Mill Creek Fish Passage Assessment

Final Report

October 2009

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Acknowledgements

This assessment and report would not have been possible without the input from local stakeholders. The assessment team was Pat Powers, Kozmo Ken Bates and Jay Kidder, working under direction of the Mill Creek Work Group and Tri State Steelheaders. Brian Burns assisted with writing the report. The authors kindly thank the following Work Group members for their time, participation and information provided.

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1.0 Introduction

Mill Creek, with a drainage area of 96 square miles, is a tributary to the Walla Walla River, and flows through the city of Walla Walla, Washington (see Figure 1.1). In the 1930s, after enduring several large floods, the people of Walla Walla, led by Virgil B. Bennington, started a petition for federal funding to build flood control structures in Mill Creek. Following approval by Congress, President Roosevelt signed the Flood Control Act of 1938 in June of that year. The Act called for two projects to be built in the Walla Walla Valley: the Mill Creek Project and the Mill Creek Channel. By 1948, both projects were completed by the U.S. Army Corps of Engineers (Corps). Some provisions for fish passage were included in the form of baffles, weirs, and fishways at various locations.

The Mill Creek Project includes two dams, about a mile of Mill Creek between the dams, a storage reservoir, and surrounding lands. Bennington Dam (or Diversion Dam) at river mile (RM) 11.5 is the uppermost of the two dams. Its purpose is to divert flood flows into the reservoir where the water is stored until it can be safely discharged. At RM 10.6, a second dam (Division Dam Head Works) controls flow into Yellowhawk and Garrison Creeks. The Mill Creek Project remains Corps property.

The Mill Creek Channel continues downstream from the Division Dam Head Works at RM 10.6, to its end at RM 4.8 (Gose St). The Channel consists of two major channel types – one type with channel-spanning stabilizers (described as sills or weirs) and the other type a concrete flume (both types described in more detail in Section 2). Starting below the Division Dam, the sills continue downstream to the start of the concrete flume at RM 8.4 (just upstream of the Roosevelt St. Bridge), where there is a three weir transition into the concrete flume. The flume then runs through downtown Walla Walla to RM 6.7, where the channel transitions back to the channel spanning sill type. The sill channel type continues to the downstream extent of the project at RM 4.8, where the channel transitions back to the natural channel. A pool and chute fishway was constructed in 2006, and new cross channel sills were constructed in 2007 to improve passage at this transition. The Mill Creek Channel is owned by the Mill Creek Flood Control Zone District. The District, as directed by the County Commissioners, is responsible for the normal operations and maintenance of the Channel.

This report includes a detailed fish passage assessment through the Mill Creek Channel and develops conceptual designs for fish passage improvement. There are a total of 263 sills in the assessment reach (there are others between the two dams on Corps property). Most of the sills are constructed of rock filled gabions encased in six inches of concrete (based on as-built drawings supplied by the Corps). Some of the sills are constructed of sheet pile. The typical channel width is 70 feet, with levees forming both banks. One area, constructed as a sediment trap, has a maximum width of over 500 feet. The sills have an average drop of 0.8 feet, but vary from 0.5 to 1.4 feet.

The concrete flume section varies in cross-sectional shape, but generally is 50 feet wide, with vertical walls, a nine foot wide low flow trench (or trenches) with staggered baffles spaced at 60 feet, and either a sloped or horizontal shoulder (overbank area) between the trench and the vertical walls. The assessment identified eight unique channel types within the flume section, with some of the channel types occurring more than once. The flume section is 10,777 feet in length and runs underground for 1,400 feet.

Summer steelhead, spring Chinook and bull trout attempt to migrate through the assessment reach during their seasonal movements. Steelhead and spring Chinook spawn and rear in Mill Creek above the flood control project (upper Mill Creek). A population of bull trout is resident in upper Mill Creek. Adults moving upstream in winter and spring can experience high flows/velocities. This has been thought to be a barrier, especially in the concrete flume. In late spring, low flow and high water temperature can strand and kill adults and juveniles. Much of the channel is dewatered in summer and fall, although some areas of the concrete channel have cold spring water inflows that provide some rearing for salmonids.

The Mill Creek Work Group (MCWG) is a technical working group of entities with water interests pertaining to Mill Creek. The Group includes federal and state regulators, local governments, local tribes, and non-governmental organizations. For years, the MCWG has assumed that barriers exist in the flood control channel based upon professional opinion and anecdotal information. In 2005, the Corps and Washington Department of Fish and Wildlife (WDFW) made a cursory evaluation of fish passage and determined there may be some passage in the 20 to 40 cfs range. Conclusions from that work stirred the MCWG to obtain a more formal fish passage assessment, which resulted in this report. The MCWG was the steering committee for this assessment, reviewed consultant bids, created the assessment scope of work, provided technical input and direction for the assessment team, and provided comments on this report. Tri-State Steelheaders acted as facilitator, and as fiscal sponsor for a Salmon Recovery Funding Board grant that funded the assessment. Regional Fisheries Enhancement Group matching funds were provided by the Tri-State Steelheaders.

The objectives of this fish passage assessment were to identify the location and type of fish passage barriers, develop a prioritized list of fish passage problems, and then develop conceptual design options and cost estimates for correction of the problems. The assessment utilized a modeling approach, where hydraulic models were developed, and a fish energetics model was used to determine passability and the nature of barriers.

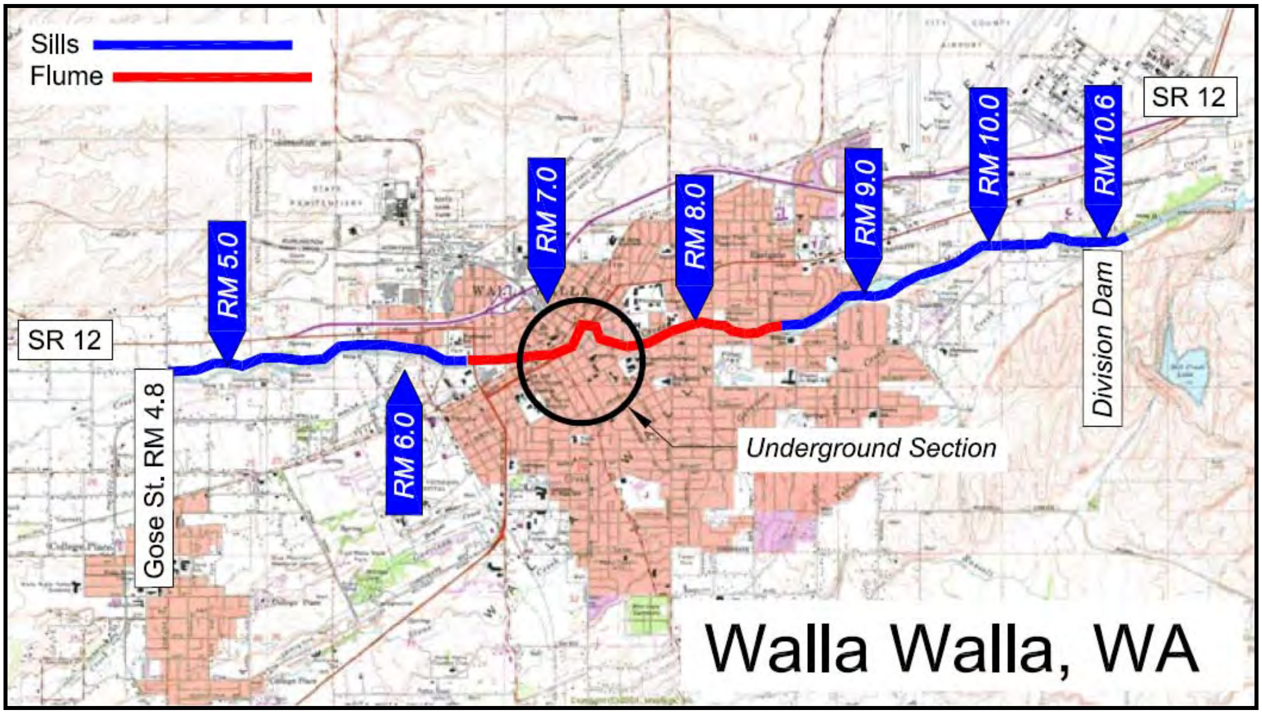

Figure 1.1 - USGS Topographic Map of Walla Walla, Washington Showing the Project Assessment Reach and River Miles of Mill Creek.

2.0 Assessment Reach Type Descriptions

There are two basic channel types in this assessment. The concrete sills channel type, with channel stabilizers which span the channel and act as weirs with plunge pools, and the concrete flume channel type, which is an open channel with a trench in the center. The Division Dam fishway was also analyzed. The overall channel profile slope for the sills and concrete flume is about one percent. For the concrete flume, at low flow all of the water is contained in the trench. The trench has concrete baffles spaced at 60 feet. At higher flow, the wetted width is outside of the trench and into an overbank area formed between the trench and the vertical sidewalls. In most cases the overbank area slopes are 5:1. This sloped overbank area and trench form a trapezoidal channel shape. In addition to the basic trapezoidal channel, there are center walls, bridge piers, transitions, and flat overbank areas, each with unique geometry and hydraulic conditions needing to be modeled for fish passage. Reach Types were assigned numbers to account for all these combinations of channel geometry. The numbering system (1 to 12) generally starts downstream and proceeds upstream until a different reach type is identified. Reach Types are not unique to a location; some are repeated in a number of segments through the study area (e.g.; Reach Type 3 is made up of 5 segments, See Table 2.1). In total 12 Reach Types were assigned. Layout of Reach Types spatially can best be seen from the aerial photos in Appendix A2.

For each Reach Type, a study plan was selected for the hydraulic modeling to 1) measure depth and velocities for a representative flow, and 2) develop a computer model that could then be used for the fish passage assessment. Flows modeled were pre-determined by the MCWG to be 10, 20, 40, 100, 250 and 400 cfs. Detailed velocity and depth measurements were made in Mill Creek at flows of 6, 20, 150 and 200 cfs, with stage/depth measurements made at 380 and 500 cfs. The terminology and stationing used is somewhat consistent with the Mill Creek Flood Control Channel drawings dated April 1948, provided by U.S. Army Corps of Engineers Walla Walla District. The drawings have two sets of stationing that do not coincide, one for the channel stabilizers (identified in this study as sills) and one for the concrete section of the flood control channel (identified in this study as the flume).

Table 2.1 - Mill Creek Fish Passage Assessment Study Reach Type Descriptions

Reach Types	Number of Sills or Baffles	Reach Type Lengths
Reach Type 1- Channel Sills	263	17161 ft (3.2 miles)
Reach Type 2 - Flume Transition		325 ft
Reach Type 3 – Trapezoidal Flume with 6 ft Long Baffles	123	*960, 660, 360, 5160, 120* Total = 7260 ft
Reach Type 4 – Trapezoidal Split Flume with 3 ft Long Baffles	3	*30, 60, 480* Total = 570 ft
Reach Type 5 – Flume Transition Trapezoidal to Rectangular	3	178 ft
Reach Type 6 – Rectangular Flume with 6 ft Long Baffles	15	*120, 60, 180, 360* Total = 840 ft
Reach Type 7 – Rectangular Split with Split 3 ft Long Baffles	21	*420, 180, 420* Total = 1200 ft
Reach Type 8 – Rectangular Double Wall Flume with 10 ft Long Baffles	4	222 ft
Reach Type 9 – Flume Transition Rectangular to Trapezoidal	3	117 ft
Reach Type 10 – Roosevelt St. Bridge	0	58 ft
Reach Type 11 – Transition Fishway	Fishway	60 ft
Reach Type 12 – Division Dam and Fishway 6" Exit	Fishway	20 ft
Reach Type 12 - Division Dam and Fishway 18" Exit	Fishway	20 ft

2.1 Reach Type 1 - Channel Sills

There are a total of 263 channel sills (172 are concrete capped and 91 are steel sheet pile). The Corps drawings refer to the sills in 'Phases' based on their order of construction. The Phase 1 construction extends from Gose Street (RM 4.8) upstream to the flume transition (Reach Type 2, RM 6.7). There are 145 sills in the Phase 1 construction (91 sheet pile and 54 concrete). The average water surface drop is 0.8 feet. Some have drops greater than 1.3 feet (See Appendix A3). The sills are spaced 70 feet apart and the channel width is 70 ft. Average overall channel slope is 1.1 percent. Typical dimensions of the concrete capped sills are shown in Figure 2.1. Dimensions of the sheet pile weirs are unknown.

Phase 3 sills extend from just upstream of Roosevelt Bridge (RM 8.6) to Tausick Way (RM 10.0). There are 77 sills in this stretch, all concrete capped. Sill spacing ranges from 70 to 205 feet. Sill lengths vary from 70 to 550 feet. This area of Reach Type 1 is wider to provide an area to trap sediment. The average water surface drop is 1.3 feet, but because the sills are partially buried in sediment, the actual drops are much less. Overall channel slope averages 1.4 percent.

Phase 2 sills extend from Tausick Way to the Division Dam (RM 10.6). Average water surface drop is 0.9 feet. The sills are spaced 70 feet and the channel width is 70 ft. Average slope is 1.3 percent. All 42 sills are capped with concrete.

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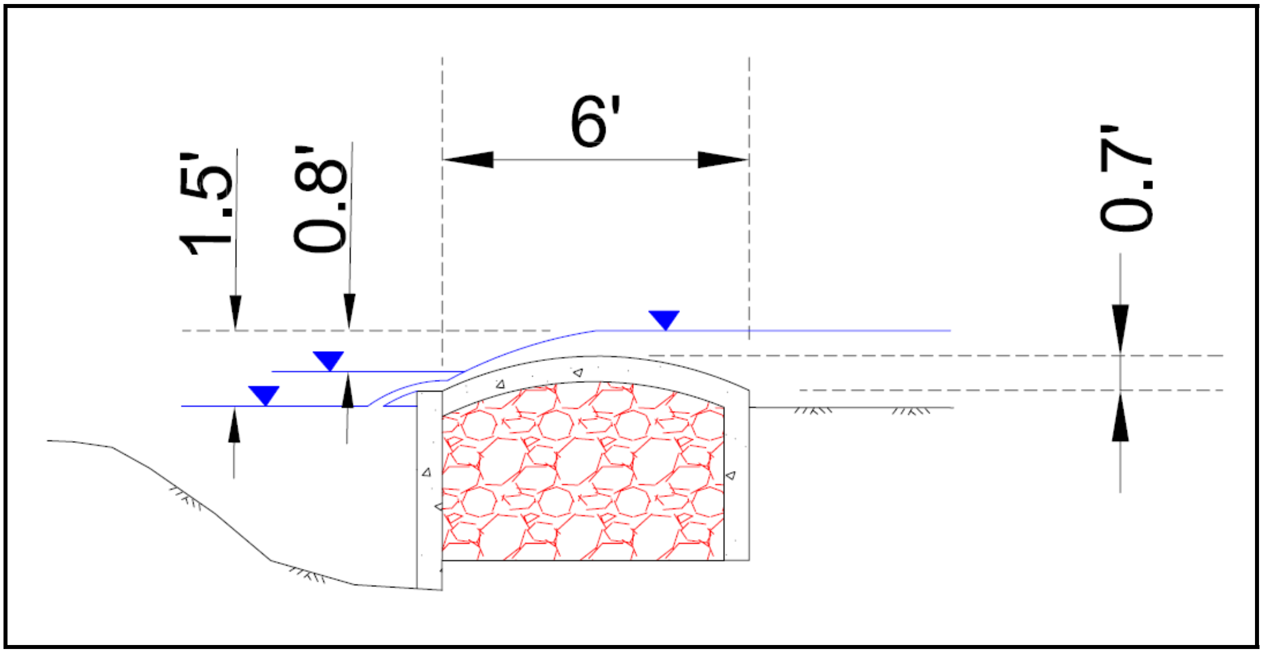

Figure 2.1 – Reach Type 1 Typical Channel Sill With 6" Thick Concrete Cap.

Photo 2.1 – A 200 foot long Reach Type 1 Sill at 208 cfs.

2.2 Reach Type 2 - Flume Transition

Photo 2.2 – Upstream View of Reach Type 2 Flume Transition at 27 cfs.

Reach Type 2 is a 325 foot long transition between the channel sills and the downstream end of the concrete flume. From the downstream end it starts with a rock sill, transitions into a 3 to 4 foot deep stilling basin and then into a 50 foot wide concrete flume. The flume transitions from a rectangular channel without a trench to the common trapezoidal channel shape with a 9 foot wide trench. As the trench depth increases an overbank area develops between the trench and the side walls. The trench bottom is horizontal, while the flume overbank slopes at one percent. Reach Type 2 ends when the trench depth reaches 1.7 feet, at which at which point the trench bottom slopes consistently with the flume overbank at one percent. There are only two baffles in Reach Type 2, at the very upper end.

2.3 Reach Type 3 – Trapezoidal Flume with 6 ft Baffles

For the concrete flume, over 80% of the length is Reach Type 3. There are six segments which vary in length from 120 to 5,160 feet. The cross-section shape is trapezoidal, 50 feet wide, with a low flow trench 9 feet wide by 1.7 feet deep. Concrete baffles within the trench are 12 inches high, 6 feet long and are spaced 60 feet apart alternating from side to side. The low flow slot is 3 feet wide. Side slopes of the overbank area are 5:1. The channel slope is one percent. Based on field measurements and observations the overbank area is assumed to be used as a passage corridor for certain flows.

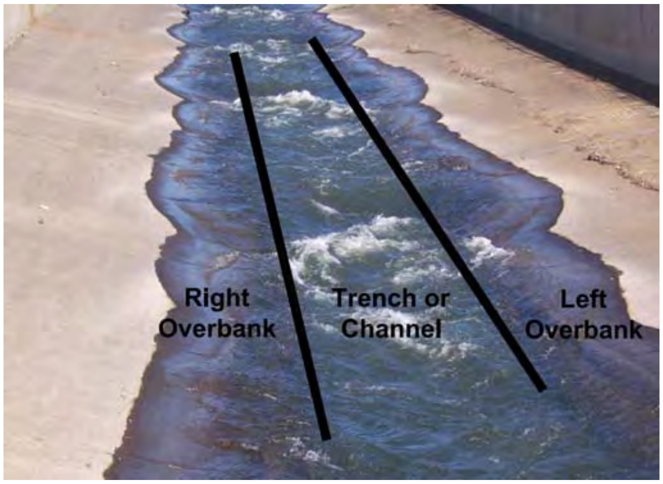

Photo 2.3 - Reach Type 3 Trapezoidal Channel with 6 foot long baffles (view upstream), at 190 cfs. Field measurements of depth and velocity identified a low velocity boundary layer corridor in the overbank area.

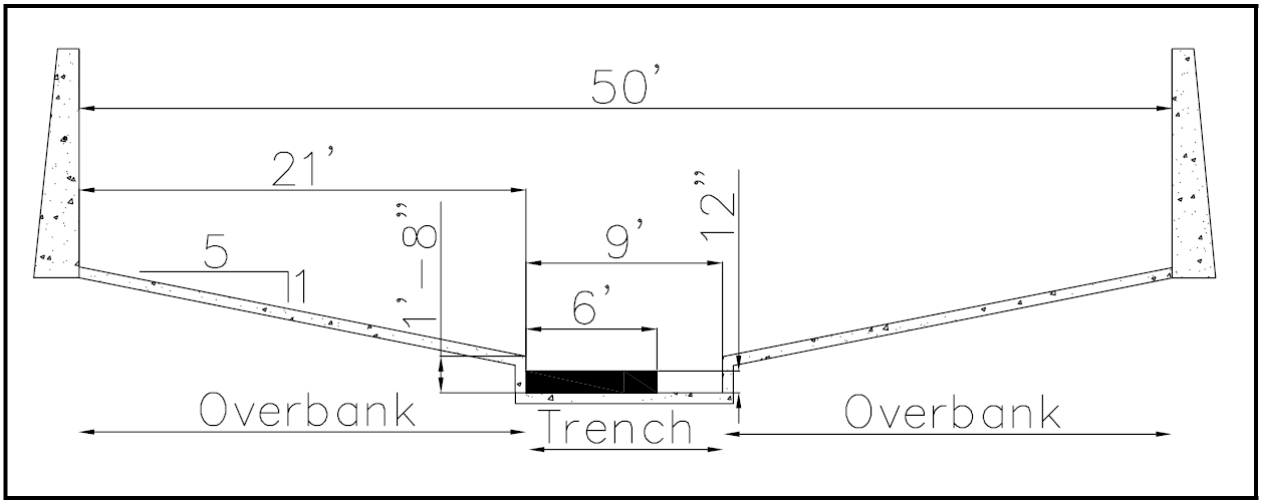

Figure 2.2 – Reach Type 3 Layout and Dimensions.

2.4 Reach Type 4 – Trapezoidal Split Flume with 3 ft Long Baffles

There are three segments defined as Reach Type 4. They are 30, 60 and 480 feet long. The cross section is a trapezoidal channel divided in half by a center wall or pier. The trench width is 4.5 feet on each side of the pier. The baffles are 3 feet long with 60 foot spacing. The channel slope is one percent. The main difference between Reach Type 4 compared to Reach Type 3 is the center pier, and the trench depth which is 2.1 feet as compared to 1.7 feet in Reach Type 3. The overall flume width of 50 feet and the 5:1 sloped overbank area does not change between Reach Type 3 and 4.

Photo 2.4 - Reach Type 4 Split Flume (Bridge Pier) at 180 cfs. View Upstream.

2.5 Reach Type 5 – Flume Transition Trapezoidal to Rectangular

Reach Type 5 is a 178 foot long section. It is the transition from a trapezoidal cross section to a rectangular cross section. The 9 foot wide trench is identical to Reach Type 3. The transition is created by the overbank areas which change from a 5:1 slope to horizontal. Channel slope is one percent.

2.6 Reach Type 6 – Rectangular Flume with 6 ft Long Baffles

Reach Type 6 is in four segments varying in length from 60 to 360 ft. The channel has a rectangular cross section with the trench in the center and baffles identical to Reach Type 3. The overall width from wall to wall is 46 to 47 feet.

Photo 2.5 - Reach Type 6 at 208 cfs. The start of underground section is visible downstream. View Downstream.

2.7 Reach Type 7 – Rectangular Split Flume with 3 ft Baffles

Reach Type 7 is the same as Reach Type 6 with the addition of a center wall or pier. The three segments of Reach Type 7 vary in length from 180 to 420 ft. Some of the sections are underground. The geometry of the base of the wall varies. The trench width on each side is 4.5 feet. Baffles are 12 inches high, 3 feet long and spaced 60 feet apart. The low flow notch is 1.5 feet wide and alternates from side to side. The overall width from wall to wall is 46 to 47 feet (see Figure 2.3).

Photo 2.6 - Typical Reach Type 7 Split Flume with Center Wall. Flow is 6 cfs. View Upstream.

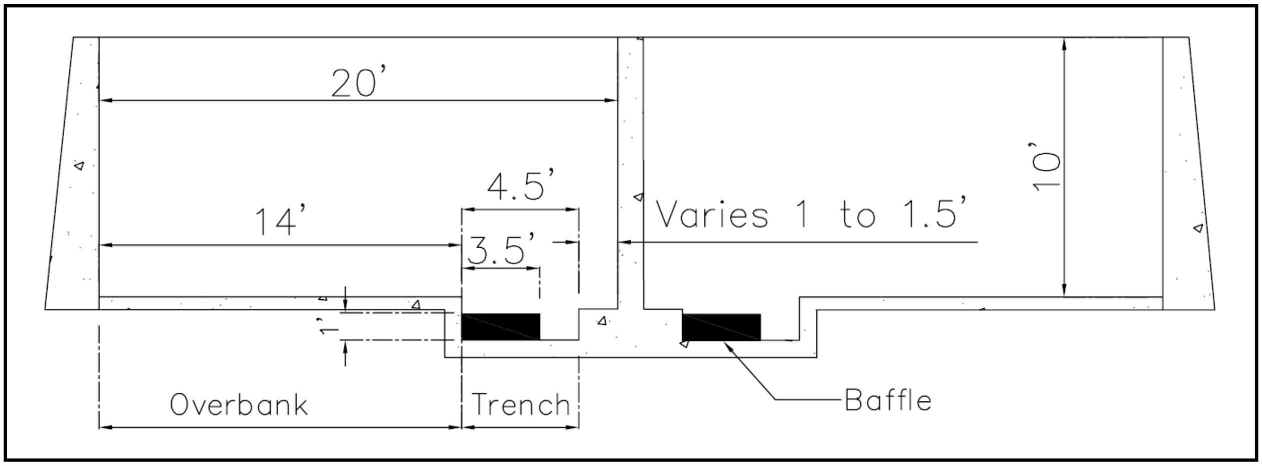

Figure 2.3 – Reach Type 7 Layout and Dimensions.

2.8 Reach Type 8 – Rectangular Double Wall with 10 ft Long Baffles

Reach Type 8 is 222 feet long. It is a rectangular channel split by two vertical walls on a 90 degree turn. The center trench is 16 feet wide by 1.8 feet deep. Concrete baffles are 12 inches high and 10 feet long spaced 60 feet apart and alternate side to side. The channel slope is one percent. Reach Type 8 is under the City of Walla Walla and completely dark.

Photo 2.7 – Downstream View of Reach Type 6 Transition into Reach 8. Flow is 208 cfs.

