Broad Brook at Interstate 89
Preliminary Retrofit Fish Passage Design

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Prepared for Vermont Department of Fish and Wildlife

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Broad Brook at Interstate 89 - Preliminary Retrofit Fish Passage Design

This memo summarizes the preliminary design of retrofit options of the Broad Brook culvert under Vermont Interstate 89. This is in response to a request from Vermont Fish and Wildlife for a conceptual design to improve fish passage with a retrofit and without greatly extending the footprint of the structure.

Most of the design process for the preferred design and background data are contained in the Broad Brook Design Data Form, which is attached. Additional background, options, and process details are described here.

Existing culvert

The location and geometry of the existing culvert is described in the attached design data form.

The photo on the cover sheet is the culvert outlet. The effect of the backwater can be seen in the photo. The following photos show the existing culvert and adjacent channel.

Figure 1. Interior of existing culvert from inlet looking downsteam.

Figure 2. Upstream channel looking upstream from the culvert inlet.

Figure 3. Downstream channel looking towards the culvert. The culvert is just out of view in the upper center of the photo.

Channel characteristics were taken from survey notes from a September 9, 2007 survey conducted by Rich Kirn of VDFW and Shayne Jaquith of Vermont River Management Program. They used procedures described in Vermont Stream Geomorphic Assessment Handbook. They surveyed channel cross-sections upstream and downstream of the culvert and a thalweg profile from 200 feet upstream to 300 feet downstream of the culvert. They conducted a pebble count in an upstream riffle.

I visited the site on October 16, 2007 and walked the stream from below River Road to above SR89.

As-built information of the culvert was provided by USFWS. The survey data provided by USFWS and VDFW were based on different datums. The VDFW data was modified to make it comply with the USFWS survey; 11.04 feet was added to all elevations. The correction was based on the elevation of the culvert outlet in both data sets.

Fish passage through the Broad Brook culvert was assessed using FishXing 3.0 software at flows up to 301 cfs; the culvert was a total barrier. See the design data form for species and fish passage design flows and see the discussion below about hydraulic modeling.

The lower end of the culvert is backwatered at low flows. At 2.3 cfs, about a half of the culvert is backwatered. It is backwatered at flows up to about 100 cfs. Except for the backwatered section, the flow is supercritical. The upper end is a depth barrier at low flows and the lower end is a velocity barrier at high flows.

Channel Characteristics and Profile Control

The downstream channel has a bankfull width of about 37 feet. The bed is gravel with some cobble. There is evidence of aggradation; the channel is shallow and it is a divided channel about a hundred feet below the culvert. The banks have no woody vegetation and have been trampled by cattle. There is a wide pasture floodplain on the left bank. Rock ledge material several hundred feet downstream of the culvert forms a permanent grade control

Assuming that the culvert was built more or less on the channel grade, there is a likelihood that the downstream channel would degrade back to that elevation if the downstream channel were restored. There is little opportunity for more aggradation downstream because of the wide floodplain and low banks.

The upstream channel appears to be channelized. There is no floodplain. The bed is cobbles to boulders and obviously coarser than the downstream bed. The differences are obvious in the previous photos. It appears that very little of the cobble and boulder material is mobilized into the culvert.

These observations and the effect of the exposed ledge downstream should be assessed in the final design effort.

Hydrology

Hydrology was developed from StreamStats. For the design, one standard error of the flow estimates was added to each of the StreamStats flood estimates to calculate the design floods. See the design data form. These estimates might be improved in the final design.

Target Species

Target species were selected by VDFW and include rainbow trout, brown trout, brook trout and Atlantic salmon. The design analysis focused on rainbow trout as the critical target species because it has a lower swim capability and it migrates in the spring when flows are generally higher. Any solution for rainbow trout will likely satisfy brook trout, brown trout and Atlantic salmon. Juvenile of these species might be present and but weren't directly addressed though passage for them would likely be improved by any of the options considered.

Hydraulic Analysis

FishXing 3.0 software was used for the hydraulic analyses for fish passage and flood capacity. Culvert characteristics were based on scaled dimensions from CAD drawings provided by USFWS. Upstream and downstream channel slopes, elevations, and cross-sections were based on survey data provided by Kirn and Jaquith. Channel roughness was estimated based on D84 from pebble counts provided by Kirn and Jaquith and calculated using a channel roughness model described by Limerinos (1970).

The culvert is a non-standard shape egg shape. A number of culvert shapes can be analyzed within FishXing but this one is not one of them. To model it, it was assumed to be a circular pipe with a diameter of 22.4 feet as shown in Figure 4. This assumption is accurate for modeling to a water depth up to about 5 feet. The floor of the culvert is not actually circular; it appears to be formed with chord segments that each have some curve to them. The culvert shape should be accurately measured in the final design.

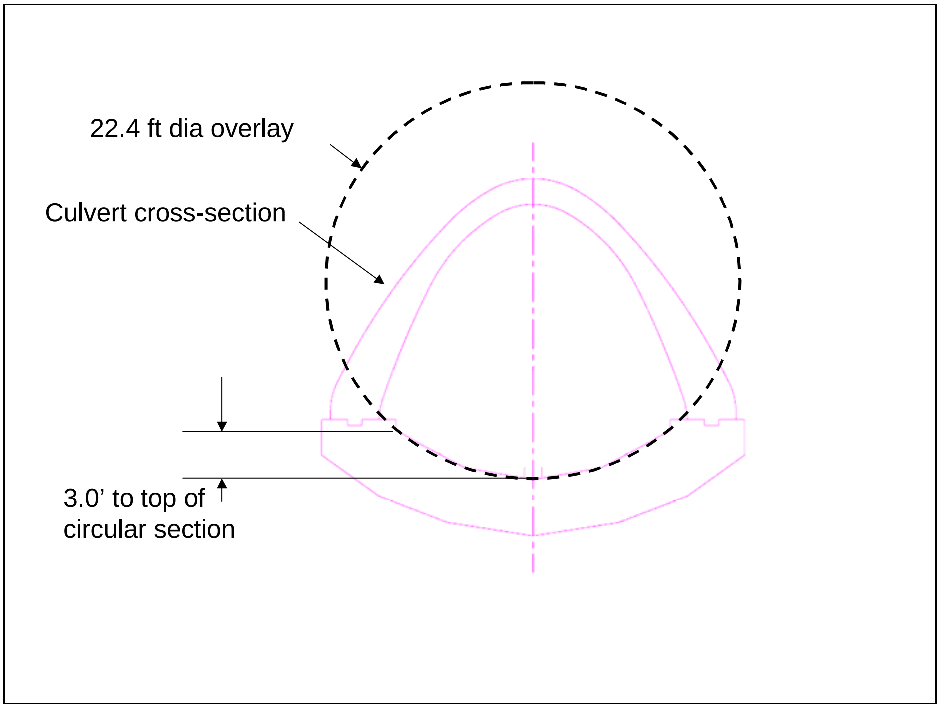

Figure 4. Broad Brook culvert cross-section with 22.4-fooot circular culvert overlay that was used for analysis.

