughly 17-ft (5.18-m), when the headwater decreases as culvert size increases. The non-uniformity in low slopes and smaller diameters is a result of the flow type conditions described in the previous section. The 1% slope samples show an increase in headwater up to the 11-ft (3.35-m) diameter culvert, corresponding with the range of sizes which exhibit outlet control. As is stated earlier, these simulations exhibit outlet control conditions, which cause the sensitivity to both inlet conditions and barrel roughness. This figure shows that, excluding culverts on a 1% slope, all culverts between 3-ft (0.91-m) and 20-ft (6.1-m) experience less than 5% headwater change due to slip lined retrofits. The figures do show however, that culverts on slopes of 2% or greater show more headwater variation due to slip lined retrofits at smaller culvert sizes than do those on 1% slopes.

Analysis of Figure 2-7 and Figure 2-8 show that while greater total variation exists among the steeper slopes, variation within the first and third quartiles is quite low, and median percent headwater changes for these slopes is very near zero. On the other hand, total variation between maximum and minimum headwater changes at 1% slope is quite low; variation within the first and third quartiles is greater. Additionally, it is important to note that slip lined culvert retrofits on a 1% slope tend to reduce headwater elevation. Retrofits on 2-5% slopes generally result in headwater changes between -2% and +2%, and generally never more than 12% except in perched culvert conditions—generally a fish passage barrier—where increases of up to 30% are calculated.

The previous four figures, when understood in combination, show that while culverts on 2%-5% slopes are less sensitive to slip lined culvert retrofit over most sizes

(4-ft to 20-ft diameter, 1.22-m to 6.1-m diameter), the increase in headwater levels on culverts smaller than 4-ft (1.22-m) can be up to 30%. Culverts on 1% slopes are more stable over this range of smaller culverts, but not over all culvert sizes analyzed. However, this instability in culverts on 1% slopes is a result of large *decreases* in headwater elevations, which are also found in culverts of 17-ft (5.18-m) diameter and larger, and would generally be considered a beneficial effect.

Admittedly, headwater changes at fish passage discharges is secondary to headwater changes at design discharges and high flows, as basic design based on human and structural safety includes accounting for the possibility of headwater changes. The maximum allowable headwater depth is generally prescribed by policy. The allowable headwater will be limited by one or more of the following:

- non-damaging to upstream property,
- below the edge of the shoulder,
- a maximum of 0.5 ft (0.15 m) increase over the existing 100-year flood elevation in FEMA mapped floodplain,
- a maximum of 1 ft (0.30 m) increase over the 100-year flood elevation in unmapped floodplains,
- equal to the elevation where flow diverts around the culvert

(UDOT 2004)

Although the allowable headwater is unique for each stream crossing, an analysis was done on headwater changes due to retrofit at flows which would produce submerged inlets, but not submerge the outlets. Over the range of culvert diameters already outlined, discharges were calculated which would cause a headwater equal to 1.5 times the culvert diameter. This ratio of headwater to culvert diameter typically results in either partly full flow with rapid flow at the inlet or full flow with a free outfall. Once obtained, this same discharge was run through a slip lined HDPE culvert sleeve to calculate the change in headwater due to slip lined culvert retrofit at high flows. The results are shown in Figure 2-9:

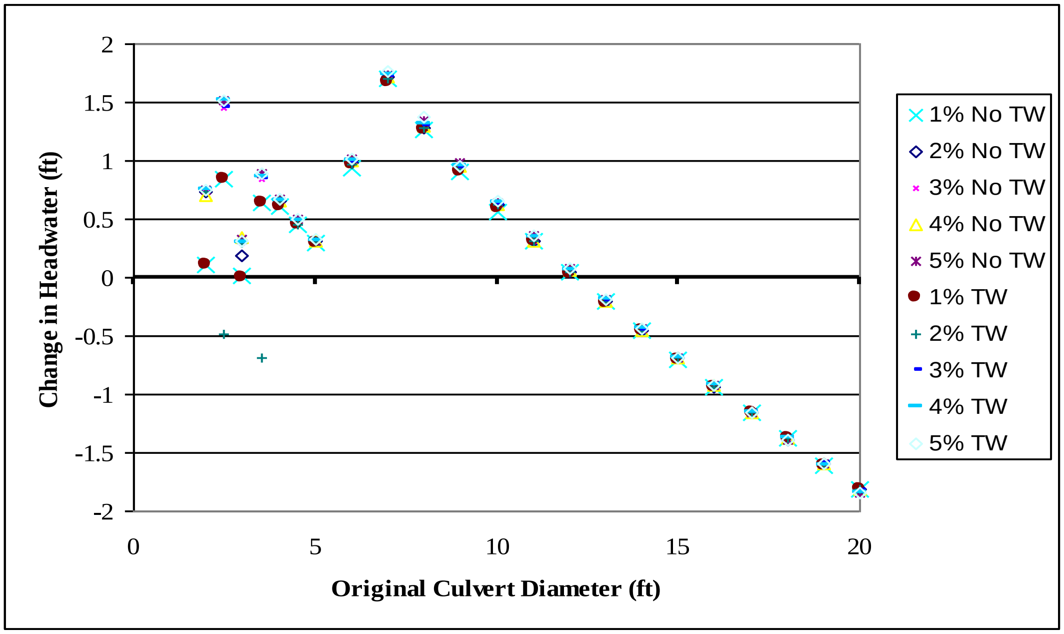

Figure 2-9: Change in headwater due to slip lined culvert retrofit for slopes 1-5% in both "No Tailwater" (No TW) and "Tailwater" (TW) conditions.

This figure shows that changes in headwater at high flows is not sensitive to tailwater conditions or channel slope at original culvert diameters greater than 3-ft (1.52-m). The change in headwater is quite sensitive to original culvert diameter, and decreases nearly linearly as culvert diameter increases from 7-ft (2.13-m) to 20-ft (6.10-m). It is also important to note that nearly every retrofit done on a culvert with diameter smaller than 12-ft (3.66-m) experienced an increase in headwater, including a few producing increases of greater than the 1-ft (0.30-m) prescribed by policy. Culverts with original diameters of 12-ft (3.66-m) or greater experience decreases in headwater when retrofitted.

2.3.3 <u>Velocity</u>

The third question to be answered by the software analysis is regarding changes in velocity due to culvert slip line retrofit. Perhaps the most basic principle of fluid dynamics is that total flow is equal to the cross sectional area of flow multiplied by the velocity (Q= V * A). Based on this fundamental principle, we expect that, given a constant flow, reducing the culvert diameter when retrofitting a culvert will result in an increase in velocity. The question is then "How much will velocities increase?" The following figures show changes in culvert velocity due to slip lining at the slopes simulated.

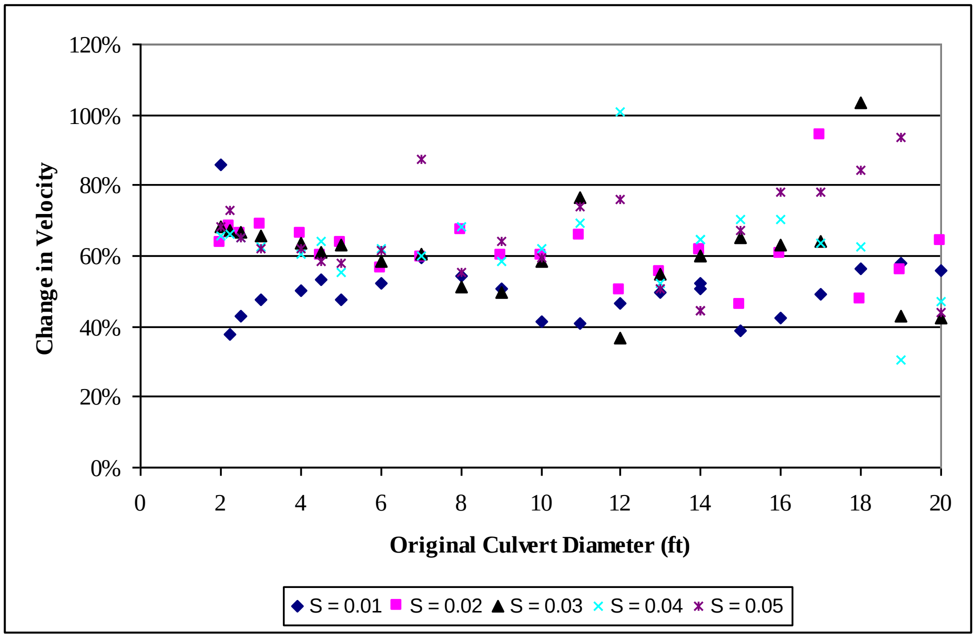

Figure 2-10: Change in outlet velocity for various culvert sizes at various slopes with no tailwater channel.

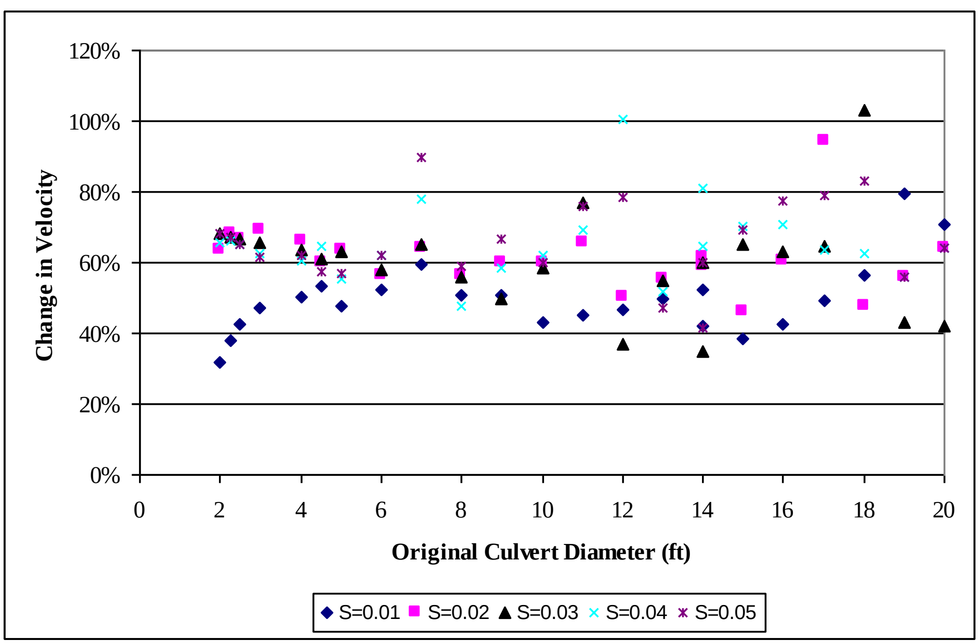

Figure 2-11: Change in outlet velocity for various culvert sizes at various slopes with a tailwater channel at the same slope.

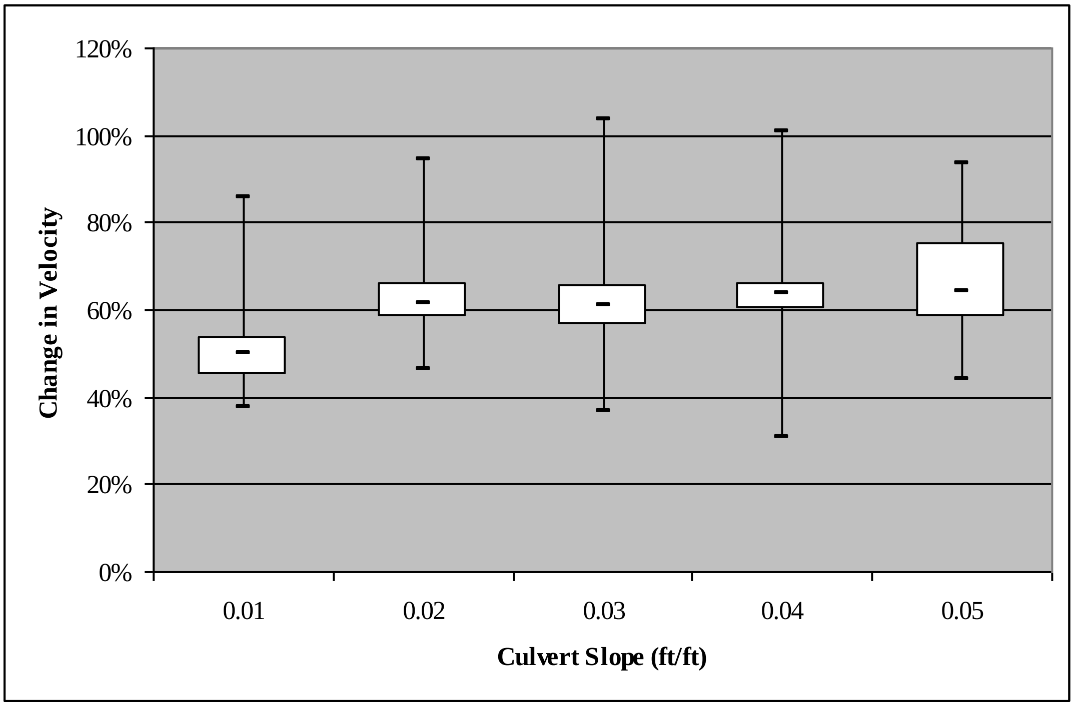

Figure 2-12: Boxplot of the percent change in outlet velocity at various slopes due to slip lined culvert retrofit with no tailwater channel.