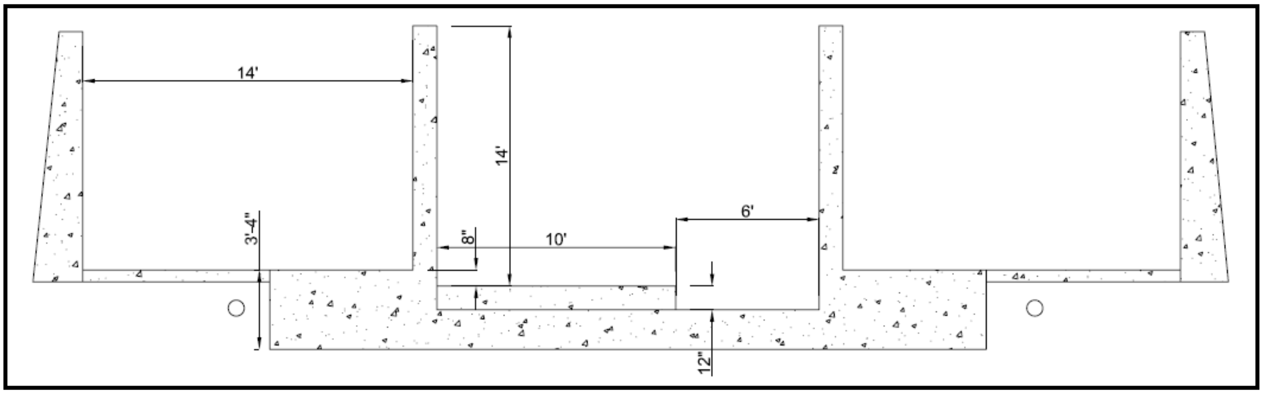

Figure 2.4 – Reach Type 8 (Underground) Layout and Dimensions.

2.9 Reach Type 9 – Flume Transition Rectangular to Trapezoidal

Reach Type 9 is a single segment 117 feet long. It is the transition from a rectangular cross section to a trapezoidal section (opposite of Reach Type 5). The 9 foot wide trench is identical to Reach Type 3. The transition is created by the overbank areas which change from horizontal to a 5:1 slope. Channel slope is one percent.

2.10 Reach Type 10 – Roosevelt Street Bridge

Reach Type 10 is only 58 feet long but represents a unique area in the flume where the baffles are spaced 100 feet apart as opposed to the typical 60 feet. Except for the baffle spacing, the dimensions of Reach Type 10 are identical to Reach Type 4.

Photo 2.8 - Reach Type 10 Roosevelt Street Bridge Pier. Flow is 6 cfs. View Downstream.

2.11 Reach Type 11 – Transition Fishway

Reach Type 11 is the very upstream end of the concrete flume. Three concrete weirs form a fishway which transitions between Reach Type 3 and Reach Type 1. The fishway weirs were poured in place over top of a Reach Type 3 segment. The weir lengths are 39, 31 and 16 feet (from upstream to downstream). Because of the difference in lengths, the water surface drops over the weirs vary. The maximum drop varies from 0.7 foot at high flow to 2.5 feet at low flow. The plunge pool depths vary from 5.7 feet at high flow to 0.3 foot at low flow.

Photo 2.9 - Reach Type 11 Transition Fishway. Flow is 150 cfs. View Upstream.

2.12 Reach Type 12 - Division Dam and Fishway

The Division Dam is owned and operated by the Corps as a part of the Mill Creek Project. The purpose of the dam is to divert flow from Mill Creek into Yellowhawk and Garrison Creeks. This structure is the upstream end of the fish passage assessment area.

The dam, its fishway and adjoining sills were surveyed to verify critical control elevations. The concrete sill (Reach Type 1) just downstream of the dam is about 0.3 to 0.4 feet below the elevation of the dam apron. Additional diversion structures are located within Yellowhawk Creek but are not part of this assessment.

Photo 2.11 - Reach Type 12 Division Dam. Flow is 150 cfs. View Upstream.

The following description of the dam and fishway and their operation is taken primarily from Corps Biological Assessment for Operation and Maintenance of the Mill Creek Flood Control Project, (Project BA) and from observations and survey measurements made by the assessment team.

The Division Dam includes four bulkhead gates, a fish ladder, and diversion headworks. Each bulkhead gate is 25 feet wide by 2 feet high. When the gates are closed, they create a dam two feet high to divert water through the headworks. Additional flow passes over the gates and through the fish ladder. The gates can be raised above the bridge deck for flood operations. The clear opening through the division works when the gates are open is 96 feet wide by 6 feet high.

The Yellowhawk division headworks is a concrete structure with three bays. The center bay includes a 14-foot-wide by 6-foot-high radial gate. The right bay has a needle gate (a series of vertical planks); except for a 16-inch-wide slot to allow for fish passage from Yellowhawk Creek to Mill Creek. The bottom of the slot is at the same elevation (1169.5) as the stream bottom (upstream) and concrete apron (downstream). With head on the slot from 1 to 3 feet, the corresponding water velocities vary from 8 to 14 fps, which can create a barrier for certain size fish. Under current operations, this slot is always open. The left headworks bay is completely sealed off with needle gates.

The Washington Department of Ecology (WDOE) is responsible for flow regulation when the flows are below flood diversion criteria. The WDOE Water Master directs the amount of water diverted from Mill Creek into the Yellowhawk/Garrison canal for the purposes of satisfying water rights and maintaining adequate flows for fish and related habitat.

When flows are less than 400 cfs, all four division dam gates are closed. The Yellowhawk and Garrison canal intake gate is then used to regulate flow into the canal. During the irrigation season, generally April through November, the gate is adjusted as necessary to meet the Water Master's directions. It is also sometimes necessary to partially or fully close the fish ladder exit gate to divert more water from Mill Creek. Virtually all flow in Mill Creek is diverted into Yellowhawk and Garrison creeks by late spring or early summer. Runoff from storm drains and some springs scattered through the city provide some low flow in Mill Creek below the division dam. Titus Creek also enters Mill Creek about 1,000 feet below the division dam.

During the non-irrigation season, generally December through March, flow adjustments continue to be made to maintain adequate flows for fish and in-stream flow rights on Yellowhawk, Garrison, and Mill Creeks. The four dam gates are closed during this time, except when flows exceed 400 cfs.

During flood events, the Corps assumes control of water releases and/or diversions in order to regulate flows in a manner that is optimal for flood protection. When flows in Mill Creek are greater than 400 cfs and less than 1,000 cfs, and are forecasted to remain over 400 cfs for more than 24 hours, the two center dam gates are open while the two outer arm gates remain closed. When flows are greater than 1,000 cfs, all four gates are open. The fish ladder exit gate is sometimes closed to prevent debris accumulation; fish can pass under the open dam gates. During a flood period, the Yellowhawk/Garrison canal intake gate is set so that a maximum staff gage height of 0.9 feet (about 70 cfs) in the canal is not exceeded.

A fishway was constructed on the right bank (north) at the dam in 1982. The ladder is about 8 feet wide, 40 feet long and 6 feet high. The three-step ladder (including entrance and exit) has a vertical slot entrance and vertical slot exit, both 18 inches wide. A slide gate at the exit is 18 inches wide by 36 inches high, and is intended to be operated fully open.

The fishway high design flow is described as 15 cfs in the Project BA. The ladder provides upstream fish passage when all four dam gates are closed. In the past the slide gate was sometimes partially or entirely closed during the summer irrigation season to divert more water to Yellowhawk Creek. Now a restrictor plate with a six inch wide slot is placed over the exit when flows at the Mill Creek at Walla Walla gage drops below about 10 cfs. The fishway flow is reduced to limit the flow to Mill Creek (Ben Tice pers. Comm.). For this assessment, the dam and fishway were analyzed for two conditions per the Corps operating criteria (6" and 18" fishway exit slot width). This width opening controls the fishway flow.

3.0 Hydraulic Model

The objective of the hydraulic modeling was to provide the needed data for the fish passability calculations (Section 4). A fish passage energetics model was developed prior to field data collection and hydraulic modeling to identify the data needed. Distance, water velocity and water depth were identified as the key data needs. HEC-RAS (Version 4.0) and spreadsheet models were developed to organize the data. HEC-RAS is a one-dimensional, steady-state water surface step-profile model developed by the U. S. Army Corps of Engineers. Spreadsheet models (developed by the authors) were used to analyze hydraulics in unique Reach Types where the HEC-RAS model was not applicable. Stream flows used for the modeling were provided by the MCWG. Mill Creek discharges for field observations, measurements, and photo documentation were recorded from the Mill Creek at Walla Walla gage STA 14015000. This gage is located just downstream of the Reach Type 12 Division Dam.

There are 16 curved sections of the concrete flume. The angles range from an extreme of 90 degrees (Reach Type 8) to 13 degrees. Lengths of these curved sections vary from 70 to 614 feet. Through the range of flows assessed for fish passage it was observed that the curvatures had minimal effect on the hydraulics. This is because the baffles control the flow profile (i.e. flow reaches critical depth upstream and downstream of the baffle). At flows above 400 cfs there is likely a super elevation effect (i.e. the water depth increases along the outside of the bend compared to the inside). As the depth increases the effect of the baffles is reduced and there is a hydraulic smoothing.

The HEC-RAS model was calibrated with field measurements and photo documentation by adjusting roughness values in the cross section for the channel (trench) and overbank areas, then comparing the field measurements to the results of the model in an iterative fashion. Typical output is shown in Figures 3.2 and 3.3. Spreadsheet models used equations and criteria from Fishway Guidelines for Washington State (2000). The following are descriptions of Reach Type specific hydraulic modeling. The depth and velocity values were used to calculate fish passability are provided in Appendix A5.

3.1 Field Measurements

Field measurements of water surface elevation, depth and velocity were taken along with survey data over a range of flows from 6 to 200 cfs. The data were used to calibrate variables in the HEC RAS model and develop fish passage spreadsheet calculations. Survey was done with a Total Station and Auto Level. Depth was measured with a survey rod. Velocity measurements were made with a Swoffer 2100 and Global Water FP 202. Locations of measurements varied within the channel cross section relative to observed fish passage routes. Access to the flume areas at flows greater than 200 cfs proved impossible due to high velocity and very slippery concrete floors (algae). The opposite was true in the underground section of the flume. Without sunlight the concrete surfaces have good traction (no algae) but the area is completely dark.

Survey and measurements were made in the following locations:

- Reach Type 1 - Velocity and depth measurements over sill at 150 cfs. Stage/discharge for sills at gage site downstream of Division Dam.
- Reach Type 2 - Survey of bed and water surface elevations at 200 cfs

- Reach Type 3 - Measurement of depth and velocity in the channel (trench) and overbank areas at 146 and 200 cfs and within the trench area at 6 and 20 cfs. Also measured water elevation at 400 and 500 cfs.
- Reach Type 6 - Measurement of depth and velocity in the channel and overbank areas at 150 cfs.
- Reach Types 4 and 10 - Split Channels With Bridge Piers - Spot measurements of depth and velocity at key points in flow transition areas.
- Reach Type 11 - Transition Fishway - A survey was completed for this area from the outlet to Roosevelt Street Bridge. Water elevations were measured at 6 cfs.
- Reach Type 12 - Division Dam - A survey was completed for this area which included channel sills upstream and downstream of the dam. Water elevations were measured at 6 cfs.

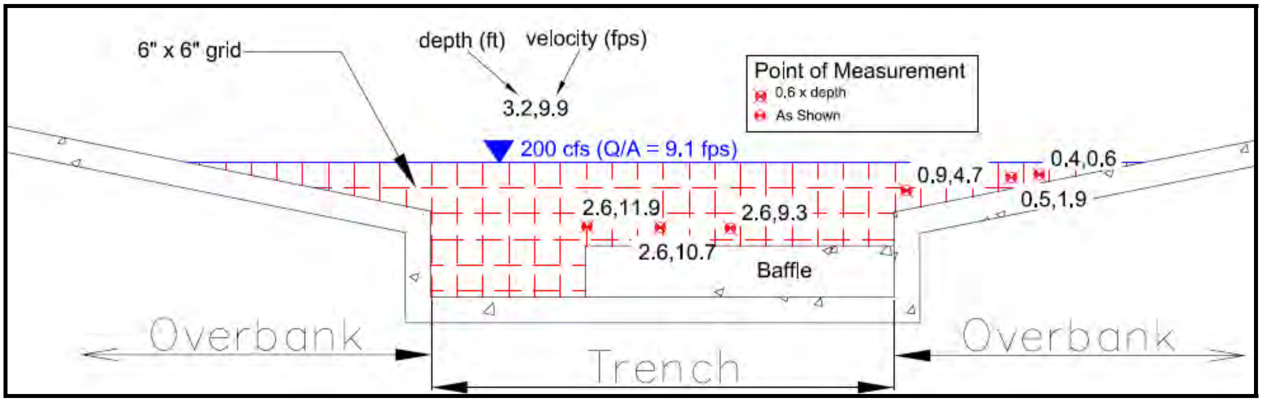

Figure 3.1 – Field Measurements of Depth and Velocity in Reach Type 3 at 200 cfs. View is downstream. Note velocities measured in channel vary from 9.3 to 11.9 fps. Velocities in the overbank area vary from 0.6 to 4.7 fps. The average velocity (Q/A) was 9.1 fps.

3.2 Reach Type Hydraulic Calculations

Reach Type 1- Channel Sills

The hydraulics for Reach Type 1 were calculated using HEC RAS. Field measurements of velocity and depth were made over the sill at a flow of 150 cfs. The HEC RAS model included a section upstream and downstream of a typical 70 foot wide concrete sill. There was no overbank area used in the calculations. Station (distance), velocity and depth data were then entered into the fish energetics model to calculate passage for the flows identified by the MCWG (10, 20, 40, 100, 250 and 400 cfs). The model was calibrated from field measurements of water surface elevation and depth. A rating curve was developed from the Mill Creek at Walla Walla stream gage (STA 14015000), which is just upstream of a concrete sill.

Results of the modeling show that at 10 cfs, the maximum velocity is 5.4 fps and the minimum depth is 0.03 feet. At 400 cfs, the maximum velocity is 9.7 fps and the minimum depth is 0.58 feet.

Reach Type 2 – Flume Transition

Reach Type 2 was modeled with HEC-RAS. The downstream starting water surface elevation was based on flow over the concrete sill (Reach Type 1) immediately downstream of the transition. The model was created with the trench as the channel and the side slopes as the overbank (See Photo 2.3). The hydraulics (depth and velocity) are highly variable because of the variation in cross section. There are only two baffles near the upstream end of Reach Type 2, and the overbank areas transition from flat to a 5:1 slope. A fish passage corridor was observed near the upper end where the trench is deep enough to function as a separate channel. The highest velocity calculated for the fish passage assessment was 6.4 fps at 100 cfs. The shallowest depth was 0.1 feet at 10 cfs.

Reach Type 3 – Trapezoidal Flume with 6 ft Long Baffles

Reach Type 3 was modeled using a spreadsheet/backwater model for low flow and HEC RAS for the higher flows. The spreadsheet model was used for low flow to enable calculations of resting area velocities upstream of the baffles. The baffles are 12 inches high and at low flow provide good resting area for a distance of about 20 feet upstream. The resting area is flow dependent. Once the baffles are overtopped (around 60 cfs), velocities increase to eliminate the resting area.

The HEC-RAS model was calibrated by varying Manning's n in the trench and overbank areas to approximate field measurements. Manning's n for the trench was calculated at 0.009 and 0.018 for the overbank area. The roughness was not modified for the baffles because the model included the actual geometry for each baffle, with cross sections immediately upstream and downstream to account for the channel constriction. The calibrated Manning's n values are only applicable within the ranges of flows at which they were measured.

Field measurements of depth and velocity and observations of flow patterns were made in Reach Type 3 at 20, 146 and 200 cfs. Locations of the measurements are provided in Appendix A1. At 200 cfs, the maximum velocity measured in the trench was 11.9 fps, compared to only 4.7 fps in the overbank area. This overbank area was identified as a possible "fish passage corridor" at certain flows. Calculations of fish passability used velocities and depths from this overbank area if the conditions were deemed appropriate. The threshold for using the overbank area was based on depth. If the depth was 0.8 feet or greater, then depths and velocities in the overbank area were used for the passage assessment. If the depth was less than 0.8 feet in the overbank area, then velocities and depth calculated in the trench were used for passage calculations. It was observed that when the depth was less than 0.8 feet in the overbank area the passage corridor was inconsistent and fish would likely be forced to move in and out of the trench area for passage.

Flow patterns vary significantly and are very complex. At low flow (10 to 40 cfs), the baffles control the flow patterns. They create a constriction (from 9 to 3 feet) in the trench which creates a backwater upstream. The flume slope is 1 percent, so the backwater (subcritical flow) only extends 20 feet upstream. At this point, the flow transitions back to supercritical (sheet flow). This supercritical flow extends upstream to the next baffle. Because the baffles alternate side to side, the flow transitions described above are in the form of oblique standing waves. In the 100 to 200 cfs flow range, the baffles still control the flow but more as roughness. The drop over each baffle is nearly 1 foot with a standing wave immediately downstream. As flow increases above 400 cfs the overall effect of the baffles are reduced and flow patterns seem to level out (although the velocity keeps increasing).

At 20 cfs all the flow is in the trench portion. The maximum velocity was 8.6 fps at a depth of 0.26 feet. Resting areas immediately upstream of the baffles had velocities of 0.2 fps and a depth of 1.4 feet. Fish (4 to 8 inch Rainbow Trout) were observed holding in these resting areas. At 100 cfs, the flow overtops the trench and extends out into the overbank area. The depth in the overbank area was less than 0.8 feet, so it was assumed fish would use the trench area to pass. Velocities ranged from 4.0 to 6.7 fps. Depths ranged from 1.6 to 2.6 feet. At 250 cfs, the depth in the overbank area was 0.9 to 1.1 feet and deemed adequate for fish to use to attempt passage. Velocities in the overbank area varied from 1.6 to 2.4 fps. Even at 250 cfs, there were isolated points in the flume where depths dropped below 0.8 feet in the overbank area. In this case, the trench velocity and depth of (8.2 fps and 3.1 feet) were used for the passage calculations. These are the calculated values from HEC RAS for the channel flow portion. Station, depth and velocity data for all the flows are provided in Appendix A5.

Reach Type 4 – Trapezoidal Split Flume with 3 ft Long Baffles

The hydraulic calculations for Reach Type 4 are similar to Reach Type 3 with the addition of a center pier which splits the channel. To address this situation only half of the channel was analyzed. It was assumed the flows were split evenly. The height of the trench wall is 2.1 feet as opposed to 1.7 in Reach Type 3. More flow is contained within the trench area before flowing into the overbank area.

Reach Type 5 – Flume Transition Trapezoidal to Rectangular

Hydraulic calculations for Reach Type 5 were similar to Reach Type 3. The only difference being the geometry of the overbank area (transition from trapezoidal to flat).

Reach Type 6 – Rectangular Flume with 6 ft Long Baffles

Hydraulic calculations for Reach Type 6 were also similar to Reach Type 3. The only difference being the geometry of the overbank area. Reach Type 6 has a flat overbank section where flow spreads out, depth is less and overall velocity less. The depth in the overbank area at 250 cfs is 0.8 feet compared to 1.1 feet in the Reach Type 3 trapezoidal section.

Field measurements were made in Reach Type 6 at 150 cfs. Details are provided in Appendix A1. The highest velocity measured in the trench area was 8.4 fps. The depth in the overbank area varied from 0.3 to 0.5 feet at 150 cfs.

Reach Type 7 – Rectangular Split Flume with 3 ft Long Baffles

The hydraulic modeling for Reach Type 7 is similar to Reach Type 6 in terms of the flat overbank area and similar to Reach Type 4 for the split trench area.

Reach Type 8 – Rectangular Double Wall with 10 ft Long Baffles

The Reach Type 8 geometry differs from other Reach Types because the center trench is 16 feet wide and the overbank areas are only 14 feet wide. The overbank areas are isolated from the center trench by concrete walls. A split flow analysis was not completed due to the modeling complexity. Depth was not adequate to consider passage in the overbank area until the flow reached 400 cfs.

Reach Type 9 – Flume Transition Rectangular to Trapezoidal

The hydraulic calculations for Reach Type 9 were similar to Reach Type 3, with the only difference being the geometry of the overbank area (transition from flat to trapezoidal).

Reach Type 10 – Roosevelt Street Bridge

The Reach Type 10 hydraulic analysis was similar to Reach Types 3 and 4, with the exception of the 100 foot baffle spacing. Because there were no baffles along the length of the bridge pier, the HEC RAS bridge pier option was used to compute the hydraulics with a split channel.

Reach Type 11 (Transition Fishway) and Reach Type 12 (Division Dam and Fishway)

Reach Types 11 and 12 were surveyed to define weir lengths and elevations and a spreadsheet model was developed to calculate the fishway hydraulics. Existing water surface elevations were collected for low flow. Parameters analyzed included hydraulic drop, energy dissipation factor (EDF) and plunge pool depth. EDF is essentially the maximum amount of turbulence allowed in a fishway pool for fish to still be able to successfully move through. It is a ratio of the kinetic and velocity energy entering a pool and the effective volume of the pool to dissipate that energy (WDFW, 2000). Detailed calculations from the spreadsheet are provided in Appendix A5.

Reach Type 11

In Reach Type 11 at low flow (6 to 10 cfs) the plunge pool depth for the most downstream weir is 0.3 feet, with a drop over the weir of 2.5 feet. At 400 cfs, EDF in the lower pool was calculated at 12.8 ft-lbs/sec per cu ft of water. A typical design value of EDF is 4.

Reach Type 12

For Reach Type 12 at low flow the fishway exit drop (most upstream) is 1.4 feet. Fish have to swim through a 9.2 fps high velocity jet to pass. EDF is high at 9.2 ft-lbs/sec per cu ft of water. There is actually a 0.2 foot drop with no depth over the dam apron. Access into the fishway requires fish to swim through a shallow area (0.2 to 0.4 deep). At higher flows the drop into the fishway is similar but EDF increases to 19.8 ft-lbs/sec per cu ft of water. The hydraulic analysis is for flows up to 400 cfs with the dam gates closed. Above that, the dam gates open, and fish can pass through the open gates.

River Sta	Profile	Vel Chnl	Hydr Depth C	Vel Left	Hydr Depth L	Vel Right	Hydr Depth R
		(ft/s)	(ft)	(ft/s)	(ft)	(ft/s)	(ft)
1025	250cfs	8.33	2.81	2.37	0.90	2.37	0.90
1025	400cfs	9.41	3.58	2.89	1.29	2.89	1.29
1040	10cfs	1.20	0.92				
1040	20cfs	1.69	1.31				
1040	40cfs	2.55	1.74	0.11	0.03	0.12	0.04
1040	100cfs	4.07	2.62	0.79	0.48	0.79	0.48
1040	250cfs	6.26	3.78	1.62	1.06	1.63	1.06
1040	400cfs	7.84	4.45	2.19	1.39	2.19	1.39
1060	10cfs	1.53	0.73				
1060	20cfs	2.00	1.11				
1060	40cfs	2.89	1.53				
1060	100cfs	4.53	2.39	0.78	0.36	0.78	0.36
1060	250cfs	6.99	3.50	1.74	0.91	1.74	0.92
1060	400cfs	8.94	4.08	2.41	1.21	2.41	1.21
1080	10cfs	2.20	0.51				
1080	20cfs	2.50	0.89				
1080	40cfs	3.41	1.30				
1080	100cfs	5.15	2.13	0.73	0.24	0.73	0.24
1080	250cfs	8.20	3.11	1.89	0.73	1.89	0.73
1080	400cfs	9.45	3.93	2.51	1.14	2.51	1.14

Figure 3.2 – HEC RAS Output Data For Fish Passage Assessment in Reach Type 3. River Stations are from the Corps drawings. Left (L) and Right (R) are as viewed downstream. Data includes trench (Channel, C) and overbank velocity and depth. Blank cells for Vel and Depth indicate all the flow is in the trench.

