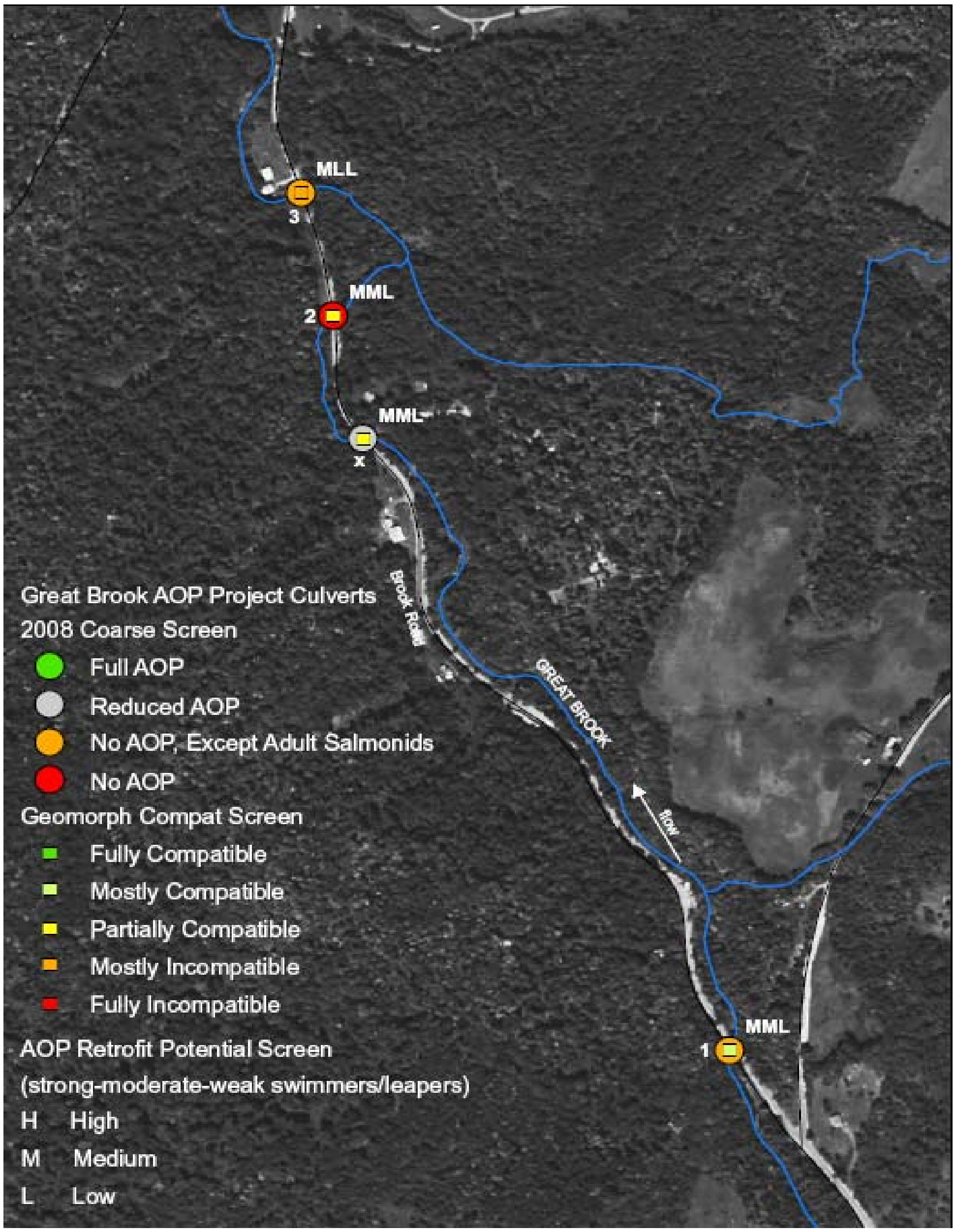
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT

MMI #3846-03

January 4, 2011



Prepared for:
The Friends of the Winooski River
Montpelier, Vermont

Prepared by:
Milone & MacBroom, Inc.
South Burlington, Vermont

CONTENTS

1.0 Introduction

Great Brook (watershed area ~ 14.5 square miles) is located in the upper Winooski River watershed. The stream originates on Signal Mountain in Groton and then flows northwest to its confluence with the Winooski River in Plainfield.

Great Brook passes under Brook Road in Plainfield several times. Three of the concrete box culverts, constructed in 1929 and maintained by the Town of Plainfield, were identified to be barriers to fish passage (Figure 1). Each of the structure outlets is perched, and the concrete box culverts are undersized with structure widths approximately 30% of the channel bankfull width. Great Brook bends mildly or sharply as it enters the structures. The outlet drops developed due to local erosion from jetting flow through the undersized structures and from long-term stream incision. Previous assessment identified the structures to be fish blocks and not passable during most of the year.

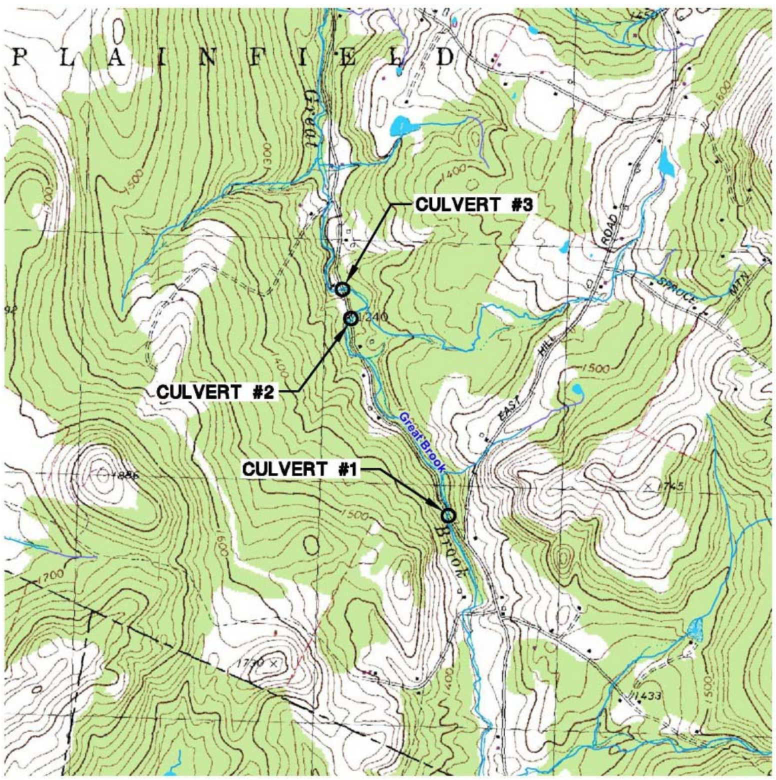


FIGURE 1: Site Location Map

Friends of the Winooski River, in partnership with the U.S. Fish and Wildlife Service, Vermont Department of Fish and Wildlife, Vermont River Management Program, and the Town of Plainfield, conducted a project to explore alternatives to improve fish passage at each of the three culverts, design the preferred alternative, implement the design, and perform evaluation monitoring.

The goal of the project was to improve fish passage on Great Brook. Project objectives included:

- Establish fish passage during high and low flows for adult and juvenile brook and rainbow trout
- Maintain existing flood capacity at the culverts
- Avoid structural changes to the culverts if possible
- Work toward stable channel equilibrium

This report presents the highlights of the recently completed *Great Brook Fish Passage Restoration Project* in Plainfield, Vermont. Supporting information to understand the existing problem, alternatives analysis, basis of design, construction, and evaluation is contained in the appendices. Additional information is available upon request from the Friends of the Winooski River (http://www.winooskiriver.org/).

2.0 Culvert Descriptions

Culvert #1 at the upstream end of the project (ID 2361, elevation 1,300 feet) had a perched outlet with a downstream plunge pool (Appendix A). The channel makes a sharp bend to the right as it enters the upstream side of the culvert. The left bank is armored with riprap to reduce erosion near the structure. This culvert has some serious structural deficiencies including cracking and dislocated concrete on the right downstream wingwall and the downstream concrete apron. The structure appears to be controlling the grade of the channel as the degree of channel incision appears to be a bit higher on the downstream side of the structure.

Culvert #2 (ID 2375, elevation 1,240 feet) had a downstream standing wave indicative of a submerged outlet drop and a plunge pool (Appendix B). Wingwalls at 45 degrees guide water in and out of the structure. Riprap is located on the outside bend as the channel approaches the structure on the upstream side. A small tributary joins Great Brook on the right bank immediately downstream of the structure. The structure appears to be in good condition.

Culvert #3 (ID 2381, elevation 1,220 feet) located at the downstream end of the project site had an outlet drop associated with the concrete bottom of the box culvert with a downstream plunge pool (Appendix C). The banks were armored with riprap downstream of the structure as the brook flows next to a house before making a bend right along a natural wall of bedrock outcrop. The channel appeared a bit more incised on the downstream side of the structure than upstream, which is common for perched and undersized concrete structures that can act as grade control. Wingwalls at approximately 45 degrees direct flow into the structure, and wingwalls parallel to the flow guide flow out of the structure. The box culvert did not appear to have serious structural deficiencies.

A fourth box culvert exists in the project area that was determined to not be a barrier to fish passage. Although this structure is undersized like the others, it does not have a perched outlet. A small tributary enters Great Brook on the left bank just downstream of the structure leading to local deposition of coarse sediment. This material is improving passage at the culvert by naturally eliminating the outlet drop, increasing water depth, and reducing water velocity.

3.0 Survey

Field survey was initially performed by the Vermont River Management Program and U.S. Fish and Wildlife Service. The longitudinal profile of the channel thalweg and water surface, the top and bottom of the culvert, and channel cross sections were recorded (Appendix D). An assumed vertical datum was used. Profiles extended upstream and downstream for 200 to 400 feet. Cross sections spanned the bankfull channel and in some cases extended up into the floodplain.

Additional field survey was conducted by the Vermont River Management Program with Milone & MacBroom, Inc. to extend the longitudinal profile and increase the number of cross sections in locations where design would require more detailed hydraulic modeling. Most of the additional survey was conducted at the downstream culvert (#3) where a house exists just downstream of the structure. All survey was combined to draft existing and proposed plan, profile, and cross section views.

4.0 Hydrology and Existing Hydraulics and Fish Passage

Peak design flows were estimated using USGS StreamStats (Olson, 2002). The 25-year storm is the design flow for these structures (VTrans, 2001) and was thus used to investigate high flow conveyance (Table 1). The 100-year flood was also evaluated to explore conditions during very large floods. Fish passage design flows and hydraulic swimming criteria of fish were determined from the *Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont* (Bates and Kirn, 2009) (Appendix E).

TABLE 1
Design Flows

	Culvert #		
Flow (cubic feet per second)	**1**	**2**	**3**
Q25	581	681	682
Q50	698	816	818
Q100	824	962	964
April Q2-20*	99	119	119
November Q2-20	29	35	35
7Q2	1	1	1

*Q2-20 = The 2-day 20% exceedance flow for the designated month.

FishXing (Furniss et al., 2009) was used to explore the existing and proposed hydraulic conditions and resulting fish passage at each culvert. The more detailed HEC-RAS hydraulic model (USACE, 2010) was used to explore the proposed design at the downstream culvert #3 where a house exists near the structure.

Each of the box culverts is inlet controlled, meaning that water conveyance is largely determined by the inlet of the structure. Low flow velocities ranged between 1.7 and 1.9 feet per second while high flow velocities were between 3.3 and 6.3 feet per second (Appendix F). Outlet drop ranges between 0 and one foot. Minimum flow depth was between 0 and 0.5 feet.

Water velocity, outlet drop, and minimum depth of flow were evaluated versus the fish swimming criteria. Multiple types of fish passage barriers existed at each culvert for brook trout (Table 2).

TABLE 2
Existing Conditions Fish Barriers

Culvert	Lifestage	Flow	Barrier Type(s)
1	Adult	Low	depth
1	Adult	High	velocity
1	Juvenile	Low	depth, velocity
1	Juvenile	High	velocity
2	Adult	Low	drop, depth
2	Adult	High	drop, velocity
2	Juvenile	Low	drop, depth, velocity
2	Juvenile	High	drop, velocity
3	Adult	Low	drop, depth
3	Adult	High	drop, velocity
3	Juvenile	Low	drop, depth, velocity
3	Juvenile	High	drop, velocity

5.0 Alternatives Analysis (Proposed Hydraulics and Fish Passage)

Alternatives explored included increasing the tailwater control downstream of the structure (0.5 to 2.0 feet), increasing the hydraulic roughness of the downstream channel (N=0.045 to 0.060), roughening the culvert (N=0.020 to 0.035), and decreasing the downstream channel slope (0.5 to 2.0%) (Appendix G). Baffles and other alternatives that would directly influence the culvert structure were not pursued as the town preferred that the structures remain unchanged. Each alternative was evaluated for adult and juvenile fish during low and high fish passage flows. In addition, alternatives were evaluated under peak flood conditions to assess conveyance.

The results of the hydraulic model indicated that increasing downstream tailwater control was the primary method of improving fish passage (Appendix H). Raising the tailwater reduced the outlet drop, lowered water velocity, and increased minimum depth of flow at each culvert. Only minor improvements in fish passage took place for other alternatives.

The alternatives analysis indicated that increasing the downstream tailwater by two feet was the preferred alternative for culvert #1 (upper) and culvert #3 (lower) to improve fish passage while maintaining flood conveyance. Flood conveyance at the shorter culvert #2 (middle) was reduced more than the other structures, so the preferred alternative was to only increase the tailwater by 1.5 feet. Fish passage conditions improved substantially under proposed conditions (Table 3).

TABLE 3
Predicted Fish Passage Improvements

		Percent Passage over Fish Passage Design Flow Range			
		Brook Trout (1-29 cubic feet per second)		Rainbow Trout (1-99 cubic feet per second)	
	Tailwater Increase	Adult	Juvenile	Adult	Juvenile
Culvert 1 (upper)					
Existing	0.0	0	0	0	0
Proposed	2.0	100	100	100	64
Culvert 2 (middle)					
Existing	0.0	0	0	0	0
Proposed	1.5	100	27	71	18
Culvert 3 (lower)					
Existing	0.0	0	0	0	0
Proposed	2.0	100	39	68	22

In the end, the hydraulic design approach (Bates and Kirn, 2009) illustrated that fish passage could be improved by increasing tailwater control while maintaining flood conveyance at the inlet-controlled box culverts (Appendix I).

6.0 Design

Design plans were drafted for each culvert including details of the design elements (Appendix J). The design for culvert #1 (upper) included increasing the tailwater control by two feet using a rock weir, roughening the channel with random boulders for 50 feet downstream of the weir, selectively placing boulders at a designated cross section to increase depth, and placing stone at the undermined outlet of the structure. The weir is the primary tailwater control. The boulders roughen the channel and increase tailwater control a small amount and also allow resting locations for fish moving upstream to the weir and culvert. Great Brook contains many falls and nearby boulders that fish naturally use to rest before or after passing challenging areas. The stone fill at the boulder cross section allows a stepped profile approaching the culvert. The fill under the structure was required to stabilize the undermined apron. This element will increase the operational life of the structure.

The design for culvert #2 (middle) included a stone weir that is 1.5 feet tall, roughening the channel with random boulders for 50 feet downstream of the weir, selectively placing boulders at a designated cross section to increase depth, and placing stone at the undermined outlet of the structure. The weir was located approximately 100 feet downstream, where the natural tailwater control existed.

The design for culvert #3 (lower) included a two-foot tall stone weir, roughening the channel with random boulders for 60 feet downstream of the weir, selectively placing boulders at a designated cross section to increase depth, and placing stone at the undermined outlet of the structure. As design progressed, a HEC-RAS model was created for culvert #3 to confirm that floodwaters would not reach the nearby house located on the right bank approximately 50 feet downstream of the culvert. This increased level of analysis was only utilized for culvert #3 where there was potential interaction with human infrastructure other than Brook Road. The modeling generally confirmed the hydraulic results from the FishXing model that capacity remained consistent in the channel and structure for existing and proposed conditions.

7.0 Construction

Hebert Excavation of Williamstown, Vermont won the bid for the project and began construction on July 28, 2010 under low flow conditions. Construction was completed on August 13, 2010. Construction generally proceeded smoothly with all design elements and regulatory requirements being met. Local landowners were supportive of and interested in the installation of the project.

Some heavy rains and short floods took place during construction. The varying flow conditions caused minor delays yet turned out to be helpful for fine-tuning the weirs to operate over as wide a range of flows as possible.

Many adjustments were required during construction to achieve a 1.5 to two-foot tailwater increase to backwater the culvert while maintaining gaps in the weir that were fish passable. The design was altered in the field, and rocks were placed in select locations immediately downstream of the weir to create a stepped water surface profile and fish passage channels through the weir. This secondary set of rocks increased the range of fish passable flows.

Another important aspect of achieving fish passage was to limit the permeability of the lower portion of the weir. This detail was essential to allow for good control of the water surface level with the boulders that made up the top row of the weir. Gravel excavated from the channel to install the base of the weir was used to fill in the gaps of the lower weir. In this method, boulders could be nudged to change the size of the gaps and increase the likelihood of fish passage.

8.0 Evaluation Monitoring

Several field trips were conducted following construction to evaluate weir stability and whether suitable fish passage conditions were being achieved over a range of flows (1.8 to 25 cubic feet per second). The installations appeared to be functioning properly, and some fish were observed in the culverts and immediately upstream of the weirs during field observations. All culverts are backwatered over almost all flow conditions leading to low velocities, suitable water depths, and no outlet drops (Appendix K). The installed weirs are now the primary fish movement obstacles, and they appear to remain passable through gaps in the rocks although bursting swimming speed will be required to pass the structures at the high fish passage flows. Weirs remain intact, and boulders appeared to be in their installed location during the latest observation on November 11, 2010, which was after the large October 1 flood in the region (2- to 25-year magnitude). Monitoring will continue whenever project team members are in the area of Great Brook. Should an adjustment be needed, the contractor will mobilize for touchup work as part of the original construction contract.

9.0 Lessons Learned

The following list highlights lessons learned that should be carried forward to future fish passage restoration projects.

- Long profile: Survey must extend far enough downstream to establish channel slope between the culvert and tailwater control, and the tailwater control and the next downstream grade control. The same holds true for upstream of the culvert. The short amount of additional time to collect the additional survey data is essential for thorough hydraulic analysis and for estimating the vertical adjustment range (Bates and Kirn, 2009).

- Cross section: Survey must close off all cross sections to high ground so that channel dimensions, floodplain elevation, and high ground are properly located. Be sure to document important sections such as expansions, contractions, and grade controls.

- Get a good understanding of channel and structure roughness values (N) during field assessment. Observations of channel particle sizes and structure material/condition will allow determination of N from tabulated values (e.g., see reference in USACE, 2010).

- Evaluate the structural condition of the culverts and if and how this would change under the proposed alternative.

- Understand the flood history at the site. Designs should maintain or improve conveyance if possible.

- Review local and upstream sediment and debris size in relation to the structure dimensions to explore the potential of a clogged structure. Consult the town, state, or landowner who owns and maintains the structure on the history of clogging.

- Explore the ice jam history at the channel and structure.

- When designing weirs, extend the typical analysis with FishXing or HEC-RAS used during the hydraulic design method to include more detailed calculations on weir flow to increase the chances of fish passage at these locations (e.g., Caltrans, 2007). Porosity of the structure at each elevation and gap size between boulders must be explicitly considered.

- At the beginning of the project, allocate time to perform post-construction monitoring to evaluate performance.

- Allocate time for the Project Engineer to work with the Construction Contractor to achieve design objectives and ensure permit compliance. Subtle changes in installation (e.g., the direction a rock is pointed), that are typically beyond the level of detail in a final design plan, can have a strong influence on the amount of fish passage achieved.

- Include contractor time in the original Request for Bids to return to the site after the first year of installation to make adjustments if needed.

- Attempt to make contact with the adjacent landowners as soon as the project begins. In addition to relying on the local land records, talk with neighbors and other local people who might know and be able to contact the landowners.

- Identify and contact all Federal, State and local agencies, boards and staff that may have jurisdiction over the culverts or river channel early in the project.

10.0 References

Bates, K. and R. Kirn, 2009. Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont. Prepared by Kozmo, Inc. with Vermont Department of Fish and Wildlife, Agency of Natural Resources, Waterbury, VT.

Caltrans, 2007. Fish Passage Design for Road Crossings: An Engineering Document Providing Fish Passage Design Guidance for Caltrans Projects. California Department of Transportation, Sacramento, CA.

Furniss, M., M. Love, S. Firor, K. Moynan, A. Llanos, J. Guntle, and B. Gubernick, 2009. Fishxing 3 (V. 3.0.15). USDA-Forest Service, Pacific Northwest Research Station, Aquatic and Land Interactions Program, Corvallis OR.

Olson, S., 2002. Flow-Frequency Characteristics of Vermont Streams. WRI Report 02-4238. U.S. Geological Survey in cooperation with the Vermont Agency of Transportation, Pembroke, NH.

USACE, 2010. Hydrologic Engineering Center River Analysis System (HEC-RAS) (V. 4.1). U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

VTrans, 2001. Hydraulics Manual. Vermont Agency of Transportation, Montpelier, VT.