A limitation of the FishXing software is that it does not calculate backwater accurately for overbank flow conditions. It does not route and calculate in-channel flow and floodplain flow separately. As stage increases from bankfull to overbank, the overall hydraulic radius of the channel is greatly reduced and the overall roughness can be greatly increased if the floodplain is rough. Because of this the tailwater rating curve is discontinuous at bankfull stage as can be seen in Figure 5, which is the tailwater rating curve from FishXing. In reality, the curve cannot cross back on itself and, for this project, would continue as an extrapolation of the lower portion of the curve from 0 to 700 cfs.

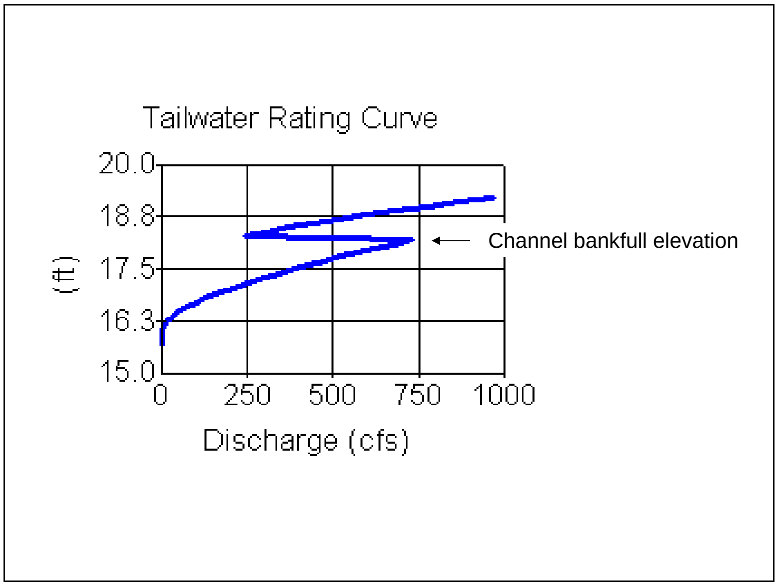

Figure 5. FishXing tailwater curve showing discontinuity as flow goes overbank.

That's not a problem for the fish passage analysis because the bankfull stage happens to occur at 300 cfs, equivalent to the high fish passage design flow. An accurate tailwater curve was developed with WinXSPro software to estimate the bankfull flow. The tailwater and analysis at lower flows are not affected by the discontinuous rating curve in FishXing. The analysis at higher flows is affected however. The tailwater curve in the analysis is likely about a foot higher than it should be for flows above about 300 cfs. This is a conservative design and should be improved in the final design with a more accurate backwater model. The next step would be to use the WinXSPro tailwater relationship in the FishXing model.

Retrofit Passage Designs Considered

At the request of VDFW, only retrofit designs were considered. Retrofit designs are based on VDFW hydraulic criteria of depth and velocity. For the primary target species of rainbow trout, a depth of at least 0.5 foot and a velocity no more than 3.2 fps are required.

The maximum velocity design criteria cannot be achieved by work solely within the culvert. As roughness is added to reduce the culvert velocity, the hydraulic profile is raised and a drawdown is created near the culvert outlet as the flow drops to the tailwater. Velocity within that drawdown cannot be controlled to satisfy the criterion.

To achieve the design criteria it is necessary to raise the downstream channel with a roughened, channel, profile control sills, or a fishway. Those options are not pursued here but are investigated to the point to know whether they can be accomplished and to be sure they are not precluded by the design recommended here.

Fish passage options were compared by their relative passability, which is defined here as the percentage of flows within the fish passage design flow range that are passable as calculated by hydraulic models. No solution could be found within the limits of the project definition that was 100% passable.

Roughen pipe with corrugated plates – Recommended Option

To add roughness, corrugated plates can be attached to the floor of the culvert. This is the recommended option.

The purpose of using corrugated plates is to add low prfile roughness. The low roughness will minimize the flow blockage and overall roughness. They will therefore minimize the increase in hydraulic profile. The resulting average cross-section velocity does not comply with the VDFW criteria but it is assumed that fish will use the boundary layer created by the corrugated plates. A design data form is included in the appendix to further describe this option.

The lower part of the culvert cross-section is about circular so standard corrugated structural plates should fit into the culvert. The plates would be bolted in place and form a continuous floor through the culvert up to about three feet above the culvert invert. Two manufacturers of structural corrugated plate were contacted and confirmed that custom diameters of corrugated plate can be produced.

As described above, the backwater effect of the downstream channel is not clear. The length of culvert to be lined with corrugated plates, or any other roughness option, will depend on a more thorough analysis of the backwater. As described above, the calculation of backwater effect of the downstream channel is not precise. Additional survey of the downstream channel and calculation or monitoring of backwater effects are recommended for final design.

The preliminary analysis shows that the entire culvert would have to be roughened. The lower third of the culvert is backwatered at 300 cfs so the roughness is not needed for that flow. The culvert is just barely backwatered at 200 cfs though so the roughness is needed. If the downstream channel degrades, the entire culvert may have to be lined.

<u>Corrugated plate baffle hydraulics</u>

This option depends on the low velocity within the boundary layer of the corrugated plates. Calculation of two-dimensional hydraulics of boundary layers is less certain than calculation of average cross-section channel hydraulics. Boundary layer hydraulics with the corrugated plates were calculated using a model by Mountjoy (1986). The accuracy of that model was confirmed by comparison with other models described by Barber and Downs (1996).