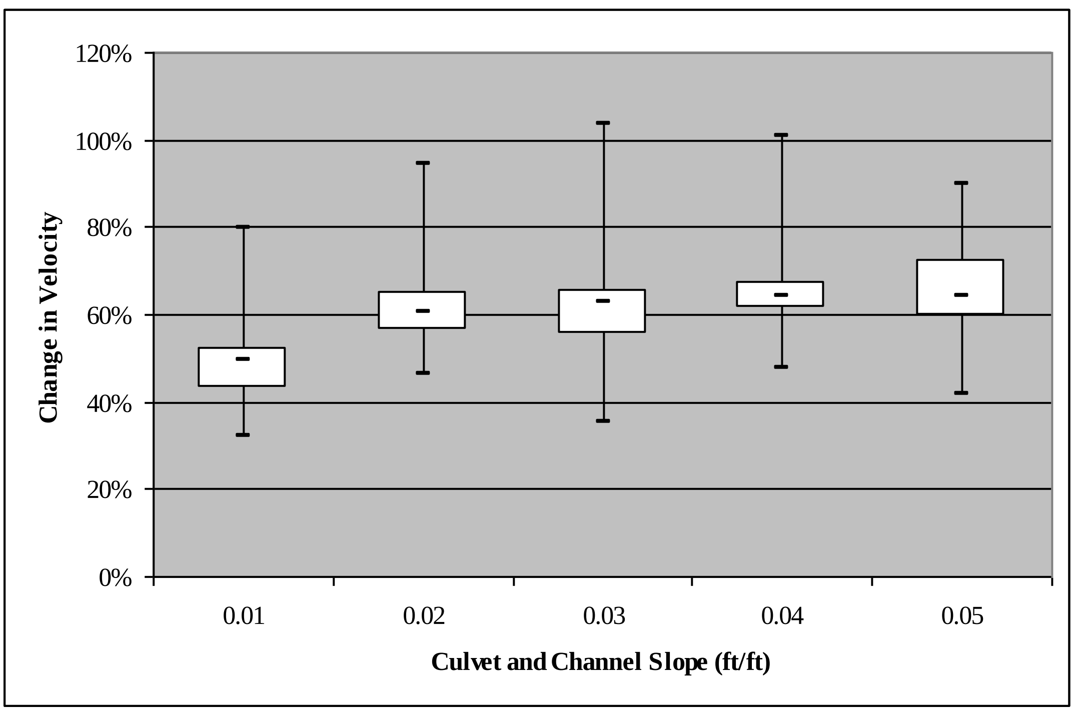

Figure 2-13: Boxplot of the percent change in outlet velocity at various slopes due to slip lined culvert retrofit with a tailwater channel.

Figure 2-10 and Figure 2-11 show that slip lined culvert retrofits do indeed result in increased culvert velocity. Aside from those culverts on 1% slopes, culverts originally having between 2-ft and 3-ft diameter exhibit almost exactly the same increase in velocity due to slip lined retrofits. The variation in increased velocity is exaggerated as original culvert size increases, though the average percent change in velocity is consistently around 60% for all culvert sizes. Is this percentage change in velocity also generally consistent for all slopes? Figure 2-12 and Figure 2-13 show again that the median increase in velocity is near 60%, with the median for slip lined retrofits on 1% slopes near 50%. Designers can expect that most slip lined retrofits will cause an increase in outlet velocity of around 60% with the understanding that increases of more than 100% or less than 25% are possible.

Headwater, velocity, flow type and flow depth are four primary metrics used assess a stream crossing for fish passage compliance. Some of the more basic variables which affect these values include:

- Culvert Size
- Culvert Material
- Culvert Slope
- Culvert Length
- Stream Slope
- Stream Discharge
- Tailwater Channel Conditions

Each variable in this list has an enormous range of possible values, and while some are more limited (culvert material, culvert size), some have an infinite number of possible values (stream discharge, stream slope, tailwater channel conditions). Each stream crossing will have unique values has a unique combination of these values which must be taken into account as unique designs for fish passage are developed. Unfortunately, the extensive calculations and analysis of the software based hydraulic analysis of slip lined culverts lacks sufficient evidence to simplify this process significantly through the identification of less significant variables. This analysis does not support a recommendation that certain ranges of flow characteristics should not be considered for slip lined culvert retrofit for fish passage.

Although specific gradients, culvert diameters, and discharges are not derived from this analysis, the results do provide general trends which should be considered in retrofit design, particularly the effects of slip lining on velocity. Slip lined culvert retrofits commonly result in velocity increases of 60%. Mitigation of these increased velocities is essential if slip lined retrofits are to provide for fish passage.

2.4 Justifiable Conditions for Slip Lined Culvert Retrofit

The most effective way to provide fish passage is through full culvert replacement, applying relevant fish passage design criteria. While slip lined culvert retrofits are significantly more inexpensive than other culvert replacement options, and may prove to provide fish passage, analysis has shown that slip lined culvert retrofits significantly increase the outlet velocity of a stream crossing. This increase will generally make the crossing a barrier to fish passage. Given this automatic increase in velocities which will occur when a slip lined retrofit is performed, it is essential to discuss mitigation techniques which can enable fish passage and therefore, compliance to Federal and State Laws. It should again be noted that while full ecological connectivity is impossible without fully spanning the entire active channel width (Chestnut 2002), there are still conditions where full replacement is difficult to justify, and slip lined and other retrofits could be considered. Before beginning the discussion of velocity mitigation techniques used in combination with slip lined retrofits, it is important to prime this discussion, specific recommendations to those considering fish passage for any culvert type, given by UDOT, is included. Those which apply to slip lined culvert retrofits follow:

- Provide a sufficient span or structure opening width so as to avoid overly constricting the stream or accelerating velocity at the 2-year high flow. [Active channel width or bed width or bank to bank width at OHW are also used in describing this dimension.]

- When using conventional closed conduit culverts place the culvert invert below the streambed elevation so that the natural stream gradient and substrate material can be re-established through the structure.

- Baffles, weirs, and similar artificial devices inside the culvert should only be employed when the use of natural stream materials is impractical. Baffles and weirs should only be used by experienced designers.

- Either avoid high outlet velocities resulting in a scour hole that precludes fish entry, or provide a permanent downstream pool that inundates the lower portion of the culvert where fish may enter the culvert during periods where passage is required.

- Evaluate draw-down and turbulence at the culvert inlet as well as barrel and outlet velocities by comparing them with similar naturally occurring and existing velocity distributions in representative adjacent upstream and downstream reaches.

- Consider placement of one or more large riprap elements [fish boulders or derrick rock] to provide a resting area on the channel periphery immediately upstream from the culvert entrance that is readily accessible to emerging fish.

(UDOT 2004)

Given these guidelines, as well as the policy outlined by the ESA, Utah Division of Water Rights and the Army Corps of Engineers, the following conditions have been identified where slip lined culvert retrofits should be among the methods considered for stream crossing rehabilitation:

- <u>Present culvert is oversized.</u> The existing culvert is already “oversized” relative to the active channel width and appropriately embedded or if the crossing can be backwatered adequately to ensure passage will be facilitated with the proposed retrofit design.

- Streams without sensitive or targeted species. Crossing is in a non-Class 3 water body, or a stream where there are no, and historically have never been, any native migratory fish at the culvert location.

- Existing up or downstream barriers. Fish movement is impeded by a natural or unnatural barrier "close" to the crossing whose mitigation is unplanned.
  - The State of Oregon grants an exemption if the Oregon Department of Fish and Wildlife deems that the total stream distance, including tributaries, affected by the artificial obstruction for which the waiver or exemption is being sought is less than or equal to 1 mile (1.61-km) to a natural barrier, or licensed hydroelectric project (ODFW 2006).

- Exemption from state fish passage laws. Possible reasons for exemptions could include:
  - Culvert is relatively new and has significant remaining design life, but has failed in some way, demanding a retrofit to ensure crossing capacity, safety and sustainability.
  - Full culvert replacement is planned as a part of a future roadway project (within 5 or 10 years). (CALTRANS 2007)
  - Design is very close to meeting fish passage criteria and is granted exemption to criteria on an experimental basis. A situation falling under this provision is described in the Falmouth, ME case study in the Site Visits section.

Policy guidelines for the Utah Department of Transportation are found in the UDOT Manual of Instruction – Roadway Drainage, Surface Water Environment (UDOT 2004), including brief descriptions and instructions relating to Federal and State permitting criteria. Given the strict limitations imposed on stream alterations for the preservation of stream and wetland ecology, it is obvious that slip lined culvert retrofits are not preferable in all—or even most—culvert repair situations. There are, however, conditions where consideration should be given for slip lined retrofits. Design in cases where slip lined retrofit is considered should generally be accompanied by measures to decrease culvert velocities.

2.5 Literature Review

Several mitigation techniques are available for application when culverts represent velocity barriers to fish. Despite a seemingly limitless number of mitigation techniques used throughout the country, the majority of the literature on this topic centers on baffles and weirs both inside and outside of a barrier culvert. This document will refer to in-culvert weirs as baffles, and external weirs as tailwater controls. This section describes the function and use of both baffles and tailwater control weirs.

2.5.1 Baffles in Theory

The concept and function of the baffled culvert is similar to most designed fishways in that the baffles create a series of short, high velocity, runs between the baffles and a series of low velocity backwater areas behind the baffles. These areas allow the fish to swim in short bursts and then rest (Bryant 1981) as they progress through the culvert length. Many materials aid in baffle design and hydraulic analysis in circular culverts, primarily work done by N. Rajaratnam and C. Katopodis (Rajaratnam et al. 1991). This work includes flow equations for many baffle types based as a function of baffle configuration, culvert diameter, depth of water, culvert slope and baffle height. Instructions on baffle design produced by UDOT are found in chapter 15 of the Roadway Drainage Manual of Instruction (UDOT 2004).

A study conducted in 1978 at the USDA’s Young Bay research facility in southeast Alaska studied a baffled culvert 30-ft (9-m) long and 36-in. (90-cm) in diameter that was installed at a gradient of 10 percent below an artificial stream channel Alternating baffles were bolted to the corrugated metal culvert at 2-ft (60-cm) intervals and tests were done on a range of salmonid species. It should be noted that the authors found little evidence relating fish passage and baffle height. Although the velocities in the culvert were generally acceptable, the report suggests that a baffled pipe may prove useful in high flows, but be detrimental at low flows. Additionally, barriers associated with outlet velocities and scour were not resolved using this method (Bryant 1981).

Another study done on baffled culverts studied various baffle shapes, sizes, and arrangements during its fish passage trials. These trials were done on a third-order tributary in southern Tasmania by scholars at the University of Tasmania. The test was done on a twin-pipe culvert that allowed for flow to be diverted through either pipe, and centered on galaxiid species in the area. This test did not did not comment on outlet velocities or scour, but discovered that fish were approximately 10 times more successful in passing through the test section when baffles were present than when absent. The most successful arrangement was 21 times more likely to pass than the least successful arrangement. It is interesting to note that this study also found that the height difference between small and large baffles had no affect on passage at any test velocity (MacDonald and Davies 2007).

Baffles are often not recommended for culvert slopes greater than 3.5%, since at steeper slopes the flow range that provides passage becomes too small. For steep slopes, baffles need to be spaced close together to meet low-flow depth requirements and reduce velocities at higher flows. This can lead to baffle spacing that fails to provide resting areas for larger fish, and potentially create a turbulence barrier at higher flows (USFS 2007).

2.5.1.1 Hydraulic Analysis: Baffles

The hydraulic analysis section of this report shows that slip lined culvert retrofits generally result in an increase in velocity, often near 60%. This increase in velocity will generally provide for an unnecessarily large culvert discharge capacity, one much greater than the initial culvert. This report also suggests that increased velocities due to retrofit can be mitigated through using culvert baffles without significantly decreasing culvert capacity. The following hydraulic analysis reiterates the effects of slip lined culvert retrofit on headwater and velocity and more importantly, explores the effects of introducing baffles into the crossing.

This example uses the data from a slip lined culvert retrofit performed near Belfast, Maine by the Maine Department of Transportation. A more detailed description of this project is found in a following section of this report (Section 3.3.3). The initial 100-ft corrugated steel culvert (n=0.024) diameter was 4.5-ft on a slope of 2.8%. The culvert was then lined with a 4-ft HDPE (n=0.012) pipe. The changes in flow type, velocity and headwater over a range of discharges are shown in Table 2-4.

Table 2-4: Changes in Culvert Flow Type, Headwater and Outlet Velocities Due to Slip Lined Culvert Retrofit

Total Discharge (cfs)	Flow Type		Headwater Elevation (ft)			Outlet Velocity (ft/s)		
	Original	Retrofitted	Original	Retrofitted	% Change	Original	Retrofitted	% Change
0	0-NF	0-NF	0	0	0	0	0	0%
10	1-S2n	1-S2n	1.28	1.23	-3.9%	6.3	9.7	54%
20	1-S2n	1-S2n	1.84	1.78	-3.3%	7.43	12.46	68%
30	1-S2n	1-S2n	2.29	2.25	-1.7%	8.34	12.74	53%
40	1-S2n	1-S2n	2.7	2.7	0.0%	9.03	13.54	50%
50	1-S2n	1-S2n	3.09	3.11	0.6%	9.64	14.17	47%
60	1-S2n	1-S2n	3.47	3.49	0.6%	10.11	14.65	45%
70	1-S2n	1-S2n	3.84	3.87	0.8%	10.52	15.12	44%
80	1-S2n	5-S2n	4.22	4.26	0.9%	10.92	15.5	42%
90	5-S2n	5-S2n	4.61	4.68	1.5%	11.25	15.88	41%
100	5-S2n	5-S2n	5.02	5.15	2.6%	11.49	16.24	41%

This table shows that slip lined culvert retrofits will only change the flow type at 80cfs, while changes in headwater are quite minimal, ranging from a decrease of 3.9% (0.05 ft) at very low flows to an increase of 2.6% (0.13 ft) at very high flows. Velocities increase from a range of 68% at low flows to 41% for high flows. Discharges greater than 40 cfs cause velocities which would prohibit all Utah fish passage in the original condition and that preventive velocities exist in the lined pipe at 10-cfs (in fact, only discharges lower than 6-cfs create passable velocities).