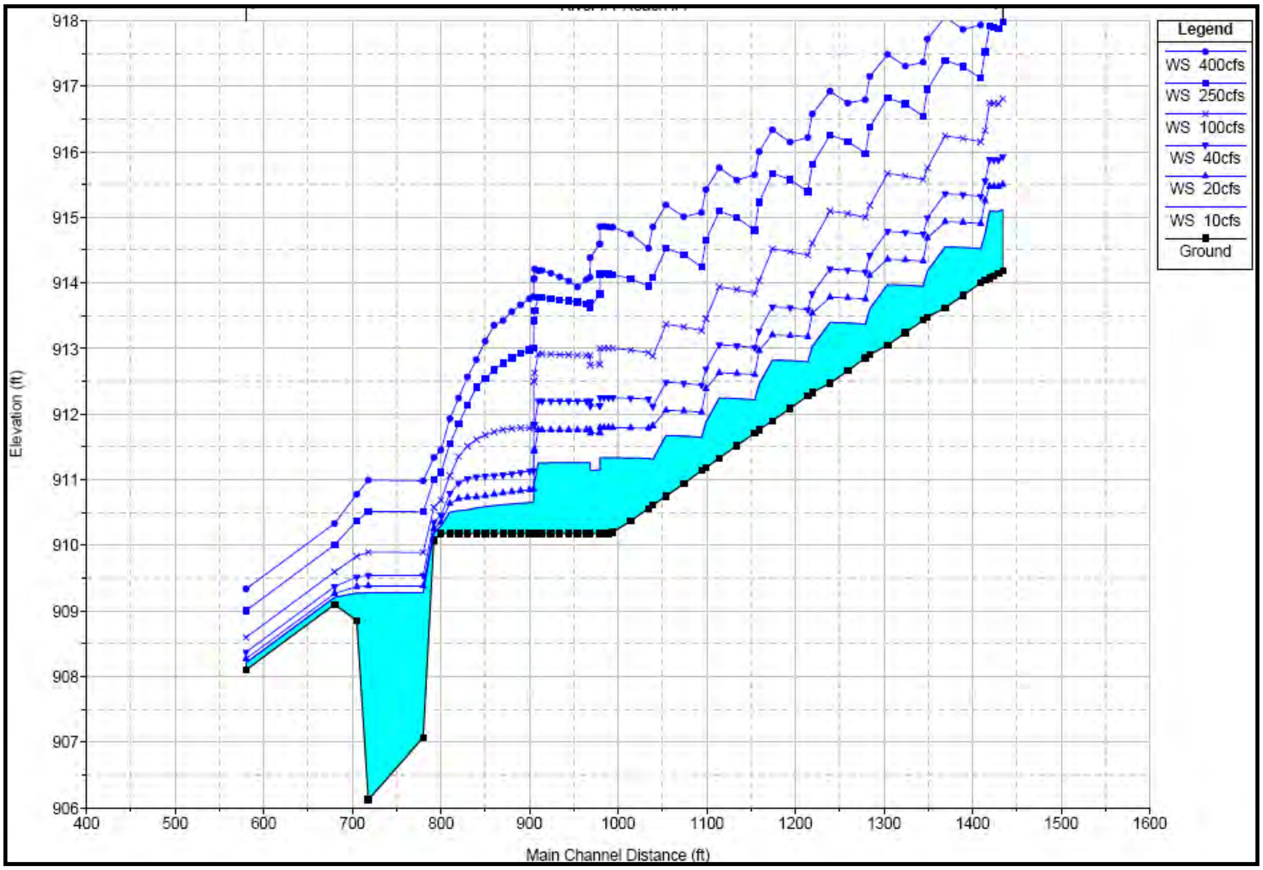

Figure 3.3 - HEC RAS Output Data Showing Water Surface Profiles For Fish Passage Assessment in Reach Type 2 and 3. River Stations are from the Corps drawings. Reach Type 2 is the downstream portion from STA 600 to 1000, and Reach Type 3 is from STA 1000 upstream.

4.0 Fish Passage Assessment

Quantitative models were used to assess fish passage in each Reach Type. The results of the models are not precise but they are intended for comparison and prioritization. The reasons for the imprecision are described in this section.

Reach Types in the concrete flume have varying characteristics that lend themselves to fish passage analyses using two models. The simplest models are deterministic models based on criteria of depth and velocity and fishway models that can be used for specific Reach Types that are hydraulically similar to weir and pool fishways. The initial proposal for this project was to assess passage based on WDFW fish passage criteria. The applicable criteria are the depth and velocity criteria for culverts.

4.1 Depth-Velocity models

The Washington Department of Fish and Wildlife (WDFW, 2003) and National Marine Fisheries Service (NMFS, 2008) have developed road crossing (culvert) guidelines for providing suitable upstream passage conditions for adult salmon and steelhead. These criteria however provide only a single value for each criterion (depth, velocity) that defines acceptable passage. If used to assess fish passage, they do not account for varying hydraulic conditions over time, through or across a flume, or for varying sizes of fish. They are also deterministic; they produce a result of only pass or fail with no variability. Because of that, they are difficult to use for prioritization of Reach Types by comparison of passability.

WDFW culvert criteria stipulate that, for steelhead adults and Chinook salmon, channels (culverts) greater than 300 feet in length, must have a maximum average cross-section velocity not exceed 3.0 fps and the depth must be greater than 1.0 foot at the high fish passage design flow. A quick analysis of the Mill Creek channel with these criteria indicates the entire assessment area is a total barrier for both species. With this approach, there is no way to identify partial passage or to prioritize remediation of barriers.

4.2 Energetics Model Applied in Baffled Flume

More complex models consider the energetics of individual fish. Energetics models account for specific hydraulic conditions and the ability of fish to swim through a channel with those conditions varying through the length and cross-section of the channel. An energetics model was used in this study to assess passability in the flume and at individual sills. The model is not used for the fishway Reach Types (11 and 12).

The energetics model works as follows. At each flow studied, a velocity profile is developed from the hydraulic model, including corrections from field measurements. If boundary conditions are favorable to passage, they are included in the profile. Specific sizes of fish are tested in the model that represents the population of each species. Each fish swims at its optimum speed (travels the furthest distance with the least amount of energy expended) and its energy consumption is tracked in terms of fatigue, hence the term “energetics model”. If conditions are suitable for resting, the fish may rest and recover from fatigue before continuing upstream. If the fish becomes 100% fatigued it is not able to continue swimming, and the location at which it becomes exhausted is noted. Based on the flow and the sizes of fish tested, the passage success is then expanded to the percentage of the population of each species. This model was used for most of the Mill Creek flume. It is a complex spreadsheet model that merges channel characteristics, hydraulics, fish sizes and swimming data. It follows the progression of an individual fish (size and species) up the channel until it passes the Reach Type successfully or it fails. It can also be used in specific local situations where burst or prolonged swimming is required to get an optimum swim speed.

The steps of analysis for each species are shown in the flow chart in Figure 4.1. This analysis is repeated for each flow studied and each species and size of fish. It is later repeated to evaluate potential projects. These steps are essentially the columns in the energetics model spreadsheet example; see Figure 4.5. Complete explanations of each step are presented in following sections.

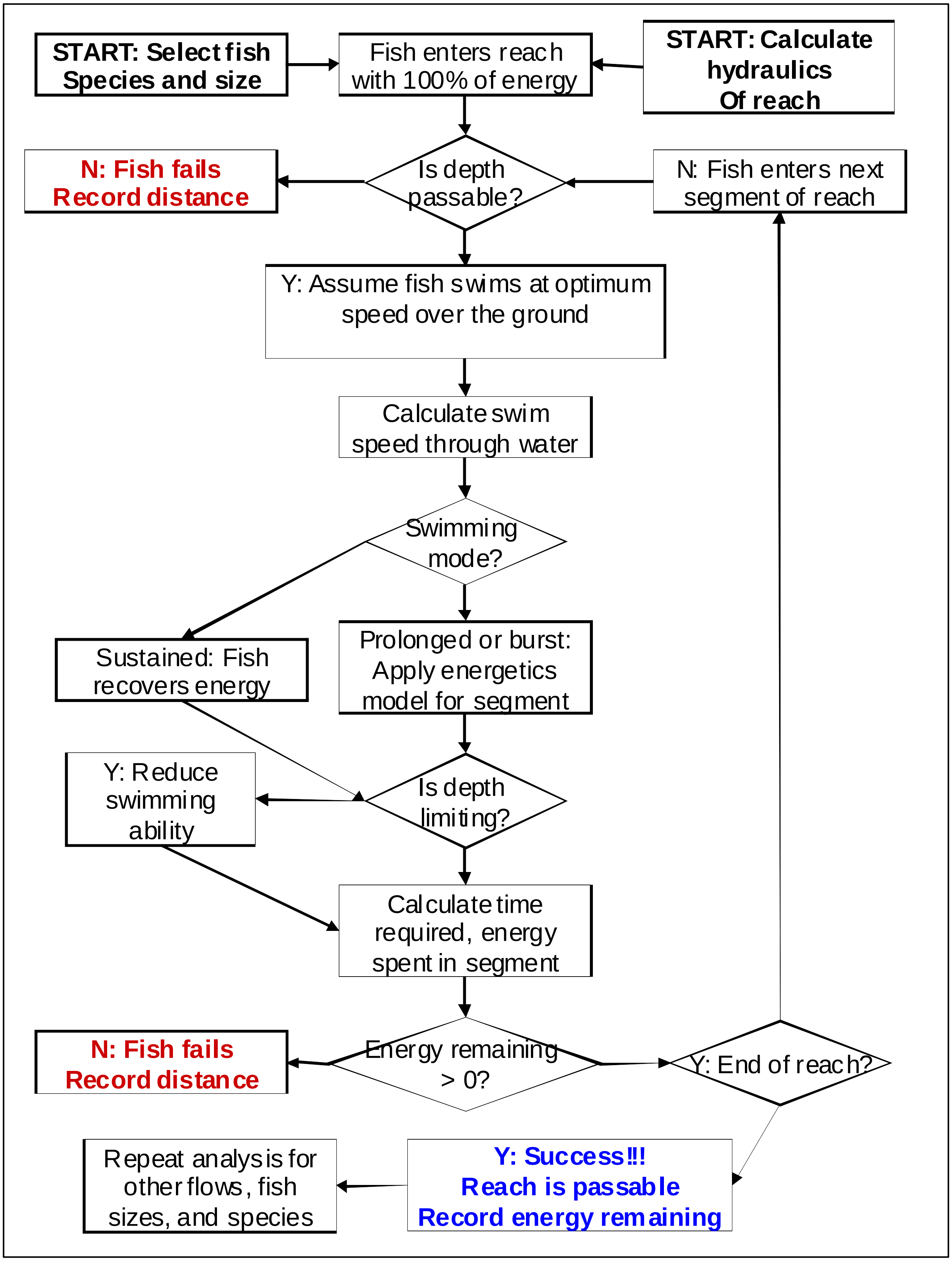

Figure 4.1 - Flow Chart of Energetics Model for a Selected Target Species and Size of Fish.

The following describes each step of the energetics modeling in more detail.

4.2.1 Calculate the hydraulics

The hydraulics for each Reach Type was calculated with either HEC-RAS or a spreadsheet model as described in Section 3. The results of the hydraulic models for each Reach Type and flow were imported into the energetics spreadsheet model. The actual depth and velocity values used from HEC-RAS are described in Section 3.

4.2.2 Distribution of Fish Sizes

Fish swimming capability is a function of the length of the fish, among other things. To analyze overall passability, the model reflects the sizes of fish within the entire population rather than a single size such as the average, largest, or smallest fish. This is done by analyzing passage for several fish sizes that span the overall range within the population of each species. Passability for a species is then determined by the combined passability of each size of fish multiplied by the portion of the population it represents, and the proportion of sizes available.

A multi-variate analysis of fish sizes, flows, and other hydraulic and biological assumptions would be an enormous task and not very useful considering how little data there are available. These complexities especially make it difficult and time consuming to compare retrofit options.

There are some data describing migration timing and sizes of fish in Mill Creek. Data for the energetics and barrier models were chosen from several sources. Data from the lower Walla Walla River at the Nursery Bridge trap were initially used and then modified based on conversations with biologists in the region (Gallion, Tice, Mendel and Volkman personal contacts). The initial data are shown in the following four figures, which are taken directly from Mahoney, etal (2006), and Anglin, etal (2004).

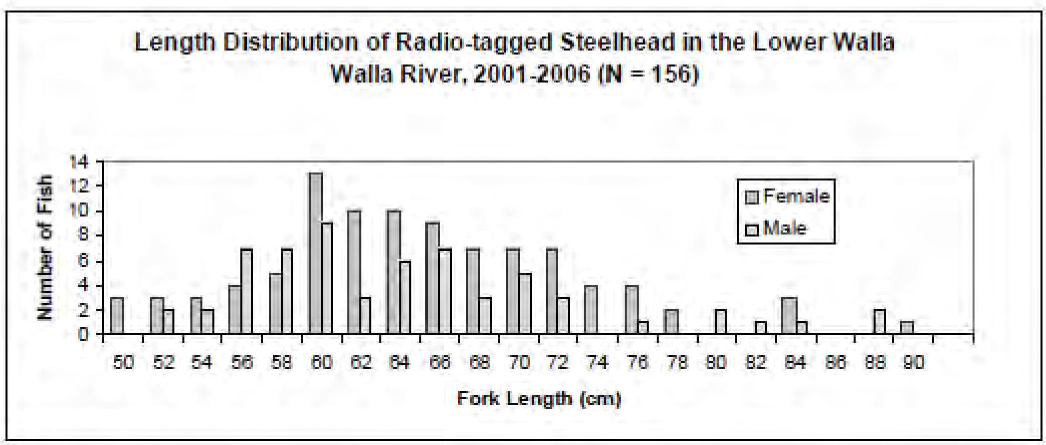

Figure 18. Length distribution of steelhead radio-tagged in the lower Walla Walla River (rkm 4.8 – 34.9), 2001-2006.

Figure 4.2 - Steelhead Fork Length Distribution

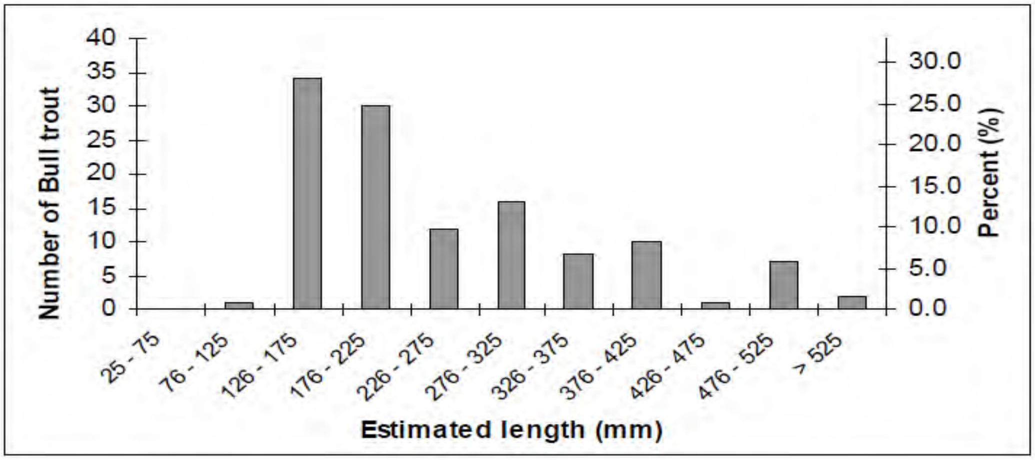

Figure 11. Length frequency histogram (n=121) for bull trout observed during daytime snorkel surveys from June through November, 2004.

Figure 4.3 - Bull Trout Fork Length Distribution

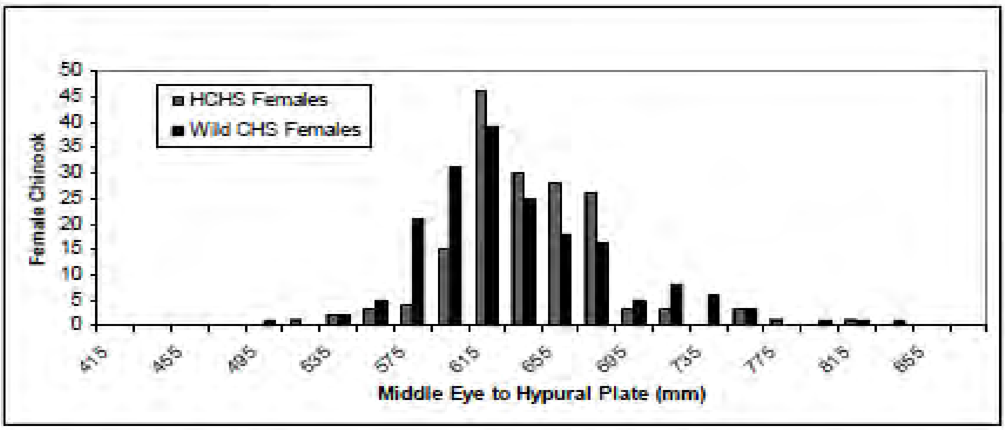

Figure 13. Length distribution of female hatchery (n = 166) and wild (n = 183) spring Chinook spawners sampled during carcass surveys in the upper mainstem and South Fork Walla Walla, and Mill Creek, 2001 – 2007.

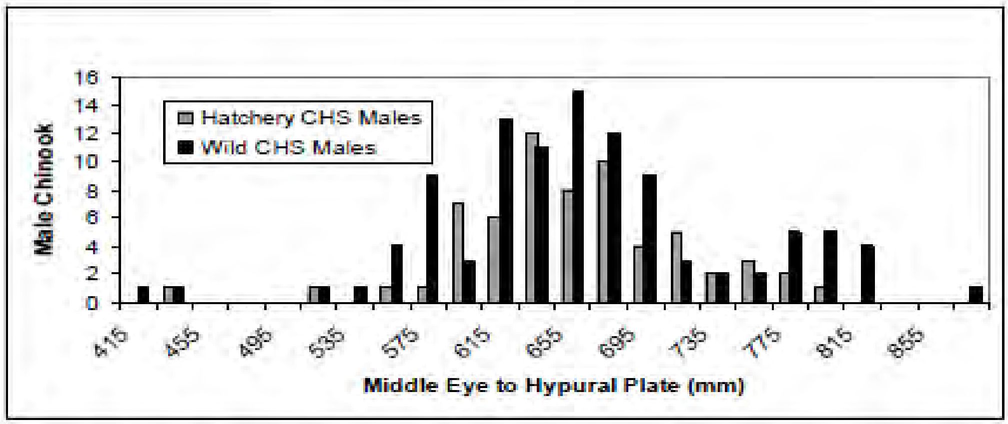

Figure 14. Length distribution of male wild (n = 102) and hatchery (n = 64) spring Chinook spawners sampled during carcass surveys in the upper mainstem and South Fork Walla Walla, and Mill Creek, 2001 – 2007.

Figure 4.4 - Spring Chinook Fork Length Distribution

It is recognized that the cameras at Nursery Bridge only monitor the ladders and they are not 100% efficient at detecting fish within the ladders. In addition, flows and temperatures are highly affected by diversions upstream from Nursery Bridge and, similar to Mill Creek, these conditions may affect passage.

The data used in the models is shown in Table 4.1.

Species	Size Range (inches)				Timing in Mill Cr	Primary source
	Range	10%	50% (median)	75%		
Steelhead	20 - 32	22	26	28	March - May	Mahoney etal, 2006. Sizes modified by comments from Bumgarner and Tice
Spring Chinook	22 - 33	24	26	27	May – June	Mahoney etal, 2006. Sizes modified by comments from Tice and Volkman
Bull trout	5 - 23	7	9	13	March - July	Timing: Mahoney etal, 2006 modified by comments from Mendel and Gallion. Sizes: Anglin etal, 2004 modified by comments from Tice

Table 4.1- Summary of Fish Sizes.

Fish sizes are represented as percentiles of fish smaller than a given size. For example, 75% of fish in a population are smaller than the 75th percentile fish (75% in Table 4.1). The 10th, 50th, and 75th percentile sizes of fish were used in the analysis for each species. The lower and upper limits of 10th and 75th percentiles were used instead of the very smallest and largest fish so the results would reflect the population rather than the extremes. Later, to summarize the passability for each species, the results of each size were weighted and combined to represent the population.

4.2.3 Assume the fish swims at the optimum swim speed

Castro-Santos (2005) showed that for prolonged and burst modes of swimming there is a speed at which a fish can swim relative to the ground that will maximize the distance it can swim regardless of the velocity of the water. He also showed that for three anadromous species tested (none of them salmonids) the optimum speeds were about the same and the fish chose to swim at that optimum speed and would change between prolonged and burst swimming mode as necessary as the water velocity changed to maintain that speed.

Castro-Santos showed that the optimum swim speed could be calculated as the speed of the water the fish is swimming against minus the inverse of the slope of a regression line of a log-linear plot of swim speed-fatigue time data.

Powers and Orsborn (1984) tested Coho and Chum salmon swimming up an 8 foot long roughened chute and found the relative fish velocity to be 1.9 to 2.1 fps.

Love etal (2006) used the original test data for steelhead that was used in the (Paulik and DeLacy, 1957) study to calculate that regression line and optimum swim speed. They calculated the swim speed to be 2.05 BL/s. This study uses that optimum speed of 2.05 BL/s for all species in the analysis.

With this assumption, and the water velocity, the actual speed of the fish through the water can be calculated. It is the sum of the swim speed relative to the ground (the optimum swim speed) and the velocity of the water. This is the speed that is used in the energetics models.

Specific optimum speeds for Chinook and Artic char (surrogate for Bull Trout; see Section 4.2.6.3) might be developed from the original swimming data by converting it into log-linear relationships. We have not attempted that analysis.

The concept of optimum swim speed as described here assumes the fish swims at a constant velocity relative to the ground. There is some evidence that in some conditions fish can improve their overall swimming ability by swimming in a burst and glide mode. There is little empirical data regarding the behavior and effectiveness of burst and glide swimming. We did not try to develop burst and glide characteristics into the model.

4.2.4 Calculate the swimming speed through the water

A fish swimming at optimum speed must adjust its speed as the water velocity changes. The speed the fish swims through the water is simply the velocity of the water plus the speed the fish is swimming relative to the ground, which we assume to be its optimum swim speed.

4.2.5 Determine whether the swimming speed is in sustained, prolonged, or burst mode

Fish can swim in sustained, prolonged, or burst swimming modes. For the model one must establish which mode a fish swims in at any point. If the fish swims in sustained swimming mode, it can recover energy. If it swims in either prolonged or burst modes, it uses energy but at different rates.

To determine which mode the fish swims in, the model has adjustable thresholds of water or swim speeds. If the water velocity is less than a given threshold, we assume the fish swims in sustained mode and recovers energy. The specific threshold of sustained swimming is not clear. Milligan etal (2000) showed that a rainbow trout holding in a water velocity of 0.9 BL/s recovered from exhaustive swimming fatigue within two hours. Other studies (Weaver, 1963 as reported by Hunter and Mayor, 1986) show rainbow trout being exhausted at swim speed rates of less than three BL/s. We therefore chose an upper sustained swimming speed of 1.0 BL/s.

If the velocity is higher than that threshold but the fish swims at less than a set speed of five BL/s, it swims in prolonged mode. If it swims faster than that, it is in burst mode.

4.2.6 Apply energetics formula

The model calculates the time a fish can swim at a given velocity based on the size of fish, swimming speed, and swimming mode as described above. Other conditions that affect these relationships are water temperature and water quality. A common model for predicting swimming stamina is in the form of Equation 4.1, as described by Hunter and Mayor (1986) and rearranged here to solve for duration time.

$$t = \left[\frac{aL^b}{V} \right]^{1/c}$$

Equation 4.1

V is the swimming velocity, *L* is the length of fish and *t* is the duration time in seconds. The constant *a* and coefficients *b* and *c* are derived from swimming studies for specific species and size ranges and vary depending on whether the fish is swimming in prolonged or burst mode. Coefficients for some species were developed from previous research and reported by Hunter and Mayor (1986). They are also reported in the swimming database in the FishXing software (USFS, 2006).

There are very little swimming stamina data for these species and sizes of fish. Most swimming research has focused on critical velocity tests and therefore does not provide relationships of swimming duration to both swimming speed and size of fish.

Data used in the energetics model comes from a variety of research sources. Most of the work was done in the 1960's through the 70's. Most of the swim data reported is for small groups of fish, typically 6 to 100 fish. Typically the mean swimming values are reported, rather than the range for the entire sample. Hunter and Mayor (1986) summarized the data statistically into generalized stamina equations such as Equation 4.1.

If the water is shallow, the swimming time is reduced. When the water is as deep as the fish's body, we assume it has full stamina. The stamina is reduced linearly for decreasing depths down to a "depth barrier threshold" at which point the depth is a complete barrier.

Water temperature, water quality, and origin of fish, testing methods, and other characteristics likely also affect swimming ability. Temperature could become significant issue in Mill Creek during summer months. We did not try to correct for these factors.

The following sections describe the fish energetics data and formulae used for the three species.

4.2.6.1 Steelhead *(Oncorhynchus mykiss)*

No prolonged swim stamina data for adult steelhead was found. We used a prolonged stamina model developed by Hunter and Mayor (1985) for all salmonids. We used steelhead burst swimming data from a combination of studies by Weaver (1963) and Paulik and DeLacy (1957) as reported by Hunter and Mayor. We also found rainbow trout burst swimming data, which might be applicable, but we did not use it.

4.2.6.2 Spring Chinook *(Oncorhynchus tshawytscha)*

We found no prolonged swim stamina data for adult Chinook salmon. We used the same prolonged stamina model as we did for steelhead developed by Hunter and Mayor (1985) for all salmonids. We used Chinook burst swimming data reported by Weaver (1963) as reported by Hunter and Mayor.

4.2.6.3 Bull Trout *(Salvelinus confluentus)*

We found no prolonged or burst swim data for bull trout. Having no data, we used Arctic char as a surrogate since both species are char, and some prolonged swim data is available for the Arctic char. We used Arctic char prolonged swimming data reported by Welsh (1979) and Beamish (1980) as reported by Hunter and Mayor. We found no burst swim stamina data for Arctic char. We used the same prolonged stamina model developed by Hunter and Mayor (1985) for all salmonids.

4.2.7 Calculate the time required for the fish to pass through the Reach Type segment.

A fish swims over the ground at a speed equal to the difference between the swimming speed and the velocity of the water. The time it takes a fish to swim through a segment of the reach is simply the length of the segment divided by the rate of travel relative to the ground.

4.2.8 Calculate the portion of energy spent swimming through the segment

The portion of energy spent swimming through a segment is the time spent divided by the time the fish is able to swim at that speed.