The results of that analysis are shown in Table 1. Deep (2x6") and shallow (1x3") corrugations were tested. The table shows the five flows that were tested, the average velocity for each condition (Vavg), the depth of flow (Yo), and the width of the low velocity zone (Y). The low velocity zone is the width of the boundary layer defined as having a velocity equal or less than the fish passage target velocity using the Mountjoy model. The target velocity is 3.2 fps, which is the allowable culvert velocity for rainbow trout for culverts longer than 200 feet.

Table 1. Results of Mountjoy model for corrugated plate baffles. Target velocity 3.2 fps.

Rainbow trout

N	0.032	2x6" corrugations			
Flow (cfs)	2.3	20	50	100	301
Vavg (fps)	1.6	3.2	4.2	5.3	7.3
Yo (ft)	0.26	0.84	1.36	1.94	3.4
Y (ft)	0.58	0.31	0.29	0.28	0.29
N	0.027	1x3" corrugations			
Flow (cfs)	2.3	20	50	100	301
Vavg (fps)	1.8	3.6	4.8	5.9	7.9
Yo (ft)	0.23	0.77	1.24	1.78	3.21
Y (ft)	0.35	0.22	0.19	0.18	0.19

The width of the calculated boundary layer varies from 0.58 to 0.28 feet with the deep corrugations and from 0.35 to 0.19 for the shallow corrugations. Even with the deep corrugations, these boundary layers are marginal for a fish passage but considered suitable for continued design.

Passage conditions are improved by either corrugation design. Conditions are most improved with the deeper corrugations, which is therefore the recommended design. There might be trade-offs of cost and constructability that would affect that choice.

The effect of the added roughness to the upstream channel is that the headwater depth is raised about two feet during a 100-year flood. This analysis is with the FishXing software, which doesn't recognize the actual shape of the culvert and uses the worse case condition of the entire culvert being rough so these estimates are not precise but conservative. That much change in headwater depth does not appear to cause flooding outside the channel though it may cause some minor temporary deposition.

The pipe was modeled based on dimensions scaled from CAD drawings provided by USFWS. Based on those drawings, the lower three feet of the culvert cross-section is approximately circular with a radius of 11.2 feet. With the deep corrugations, the water depth is 3.6 feet at 301 cfs, slightly higher than the circular section. Culvert dimensions must be field verified for further design.

Figure 6, Figure 7, and Figure 8 show the hydraulic conditions with the corrugated baffles at 3.2, 75, and 301 cfs. The average velocities and the velocities in the occupied zone are shown. These are calculated from FishXing by using a velocity reduction factor so the velocity in the occupied area was near 3.2 fps at 301 cfs. These correspond with conditions in Table 1.

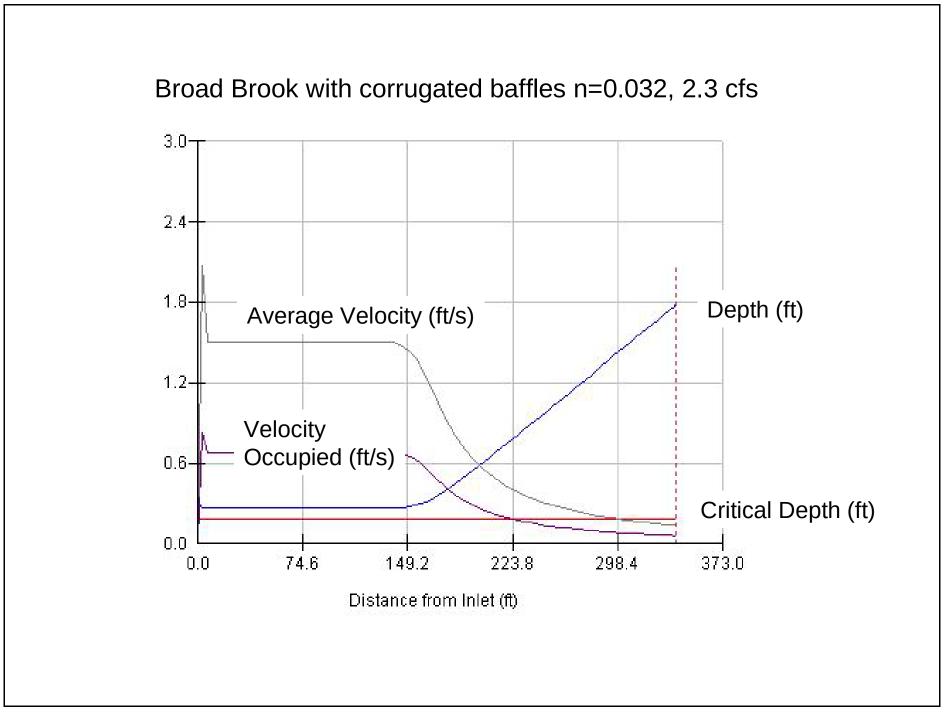

Figure 6. Hydraulics of corrugated baffles at 2.3 cfs.

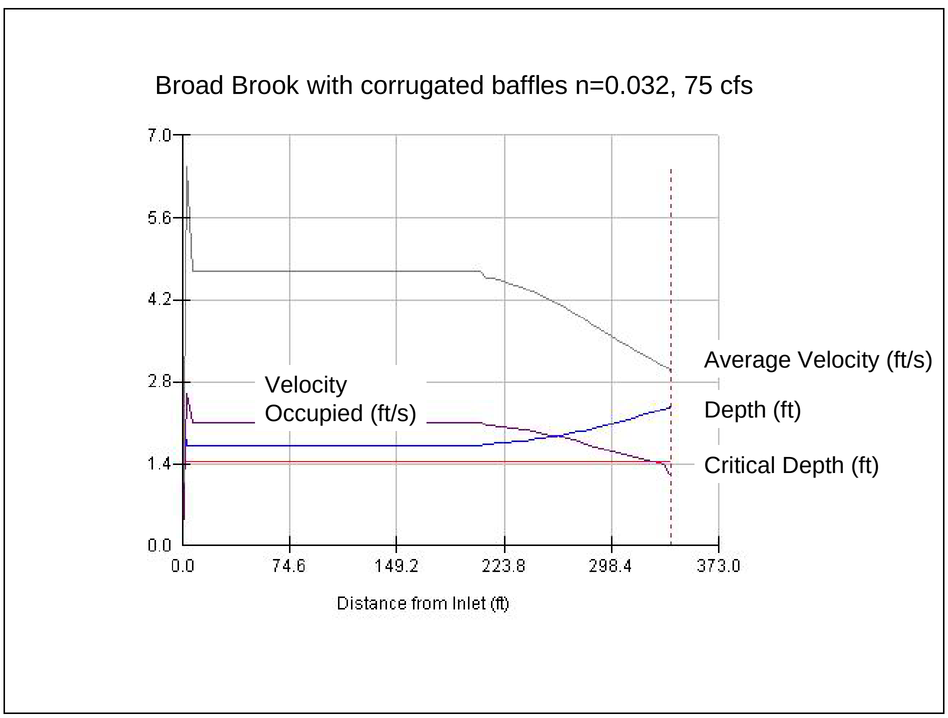

Figure 7. Hydraulics of corrugated baffles at 75 cfs.