The following table shows the results of the slip lined culvert retrofit with baffles on headwater and velocity. This example uses a total of (17) 6-in. baffles along the 100-ft length of the slip lined culvert pipe. Using the design guidelines for internal (integrated) dissipators found in HEC-14 (Thompson and Kilgore 2006), the composite Manning's roughness value for the baffled culvert was calculated to be n = 0.032.

Table 2-5: Changes in Culvert Flow Type, Headwater and Outlet Velocities Due to Slip Lined Culvert Retrofit with Baffles

Total Discharge (cfs)	Flow Type		Headwater Elevation (ft)			Outlet Velocity (ft/s)		
	Original	Retrofitted with Baffles	Original	Retrofitted with Baffles	% Change	Original	Retrofitted with Baffles	% Change
0	0-NF	0-NF	0	0	0	0	0	0%
10	1-S2n	1-S2n	1.28	1.23	-3.9%	6.3	4.97	-21%
20	1-S2n	1-S2n	1.84	1.78	-3.3%	7.43	6.08	-18%
30	1-S2n	1-S2n	2.29	2.25	-1.7%	8.34	6.77	-19%
40	1-S2n	1-S2n	2.7	2.7	0.0%	9.03	7.3	-19%
50	1-S2n	1-S2n	3.09	3.11	0.6%	9.64	7.74	-20%
60	1-S2n	1-S2n	3.47	3.49	0.6%	10.11	8.08	-20%
70	1-S2n	2-M2c	3.84	4.15	8.1%	10.52	8.39	-20%
80	1-S2n	2-M2c	4.22	4.49	6.4%	10.92	8.85	-19%
90	5-S2n	2-M2c	4.61	4.84	5.0%	11.25	9.33	-17%
100	5-S2n	2-M2c	5.02	5.22	4.0%	11.49	9.83	-14%

This table shows that subcritical flows are created by the baffles at discharges of 70-cfs or greater. Additionally, the increase in headwater elevation is more pronounced, but still relatively small, peaking at 8.1% (0.31-ft). Finally, culvert velocity actually decreases due to the slip lined culvert retrofit with baffles, as much as 21%. Because most culverts built in the 1960s and 1970s that are experiencing failure often created fish passage velocity barriers, this decrease in velocities is an added benefit of the retrofitting process.

This brief example shows the benefit of adding baffles to a slip lined retrofit project. Headwater increases do result from the retrofit, and continue to increase as baffles are installed into the pipe; however, with a maximum increase of 0.31-ft, this increase is considered acceptable. Velocities increase dramatically due to slip lined retrofit, but can be mitigated using culvert baffles, to the point that the velocities decrease up to 21%.

2.5.2 Tailwater Control Structures in Theory

The Maine Department of Transportation (MDOT) Fish Passage Policy and Design Guide suggests two mitigation measures to be considered before in-culvert baffles. When a culvert is slip lined, an automatic outlet drop of the liner thickness accompanies. This publication suggests that if this jump is small, a sluice channel, or ramped notch can be cut into the end of the culvert to smoothly transition between the outlet invert and the interior of the liner. This treatment is used to eliminate small hanging inverts, and the paper suggests that hydraulic analysis should be performed to ensure that adequate flow depth in the upper portion of the pipe is achieved and that the velocity standard is not exceeded in the notch channel or pipe (Michaud 2004).

The second mitigation measure discussed in the Maine report is a tailwater control weir. This idea is to place tailwater control weirs near the outlet of retrofitted culverts. This causes water to slow down and back up into the culvert itself, providing favorable depth and reduced velocities within the culvert. In addition to backing water into the culvert, carefully designed tailwater controls can also serve as grade controls to reduce the outlet scouring which often causes a perched outlet invert. The UDOT recommendations included embedding, or countersinking, the culvert to provide a natural invert for fish passage; this can also be attained over time using grade control, though the reduction in flow area must be accounted for in initial retrofit design. Figure 2-14 shows how tailwater weirs can act as grade controls.

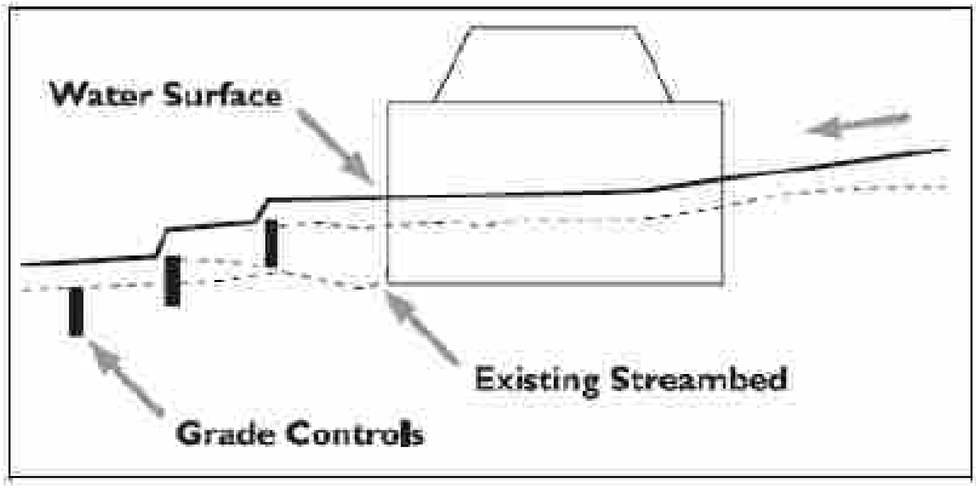

Figure 2-14: Diagram of the effect of grade controls on water surface profile and existing streambed.

The required tailwater elevation can be determined using approved culvert hydraulics calculations. The minimum depth required for passage must be obtained up to and including the inlet. The design of tailwater control structures for fish passage involves identifying a discharge, or range of discharges that target fish will experience at peak movement seasons. A tailwater control weir is then designed to provide the appropriate flow velocity and flow depth for successful fish passage. Carefully designed tailwater control structures, when keyed into this particular velocity and flow depth, can produce desirable subcritical flows in fish passage design discharges, without significantly disturbing culvert conveyance capacity by providing for supercritical flows at high flows. Design recommendations for tailwater structures are legion (Hotchkiss and Frei 2007, Bates et al. 2003, Thompson and Kilgore 2006, CALTRANS 2007, Biedenharn and Hubbard 2001). Schematics and exhaustive design steps are also included in the MDOT report (Michaud 2004). Tailwater control weirs are made from many materials, including concrete, HDPE, boulders, and wood, among many others. Placement of weirs in turn creates drops in water elevation downstream of the culvert and creates the possibility that the solution to fish passage (the weir) in turn becomes a barrier (jump height) (Michaud 2004).

In addition to in-culvert baffles and external tailwater control weirs, a third structure which should be briefly noted is a longitudinal channel weir. This structure is really only feasible in larger culvert diameters. Figure 2-15 and Figure 2-16 show a longitudinal weir installed through the length of a flat-bottomed culvert in Crooked Creek in Mono County, California.

Figure 2-15: Looking towards culvert outlet. Longitudinal channel on right. (CALTRANS 2007)

Figure 2-16: Looking at culvert outlet. Longitudinal Channel on left. (CALTRANS 2007)

This is done to concentrate flows in order to increase flow depth at low flows. The photo on the right shows a step pool fishway structure to provide for fish passage given the perch of the culvert at higher flows. Again, this would only be feasible in culverts with larger diameters where fill is placed within the culvert to simulate a natural channel bottom. (CALTRANS 2007)

2.5.3 General Strategy

Baffles and tailwater control weirs may be utilized in a variety of applications in fish passage design. Basic recommendations for in-culvert and external structures to provide fish passage when faced with velocity barriers, low flow barriers, and perched culverts are summarized below.

- Flow Depth Barrier
    - Baffles to create pools
    - Tailwater Control Weirs
    - Longitudinal Channel Weir
- Velocity Barrier
    - Baffles to create roughness
    - Tailwater Control Weirs
- Jump Height Barrier
    - Tailwater Control Weirs
        - provide higher water surface elevations
        - provide grade control to prevent further perching
        - provide step pool fishway

3 Survey of Current Practices

While full ecological connectivity cannot be accomplished without spanning the entire active width of the channel, fish passage can be provided in slip lined culvert retrofits. The need for the mitigation of increased velocities due to slip lined culvert retrofit, as well as potential mitigation techniques is outlined in the previous section. This section discusses the results of a nation-wide survey of agencies to discover the state of current practice in employing slip lined retrofits. This section notes the relatively scarce number of slip lined retrofit projects that consider fish passage, speaks to the sustainability of such projects, discusses the application of previously discussed mitigation techniques, and concludes with descriptions of a few slip lined culvert retrofit projects which, through post-project monitoring, have been shown to successfully provide passage for targeted species.

3.1 State Departments of Transportation and Fish and Wildlife Departments Survey Results

A nation-wide survey of all U.S. state Departments of Transportation as well as state Fish and Wildlife Departments has shown that there has been very limited experience in providing for fish passage through slip lined culverts. The Oregon Department of Fish and Wildlife requires that a structure is completely backwatered throughout the entire migration period at all discharges. In order to provide this condition, baffles, weirs, bedload retention grids, tailwater control weirs, and over-steepened channel reconstruction are utilized. The California Department of Transportation (CALTRANS) has little experience with liners where fish passage is a concern, and warns that attaching baffles to HDPE liners can be difficult and may be prone to getting torn out during heavy storms. Another study suggests that baffled culverts may create a barrier to the downstream passage of juvenile Chinook salmon smolt, as the smolt avoided the structural complexity provided by baffles and selected a control channel over a baffled channel (Kemp and Williams 2008). The Ohio Department of Transportation often buries the invert of slip lined culverts to decrease culvert velocity. The Connecticut Department of Transportation has completed several slip lined retrofits on culverts 6-ft (1.8-m) in diameter or larger. MDOT discourages considering slip lined culvert retrofits which will result in a culvert less than 4-ft (1.2-m) in diameter, while CALTRANS suggests no smaller than 3.6-ft (1.1-m). Smaller retrofits can cause too great of a velocity change, as well as create maintenance issues due to the increased possibility debris impaction. Maine also suggests that careful attention be paid to the increased elevation of culvert inverts due to slip lined retrofitting, which can cause outlet pool degradation.

The Vermont Agency of Transportation rarely slip lines culverts, but also mentions that they "have had success only in those instances where backwater through the full length of the barrel could be achieved." Vermont has been very creative in their mitigation techniques.

> "In large multi plate systems where the problem is confined to the invert area of the structure, where deformation has not progressed, where the danger appears to be loss of fines from around the pipe, we have installed up to a foot of concrete in the invert. Rebar is placed on a 12 x 12 in. (0.30 x 0.30 m) grid and tack welded where possible. This type of repair can be used with a roughened surface, baffles, or random placement of embedded stone. In these cases, the goal is to simulate velocity and depth in the adjacent stream reach. Well placed stone clusters may recruit sediment and debris that could facilitate passage. Bottom characteristics will change yearly based on timing and distribution of large storm events that may scour the concrete surface."

The following photos from a visit to Vermont show many of these mitigation techniques used in non-lined culvert retrofits.

Figure 3-1: Various techniques for velocity mitigation in stream crossings.

Unfortunately, as is true with much advancement in engineering practice, the survey has also shown that many of the treatments for velocity mitigation remain unproven. Several respondents suggested that finding funding for post-construction monitoring is often difficult to obtain. This leaves the hydraulic engineer or biologist with untested conduits and without feedback necessary for design development and adaptive management in culvert rehabilitation. In order to further the science and continue creative developments in culvert treatments, both pre- and post-construction monitoring must be a priority. Section 3.3 contains four case studies which have undergone some type of pre-construction assessment, and post-construction monitoring.

The actual survey responses from the more helpful entrants to the internet survey can be found in Appendix C: Results of Internet Survey.

3.2 Sustainability

One of the questions quickly brought up as culvert retrofits are discussed is: “Are these retrofits sustainable?” Can baffles, tailwater controls and slip lined retrofits provide for the transport of sediment, flow and wildlife without degradation of either the channel or the hydraulic structures? Of particular interest is the affect of baffles and tailwater control weirs on sediment transport. Are baffles able to withstand shear stresses and impact of normal bedload, not to mention the variety in size and type of debris transported in high flows? Do baffles contribute to debris accumulation and culvert blockage? Does intense scouring occur as water plunges over a tailwater weir? Despite limited experience in slip lined culvert retrofits, several agencies have gained experience with baffled culverts and tailwater control weirs. Several respondents with experience in these methods responded to specific questions regarding constructability, durability and maintenance.

3.2.1 Baffles in Practice

Baffles are typically designed on a culvert by culvert basis dependent upon specific ranges of flows and species of interest. Because of this, it is difficult to make anything but very general comments on baffle sustainability. Discussions with various agencies familiar with baffled culverts, as well as slip lined retrofits that utilize baffles, have yielded these general observations:

- It is clear that baffles will experience a greater shear stress on them from the culvert flow than will the culvert itself. Additionally, if cobbles are transported through the structure, steel and plastic baffles experience severe stresses and will bend or break apart over time. This would suggest that baffle design life, as opposed to culvert design life, would be the limiting factor in the overall design life of the retrofit. Figure 3-2 shows failure due to insufficient anchoring

Figure 3-2: Failure due to insufficient anchoring. (CALTRANS 2007)

- Sharp crested and v-notch baffles or weirs tend to trap organic matter. Lower, smoother weirs have lower potential for debris accumulation. If organic debris does accumulate, the combination of debris and baffles can significantly reduce the flow capacity of the culvert. Figure 3-3 shows debris accumulation in a baffled culvert.

Figure 3-3: Debris caught on a baffle. (CALTRANS 2007)

Using corner, side, or alternating baffles often helps decrease debris buildup. It is important to also note that maintenance of debris seems to be less of an issue with retrofitted culverts. It seems that if a culvert had debris accumulation issues prior to baffled retrofit, the retrofit tends to exacerbate the problem, therefore, sites being evaluated for potential retrofit action which already have high debris loading should give strong consideration to not constructing baffles. Despite this tendency to increase debris accumulation, no experience suggested that retrofitted culverts which had relatively little or no debris accumulation prior to retrofit experienced considerable debris accumulation problems after retrofit, in fact, some have suggested that roughness elements which induce turbulence may even increase transport capability (Peterson and Mohanty 1960).