4.2.9 Calculate the remaining energy of the fish.

The remaining energy is the energy the fish had entering the segment less the energy spent in the segment. If the fish becomes 100% fatigued it is not able to continue swimming, and the location in which it becomes exhausted is recorded. A reach is considered passable if a fish has energy remaining at the end of the Reach Type. The remaining energy is recorded (See Appendix A7 – Fish Passability Detail Spreadsheet).

Theoretically, that remaining energy is what the fish will start with as it enters the next reach of the project. We assume here the fish will start each reach with 100% of its energy so the analysis of each reach is independent and therefore prioritization and treatments can be independently considered.

If conditions are suitable for resting, the fish may rest and recover from fatigue before continuing upstream. The model includes a fatigue recovery factor, which is the energy regained by the fish before it attempts to swim further upstream. An assumption is made that the fish rests whenever the velocity is less than the fish's sustained swimming ability and the water depth is equal or greater than the depth of the fish.

This model of energy spent and energy remaining is the essence of the energetics model and is further described by Castro-Santos (2006). Resting capability, a depth modifier and an occupied velocity factor (V_{occ}) $_{was}$ added to this model. V_{occ} is a factor ranging from 0.5 to 1.0 which allows one to further adjust the water velocity the fish is swimming against to account for boundary layers. In most cases V_{occ} is set to 1.0, because of the smooth concrete.

Each run (species, size of fish, flow) is summarized by recording whether the run was a barrier or not, a description of the barrier (velocity, depth, turbulence, and combination), the distance the fish swam through the reach if it was a barrier, and the fish's remaining energy if it was able to complete the channel segment.

An example of a model run is shown in Figure 4.5. This run is for Reach Type 3 for 22-inch steelhead at a 20 cfs. The reach is split into five-foot segments for the analysis. In this case, a steelhead passes through 120 feet of the flume and has 69% of its energy remaining. This is seen in the column labeled "Energy remaining" in the table. Baffles are located at stations 905, 965 and 1025. Just downstream of the baffle locations the water depth is only 0.2 feet. The body depth of a 22 inch adult steelhead is 0.4 feet, so a depth modifier is applied and more energy is spent swimming through those segments.

Hydraulics - Linear Models

Power models. Hunter Mayor, 1986

$$V = aL^b t^{-c}$$

$$t = \left[\frac{a(L)^b}{V}\right]^{1/c}$$

V: swim speed; fps
L: length of fish; inches
t: time to fatigue; seconds
a, b, c; empircial coefficients

Swim data	Species	Mode	a	b	c	Data Reference and notes
1	Steelhead	B	12.3	0.62	0.51	Weaver 1963; Paulik and DeLacy 1957 formulated by Hunter and Mayor 1986
2	Steelhead	B	12.81	1.07	0.48	Bainbridge 1960; Weaver 1963; Paulik and DeLacy 1957 formulated by H&M 1986
3	Rainbow	B	7.16	0.77	0.46	Bainbridge 1960. Small fish
4	Rainbow	B	12.56	0.80	0.50	Bainbridge, Weaver, Beamish formulated by H&M 1996
5	Chinook	B	11.49	0.32	0.5	Weaver 1963 reported by Hunter and Mayor 1986
6	Arctic char	P	3.74	0.606	0.13	Welsh 1979, Beamish (pers com) reported Hunter and Mayor 1986
7	Arctic char	P	2.69	0.606	0.08	Beamish 1980a, Welsh 1979
8	All salmonid	P	4.37	0.6	0.096	Hunter and Mayor 1986
9	All salmonid	B	11.4	0.71	0.5	Hunter and Mayor 1986

Fish				
D/L	0.22			values from FishBase
D	0.40	ft		
Optimum Vg	2.05	3.76	fps	assumed swim speed over ground. Castro-Santos 2005. Love etal 2006
Max sustained Vs	1	1.8	fps	value of 1.0 from Love etal
Max prolonged Vs	5.0	9.2	fps	
Max burst Vs	15	27.5	fps	

	data source	species	mode	a	b	c			
prolonged	8	**All salmonids**	P	4.37	0.60	0.10	Vocc multiplier	0.9	(0.1-1.0)
burst	1	**Steelhead**	B	12.30	0.62	0.51	Depth barrier threshold	0.25	(0.1-0.9)
							Fatigue recovery level	0.50	(0.1-1.0)

Steelhead Energetics

Fish Length 22 inches FL
sthd: 22, 30

Sta	Water velocity Vf	Water depth	Vocc	Swim speed V	Swim mode	Time to exhaust prolonged	Time to exhaust burst	Depth modifier	Time to exhaust (w/ d mod)	Time interval ti	Energy spent	Energy remaining	Length
ft	fps	ft	fps	fps		sec	sec		sec	sec	%	%	ft
Reach 3, 20 cfs													
905	4.23	0.53	3.81	7.57	P	21.04	13.19	1.00	21.04			100%	0
910	0.20	1.43	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	100%	5
915	0.20	1.38	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	100%	10
920	0.20	1.33	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	100%	15
925	1.74	1.27	1.57	5.32	P	816.87	26.27	1.00	816.87	0.94	0%	100%	20
930	1.82	1.22	1.64	5.40	P	710.21	25.58	1.00	710.21	0.93	0%	100%	25
935	1.90	1.17	1.71	5.47	P	618.62	24.93	1.00	618.62	0.91	0%	100%	30
940	1.99	1.12	1.79	5.55	P	530.77	24.22	1.00	530.77	0.90	0%	99%	35
945	2.09	1.07	1.88	5.64	P	448.88	23.47	1.00	448.88	0.89	0%	99%	40
950	2.20	1.01	1.98	5.74	P	374.45	22.68	1.00	374.45	0.87	0%	99%	45
955	2.32	0.96	2.09	5.85	P	308.35	21.86	1.00	308.35	0.86	0%	99%	50
960	8.57	0.26	7.71	11.47	B	0.28	5.83	0.53	3.07	0.44	14%	85%	55
965	4.23	0.53	3.81	7.57	P	21.04	13.19	1.00	21.04	0.66	3%	81%	60
970	0.20	1.43	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	81%	65
975	0.20	1.38	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	81%	70
980	0.20	1.33	0.18	3.94	P	18890.51	47.44	1.00	18890.51	1.27	0%	81%	75
985	1.74	1.27	1.57	5.32	P	816.87	26.27	1.00	816.87	0.94	0%	81%	80
990	1.82	1.22	1.64	5.40	P	710.21	25.58	1.00	710.21	0.93	0%	81%	85
995	1.90	1.17	1.71	5.47	P	618.62	24.93	1.00	618.62	0.91	0%	81%	90
1000	1.99	1.12	1.79	5.55	P	530.77	24.22	1.00	530.77	0.90	0%	81%	95
1005	2.09	1.07	1.88	5.64	P	448.88	23.47	1.00	448.88	0.89	0%	81%	100
1010	2.20	1.01	1.98	5.74	P	374.45	22.68	1.00	374.45	0.87	0%	80%	105
1015	2.32	0.96	2.09	5.85	P	308.35	21.86	1.00	308.35	0.86	0%	80%	110
1020	8.57	0.26	7.71	11.47	B	0.28	5.83	0.53	5.83	0.44	7%	73%	115
1025	4.23	0.53	3.81	7.57	P	21.04	13.19	1.00	21.04	0.66	3%	69%	120

Figure 4.5 - Example of Fish Energetics Calculation For Reach Type 3 at 20 cfs.

4.2.10 Calculate passability

Passability is the proportion of fish that pass the Reach Type for the flow being analyzed. Fish passability at a given flow is not affected directly by migration timing. Migration timing in the model only affects overall passability for a species.

Overall passability for a size of fish is the sum product of fish that pass at each flow and the portion of the migration season which that flow represents. Each flow analyzed represents a range of flows from the midpoint between it and the next lesser flow studied to the midpoint between it and the next higher flow. Flows of zero and 800 cfs were the boundaries of the analysis.

Overall passability for the species is then the sum product of the overall passability for each size and the portion of the population made up of that size. Overall passability is an indicator but not likely an accurate estimate of the proportion of each species that is able to pass the reach.

4.2.11 Summary of energetic model assumptions

A number of assumptions were made to build the energetics model. The user should be aware of these assumptions and how they might affect the results. The assumptions are mentioned in the previous description of the model and are summarized here.

- Swimming stamina data are accurate.
- The basic energetics model of reducing energy stores proportionately to distance swum is appropriate.
- Fish swim in prolonged mode when the swim velocity is below a prolonged mode threshold and in burst when above.
- Fish swim at their optimal swim speed.
- When a resting area is available, fish recover from fatigue to at least a pre-determined level.
- Water shallower than the body of a fish causes increased energy expenditure proportional to the depth of the water relative to the depth of the fish body down to a threshold that is then a barrier.
- Fish use low velocity boundary layers when available.

4.3 Passage Assessment at Fishways

A deterministic model was developed to describe passage at the two fishways (Reach Type 11 and 12). The model uses four parameters that together describe passability at a fishway; leap height, pool depth, turbulence, and fishway attraction. The first three parameters are defined quantitatively for each pool of each fishway and at each flow.

Passability is defined by Equation 4.2.

$$P = HDTA \qquad \textbf{Equation 4.2}$$

P is passability and ranges from zero (impassable) to 1.0 (passable)

H is the passability due to leap height. H varies linearly with body length of the fish, which can be translated to burst speed and therefore potential leap height.

D is the passability due to depth. D also varies linearly with body length of the fish. It is the pool depth from which the fish must leap.

T is the passability due to turbulence in the pool. It is the expressed as the value of the Energy Dissipation Factor (EDF) in the pool. T varies exponentially with body length of the fish (body length to the 0.4 power). The model was based on best professional judgment by the authors.

A is the passability due to fishway attraction. The value of A is based on professional judgment and is based on head differential and flow at the entrance compared to hydraulic conditions at the dam apron (i.e. false attraction).

All of the parameters range from 0.0 (impassable) to 1.0 (passable). Algebraic models were written to calculate each parameter from the hydraulic conditions associated with it so they could be calculated in a spreadsheet model. Coefficients were selected to get results that were judged appropriate for each parameter. The ranges of values for each parameter are shown in Table 4.2 and how they vary with fish body length.

	Height (ft)		Depth (ft)		Turbulence (EDF) (ft-lb/s/cu ft)	
Fish Body Length (in)	Passable (H=1.0)	Barrier (H=0.0)	Passable (D=1.0)	Barrier (D=0.0)	Passable (T=1.0)	Barrier (T=0.0)
7	0.7	1.5	0.3	0.1	4.0	8.1
9	0.9	1.9	0.4	0.2	4.5	8.9
13	1.4	2.7	0.5	0.3	5.2	10.3
22	2.3	4.6	0.9	0.5	6.4	12.7
24	2.5	5.0	1.0	0.5	6.6	13.2
26	2.7	5.4	1.1	0.5	6.8	13.6
27	2.8	5.6	1.1	0.6	6.9	13.8
28	2.9	5.8	1.2	0.6	7.0	14.0

Table 4.2 – Variation of Fishway Assessment Parameters with Body Length.

The values under "passable" are the values of each parameter at which conditions are totally passable (parameter has a value of 1.0). The values under "barrier" are the values of each parameter at which conditions are totally impassable (value of 0.0). Values of parameters that are between the two extremes are linearly interpolated from 0.0 to 1.0. Values of parameters beyond the range in Table 4.2 have values of either zero or one, depending on whether they are above or below the range.

As an example, consider a 13-inch fish in a fishway pool with a drop height of 2.5 feet, a water depth of 2.0 feet below the drop, and an EDF of 6.7 ft-lb/sec/cu ft. Assume fishway attraction is very good with a value of 1.0. Values of the parameters are H=0.2 (height of 2.5 interpolated between 1.4 and 2.7), D=1.0 (depth of 2.0 is greater than 0.5), T=0.7 (EDF of 6.7 interpolated between 5.2 and 10.3), and A=1.0. Passability of the pool would be 0.1 (P = 0.2 x 1.0 x 0.7 x 1.0 = 0.1). The value of H is low indicating that the height of the drop is the primary reason the passability is so low.

The values of the parameters were developed only based on fish body length; no difference was accounted for species of fish. In reality, species, as well as water quality, will affect each of the parameters in passability.

The values selected for fishway attraction (A) were 1.0 for the transition fishway at all flows; the fishway spans the channel so attraction is not an issue at any flow. Attraction at the Division Dam fishway is 1.0 at flows up through 100 cfs. At the lowest flows, all of the flow comes from the fishway. At flows of 200 and 400 cfs, fishway attraction values are 0.9 and 0.7; 11% and 7.5% of the flow comes from the fishway at those flows respectively.

The analysis at the Division Dam fishway is done for drop height, depth, and turbulence at each weir within the fishway, including the entrance and exit. The recorded value is the worst case (lowest value) of those parameters multiplied by the value for attraction at each flow. The values of passability don't mean to imply that that portion of the population can pass that fishway pool. Passability as used here is merely an index.

4.4 Fish Passage Results

The detailed and summary spreadsheet results of the passage analysis for each Reach Type, species and flow are provided in Appendix A7. Table 4.3 is a summary for each Reach Type and species. The values were calculated by multiplying the passability for each flow and the corresponding exceedence duration value in terms of time. For example, 20 cfs and less only occurs 9% of the time, but 100 cfs and less occurs 32% of the time. The passability is therefore weighted towards the 100 cfs value. A consistent pattern in the passage assessment is depth barriers at low flow and stamina (velocity and time) barriers for higher flows.

Within the concrete flume (Reach Types 2 to 9), passability varies little (24% to 37%). This is likely because the center trench (which is 9 feet wide with baffles spaced 60 feet on center) is common among most Reach Types. Even in the split wall or bridge pier areas the resultant channel geometry is similar.

Passage occurs over a wide range of flows and species for different Reach Types. There is not a single flow where all the Reach Types are passable.

	Steelhead	Spring Chinook	Bull Trout	Reach Type Average
Reach Type 1	59%	42%	89%	63%
Reach Type 2	44%	43%	0%	29%
Reach Type 3	60%	50%	0%	37%
Reach Type 4	60%	50%	0%	37%
Reach Type 5	33%	40%	0%	24%
Reach Type 6	59%	50%	0%	36%
Reach Type 7	33%	40%	0%	24%
Reach Type 8	39%	42%	4%	28%
Reach Type 9	47%	50%	0%	32%
Reach Type 10	68%	67%	0%	45%
Reach Type 11	69%	70%	39%	59%
Reach Type 12	37%	30%	31%	33%

Table 4.3 – Summary Table of Reach Type Passabilities by Species

The following is an explanation of the detailed fish passage spreadsheet in Appendix A7. The spreadsheet is separated into two blocks (6, 20, 60 cfs and 100, 200, 400 cfs). Each block is separated into three segments, which represent each flow. Within each segment are three species. For each species of fish there are three additional columns that provide information about passability (A), energy left or distance swam (B) and notes about what the failure mechanism was (C). If a fish did not pass through the Reach Type, it is recorded as "0" passage and the station at which the fish was exhausted is recorded. If a fish was able to pass through the Reach Type, the remaining energy of the fish was recorded.

In the notes column the letters represent the following:

S = stamina (energy) failure

R = the fish was able to rest within the Reach Type

The rows represent the Reach Types. Reach Type 12 has two rows for the two fishway exit slot widths. Also, Reach Types 11 and 12 are analyzed as fishways so the A, B and C columns represent different numbers as was described in Section 4.3. The notes column is described as:

H = height barrier

D = depth barrier

T = turbulence barrier (EDF)

V = velocity barrier

Fw = passage best at fishway

Dm = passage best at dam

For Example:

Reach Type 1, 20 cfs: Steelhead and Chinook were not able to pass due to depth. Bull Trout were able to pass with 70% of their energy left, but the depth diminished their stamina.

Reach Type 2, 100 cfs: All fish failed to pass due to stamina failure. Steelhead swam 34 feet, Chinook 20 feet and Bull Trout 22 feet.

Reach Type 3, 60 cfs: Steelhead were able to pass with 23% of their energy left and they rested to pass. Chinook were able to pass with only 7% of their energy left and they rested to pass. Bull Trout failed due to stamina and were able to swim 45 feet. Reach Type 3 lengths are given in Table 2.1.

Note: It is important to remember that "23% of the Steelhead", is the weighted average of the three size ranges analyzed. The actual remaining energy for the steelhead sizes of 22, 26 and 28 inches were 13%, 24% and 26% respectively.

Reach Type 11, 200 cfs: 30% of Steelhead and Chinook can pass but are limited by turbulence. Bull Trout cannot pass due to height and turbulence barrier.

Reach Type 12, 100 cfs: 60% of the Steelhead and Chinook can pass with turbulence affecting passage. 30% of the Bull Trout can pass with passage affected by velocity and turbulence. Note: Data from the Corps in 2009 showed at least 60 steelhead, 23 Chinook and 6 bull trout successfully passed the ladder when flows were between 60 to 400 cfs.

4.5 Comparison of these results to WDFW Fish Passage Criteria

In Washington State the standard for fish passage design guidance is provided in two documents Design of Road Culvert for Fish Passage (2003) and Fishway Guidelines for Washington State (2000). Table 4.5.1 is the design criteria for a hydraulic design. The length criteria was developed for culverts but can be used in general for passage through some specified channel length. In Mill Creek Reach Types 2 to 10, there are no resting areas so the design length is greater than 200 feet.

	Adult Trout >6 in. (150 mm)	Adult Pink, Chum Salmon	Adult Chinook, Coho, Sockeye, Steelhead
Culvert Length	Maximum velocity (fps)		
10 - 60 feet	4.0	5.0	6.0
60 - 100 feet	4.0	4.0	5.0
100 - 200 feet	3.0	3.0	4.0
Greater than 200 feet	2.0	2.0	3.0
	Minimum water depth (ft)		
	0.8	0.8	1.0
	Maximum hydraulic drop in fishway (ft)		
	0.8	0.8	1.0

Table 4.5.1 - WDFW Fish Passage Criteria From Design of Road Culverts, 2003.

To compare the WDFW Criteria to the calculated values for each Reach Type in Mill Creek, the Q/A velocities were calculated for each Reach Type (Table 4.5.2). The high and low fish passage design flows are 320 and 10 cfs, respectively. For example, in Reach Type 3 the Q/A velocity for the high fish passage design flow is 4.8 fps. Using the WDFW criteria, this would indicate a resting pool is needed at least every 100 feet.

Reach Type	Velocity (fps)		Depth (ft)		Drop (ft)		EDF
	320 cfs	*10 cfs*	*320 cfs*	*10 cfs*	*400 cfs*	*10 cfs*	*400 cfs*
1	9.0	5.4	0.6	.03	0.8	0.8	1.0
2							
3	4.8	6.7	2.9	.11			
4							
5	5.3	4.9	2.9	.11			
6	4.7	4.8	2.9	.11			
7	5.3	4.8	2.9	.11			
8	5.2	4.8	2.9	.07			
11					1.4	2.5	12.8
12					1.2	2.2	19.8

Table 4.5.2 – Estimates of Q/A Velocities, Depth, Drop and EDF by Reach Type For Comparison to the WDFW Criteria.

	6” Trout		28” Steelhead	
WDFW Culvert Length (ft) (Column 1)	Maximum Water Velocity (fps)	**Distance Fish Can Swim by Energetics Model (ft) (Column 3)**	Maximum Water Velocity (fps)	**Distance Fish Can Swim by Energetics Model (ft) (Column 5)**
10 – 60	4.0	**18**	6.0	**30**
60 – 100	4.0	**18**	5.0	**60**
100 - 200	3.0	**22**	4.0	**175**
>200	2.0	**30**	3.0	**545**
	1.5	**36**		
	1.4	**2130**		

Table 4.5.3 - Comparison of WDFW Culvert Length Criteria (Column 1) to Length Calculations for 6” Trout (Column 3) and 28” Steelhead (Column 5) Using Energetics Model.

Another way to compare the WDFW Criteria to the Energetics Model calculations is to calculate the actual distance a fish can swim and compare it to the culvert length intervals in the WDFW Criteria (Table 4.5.3). For example, the design criteria for adult steelhead indicate they can swim through a 60-foot long culvert with a water velocity of 5.0 fps. The distance a steelhead can swim calculated using the energetics model is 30 feet. The criteria assume that a fish is using a prolonged speed mode and the energetics model takes into account the most efficient use of swimming energetics regardless of water velocity or swimming mode. If you used only burst swimming the steelhead could swim 84 feet before failure in this example. In general, the energetics model (for adult steelhead) calculates a swimming distance less than the WDFW length criteria, except when velocities are 2.0 fps or less. For a 6 inch trout, the calculated length a fish can swim from the energetics model is also less than the WDFW length criteria. The most significant difference occurs when one analyzes a velocity of 1.4 fps or less. At this velocity (which is the sustained swimming speed for a 6-inch trout) the energetics calculates the 6-inch trout can swim 2130 feet.

The main difference between the two methods is that the energetics model calculates passage based on the velocities fish are swimming against. For a smooth channel with no boundary layer the two methods are easier to compare.

5.0 Conceptual Designs, Design Criteria and Cost Estimates

Based on results of the fish passage assessment, and discussions with the MCWG it was decided to pursue conceptual designs for Reach Types 1, 5, 7 and 8. In general passage problems were due to shallow depths at low flow and no resting pools at higher flows. The following design flows were discussed with the MCWG and agreed upon:

Species	Steelhead	Chinook	Bull Trout
Migration Timing	Jan - May	May - June	March – July
10 / 90% exceedence flows (cfs)	**320** / 36	148 / **10**	**194** / 36
50% exceedence flow (cfs)		**92 cfs**	
10 / 90 percentile fish sizes (inches)	22 / 30	24 / 29	7 / 17

The flows highlighted in bold and underlined above will be the design flows modeled with checks on the other flows to verify species specific criteria. Flows were calculated by averaging the 10 and 90% exceedence flows for the months of migration for the USGS gage 14015000 Mill Creek at Walla Walla for years 1941-2003. The 50% flow represents a mid range flow where a critical transition occurs from the trench to the overbank area of the flume.

Fish sizes were presented in the energetics model description. For the barrier analysis, the 10th and 75th percentile fish sizes were used because they best represent the population. For design the MCWG suggested the 10 and 90 percentile fish sizes be used because they better represent the extreme sizes. Passage for smaller fish will be limited by velocities, whereas passage for larger fish will be limited by resting areas and depth.

Due to stamina being the main fish passage problem, the best tool for design of fish passage would be the energetics model built for the assessment. This model will be used and have site specific data which will support the conclusions for passage. The importance of meeting state and federal fish passage criteria is also recognized. Those criteria are based on some of the same data used for the energetics model. The data that were available at the time the criteria were written were greatly simplified and conservative values were chosen as the criteria. There are no specific agency criteria for bull trout.

The agency criteria are based on average velocities (Q/A) and maximum depths within any channel cross-section. To achieve such velocities in the Mill Creek flume, the flume would have to be about twice as wide as it is. This makes it impractical to use the agency criteria directly.

Based on the stated desire of the MCWG, however, we will apply agency criteria for depth and velocity as a check at the high and low fish passage design flows. We propose to apply the fish passage criteria to the modeled portions of the flume for passage, i.e. channel flow and overbank flow. We feel this method is valid based on how the passage assessment was conducted, that is calibrating the flume hydraulics and identifying passage routes based on measurements, photos and observations. The Q/A in the overbank area will not apply at flows below about 60 cfs and less and when depth in the overbank is less than 0.8 feet (again consistent with the passage assessment). For flood analysis, the 100-year flood flow of 3500 cfs will be used. Designs will only be selected which show no increase in flood stage elevation. In addition, careful attention will be made to look at channel stability and operation issues such as, scour, cavitation and debris passage.

The conceptual design includes a location or aerial map where the work is to take place, a plan and profile and section of a typical Reach Type being considered, and cost estimate. The intent is to provide a cost estimate for passage correction for the total Reach Type length, but this will also be converted to a unit cost per 100 feet for other potential funding applications. It will not include utilities, site access, etc (but these will be accounted for in the cost estimate). The next step for the project would be to secure funding for preliminary and final design and/or construction. The final design would include construction details for utilities, concrete details, and construction access issues.

Conceptual designs will use the following design methodology to ensure fish passage and not increase the 100 year flood flow.

1. Select a Reach Type

2. Using the HEC RAS model from the fish passage assessment, calculate the hydraulics for the design flows (10, 92, 194, 320 and 3500 cfs). Export the data into a Reach Type Hydraulics Spreadsheet (RHS) and the flood flow elevations into a Flood Flow Comparison Spreadsheet (FFCS).

3. Select a design and modify the HEC RAS geometry. Run HEC RAS. Check and verify the correct output format.

4. Export the station and water surface elevation for the 3500 cfs run into the FFCS. Plot the data compared to the existing conditions and run a trendline analysis. If the design causes an increase in water surface elevation, go back to Step 3 and modify the design by either increasing the flow area or decreasing the roughness.

5. Open the Energetics Model Spreadsheet. Select a flow to analyze for fish passage and export the station, velocity and depth data from HEC RAS into the Energetics Model. Decide on a Reach Type length to be analyzed. Input the fish species and length:

Steelhead:	22 and 30 inches
Spring Chinook:	24 and 30 inches
Bull Trout:	7 and 17 inches

Input the V_{occ} factor.

a. For existing concrete surfaces the V_{occ} multiplier = 1.0 (n = 0.01 to 0.018)

b. For other surfaces V_{occ} multiplier = f(roughness)

Energetics model calculates percent energy remaining at the end of the Reach Type length or the distance the fish can swim before running out of energy. This distance will be used for the spacing of resting pools, with some percentage of energy left over.