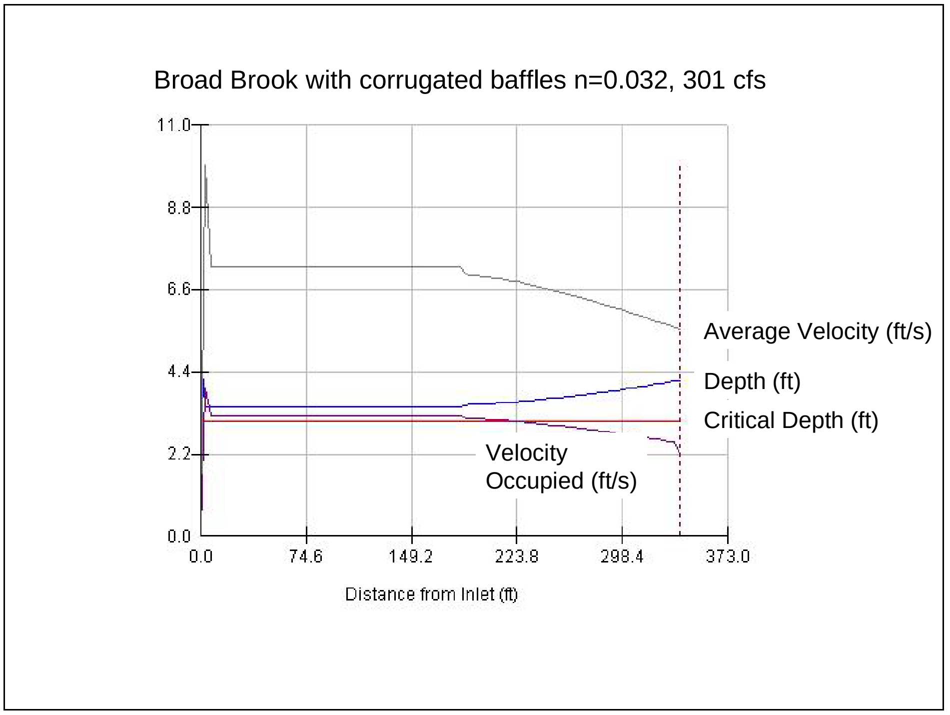

Figure 8. Hydraulics of corrugated baffles at 301 cfs.

<u>Corrugated plate baffle details</u>

Corrugated steel or aluminum plates would be bolted directly to the floor of the culvert. Some of the gaps behind the plates should be grouted or otherwise sealed so leakage does not develop behind the plates.

Two culvert manufacturers were contacted. They are able to supply the custom diameter plates. Since the culverts are bolted in place, they only need strength for lifting them into place without buckling. Further discussion with the culvert manufacturers is necessary to finalize the design and the gauge of the material.

<u>Recommendation</u>

This option is the recommended option for passage, constructability, and durability reasons. The design complies with the Vermont average cross-section velocity criteria for flows up to 20 cfs and the boundary layer hydraulics provide passage conditions through the entire fish passage design flow range to 301 cfs. Since the corrugated plates are low in profile, they have little risk of damage or blockage of debris or sediment. They are relatively easy to install and no additional fabrication is needed.

Roughen pipe with baffles

Roughening the pipe with high plate baffles was considered. FishXing 3.0 software was used to find the roughness value that would satisfy the VDFW velocity and depth criteria and then a baffle configuration was selected that would create that roughness. A design data form is included in the appendix for this option.

Baffle hydraulics

VDFW fish passage criteria are not satisfied with the plate baffles. Three characteristics of the baffles limit the overall passage.

First, the hydraulic benefit of baffles is limited by a maximum real roughness that can be created. Calculations from FishXing showed the Manning's roughness of 0.13 is needed to achieve the criterion velocity of 3.2 fps at 301 cfs. That is not a realistic roughness. The highest Manning's n typically used for boulder streams is about 0.05.

Model studies reported by Rajaratnam and Katopodis (1990) and described by Bates and Kirn (2008) show a Manning's roughness of 0.08 is created by the most severe baffles (highest baffles and closest spacing). By that model, two-foot high baffles at twelve-foot spacings would be needed to create the roughness of n=0.08. One-foot baffles create a roughness of n=0.07.

Due to considerations of bedload deposition, water surface profile, constructability, and durability, the one-foot-high baffle design was developed. FishXing results show a passability of 19% but it shows that a barrier is caused by a contraction velocity at the culvert inlet at flows from 60 to 75 cfs. That contraction can be remedied by appropriate placement of the upstream baffle within the culvert. With contraction treated, 25% of flows are passable. That means 25% of the flows within the fish passage design flow range achieved the velocity and depth criteria.

With that configuration, the target of 3.2 fps is achieved throughout the culvert at flows up to 75 cfs with the velocity increasing near the outlet to about 3.2 fps due to a drawdown of about 0.3 foot.

The second limitation is that the space between these baffles could at least partially be filled with bed material and thus their effectiveness would be reduced. This issue is at least partially rectified by using sloping baffles with a center slot open between them. The suggested configuration is show in Figure 9.