- Baffles placed on CMP, steel plate, or other metal culverts can be affixed to the culvert using various methods. Expansion-ring anchors work well in round pipes and can be installed without diverting flow from the work area. Also, J-type bolts can be placed in the field or welded directly by the culvert manufacturer.

- While many methods of baffle attachment exist for concrete and steel culverts, baffles placed in HDPE or other smooth pipe is generally plastic welded onto the culvert sleeve, or bolted to expansion ring anchors. Baffles can be plastic welded to slip lined culverts either in the field, or by the manufacturer. Figure 3-4 shows a plastic welded baffle near Belfast, Maine.

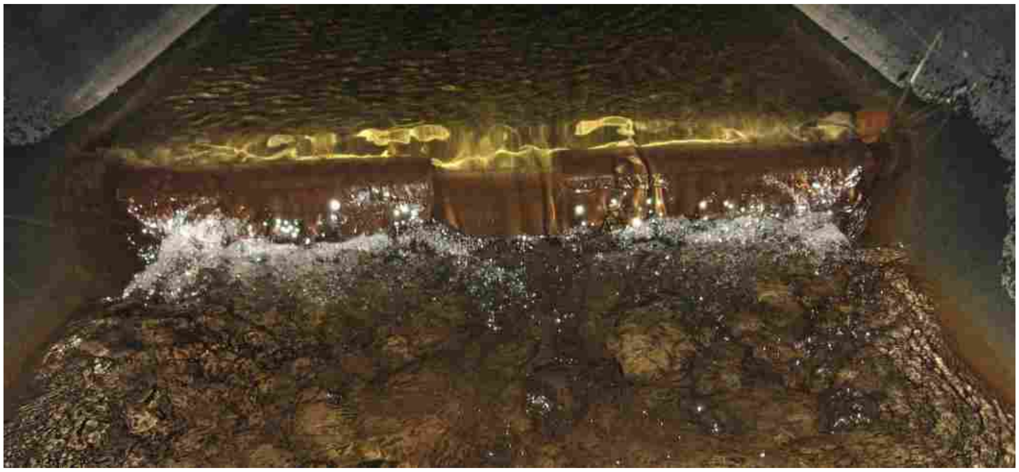

Figure 3-4: HDPE baffles plastic welded into an HDPE culvert sleeve.

- Maine DOT suggests that baffles should not be considered for circular culverts less than 4-ft in diameter, while CALTRANS suggests no smaller than 3.6"diameter, due to difficulties accessing the culvert interior for installation and maintenance.

3.2.2 Tailwater Control Structures in Practice

The primary aims of tailwater control structures are to establish a desired flow depth and flow velocity within the culvert. As with baffles, tailwater control structures are typically designed on a culvert by culvert basis dependent upon specific ranges of flows and species of interest. Discussions with various agencies familiar with tailwater control structures have yielded these general observations:

- Tailwater control structures should always be considered before baffles because they are much easier to install and more simply maintained due to the structure's position outside of the culvert. Not only is structure access an issue, but because the structure is in an open channel, the tendency to clog is greatly reduced.

- State transportation agencies have popularized the use of embedded "Jersey Barriers", or "K-rail", in tailwater controls because these barriers are so readily available to these agencies. Low flow notches are often cut into these barriers. Additionally, these structures are likely to be more resistant to failure due the impact from cobbles and other debris.

- The primary modes of failure are not material based, but are due to poor design and construction. Specific flow depths are to be provided within the culvert by the tailwater control weir. Improper installing the tailwater control weir at the specified elevation causes improper flow depths. Close oversight provided in the construction phase will prevent this failure. Even when the barrier is anchored into the streambank, scouring both downstream of the weir and at the streambank is possible. Figure 3-5, taken at the John Hatt Creek, California site, discussed further in the Site Visits section of the report, shows erosion beginning to flank the downstream weir.

Figure 3-5: Erosion flanking tailwater control weirs at John Hatt Creek.

This picture shows streambank degradation at the site of tailwater control weirs. Continuing degradation will cause improper backwater elevations, not to mention the potential for the structure to be displaced over time.

- Rock weirs are a popular alternative to Jersey Barriers because they provide a natural aesthetic, as well as more natural cover for fishes. These types of weirs require much more skill and labor, and their success depends heavily on the size and quality of material used. The survey of agencies suggests that rock weirs being improperly designed or constructed has resulted in weirs being washed out completely, or simple degradation which has eliminated the desired hydraulic impact. CALTRANS suggests that the sustainability of rock weirs “should be durable and of a shape that allows individual rocks to be keyed together. Boulders with somewhat rectangular form are much more stable than round boulders.” (CALTRANS 2007)

3.3 Site Visits

As a result of information provided by survey respondents, site visits have been made a few states with this experience to assess developing technologies and record successful and unsuccessful installations. Visits were made to slip lined culvert retrofits in northern California, Maine, Vermont and Connecticut. These culvert tours included discussions on design considerations, post-construction observations, and general recommendations from those familiar with the installations. Brief case studies of four of these improved crossings follow.

3.3.1 John Hatt Creek Retrofit

The California Fish and Game approved a slip lined retrofit of a culvert in Mendocino County on John Hatt Creek. In this case, a 5.5-ft (1.68-m) diameter corrugated steel pipe culvert was lined with a 5-ft (1.52-m) diameter welded steel pipe with 43 corner baffles, and was enhanced with three precast concrete weirs with wooden low-flow notches below the culvert outlet. These tailwater controls with removable notches, as shown in Figure 3-6.

Figure 3-6: Outlet of slip lined culvert retrofit of John Hatt Creek showing corner baffles and one of the three tailwater control barriers.

The stream bottom is at least 20-ft (6-m) below the road crest elevation and is adjacent to upstream private property. The prohibitive costs associated with the removal of the fill were the chief impetus to attempt a slip lined culvert retrofit. An upstream barrier whose mitigation is not planned also affected the decision. The total cost of the retrofit was $140,000. The baffles appear to be effective at reducing water velocities and increasing water depth within the pipe. A more detailed project description, including many more photographs of this retrofit site, is found in the Design for Fish Passage at Roadway-stream Crossings: Synthesis Report (Hotchkiss and Frei 2007).

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3.3.2 Cape Elizabeth Retrofit

The first stream crossing in Maine to be discussed is located near Cape Elizabeth, Maine, just south of the capital city Portland. The 7-ft (2.13-m) CMP culvert at the Cape Elizabeth site is replaced by a 6-ft (1.8-m) Weholite pipe. The aquatic organisms of interest in this case are the American Eel and Alewife, which come inland in the spring as adults to spawn, and whose elvers return in the following spring. These animals are strong swimmers, but exhibit no leaping ability; therefore, it was expedient that water be backed up into and through the culvert during spring flows to prevent a jump height barrier. In order to back subcritical flows into the culvert an HDPE weir, costing approximately $3000 was placed downstream of the culvert. This weir creates a subcritical condition to within roughly 5-ft to 6.5-ft (1.5-m to 2-m) of the culvert inlet. Figure 5 shows the outlet of the retrofitted culvert. At the time of the site visit, the tailwater weir was completely submerged. The white pole sticking out of the water is a stage gauge used in monitoring.

Figure 3-7: Culvert retrofit on Alewife Creek near Cape Elizabeth, Maine. Tailwater weir is submerged.

Since construction, alewives have been found upstream and within the retrofitted culvert. It is suggested that observational, as well as formal post-construction monitoring is essential to determining the viability of such retrofits under similar conditions.

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3.3.3 Belfast Retrofit

State Highway 1 runs along the Atlantic coast of Maine. This highway is the only road which connects the quaint coastal villages on the coast of Maine which are so important to the tourism industry of the state. Given that the seasonal construction window coincides with the peak of the tourist season, full replacement of this culvert would create a dramatic disruption. This culvert is only about 200-ft (60-m) from the ocean, and is a thermal refuge for juvenile brook trout. As a conduit for juvenile brook trout, the retrofit was designed for low flows. Figure 3-8 and Figure 3-9 show the completed project.

Figure 3-8: Culvert retrofit outside Belfast, Maine, showing tailwater control weir.

Figure 3-9: Welding of culvert segments. Attachment used as opportunity to provide anchoring for baffle.

A total of 17 baffles are inside the 4-ft (1.2-m) culvert. These weirs are 6-in. (15.24-cm) tall with 1-in. x 6-in. (15.24-cm x 2.54-cm) notches. Figure 3-10 and Figure 3-11 show the baffles in the culvert after the retrofit, and Figure 3-12 shows the design detail of these baffles.

Figure 3-10: View of all baffles within Belfast, Maine culvert retrofit.

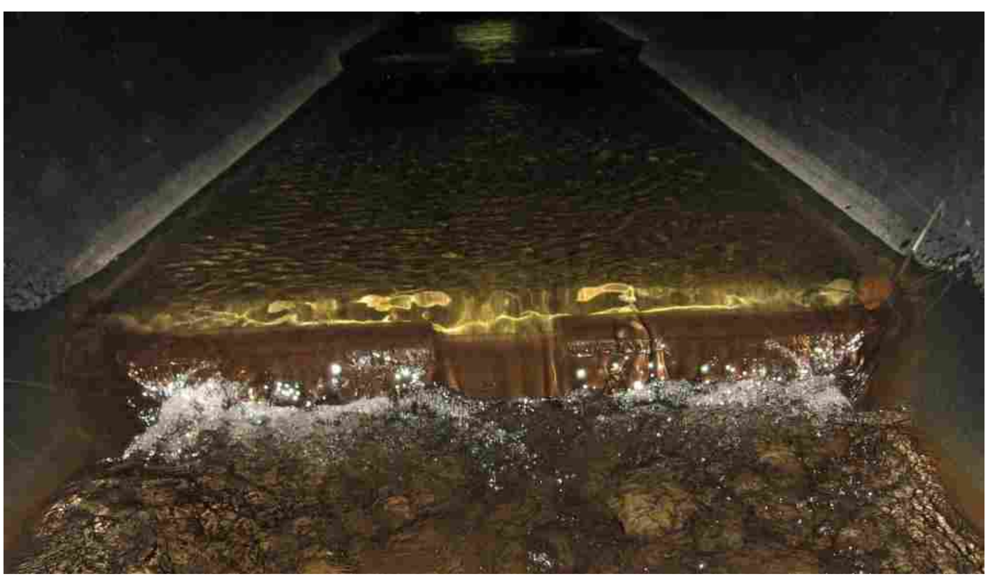

Figure 3-11: Baffles within Belfast, Maine culvert retrofit.

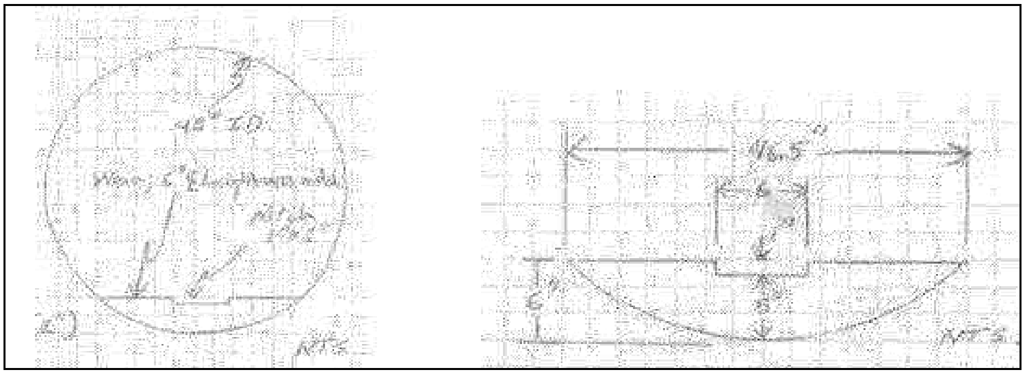

Figure 3-12: Design detail of Belfast, Maine culvert baffles. (Courtesy of MDOT)

Readily available jersey barriers were used for tailwater control weirs, and are designed to back the water into the culvert at a depth of 3-in. (7.7-cm) over each baffle at the design flow. Figure 3-13 shows the design of one tailwater control weir.

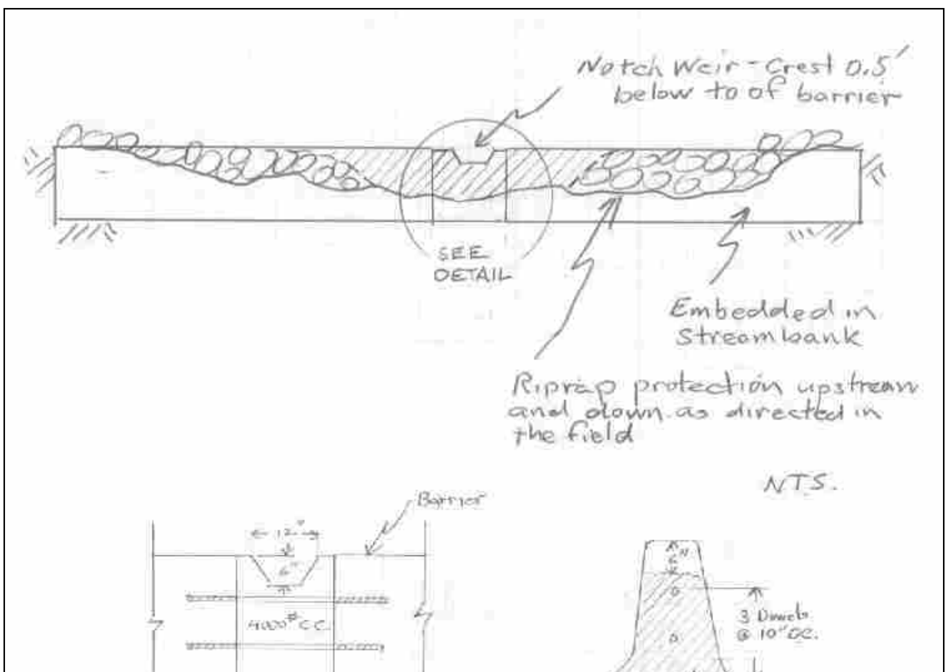

Figure 3-13: Design detail of Belfast, Maine tailwater control weirs. (Courtesy of MDOT)

This figure shows reasonable embedment of the tailwater control weir. Sufficiently embedding these weirs and providing riprap near the edges provides erosional flanking, as well as piping. Prior to the retrofit of this culvert, the roughly 200-ft (60-m) of stream above the culvert had no juvenile brook trout. A study after the retrofit found 80 juvenile brook trout in the same reach. Further observation has revealed that rocks tend to pile up below the downstream weirs, and between larger flows, rocks and sediment build up next to the baffles. In all, the Department of Transportation was able to retrofit this culvert for fish passage without closing the road for long periods of time and saved more than $100,000 dollars.