6. Run 22 different combinations of fish species, length and flow and enter the data into the fish passage spreadsheet (FPS). This represents the final result for the design selected.

7. Check the transitions with other Reach Types.

5.1 Reach Type 1

The fish passage assessment identified low flow (depth) over the sills as the passage problem. At flows of 100 cfs and greater the sills are passable. The design criteria agreed to by the MCWG was a drop of 0.8 feet. For sills with drops of 0.8 feet or less, the proposed solution is to cut a slot in the existing sill, remove any fill as needed and form, pour and seal the sill. For drops greater than 0.8 feet, two options were developed, a pool and weir fishway and a roughened channel. Both would provide passage but in different ways. The pool and weir fishway would split a sill drop of up to 1.6 feet into two smaller drops of 0.8 feet or less. Fish would pass by jumping and/or swimming over each weir. For the roughened channel design, the drop would be dissipated over a length of 15 feet. Slope would vary from 4 to 6%. Concrete walls would be formed on the outside edges to create a bank area for the channel. Fish would pass by swimming up the roughened channel. Bed material in the roughened channel would be designed to provide roughness, increase depth and reduce velocity.

For all three options, the sills would still be passable at higher flows. Flood flows would not increase because the sill control elevation would stay the same.

Conceptual level cost estimates are (for detailed estimates see Appendix A5).

Slot Cut: $ 9,200 per sill *(only for sill drops 0.8 feet or less)*

Fishway: $ 28,000 per sill

Roughened Channel: $ 29,000 per sill

5.2 Reach Type 7

Proposed design options are to modify the baffles to improve passage at low flow and modify the overbank area with either resting pools and/or modifications to the cross section by cutting out concrete and adding roughness. Design options include:

Design A: Lower the existing baffles 0.2 feet and add new baffles at 20 ft spacings. Modify the sides of the overbank area to provide resting pools. Primary resting pools will be spaced 190 feet, secondary resting pools spaced every 20 feet for small Bull Trout (See Appendix A5).

Design B: Same as design A (for the baffles) with a 5 foot wide section cut out of the overbank area. The area will be poured back in place with 2 inch high roughness.

Design C: Same as design A (for the baffles) with a 10 foot wide section cut out of the overbank area. The area will be poured back in place with 6 inch high roughness.

Cost estimates for the following designs are:

Design A: $536 per foot

Design B: $352 per foot

Design C: $897 per foot

Design A can stand alone. Design B and C are intended as options to be worked in with Design A. The fish passage energetics model will need to be checked once designs are combined. Also, with maintenance issues, designs will likely need to be modified to accommodate trucks working in flume.

5.3 Reach Type 8

The proposed design for Reach Type 8 is a pool and weir fishway. The calculations for passage were made with a spreadsheet for flows up to 194 cfs. At 320 cfs, the flow is streaming and the passage analysis uses the Energetics Model to assure passage for adult steelhead.

Reach Type 8 is 222 feet long. The design proposes to cut out the floor of the flume and form and pour a pool and weir fishway. The drop over each weir will be 0.6 feet. The weirs will have a low flow notch. The existing width is 16 feet. The proposed concrete cut will start 12 inches out from the existing wall and extend down about 2.5 feet below the existing slab. Structural design and construction shoring will be key to the design. The concept follows similar past WDFW designs where slabs were cut out of concrete box culverts and lowered. After forming and pouring, ports in the walls are pumped with grout. Dimensions shown on the drawings are approximate. Only enough detail was included to verify the concept would work for fish passage and not increase flooding. This construction is all underground, which may create significant challenges to staging and mobilization.

The cost estimate for Reach Type 8 is $711,200 (or $3200 per foot).

5.4 Reach Type 5

Conceptual design options were not developed for Reach Type 5. Reach Type 5 is a transition between Reach Types 3 and 6 which were not included in the conceptual design analysis. Further modeling of Reach Types 3 and 6 is needed before a conceptual design can be completed for Reach Type 5 which transitions between Reach Types 3 and 6.

6.0 Maintenance of Flood Control Channel

The fact that the entire study area is primarily a flood control channel cannot be ignored. The project designers and MCWG have focused on improvements which will not increase flooding. Maintenance of the flood control channel is another design issue which needs to be considered. Some of the issues are summarized below:

- Once a year in September, small pickup trucks drive up and down the flume to cut brush and trees which overhang the walls and pull debris from the channel.
- Trucks enter the flume upstream of Reach Type 11 on the right bank, drive into the flume and place a small wooden bridge to cross the trench.
- Trucks cross the flume at the lower end (Reach Type 2) by driving over a flat apron area.
- There are vertical clearance issues for driving vehicles under bridges. From Roosevelt Street to the underground section the vertical clearance is the very tight. All bridges have clearance issues. The underground section does not have vertical clearance issues.
- The horizontal (width) clearance issues for vehicles occurs in the underground section, under some bridges (buttresses in both cases), and throughout Reach Type 7, because of the split flume.
- The vehicles used are a small pickup, a one-ton truck with a dump bed, and a skid steer. It is difficult to find newer vehicles that fit the clearances.

- Mill Creek maintenance is funded by a tax on the residents along the channel - basically a finite amount of funds each year.
- Passage improvements may increase staff time and costs of routine maintenance, or create new maintenance issues.
- The affect of passage corrections at sills is unknown. Movement and deposition of bedload between sills may have negative impacts to flood capacity.

At the time of this report, all proposed passage corrections are in the conceptual phase. The concerns identified here will be addressed as conceptual designs are advanced to final designs.

7.0 Summary, Conclusions, and Recommendations

The Mill Creek Fish Passage Assessment identified and analyzed 12 separate Reach Types for fish passage. A range of fork lengths of Steelhead, Spring Chinook and Bull Trout were analyzed at flows of 10, 20, 60, 100, 200 and 400 cfs for passage. Field calibrated HEC RAS and spreadsheet models were used to calculate the hydraulics. Data from the models were exported into a Fish Energetics Model to calculate passability, mode of passage and identify the type of barrier. The analysis included a separate spreadsheet model for calculating passability at fishways.

Reach Type 1 channel sills are barriers at flows less than 100 cfs. Reach Types 2 through 10 (concrete flume) showed some passage at flows in the 20 to 60 cfs range, but generally were barriers at low and high flows. Reach Type 11 had some passability in the middle range of flows as did Reach Type 12. Overall the average passability ranged from 24% to 63%, with a 37% average for the entire assessment length.

Design criteria for fish passage correction and flood analysis was developed. Conceptual designs and cost estimates were developed for Reach Types 1, 7 and 8. Reach Type 1 designs consisted of creating low flow notches in the concrete sills. Reach Type 7 designs consisted mainly of modifying the existing baffles and, making channel modifications to the transition between the trench and overbank area. The Reach Type 8 design creates a pool and weir fishway in place of the baffles.

Flooding, flume maintenance concerns and construction issues were considered as part of the conceptual designs. There are likely design issues which need to be addressed. The conceptual designs were based mainly on hydraulics (fish and floods). The next step is to take these to the preliminary design level with actual site survey information (utilities, drainage, and structural design and construction access considerations).

The initial estimated conceptual level cost for correction of the entire project reach is $11,788,000. Before a large portion of the construction work is funded it is recommended that a small physical hydraulic model study be completed (for a short segment of the Reach Type 3 and 6 flume sections). The objective would be to assess the proposed design changes and flow interactions with the baffles and resting pools. The estimated cost for this study varies from $40,000 to $125,000. The suggested model scale is 1:10 and/or 1:20. It is not the intent to analyze the 3500 cfs 100 year flood flow, but only flows less than 320 cfs.

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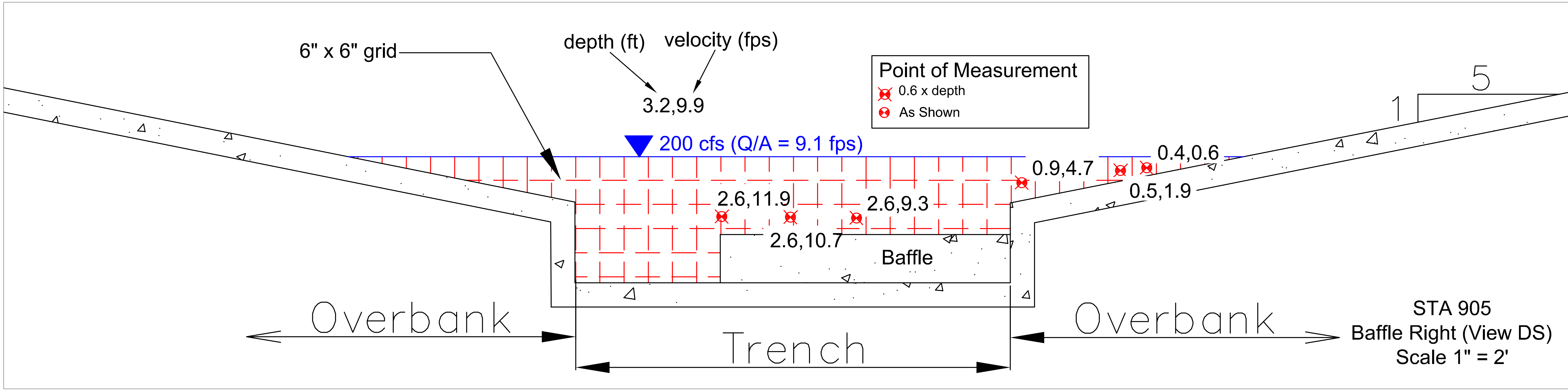
Note: The following are personal communications (email and phone) regarding fish timing and fish sizes included:

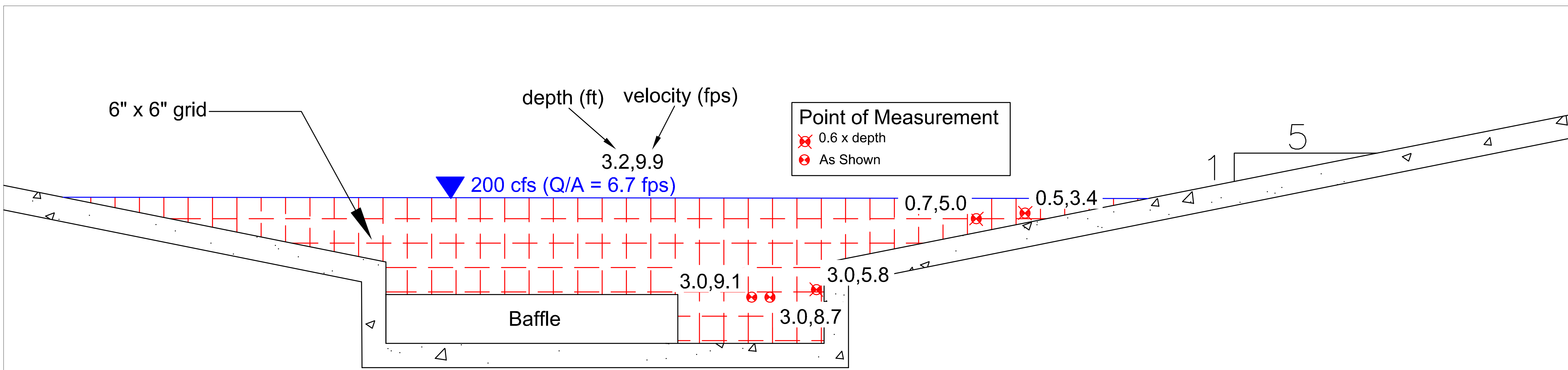
Darron Gallion, Fish Biologist, USFWS 5/20/08
Ben Tice, Fish Biologist, Corps 5/21/08
Glen Mendel, Fish Biologist, WDFW, 05/22/2008
Jed Volkman, Fish Biologist, email 5/22/08

APPENDICES

Appendix A1 – Field Measurements



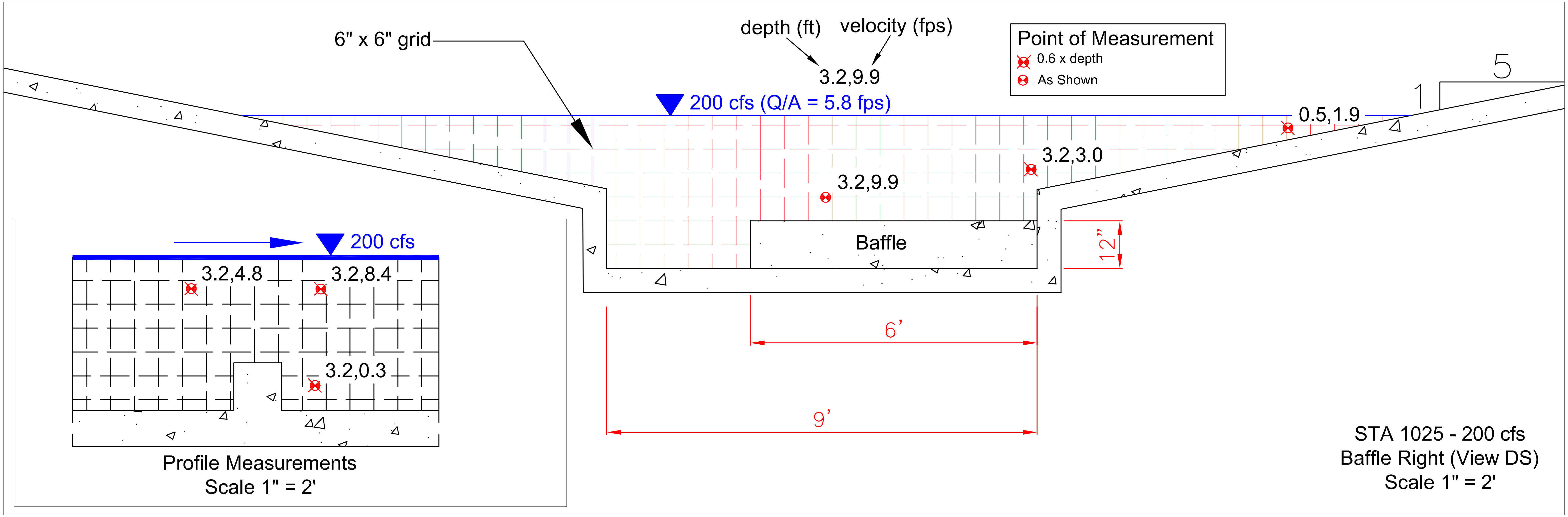
STA 905
Baffle Right (View DS)
Scale 1" = 2'



STA 1085 - 200 cfs
Baffle Left (View DS)
Scale 1" = 2'

Mill Creek Fish Passage Assessment

Figure A1 - Reach Type 3 - Velocity and Depth Field Measurments
STA 925 and 1085
Baffle - 200 cfs



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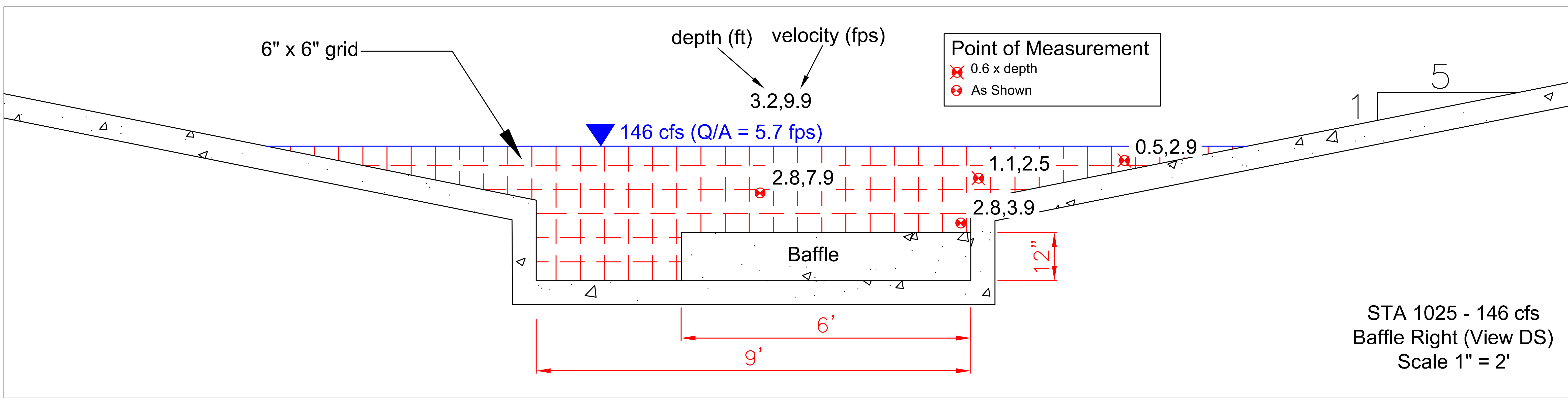
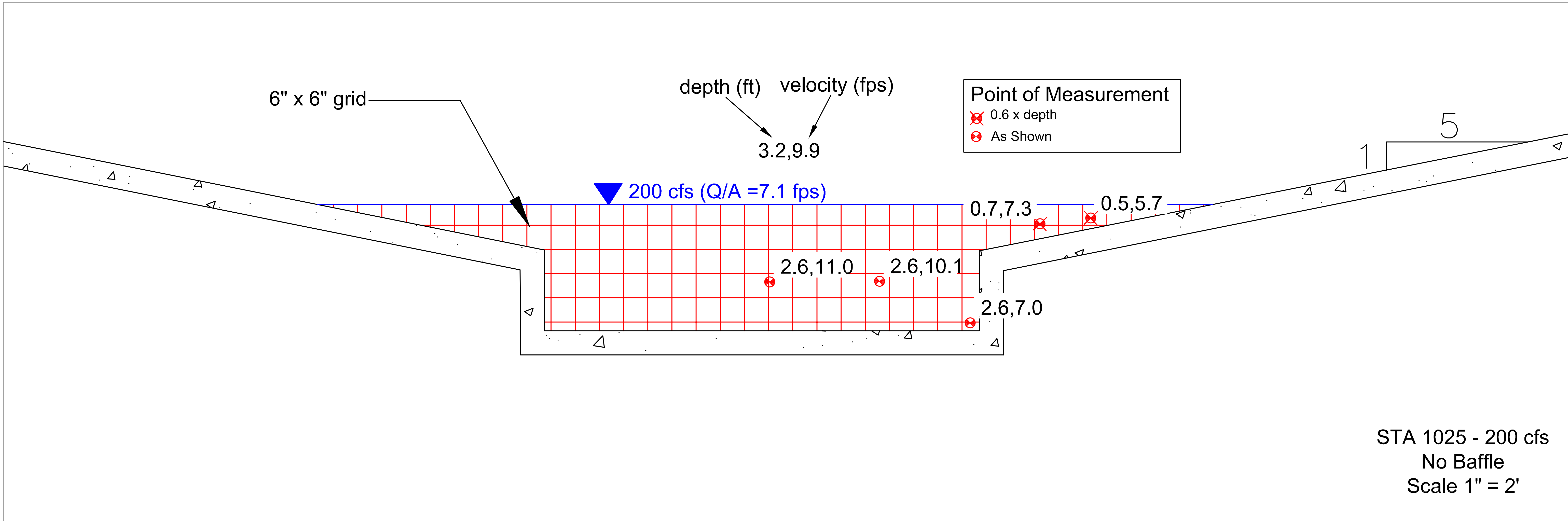
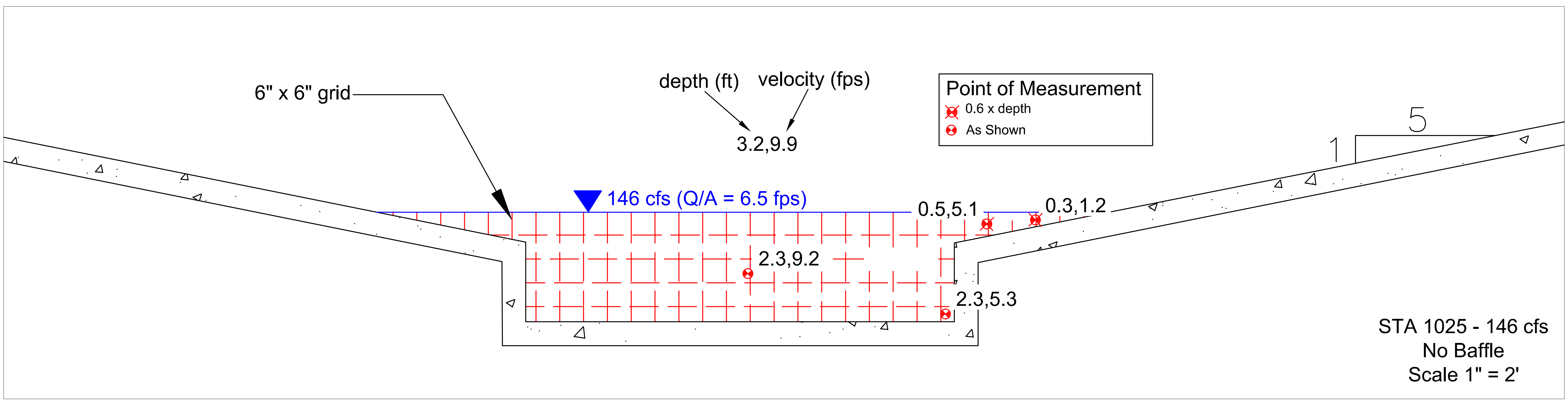


STA 1025 - 146 cfs
Baffle Right (View DS)
Scale 1" = 2'

Mill Creek Fish Passage Assessment

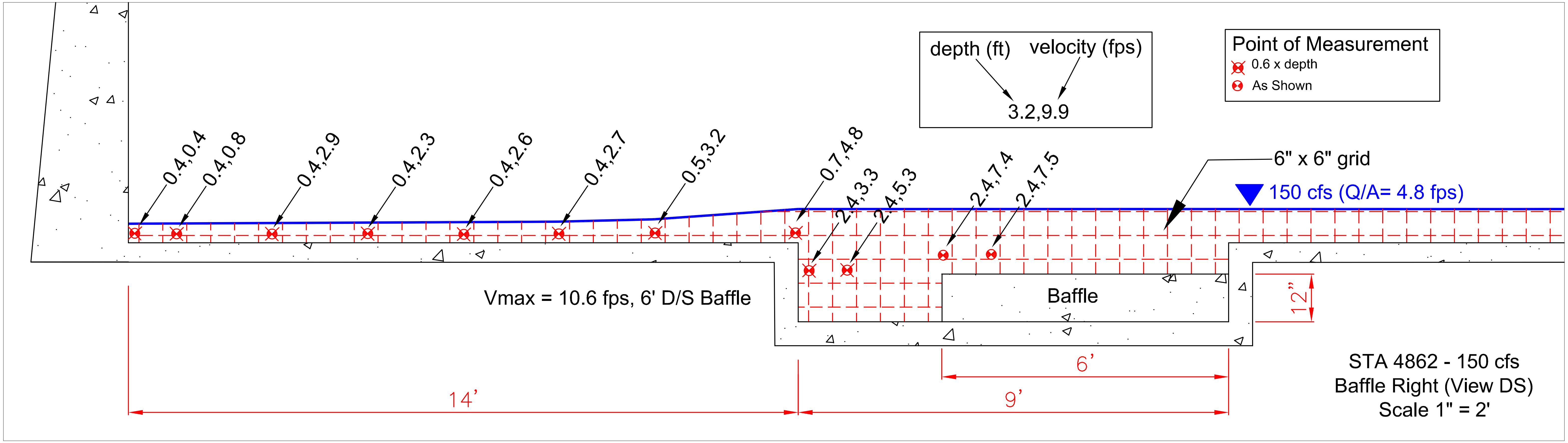
Figure A2 - Reach Type 3 - Velocity and Depth Field Measurments
STA 1025 Baffle
200 and 146 cfs