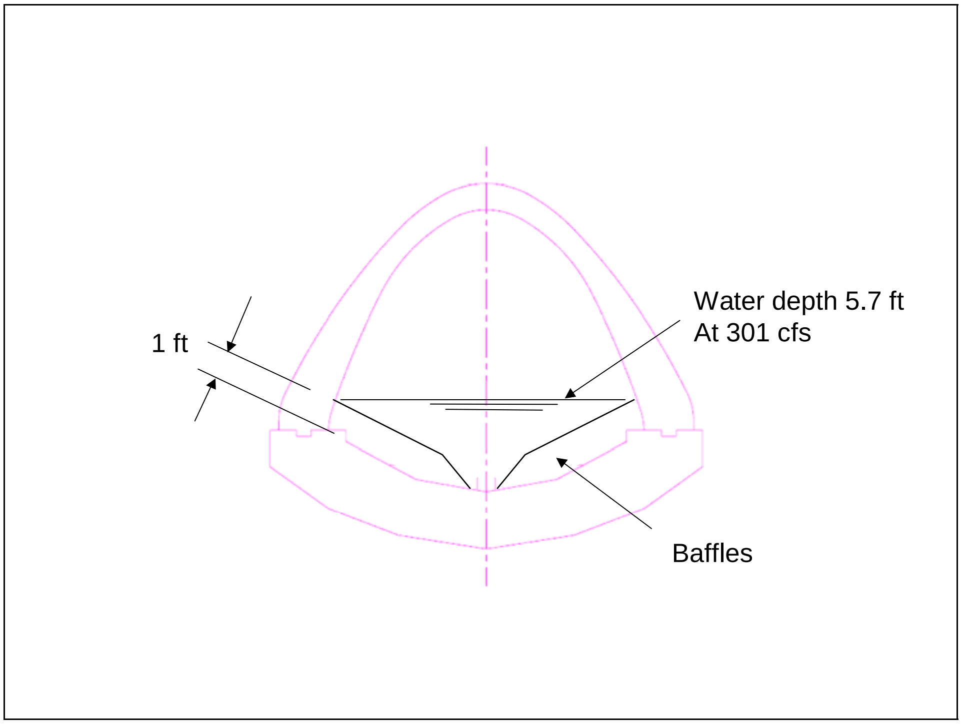

Figure 9. Broad Brook culvert with plate baffles.

The third limitation of baffles in this case is that as the roughness is increased, the hydraulic profile within the culvert is also raised and the differential between the culvert and tailwater hydraulic profiles creates a barrier at the culvert outlet. The hydraulic profile is much more affected by the plate baffles than the corrugated baffles because the overall roughness is much greater.

With the baffles described here, the hydraulic profile in the culvert is raised about 2.8 feet at 300 cfs. The velocity in the upper part of the pipe is reduced from about 11.0 fps for a bare pipe to 4.2 fps if there's an inlet contraction. The raised profile causes the velocity near the culvert outlet to be about 5.7 fps. The hydraulics of this configuration are shown at 75 and 301 cfs in Figure 10 and Figure 11.

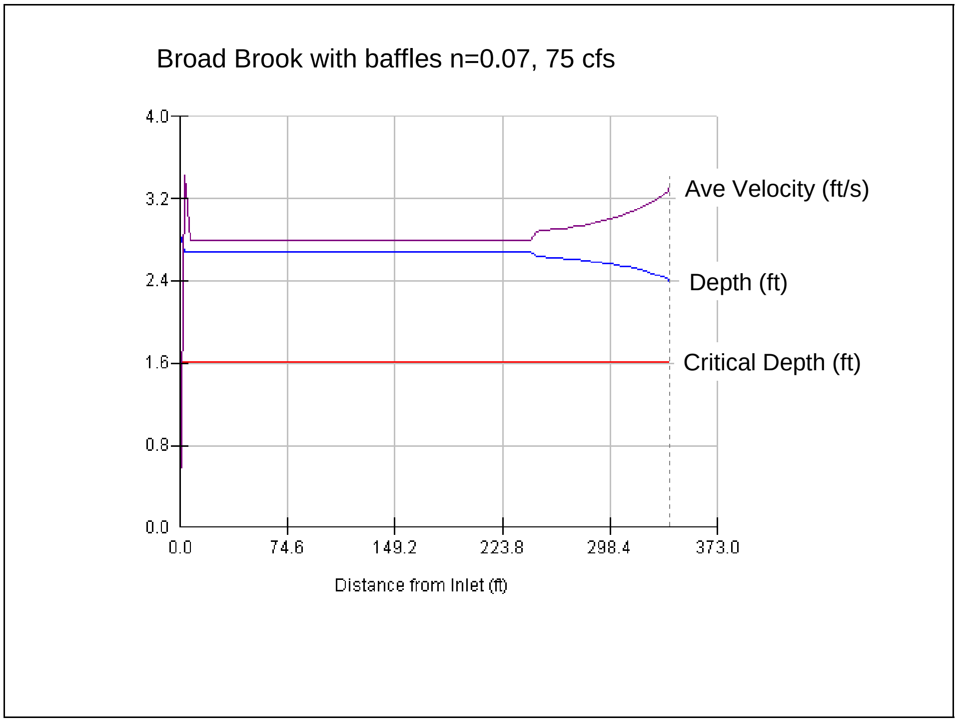

Figure 10. Hydraulics of 1-ft plate baffles at 75 cfs.

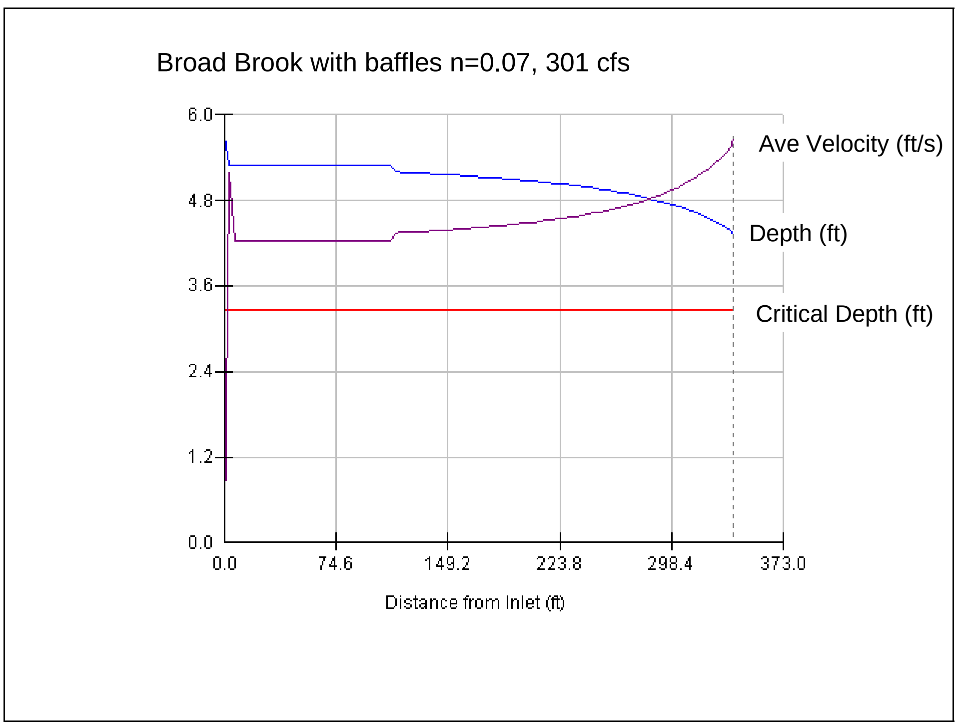

Figure 11. Hydraulics of 1-ft plate baffles at 301 cfs.