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APPENDIX A – Pictures of Culvert #1 (Upper)

Upstream Channel

Upstream Face

Downstream Face

Downstream Channel

APPENDIX B – Pictures of Culvert #2 (Middle)

Upstream Channel

Upstream Face

Downstream Face

Downstream Channel

APPENDIX C – Pictures of Culvert #3 (Lower)

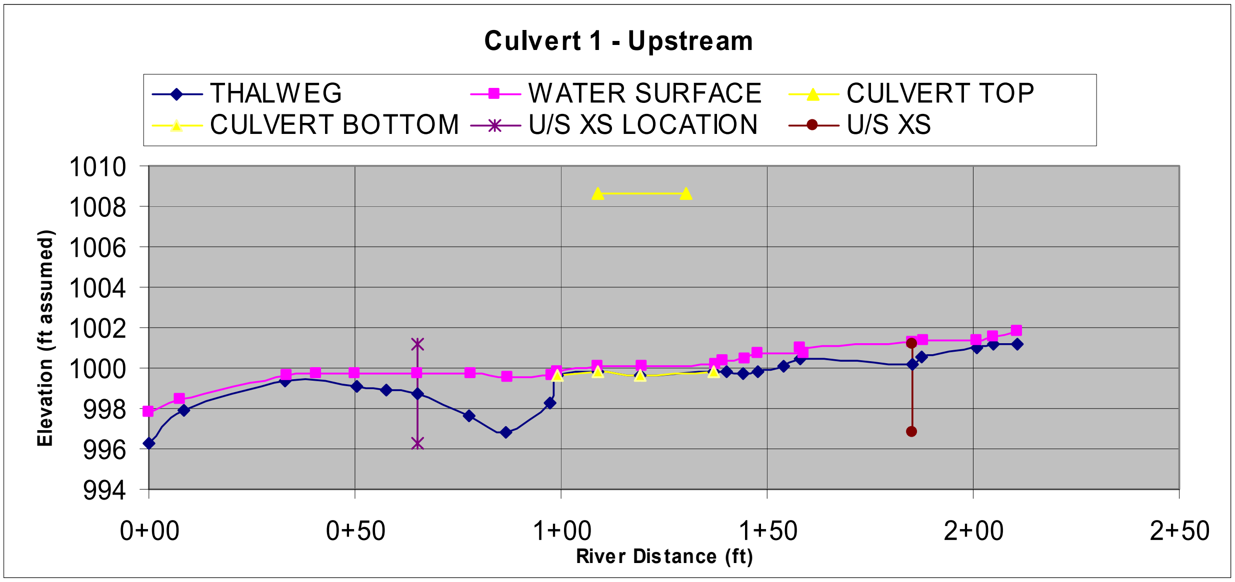
Upstream Channel

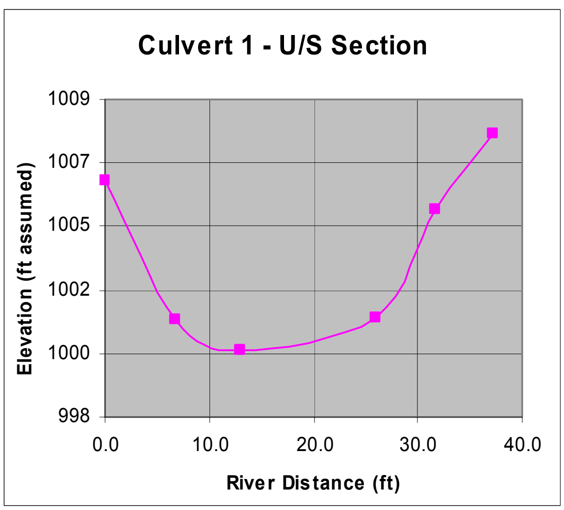
Upstream Face

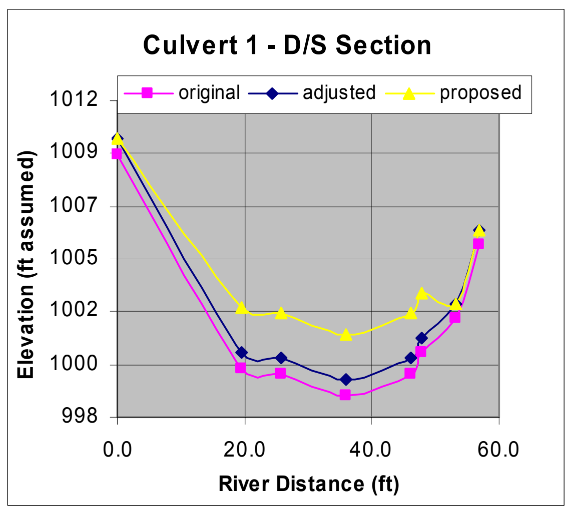
Downstream Face

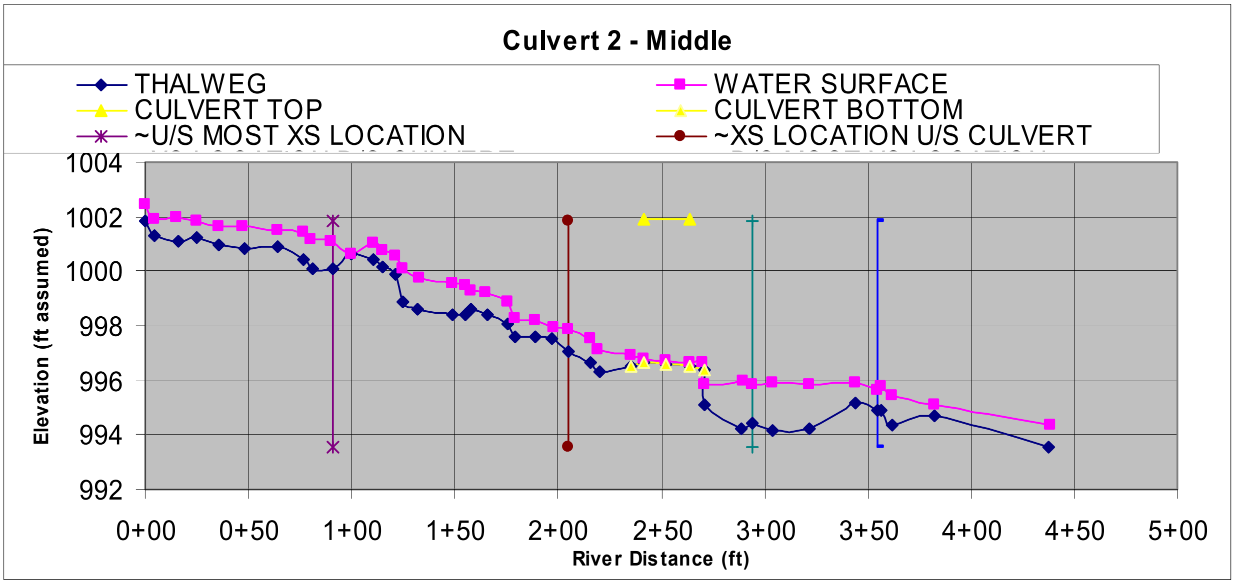
Downstream Channel

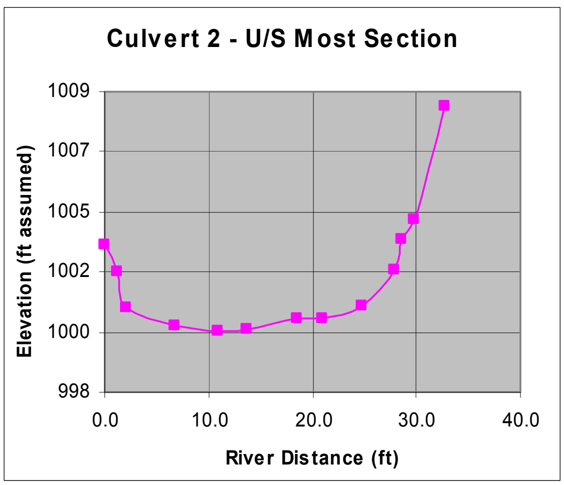
APPENDIX D – Plots of Channel Profile and Cross Section

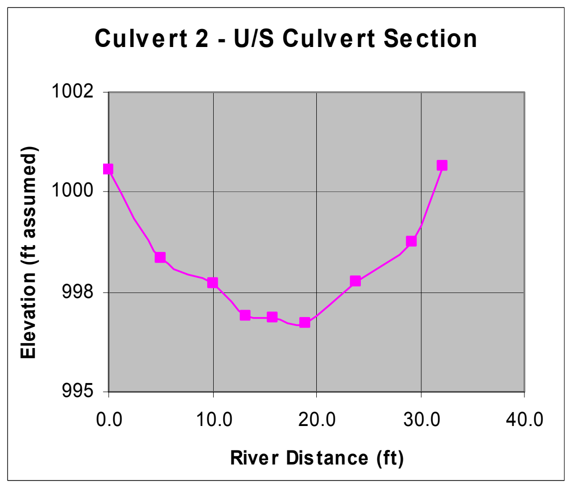







Culvert 2 - Middle
THALWEG
WATER SURFACE
CULVERT TOP
CULVERT BOTTOM
~U/S MOST XS LOCATION
~XS LOCATION U/S CULVERT
Elevation (ft assumed)
1004
1002
1000
998
996
994
992
0+00
0+50
1+00
1+50
2+00
2+50
3+00
3+50
4+00
4+50
5+00
River Distance (ft)


Culvert 2 - U/S Most Section
Elevation (ft assumed)
1009
1007
1005
1002
1000
998
0.0
10.0
20.0
30.0
40.0
River Distance (ft)


Culvert 2 - U/S Culvert Section
Elevation (ft assumed)
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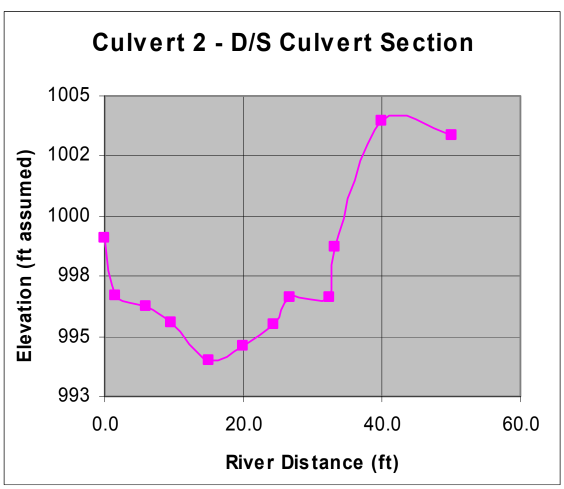
1000
998
995
0.0
10.0
20.0
30.0
40.0
River Distance (ft)


Culvert 2 - D/S Culvert Section
Elevation (ft assumed)
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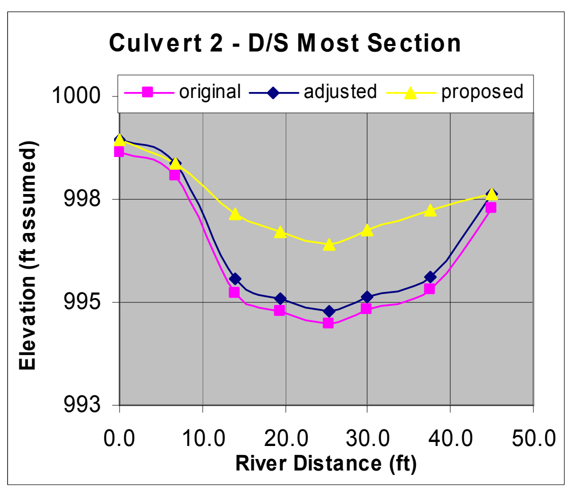
1002
1000
998
995
993
0.0
20.0
40.0
60.0
River Distance (ft)


Culvert 2 - D/S Most Section
original
adjusted
proposed
Elevation (ft assumed)
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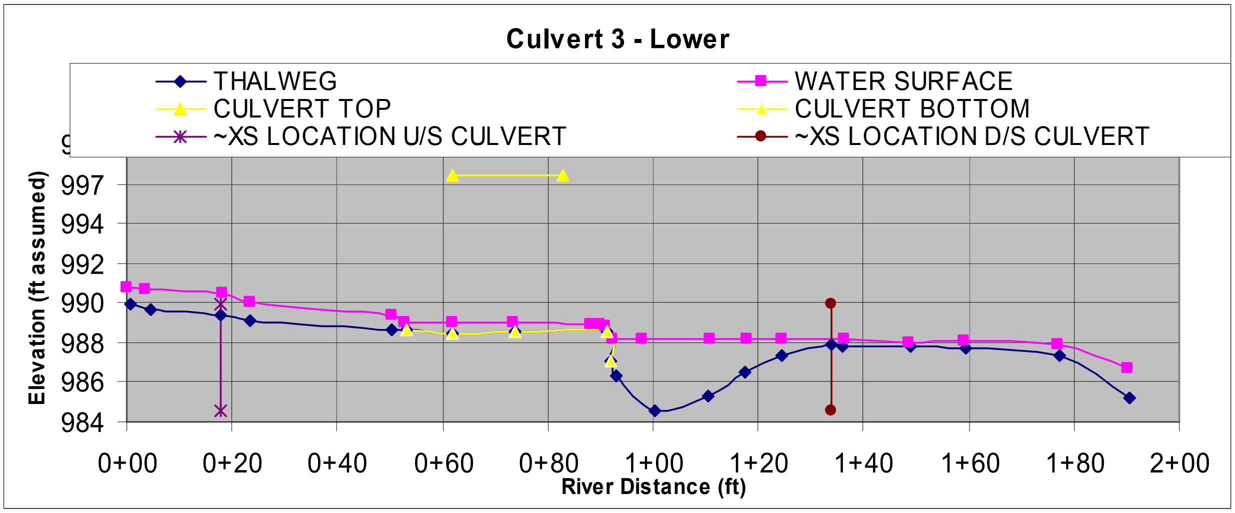
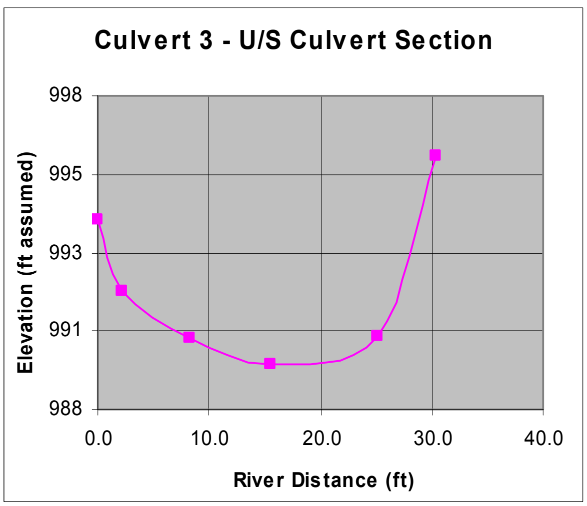
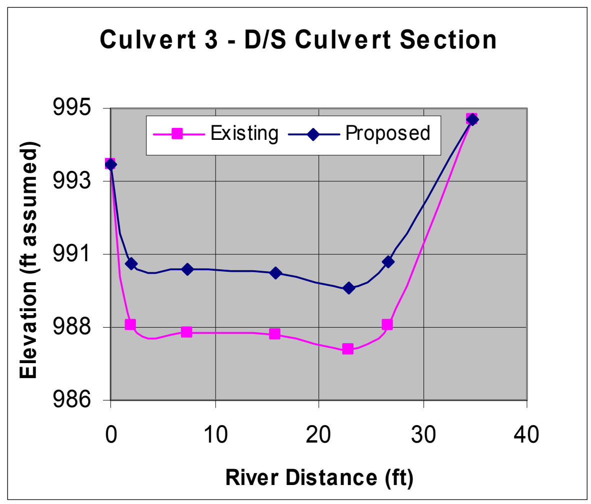
998
995
993
0.0
10.0
20.0
30.0
40.0
50.0
River Distance (ft)


Culvert 3 - Lower
THALWEG
WATER SURFACE
CULVERT TOP
CULVERT BOTTOM
~XS LOCATION U/S CULVERT
~XS LOCATION D/S CULVERT
Elevation (ft assumed)
997
994
992
990
988
986
984
0+00
0+20
0+40
0+60
0+80
1+00
1+20
1+40
1+60
1+80
2+00
River Distance (ft)


Culvert 3 - U/S Culvert Section
Elevation (ft assumed)
998
995
993
991
988
0.0
10.0
20.0
30.0
40.0
River Distance (ft)


Culvert 3 - D/S Culvert Section
Existing
Proposed
Elevation (ft assumed)
995
993
991
988
986
0
10
20
30
40
River Distance (ft)

APPENDIX E – Hydrology

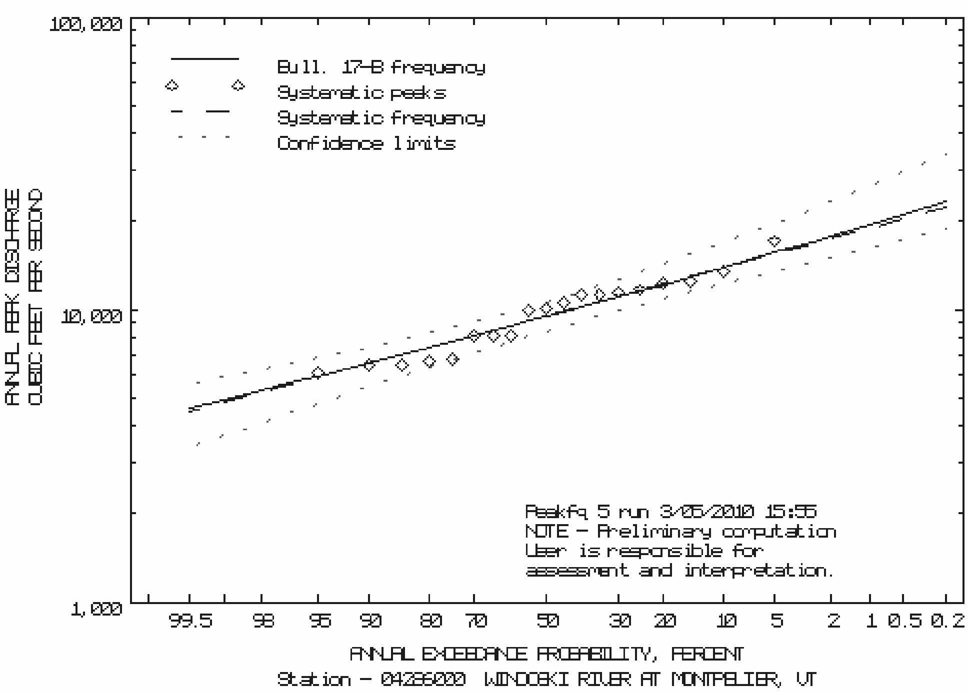
Hydrology Calculations
Great Brook Fish Passage Restoration Project
December 9, 2009

INFORMATION				
Culvert #	**1**	**2**	**3**	
Culvert location	Upstream	Middle	Downstream	
Lat	44.22453	44.23168	44.23308	
Long	-72.4013	-72.4063	-72.40652	
Elevation	1,300	1,240	1,220	
USGS STREAMSTATS (Interactive Website)				
Lat	44.2247	44.232	44.2329	
Long	-72.4013	-72.4063	-72.4068	
DA (sq mi)	6.18	7.39	7.41	
DA Lakes (%)	0.0601	0.0576	0.0574	
DA >1200ft (%)	100	100	100	
GF	190,257	190,579	190,584	
Q2 (cfs)	234	275	276	
Q5	352	414	415	
Q10	441	517	519	
Q25	581	681	682	
Q50	698	816	818	
Q100	824	962	964	
Q500	1,160	1,350	1,350	
VT FISH PASSAGE DESIGN FLOWS (Bates and Kirn, 2009)				
Northing (VSPC)	191,584	192,387	192,522	GIS
P (in)	40	40	40	Olson, 2002
April $Q_{2\text{-}20}$ (cfs)	99	119	119	April Q2-20 = ABasin x (- 41.15 + 0.000038 x Northing + 1.248 x P)
Nov $Q_{2\text{-}20}$ (cfs)	29	35	35	Nov Q2-20 = ABasin x (-13.709 + 0.4555 x P + 3.0855 x logN (1+ ALakes))
7Q2 (cfs)	1	1	1	0.139 cfs per square mile

Approximate summary of floods where Brook Road in Plainfield was overtopped

Year	Flow in Montpelier	Frequency (year) in Montpelier
1927	57,000	500
1989	10,100	2
1973	13,800	10
1985	3,000	1

*Assume that large floods are regional nor'easters so local flows may be of the same relative magnitude as the main stem gauge data. Flood data and frequency analysis from USGS gauge Winooski River at Montpelier (04286000). Flow and flood frequency data only approximate for Great Brook.



APPENDIX F – Hydraulic Existing Conditions

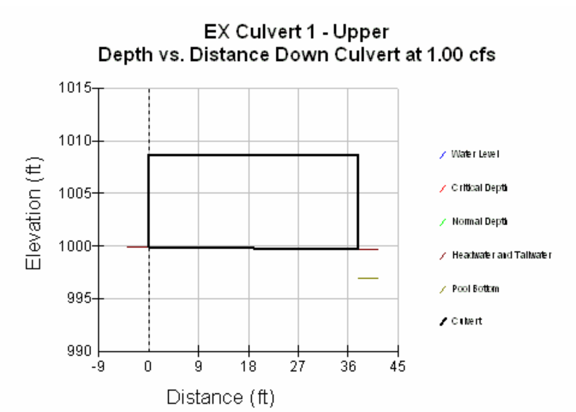
Hydraulic Criteria and Existing Conditions Aquatic Organism Passage Results
Great Brook Fish Passage Restoration Project
December 21, 2009

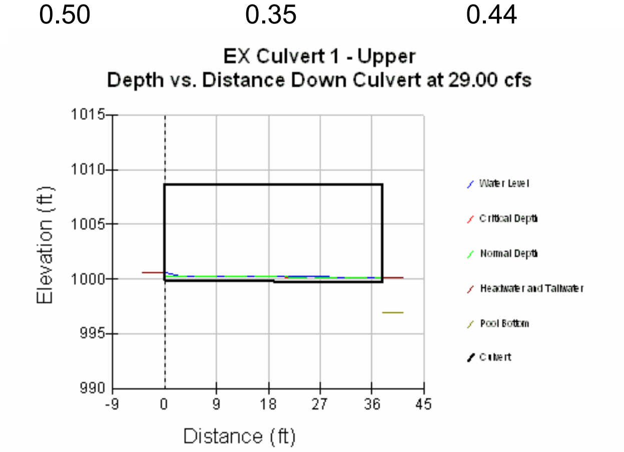
VT BROOK TROUT HYDRAULIC CRITERIA (BATES AND KIRN, 2009)

Lifestage	**Adult**	**Juvenile**
Maximum velocity (fps)	2.60	1.00
Maximum outlet drop (ft)	0.67	0.33
Target low flow depth (ft)	0.35	0.18

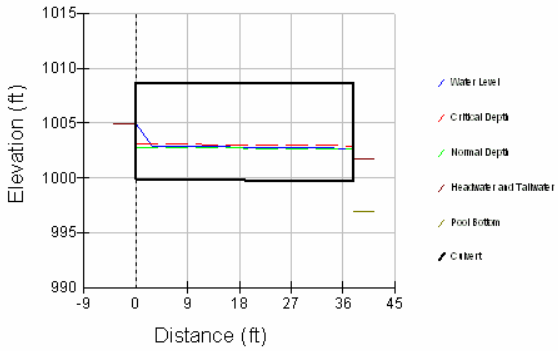
EXISTING CONDITIONS CULVERT HYDRAULICS

Culvert #	**1**	**2**	**3**
Culvert location	Upstream	Middle	Downstream
Low flow - maximum velocity (fps)	1.73	1.72	1.91
Low flow - outlet drop (ft)	0.09	1.00	1.03
Low flow - minimum depth (ft)	0.03	0.03	0.04
High flow - maximum velocity (fps)	3.31	5.65	6.27
High flow - outlet drop (ft)	0.00	0.69	0.82
High flow - minimum depth (ft)	0.50	0.35	0.44

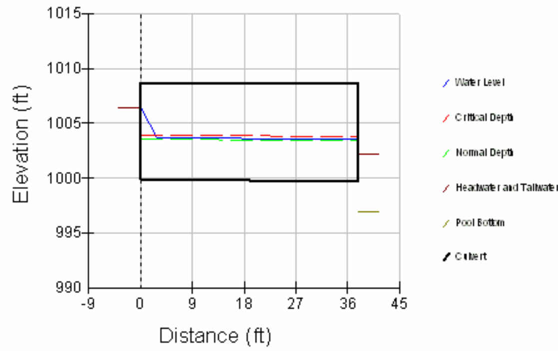




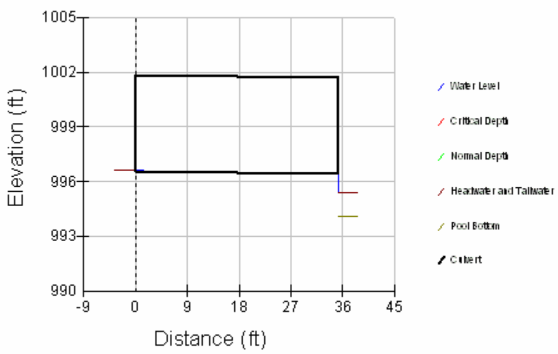
EX Culvert 1 - Upper
Depth vs. Distance Down Culvert at 581.00 cfs