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3.3.4 Falmouth Retrofit

An interesting case study is the retrofit of a stream crossing near Falmouth, Maine. The Town of Falmouth applied to the Maine Department of Environmental Protection to lengthen a culvert using slip lined techniques, which were favored due to steep ravines which would cause entire culvert replacement to be extremely costly. The Maine Department of Inland Fisheries and Wildlife (MDIFW) reviewed the application and were concerned that this improvement might prevent or limit the passage of juvenile wild brook trout which persist in the stream system. Calculations performed by MDIFW resulted in the suggestion that corrugated metal pipe be used for the retrofit, in conjunction with a tailwater control at the outlet pool in order to back water into the pipe. "The Town really wanted to try plastic pipe . . . (and because of) an existing manmade barrier to passage was located a short distance downstream, it was decided to proceed with (the) project on an experimental basis" with the Town agreeing to provide a grade control structure downstream and that further modifications would take place if fish were unable to pass the retrofitted pipe. The outlet of the pipe is shown in Figure 3-14.

Figure 3-14: Outlet of Falmouth, Maine slip lined culvert retrofit. Rock tailwater grade control also shown.

Figure 3-15 shows the possible fish barrier downstream of the Falmouth slip lined retrofit project. The presence of this very old retention structure allowed for experimental retrofit.

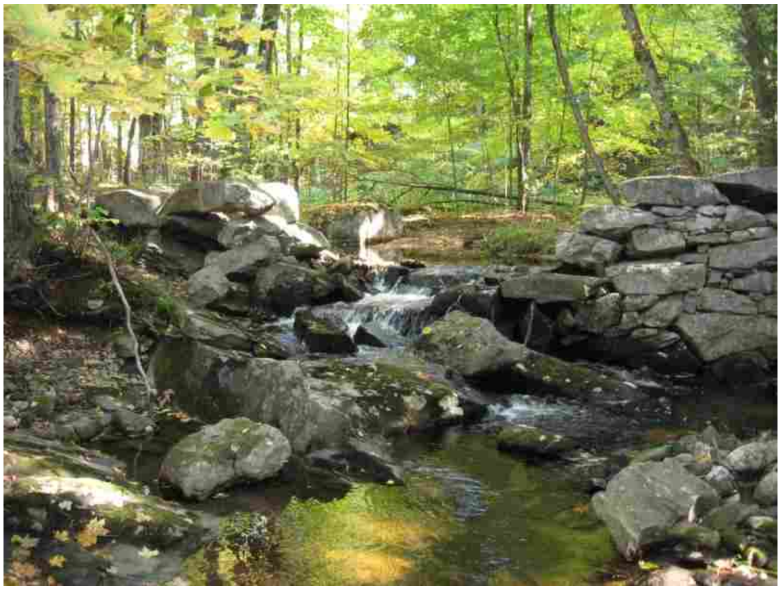

Figure 3-15: Possible fish barrier downstream of Falmouth culvert. The presence of this very old retention structure allowed for experimental retrofit.

In order to verify the success of the project, 60 marked hatchery farmed brook trout were introduced just downstream from the culvert, with nets downstream from the outlet pool and 367-ft (112-m) upstream from the inlet. After 24 hours, the site was revisited and fish were caught using an electrofishing unit. The study found 62% of the fish within the pipe, 28% of the fish upstream of the culvert and 10% unaccounted for. The retrofit was deemed a success, and no further construction was done on the site.

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It has been shown that many states have begun utilizing slip lined culvert retrofit technology. Some agencies refuse to use slip lining when fish passage is an issue, while others have chosen to modify retrofit designs to provide for passability. These have been done using varying techniques and have been met with varying degrees of success. This paper has shown four such cases. The Fish Xing software website also has descriptions of a few case studies, including the John Hatt Creek retrofit (USFS 2007). It is almost certain that there are more slip lined culvert retrofit success stories throughout the country, as well as more failures. Unfortunately, many of these retrofits have not been documented, and have not included pre-construction assessment and post-construction monitoring. It is suggested that increased documentation of design methods and monitoring results is essential to identifying conditions where slip lined retrofits are favorable, as well as evaluating the plethora of structural improvement methods that can be applied to the retrofitting process.

3.3.5 Monitoring

The science of culvert retrofitting for fish passage is relatively new and the science of slip lined culvert retrofitting for fish passage has just begun. Imperative to the furthering of this practice is reporting on successes, as well as failures, of slip lined culvert retrofit projects relating to fish passage. In order to identify failures and successes, careful measurement must be taken after projects are completed.

Unfortunately, monitoring is often an afterthought to culvert projects only done when an excess of funds provides for it. It is imperative that given the vast cost savings associated with slip lined culvert retrofits, a portion of these savings be allocated for stream crossing monitoring. Post project testing, such as the Falmouth, Maine retrofit, is an important way to justify using or ceasing to use this method in similar cases. In this way, the costs and effort expended in the monitoring of initial projects can be leveraged over future projects and can be viewed as a program investment as opposed to an unacceptable burden imposed on one small culvert project.

The suggested intensive monitoring approach for pioneering retrofit projects is followed on the Cape Elizabeth retrofit site. By its own admission, the rigor of this monitoring and maintenance plan is "unusual for a culvert improvement project, even one involving fish passage in a plastic pipe." Main points of the monitoring plane are shown below:

- Three year monitoring effort
- Biology Monitoring: Eel and Alewive trap monitoring on a daily basis in April and May 9 (typical migration period).
- Hydrology/Hydraulics Monitoring: Continuous monitoring from March thru November using stage gauge datalogger.
- Maintenance Monitoring – Monitoring changes in hardware and channel morphology.
    - December thru Ice Out: No Inspections
    - Ice Out thru end of June: Once every two weeks
    - June thru December: Once per month
    - Storm Events: Within 72 hours of the end of the Event

The entire plan is provided in Appendix D.

4 Project Summary and Conclusion

This section restates the problem with slip lined culvert retrofits associated with fish passage, reviewing the effects of slip lined culvert retrofits on flow type, headwater and velocity. In addition to synthesis of literature and the survey of current practice, this section includes the overall general conclusions drawn from this research.

4.1 Problem

This document contains information relating to fish passage in slip lined culvert retrofits, an inexpensive solution to the problem of a failing inventory of culverts nationwide. In addition to outlining the process and advantages of slip lined culvert retrofits and the typical savings due to application of this method, this document includes a as a description of general fish passage theory. Also documented through detailed hydraulic analysis is the fact that the same thing that makes slip lined culvert retrofits possible—increased velocity due to lower Manning's roughness values—can create a velocity barrier to fish passage. This extensive hydraulic analysis is included which shows the results of calculating trends in the change in flow type, velocity and headwater due to slip lined culvert retrofit. This analysis was limited by discharges that produced velocities within the range of maximum fish swimming capabilities for Utah fishes. While specific recommendations of gradients, culvert diameters and discharges are not derived from this analysis, the results do provide general trends which should be considered in retrofit design.

Important conclusions include:

- Flow Type
    - For inlet control, specifically the 1-S2n flow type, flow type is mostly unchanged after slip lined retrofit when no tailwater augmentation is employed.
    - Before retrofit, culverts with 11-ft (3.35-m) diameters and smaller on 1% slopes, are in outlet control, primarily the 2-M2c flow type. After retrofit, 1-S2n profiles are exhibited with significant increases in velocity.
    - Culverts 3-ft (0.91-m) in diameter and smaller exhibit mixed flow types according to discharge before retrofit. After retrofit, 1-S2n profiles are exhibited.
- Headwater
    - Changes in headwater are usually very small on slopes greater than 1%.
    - Headwater decreases as a result of retrofits of culverts whose original diameter is 17-ft (5.018-m) or greater. In this range, the decrease in headwater increases as original culvert diameter increases.
- Velocity
    - Slip lined culvert retrofits commonly result in velocity increases of 60%.
    - Percentage increase in velocity due to retrofits does not show a trend due to culvert size or culvert slope.
    - All slip lined retrofit simulations produced velocities which were not conducive to fish passage

Mitigation of increased velocities must go hand-in-hand with slip lined culvert retrofit design when fish passage is to be provided.

Conditions where slip lined culvert retrofit should be considered among other design alternatives:

- <u>Present culvert is oversized.</u> The existing culvert is already “oversized” relative to the active channel width and appropriately embedded or if the crossing can be backwatered adequately to ensure passage will be facilitated with the proposed retrofit design.

- Streams without sensitive or targeted species. Crossing is in a non-Class 3 water body, or a stream where there are no, and historically have never been, any native migratory fish at the culvert location.
- Existing up or downstream barriers. Fish movement is impeded by a natural or unnatural barrier "close" to the crossing whose mitigation is unplanned.
- Exemption from state fish passage laws. Possible reasons for exemptions could include:
    - Culvert is relatively new and has significant remaining design life, but has failed in some way, demanding a retrofit to ensure crossing capacity, safety and sustainability.
    - Full culvert replacement is planned as a part of a future roadway project (within 5 or 10 years).
    - Design is very close to meeting fish passage criteria and is granted exemption to criteria on an experimental basis.

4.2 Survey of Current Practices

A survey of states reveals:

Baffles

- Baffles create a series of short, high velocity, runs between baffles and a series of low velocity backwater areas behind baffles. This allows fish to swim in short bursts and then rest as they progress through the length of the culvert
- Extensive research has been done to show the positive effect of baffles on both culvert velocities and on fish passage.
- Baffles are not recommended for slopes greater than 3.5% since at steeper slopes the flow range that provides passage becomes very small.
- Outlet velocity and scour barriers are not resolved with this method.

Tailwater Control Structures

- Tailwater control structures cause water to slow down and back up into the culvert itself, providing favorable depth and reduced velocities within the culvert.
- Over time, tailwater control structures can create the embedded condition of slip lined culverts.
- Proper tailwater control design can provide a crossing with both subcritical water profiles at fish passage design discharges and supercritical water profiles for high flow conveyance.
- References to this literature, as well as descriptions are included

A general strategy for determining which structures to use when faced with common passage barriers includes:

- Flow Depth Barrier
  - Baffles to create pools
  - Tailwater Control Weirs
  - Longitudinal Channel Weir
- Velocity Barrier
  - Baffles to create roughness
  - Tailwater Control Weirs
- Jump Height Barrier
  - Tailwater Control Weirs
    - provide higher water surface elevations
    - provide grade control to prevent further perching
    - provide step pool fishway

An internet survey of state transportation and fish and game agencies shows that few agencies have considered slip lined culvert retrofit as a solution when fish passage is required, while still fewer have installed compliant structures. Case studies of four such successful installations are included in this report.

- John Hatt Creek Retrofit. Mendocino County, California
- Cape Elizabeth, Maine Retrofit

- Belfast, Maine Retrofit
- Falmouth, Maine Retrofit

Practical issues such as: constructability, durability, sediment clogging and maintenance were posed to those individuals with experience in baffles and tailwater controls. Specific key comments relating to slip lined culvert retrofits are also included in the document and described in detail, including:

Baffles

- Culvert retrofit design life is generally limited by baffle design life
- Sharp crested and v-notch baffles and weirs tend to trap organic matter more than broad-crested baffles and weirs.
- Baffles attached through plastic welding either in the field or by culvert manufacturers.
- Baffles should not be considered for culverts less than 3.5-ft in diameter due to difficulties accessing the culvert interior for installation and maintenance.

Tailwater Control Structures

- Should be considered before baffles because installation and maintenance is much more simple
- Embedded “Jersey Barriers” or “K-rails” are attractive because these structures are durable and readily available to transportation agencies
- Primary mode of failure is not material based, but design based.
- Rock weirs are an attractive alternative that requires more elegant design.

Because the science of slip lined culvert retrofitting for fish passage is relatively new, it is imperative to further the practice through reporting on successes and failures of these projects. Monitoring is essential to identifying these successes and failures, and costs and effort expended in the monitoring of initial projects can be leveraged over future projects and should be vied as a program investment.

4.3 Conclusions

We conclude that:

- Slip lined culvert retrofits are a simple and inexpensive option which should be considered only given specific conditions.
- Almost all slip lined culvert retrofits should be accompanied by velocity mitigation.
- Successful velocity mitigation is possible, and will usually include:
    - Culvert baffles
    - Tailwater control structures
- Post-project monitoring is essential to the advancement of slip lined culvert retrofit technology.

5 Recommendations

Slip lined culvert retrofits can successfully rehabilitate culverts at a fraction of the material cost, time, and traffic impedance that would be incurred by full excavation and replacement. While many organizations refuse to consider this method at all, it is the opinion of the authors that choosing to use this method when conditions permit may free up funds to allocate to higher priority crossings. Many recommendations for successful installation are found within the text of this document. This section discusses recommendations for future research.