The average cross-section velocity is shown. The drawdown and increased velocity at the outlet and the inlet contraction can be seen at both flows. There is no backwater from downstream at flows greater than about 50 cfs. Hydraulics of lower flows are not shown because at low flows the baffles act as weirs.

Without backwatering the culvert by raising the downstream channel, the outlet drawdown ultimately limits the level of passage that can be achieved. Adding profile control structures below the culvert could mitigate the effect of the raised profile. Profile control structures would extend the project at least 100 feet downstream of the culvert so were not considered further. A brief description of of profile control structures is included below.

An attempt was made to reduce the drawdown by decreasing the height and increasing the spacing of baffles in the lower end of the pipe. No better fish passage conditions were created with this change in the FishXing model.

The baffle option can also be successful. It has the advantage that fish resting areas exist at each baffle but passage is not likely to occur through as wide a range of flows as with the corrugated baffle design. Compared to the corrugated baffle option, it likely provides better passage at flows up to about 50 cfs and less passage at higher flows.

Baffle design

Baffles can be built out of wood, steel, or other durable materials. The one-foot-high baffle design is recommended because the two-foot baffles would be much more difficult to construct and would be less durable and the effect of the additional roughness is marginal.

The baffles could a fabricated with a steel base plate shaped to fit the floor of the culvert. Each piece would be half of the baffle length so there is a left and right piece for each baffle. A center notch width of one foot at the floor expanding to 30 inches at the shoulder of the baffle would just be filled at the low flow of 3.2 cfs.

The vertical baffle plate can be either directly welded or set into brackets welded to the base plate. If the shape of the culvert varies much, consider using the bracket design so the base plate can be bolted flush against the varying culvert floor shape. The baffle plate or brackets would be supported by steel gussets, likely on the upstream side and away from the notch. The gussets would be vertical, spaced several feet apart, and would extend to about half the height of the baffle plate. The base plate would be bolted to the floor. Seal material should be placed between the culvert floor and the base plate. To protect fish, all sharp edges and corners should be ground to a radius or a pipe can be welded to the edges. The baffle pieces should be galvanized after fabrication.

The baffle nearest the upstream end should be placed about fifteen feet from the inlet so it does not contribute to the inlet contraction. The baffle nearest the downstream end should be placed near the outlet.

Roughen pipe with roughened channel

A roughened channel could provide roughness similar to the baffles described above. A roughened channel would be made of cobbles and boulders placed in the culvert ot form a rough channel. The roughened channel would create more diverse hydraulic conditions and likely better passage compared to either baffle option described above. The diversity would mitigate the high average velocities and would not have the decreased roughness due to deposition that would occur with the baffles.

Limerinos (1970) was used to calculate the hydraulic conditions associated with a roughened channel with D84 equal to 2.0 feet. This size of rock was chosen as the largest size that could practically and effectively be anchored in the culvert.

Roughness is appropriately a function of depth (hydraulic radius) in the Limerinos formula. Passage calculations using FishXing are iterative at each flow because the predicted value of n is a function of depth, which is controlled by the roughness.

Because of the diversity, a velocity reduction factor of 0.6 was used in FishXing for the barrel, inlet, and outlet. The value of 0.6 is based on judgment and has a high level of uncertainty. The certainty could be reduced with biological research to assess passability of roughened channels.

The conclusion is that with a bed mixture with D84 of 2.0 feet, the value of n varies from 0.10 at 50 cfs to 0.074 at 250 cfs, which is the highest flow at which FishXing predicts passage success. The culvert is a velocity barrier at higher flows. This is a passability of about 80%.

The stability of the bed material was roughly checked with a Corps of Engineers riprap stability equation developed by Maynord (1994). The method predicts that a riprap bed with D50 of 2.4 would be stable with a safety factor of 1.5 and at a 100-year flood event of 2822 cfs. It is assumed that bed retention sills would be anchored into the concrete floors and walls to hold the material.

The elevated hydraulic profile and drawdown at the culvert outlet as described above for baffles would also occur with the roughened channel

The final considerations of a roughened channel is how to build it. Issues such as how to move material into the culvert, how to stabilize the bed with the deep scour hole at the culvert outlet, and certainty of the fish passage and stability predictions should all be addressed. For these reasons, the roughened channel was not recommended.

Raise tailwater with Profile Control

As described previously, an elevated tailwater is needed to maximize passage for the baffled culvert and roughened channel options. Regardless of the culvert retrofit used, a pool and chute fishway or a roughened channel could be built downstream.

With the baffles described above, the hydraulic profile in the culvert is raised about 2.8 feet at 300 cfs. To eliminate the drawdown effect, the high flow tailwater would have to be raised an equivalent amount.

A roughened channel with an overall slope of about 2.25% would have a comparable unit discharge to other similar projects (Cedar River, Salmon Creek, Washington). At that slope and with an existing channel slope below the culvert of 1.4%, a roughened channel would have to be about 330 feet long. The upstream end would be at the outlet of the existing plunge pool because the plunge pool energy dissipation would be needed to protect the roughened channel.

A pool and chute fishway could have a slope of about 7%. With the same channel characteristics as described above, the fishway would be 50 feet long. It would be similar to the Town Fishway on the Yakima River in Washington.

Either profile control option should be extended further than described here so any downstream channel degradation, either natural or due to the project, would not create a barrier at the end of the structure.