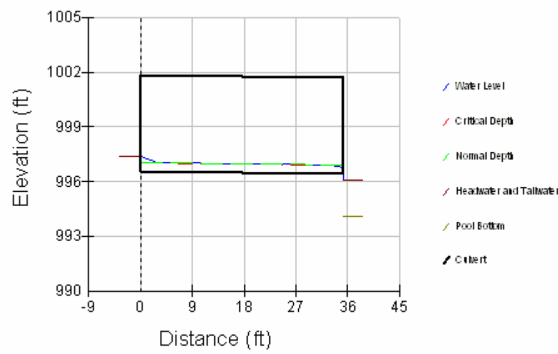
EX Culvert 1 - Upper
Depth vs. Distance Down Culvert at 824.00 cfs



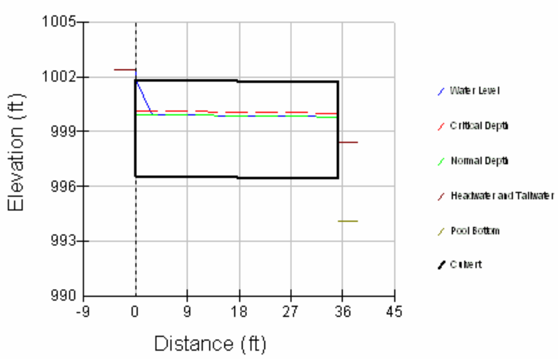
EX Culvert 2 - Middle
Depth vs. Distance Down Culvert at 1.00 cfs



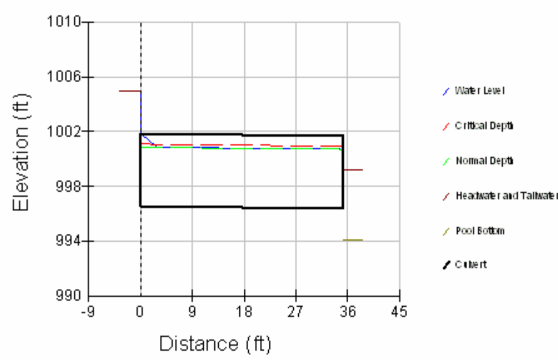
EX Culvert 2 - Middle
Depth vs. Distance Down Culvert at 35.00 cfs

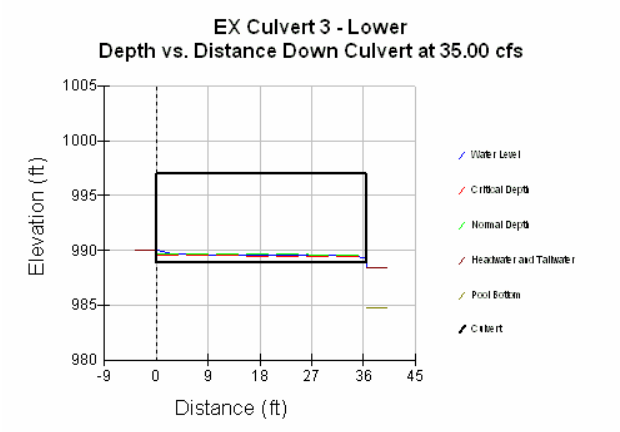


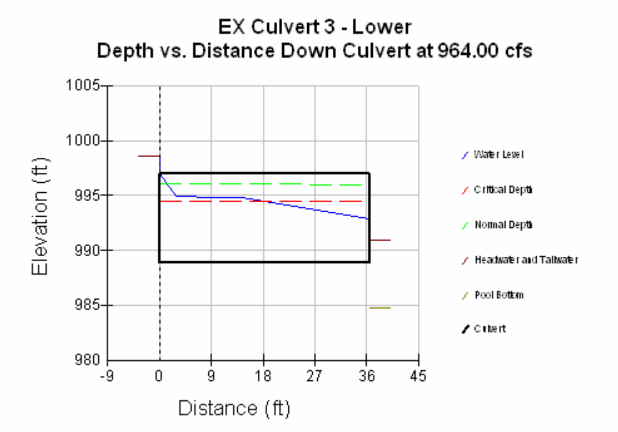
EX Culvert 2 - Middle
Depth vs. Distance Down Culvert at 681.00 cfs

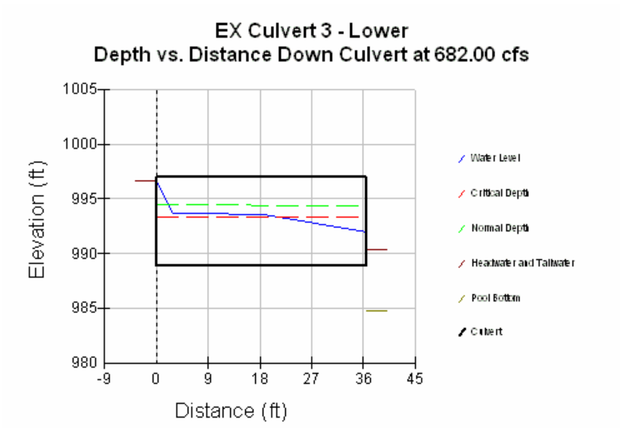


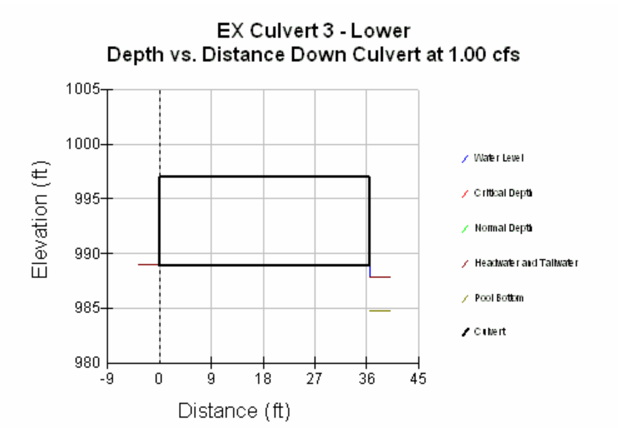
EX Culvert 2 - Middle
Depth vs. Distance Down Culvert at 962.00 cfs




EX Culvert 3 - Lower
Depth vs. Distance Down Culvert at 35.00 cfs
Elevation (ft)
Distance (ft)
Water Level
Critical Depth
Normal Depth
Headwater and Tailwater
Pool Bottom
Culvert


EX Culvert 3 - Lower
Depth vs. Distance Down Culvert at 964.00 cfs
Elevation (ft)
Distance (ft)
Water Level
Critical Depth
Normal Depth
Headwater and Tailwater
Pool Bottom
Culvert


EX Culvert 3 - Lower
Depth vs. Distance Down Culvert at 682.00 cfs
Elevation (ft)
Distance (ft)
Water Level
Critical Depth
Normal Depth
Headwater and Tailwater
Pool Bottom
Culvert


EX Culvert 3 - Lower
Depth vs. Distance Down Culvert at 1.00 cfs
Elevation (ft)
Distance (ft)
Water Level
Critical Depth
Normal Depth
Headwater and Tailwater
Pool Bottom
Culvert

EXISTING CONDITIONS AQUATIC ORGANISM PASSAGE (AOP) RESULTS				
(Differences = Culvert value - AOP criteria: velocity barrier > 0; drop barrier > 0; depth barrier < 0. Underline indicates barrier.)				
CULVERT 1 (UPSTREAM)				
Lifestage	Adult	Adult	Juvenile	Juvenile
Flow	Low	High	Low	High
Barrier type(s)	depth	velocity	depth, velocity	velocity
Location(s) of barrier	throughout	outlet	throughout, outlet	outlet
Maximum velocity difference (fps)	-0.87	0.71	0.73	2.31
Outlet drop difference (ft)	-0.58	-0.67	-0.24	-0.33
Minimum depth difference (ft)	-0.32	0.15	-0.15	0.33
CULVERT 2 (MIDDLE)				
Lifestage	Adult	Adult	Juvenile	Juvenile
Flow	Low	High	Low	High
Barrier type(s)	drop, depth	drop, velocity	drop, depth, velocity	drop, velocity
Location(s) of barrier	outlet, throughout	outlet, outlet	outlet, throughout, outlet	outlet, outlet
Maximum velocity difference (fps)	-0.88	3.05	0.72	4.65
Outlet drop difference (ft)	0.33	0.02	0.67	0.36
Minimum depth difference (ft)	-0.32	0.00	-0.15	0.18
CULVERT 3 (DOWNSTREAM)				
Lifestage	Adult	Adult	Juvenile	Juvenile
Flow	Low	High	Low	High
Barrier type(s)	drop, depth	drop, velocity	drop, depth, velocity	drop, velocity
Location(s) of barrier	outlet, throughout	outlet, outlet	outlet, throughout, outlet	outlet, outlet
Maximum velocity difference (fps)	-0.69	3.67	0.91	5.27
Outlet drop difference (ft)	0.36	0.15	0.70	0.49
Minimum depth difference (ft)	-0.31	0.09	-0.14	0.27

APPENDIX G – Summary of Alternatives

Proposed Conditions Planning
Great Brook Fish Passage Restoration Project
December 21, 2009

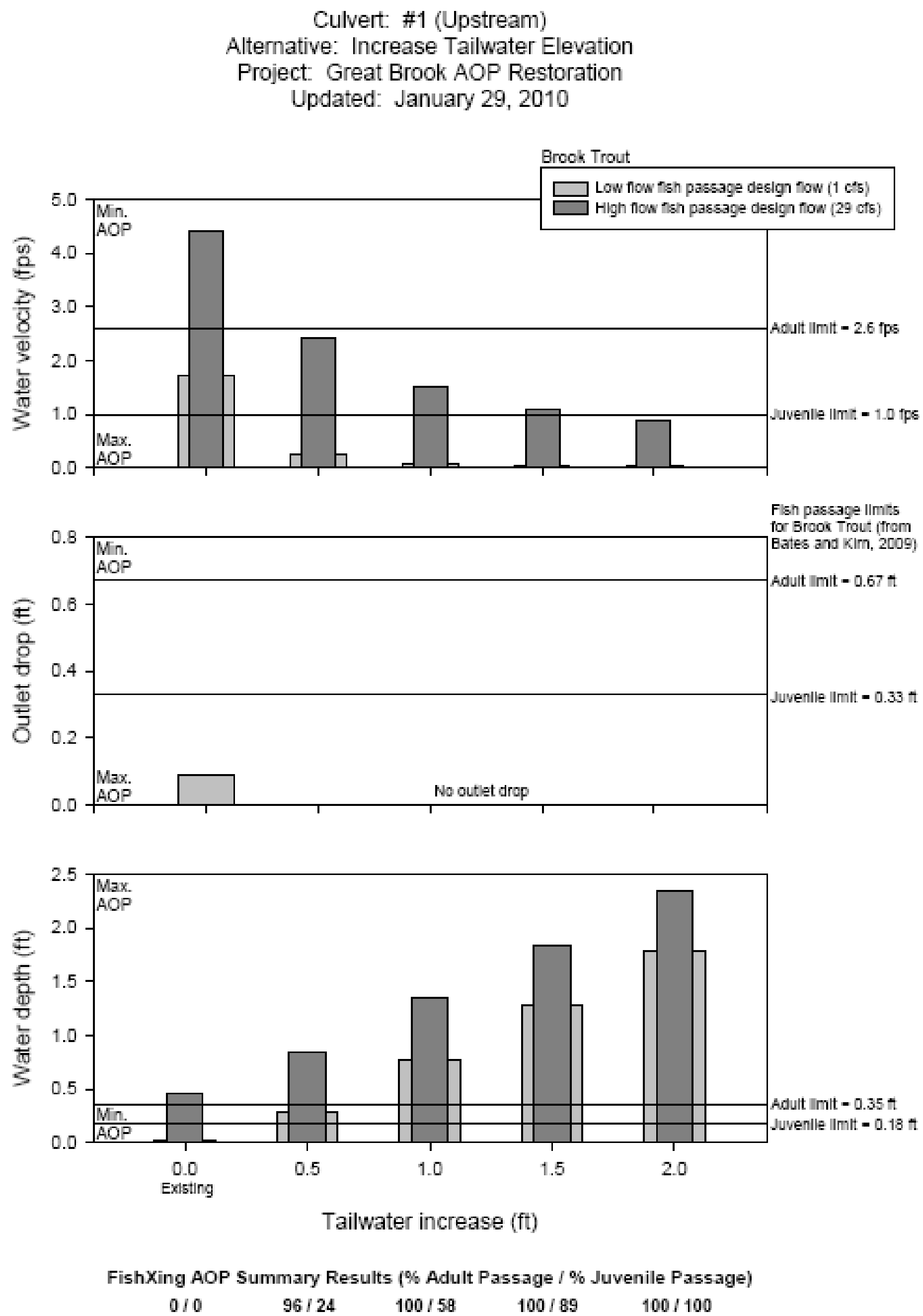
PROPOSED CONDITIONS

Raise tailwater (ft)	Roughen channel (n)	Roughen culvert (n)	Decrease downstream channel slope by (%)
0.5	0.045	0.020	0.5
1.0	0.050	0.025	1.0
1.5	0.055	0.030	1.5
2.0	0.060	0.035	2.0

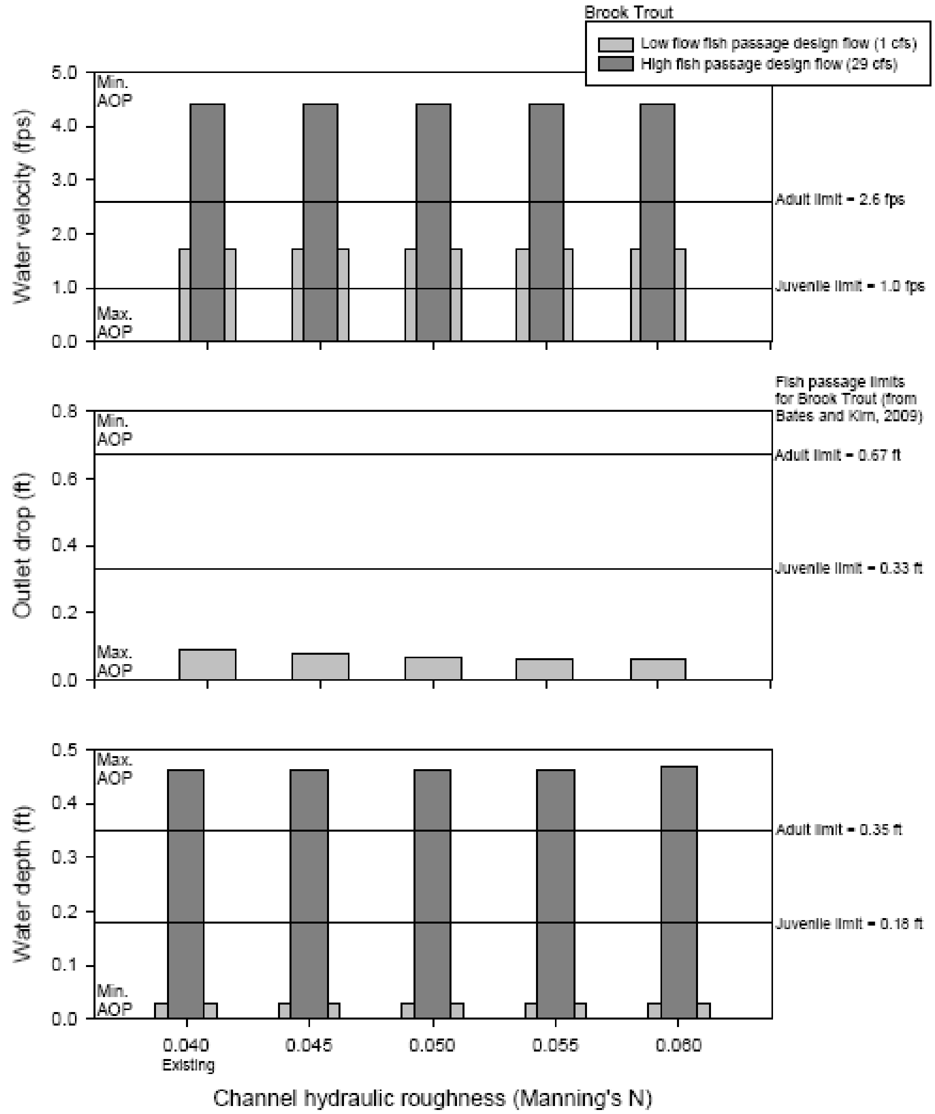
OBJECTIVES

Aquatic Organism Passage Level	Lifestage	Flow
1	Adult	Low
2	Adult	High
3	Juvenile	Low
4	Juvenile	High

APPENDIX H – Alternative Analysis Results



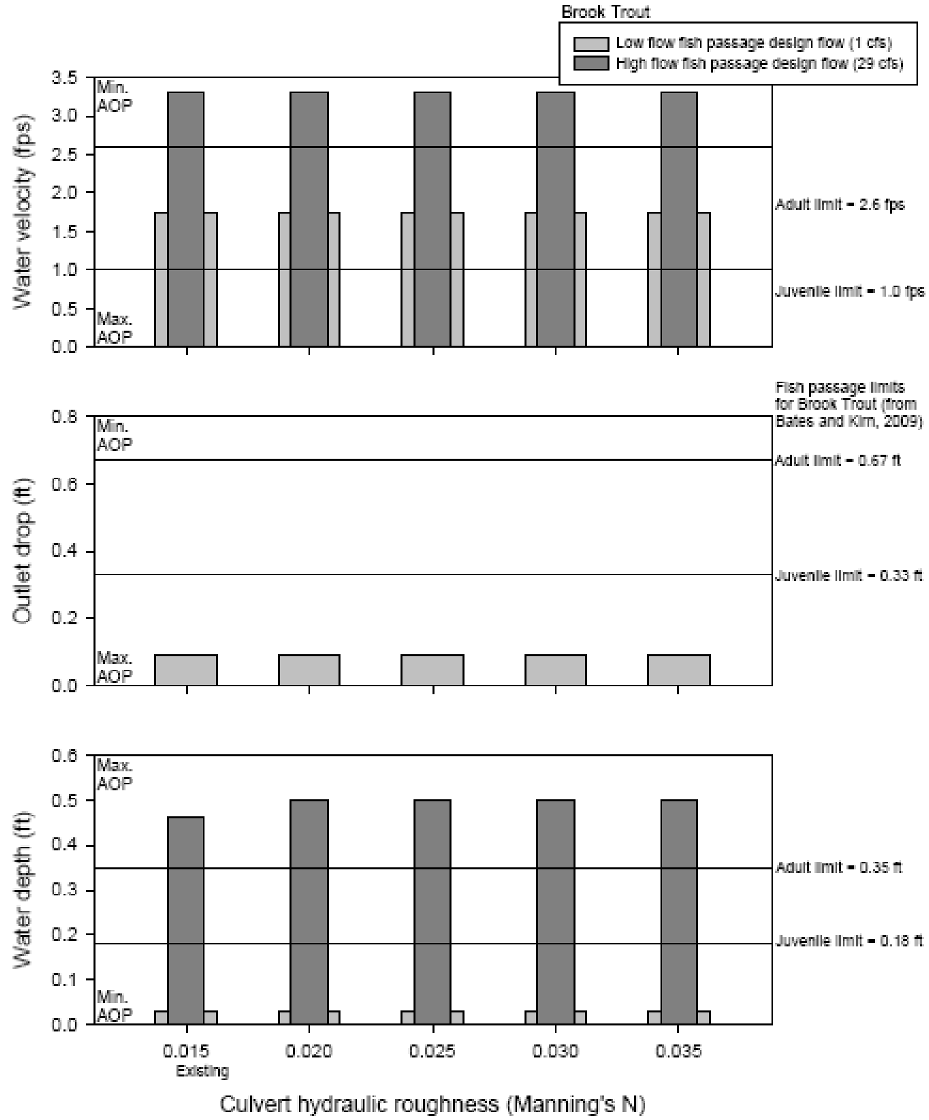
Culvert: #1 (Upstream)
Alternative: Increase Roughness of Downstream Channel
Project: Great Brook AOP Restoration
Updated: January 29, 2010



FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

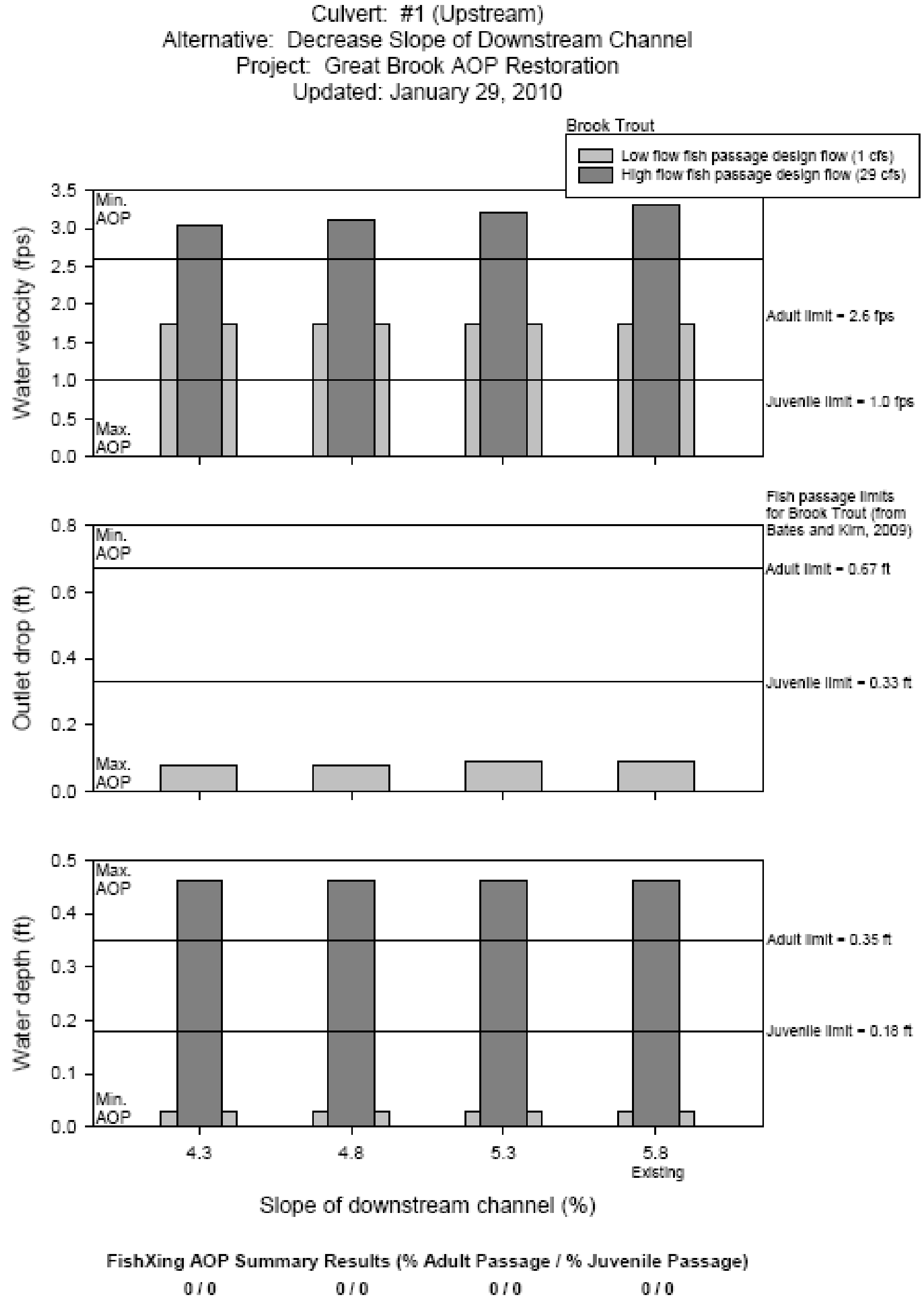
0.040	0.045	0.050	0.055	0.060
0 / 0	0 / 0	0 / 0	0 / 0	0 / 0