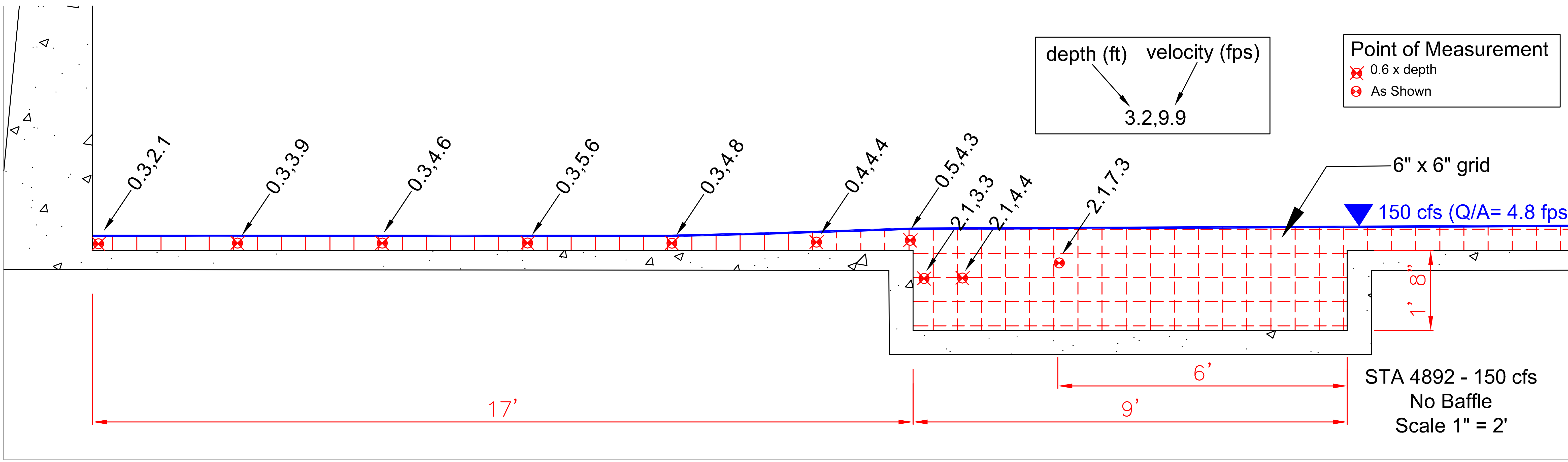




Mill Creek Fish Passage Assessment

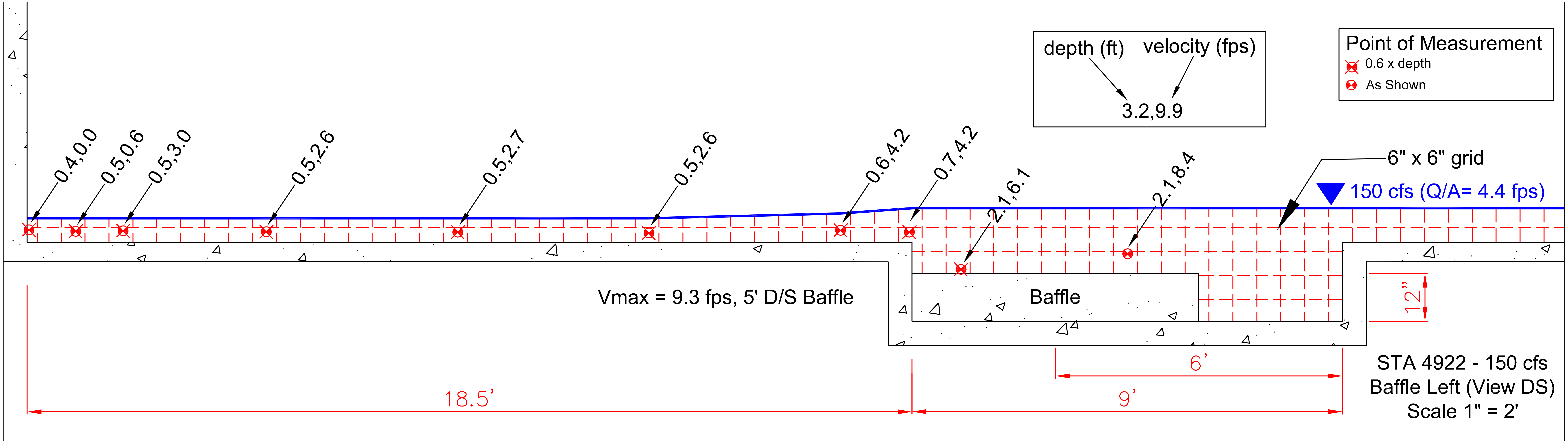
Figure A3 - Reach Type 3 - Velocity and Depth Field Measurments
STA 1025 No Baffle
200 and 146 cfs

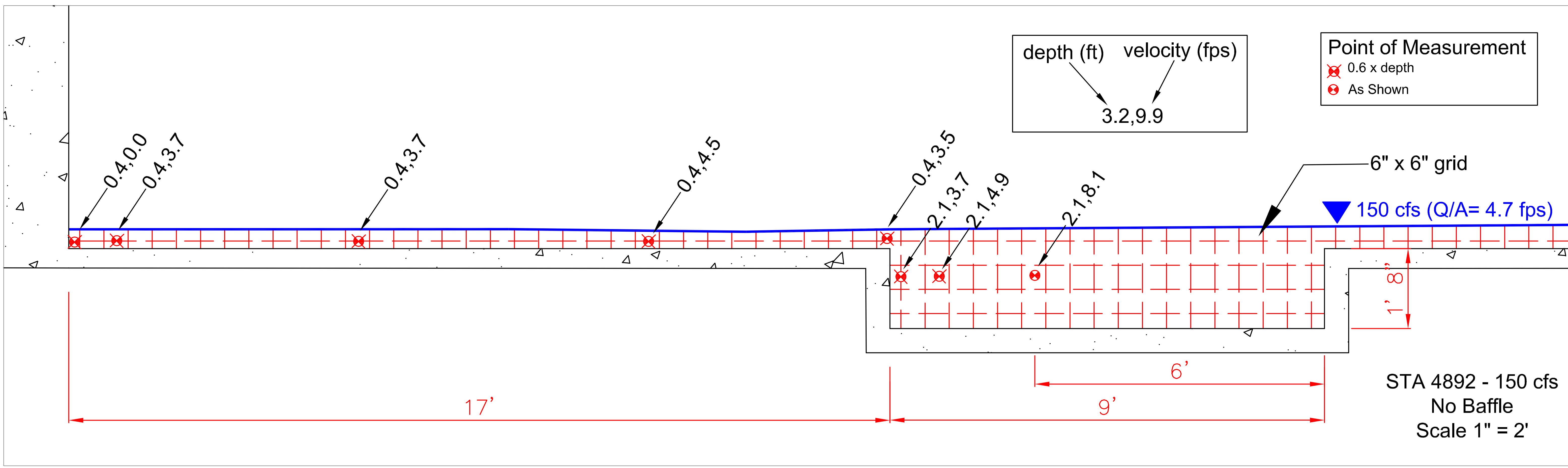




Mill Creek Fish Passage Assessment

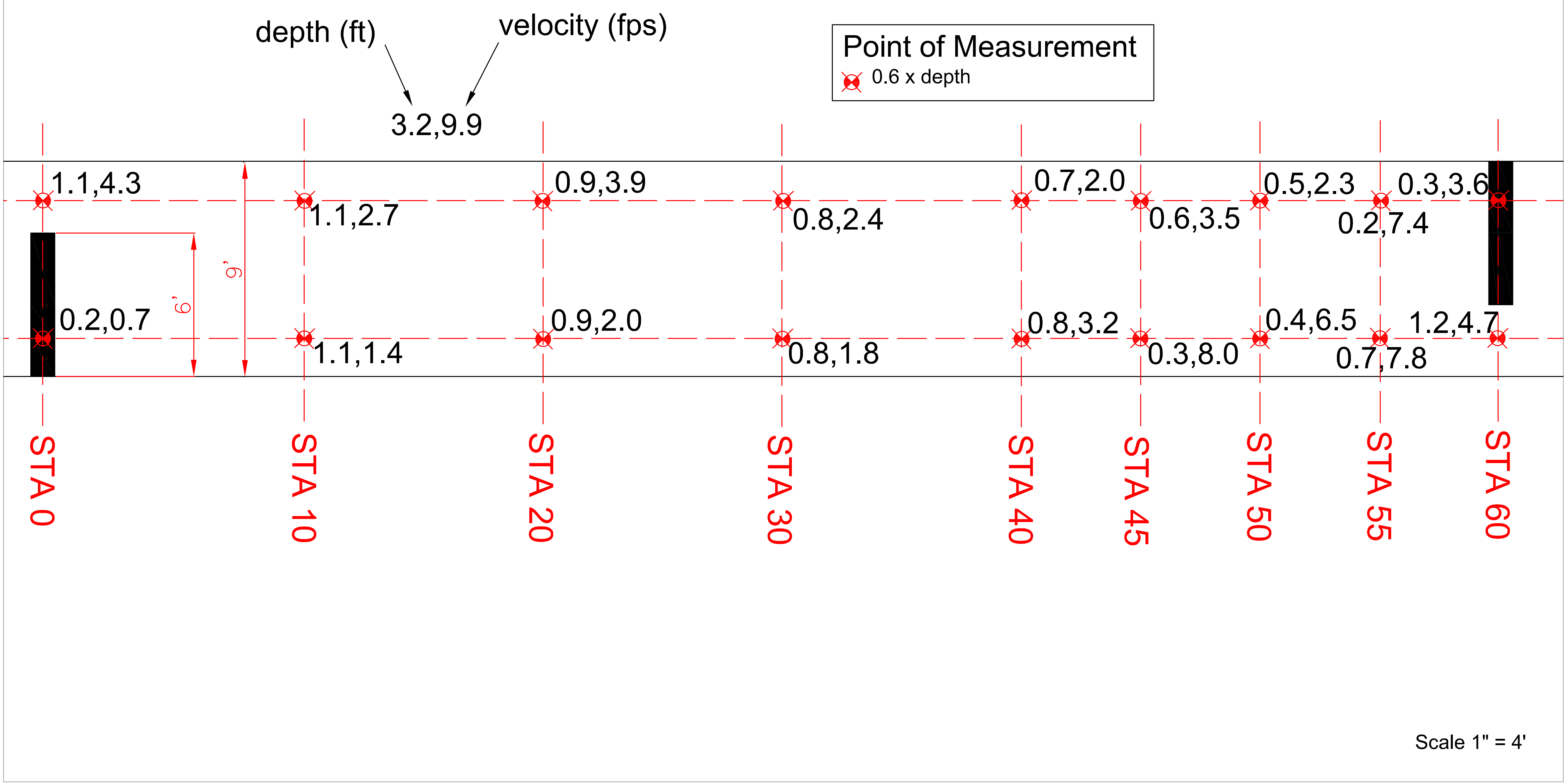
Figure A4 - Reach Type 6 - Velocity and Depth Field Measurments
STA 4862 Baffle and STA 4892 No Baffle
150 cfs





Mill Creek Fish Passage Assessment

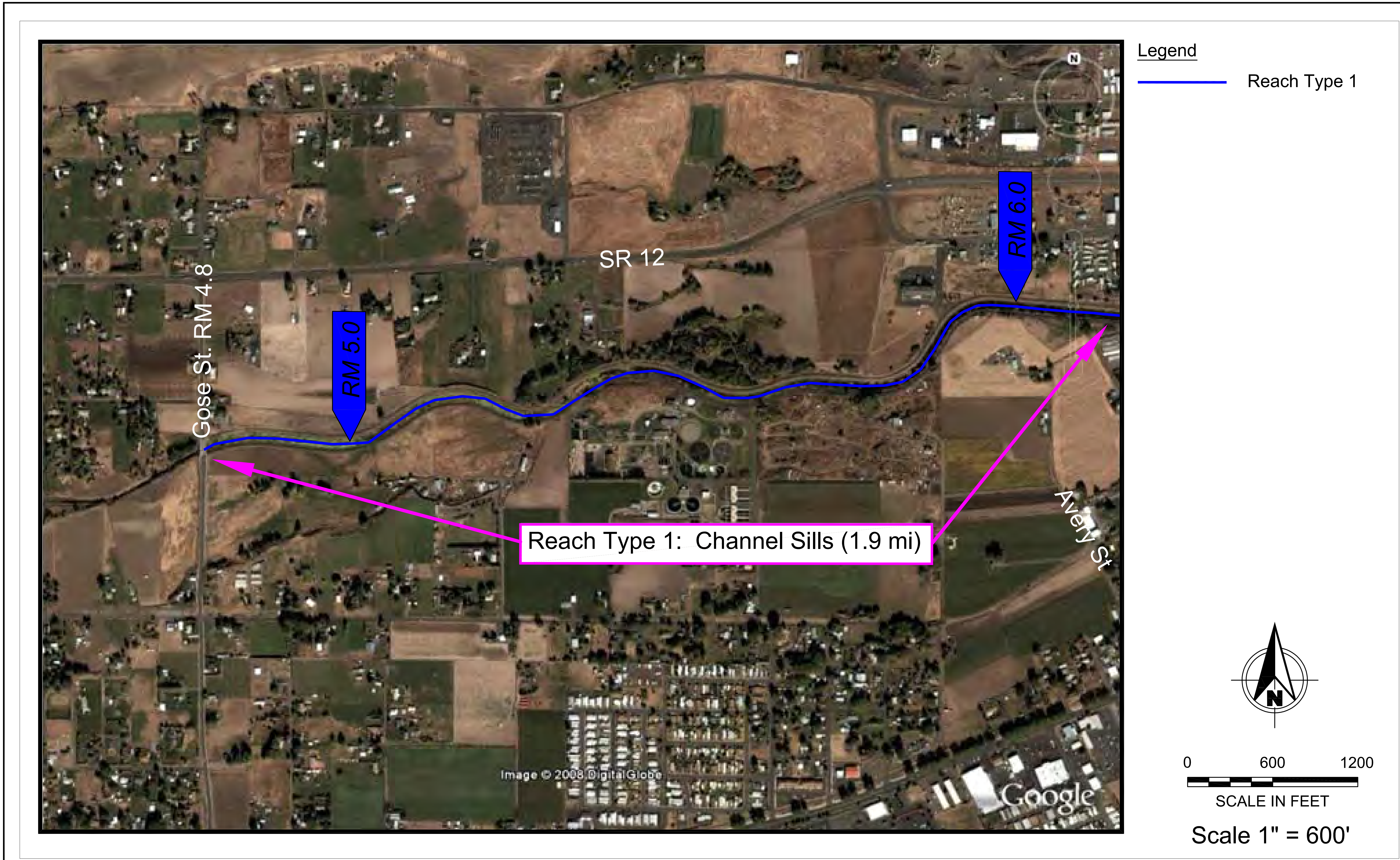
Figure A5 - Reach Type 6 - Velocity and Depth Field Measurments
STA 4922 Baffle and STA 4952 No Baffle
150 cfs



Mill Creek Fish Passage Assessment

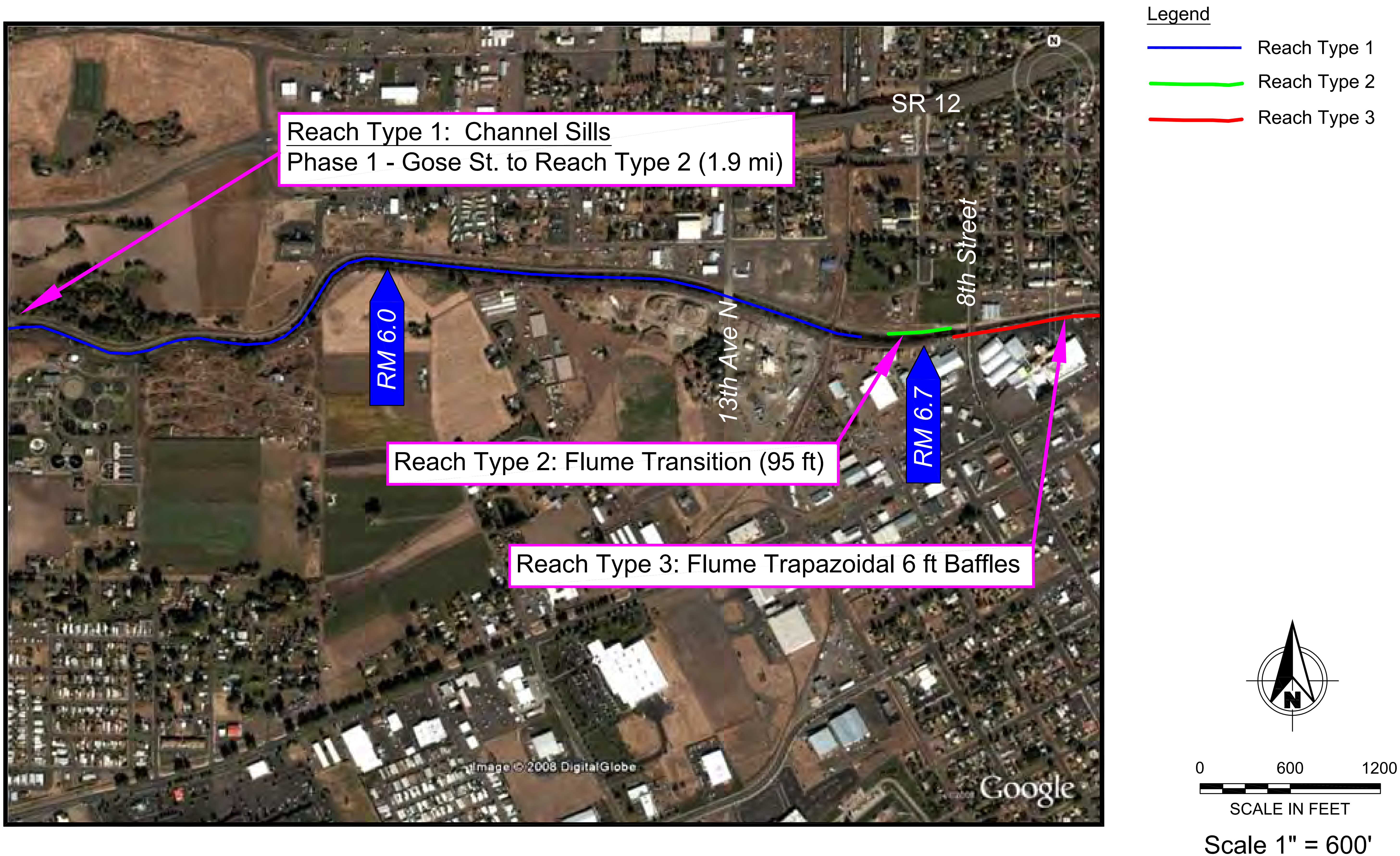
Figure A6 - Reach Type 3 - Velocity and Depth Field Measurments
STA 11506 to 11564
20 cfs

Appendix A2 – Aerial Photos Showing Reach Type Layout



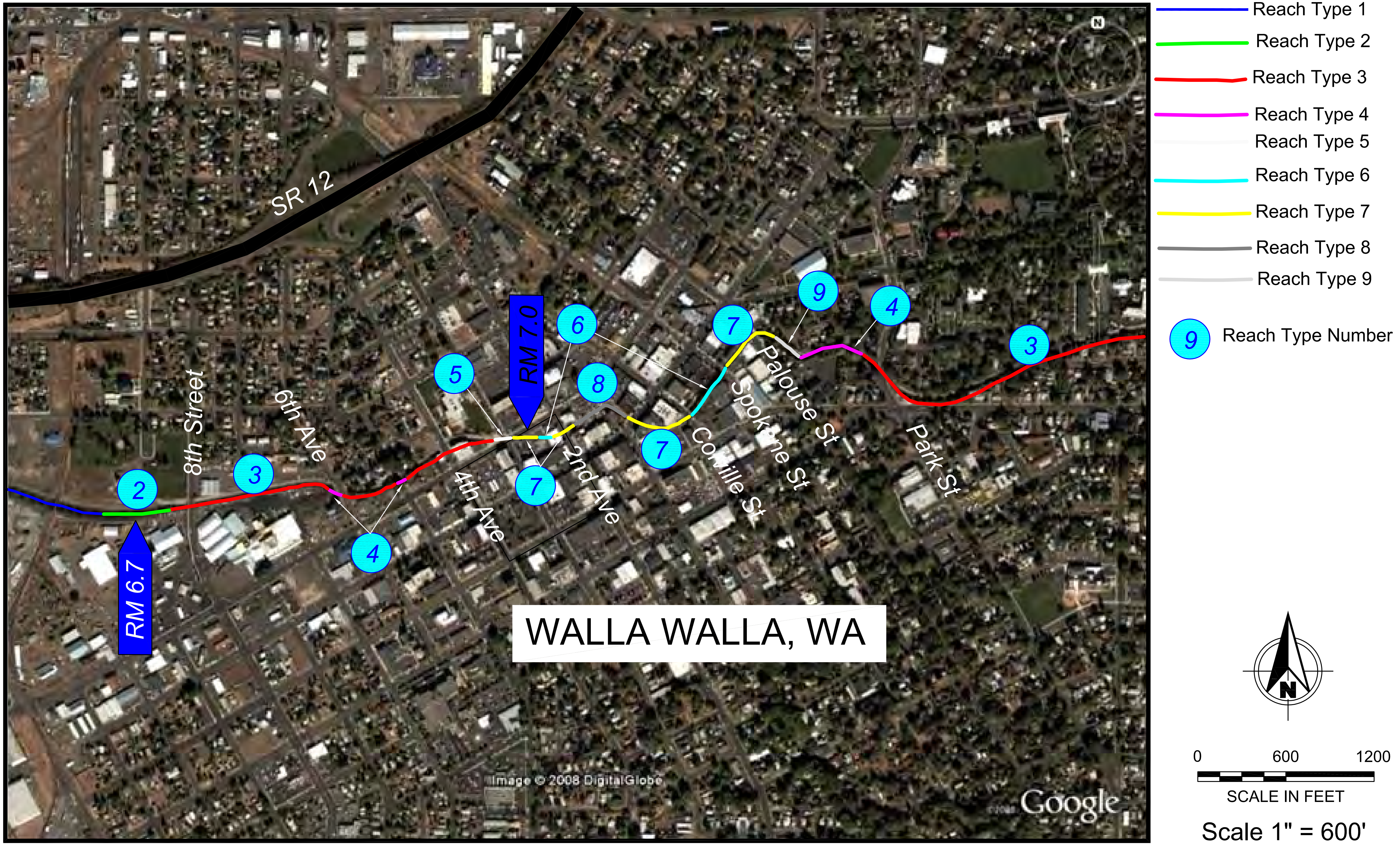
Aerial Photo Showing Reach Type Layout - Mill Creek RM 4.8 to 6.2

Sheet 1 of 6



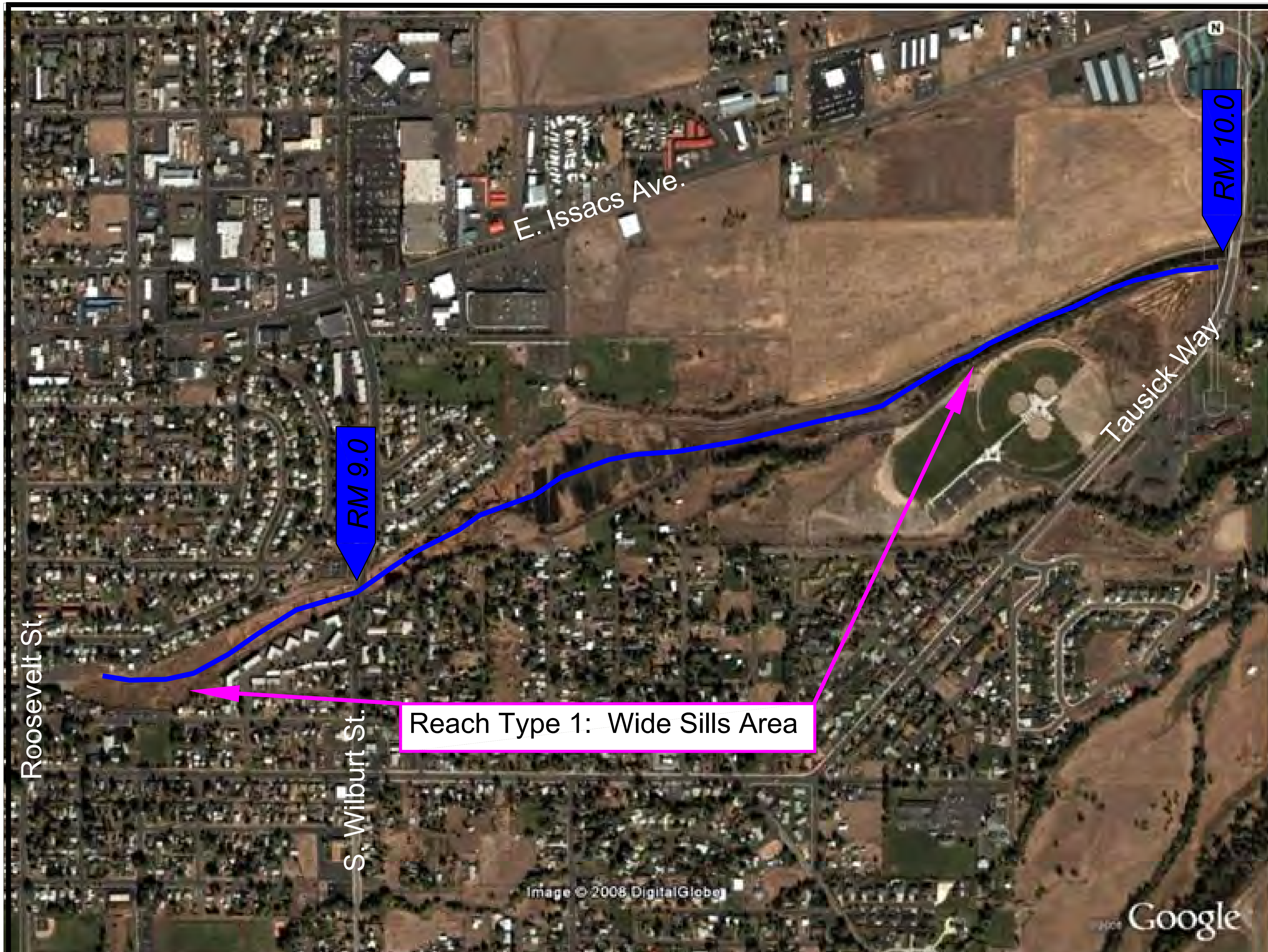
Aerial Photo Showing Reach Type Layout - Mill Creek RM 5.5 to 7.0