The floodplain on the left bank downstream of the culvert is at an elevation of 18.2 and would be overtopped at 300 cfs with any increased tailwater. A levee (or fishway walls) at least on the left bank would have to be constructed to contain the high fish passage flows as well as to mitigate the risk of increased flooding at higher flows.

The downstream channel slope and bankfull elevations should be checked if these options are considered further.

Photos and details of the examples mentioned here are available.

Next Design Steps

The following design steps are recommended if the designs of the corrugated or plate baffles are pursued. The priority of next steps will vary depending on which option is developed.

All of the calculations described for the analysis should be reviewed. The analysis spreadsheets, FishXing, and WinXSPro data sets are available for review.

A more accurate hydraulic backwater model should be developed for flood flows. The FishXing model does not have the option for the variable roughness and the shape of the culvert described here. The model would also include an accurate tailwater rating curve. The purpose of the model is primarily to check upstream effects (flooding, deposition, debris passage) of the increased roughness.

Corrugated pipe manufacturers in the Northeast should be contacted to confirm the availability of the corrugated plates to fit into the culvert invert.

Channel slopes, roughness, and tailwater control cross-section should be confirmed.

Detail cross-section dimensions of the culvert are needed.

High design flow estimates should be confirmed.

Attachment and other details of the baffles should be developed.

Reference Cited

Barber, Michael E., and Randall Craig Downs (1996). Investigation of culvert hydraulics related to juvenile fish passage. Pullman, WA: Washington State Transportation Center.

Bates, Kozmo K. and Rich Kirn (2007). Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont. Montpelier, VT: Vermont Department of Fish and Wildlife.

Limerinos, J. T. (1970). Determination of the Manning coefficient from measured bed roughness in natural channels.

Maynord, S.T. (1994). Streams above the line: Channel morphology and flood control. US Army Corps of Engineers

Mountjoy, P.K. (1986). Velocity profile prediction in culverts for fish passage design considerations. Fairbanks: University of Alaska.

Rajaratnam, N., and C. Katopodis (1990). Hydraulics of culvert fishways III: weir and baffle culvert fishways. Canadian Journal of Civil Engineering, 17(4), 558-568.

Appendix – Design Data Forms

Vermont Fish Passage Design Data Checklist
Hydraulic and Low-Slope Designs

This is a summary for design and review of a road / stream crossing using the Hydraulic or Low-Slope design methods for fish passage at culverts. Data is summarized to show design milestones, assumptions, and conclusions. This isn't necessarily all of the data required for a complete design. All parts of the data data sheet are normally needed for a Hydraulic Design. Those marked with "(LS)" are normally needed for a Low-Slope Design.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project (LS)

Project name and ID		
Stream	Broad Brook	
Road, location	@ Interstate 89	
Lat / Long (d/m/s)	72 / 29 / 5.37 W	43 / 47 / 0.38 N
ID Team members	Analysis by Kozmo Bates	
Date	7/1/2008	

Brief description of project: Install corrugated plate roughness into the floor of the culvert

Project type (new, retrofit, replacement): Retrofit

Design method: (hydraulic or low-slope): Hydraulic

Does this design satisfy design method criteria? If not, explain deviations and limitations.

Y / (N) Project achieves passage within occupied zone. Limitation is culvert elevation and project footprint limitations.

Site characteristics (LS)

mpariso Is there an existing Culvert(s)? (Y) / N

Existing culvert perched? Y / (N) Height of perch ______

Downstream channel incised? Y / (N) Depth of incision ______

Evidence of incision: none

Upstream backwater deposition Y / (N)

Evidence and extent ______

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Max velocity (fps)	Swim mode	Min depth (ft)
Rainbow trout	adult	6-18	Apr-May	3.2	P	0.5
Brown trout	adult	6-21	O - mid D	4.1	P	0.6

Describe data sources VDFG - RK email 9/13/2007 and VT guideline. Juvenile rainbow, brook trout, brown trout, and Atlantic salmon might also be present.

Hydrology

Watershed characteristics (LS)

Area 16.9 sq miles Mean elevation ________ ft above sea level

Mean annual precipitation 43 inches

Other hydrologic or flow characteristics (hydrologic province, area of lakes, northing, etc.) (LS)

69% above elev 1200. Northing 139609. 0.19% in lakes.

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)
2 - yr event	570	42	809
25 - yr event	1400	42	1988
100 - yr event	1960	44	2822

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)
Rainbow	adult	301	2.3
Brown	adult	99	2.3

Describe how hydrology was calculated and any assumptions (e.g. future conditions) made. (LS)

Source: Peak flows: StreamStats, passage flows: VT passage guideline hydrology.

3 - DESIGN

Channel (LS)

	Downstream		Upstream	
Average slope	1.4	%	1.1	%
Average bankfull width	37.0	ft	73.0	ft
Bed Elevation - low potential profile	14.5		16.8	
Bed Elevation - high potential profile	17.6		17.6	
Description of channel	G-C plane bed, rfl pool		C-B plane bed	
Channel roughness (n)	0.047			
Bed Elevation - project profile	no change		no change	
Elevation of downstream control	15.6			

How is profile controlled? ____

____

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert		Proposed Culvert	
Span	17.8	ft	no change	
Rise	15.6	ft		ft
Upstream Invert Elevation	16.8			
Downstream Invert Elevation	14.2			
Culvert Length	320.0	ft		ft
Slope	0.8	%		%

Note: for bottomless structures, report elevations of tops of footings.

Description of proposed culvert; Chose one or more in each line

Shape: Round - Arch - Box

Culvert is vertical egg-shape. Bottom 5' is equivalent to 22.4 ' diameter culvert

Material: Corrugated metal - Smooth metal - Concrete (circled)

Corrugation dimensions: ________________

Style Full pipe (circled) - Bottomless

4 - DESIGN

Fish Passage Hydraulics

Flow (cfs)	Tailwater elev	Rough-ness (n)	Velocity (fps)	Depth (ft)	EDF (ft-lb/sec/cuft)	Passability (%)
2.3	16.0	0.32	0.2 -1.7 (0.8)	0.4 - 1.8	0.1 - 0.9	
50	16.6	0.32	2.4 - 4.3 (1.9)	1.5 - 2.3	1.3 - 2.3	
99	16.8	0.32	4.1 - 5.3 (2.4)	2.1 - 2.5	2.2 - 2.8	97%
301	18.4	0.32	5.9 - 7.3 (3.2)	3.6 - 4.2	3.2 - 3.9	44%

Describe roughness (corrugation dimensions, bed material or roughened channel description, baffle geometry, etc)

6 x 2" corrugated baffles anchored into the lower 3' of the culvert cross-section. Does not meet average velocity criterion. Criterion satisfied in boundary layer to high design flow (noted in table).