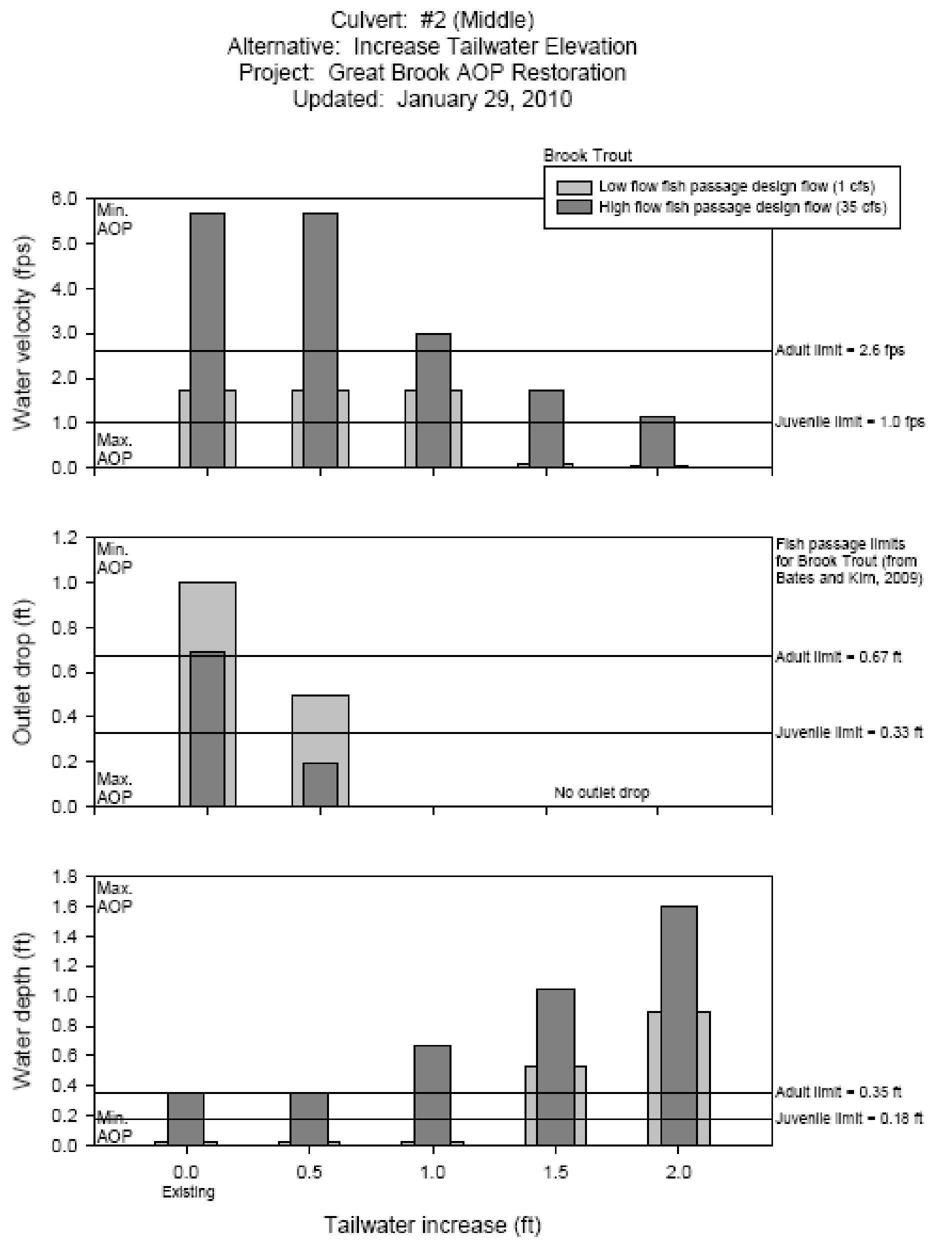
Culvert: #1 (Upstream)
Alternative: Increase Roughness of Culvert
Project: Great Brook AOP Restoration
Updated: January 29, 2010



FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

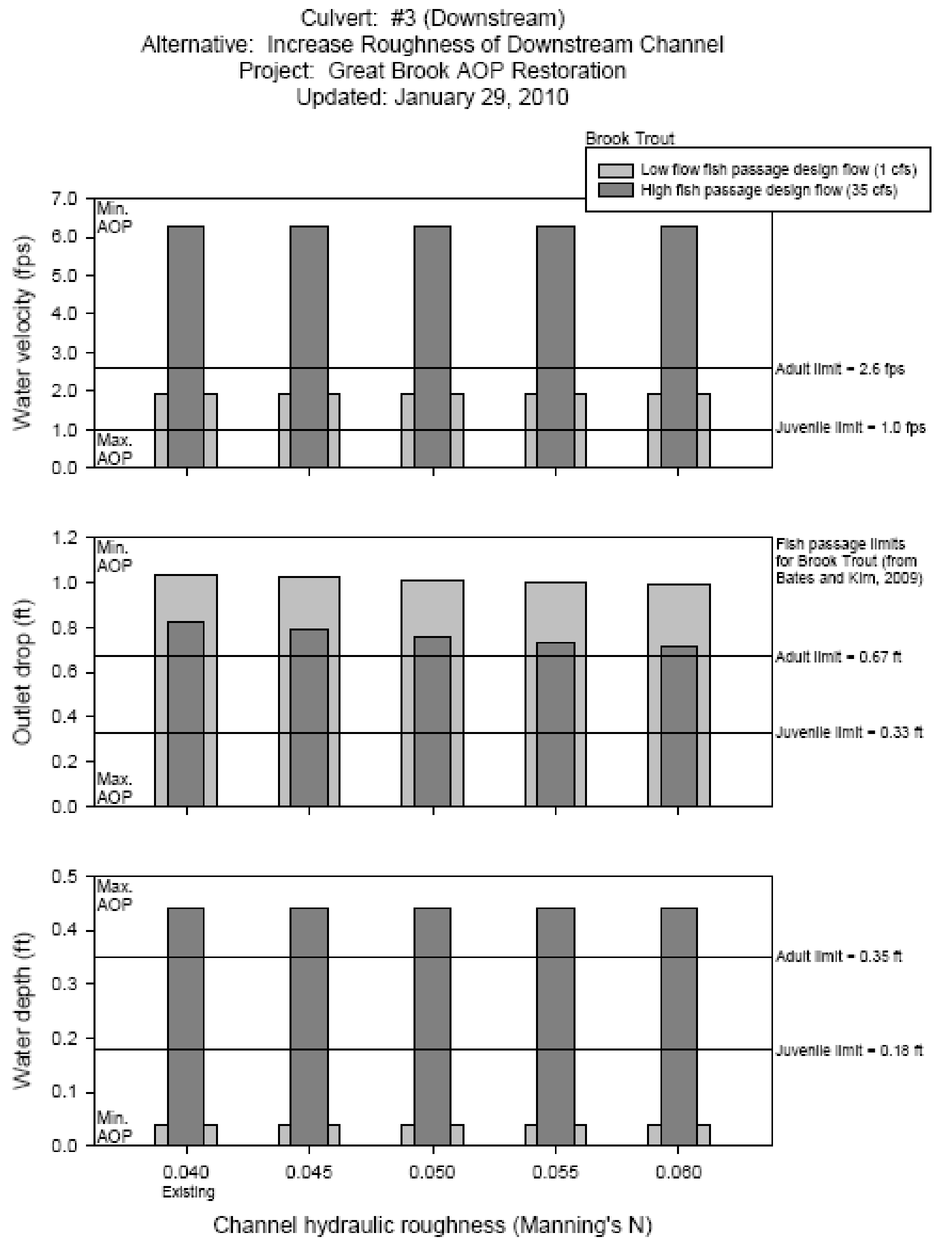
0 / 0	0 / 0	0 / 0	0 / 0	0 / 0


Culvert: #1 (Upstream)
Alternative: Decrease Slope of Downstream Channel
Project: Great Brook AOP Restoration
Updated: January 29, 2010
Brook Trout
Low flow fish passage design flow (1 cfs)
High flow fish passage design flow (29 cfs)
Water velocity (fps)
Min. AOP
Max. AOP
Adult limit = 2.6 fps
Juvenile limit = 1.0 fps
Fish passage limits for Brook Trout (from Bates and Kirn, 2009)
Outlet drop (ft)
Adult limit = 0.67 ft
Juvenile limit = 0.33 ft
Water depth (ft)
Adult limit = 0.35 ft
Juvenile limit = 0.18 ft
4.3
4.8
5.3
5.8
Existing
Slope of downstream channel (%)
FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)
0 / 0
0 / 0
0 / 0
0 / 0



FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

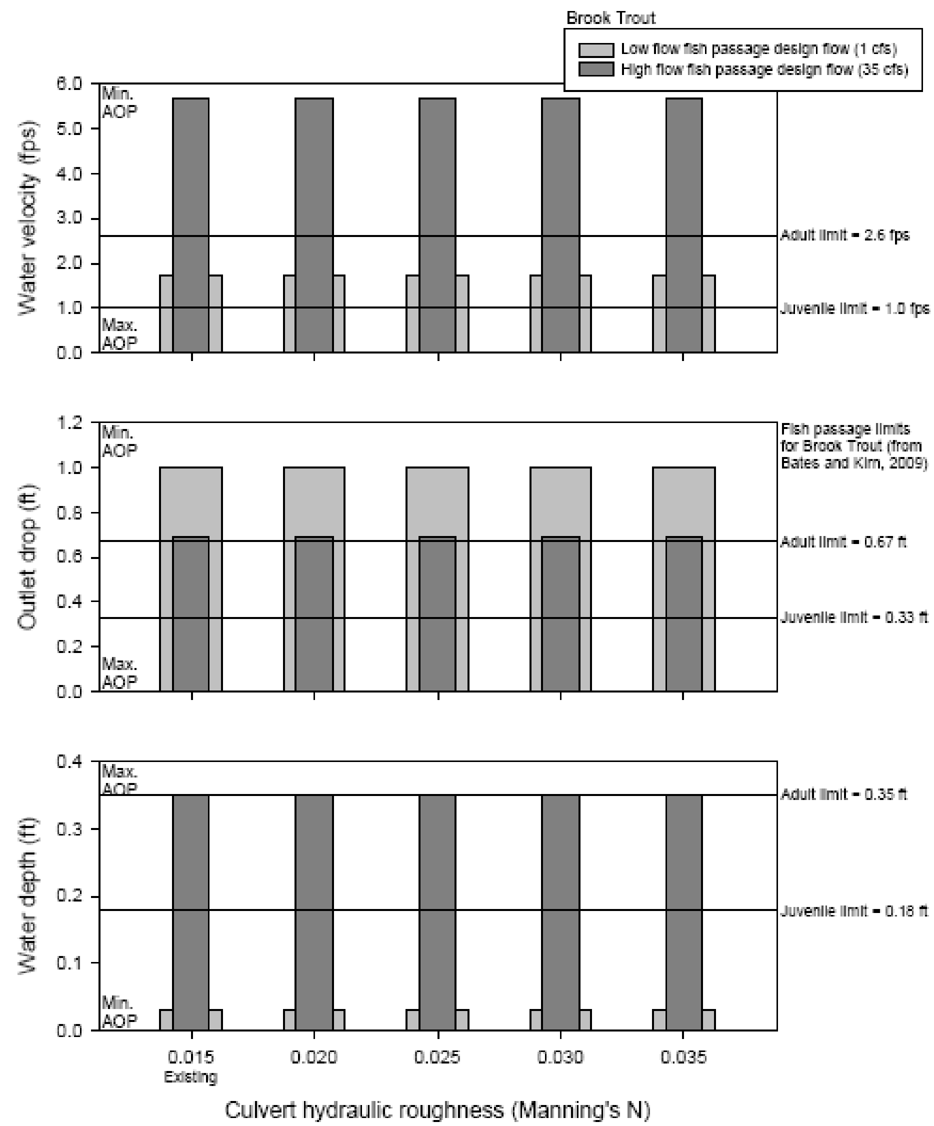
0.0	0.5	1.0	1.5	2.0
0 / 0	0 / 0	0 / 0	100 / 27	100 / 55



FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

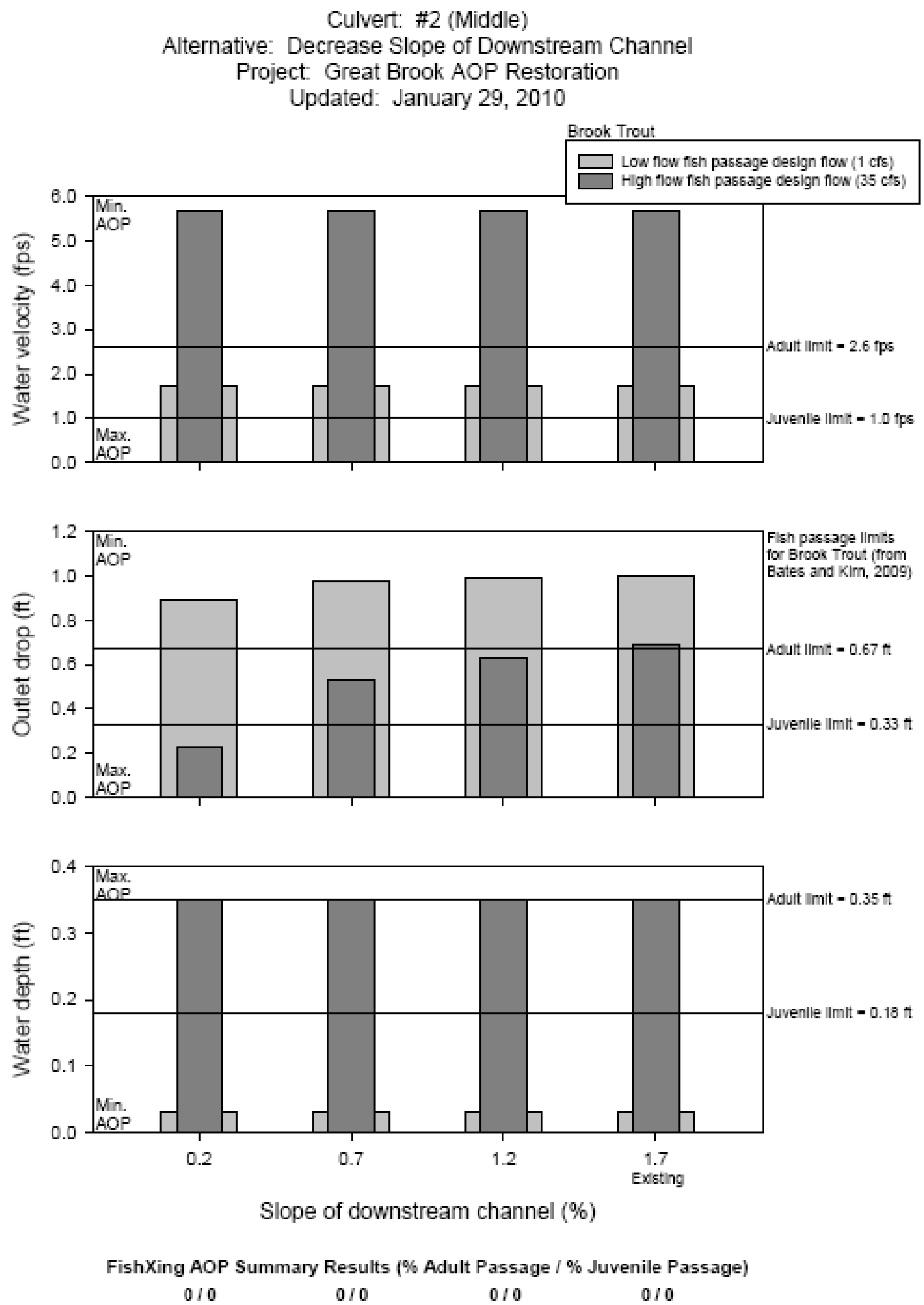
0.040 Existing	0.045	0.050	0.055	0.060
0 / 0	0 / 0	0 / 0	0 / 0	0 / 0

Culvert: #2 (Middle)
Alternative: Increase Roughness of Culvert
Project: Great Brook AOP Restoration
Updated: January 29, 2010



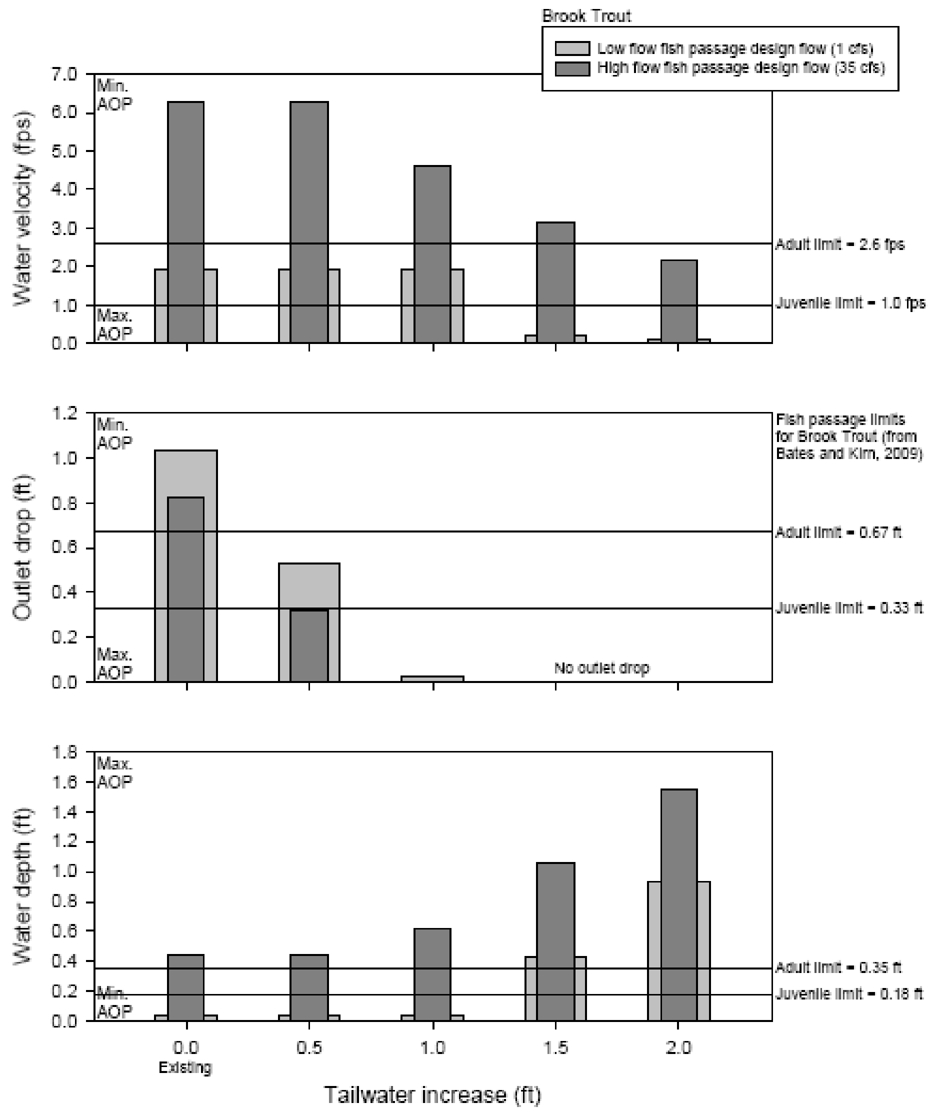
FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

0 / 0 **0 / 0** **0 / 0** **0 / 0** **0 / 0**



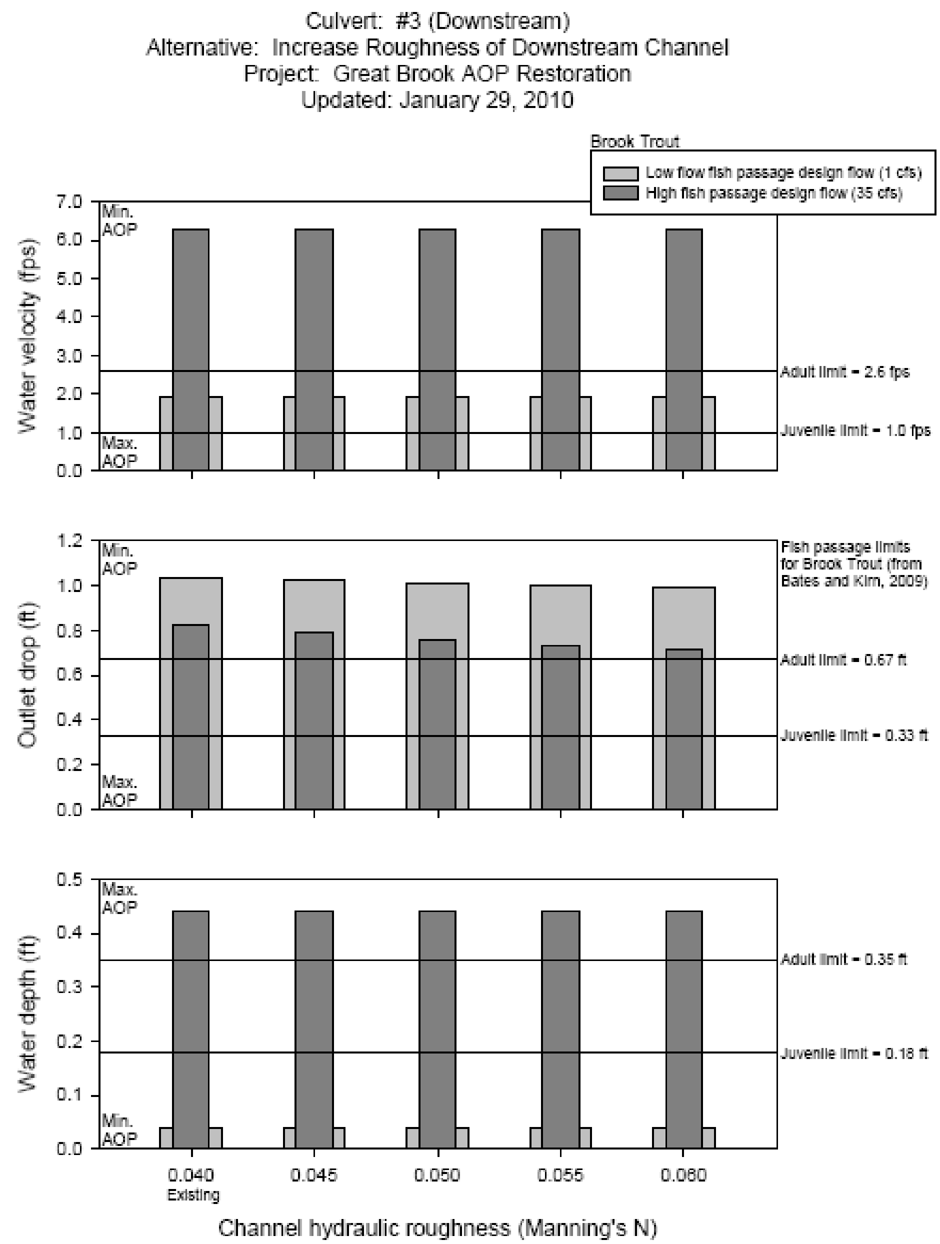
Culvert: #2 (Middle)
Alternative: Decrease Slope of Downstream Channel
Project: Great Brook AOP Restoration
Updated: January 29, 2010
Brook Trout
Low flow fish passage design flow (1 cfs)
High flow fish passage design flow (35 cfs)
Water velocity (fps)
Min. AOP
Max. AOP
Adult limit = 2.6 fps
Juvenile limit = 1.0 fps
Outlet drop (ft)
Fish passage limits for Brook Trout (from Bates and Kim, 2009)
Adult limit = 0.67 ft
Juvenile limit = 0.33 ft
Water depth (ft)
Adult limit = 0.35 ft
Juvenile limit = 0.18 ft
0.2
0.7
1.2
1.7 Existing
Slope of downstream channel (%)
FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)
0 / 0
0 / 0
0 / 0
0 / 0