It is fundamental that this technology be further vetted through the reporting of design, application, monitoring, and post-project assessment. The numbers of culvert rehabilitation or replacement projects which have employed slip lined culvert retrofit when fish passage is essential is so sparse that conclusions are somewhat compromised by the small of sample size. This can be accomplished by creating a culvert test facility and following up with a survey of current practices 5 or 10 years in the future.

5.1 Culvert Test Facility

It is difficult to champion specific design techniques for the vast range of potential culvert rehabilitation and replacement projects. This becomes increasingly difficult as issues of biological importance are considered, namely fish passage. Carefully recorded and measured practice is essential to developing general guidelines for fish passage in slip lined retrofitted culverts. Accumulating experience in practical application in this field is rife with delay. Agencies have been hesitant to grant permits to slip lined retrofits without more data, specifically successful data. When projects are permitted, reporting successes and failures is rare due to insufficient monitoring, often due to a lack of funding.

A proposed culvert test facility would provide an arena to build data to support or refute the benefit of slip lined culvert retrofits for fish passage. This culvert test facility should be capable of:

a. Interchanging pipe sizes and materials
b. Slope adjustment
c. Various tailwater conditions (i.e. tailwater weirs, grade controls, etc.)
d. Live testing of native Utah fishes
e. Recording instrumentation
    i. Analyze hydraulic characteristics
    ii. Fish behavior

A number of potential retrofit sites should be selected. These should be sites that do not require immediate attention, but are on the horizon and conform to the justifiable conditions found in the body of this document. Multiple slip lined retrofit design alternatives should be tested and assessed. Data of successful designs should be included in permit applications for retrofit sites. Implementation of design in the field, as well as monitoring data should inform more testing. This recommendation will be considered in Phase II of the project.

5.2 Follow-up Industry Survey

Slip lined culvert retrofit is a young technology and involving fish passage is an even younger technology. While the survey described in this document resulted in a few cases where retrofits have been performed with fish passage in mind, these cases were also relatively new. The long-term sustainability, durability, and more data relating to maintenance and debris accumulation of these projects are not tested. Additionally, several agencies were interested to learn of the results of this study, and should be sent a copy of this report. Some of these agencies are interested because they have not considered slip lined retrofits capable of fish passage. Others have expressed a desire to expand the methods available to them to include slip lined culvert retrofits for fish passage while still others have multiple projects in design that involve slip lined culvert retrofit for fish passage. There is excitement throughout the country regarding this cost-effective and simple retrofit method.

It is recommended that the Utah Department of Transportation establish a plan to follow-up on this study with another similar industry practice survey in 5 or 10 years. The aim of this survey would be to increase the amount of data available to UDOT design engineers. The goals of this recommended study would be very similar to this report. Specific points of emphasis should include:

a. Reporting of case studies – Successes AND Failures
b. Pre-retrofit conditions conducive and not conducive to slip lined culvert retrofit for fish passage
c. Velocity mitigation techniques related to pre-design and desired conditions
d. Experiences relating to constructability
e. Sustainability
    a. Durability
    b. Maintenance, and
    c. Debris accumulation – particularly because the primary respondents addressing debris accumulation came from Maine and California, hardly representative of the geology of Utah.
f. Future plans utilizing this technology, if any

This survey should also include the experience of UDOT retrofits, as well as details relating to culvert test facility.

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Appendix A Hydraulic Analysis Data

Calculations used to populate the tables and figures in the Culvert Hydraulics Software Analysis section of this document can be found on the accompanying compact disk.

Appendix B List of Acronyms

This section contains a list of the acronyms used in this report and their definitions.

CALTRANS: California Department of Transportation

CAP: Corrugated aluminum pipe

CHDPE: Corrugate high density polyethylene

CMP: Corrugated metal pipe

CSP: Corrugated steel pipe

ESA: Endangered Species Act of 1973

FEMA: Federal Emergency Management Agency

FHWA: Federal Highway Administration

HDPE: High density polyethylene

HDS: Hydraulic Design Series

MDIFW: Maine Department of Inland Fisheries and Wildlife

MDOT: Maine Department of Transportation

OHW: Ordinary high water

PVC: Polyvinyl chloride

UDOT: Utah Department of Transportation

USDA: United States Department of Agriculture

Appendix C Results of Internet Survey

The following section contains the questions and answers of respondents to the online survey of state transportation and fish and game agencies, as well as some nation-wide agencies. Over 100 survey requests were sent to these various agencies, with a total of 24 responses cataloged. Several others responded by email that they had no experience with slip lined retrofits which included fish passage considerations.

Alabama Department of Transportation

Organization or Agency Address

Alabama Department of Transportation
1409 Coliseum Blvd
Montgomery, AL 36110

Preferred Contact

Dave Ramsey
ramseyd@dot.state.al.us

What experience does your organization have with slip lining culverts?

None.

Has this experience included mitigation measures for fish passage?

No response.

Alaska Department of Fish and Game

Organization or Agency Address

Alaska Department of Fish and Game

333 Raspberry Road

Anchorage, AK 99518

Preferred Contact

Steve Albert

Steve.albert@alaska.gov

What experience does your organization have with slip lining culverts?

We have essentially no experience with sliplining technology. A small local subsidiary was recently formed to introduce sliplined culverts and prepared a brief informal presentation to us. I am not aware of any participation by ADF&G in any actual project reviews or proposals.

Has this experience included mitigation measures for fish passage?

No response.

What tools (software, forms, etc.) have you used to analyze these cases?

No response.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

We have been involved with a small number of culvert projects utilizing baffles and to a lesser extent, outlet area step-pools.

What methods have been successful/unsuccessful? Why?

As mentioned, we have a very limited number of road-stream crossing where retrofits have been employed. Where the department has had the opportunity to be involved early in the project to represent fishery values, swimming performance, etc., we have experienced varying degrees of success in re-establishing fish passage. As previously mentioned, we view retrofits as a last resort solution to achieve fish passage. Nevertheless, we have obtained funding to implement a retrofit design (outlet step-pools) in an extremely high-value fish stream to restore fish passage for juvenile salmonids through a set of perched culverts.

What are your future plans (if any) relating to slip lined culvert retrofits?

We have no specific future plans or interest in slip-lined culvert retrofits. We have specific statutes in place that require project proponents to provide for free and efficient fish passage and believe that culverts should be designed to achieve that result. If, over time, culverts cannot pass fish, we are generally hesitant to rely on retrofits as they are generally short-term solutions that require and increase existing maintenance responsibilities.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

Alaska Department of Transportation/Public Facilities – Mike Knapp
Tongass National Forest – Robert Gubernick

California Department of Transportation

Organization or Agency Address

No response.

Preferred Contact

Glenn DeCou, Chief
Office of Highway Drainage Design
916-653-1302

What experience does your organization have with slip lining culverts?

Our Department has no experience, per se, with such types of liners where fish passage is a concern. It is a rare situation where construction/installation of a liner would lead to fish passage compatible conditions due to the reduced diameter and decreased barrel roughness that would ensue. Where fish passage is an issue to address, and here in California we have to obtain what's called a streambed alteration permit from our Department of Fish and Game whenever wee touch a "blue line" (or even smaller) stream, and that will immediately invoke the requirement to address fish passage if it is a fish bearing stream, we have to show that what we're doing will accommodate passage. So it's a situation where we simply aren't going to be able to get a permit if fish passage has to be addressed and we try to use a liner. We would be very leery of putting any kind of baffles in culverts that get lined since: a) these would typically be relatively small culverts that get lined and any baffle would create a significant clogging potential, and b) we generally use HDPE liners, and attaching a baffle to HDPE liners is very difficult and are likely to get torn out during heavy storms.

Has this experience included mitigation measures for fish passage?

No response.

What tools (software, forms, etc.) have you used to analyze these cases?

No response.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

From Marcin Whitman (California Department of Fish and Game; mwhitman@dfg.ca.gov): I know of only one slip culvert job completed in my area that was on a Caltrans project on Rt. 128. The new culvert had baffles placed in it and a series of weirs were placed to address the perch downstream. This situation is unusual because of a fish barrier 50 or so yards upstream of the culvert in question.

Connecticut Department of Transportation

Organization or Agency Address

Connecticut Department of Transportation
2800 Berlin Turnpike
Newington, CT 06131-7546

ConnDOT
PO Box 317546
Newington, CT 06131-7546

Preferred Contact

Michael Kelley, P.E.
Hydraulics and Drainage Section
michael.kelley@po.state.ct.us
860-594-3240

What experience does your organization have with slip lining culverts?

We have some slip lining experience on culverts 6 ft in diameter and larger. Maybe 6-10 ft. We have a number of slip lining projects in design. Typically, metal culverts have been used as the liner, while PVC and HDPE have been used occasionally. We anticipate the use of more 'plastic' pipes as liners.

Has this experience included mitigation measures for fish passage?

No fish passage included yet, however the CT Department of Environmental Protection has requested wildlife passage for some of the slip line projects that are in design.

What tools (software, forms, etc.) have you used to analyze these cases?

HY-8, HY-8 Energy, I would anticipate that HEC-RAS may be used when appropriate.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

The wildlife passage request was addressed by forming a low flow channel in the concrete paved invert of the CMP arch liner. Small baffles (say 2" high) will be used in a 6 ft diameter HDPE liner, again for wildlife, not fish passage.

What methods have been successful/unsuccessful? Why?

These projects have not been constructed yet.

What are your future plans (if any) relating to slip lined culvert retrofits?

We anticipate a significant number of slip line projects in the near future. We will be looking at HDPE & PVC materials. It is presumed that the baffles, roughness elements and rock weirs at the outlet will be used as the need arises.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

Try

CT-DEP Fisheries Inland Fisheries Division Headquarters
79 Elm Street
Hartford, CT 06106
Phone: 860-424-3474
Fax: 860-424-4070
Email: dep.inland.fisheries@po.state.ct.us

Maine Department of Inland Fisheries and Wildlife

Organization or Agency Address

Maine Department of Inland Fisheries and Wildlife
358 Shaker Rd.
Gray, Maine 04038

Preferred Contact

James Pellerin

James.pellerin@maine.gov

What experience does your organization have with slip lining culverts?

As a fishery resource agency we are very concerned about the use of slip liners, and their expanding use by local municipalities and State Transportation agencies. Polyethylene slip liners and smooth bore plastic culverts are becoming more popular for new or replacement installations due their longevity and low cost; however, we believe they are creating serious fish passage problems around the State. A review of flow capacity specifications for Snap-Tite, a local distributor of slip liner technology, reveals that in all applications where smaller diameter Snap-Tite Solid liners are installed in existing corrugated metal pipes (CMP) flow capacities are increased, even though effective pipe size is decreased. For example, when a 28-inch (26 inch inside diameter) solid liner is installed in a 30 inch (inside diameter) CMP the new liner provides 187% of the original capacity provided by the metal pipe. The increase in capacity results from the smooth walls and nonwetting characteristic of polyethylene, which reduce friction within the pipe. Based on some hydraulic modeling software provided by the MDOT, the increased velocities that result from slip liner and smooth bore polyethylene culverts usually far exceed that which can be negotiated by most fish typically occurring in Maine streams. Furthermore slip liner projects effectively increase the invert elevation, creating a hydraulic drop at the outlet, which creates an additional obstacle to fish passage. Increased flow velocities within the pipe also increase downstream scour, which can lead to degradation of the outlet plunge pool, important staging habitat for fish attempting to pass through culverts. Resulting erosion can also create “head cuts” or nick points that cause additional scouring of the stream channel and associated habitat degradation.

We have evaluated fish passage of a full size replacement plastic culvert under a very low gradient situation with some tailwater control to back up water the full length of the pipe. Results are presented below.

STREAM FISHERY INVESTIGATION (08/06/03)

- Stream
    - Meader Brook, Falmouth (043005)
- Purpose
    - To evaluate fish passage of juvenile BKT through an experimental installation of smooth plastic pipe. If juvenile fish unable to pass, Town has agreed to modify pipe as needed to provide adequate passage.
- Regulations
    - Open under general law regulations.
- Stocking History
    - Not stocked, wild trout are present in the system. However, 60 juvenile BKT ranging from 84-148 mm were stocked in 2003 to examine passage through the pipe.
- Background
    - An MDEP application by the Town of Falmouth for a culvert replacement involved the installation of a longer culvert due to a steep ravines and the use of a smooth, plastic culvert. MDIFW reviewed the document and was concerned that the extensive length of the pipe (122 ft) and accelerated flows through a smooth pipe might prevent, limit fish passage of juvenile, wild BKT present in the stream system. A high percentage (92-98%) of our wild BKT populations consist of individuals less than 6 inches in length.

Although somewhat variable, the literature I reviewed suggests recommended maximum velocities for upstream passage of juvenile salmonids to be in the 0.5 to 1.8 fps range, depending on fish length. The Town's engineer, Steve Stearns, was asked to predict/estimate velocities for the proposed installation. Predicted low flow velocities in the pipe were estimated to be 3.28 fps, which was substantially higher than literature recommendations. We suggested the applicant review other options (i.e. corrugated pipe, baffles) to reduce the velocity to at least 1 fps. Although corrugated pipe came close to the desired 1 fps, the Town really wanted to try plastic pipe. Steve ran through a myriad of scenarios and calculations to come up with a solution, but theoretically calculations kept indicating even baffle systems wouldn't pass fish due to velocities through the notch that exceeded juvenile burst speeds. In reality, this just didn't make any sense given the extremely low slope (0.4%) of the proposed pipe. In addition, Jim Morrison of Wildstone Engineering had conducted experiments where he has passed juvenile rainbow trout (50mm) through his notched baffles in pipes with slopes as high as 5.0%.