Describe methods and sources of data for fish passage hydraulic calculations.

FishXing. Assumed 22' circular pipe valid only to depth of about 5'

High flow hydraulics (LS)

Event	Flow (cfs)	Tailwater elevation	Rough-ness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)
Q2	809	19.9		25.8	0.39
Q25	1988	23.2		31.2	0.63
Q100	2822	25.0		34.3	0.77

Describe methods and sources of data high flow hydraulic calculations.

Calcs with FishXing not accurate at depths over 5'. Further calcs needed.

Assume 22' circular pipe valid only to depth of about 5'.

Road and Alignment (LS)

Height of fill on upstream face: approx 30 ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel _________ degrees   Road to culvert _________ degrees

Proposed alignment, transition changes _______________

Describe permanent benchmark and elevation _______________

Vermont Fish Passage Design Data Checklist
Hydraulic and Low-Slope Designs

This is a summary for design and review of a road / stream crossing using the Hydraulic or Low-Slope design methods for fish passage at culverts. Data is summarized to show design milestones, assumptions, and conclusions. This isn't necessarily all of the data required for a complete design. All parts of the data data sheet are normally needed for a Hydraulic Design. Those marked with "(LS)" are normally needed for a Low-Slope Design.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project (LS)

Project name and ID		
Stream	Broad Brook	
Road, location	@ Interstate 89	
Lat / Long (d/m/s)	72 / 29 / 5.37 W	43 / 47 / 0.38 N
ID Team members	Analysis by Kozmo Bates	
Date	7/1/2008	

Brief description of project Install baffles

Project type (new, retrofit, replacement) Retrofit

Design method: (hydraulic or low-slope) Hydraulic

Does this design satisfy design method criteria? If not, explain deviations and limitations.

Y / (N) Project achieves 19% passability (FishXing). Limitation is culvert elevation and project footprint limitations.

Site characteristics (LS)

mpariso Is there an existing Culvert(s)? (Y) / N

Existing culvert perched? Y / (N) Height of perch

Downstream channel incised? Y / (N) Depth of incision

Evidence of incision none

Upstream backwater deposition Y / (N)

Evidence and extent

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Max velocity (fps)	Swim mode	Min depth (ft)
Rainbow trout	adult	6-18	Apr-May	3.2	P	0.5
Brown trout	adult	6-21	O - mid D	4.1	P	0.6

Describe data sources VDFG - RK email 9/13/2007 and VT guideline. Juvenile rainbow, brook trout, brown trout, and Atlantic salmon might also be present.

Hydrology

Watershed characteristics (LS)

Area 16.9 sq miles   Mean elevation ________ ft above sea level

Mean annual precipitation 43 inches

Other hydrologic or flow characteristics (hydrologic province, area of lakes, northing, etc.) (LS)

69% above elev 1200. Northing 139609. 0.19% in lakes.

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)
2 - yr event	570	42	809
25 - yr event	1400	42	1988
100 - yr event	1960	44	2822

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)
Rainbow	adult	301	2.3
Brown	adult	99	2.3

Describe how hydrology was calculated and any assumptions (e.g. future conditions) made. (LS)

Source: Peak flows: StreamStats, passage flows: VT passage guideline hydrology.

3 - DESIGN

Channel (LS)

	Downstream		Upstream	
Average slope	1.4	%	1.1	%
Average bankfull width	37.0	ft	73.0	ft
Bed Elevation - low potential profile	14.5		16.8	
Bed Elevation - high potential profile	17.6		17.6	
Description of channel	G-C plane bed, rfl pool		C-B plane bed	
Channel roughness (n)	0.047			
Bed Elevation - project profile	no change		no change	
Elevation of downstream control	15.6			

How is profile controlled? ____

____

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert		Proposed Culvert	
Span	17.8	ft	no change	
Rise	15.6	ft		ft
Upstream Invert Elevation	16.8			
Downstream Invert Elevation	14.2			
Culvert Length	320.0	ft		ft
Slope	0.8	%		%

Note: for bottomless structures, report elevations of tops of footings.

Description of proposed culvert; Chose one or more in each line

Shape: Round - Arch - Box

Culvert is vertical egg-shape. Bottom 5' is equivalent to 22.4 ' diameter culvert

Material: Corrugated metal - Smooth metal - Concrete (circled)

Corrugation dimensions: ________________

Style Full pipe (circled) - Bottomless

4 - DESIGN

Fish Passage Hydraulics

Flow (cfs)	Tailwater elev	Rough-ness (n)	Velocity (fps)	Depth (ft)	EDF (ft-lb/sec/cuft)	Passability (%)
2.3	16.0	0.07	0.2 -1.2	0.5 - 1.8	0.1 - 0.5	
50	16.6	0.07	2.4 - 3.0	2.2 - 2.3	1.3	
99	16.8	0.07	2.8 - 3.9	2.6 - 3.3	1.5 - 2.0	59%
301	18.4	0.07	4.2 - 5.7	4.3 - 5.3	2.3 - 2.9	19%

Describe roughness (corrugation dimensions, bed material or roughened channel description, baffle geometry, etc)

6 x 2" corrugated baffles anchored into the lower 3' of the culvert cross-section

Velocity criteria satisfied to 75 cfs (25% passability)

Describe methods and sources of data for fish passage hydraulic calculations.

FishXing. Assumed 22' circular pipe valid only to depth of about 5'

High flow hydraulics (LS)

Event	Flow (cfs)	Tailwater elevation	Rough-ness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)
Q2	809	20.2	0.07	26.5	0.42
Q25	1988	23.6	0.07	32.3	0.72
Q100	2822	25.46	0.07	35.7	0.83

Describe methods and sources of data high flow hydraulic calculations.

Calcs with FishXing not accurate at depths over 5'. Further calcs needed.

Assume 22' circular pipe valid only to depth of about 5'.

Road and Alignment (LS)

Height of fill on upstream face: approx 30 ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel _________ degrees   Road to culvert _________ degrees

Proposed alignment, transition changes _______________

Describe permanent benchmark and elevation _______________