Culvert: #3 (Downstream)
Alternative: Increase Tailwater Elevation
Project: Great Brook AOP Restoration
Updated: January 29, 2009



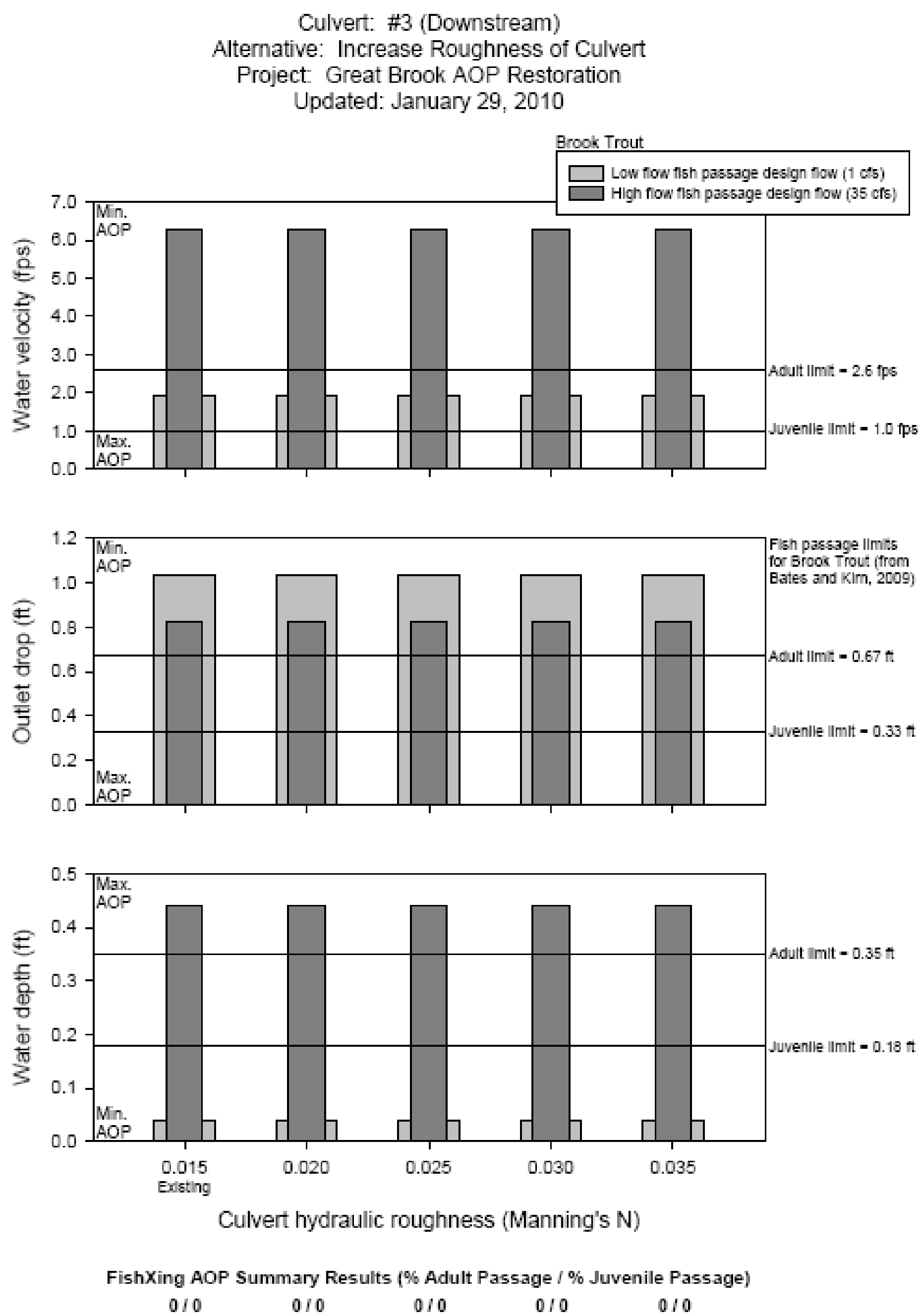
FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

0 / 0	**0 / 0**	**0 / 0**	**77 / 20**	**100 / 39**

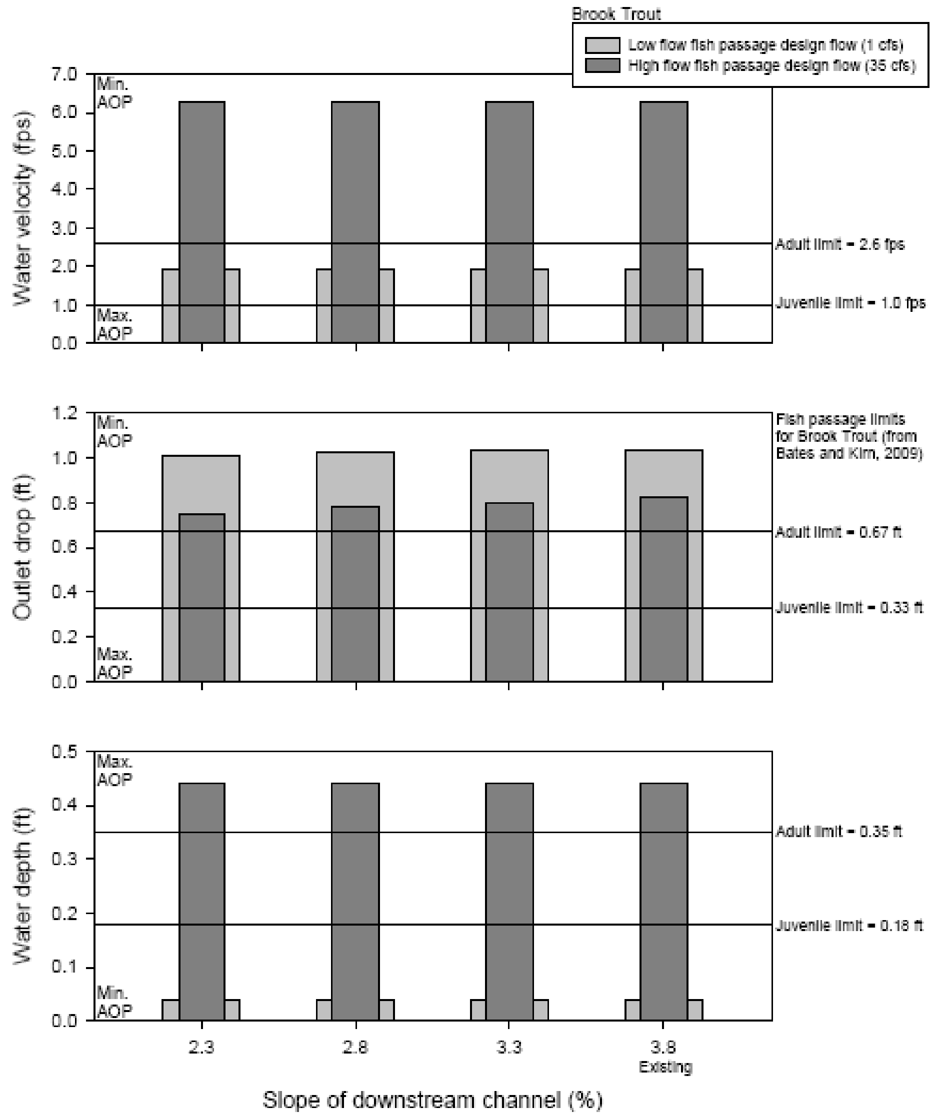


FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

0 / 0	0 / 0	0 / 0	0 / 0	0 / 0


Culvert: #3 (Downstream)
Alternative: Increase Roughness of Culvert
Project: Great Brook AOP Restoration
Updated: January 29, 2010
Brook Trout
Low flow fish passage design flow (1 cfs)
High flow fish passage design flow (35 cfs)
Water velocity (fps)
Min. AOP
Max. AOP
Adult limit = 2.6 fps
Juvenile limit = 1.0 fps
Outlet drop (ft)
Fish passage limits for Brook Trout (from Bates and Kirn, 2009)
Adult limit = 0.67 ft
Juvenile limit = 0.33 ft
Water depth (ft)
Adult limit = 0.35 ft
Juvenile limit = 0.18 ft
0.015 Existing
0.020
0.025
0.030
0.035
Culvert hydraulic roughness (Manning's N)
FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)
0 / 0
0 / 0
0 / 0
0 / 0
0 / 0

Culvert: #3 (Downstream)
Alternative: Decrease Slope of Downstream Channel
Project: Great Brook AOP Restoration
Updated: January 29, 2010



FishXing AOP Summary Results (% Adult Passage / % Juvenile Passage)

2.3	2.8	3.3	3.8
0 / 0	0 / 0	0 / 0	0 / 0

Aquatic Organism Passage Results Summary - Increase Tailwater Alternative
Great Brook Fish Passage Restoration Project
February 1, 2010

Culvert 1 (upper)

	Percent Passage Over Fish Passage Design Flow Range			
	Brook Trout (1-29 cfs)		Rainbow Trout (1-99 cfs)	
Tailwater Increase	Adult	Juvenile	Adult	Juvenile
0.0	0	0	0	0
0.5	96	24	65	16
1.0	100	58	100	33
1.5	100	89	100	49
2.0	100	100	100	64

Culvert 2 (middle)

	Percent Passage Over Fish Passage Design Flow Range			
	Brook Trout (1-29 cfs)		Rainbow Trout (1-99 cfs)	
Tailwater Increase	Adult	Juvenile	Adult	Juvenile
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	2	0
1.5	100	27	71	18
2.0	100	55	100	34

Culvert 3 (lower)

	Percent Passage Over Fish Passage Design Flow Range			
	Brook Trout (1-29 cfs)		Rainbow Trout (1-99 cfs)	
Tailwater Increase	Adult	Juvenile	Adult	Juvenile
0.0	0	0	0	0
0.5	0	0	0	0
1.0	0	0	8	0
1.5	77	20	44	12
2.0	100	39	68	22

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	Great Brook AOP Restoration (MMI # 3846-03)	
Stream	Great Brook	
Road, location	Brook Road, culvert (#1) (upstream)	
Lat / Long (~~d/m/s~~) (dec.)	44.22453	-72.4013
ID Team members	Ann S., Madeleine L., Shayne J., Rich K., Roy	
Date	1/5/2010	

Brief description of project: Improve passage for brook trout at series of three culverts on Great Brook. Culvert #1 Screens: AOP = orange, RP = MML, GC = Lemon-lime

Project type (new, retrofit, replacement): Channel work, possibly retrofit

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

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

(Y) / N

Site characteristics (LS)

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

Existing culvert perched? (Y) / N Height of perch: 1 ft +/- (Key issue is outlet drop)

Downstream channel incised? (Y) / N Depth of incision: 0.5 ft +/-

Evidence of incision: Minor erosion on bank toe

Upstream backwater deposition: Y / (N)

Evidence and extent: Some minor accumulation of cobble but no strong backwater effects. Accumulation could be due to bend reducing sediment transport.

Project Great Brook AOP - Culvert 1

Project ID MMI # 3846-03
Date 1/5/2010

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Swim speed (fps)	~~Swim mode~~ Max. Drop (ft)	Min depth (ft)
Brook Trout	Adult	6-10	Sept - Nov	2.6	0.67	0.35
Brook Trout	Juv.	3-5	Sept - Nov	1.0	0.33	0.18

Describe data sources VT AOP Guidelines (Bates + Kirn, 2009)

Hydrology

Watershed characteristics (LS)

Area 6.18 sq miles Mean elevation 1,300 ft above sea level

Mean annual precipitation 40 inches

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

% DA lakes = 0.06, % DA with elevation over 1,200 ft = 100, GF = 190,257
Northing (VSPC) = 191,584

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)	90% prediction
2 - yr event	234	42	234	122 - 449
25 - yr event	581	42	581	301 - 1120
100 - yr event	824	44	824	412 - 1650

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)
Brook Trout	Adult/Juv	29	1

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

VT AOP Guidelines (Bates and Kirn, 2009); USGS Stream Stats

Project Great Brook AOP - Culvert 1

Project ID AN1 # 3846-03

Date 1/5/2010

3 - DESIGN

Channel (LS)

	Downstream	Upstream
Average slope	5.8 %	2.0 %
Average bankfull width	~30 ft	~30 ft
Bed Elevation - low potential profile	~997	~999
Bed Elevation - high potential profile	~1000	~1001
Description of channel	scour pool glide bending left w bankfull benches, gravel/cobble	cobble/boulder run that bends right w/. RB riprap
Channel roughness (n)	0.040	0.045
Bed Elevation - project profile	999.7	999.8
Elevation of downstream control	999.4	TW riffle

Verify w/. surveyors + more obs.

not clearly labelled in survey

assumed datum (ft)

How is profile controlled? Tailwater riffle downstream of scour pool w/ very large boulder, bend at inlet, roughness due to cobble + boulder, culvert bottom to remain

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	17.5 ft	
Rise	8.9 ft	ft
Upstream Invert Elevation	999.84	same
Downstream Invert Elevation	999.67	
Culvert Length (incl apron)	37.8 ft	ft
Slope	0.5 %	%

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 to likely remain unchanged)

Material: Corrugated metal - Smooth metal - Concrete

Corrugation dimensions: ________

Style Full pipe - Bottomless

Project Great Brook AOP - Culvert 1

Project ID MMI # 3846-03
Date 1/5/2010

4 - DESIGN

Fish Passage Hydraulics

	Flow (cfs)	Tailwater elev	Roughness (n) culvert	Velocity (fps) max	Depth (ft) min	EDF (ft-lb/sec/cuft)	Adult / Juv Passability (%)	
EX 7Q2	1	999.59	0.015	1.73	0.03	0.48	0/0	inlet cont.
EX Nov Q_{2-20}	29	1000.1	↓	4.39	0.46	1.01		
PR 7Q2	1	1001.5	↓	0.04	1.78	0.01	100/100	Raise TW 2 ft
PR Nov Q_{2-20}	29	1002.1	↓	0.87	2.34	0.20		

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

Boulders / cobbles in channel and warn concrete in culvert.
Proposed tailwater control to add roughness and control grade.

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

Fish Xing

High flow hydraulics (LS)

	Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)	
PR	Q2	234	1003.0	0.015	1003.47	0.41	* maintain, yet reduce inlet control
PR	Q25	581	1003.7	↓	1005.39	0.63	✓
PR	Q100	824	1004.0	↓	1006.38	0.73	good capacity ex + pr.
	EX Q25	581	1001.7	↓	1004.97	0.58	

Describe methods and sources of data high flow hydraulic calculations.

Stream Stats + Fish Xing. Check w/ HDS #5 nomographs as needed.

Road and Alignment (LS)

~13' [culvert inv. 999.8; culvert top 1008.6; road ℄ 1012.8] ~4' cover

Height of fill on upstream face: ~13 ft. (bottom of slope ≅ bottom of culvert to road)

Proposed culvert skew (parallel is 0 degrees) To remain as existing.

Culvert to channel ~0 degrees Road to culvert ~60 degrees

Proposed alignment, transition changes none

Describe permanent benchmark and elevation "STA-1" EL 1000 assumed datum near D/S section on right bank. "STA-2" EL 1001.31 near U/S section on LB.

VT Hydraulic / Low-Slope Design Data Form - 02/08 Page 4 / 4

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	Great Brook AOP Restoration (MMI# 3846-03)	
Stream	Great Brook	
Road, location	Brook Road, culvert (#2) (middle)	
Lat / Long (~~d/m/s~~) (Dec)	44.23168	-72.4063
ID Team members	Ann S., Madeleine L., Shayne J, Rich K, Roy S	
Date	1/5/2010	

Brief description of project: Improve passage for brook trout at series of three culverts on Great Brook

Culvert #2 screens: AOP = Red, RPS = MML, GC = Yellow

Project type (new, retrofit, replacement): Channel work. Possibly retrofit

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

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

(Y) / N

Site characteristics (LS)

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

Existing culvert perched? (Y) / N Height of perch: 1 ft +/- (key issue is outlet drop)

Downstream channel incised? (Y) / N Depth of incision: 1 ft +/-

Evidence of incision: Some bank erosion / collapse. Fallen trees spanning channel. Culvert foundation partly exposed

Upstream backwater deposition Y / (N)

Evidence and extent: Some minor accumulation but no strong backwater effects

VT Hydraulic / Low-Slope Design Data Form - 02/08 Page 1 / 4

Project Great Brook AOP - Culvert 2

Project ID MMI # 3846-03

Date 1/5/2010

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Swim speed (fps)	~~Swim mode~~ max drop (ft)	Min depth (ft)
Brook Trout	Adult	6-10	Sept-Nov	2.6	0.67	0.35
Brook Trout	Juv	3-5	" "	1.0	0.33	0.18

Describe data sources VT AOP Guidelines (Bates + Kirn, 2009)

Hydrology

Watershed characteristics (LS)

Area 7.4 sq miles Mean elevation 1,240 ft above sea level

Mean annual precipitation 40 inches

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

% DA lakes = 0.06, % DA EL over 1200 ft = 100, GF = 190,579,
Northing (VSPC) = 192,387

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)	90% prediction range
2 - yr event	275	42	275	143-529
25 - yr event	681	42	681	353-1310
100 - yr event	962	44	962	481-1920

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)
Brook Trout	Adult/Juv	35	1

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

VT AOP Guidelines (Bates + Kirn, 2009) fish passage design flows;
USGS Stream Stats

Project Great Brook AOP- Culvert 2 Project ID MMI # 3846-03
Date 1/5/2010

3 - DESIGN

Channel (LS)

	Downstream	Upstream
Average slope	1.7 %	2.3 %
Average bankfull width	~35 ft	~30 ft
Bed Elevation - low potential profile	~995	~996
Bed Elevation - high potential profile	~998	~998
Description of channel	boulder/cobble riffle, bend right, trib enters RB	scour pool, tw riffle control, pool, channel bend left
Channel roughness (n)	0.040	0.045
Bed Elevation - project profile	996.3	996.5
Elevation of downstream control	995.2	TW riffle

Verify w. surveyors + more field obs.

How is profile controlled? Tailwater riffle downstream of scour pool, minor bend at inlet, boulder/cobble roughness, culvert bottom (to remain)

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	17.5 ft	
Rise	5.3 ft	ft
Upstream Invert Elevation	996.53	(same)
Downstream Invert Elevation	996.39	
Culvert Length	35.14 ft	ft
Slope	0.40 %	%

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 to likely remain unchanged)

Material: Corrugated metal - Smooth metal - Concrete

Corrugation dimensions: ______

Style Full pipe - Bottomless

Project Great Brook AOP - Culvert 2

Project ID MMI # 3846-03
Date 1/5/2010

4 - DESIGN

Fish Passage Hydraulics

		Flow (cfs)	Tailwater elev	Roughness (n)	Velocity (fps) max	Depth (ft) min	EDF (ft-lb/sec/cuft)	Adult / Juv. Passability (%)	
EX	7Q2	1	995.4	0.015	1.7	0.03	0.4	0/0	inlet cont
	Nov Q2-20	35	996.1	↓	5.7	0.4	1.4		
PR	7Q2	1	996.9		0.2	0.4	0.04	100/27	Raise TW 1.5'
	Nov Q2-20	35	997.5	↓	2.4	1.0	0.5		

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

Boulders / cobbles mortared concrete on culvert bottom and sidewalls, Tailwater control to add roughness

(loose 28% to match current flood since can't get 2ft)

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

Fish Xing, previous survey

High flow hydraulics (LS)

	Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)	
PR	Q2	275	999.2	0.015	1000.0	0.65	
	Q25	681	1001.7	↓	1003.1 2ft below rd	1.24	sub-critical
	Q100	962	1003.5		1006.2 1ft above rd	1.83	
EX	Q25	681	998.4	↓	1002.3 3ft below rd	1.10	super-critical

Describe methods and sources of data high flow hydraulic calculations. Stream Stats, Fish Xing, HDS #5 Nomographs

Road and Alignment (LS)

~9' [culvert invert 996.4, culvert top 1001.9, road ℄ 1005.1] ~3'

Height of fill on upstream face: ~9 ft. (bottom embankment ~ @ bottom culvert)

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel ~0 degrees Road to culvert ~65 degrees

Proposed alignment, transition changes none

Describe permanent benchmark and elevation "STA-1" EL1000 assumed datum LB U/S; "STA-2" EL 1005.28 RB near culvert

VT Hydraulic / Low-Slope Design Data Form - 02/08 Page 4 / 4

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	Great Brook AOP Restoration (MMI # 3846-08)	
Stream	Great Brook	
Road, location	Brook Road, culvert (#3) (downstream)	
Lat / Long (~~d/m/s~~) (dec.)	44.23308	-72.40652
ID Team members	Ann S., Madeleine L., Shayne J., Rich K., Roy S.	
Date	1/4/10	

Brief description of project: Improve passage for brook trout at series of three culverts on Great Brook. Culvert #3 Screens: AOP = Orange, RP = MLL, GC = Orange

Project type (new, retrofit, replacement): Channel work. Possibly retrofit.

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

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

(Y) / N

Site characteristics (LS)

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

Existing culvert perched? (Y) / N Height of perch: 1 ft +/- (outlet drop key issue)

Downstream channel incised? (Y) / N Depth of incision: 1 ft +/-

Evidence of incision: Riprap on d/s banks along house on straight channel section, outlet drop, profile appears to show incision d/s TW control.

Upstream backwater deposition (Y) / N

Evidence and extent: local aggradation of cobbles u/s culvert riprap lining outside of bend on right bank approach.

Project Great Brook AOP - Culvert 3

Project ID MM # 3846-03
Date 1/4/2010

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Swim speed (fps)	max drop (ft) ~~Swim mode~~	Min depth (ft)
Brook Trout	Adult	6-10	Sept-Nov	2.6	0.67	0.35
"	Juv	3-5	"	1.0	0.33	0.18

Describe data sources VT AOP Guidelines (Bates + Kirn, 2009)

Hydrology

Watershed characteristics (LS)

Area 7.41 sq miles Mean elevation 1,220 ft above sea level

Mean annual precipitation 40 inches

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

% DA lakes = 0.06, % DA EL > 1200 ft = 100, GF = 190,584, Northing (VSPC) = 192,522

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)	90% prediction range
2 - yr event	276	42	276	144-530
25 - yr event	682	42	682	354-1310
100 - yr event	964	44	964	482-1930

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)
Brook Trout	Adult/Juv	35	1

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

VT AOP Guidelines (Bates + Kirn, 2009) fish passage design flows, USGS StreamStats

Project Great Brook AOP - Culvert 3

Project ID MMI # 3846-03
Date 1/4/10

3 - DESIGN

Channel (LS)

Verify w/ surveyors & more field dox.