Sheet 2 of 6



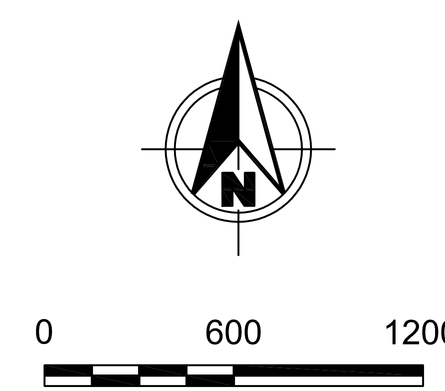
Aerial Photo Showing Reach Type Layout - Mill Creek RM 6.6 to 7.9

Aerial Photo Showing Reach Type Layout - Mill Creek RM 8



Legend

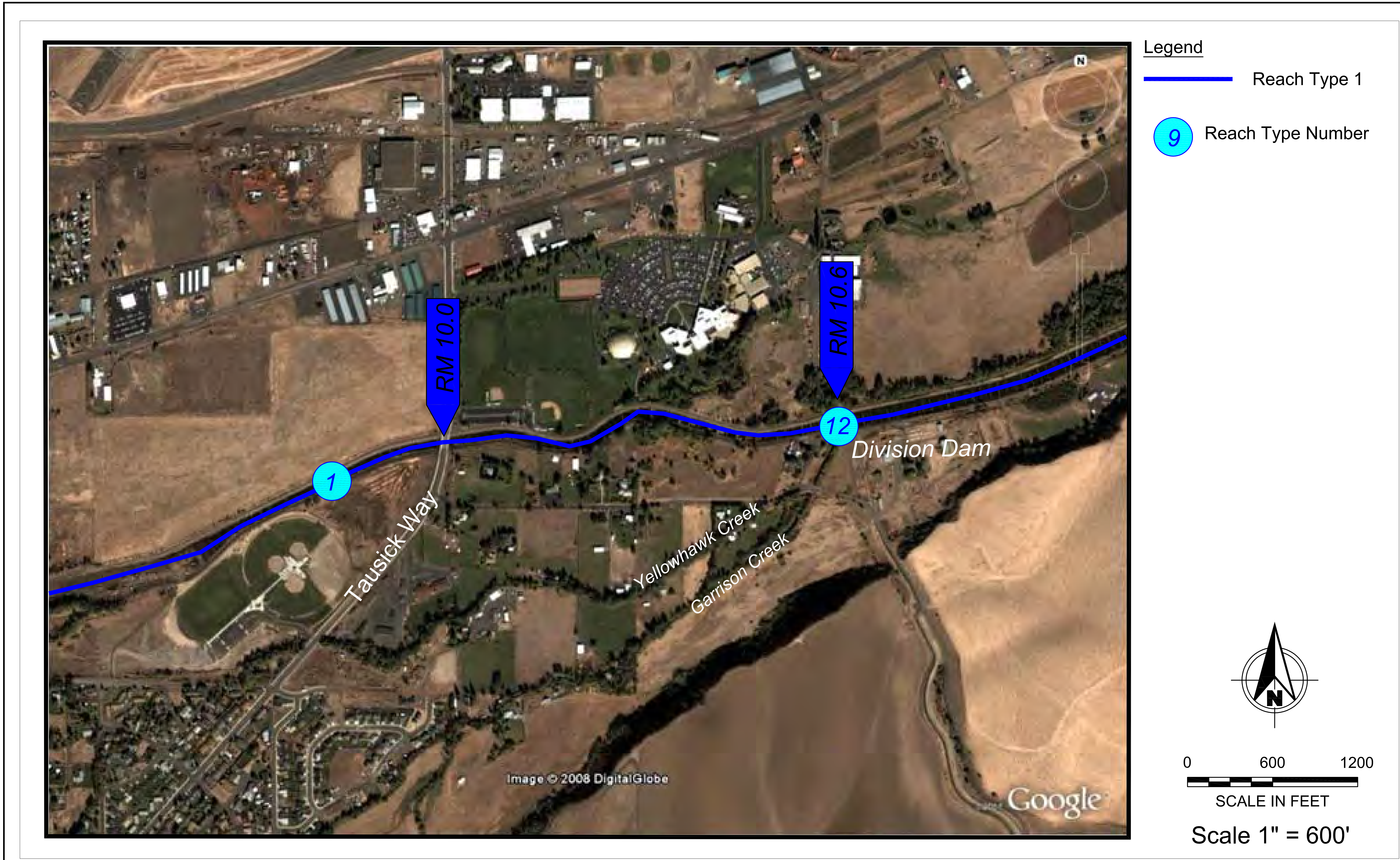
Reach Type 1



Scale 1" = 600'

Aerial Photo Showing Reach Type Layout - Mill Creek RM 9 Roosevelt St. to Tausick Way

Sheet 5 of 6



Aerial Photo Showing Reach Type Layout - Mill Creek RM 10 Tausick Way to Division Dam

Appendix A3 – Mill Creek Channel Sill Details

Mill Creek Channel Sills - Phase 1 Gose Street to Reach Type 2 Flume Transition

							Sheet 1 of 3
Number	**Station**	**Type**	**Spacing (ft)**	**Length (ft)**	**Elevation**	**Drop (ft)**	**Slope (ft/ft)**
1	600	New Concrete		70	797.2		
2	631	New Concrete	31	70	798.4	1.2	0.039
3	671	New Concrete	40	70	800.0	1.6	0.040
4	710	New Concrete	39	70	801.5	1.5	0.038
5	800	Sheet Pile	90	70	802.5	1	0.011
6	870	Sheet Pile	70	70	803.2	0.7	0.010
7	940	Sheet Pile	70	70	803.9	0.7	0.010
8	1010	Sheet Pile	70	70	804.6	0.7	0.010
9	1080	Sheet Pile	70	70	805.3	0.7	0.010
10	1150	Sheet Pile	70	70	806.0	0.7	0.010
11	1220	Sheet Pile	70	70	806.7	0.7	0.010
12	1290	Sheet Pile	70	70	807.4	0.7	0.010
13	1360	Sheet Pile	70	70	808.1	0.7	0.010
14	1430	Sheet Pile	70	70	808.8	0.7	0.010
15	1500	Sheet Pile	70	70	809.5	0.7	0.010
16	1570	Sheet Pile	70	70	810.2	0.7	0.010
17	1640	Sheet Pile	70	70	810.9	0.7	0.010
18	1710	Sheet Pile	70	70	811.6	0.7	0.010
19	1780	Sheet Pile	70	70	812.3	0.7	0.010
20	1850	Sheet Pile	70	70	813.0	0.7	0.010
21	1920	Sheet Pile	70	70	813.7	0.7	0.010
22	1990	Sheet Pile	70	70	814.4	0.7	0.010
23	2060	Sheet Pile	70	70	815.1	0.7	0.010
24	2130	Sheet Pile	70	70	815.8	0.7	0.010
25	2200	Sheet Pile	70	70	816.5	0.7	0.010
26	2270	Sheet Pile	70	70	817.2	0.7	0.010
27	2340	Sheet Pile	70	70	817.9	0.7	0.010
28	2410	Sheet Pile	70	70	818.6	0.7	0.010
29	2480	Sheet Pile	70	70	819.3	0.7	0.010
30	2550	Sheet Pile	70	70	820.0	0.7	0.010
31	2620	Sheet Pile	70	70	820.7	0.7	0.010
32	2690	Sheet Pile	70	70	821.4	0.7	0.010
33	2760	Sheet Pile	70	70	822.1	0.7	0.010
34	2830	Sheet Pile	70	70	822.8	0.7	0.010
35	2900	Sheet Pile	70	70	823.5	0.7	0.010
36	2970	Sheet Pile	70	70	824.2	0.7	0.010
37	3040	Sheet Pile	70	70	824.9	0.7	0.010
38	3110	Sheet Pile	70	70	825.7	0.8	0.011
39	3180	Sheet Pile	70	70	826.5	0.8	0.011
40	3250	Sheet Pile	70	70	827.3	0.8	0.011
41	3320	Sheet Pile	70	70	828.0	0.7	0.010
42	3390	Sheet Pile	70	70	828.8	0.8	0.011
43	3460	Sheet Pile	70	70	829.6	0.8	0.011
44	3530	Sheet Pile	70	70	830.3	0.7	0.010
45	3600	Sheet Pile	70	70	831.1	0.8	0.011
46	3670	Sheet Pile	70	70	831.9	0.8	0.011
47	3740	Sheet Pile	70	70	832.6	0.7	0.010
48	3810	Sheet Pile	70	70	833.4	0.8	0.011
49	3880	Sheet Pile	70	70	834.2	0.8	0.011
50	3949	Sheet Pile	69	70	834.9	0.7	0.010
51	4007	Sheet Pile	58	70	835.6	0.7	0.012
52	4088	Sheet Pile	81	70	836.5	0.9	0.011
53	4158	Sheet Pile	70	70	837.2	0.7	0.010
54	4229	Sheet Pile	71	70	838.0	0.8	0.011
55	4300	Sheet Pile	71	70	838.8	0.8	0.011
56	4370	Sheet Pile	70	70	839.6	0.8	0.011
57	4440	Sheet Pile	70	70	840.3	0.7	0.010
58	4510	Sheet Pile	70	70	841.1	0.8	0.011
59	4580	Sheet Pile	70	70	841.9	0.8	0.011
60	4650	Sheet Pile	70	70	842.7	0.8	0.011

							Sheet 2 of 3
Number	Station	Type	Spacing (ft)	Length (ft)	Elevation	Drop (ft)	Slope (ft/ft)
61	4720	Sheet Pile	70	70	843.4	0.7	0.010
62	4790	Sheet Pile	70	70	844.2	0.8	0.011
63	4860	Sheet Pile	70	70	845.0	0.8	0.011
64	4930	Sheet Pile	70	70	845.7	0.7	0.010
65	5000	Sheet Pile	70	70	846.5	0.8	0.011
66	5070	Sheet Pile	70	70	847.3	0.8	0.011
67	5140	Sheet Pile	70	70	848.0	0.7	0.010
68	5212	Sheet Pile	72	70	848.8	0.8	0.011
69	5281	Sheet Pile	69	70	849.6	0.8	0.012
70	5350	Sheet Pile	69	70	850.3	0.7	0.010
71	5421	Sheet Pile	71	70	851.1	0.8	0.011
72	5489	Sheet Pile	68	70	851.8	0.7	0.010
73	5558	Sheet Pile	69	70	852.5	0.7	0.010
74	5629	Sheet Pile	71	70	853.3	0.8	0.011
75	5700	Sheet Pile	71	70	854.0	0.7	0.010
76	5770	Sheet Pile	70	70	854.8	0.8	0.011
77	5839	Sheet Pile	69	70	855.5	0.7	0.010
78	5910	Sheet Pile	71	70	856.3	0.8	0.011
79	5980	Sheet Pile	70	70	856.8	0.5	0.007
80	6050	Sheet Pile	70	70	857.7	0.9	0.013
81	6121	Sheet Pile	71	70	858.4	0.7	0.010
82	6190	Sheet Pile	69	70	859.0	0.6	0.009
83	6260	Sheet Pile	70	70	859.7	0.7	0.010
84	6331	Sheet Pile	71	70	860.6	0.9	0.013
85	6400	Sheet Pile	69	70	861.4	0.8	0.012
86	6470	Sheet Pile	70	70	862.1	0.7	0.010
87	6540	Sheet Pile	70	70	862.7	0.6	0.009
88	6610	Sheet Pile	70	70	863.5	0.8	0.011
89	6680	Sheet Pile	70	70	864.3	0.8	0.011
90	6750	Sheet Pile	70	70	865.1	0.8	0.011
91	6820	Concrete Capped	70	70	865.8	0.7	0.010
92	6890	Concrete Capped	70	70	866.7	0.9	0.013
93	6960	Concrete Capped	70	70	867.2	0.5	0.007
94	7030	Concrete Capped	70	70	868.7	1.5	0.021
95	7101	Concrete Capped	71	70	869.7	1	0.014
96	7170	Concrete Capped	69	70	870.3	0.6	0.009
97	7240	Concrete Capped	70	70	870.9	0.6	0.009
98	7309	Concrete Capped	69	70	871.7	0.8	0.012
99	7380	Concrete Capped	71	70	872.4	0.7	0.010
100	7450	Concrete Capped	70	70	873.4	1	0.014
101	7520	Concrete Capped	70	70	874.0	0.6	0.009
102	7590	Concrete Capped	70	70	874.8	0.8	0.011
103	7660	Concrete Capped	70	70	875.3	0.5	0.007
104	7730	Concrete Capped	70	70	876.3	1	0.014
105	7798	Concrete Capped	68	70	876.8	0.5	0.007
106	7870	Concrete Capped	72	70	877.7	0.9	0.013
107	7940	Concrete Capped	70	70	878.4	0.7	0.010
108	8010	Concrete Capped	70	70	879.0	0.6	0.009
109	8080	Concrete Capped	70	70	879.8	0.8	0.011
110	8150	Concrete Capped	70	70	880.5	0.7	0.010
111	8220	Concrete Capped	70	70	881.2	0.7	0.010
112	8290	Concrete Capped	70	70	881.7	0.5	0.007
113	8360	Concrete Capped	70	70	882.5	0.8	0.011
114	8430	Concrete Capped	70	70	883.4	0.9	0.013
115	8500	Concrete Capped	70	70	883.5	0.1	0.001
116	8570	Concrete Capped	70	70	884.6	1.1	0.016
117	8636	Concrete Capped	66	70	885.0	0.4	0.006
118	8710	Concrete Capped	74	70	886.0	1	0.014
119	8781	Concrete Capped	71	70	886.6	0.6	0.008
120	8850	Concrete Capped	69	70	887.6	1	0.014
121	8920	Concrete Capped	70	70	888.3	0.7	0.010

							Sheet 3 of 3
Number	**Station**	**Type**	**Spacing (ft)**	**Length (ft)**	**Elevation**	**Drop (ft)**	**Slope (ft/ft)**
122	8990	Concrete Capped	70	70	889.2	0.9	0.013
123	9060	Concrete Capped	70	70	890.0	0.8	0.011
124	9130	Concrete Capped	70	70	891.0	1	0.014
125	9190	Concrete Capped	60	70	892.0	1	0.017
126	9268	Concrete Capped	78	70			
127	9336	Concrete Capped	68	70	893.4	1.4	0.021
128	9405	Concrete Capped	69	70	894.1	0.7	0.010
129	9474	Concrete Capped	69	70	894.9	0.8	0.012
130	9542	Concrete Capped	68	70	895.7	0.8	0.012
131	9611	Concrete Capped	69	70	896.6	0.9	0.013
132	9680	Concrete Capped	69	70	897.6	1.0	0.014
133	9757	Concrete Capped	77	70	898.4	0.8	0.010
134	9834	Concrete Capped	77	70	899.3	0.9	0.012
135	9914	Concrete Capped	80	70	900.2	0.9	0.011
136	9977	Concrete Capped	63	70	901.2	1.0	0.016
137	10048	Concrete Capped	71	70	902.0	0.8	0.011
138	10116	Concrete Capped	68	70	903.0	1.0	0.015
139	10184	Concrete Capped	68	70	903.9	0.9	0.013
140	10252	Sheet Pile	68	70	904.2	0.3	0.004
141	10319	Sheet Pile	67	70	905.0	0.8	0.012
142	10387	Sheet Pile	68	70	905.8	0.8	0.012
143	10456	Sheet Pile	69	70	906.6	0.8	0.012
144	10524	Sheet Pile	68	70	907.4	0.8	0.012
145	10591	Sheet Pile	67	70	908.2	0.8	0.012
Total Sheet Pile		91			Min	0.1	0.001
Total Concrete Capped		54			Ave	0.8	0.011
					Max	1.5	0.021

Mill Creek Channel Sills - Phase 2 Tausick Way to Division Dam

									Sheet 1 of 1
Number	**Station**	**Type**	**Spacing (ft)**	**Length (ft)**	**Elevation Top of Sills**			**Avg. Drop (ft)**	**Slope**
					Left	**Right**	**Average**		
1	29240	Concrete Capped		70	1133.4	1133.3	1133.35		
2	29320	Concrete Capped	80	70	1134.1	1134.0	1134.05	0.70	0.88%
3	29400	Concrete Capped	80	70	1135.0	1135.0	1135.00	0.95	1.19%
4	29470	Concrete Capped	70	70	1136.0	1135.9	1135.95	0.95	1.36%
5	29540	Concrete Capped	70	70	1137.0	1137.0	1137.00	1.05	1.50%
6	29610	Concrete Capped	70	70	1137.8	1137.8	1137.80	0.80	1.14%
7	29680	Concrete Capped	70	70	1138.8	1138.7	1138.75	0.95	1.36%
8	29750	Concrete Capped	70	70	1139.9	1139.9	1139.90	1.15	1.64%
9	29820	Concrete Capped	70	70	1140.4	1140.5	1140.45	0.55	0.79%
10	29890	Concrete Capped	70	70	1141.6	1141.8	1141.70	1.25	1.79%
11	29960	Concrete Capped	70	70	1142.6	1142.6	1142.60	0.90	1.29%
12	30030	Concrete Capped	70	70	1143.4	1143.3	1143.35	0.75	1.07%
13	30100	Concrete Capped	70	70	1144.4	1144.6	1144.50	1.15	1.64%
14	30170	Concrete Capped	70	70	1145.4	1145.4	1145.40	0.90	1.29%
15	30240	Concrete Capped	70	70	1146.0	1146.1	1146.05	0.65	0.93%
16	30310	Concrete Capped	70	70	1147.4	1147.2	1147.30	1.25	1.79%
17	30380	Concrete Capped	70	70	1148.0	1148.0	1148.00	0.70	1.00%
18	30450	Concrete Capped	70	70	1148.7	1148.7	1148.70	0.70	1.00%
19	30520	Concrete Capped	70	70	1149.9	1149.9	1149.90	1.20	1.71%
20	30590	Concrete Capped	70	70	1150.8	1150.7	1150.75	0.85	1.21%
21	30660	Concrete Capped	70	70	1151.6	1151.4	1151.50	0.75	1.07%
22	30730	Concrete Capped	70	70	1152.7	1152.7	1152.70	1.20	1.71%
23	30800	Concrete Capped	70	70	1153.5	1153.5	1153.50	0.80	1.14%
24	30870	Concrete Capped	70	70	1154.2	1154.1	1154.15	0.65	0.93%
25	30940	Concrete Capped	70	70	1155.3	1155.3	1155.30	1.15	1.64%
26	31010	Concrete Capped	70	70	1156.2	1156.2	1156.20	0.90	1.29%
27	31080	Concrete Capped	70	70	1156.8	1156.8	1156.80	0.60	0.86%
28	31150	Concrete Capped	70	70	1158.2	1158.1	1158.15	1.35	1.93%
29	31220	Concrete Capped	70	70	1158.9	1159.0	1158.95	0.80	1.14%
30	31290	Concrete Capped	70	70	1159.6	1159.5	1159.55	0.60	0.86%
31	31360	Concrete Capped	70	70	1160.9	1160.8	1160.85	1.30	1.86%
32	31430	Concrete Capped	70	70	1161.7	1161.8	1161.75	0.90	1.29%
33	31500	Concrete Capped	70	70	1162.2	1162.3	1162.25	0.50	0.71%
34	31570	Concrete Capped	70	70	1163.6	1163.5	1163.55	1.30	1.86%
35	31640	Concrete Capped	70	70	1164.6	1164.5	1164.55	1.00	1.43%
36	31710	Concrete Capped	70	70	1164.9	1165.1	1165.00	0.45	0.64%
37	31770	Concrete Capped	60	70	1166.0	1166.0	1166.00	1.00	1.67%
38	31830	Concrete Capped	60	70	1166.7	1166.9	1166.80	0.80	1.33%
39	31895	Concrete Capped	65	77	1167.8	1167.6	1167.70	0.90	1.38%
40	31960	Concrete Capped	65	89	1168.4	1168.6	1168.50	0.80	1.23%
41	32020	Concrete Capped	60	98	1169.4	1169.3	1169.35	0.85	1.42%
							min	0.5	0.64%
							ave	0.9	1.30%
							max	1.4	1.93%

Mill Creek Channel Sills - Phase 3 Reach Type 11 Flume Transition to Tausick Way

									Sheet 1 of 1
Number	**Station**	**Type**	**Spacing (ft)**	**Length (ft)**	**Elevation Top of Sill**			**Avg. Drop (ft)**	**Slope**
					Left	**Right**	**Average**		
1	21840	Concrete Capped		161	1032.4	1032.1	1032.25		
2	21985	Concrete Capped	145.00	188	1034.3	1034.0	1034.15	1.90	
3	22125	Concrete Capped	140.00	224	1036.5	1036.2	1036.35	2.20	1.57%
4	22275	Concrete Capped	150.00	235	1038.6	1038.6	1038.60	2.25	1.50%
5	22425	Concrete Capped	150.00	255	1040.7	1040.7	1040.70	2.10	1.40%
6	22570	Concrete Capped	145.00	231	1042.8	1042.7	1042.75	2.05	1.41%
7	22725	Concrete Capped	155.00	205	1045.5	1045.4	1045.45	2.70	1.74%
8	22840	Concrete Capped	115.00	186	1047.2	1047.3	1047.25	1.80	1.57%
9	22955	Concrete Capped	115.00	175	1049.0	1049.0	1049.00	1.75	1.52%
10	23070	Concrete Capped	115.00	170	1050.7	1050.7	1050.70	1.70	1.48%
11	23185	Concrete Capped	115.00	160	1052.3	1052.3	1052.30	1.60	1.39%
12	23300	Concrete Capped	115.00	169	1053.8	1054.0	1053.90	1.60	1.39%
13	23405	Concrete Capped	105.00	152	1055.3	1055.2	1055.25	1.35	1.29%
14	23505	Concrete Capped	100.00	132	1056.9	1057.1	1057.00	1.75	1.75%
15	23710	Concrete Capped	205.00	129	1058.7	1058.9	1058.80	1.80	0.88%
16	23810	Concrete Capped	100.00	150	1060.3	1060.2	1060.25	1.45	1.45%
17	23930	Concrete Capped	120.00	175	1062.2	1062.2	1062.20	1.95	1.63%
18	24050	Concrete Capped	120.00	196	1064.0	1063.9	1063.95	1.75	1.46%
19	24195	Concrete Capped	145.00	237	1065.6	1065.5	1065.55	1.60	1.10%
20	24345	Concrete Capped	150.00	300	1068.0	1067.8	1067.90	2.35	1.57%
21	24495	Concrete Capped	150.00	210	1069.8	1070.1	1069.95	2.05	1.37%
22	24625	Concrete Capped	130.00	236	1071.6	1071.6	1071.60	1.65	1.27%
23	24720	Concrete Capped	95.00	314	1073.1	1073.2	1073.15	1.55	1.63%
24	24810	Concrete Capped	90.00	437	1074.3	1074.7	1074.50	1.35	1.50%
25	24910	Concrete Capped	100.00	532	1075.2	1076.5	1075.85	1.35	1.35%
26	24960	Concrete Capped	50.00	275	1076.5		1076.50	0.65	1.30%
27	25050	Concrete Capped	90.00	548	1078.0	1077.9	1077.95	1.45	1.61%
28	25180	Concrete Capped	130.00	534	1079.8	1079.6	1079.70	1.75	1.35%
29	25335	Concrete Capped	155.00	504	1081.6	1081.6	1081.60	1.90	1.23%
30	25425	Concrete Capped	90.00	453	1083.4	1083.5	1083.45	1.85	2.06%
31	25550	Concrete Capped	125.00	381	1085.2	1085.3	1085.25	1.80	1.44%
32	25675	Concrete Capped	125.00	310	1087.0	1087.0	1087.00	1.75	1.40%
33	25800	Concrete Capped	125.00	244	1088.7	1088.6	1088.65	1.65	1.32%
34	25910	Concrete Capped	110.00	166	1090.7	1090.6	1090.65	2.00	1.82%
35	26025	Concrete Capped	115.00	199	1092.6	1092.6	1092.60	1.95	1.70%
36	26135	Concrete Capped	110.00	176	1094.1	1094.1	1094.10	1.50	1.36%
37	26245	Concrete Capped	110.00	172	1095.5	1095.5	1095.50	1.40	1.27%
38	26355	Concrete Capped	110.00	189	1097.5	1097.4	1097.45	1.95	1.77%
39	26465	Concrete Capped	110.00	231	1098.8	1098.6	1098.70	1.25	1.14%
40	26575	Concrete Capped	110.00	236	1100.3	1100.1	1100.20	1.50	1.36%
41	26655	Concrete Capped	80.00	195	1101.6	1101.3	1101.45	1.25	1.56%
42	26740	Concrete Capped	85.00	177	1102.6	1102.6	1102.60	1.15	1.35%
43	26810	Concrete Capped	70.00	178	1103.8	1103.7	1103.75	1.15	1.64%
44	26880	Concrete Capped	70.00	185	1104.4	1104.3	1104.35	0.60	0.86%
45	26950	Concrete Capped	70.00	201	1105.2	1105.0	1105.10	0.75	1.07%
46	27020	Concrete Capped	70.00	217	1105.8	1105.0	1105.40	0.30	0.43%
47	27090	Concrete Capped	70.00	218	1106.7	1106.7	1106.70	1.30	1.86%
48	27160	Concrete Capped	70.00	200	1108.5	1108.4	1108.45	1.75	2.50%
49	27230	Concrete Capped	70.00	182	1109.4	1109.4	1109.40	0.95	1.36%
50	27300	Concrete Capped	70.00	165	1110.7	1110.6	1110.65	1.25	1.79%
51	27370	Concrete Capped	70.00	135	1111.2	1111.2	1111.20	0.55	0.79%
52	27440	Concrete Capped	70.00	100	1111.7	1111.8	1111.75	0.55	0.79%
53	27510	Concrete Capped	70.00	90	1111.9	1112.0	1111.95	0.20	0.29%
54	27580	Concrete Capped	70.00	81	1112.8	1112.8	1112.80	0.85	1.21%
55	27650	Concrete Capped	70.00	74	1113.5	1113.6	1113.55	0.75	1.07%
56	27720	Concrete Capped	70.00	76	1114.6	1114.5	1114.55	1.00	1.43%
57	27790	Concrete Capped	70.00	74	1115.3	1115.3	1115.30	0.75	1.07%
58	27860	Concrete Capped	70.00	75	1116.2	1116.1	1116.15	0.85	1.21%
59	27930	Concrete Capped	70.00	76	1117.2	1117.2	1117.20	1.05	1.50%
60	28000	Concrete Capped	70.00	75	1118.0	1118.0	1118.00	0.80	1.14%
61	28070	Concrete Capped	70.00	75	1118.8	1118.8	1118.80	0.80	1.14%
62	28140	Concrete Capped	70.00	75	1119.7	1119.7	1119.70	0.90	1.29%
63	28210	Concrete Capped	70.00	74	1120.5	1120.5	1120.50	0.80	1.14%
64	28280	Concrete Capped	70.00	76	1121.3	1121.3	1121.30	0.80	1.14%
65	28350	Concrete Capped	70.00	76	1122.2	1122.2	1122.20	0.90	1.29%
66	28420	Concrete Capped	70.00	76	1123.1	1123.1	1123.10	0.90	1.29%
67	28490	Concrete Capped	70.00	76	1124.5	1124.0	1124.25	1.15	1.64%
68	28560	Concrete Capped	70.00	76	1125.1	1125.1	1125.10	0.85	1.21%
69	28630	Concrete Capped	70.00	76	1125.8	1125.6	1125.70	0.60	0.86%
70	28700	Concrete Capped	70.00	76	1126.4	1126.5	1126.45	0.75	1.07%
71	28770	Concrete Capped	70.00	76	1127.9	1127.6	1127.75	1.30	1.86%
72	28840	Concrete Capped	70.00	76	1128.3	1128.5	1128.40	0.65	0.93%
73	28910	Concrete Capped	70.00	76	1129.4	1129.0	1129.20	0.80	1.14%
74	28980	Concrete Capped	70.00	75	1130.2	1130.1	1130.15	0.95	1.36%
75	29050	Concrete Capped	70.00	75	1131.1	1131.7	1131.40	1.25	1.79%
76	29120	Concrete Capped	70.00	74	1132.1	1132.1	1132.10	0.70	1.00%
77	29180	Concrete Capped	60.00	74	1133.2	1133.9	1133.55	1.45	2.42%