Steve conducted some additional calculations of velocities taking into consideration the proposed 6 ft of embedment. These figures suggested velocities that were approaching the desired 1 fps at the outlet end of the pipe, but velocities would likely increase as one proceeded up slope towards the inlet. In addition, I recommend the construction of a small hydraulic grade at the outlet pool to further impound water within the pipe. Given that an existing manmade and natural barrier to passage was located a short distance downstream, it was decided to proceed with his project on an experimental basis. The pipe would be installed proposed including the 6-inch embedment and a small hydraulic grade at the outlet. Fish passage would then be tested with actual juvenile trout by stocking and observing their ability to migrate through the culvert. If fish were unable to pass, the Town agreed to further modify the pipe with artificial corrugations and/or baffles to try and achieve passage.

- Procedure
  - Sixty FF brook trout were hand selected from the Dry Mills hatchery for the project, which ranged in size from 84mm-148mm. Stocked fish were marked with an adipose fin clip to differentiate from wild fish already present in the system. A blocking seine was placed at the outlet end of the culvert including a small area of the pool for resting, and another was placed 112 ft upstream of the inlet end of the culvert. Brook trout were then stocked at the outlet end of the culvert. Signs were posted explaining the project and requesting individuals to not disturb the site.

    After approximately 24 hours, we revisited the site and immediately placed a blocking seine at the inlet end of the pipe to prevent fish that had or had not migrated through the pipe from moving into or out of the pipe during sampling. We inspected the site to insure that the original barriers were still intact before proceeding. We then conducted a 3-pass removal with a backpack electrofishing unit to estimate the number of trout within the pipe, and in the 112 ft section immediately above the pipe. All trout sampled were also measured and weighed.
- Findings
  - Temperature was 18oC.
  - Immediate reaction based on viewing the site was that juvenile trout should be able to pass through the culvert. The slope was very gentle and water was impounded almost the entire length of the pipe.

- The following table characterizes water depth, material depth, and flow within the pipe:

Culvert Location	Velocity (fps)	Water Depth (in.)	Substrate Depth (in.)
Inlet end	0-0.6*	4.13	0
Mid-pipe	0	3	3.5
Outlet end	0	6.75	4

*Readings were very unstable; it appears flow meter is not very sensitive to flows less than 1fps.

- Checked several natural riffles and runs with flow meter, fastest measured flow was 1.6 fps. Based on my observations, I would predict juvenile trout would have no problem navigating these velocities through natural materials and most of these sections were very short reaches with resting areas created by natural materials.
- The following table summarizes our electrofishing results:

Site	Stocked Brook		Wild Brook Trout	
	Total #	Pop. Est. (95% CI)	Total #	Pop. Est. (95 % CI)
Within Pipe	37	37 (+/- 0.15)	7	NA
Above Pipe	17	17 (+/- 0.3)	23	23 (+/- 1.3)

- We recovered 54 (90%) of the stocked brook trout. Given our high degree of confidence, we suspect the remaining 6 fish escaped the study area or were removed by predators (a mink was observed immediately below the site while electrofishing).
- 31.5% of the stocked trout recovered had migrated through the entire length of pipe and were distributed throughout the 112â€™ upstream reach.
- 68.5% of the stocked trout recovered were still located within the pipe. However, the majority of fish easily evaded the electric current though

the entire length of the pipe and were not captured until they were trapped by the blocking seine at the upper end of the pipe. I suspect many of the trout liked the seclusion/cover offered by the pipe and would have dispersed given more time.

  - We recovered a fair number of wild trout during the sampling indicating that a good population of wild fish is still present in the system. Wild trout ranged from 49-137mm, again suggesting the relatively high percentage of juvenile or sub-legal trout in our wild populations and the importance of providing adequate passage for smaller sized salmonids.

- Conclusions
  - The pipe appears to provide adequate passage for juvenile brook trout, and the Town of Falmouth does not need to do any further modifications to the culvert.
  - It is believed the combination of embedding the pipe and providing a hydraulic grade control structure at the outlet substantially improved fish passage at the site.
  - This experiment suggests the use of plastic culverts in similar situations (slopes less than or equal to 0.4%) with similar techniques (i.e. embedding pipe, grade control structures) will likely pass juvenile salmonids. Based on flow measurements within the pipe, even slightly higher gradients may accommodate juvenile fish passage.
  - Given the longevity of plastic pipe, the long-term environmental benefits would be a benefit to stream systems over continual replacements of metal culverts having much shorter life expectancies. However, fish passage is still a concern with the use of smooth bore plastic pipes, which tend to significantly increase flow velocities over standard corrugated metal pipes. The plastic pipe industry should redesign their culverts with interior corrugations or additional roughness to address this concern.

  - In regards to fish passage, slip liners are still another story. Unlike the plastic culvert used in this study, liners tend to significantly reduce the interior volume of the original culvert designed for the site, yet pass more or equal flow due to the extreme smoothness of their interior. This equates to velocities and depths within the liner that often impede passage even at relatively shallow slopes. In addition, the thickness of the liner and/or pumped concrete between liner/original may create or further enhance hanging culvert situations.
  - Slip liners are very attractive due to their substantial cost savings, and the ability to restore culverts without closing down roads for new installations. As a result, liners are being installed by many Towns without MDEP or MDIFW review under the maintenance exemption. Yet, in many cases they are likely impeding passage and fragmenting fish habitat. Given the longevity of liners, these fragmentations will likely not be corrected for decades or even over a century.
- Recommendations
  - Check velocities at the Meader Brook culvert during higher flow events to collect additional information. Based on the water line in the pipe, the culvert passes substantial flows in the spring; however, bottom velocities are expected to be relatively low given the 2-3â€™ of water depth in the pipe.
  - MDEP should review the use of slip liners, and provide guidelines for sites where liners are suitable for use under the maintenance clause.
- Prepared by James Pellerin

Has this experience included mitigation measures for fish passage?

Tailwater control and burying the pipe has been used successfully in a very low gradient, non slipline situation (above)

What tools (software, forms, etc.) have you used to analyze these cases?

No response.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

Strips of PE welded to bottom of culvert has been used by MDOT, evaluations unknown.

What methods have been successful/unsuccessful? Why?

See above.

What are your future plans (if any) relating to slip lined culvert retrofits?

In our opinion, impediments and barriers to fish passage will generally be created using slip liners and smooth bore culverts. They also change stream morphology (bankful width, velocity, headcuts) in manner that greatly increases the likelyhood of stream degradation. Consequently, we cureently discourage their use and only recommend they be used under the following situations: 1) In drainage ditches or similar circumstances where water is not being conveyed in a jurisdictional stream channel; 2) In streams where there are no fish present or where the presence of natural/artificial barriers prevent seasonal use by fish species lower in the drainage; 3) In very low gradient settings where water backs up the entire length of the pipe, and where the water depth at the inlet end of the liner/culvert is at least 4-6 inces deep at low flows; 4) Where a permanent, natural barrier is located upstream/downstream within 150 feet of the stream crossing. A permanent/natural barries is defined as a vertical drop of at least 4 feet over a rock/ledge substrate, as measured during summer low flows. Beaver dams would not be considered a permanent impassable barrier.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No response.

Massachusetts Highway Department (MassHighway)

Organization or Agency Address

MassHighway
10 Park Plaza
Boston, MA 02116

Preferred Contact

Rich Murphy
Richard.murphy@EOT.state.ma.us

What experience does your organization have with slip lining culverts?

MassHighway may use slip lining to rehabilitate highway cross culverts provided:

- there is a large differential between the roadway surface elevation and the culvert's invert elevations.
- and it can be demonstrated that the reduction in the culvert's diameter will not adversely affect it's capacity to convey design flows

Has this experience included mitigation measures for fish passage?

Not to my knowledge.

Montana Department of Transportation

Organization or Agency Address

Montana Department of Transportation
2701 Prospect Ave.
Helena, Mt

Preferred Contact

Mark Goodman, P.E.
Hydraulic Engineer
406-444-6246
mgoodman@mt.gov

What experience does your organization have with slip lining culverts?

Some, we have slip lined some larger CSP culverts along with smaller diameter PVC.

Has this experience included mitigation measures for fish passage?

None to date.

What tools (software, forms, etc.) have you used to analyze these cases?

No response.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

We have used baffles, downstream control structures, buried pipes, etc. for new installations but none for liners. Typically, the pipes we have lined have been almost entirely intermittent drainages.

What methods have been successful/unsuccessful? Why?

No response.

What are your future plans (if any) relating to slip lined culvert retrofits?

We will continue to look at sliplining and bore and jacking installations as a cost effective means of rehabbing existing culverts that are experiencing structural or corrosion issues.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No response.

Nevada Department of Transportation

Organization or Agency Address

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

Preferred Contact

Paul Frost, P.E.
Chief Hydraulic Engineer
775-888-7797

What experience does your organization have with slip lining culverts?

NDOT has lined numerous failing culverts. Mostly smaller diameter, 18-in. to 36-in. CMP that has corroded.

Has this experience included mitigation measures for fish passage?

The culverts we have lined have not had a need to consider fish passage. To date, they have included storm drains or washes that do not support fish habitat.

What tools (software, forms, etc.) have you used to analyze these cases?

None. But if we did look at this, we'd most likely use the HYDRIN package to estimate velocities, depths, etc.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

We have specifically designed culverts for fish passage, that have included baffles and ladders, but these were not slip lined applications.

What methods have been successful/unsuccessful? Why?

Our relatively few installations appear to have been successful, with ladders, etc. Again, no slip lined applications.

What are your future plans (if any) relating to slip lined culvert retrofits?

NDOT is anticipating lining numerous CMP locations in the future, mainly due to corrosion. We do not really have a plan for fish passage, as the anticipated locations currently do not support a fish population. All locations at this time are storm drains or typically dry washes.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

Possibly Nevada Department of Wildlife; ndowinfo@ndow.org

New York State Department of Transportation

Organization or Agency Address

New York State Department of Transportation
50 Wolf Road
Albany NY 12232

Preferred Contact

Wayne Gannett, P.E.
Hydraulic Engineering Office of Structures, Pod 4-3
518-457-9215

What experience does your organization have with slip lining culverts?

NYSDOT does culvert slip lining; don't have statistics on how many

Has this experience included mitigation measures for fish passage?

Not aware of fish passage provisions for plastic linings. In a few instances a concrete invert as been placed in existing large diameter corrugated metal pipe arch structures, to repair deteriorated inverts. A system of 6x6 wood baffles has been installed in the invert in some cases.

What tools (software, forms, etc.) have you used to analyze these cases?

No formal analysis that we are aware of.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

Wood baffles.

What methods have been successful/unsuccessful? Why?

Not aware of specific monitoring measures. In one instance a pipe with baffles installed requires additional downstream work to eliminate a headcut-induced outlet drop of several feet.

What are your future plans (if any) relating to slip lined culvert retrofits?

No specific plans, but we are interested in data on successful techniques for fish passage in slip lined culverts.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No response.

Ohio Department of Transportation

Organization or Agency Address

Ohio Department of Transportation

1980 West Broad Street

Columbus, OH 43223

Preferred Contact

Becky Humphreys, P.E.

becky.humphreys@dot.state.oh.us

What experience does your organization have with slip lining culverts?

We have slip lined many culverts.

Has this experience included mitigation measures for fish passage?

We do not design any culvert for fish. We just bury the invert to provide a natural channel bottom. When slip lined, the lining would also be buried in the same manner.

What tools (software, forms, etc.) have you used to analyze these cases?

No response.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

No response.

What methods have been successful/unsuccessful? Why?

No response.

What are your future plans (if any) relating to slip lined culvert retrofits?

No response.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No response.

Oklahoma Department of Transportation

Organization or Agency Address

Oklahoma Department of Transportation
200 NE 21st St. Rm 2-B-2
Oklahoma City, OK 73105

Preferred Contact

Leslie Lewis
llewis@odot.org

What experience does your organization have with slip lining culverts?

No Response.

What are your future plans (if any) relating to slip lined culvert retrofits?

No specific plans, but we are interested in data on successful techniques for fish passage in slip lined culverts.

Oregon Department of Fish and Wildlife

Organization or Agency Address

Oregon Department of Fish and Wildlife
3406 Cherry Ave. NE
Salem, OR 97303

Preferred Contact

Art Martin

503-947-6095

art.c.martin@state.or.us

What experience does your organization have with slip lining culverts?

We work closely with the Oregon Department of Transportation in a role as technical advisors on fish, wildlife, and habitat impacts, avoidance, minimization, and mitigation measures associated with transportation systems. We also specifically regulate all fish passage projects through our fish passage statutes. This process requires applicants to submit fish passage plans for ODFW review and approval including slip lining projects prior to construction of replacements or major repairs of any crossing that overlap with current or historic native migratory fish distributions.

Has this experience included mitigation measures for fish passage?

Absolutely.

What tools (software, forms, etc.) have you used to analyze these cases?

Review of various HEC-RAS modeling, project plan sheets, and a fish passage plan form provided by ODFW: http://www.dfw.state.or.us/fish/passage/

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

Baffles, weirs, bedload retention grids, tailwater control weirs, oversteepened channel reconstruction (roughened chutes), etc.

What methods have been successful/unsuccessful? Why?

They are all somewhat successful at improving upstream fish passage but unless a structure is completely backwatered throughout the entire migration period at all discharges, undersized culverts cannot meet state fish passage criteria and are therefore not allowed unless mitigated for elsewhere in the basin per our fish passage waiver option in our rules.

What are your future plans (if any) relating to slip lined culvert retrofits?

Slip lining culverts should not be used to facilitate fish passage except under a few unique hydraulic conditions in Oregon (see above).

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

Oregon Department of Transportation
Greg Apke
503-986-3518
greg.d.apke@odot.state.or.us

South Carolina Department of Transportation (SCDOT)

Organization or Agency Address

South Carolina Department of Transportation	SCDOT
955 Park Street	PO Box 191
Columbia, SC 29202-0191	Columbia, SC 29202-0191

Preferred Contact

Charles Smoak
803-737-1369

What experience does your organization have with slip lining culverts?

We have not used this method in any known projects to this date.