	Downstream	Upstream
Average slope	3.8 %	1.7 %
Average bankfull width	~30 ft	~30 ft
Bed Elevation - low potential profile	~986	~988
Bed Elevation - high potential profile	~989.5	~990
Description of channel	riprap RB, bed left, cobble/boulder riffle	scour pool, cobble agg, bedrock LB, bend right, riprap
Channel roughness (n)	0.040	0.045
Bed Elevation - project profile	989	989.2
Elevation of downstream control	988.1	

How is profile controlled? Tailwater riffle d/s scour pool consisting of deposited cobble. Bend right along bedrock bank adding control.

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	12.8 ft	
Rise	8.1 ft	ft
Upstream Invert Elevation	988.91	(same)
Downstream Invert Elevation	988.83	
Culvert Length	36.65 ft	ft
Slope	0.22 %	%

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 likely to remain unchanged)

Material: Corrugated metal - Smooth metal - Concrete

Corrugation dimensions: ____________

Style Full pipe - Bottomless

Project Great Brook AOP-Culvert 3

Project ID MMI# 3846-03
Date 1/4/10

4 - DESIGN

Fish Passage Hydraulics

	Flow (cfs)	Tailwater elev	Rough-ness (n)	Velocity (fps)	Depth (ft)	EDF (ft-lb/sec/cuft)	Adult / Juv Passability (%)	
EX 7Q2	1	987.9	0.015	1.9	0.04	0.26	0/0	inlet cont.
EX Nov Q2-20	35	988.5	(same)	6.3	0.4	0.86		
PR 7Q2	1	989.8	(same)	0.1	0.9	0.01	100/39	raise TW
PR Nov Q2-10	35	990.4		2.2	1.6	0.24		

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

Deposited cobble + boulder, roughened culvert bottom (to remain)

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

Fish Xing, previous survey

High flow hydraulics (LS)

	Event	Flow (cfs)	Tailwater elevation	Rough-ness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)	
PR	Q2	276	991.4	0.015	993.1	0.5	
PR	Q25	682	992.3	(same)	996.6 (1.7 ft below rd.)	0.95	✓
PR	Q100	964	992.9	(same)	998.6	1.2	
EX	Q25	682	990.3	(same)	996.6	0.95	✓

Describe methods and sources of data high flow hydraulic calculations.

Stream Stats, Fish Xing, HDS #5 Nomographs

Road and Alignment (LS)

~12 ft [culvert inv. 988.8; culvert top 997.0; road ℄ 1000.3] ~3 ft cover

Height of fill on upstream face: ~12 ft. (~ culvert bottom to road ℄)

Proposed culvert skew (parallel is 0 degrees) (remain as existing)

Culvert to channel ~10 degrees Road to culvert 86 degrees

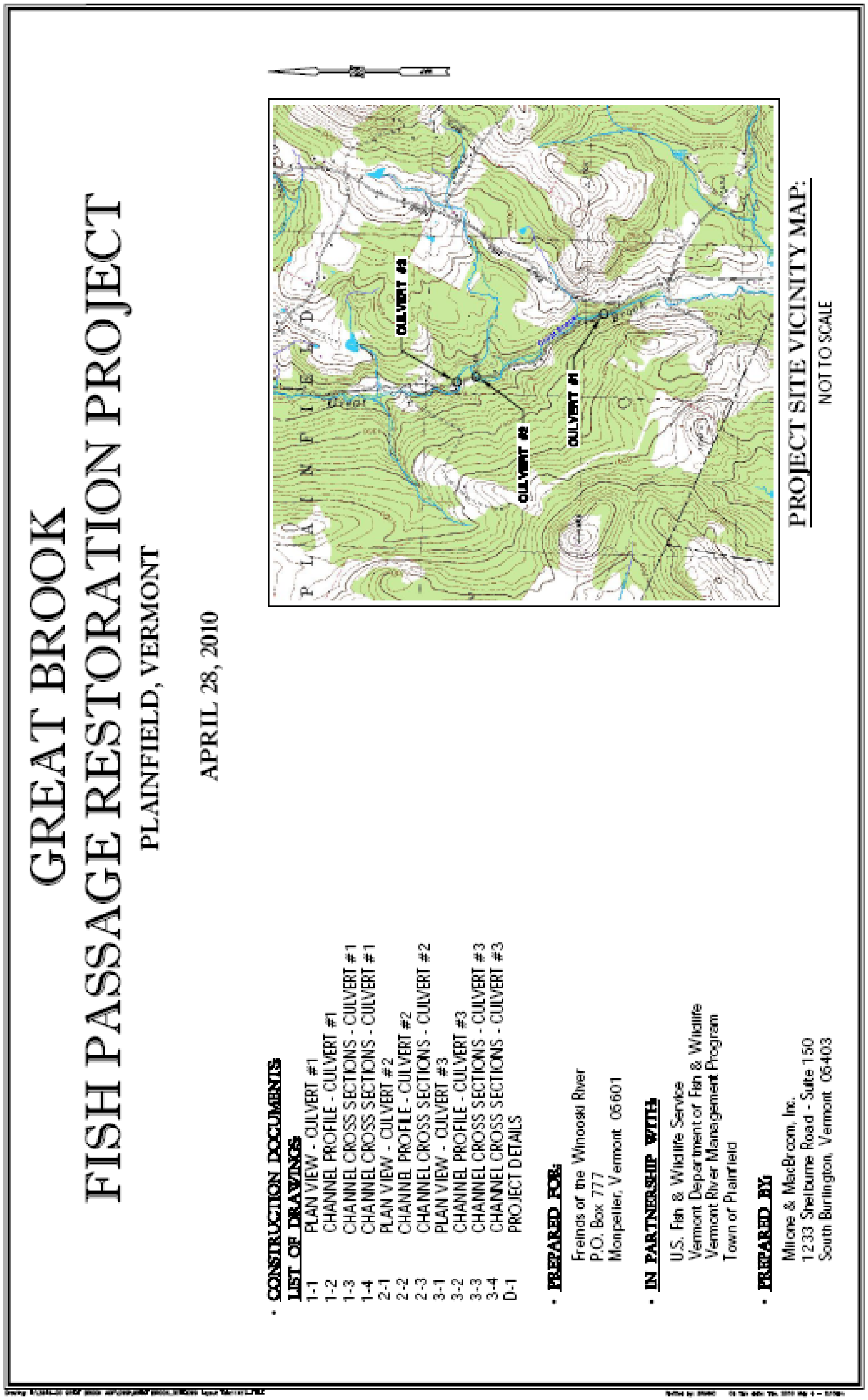
Proposed alignment, transition changes none

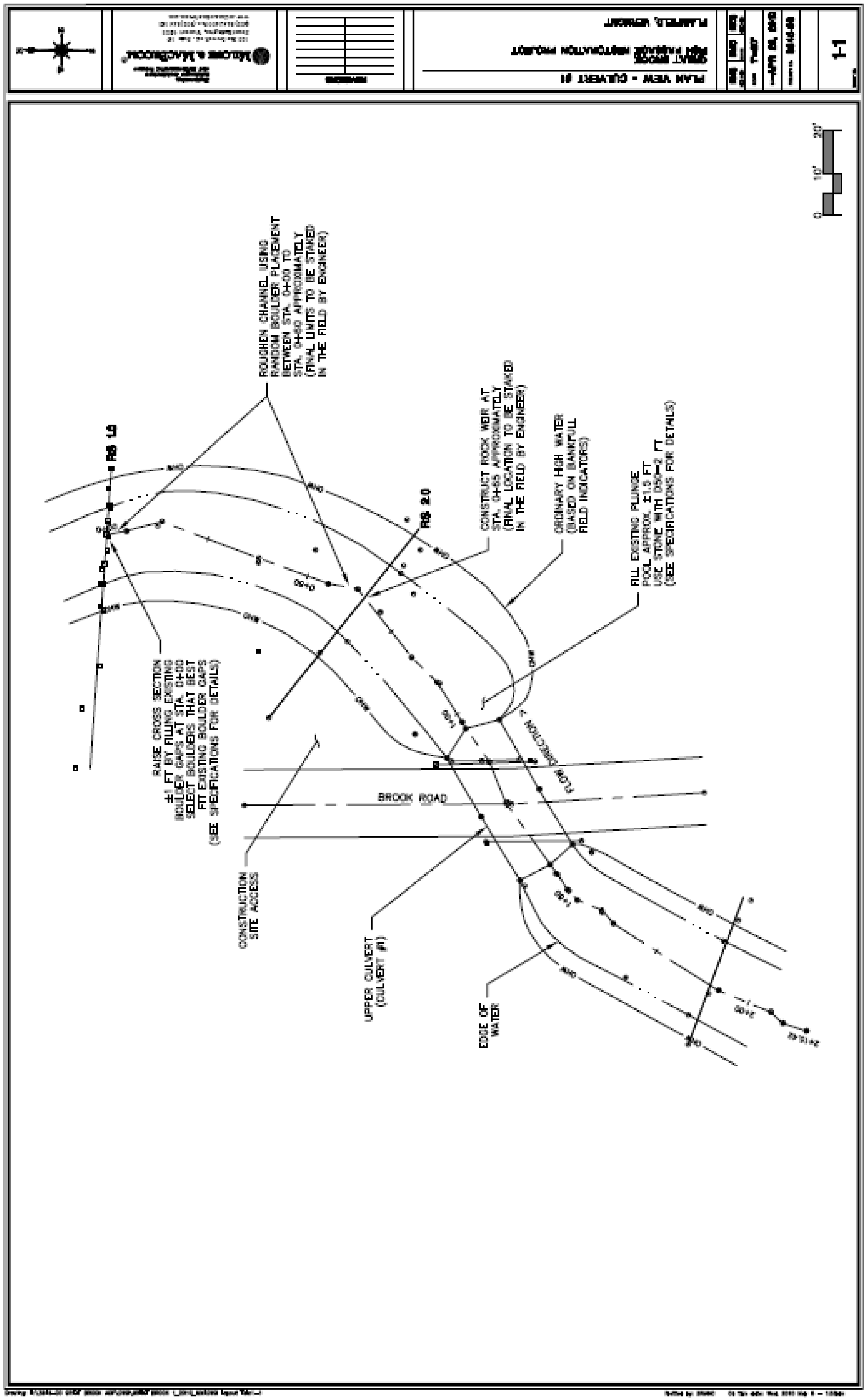
Describe permanent benchmark and elevation "STA-1" EL 1000 Assumed datum RB near culvert, TBM (at 101) 993.01 U/S RB,

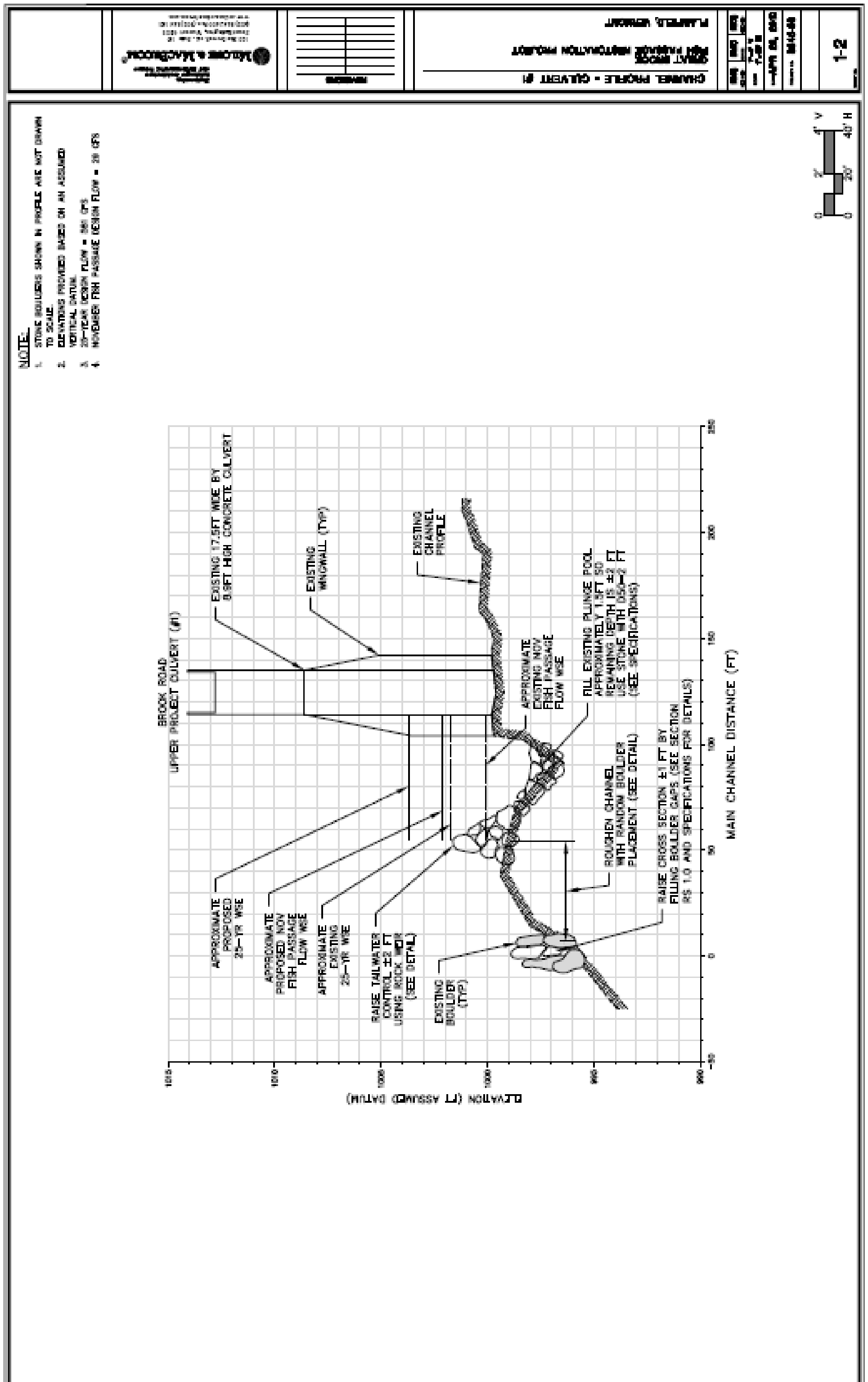
VT Hydraulic / Low-Slope Design Data Form - 02/08

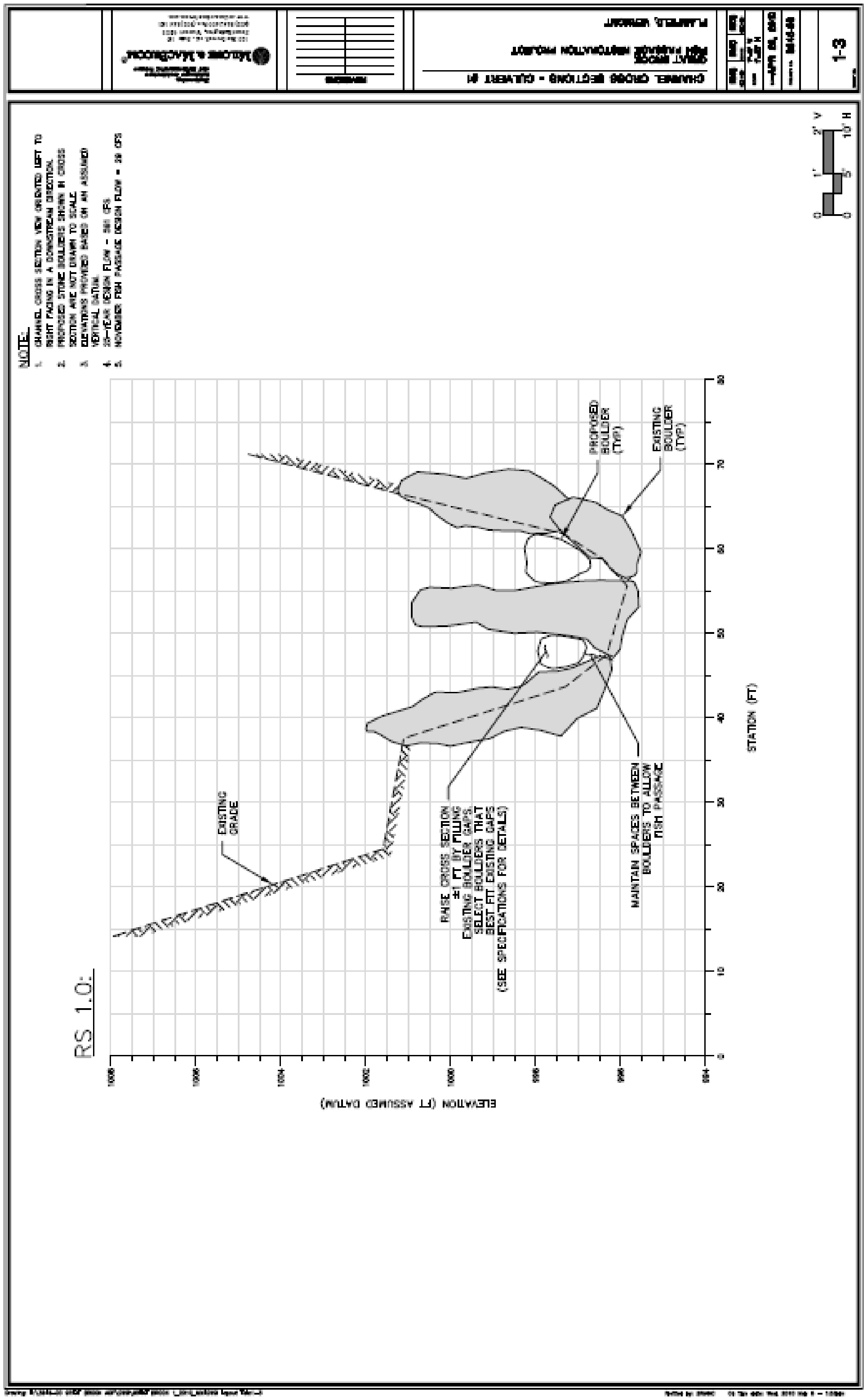
Page 4 / 4

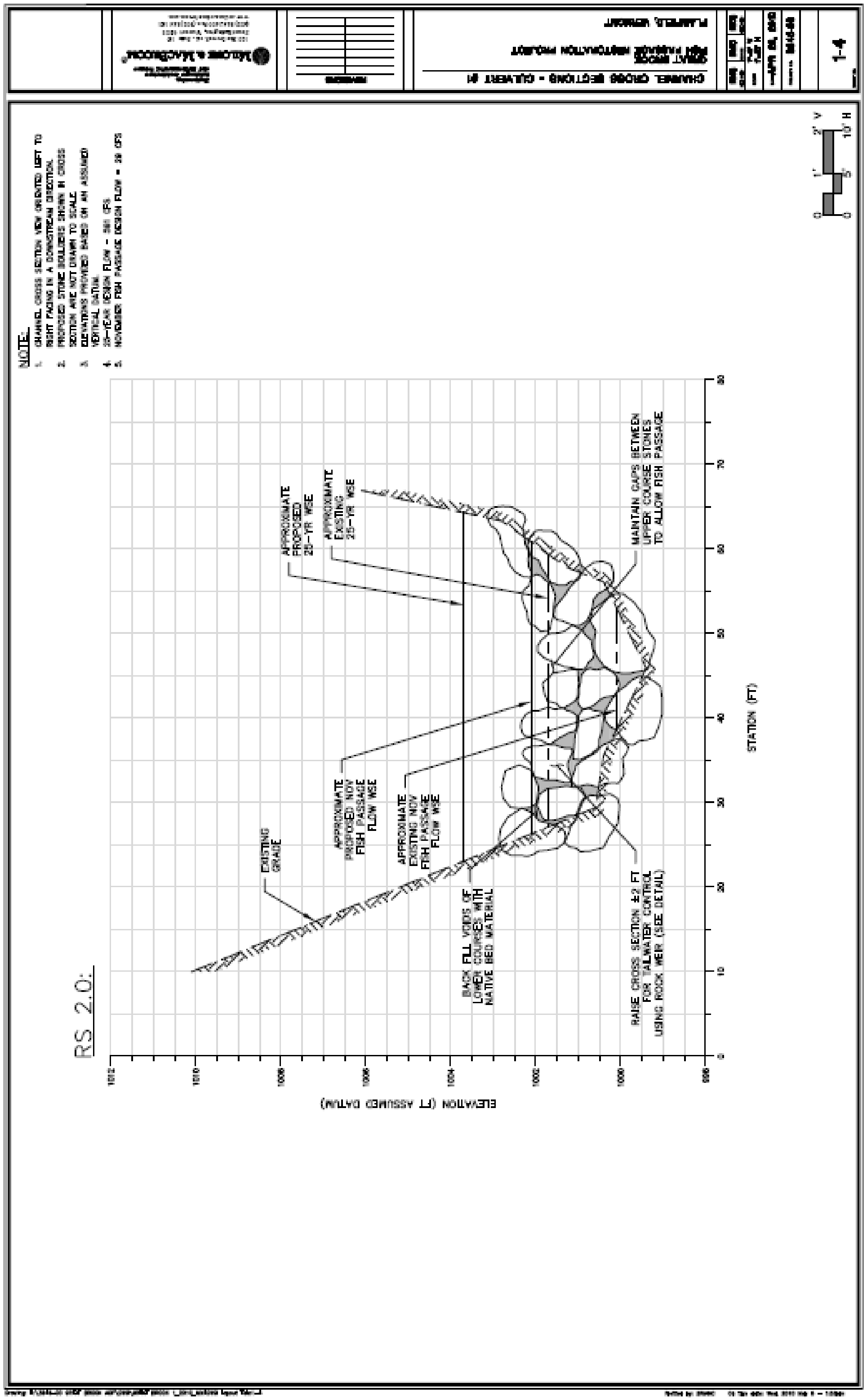
APPENDIX J – Final Design Plans (Reduced Size)



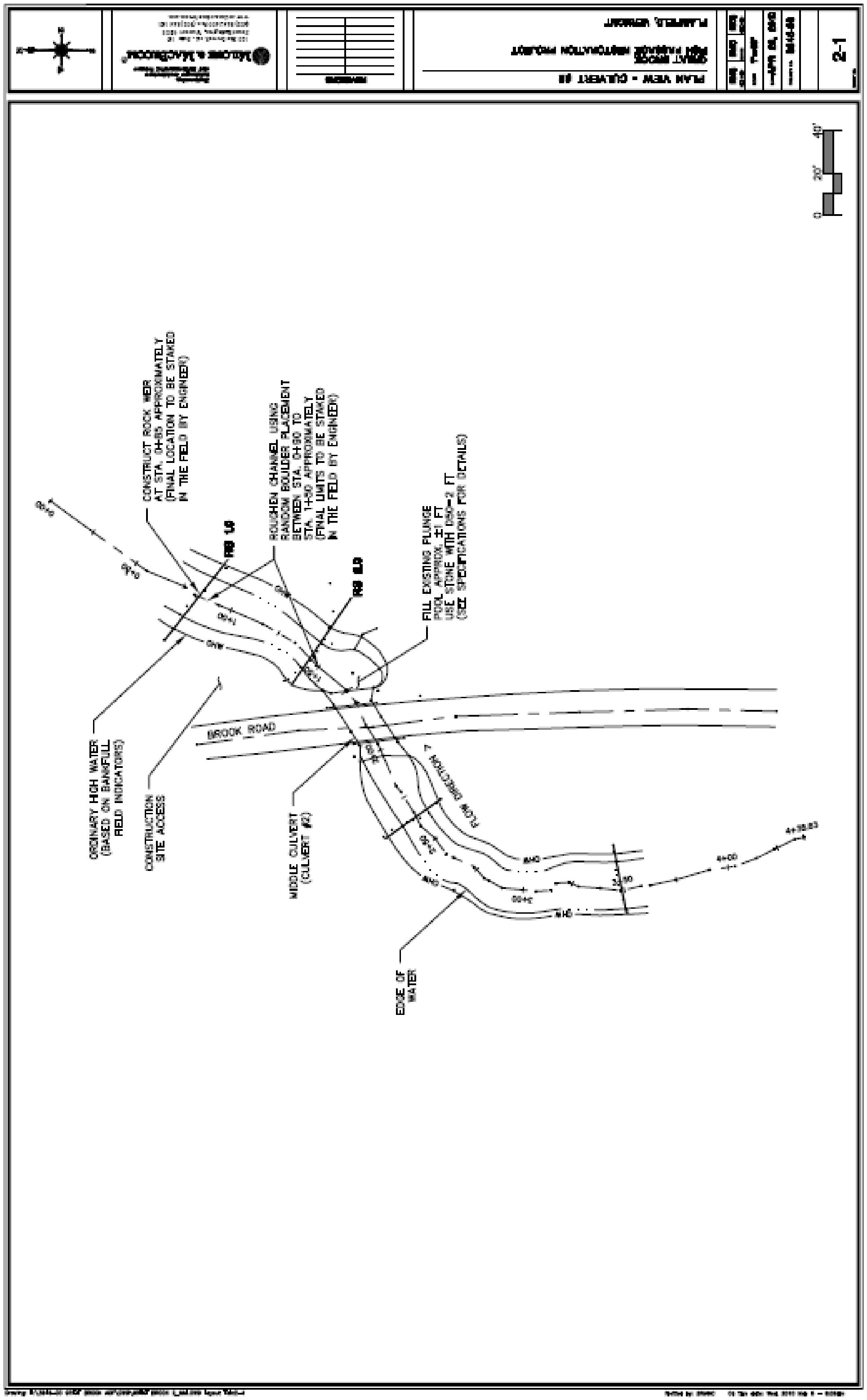

PLAN VIEW - CULVERT #1
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
1-1
ROUGHEN CHANNEL USING RANDOM BOULDER PLACEMENT BETWEEN STA. 0+00 TO STA. 0+50 APPROXIMATELY (FINAL LIMITS TO BE STAKED IN THE FIELD BY ENGINEER)
CONSTRUCT ROCK WEIR AT STA. 0+65 APPROXIMATLY (FINAL LOCATION TO BE STAKED IN THE FIELD BY ENGINEER)
ORDINARY HIGH WATER (BASED ON BANKFULL FIELD INDICATORS)
FILL EXISTING PLUNGE POOL APPROX. ±1.5 FT USE STONE WITH D50=2 FT (SEE SPECIFICATIONS FOR DETAILS)
RS 1.0
RS 2.0
RAISE CROSS SECTION ±1 FT BY FILLING EXISTING BOULDER GAPS AT STA. 0+00 SELECT BOULDERS THAT BEST FIT EXISTING BOULDER GAPS (SEE SPECIFICATIONS FOR DETAILS)
CONSTRUCTION SITE ACCESS
BROOK ROAD
FLOW DIRECTION
UPPER CULVERT (CULVERT #1)
EDGE OF WATER


NOTE:
1. STONE BOULDERS SHOWN IN PROFILE ARE NOT DRAWN TO SCALE.
2. ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
3. 25-YEAR DESIGN FLOW = 380 CFS
4. NOVEMBER FISH PASSAGE DESIGN FLOW = 28 CFS
BROOK ROAD
UPPER PROJECT CULVERT (#1)
EXISTING 17.5FT WIDE BY 8.6FT HIGH CONCRETE CULVERT
EXISTING WINGWALL (TYP)
EXISTING CHANNEL PROFILE
APPROXIMATE EXISTING NOV FISH PASSAGE FLOW WSE
FILL EXISTING PLUNGE POOL APPROXIMATELY 1.5FT SO REMAINING DEPTH IS ±2 FT USE STONE WITH D50=2 FT (SEE SPECIFICATIONS)
ROUGHEN CHANNEL WITH RANDOM BOULDER PLACEMENT (SEE DETAIL)
RAISE CROSS SECTION ±1 FT BY FILLING BOULDER GAPS (SEE SECTION RS 1.0 AND SPECIFICATIONS FOR DETAILS)
APPROXIMATE PROPOSED 25-YR WSE
APPROXIMATE PROPOSED NOV FISH PASSAGE FLOW WSE
APPROXIMATE EXISTING 25-YR WSE
RAISE TAILWATER CONTROL ±2 FT USING ROCK WEIR (SEE DETAIL)
EXISTING BOULDER (TYP)
MAIN CHANNEL DISTANCE (FT)
ELEVATION (FT ASSUMED DATUM)
CHANNEL PROFILE - CULVERT #1
1-2

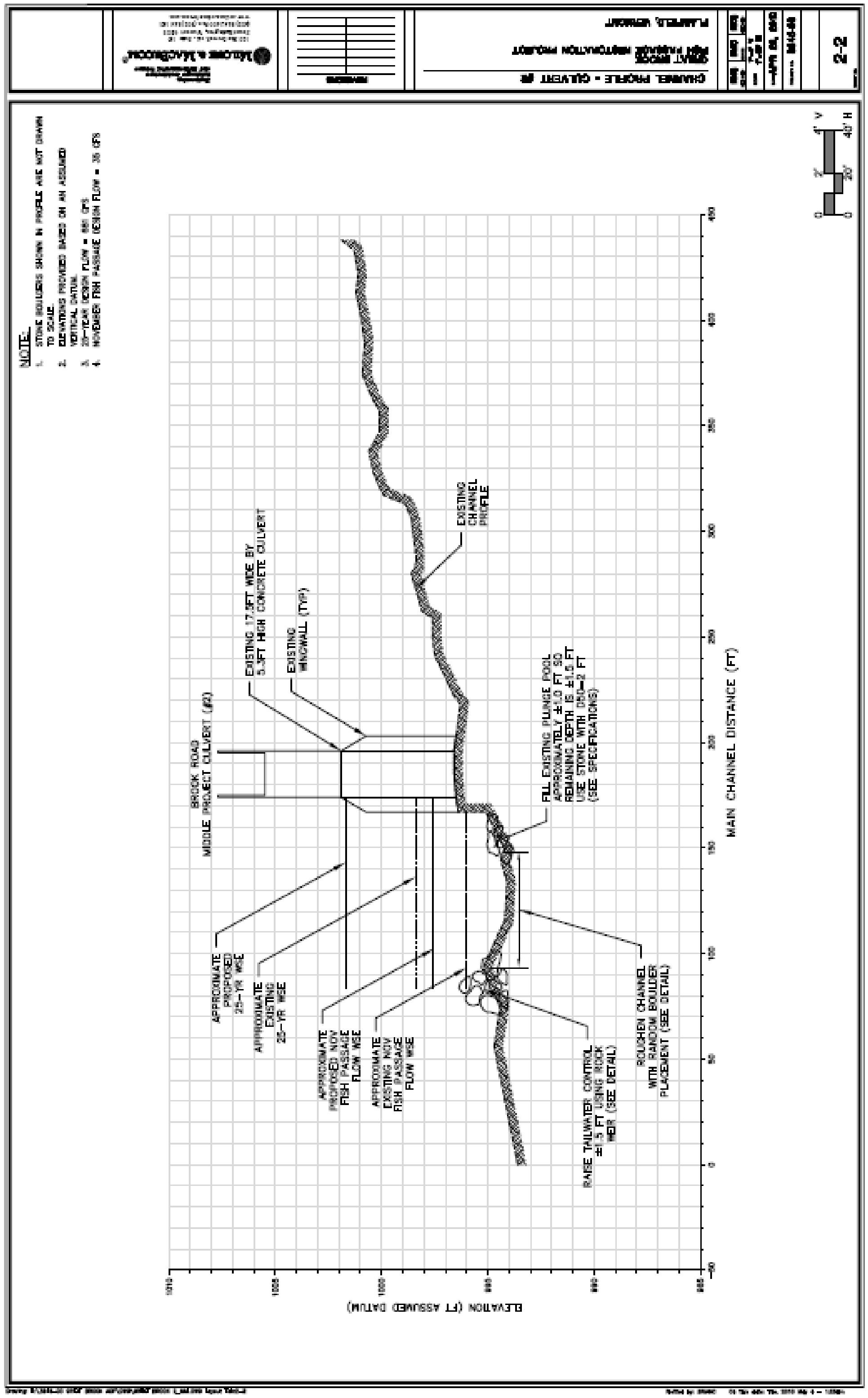

CHANNEL CROSS SECTIONS - CULVERT #1
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
1-3
NOTE:
1. CHANNEL CROSS SECTION VIEW ORIENTED LEFT TO RIGHT FACING IN A DOWNSTREAM DIRECTION.
2. PROPOSED STONE BOULDERS SHOWN IN CROSS SECTION ARE NOT DRAWN TO SCALE.
3. ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
RS 1.0:
EXISTING GRADE
PROPOSED BOULDER (TYP)
EXISTING BOULDER (TYP)
RAISE CROSS SECTION ±1 FT BY FILLING EXISTING BOULDER GAPS. SELECT BOULDERS THAT BEST FIT EXISTING GAPS (SEE SPECIFICATIONS FOR DETAILS)
MAINTAIN SPACES BETWEEN BOULDERS TO ALLOW FISH PASSAGE
STATION (FT)
ELEVATION (FT ASSUMED DATUM)

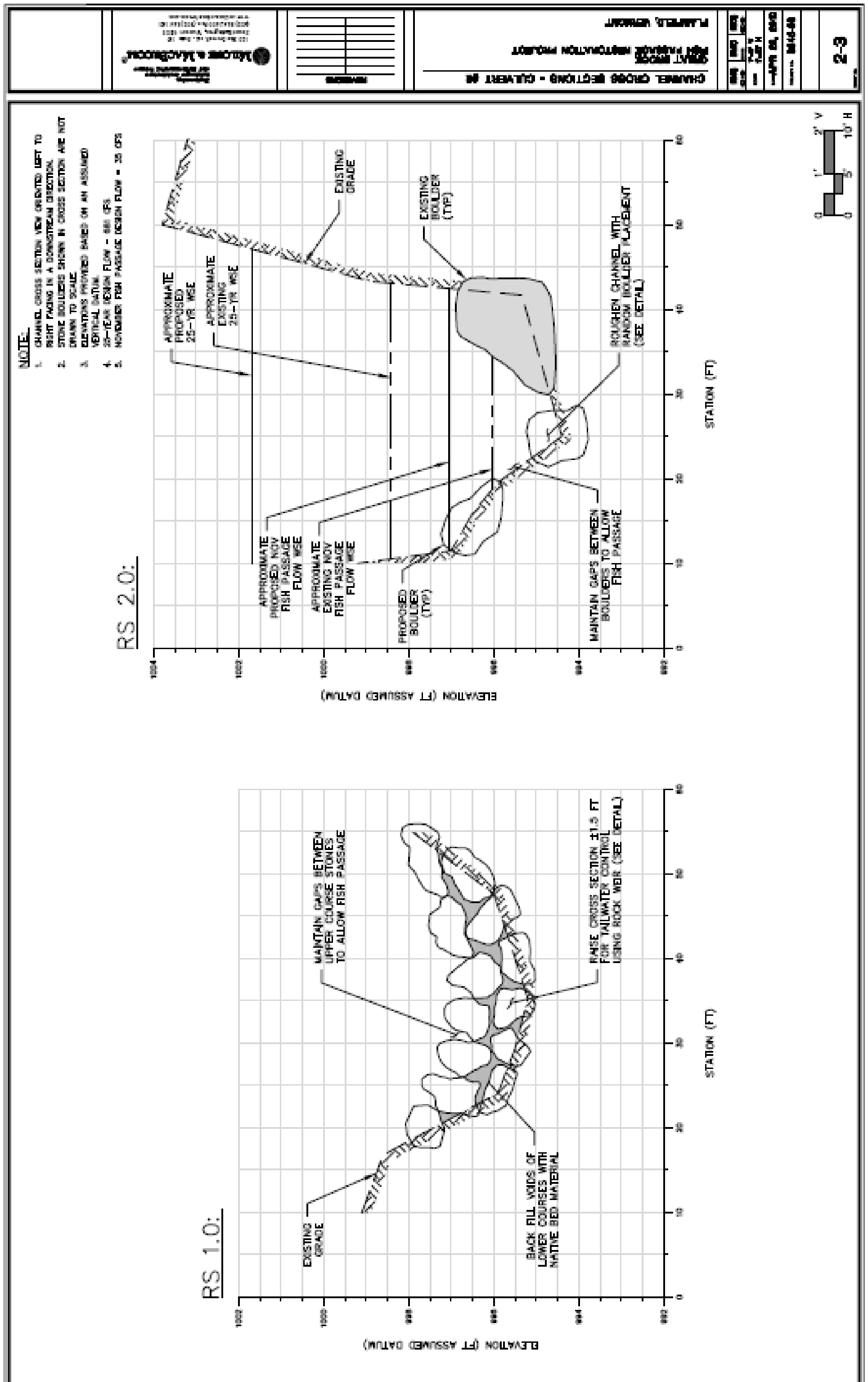


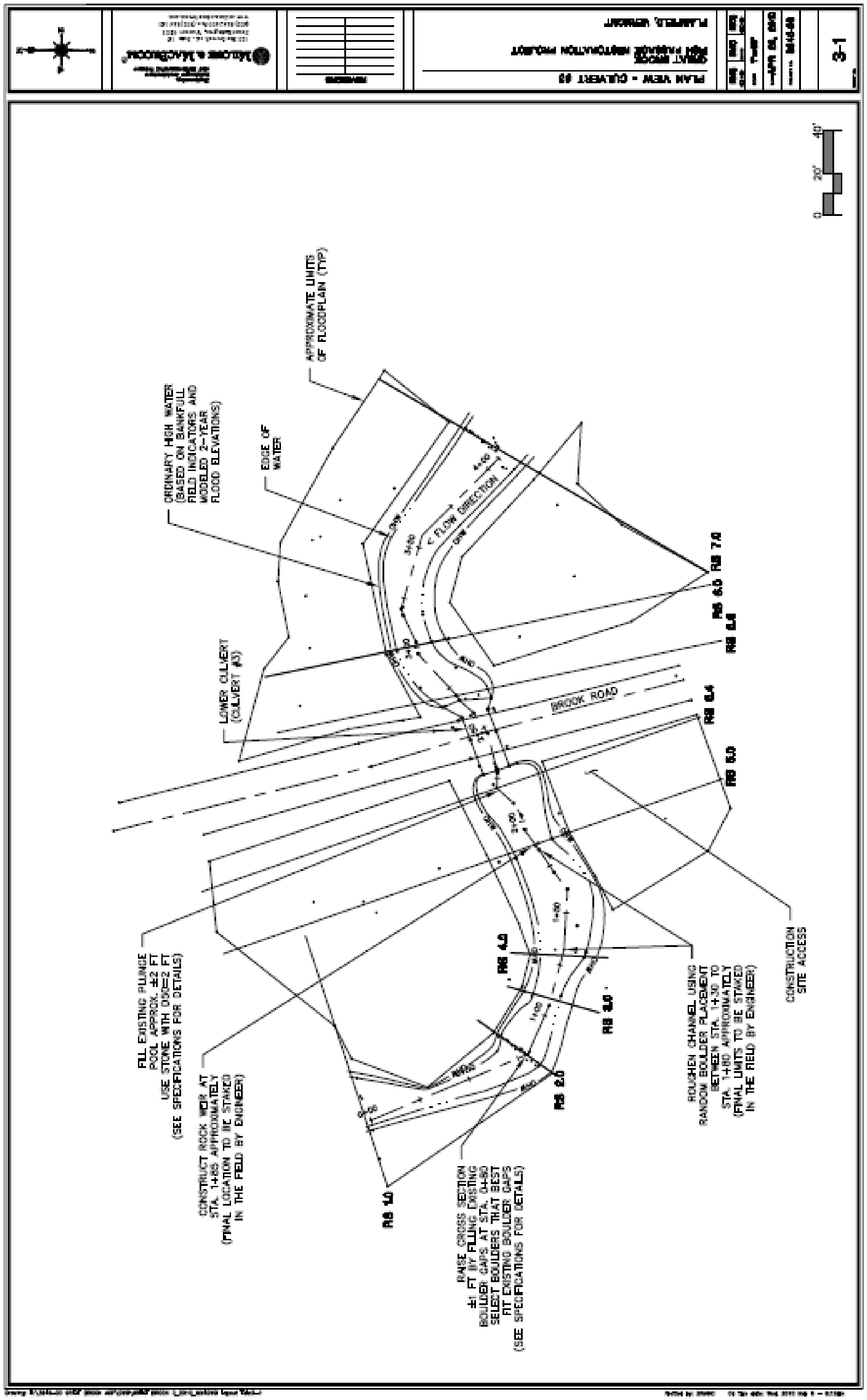
CHANNEL CROSS SECTIONS - CULVERT #1
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
1-4
NOTE:
1. CHANNEL CROSS SECTION VIEW ORIENTED LEFT TO RIGHT FACING IN A DOWNSTREAM DIRECTION.
2. PROPOSED STONE BOULDERS SHOWN IN CROSS SECTION ARE NOT DRAWN TO SCALE.
3. ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
4. 25-YEAR DESIGN FLOW
5. NOVEMBER FISH PASSAGE DESIGN FLOW
RS 2.0:
EXISTING GRADE
APPROXIMATE PROPOSED 25-YR WSE
APPROXIMATE EXISTING 25-YR WSE
MAINTAIN GAPS BETWEEN UPPER COURSE STONES TO ALLOW FISH PASSAGE
APPROXIMATE PROPOSED NOV FISH PASSAGE FLOW WSE
APPROXIMATE EXISTING NOV FISH PASSAGE FLOW WSE
BACK FILL VOIDS OF LOWER COURSES WITH NATIVE BED MATERIAL
RAISE CROSS SECTION ±2 FT FOR TAILWATER CONTROL USING ROCK WEIR (SEE DETAIL)
STATION (FT)
ELEVATION (FT ASSUMED DATUM)

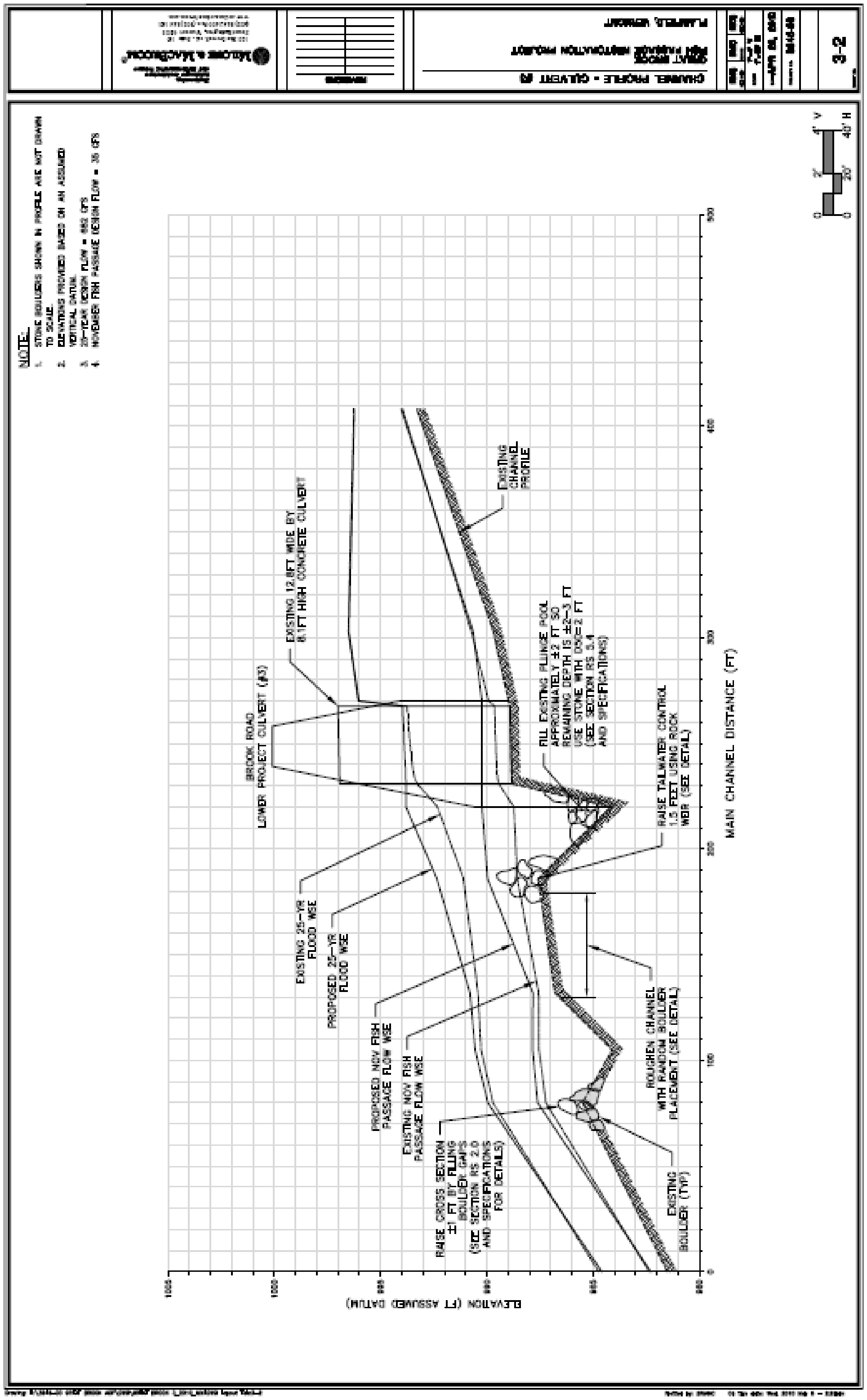


PLAN VIEW - CULVERT #2
PLAINFIELD, VERMONT
2-1
CONSTRUCT ROCK WEIR AT STA. 0+85 APPROXIMATELY (FINAL LOCATION TO BE STAKED IN THE FIELD BY ENGINEER)
ROUGHEN CHANNEL USING RANDOM BOULDER PLACEMENT BETWEEN STA. 0+90 TO STA. 1+50 APPROXIMATELY (FINAL LIMITS TO BE STAKED IN THE FIELD BY ENGINEER)
FILL EXISTING PLUNGE POOL APPROX. ±1 FT USE STONE WITH D50=2 FT (SEE SPECIFICATIONS FOR DETAILS)
ORDINARY HIGH WATER (BASED ON BANKFULL FIELD INDICATORS)
CONSTRUCTION SITE ACCESS
MIDDLE CULVERT (CULVERT #2)
BROOK ROAD
FLOW DIRECTION
EDGE OF WATER
4+00
4+38.83