Vermont Agency of Transportation

Organization or Agency Address

Vermont Agency of Transportation
Program Development Division
One National Life Drive
Montpelier, VT 05633-5001

Preferred Contact

Nick Wark, P.E.
Hydraulics Engineer
Vermont Agency of Transportation
One National Life Drive,
Montpelier, VT 05633
Phone: 802-828-3987
Fax: 802-828-5742
Nick.Wark@state.vt.us

What experience does your organization have with slip lining culverts?

We slip line an increasing number of culvers every year. We have used Snap-Tite, aluminum plate pipes and arches pulled or pushed through on a rail system, CIPP such as Insituform, fold and form PVC, and have tried a spray-on system.

The inserts require pressure grouting the annular space to fill voids. Depending on issues at the ground surface or roadway, injection grouting through bore holes may be required. We have also used GPR to try and detect subsurface problems.

Has this experience included mitigation measures for fish passage?

Rarely. It has been our experience that we cannot meet fish passage design parameters for depth and velocity at desired flow rates. We have had success only in those instances where backwater through the full length of the barrel could be achieved. This may be a natural condition ath the crossing location, or accomplished through installation of downstream weir(s) providing a max 6 inch lift/weir.

What tools (software, forms, etc.) have you used to analyze these cases?

Flow rates are determined from USGS regression equations for mean annual flow applied at seasonal distributions. Elevations are determined by ground survey. HY-8 is used for depth/velocity determination. We have limited experience using FishPass.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

Issues with capacity have precluded use of baffles in slip lined retrofit situations. Downstream weir control has been utilized where ROW has been sufficient or permission of the landowner received. We have not attempted to add baffles to a slip lined pipe due to difficulties of installation and maintenance in various pipe materials, along with reduced waterway areas that make passage criteria that much harder to achieve.

What methods have been successful/unsuccessful? Why?

In large multi plate systems where the problem is confined to the invert area of the structure, where deformation has not progressed, where the danger appears to be loss of fines from around the pipe, we have installed up to a foot of concrete in the invert. Rebar is placed on a 12 x 12 in. grid and tack welded where possible. This type of repair can be used with a roughened surface, baffles, or random placement of embedded stone. In these cases, the goal is to simulate velocity and depth in the adjacent stream reach. Well placed stone clusters may recruit sediment and debris that could facilitate passage. Bottom characteristics will change yearly based on timing and distribution of large storm events that may scour the concrete surface. We have a couple of these in place with more planned for the ’08 construction season. Success and refinement of process will depend on long term experience.

We do not currently have a formal project to follow up with AOP monitoring at these sites. This is something we hope to work out with our resource agency in the future.

What are your future plans (if any) relating to slip lined culvert retrofits?

We plan to line as many as we can. The VTF&W Department, in many cases, has deferred AOP passage requirement until such time as replacement is warranted.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No Response.

Washington State Department of Transportation

Organization or Agency Address

Washington State Department of Transportation
310 Maple Park Ave. SE
Olympia, WA 9504

Preferred Contact

Matt Witecki	witeckm@wsdot.wa.gov
Jay Christianson	christj@wsdot.wa.gov

What experience does your organization have with slip lining culverts?

We have slip lined several culverts however none have been to mitigate fish passage barriers, all of our fish passage projects have upsized the culvert, or replaced it completely with a 3 sided structure, arch, or in some cases, a bridge.

Has this experience included mitigation measures for fish passage?

We have slip lined several culverts however none have been to mitigate fish passage barriers, all of our fish passage projects have upsized the culvert, or replaced it completely with a 3 sided structure, arch, or in some cases, a bridge.

What tools (software, forms, etc.) have you used to analyze these cases?

Depending on the size of the drainage, we could use something as simple as the rational method, or on larger systems something like HEC-RAS.

What methods have you used to mitigate? (i.e. baffles, tailwater control structures, etc.)

Upsizing, replacing with 3 sided structures so there is a natural streambed, etc.

What methods have been successful/unsuccessful? Why?

Leaving a natural streambed is very successful both in eliminating the fish passage barrier and in permitting issues.

What are your future plans (if any) relating to slip lined culvert retrofits?

They will continue to be used where fish passage is not an issue.

Are you aware of any specific organization or agency that has experience in this area or other contacts that would be beneficial to the purpose of this survey?

No response.

Appendix D Monitoring and Maintenance Plan

The following contains the Maine Department of Transportation Fish Movement and Hydrology/Hydraulics Monitoring and Maintenance Plan for Alewife Brook, Cape Elizabeth, Maine. This is the monitoring and maintenance plan for the Cape Elizabeth Retrofit case study.

Fish Movement and Hydrology/Hydraulics Monitoring and Maintenance Plan
MaineDOT Project 12992
Alewife Brook, Cape Elizabeth
23 August 2007

As a condition of permit, USFWS has requested that a rigorous, quantitative program of fish sampling and continuous hydrology/hydraulics monitoring be implemented from March thru November. This window corresponds to the complete annual period of alewife movement. Adults move up to spawn from late spring through early summer, while juveniles move out to sea from late summer thru late fall. The program description given here is general; a detailed protocol will be developed in time for start-up in March 2008.

This level of monitoring is unusual for a culvert improvement project, even one involving fish passage in a plastic pipe. However, the reservations of the resource agencies with regards to the continued use of plastic pipe are well known. In addition to advancing the permit of this particular project, the results of this program will be used to support the design and application, directly or indirectly, of future plastic pipe fish passage projects by MaineDOT. Thus, the cost and effort expended here will be leveraged over future projects and can be viewed as a program investment as opposed to an unacceptable burden imposed on one small culvert project.

The MaineDOT monitoring program can be no more effective than the maintenance of the fishery, the performance of the town culvert downstream, and the monitoring program for the town culvert. Significant MaineDOT resources are being invested in this program, in support of efforts to reestablish the alewife run. Success also hinges on efforts at the town culvert. MaineDOT understands that it cannot impose contingencies on the monitoring program or permit. In the spirit of collaboration in working towards reestablishing the alewife run, MaineDOT wishes to express the following hopes:

- MaineDOT hopes that the town monitoring program will be to same level of scientific rigor as the MaineDOT program, particularly with regards to quantitative fish counting and hydrologic/hydraulic data collection and analysis. MaineDOT is happy to share the contents of this program, along with follow-up technical details, with the town. (MaineDOT would also consider exploring an agreement with the Town of Cape Elizabeth, whereby MaineDOT would develop and implement a monitoring and reporting program for the town culvert. This arrangement offers the significant benefit of a consistent and systematic monitoring program along Alewife Brook.)

- MaineDOT's investment in fish passage measures and monitoring only make sense if there are reasonable expectations of successful alewife reestablishment and responsible management of the run. Therefore, MaineDOT hopes that the regulatory and resource agencies, as well as the Town of Cape Elizabeth, will manage a reestablished alewife run to prevent destruction by overharvesting as happened in the mid- to late-1980s.

MaineDOT commits to monitor fish passage for three years, subject to the following qualifications as accepted by USFWS:

- The program may be terminated prior to three years if federal and state resource agencies agree that sufficient data has been collected.
- The program also may be terminated prior to three years if federal and state resource agencies agree that issues with the town culvert warrant said termination.

MaineDOT will report annually on the results of monitoring. MaineDOT will submit reports no later than March 1 following the previous year's monitoring.

In addition to monitoring for three years, MaineDOT will also inspect and maintain the structure for the life of the structure.

Fish Movement Monitoring

American eels

Monitoring of American eels should begin in April and may continue into June, depending on flow in Alewife Brook. Conceptually, traps or fyke nets will be installed to capture eels moving upstream through the culvert. In order to determine efficacy of the MaineDOT structure, an additional trap/net will be placed downstream of the rock weir; efficacy of the structure will then be determined by comparing the fish counts in the upstream trap versus the downstream trap. All by-catch will be documented.

Because elvers (all juvenile eels <6") typically make their movements at night, some nighttime monitoring will be required, especially if no elvers are documented in the upstream trap.

Equipment Needs

For monitoring of the MaineDOT structure, two fyke nets or lumber and mesh material (to construct a trap) will be needed. In addition, a set of scales and a measuring board will be needed to weigh the elvers (depending on the size of the run it may be easier/quicker to weigh elvers than count them).

Staffing Requirements

Because the trap/net will span the stream channel, monitoring may need to be conducted on a daily basis, at least during the month of April into May, the peak of the migration. Some nighttime monitoring may also be required. It may be possible to partner with the Southern Maine Community College for staffing purposes. No fall monitoring of out-migrating adult eels is required.

Alewives

Conceptually, the monitoring of alewives will be similar to American eels—capture in-migrating alewives upstream of the MaineDOT structure. Two nets (upstream and downstream) will be monitored daily to determine efficacy of the structure. Alewives typically begin to move into freshwater beginning in early May through June. All by-catch will be documented.

Equipment Needs

For monitoring of the MaineDOT structure, two fyke nets or lumber and mesh material (to construct trap) will be needed. Depending upon the mesh size required MaineDOT may need to purchase two sets of nets (for a total of 4 nets) to account for the different species sizes (elvers <6"; alewives 10" – 12").

Staffing Requirements

Because the trap/net will span the stream channel, monitoring may need to be conducted on a daily basis during the run, at least during the month of May into June during the peak of the migration. It may be possible to partner with the Southern Maine Community College for staffing purposes. No late summer/fall monitoring of alewives (both adults and juveniles) will be required.

Cape Elizabeth Crossing

It is important that monitoring at the state and town culverts be held to a common level of expectations. Assuming that the town will be held to the same standards as MaineDOT, it may be desirable for MaineDOT staff to monitor eel and alewife passage, as well as hydrology and hydraulics, in the town structure as well. This arrangement would insure a high level of consistency in monitoring results and a more systematic approach to analysis and reporting. MaineDOT would be happy to explore an arrangement with the Town of Cape Elizabeth whereby an integrated monitoring program could be developed.

Hydrology/Hydraulics Monitoring

The basic program is one of continuous monitoring from March thru November. The objective is to quantify water levels and flow rates actually achieved. The information will be to document whether the design performs as expected, and also to provide data that can be used to modify the weir notch dimensions if necessary. The essential hydraulic measures governing fish passage are flow depth and velocity. Furthermore, alewife move in response to water temperature and flow rates. Thus, a useful monitoring program will address most, if not all, of these criteria.

General Description

A network of continuous water level (stage) dataloggers comprises the heart of the program. These loggers will continuously record water level and temperature at suitably small time intervals over the period March 30- November 30. Loggers will be located upstream and downstream of the culvert and rock weir so that a detailed water surface profile can be developed.

These loggers will be complemented by a logger recording barometric pressure and air temperature. This data network will allow for a comprehensive and systematic characterization of the watershed hydrology and hydraulics.

Continuous stage data logging will be augmented by discrete data collection assignments. Velocity transects will taken in the pipe and channel over a range flows so that stage-discharge-velocity rating curves can be calibrated for the pipe and weirs. Point velocity, water depth, and water temperature measurements will be included as routine elements in all site visits so as to provide quality checks against the continuous record.

Equipment Needs

- At least 3 continuous data loggers (e.g. Solinst Levelogger)
- 1 barometric logger (e.g. Solinst Barologger)
- velocity meter
- surveying equipment

Staffing Requirements

Some combination of the following will be used over the course of monitoring:

- hydrologist/hydraulic engineer
- fisheries biologist
- intern / technician

Appendix E Utah State DNR DWR Sensitive Species List

The following contains the introduction to the UDWR SSL and the list of target Utah fish species which possess some level of federal or state protected or threatened status.

State of Utah
Department of Natural Resources
Division of Wildlife Resources

Utah Sensitive Species List

December 14, 2007

This list has been prepared pursuant to Utah Division of Wildlife Resources Administrative Rule R657-48. By rule, wildlife species that are federally listed, candidates for federal listing, or for which a conservation agreement is in place automatically qualify for the *Utah Sensitive Species List*. The additional species on the *Utah Sensitive Species List*, "wildlife species of concern," are those species for which there is credible scientific evidence to substantiate a threat to continued population viability. It is anticipated that wildlife species of concern designations will identify species for which conservation actions are needed, and that timely and appropriate conservation actions implemented on their behalf will preclude the need to list these species under the provisions of the federal Endangered Species Act. Please see Appendix A for the rationale behind each wildlife species of concern designation.

Figure E-1: Introduction to UDWR SSL.

Utah Sensitive Species List

Fishes

Federal Candidate Species
(None)

Federally Threatened Species	
Lahontan Cutthroat Trout (introduced)	*Oncorhynchus clarkii henshawi*
Federally Endangered Species	
Humpback Chub	*Gila cypha*
Bonytail	*Gila elegans*
Virgin Chub	*Gila seminuda*
Colorado Pikeminnow	*Ptychocheilus lucius*
Woundfin	*Plagopterus argentissimus*
June Sucker	*Chasmistes liorus*
Razorback Sucker	*Xyrauchen texanus*
Conservation Agreement Species	
Bonneville Cutthroat Trout	*Oncorhynchus clarkii utah*
Colorado River Cutthroat Trout	*Oncorhynchus clarkii pleuriticus*
Virgin spinedace	*Lepidomeda mollispinis mollispinis*
Least Chub	*Iotichthys phlegethontis*
Roundtail Chub	*Gila robusta*
Bluehead Sucker	*Catostomus discobolus*
Flannelmouth Sucker	*Catostomus latipinnis*
Wildlife Species of Concern	
Northern Leatherside Chub	*Lepidomeda copei*
Southern Leatherside Chub	*Lepidomeda aliciae*
Desert Sucker	*Catostomus clarkii*
Yellowstone Cutthroat Trout	*Oncorhynchus clarkii bouvieri*
Bear Lake Whitefish	*Prosopium abyssicola*
Bonneville Cisco	*Prosopium gemmifer*
Bonneville Whitefish	*Prosopium spilonotus*
Bear Lake Sculpin	*Cottus extensus*

Figure E-2: List of Fish on UDWR SSL.