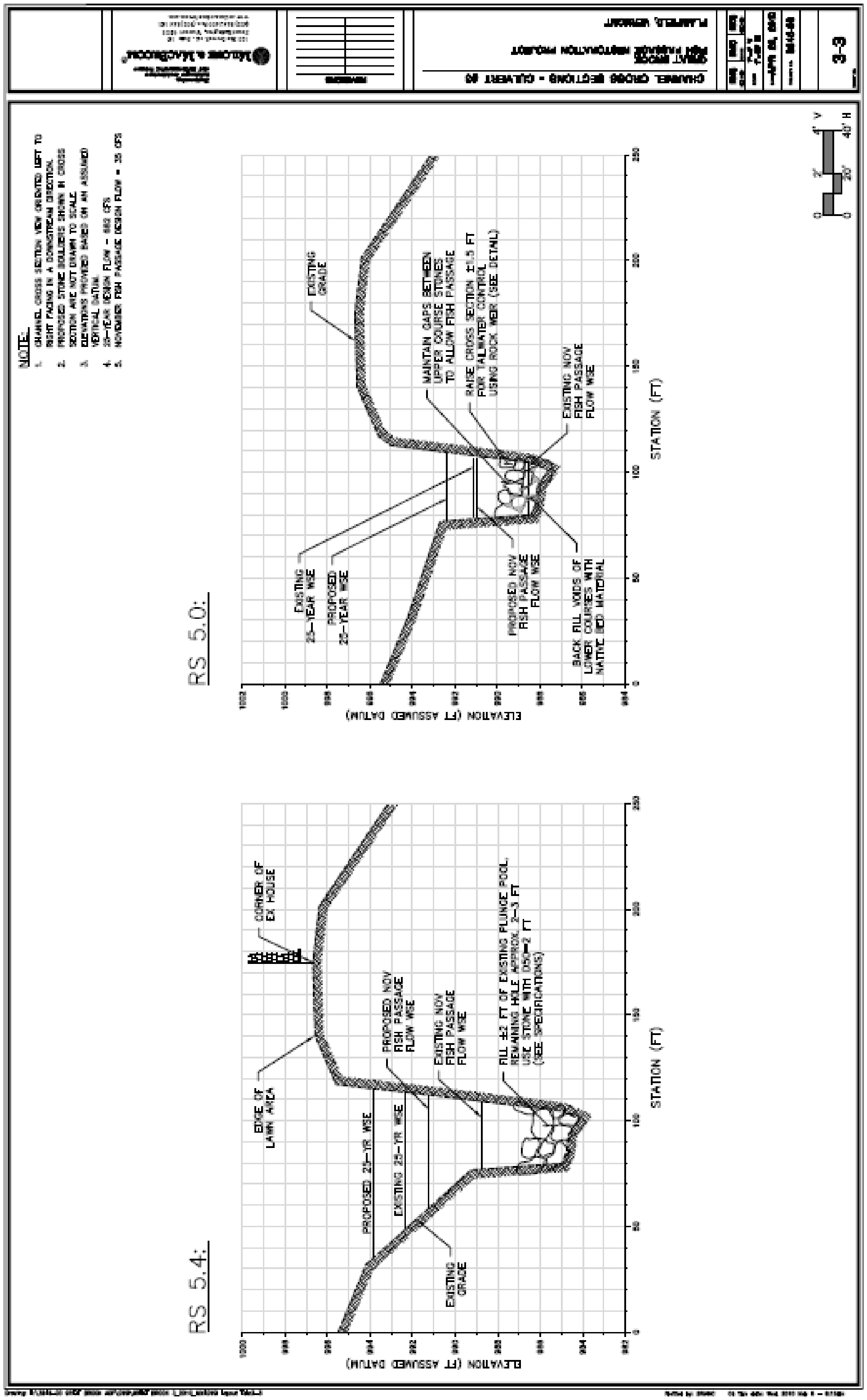

CHANNEL PROFILE - CULVERT #2
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
MILONE & MACBROOM
2-2
NOTE:
1. STONE BOULDERS SHOWN IN PROFILE ARE NOT DRAWN TO SCALE.
2. ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
BROOK ROAD MIDDLE PROJECT CULVERT (#2)
EXISTING 17.5FT WIDE BY 5.3FT HIGH CONCRETE CULVERT
EXISTING WINGWALL (TYP)
EXISTING CHANNEL PROFILE
FILL EXISTING PLUNGE POOL APPROXIMATELY ±1.0 FT SO REMAINING DEPTH IS ±1.5 FT USE STONE WITH D50=2 FT (SEE SPECIFICATIONS)
APPROXIMATE PROPOSED 25-YR WSE
APPROXIMATE EXISTING 25-YR WSE
APPROXIMATE PROPOSED NOV FISH PASSAGE FLOW WSE
APPROXIMATE EXISTING NOV FISH PASSAGE FLOW WSE
RAISE TAILWATER CONTROL ±1.5 FT USING ROCK WEIR (SEE DETAIL)
ROUGHEN CHANNEL WITH RANDOM BOULDER PLACEMENT (SEE DETAIL)
MAIN CHANNEL DISTANCE (FT)
ELEVATION (FT ASSUMED DATUM)


RS 2.0:
APPROXIMATE PROPOSED 25-YR WSE
APPROXIMATE EXISTING 25-YR WSE
EXISTING GRADE
EXISTING BOULDER (TYP)
ROUGHEN CHANNEL WITH RANDOM BOULDER PLACEMENT (SEE DETAIL)
APPROXIMATE PROPOSED NOV FISH PASSAGE FLOW WSE
APPROXIMATE EXISTING NOV FISH PASSAGE FLOW WSE
PROPOSED BOULDER (TYP)
MAINTAIN GAPS BETWEEN BOULDERS TO ALLOW FISH PASSAGE
STATION (FT)
ELEVATION (FT ASSUMED DATUM)
RS 1.0:
EXISTING GRADE
MAINTAIN GAPS BETWEEN UPPER COURSE STONES TO ALLOW FISH PASSAGE
RAISE CROSS SECTION ±1.5 FT FOR TAILWATER CONTROL USING ROCK WEIR (SEE DETAIL)
BACK FILL VOIDS OF LOWER COURSES WITH NATIVE BED MATERIAL
STATION (FT)
ELEVATION (FT ASSUMED DATUM)
2-3

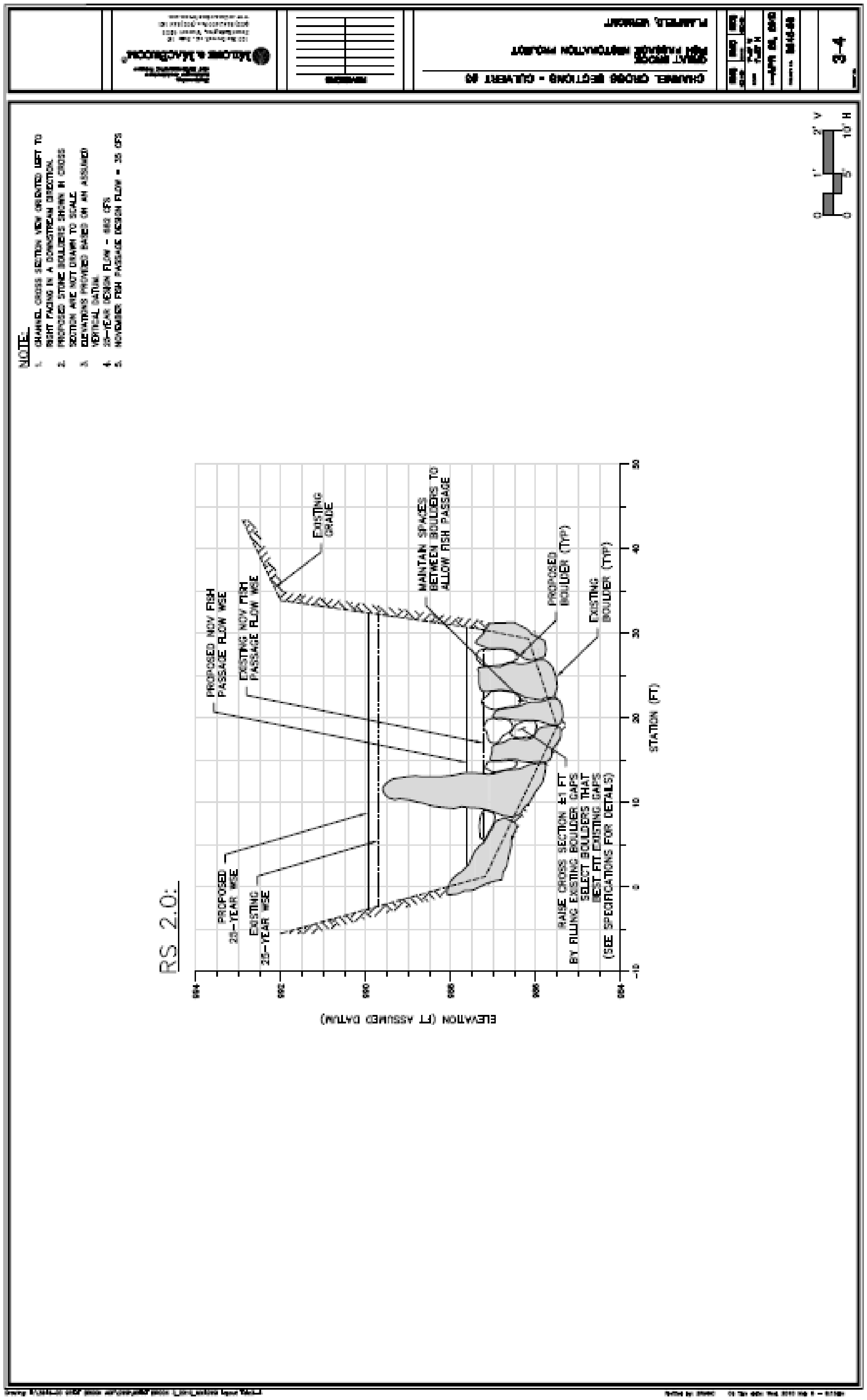

PLAN VIEW - CULVERT #3
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
MILONE & MACBROOM
3-1
APPROXIMATE LIMITS OF FLOODPLAIN (TYP)
ORDINARY HIGH WATER (BASED ON BANKFULL FIELD INDICATORS AND MODELED 2-YEAR FLOOD ELEVATIONS)
EDGE OF WATER
FLOW DIRECTION
LOWER CULVERT (CULVERT #3)
BROOK ROAD
RS 7.0
RS 6.0
RS 5.0
RS 4.0
RS 3.0
RS 2.0
RS 1.0
FILL EXISTING PLUNGE POOL APPROX. ±2 FT USE STONE WITH D50=2 FT (SEE SPECIFICATIONS FOR DETAILS)
CONSTRUCT ROCK WEIR AT STA. 1+65 APPROXIMATELY (FINAL LOCATION TO BE STAKED IN THE FIELD BY ENGINEER)
RAISE CROSS SECTION ±1 FT BY FILLING EXISTING BOULDER GAPS AT STA. 0+80 SELECT BOULDERS THAT BEST FIT EXISTING BOULDER GAPS (SEE SPECIFICATIONS FOR DETAILS)
ROUGHEN CHANNEL USING RANDOM BOULDER PLACEMENT BETWEEN STA. 1+30 TO STA. 1+80 APPROXIMATELY (FINAL LIMITS TO BE STAKED IN THE FIELD BY ENGINEER)
CONSTRUCTION SITE ACCESS

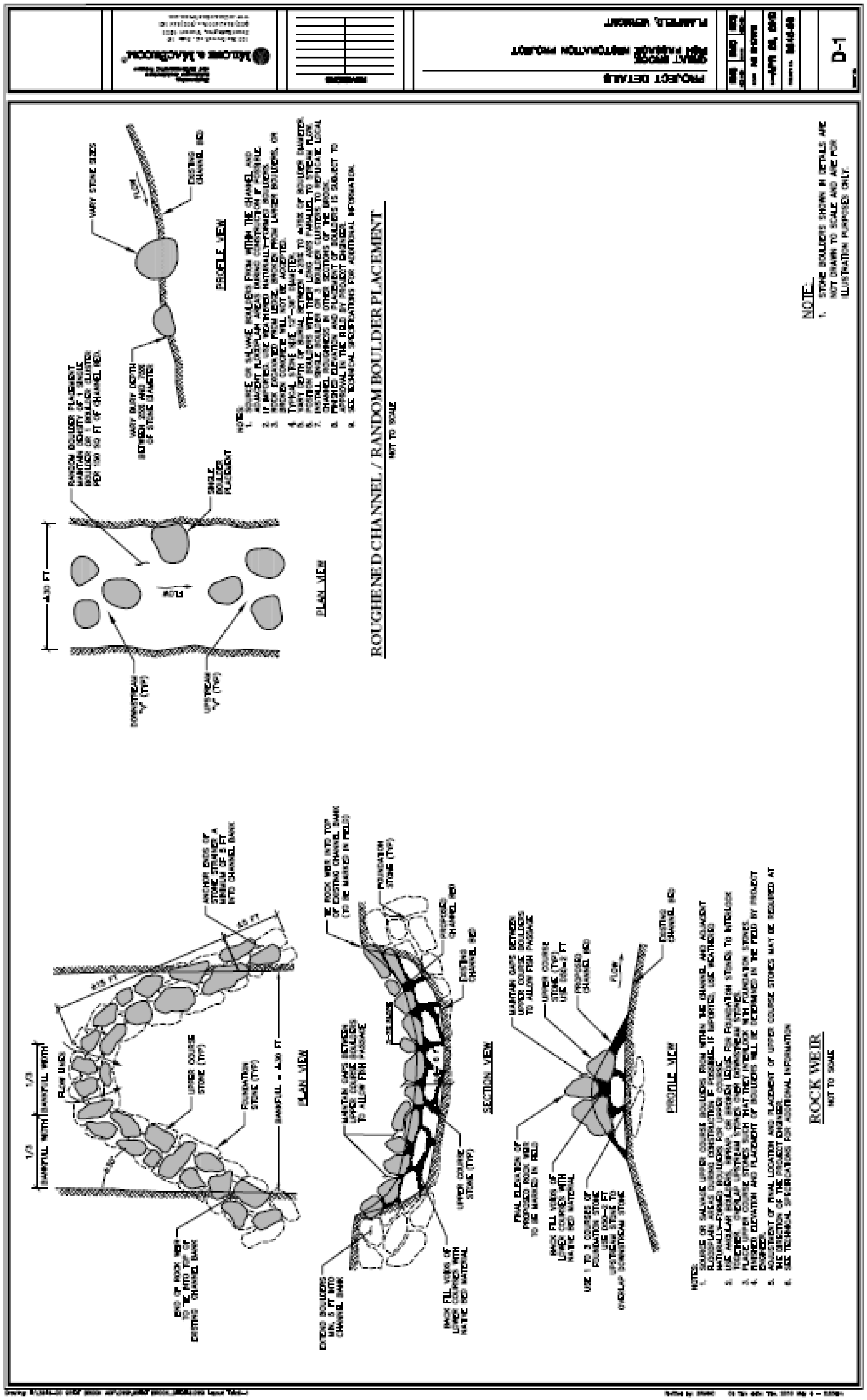


MILONE & MACBROOM®



NOTE:
CHANNEL CROSS SECTION VIEW ORIENTED LEFT TO RIGHT FACING IN A DOWNSTREAM DIRECTION.
PROPOSED STONE BOULDERS SHOWN IN CROSS SECTION ARE NOT DRAWN TO SCALE.
ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
RS 5.4:
RS 5.0:
EDGE OF LAWN AREA
CORNER OF EX HOUSE
PROPOSED 25-YR WSE
EXISTING 25-YR WSE
PROPOSED NOV FISH PASSAGE FLOW WSE
EXISTING NOV FISH PASSAGE FLOW WSE
EXISTING GRADE
EXISTING 25-YEAR WSE
PROPOSED 25-YEAR WSE
MAINTAIN GAPS BETWEEN UPPER COURSE STONES TO ALLOW FISH PASSAGE
RAISE CROSS SECTION FOR TAILWATER CONTROL USING ROCK WEIR (SEE DETAIL)
BACK FILL VOIDS OF LOWER COURSES WITH NATIVE BED MATERIAL
STATION (FT)
ELEVATION (FT ASSUMED DATUM)
CHANNEL CROSS SECTIONS - CULVERT #6
3-3


NOTE:
1. CHANNEL CROSS SECTION VIEW ORIENTED LEFT TO RIGHT FACING IN A DOWNSTREAM DIRECTION.
2. PROPOSED STONE BOULDERS SHOWN IN CROSS SECTION ARE NOT DRAWN TO SCALE.
3. ELEVATIONS PROVIDED BASED ON AN ASSUMED VERTICAL DATUM.
4. 25-YEAR DESIGN FLOW
5. NOVEMBER FISH PASSAGE DESIGN FLOW
RS 2.0:
PROPOSED 25-YEAR WSE
EXISTING 25-YEAR WSE
PROPOSED NOV FISH PASSAGE FLOW WSE
EXISTING NOV FISH PASSAGE FLOW WSE
EXISTING GRADE
MAINTAIN SPACES BETWEEN BOULDERS TO ALLOW FISH PASSAGE
PROPOSED BOULDER (TYP)
EXISTING BOULDER (TYP)
RAISE CROSS SECTION ±1 FT BY FILLING EXISTING BOULDER GAPS SELECT BOULDERS THAT BEST FIT EXISTING GAPS (SEE SPECIFICATIONS FOR DETAILS)
STATION (FT)
ELEVATION (FT ASSUMED DATUM)


PROJECT DETAILS
GREAT BROOK FISH PASSAGE RESTORATION PROJECT
PLAINFIELD, VERMONT
D-1
PLAN VIEW
SECTION VIEW
PROFILE VIEW
ROCK WEIR
NOT TO SCALE
ROUGHENED CHANNEL / RANDOM BOULDER PLACEMENT
NOT TO SCALE
NOTE:
1. STONE BOULDERS SHOWN IN DETAILS ARE NOT DRAWN TO SCALE AND ARE FOR ILLUSTRATION PURPOSES ONLY.

APPENDIX K – Project Evaluation Results and Photographs

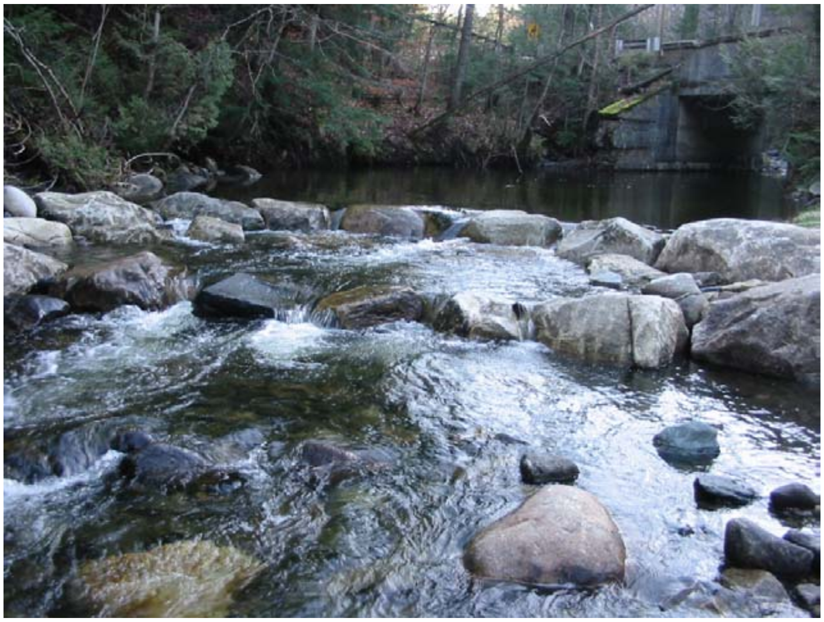
Date	ID	Flow (cfs)	Rainfall	Culvert	Weir
8/4/10	Lower	25	Rising limb, short, intense rainfall past 24 hours	dwater~1 foot, v~2 fps, subcritical, no outlet drop	turbulent flow at weir, some deep tongues with high velocity, depth ranges between 0.7 and 1.5 feet between boulders, velocity about 4 fps, 7 fps in main plunging flow
8/5/2010	Lower	5.9	Flow dropping rapidly from past rains	dwater~0.4 feet, v~1.4 fps, subcritical, no outlet drop	tuned weir to eliminate drop at lower flows, dwater~0.7 feet in main chute, v~2.5 fps, small surface drop with deeper flow in narrow channel, subcritical
8/9/2010	Lower	3.1	Flow dropping rapidly from past rains	dwater~0.3 feet, v~1.0 fps, subcritical, no outlet drop	tuned weir again to eliminate drop at lower flows, dwater~0.7 feet in main chute, v~2.9 fps, deeper flow in narrow channel, turbulent, yet still appears subcritical as raised local tailwater to create additional step
8/9/2010	Middle	3.0	Flow dropping rapidly from past rains	dwater~0.3 feet, v~0.5 fps, subcritical, no outlet drop	tuned weir to eliminate drop at lower flows, dwater~0.6 feet in main chute, v~2.1 fps, flow in narrow channel, turbulent, raised local tailwater to create additional step
8/13/2010	Lower	2.5	None in last few days, low flow	dwater~0.2 feet, v~1.5 fps, subcritical, no outlet drop	dwater~0.6 feet in main chute entrance, v~2.9 fps, dwater~0.7 feet in main chute drop area, v~4.4 fps
8/13/2010	Middle	2.1	None in last few days, low flow	dwater~0.8 feet, v~1.1 fps at main chute entrance; dwater~0.7 feet, v~4.4 fps at main chute drop	tuned weir to eliminate drop at lower flows, dwater~0.6 feet in main chute, v~2.1 fps, flow in narrow channel, turbulent, raised local tailwater to create additional step
8/13/2010	Upper	1.8	None in last few days, low flow	dwater~0.6 feet, v~1.8 fps at main chute entrance; dwater~0.6 feet, v~3.8 fps at main chute drop	tuned weir to eliminate drop at lower flows, dwater~0.6 feet in main chute, v~2.1 fps, flow in narrow channel, turbulent, raised local tailwater to create additional step
11/12/2010	Lower	13.7	None in last few days, moderate flow, appears to be good fish passage flow	dwater~0.8 feet, v~2.0 fps, subcritical, no outlet drop, smooth sediment transition in and out of structure	dwater~1.2 feet in main chute entrance, v~2.2 fps, dwater~1.2 feet in main chute drop area, v~5.0 fps
11/12/2010	Middle	n/m	None in last few days, low flow	good depth and low velocity, subcritical, no outlet drop, smooth sediment transition in and out of structure	depth and velocity challenging at weir, yet passable, sediment built up against structure
11/12/2010	Upper	n/m	None in last few days, low flow	good depth and low velocity, subcritical, no outlet drop, smooth sediment transition in and out of structure	depth and velocity challenging at weirs, yet passable

Photograph looking upstream over the rock weir with a fish passage channel and the backwatered Culvert #1 (Upper) taken on August 13, 2010 during low flow.

Photograph looking downstream over the rock weir with fish passage channels and the roughened channel at Culvert #2 (Middle) taken on August 13, 2010 during low flow.

Photograph looking upstream at the backwatered channel at Culvert #2 (Middle) taken on August 13, 2010 during low flow.

Photograph looking upstream over the rock weir with fish passage channel and backwatered Culvert #3 (Lower) taken on August 13, 2010 during low flow.



Photograph looking upstream over the rock weir with fish passage channels and the backwatered Culvert #1 (Upper) taken on November 12, 2010 during moderate flow.

Photograph at the rock weir with fish passage channels from the left bank at Culvert #2 (Middle) taken on November 12, 2010 during moderate flow.

Photograph looking upstream over the rock weir with fish passage channels and backwatered Culvert #3 (Lower) taken on November 12, 2010 during moderate flow.