Appendix A4 – Mill Creek Flume Baffle Details

Appendix A4 – Mill Creek Flume Baffle Details

					View Downstream	Sheet 1 of 4
STA	**Channel Shape**	**Baffle Length (ft)**	**Reach**	**Spacing**	**Description**	**Location**
905	transition	6	2		Bafffle Right	
965	transition	6	2	60	Baffle Left	Mullan Ave.
1025	Trapezoidal	6	3	60	Bafffle Right	
1085	Trapezoidal	6	3	60	Baffle Left	
1145	Trapezoidal	6	3	60	Bafffle Right	
1205	Trapezoidal	6	3	60	Baffle Left	
1265	Trapezoidal	6	3	60	Bafffle Right	
1325	Trapezoidal	6	3	60	Baffle Left	
1385	Trapezoidal	6	3	60	Bafffle Right	
1445	Trapezoidal	6	3	60	Baffle Left	
1505	Trapezoidal	6	3	60	Bafffle Right	
1565	Trapezoidal	6	3	60	Baffle Left	
1625	Trapezoidal	6	3	60	Bafffle Right	
1685	Trapezoidal	6	3	60	Baffle Left	
1745	Trapezoidal	6	3	60	Bafffle Right	
1805	Trapezoidal	6	3	60	Baffle Left	
1865	Trapezoidal	6	3	60	Bafffle Right	
1925	Trapezoidal	6	3	60	Baffle Left	
1985	Trapezoidal	3	4	60	Baffle Right	6th Ave Bridge Pier
2045	Trapezoidal	3	4	60	Baffle Left	6th Ave Bridge Pier
2105	Trapezoidal	6	3	60	Baffle Right	
2160	Trapezoidal	6	3	55	Baffle Left	
2215	Trapezoidal	6	3	55	Baffle Right	
2270	Trapezoidal	6	3	55	Baffle Left	
2325	Trapezoidal	6	3	55	Baffle Right	
2380	Trapezoidal	6	3	55	Baffle Left	
2440	Trapezoidal	3	4	60	Baffle Right	5th Ave. Bridge Pier
2500	Trapezoidal	6	3	60	Baffle Left	
2559	Trapezoidal	6	3	59	Baffle Right	
2618	Trapezoidal	6	3	59	Baffle Left	
2677	Trapezoidal	6	3	59	Baffle Right	
2736	Trapezoidal	6	3	59	Baffle Left	
2795	Trapezoidal	6	3	59	Baffle Right	Fourth Ave.
2854	Trapezoidal	6	3	59	Baffle Left	Fourth Ave.
2913	Trapezoidal	6	3	59	Baffle Right	
2972	Trapezoidal	6	3	59	Baffle Left	
3031	Trapezoidal	6	3	59	Baffle Right	
3090	Trapezoidal	6	3	59	Baffle Left	Begin Existing Guide Wall
3150	transition	3	5	60	Baffle Right	Third Ave.
3210	transition	3	5	60	Baffle Left	Third Ave.
3270	transition	3	5	60	Baffle Right	Third Ave.
3330	Flat	3	7	60	Baffle Left	
3390	Flat	3	7	60	Baffle Right	
3450	Flat	3	7	60	Baffle Left	
3510	Flat	3	7	60	Baffle Right	
3570	Flat	6	6	60	Baffle Left	End Existing Guide Wall 3554
3630	Flat	6	6	60	Baffle Right	Begin Existing Guide Wall
3690	Flat	3	7	60	Baffle Left	Begin Existing Guide Wall
3750	Flat	3	7	60	Baffle Right	Second Ave.
3810	Flat	3	7	60	Baffle Left	
3850	Flat	6	6	40	Baffle Left	End Existing Guide Wall
3910	Flat	10	8	60	Baffle Right	Double Guide Walls
3970	Flat	10	8	60	Baffle Left	Double Guide Walls
4030	Flat	10	8	60	Baffle Right	Double Guide Walls
4090	Flat	10	8	60	Baffle Left	Double Guide Walls
4150	Flat	6	6	60	Baffle Right	

Appendix A4 (Cont)

					View Downstream	Sheet 2 of 4
STA	Channel Shape	Baffle Length (ft)	Reach	Spacing	Description	Location
4210	Flat	6	6	60	Baffle Left	Main St.
4270	Flat	6	6	60	Baffle Right	Main St.
4330	Flat	3	7	60	Baffle Left	Begin Existing Guide Wall
4390	Flat	3	7	60	Baffle Right	
4450	Flat	3	7	60	Baffle Left	
4510	Flat	3	7	60	Baffle Right	Begin New Guide Wall; End Existing Guide Wall
4570	Flat	3	7	60	Baffle Left	Jensen Beam 4575
4630	Flat	3	7	60	Baffle Right	Begin Existing Guide Wall; End New Guide Wall 4652; Colville St.
4690	Flat	3	7	60	Baffle Left	Colville St.
4750	Flat	6	6	60	Baffle Right	End Existing Guide Wall 4725
4810	Flat	6	6	60	Baffle Left	
4870	Flat	6	6	60	Baffle Right	
4930	Flat	6	6	60	Baffle Left	
4990	Flat	6	6	60	Baffle Right	
5050	Flat	6	6	60	Baffle Left	Spokane St
5110	Flat	3	7	60	Baffle Right	Begin Existing Guide Wall 5095
5170	Flat	3	7	60	Baffle Left	
5230	Flat	3	7	60	Baffle Right	
5290	Flat	3	7	60	Baffle Left	
5350	Flat	3	7	60	Baffle Right	Palouse St.
5410	Flat	3	7	60	Baffle Left	Palouse St.
5470	Flat	3	7	60	Baffle Right	Palouse St.
5530	transition	6	9	60	Baffle Left	End Existing Guide Wall
5580	transition	6	9	50	Baffle Right	
5630	transition	6	9	50	Baffle Left	
5690	Trapezoidal	3	4	60	Baffle Right	
5750	Trapezoidal	3	4	60	Baffle Left	
5810	Trapezoidal	3	4	60	Baffle Right	
5870	Trapezoidal	3	4	60	Baffle Left	Guide Wall Change
5930	Trapezoidal	3	4	60	Baffle Right	
5990	Trapezoidal	3	4	60	Baffle Left	Foot Bridge 6021
6050	Trapezoidal	3	4	60	Baffle Right	
6110	Trapezoidal	3	4	60	Baffle Left	
6170	Trapezoidal	6	3	60	Baffle Right	End New Guide Wall STA 6148
6230	Trapezoidal	6	3	60	Baffle Left	
6290	Trapezoidal	6	3	60	Baffle Right	
6350	Trapezoidal	6	3	60	Baffle Left	
6410	Trapezoidal	6	3	60	Baffle Right	Park Street Bridge STA 6390
6470	Trapezoidal	6	3	60	Baffle Left	
6530	Trapezoidal	6	3	60	Baffle Right	
6590	Trapezoidal	6	3	60	Baffle Left	
6650	Trapezoidal	6	3	60	Baffle Right	
6710	Trapezoidal	6	3	60	Baffle Left	
6770	Trapezoidal	6	3	60	Baffle Right	
6830	Trapezoidal	6	3	60	Baffle Left	
6890	Trapezoidal	6	3	60	Baffle Right	
6950	Trapezoidal	6	3	60	Baffle Left	
7010	Trapezoidal	6	3	60	Baffle Right	Nokomis Lane
7070	Trapezoidal	6	3	60	Baffle Left	
7130	Trapezoidal	6	3	60	Baffle Right	
7190	Trapezoidal	6	3	60	Baffle Left	
7250	Trapezoidal	6	3	60	Baffle Right	Otis Street Bridge STA 7280
7310	Trapezoidal	6	3	60	Baffle Left	
7370	Trapezoidal	6	3	60	Baffle Right	
7430	Trapezoidal	6	3	60	Baffle Left	
7490	Trapezoidal	6	3	60	Baffle Right	
7550	Trapezoidal	6	3	60	Baffle Left	

Appendix A4 (Cont)

					View Downstream	Sheet 3 of 4
STA	**Channel Shape**	**Baffle Length (ft)**	**Reach**	**Spacing**	**Description**	
7610	Trapezoidal	6	3	60	Baffle Right	
7670	Trapezoidal	6	3	60	Baffle Left	Merriam Street Bridge STA 7689
7730	Trapezoidal	6	3	60	Baffle Right	
7790	Trapezoidal	6	3	60	Baffle Left	
7850	Trapezoidal	6	3	60	Baffle Right	
7910	Trapezoidal	6	3	60	Baffle Left	
7970	Trapezoidal	6	3	60	Baffle Right	
8030	Trapezoidal	6	3	60	Baffle Left	
8090	Trapezoidal	6	3	60	Baffle Right	
8150	Trapezoidal	6	3	60	Baffle Left	
8210	Trapezoidal	6	3	60	Baffle Right	
8270	Trapezoidal	6	3	60	Baffle Left	
8330	Trapezoidal	6	3	60	Baffle Right	
8390	Trapezoidal	6	3	60	Baffle Left	
8450	Trapezoidal	6	3	60	Baffle Right	
8510	Trapezoidal	6	3	60	Baffle Left	
8580	Trapezoidal	6	3	70	Baffle Right	Clinton St. Bridge
8643	Trapezoidal	6	3	63	Baffle Left	
8706	Trapezoidal	6	3	63	Baffle Right	
8769	Trapezoidal	6	3	63	Baffle Left	
8832	Trapezoidal	6	3	63	Baffle Right	
8895	Trapezoidal	6	3	63	Baffle Left	
8958	Trapezoidal	6	3	63	Baffle Right	
9021	Trapezoidal	6	3	63	Baffle Left	
9084	Trapezoidal	6	3	63	Baffle Right	
9147	Trapezoidal	6	3	63	Baffle Left	
9210	Trapezoidal	6	3	63	Baffle Right	
9273	Trapezoidal	6	3	63	Baffle Left	
9336	Trapezoidal	6	3	63	Baffle Right	
9399	Trapezoidal	6	3	63	Baffle Left	
9459	Trapezoidal	6	3	60	Baffle Right	Division St. Bridge
9520	Trapezoidal	6	3	61	Baffle Left	
9581	Trapezoidal	6	3	61	Baffle Right	
9642	Trapezoidal	6	3	61	Baffle Left	
9703	Trapezoidal	6	3	61	Baffle Right	
9764	Trapezoidal	6	3	61	Baffle Left	
9825	Trapezoidal	6	3	61	Baffle Right	
9886	Trapezoidal	6	3	61	Baffle Left	
9947	Trapezoidal	6	3	61	Baffle Right	
10008	Trapezoidal	6	3	61	Baffle Left	
10069	Trapezoidal	6	3	61	Baffle Right	
10130	Trapezoidal	6	3	61	Baffle Left	
10191	Trapezoidal	6	3	61	Baffle Right	
10252	Trapezoidal	6	3	61	Baffle Left	
10313	Trapezoidal	6	3	61	Baffle Right	
10374	Trapezoidal	6	3	61	Baffle Left	
10435	Trapezoidal	6	3	61	Baffle Right	
10496	Trapezoidal	6	3	61	Baffle Left	
10557	Trapezoidal	6	3	61	Baffle Right	
10618	Trapezoidal	6	3	61	Baffle Left	
10679	Trapezoidal	6	3	61	Baffle Right	
10740	Trapezoidal	6	3	61	Baffle Left	
10801	Trapezoidal	6	3	61	Baffle Right	
10862	Trapezoidal	6	3	61	Baffle Left	
10923	Trapezoidal	6	3	61	Baffle Right	
10984	Trapezoidal	6	3	61	Baffle Left	
11045	Trapezoidal	6	3	61	Baffle Right	

Appendix A4 (Cont)

					View Downstream	Sheet 4 of 4
STA	**Channel Shape**	**Baffle Length (ft)**	**Reach**	**Spacing**	**Description**	
11106	Trapezoidal	6	3	61	Baffle Left	
11167	Trapezoidal	6	3	61	Baffle Right	
11228	Trapezoidal	6	3	61	Baffle Left	
11289	Trapezoidal	6	3	61	Baffle Right	
11350	Trapezoidal	6	3	61	Baffle Left	
11354			10			Roosevelt St. Bridge
11410			10			Roosevelt St. Bridge
11450	Trapezoidal	6	3	100	Baffle Right	
11508	Trapezoidal	6	3	58	Baffle Left	
11566	Trapezoidal	6	11	58	Baffle Right	Fishway
11624	Trapezoidal	6	11	58	Baffle Left	Fishway
11682	Trapezoidal	6	11	58	Baffle Right	Fishway

Appendix A5 – Hydraulic Data Used For Passage Assessment

Reach 1 - Hydraulic Data For Energetics Model

	10 cfs		20 cfs		40 cfs		100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
79	0.42	0.34	0.66	0.42	1.06	0.53	1.64	0.85	2.67	1.28	3.4	1.59
89	0.11	1.3	0.2	1.39	0.36	1.5	0.74	1.82	1.46	2.29	2.02	2.63
93.9	0.06	2.24	0.12	2.33	0.22	2.44	0.49	2.75	1.03	3.22	1.47	3.57
94.0	5.44	0.03	6.22	0.05	6.84	0.08	3	0.47	8.94	0.39	9.68	0.58
94.4	5.02	0.03	5.67	0.05	6.23	0.09	5.83	0.24	8.32	0.42	9.09	0.61
94.8	4.46	0.03	5.07	0.06	5.53	0.1	4.71	0.3	7.67	0.46	8.44	0.66
95.2	4.42	0.03	4.88	0.06	5.3	0.11	3.58	0.39	7.36	0.48	8.17	0.68
95.6	3.5	0.04	3.92	0.07	4.3	0.13	5.37	0.26	6.48	0.54	7.32	0.76
96.0	2.96	0.05	3.35	0.08	3.72	0.15	4.85	0.29	5.92	0.59	6.73	0.82
96.4	2.31	0.06	2.61	0.11	3.03	0.19	4.22	0.33	5.40	0.64	6.24	0.88
96.8	1.71	0.08	2.1	0.14	2.64	0.21	3.59	0.39	4.86	0.71	5.69	0.96
97.2	1.56	0.09	2.05	0.14	2.6	0.22	3.55	0.4	4.83	0.72	5.62	0.97
97.6	1.07	0.13	1.47	0.19	1.99	0.28	2.91	0.48	4.17	0.83	4.98	1.1
98.0	0.73	0.19	1.1	0.26	1.58	0.36	2.44	0.57	3.67	0.93	4.47	1.21
98.4	0.53	0.27	0.84	0.33	1.28	0.44	2.09	0.66	3.27	1.05	4.04	1.34
98.8	0.34	0.42	0.57	0.49	0.93	0.6	1.65	0.83	2.75	1.24	3.48	1.54
99.2	0.3	0.47	0.51	0.55	0.85	0.66	1.53	0.9	2.60	1.30	3.32	1.61
99.6	0.22	0.62	0.4	0.69	0.69	0.81	1.31	1.05	2.30	1.47	2.99	1.78
100.0	0.18	0.77	0.33	0.85	0.57	0.96	1.13	1.21	2.06	1.63	2.72	1.95
100.1	0.13	1.1	0.23	1.17	0.43	1.28	0.88	1.53	1.70	1.97	2.3	2.3
105.0	0.13	1.1	0.23	1.17	0.43	1.28	0.88	1.53	1.70	1.97	2.3	2.3
120.0	0.13	1.1	0.23	1.17	0.43	1.28	0.88	1.53	1.70	1.97	2.3	2.3

Reach 2 - Hydraulic Data For Energetics Model

	10 cfs		20 cfs		40 cfs		100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
580	1.85	0.11	2.34	0.17	2.94	0.27	3.97	0.49	5.34	0.88	6.2	1.18
680	1.87	0.11	2.41	0.16	2.93	0.27	3.96	0.49	5.34	0.88	6.21	1.18
705	0.47	0.42	0.76	0.51	1.17	0.65	1.97	0.95	3.12	1.45	3.89	1.82
718	0.06	3.14	0.12	3.24	0.24	3.4	0.54	3.75	1.15	4.38	1.66	4.85
780	0.09	2.19	0.17	2.3	0.33	2.46	0.71	2.81	1.46	3.43	2.05	3.9
792	1.95	0.1	2.34	0.17	2.95	0.27	4.02	0.5	5.45	0.92	6.37	1.26
800	1.89	0.11	2.44	0.17	2.98	0.27	4.04	0.5	5.49	0.93	6.41	1.27
810	2.81	0.32	3.4	0.46	4.16	0.61	5.87	0.88	3.41	1.07	4.16	1.45
820	3.08	0.35	3.67	0.53	4.38	0.77	5.56	1.17	2.96	1.07	3.73	1.46
830	3.08	0.36	3.85	0.55	4.58	0.83	5.86	1.33	2.62	1.05	3.35	1.48
840	2.85	0.39	3.94	0.56	4.72	0.86	5.99	1.43	2.34	1.03	3.1	1.45
850	2.71	0.41	3.86	0.57	4.88	0.87	6.14	1.5	2.29	0.94	2.86	1.43
860	2.62	0.42	3.73	0.6	4.96	0.88	6.28	1.55	2.16	0.98	2.55	1.41
870	2.53	0.44	3.6	0.62	4.92	0.89	6.37	1.58	2.27	0.96	2.72	1.29
880	2.47	0.45	3.5	0.63	4.85	0.91	6.48	1.6	2.26	0.96	2.71	1.31
890	2.41	0.46	3.41	0.65	4.75	0.93	6.59	1.61	2.25	0.94	2.71	1.31
900	2.36	0.47	3.34	0.66	4.65	0.95	6.69	1.61	2.24	0.93	2.72	1.31
904.5	2.32	0.48	3.27	0.68	4.56	0.97	5.83	1.81	2.08	1.03	2.54	1.41
904.786	4.76	0.7	4.74	1.26	5.75	1.66	2.98	0.98	4.19	1.52	4.84	1.86

Reach 3 - Hydraulic Data For Energetics Model
Low Flow

	6 cfs		*20 cfs*		*60 cfs*	
Sta	**Vel**	**Depth**	**Vel**	**Depth**	**Vel**	**Depth**
905	4.00	0.50	4.23	0.53	6.04	1.1
910	0.10	0.73	0.20	1.43	1.4	2.15
915	0.10	0.68	0.20	1.38	1.4	2.16
920	0.10	0.63	0.20	1.33	1.4	2.11
925	1.15	0.58	1.74	1.27	3.25	2.05
930	1.27	0.53	1.82	1.22	3.34	2
935	1.41	0.47	1.90	1.17	3.43	1.94
940	1.59	0.42	1.99	1.12	3.53	1.89
945	1.83	0.36	2.09	1.07	3.64	1.83
950	4.37	0.15	2.20	1.01	3.75	1.78
955	5.03	0.13	2.32	0.96	10.04	0.66
960	6.23	0.11	8.57	0.26	10.15	0.66
965	4.00	0.50	4.23	0.53	6.04	1.1
970	0.10	0.73	0.20	1.43	1.4	2.15
975	0.10	0.68	0.20	1.38	1.4	2.16
980	0.10	0.63	0.20	1.33	1.4	2.11
985	1.15	0.58	1.74	1.27	3.25	2.05
990	1.27	0.53	1.82	1.22	3.34	2
995	1.41	0.47	1.90	1.17	3.43	1.94
1000	1.59	0.42	1.99	1.12	3.53	1.89
1005	1.83	0.36	2.09	1.07	3.64	1.83
1010	4.37	0.15	2.20	1.01	3.75	1.78
1015	5.03	0.13	2.32	0.96	10.04	0.66
1020	6.23	0.11	8.57	0.26	10.15	0.66
1025	4.00	0.50	4.23	0.53	6.04	1.1

Reach 3 - Hydraulic Data For Energetics Model
High Flow

	100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
950	6.72	1.61	2.37	0.9	2.89	1.29
980	3.67	2.84	1.54	1.19	2.01	1.57
1000	4.01	2.65	1.62	1.06	2.15	1.43
1020	4.46	2.42	1.73	0.92	2.34	1.26
1025	6.72	1.61	2.37	0.9	2.89	1.29
1040	4.07	2.62	1.62	1.06	2.19	1.39
1060	4.53	2.39	1.74	0.91	2.41	1.21
1080	5.15	2.13	8.2	3.11	2.51	1.14
1085	6.72	1.61	2.37	0.9	2.89	1.29
1100	4.09	2.61	1.63	1.06	2.2	1.39
1120	4.56	2.38	1.74	0.91	2.42	1.2
1140	5.16	2.13	8.26	3.09	2.51	1.13
1145	6.72	1.61	2.37	0.9	2.89	1.29
1160	4.07	2.62	1.62	1.05	2.2	1.39
1180	4.53	2.39	1.74	0.91	2.42	1.2
1200	5.13	2.14	8.18	3.11	2.51	1.13
1205	6.72	1.61	2.37	0.9	2.89	1.29
1220	4.07	2.62	1.62	1.06	2.19	1.39
1240	4.53	2.39	1.74	0.92	2.42	1.21
1260	5.14	2.13	8.19	3.11	2.51	1.14
1265	6.71	1.61	2.38	0.91	2.89	1.29
1280	4.09	2.6	1.63	1.06	2.21	1.39
1300	4.54	2.39	1.74	0.91	2.42	1.2
1320	5.12	2.14	8.2	3.11	2.5	1.13
1325	6.71	1.61	2.38	0.91	2.9	1.29
1340	4.07	2.62	1.63	1.05	2.2	1.38
1360	4.53	2.39	1.74	0.91	2.43	1.19
1380	5.1	2.15	8.16	3.12	2.5	1.13
1385	6.72	1.61	2.37	0.9	2.89	1.29
1387	4.5	2.34	1.74	1.09	2.27	1.43
1390	4.6	2.3	1.77	1.06	2.31	1.41
1395	4.68	2.28	1.78	1.03	2.35	1.36
1400	4.12	2.59	1.62	1.06	2.17	1.4

Reach 4 - Hydraulic Data For Energetics Model

	6 cfs		20 cfs		60 cfs		100 cfs		250 cfs		400 cfs	
Sta	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth
1985	4.00	0.50	4.23	0.53	5.96	1.12	3.67	2.84	1.54	1.19	2.01	1.57
1990	0.10	0.73	0.50	1.43	1.90	1.77	4.01	2.65	1.62	1.06	2.15	1.43
1995	0.10	0.68	0.50	1.38	1.90	2.16	4.46	2.42	1.73	0.92	2.34	1.26
2000	0.10	0.63	0.50	1.33	1.90	2.11	6.72	1.61	2.37	0.9	2.89	1.29
2005	1.15	0.58	1.74	1.28	3.24	2.06	4.07	2.62	1.62	1.06	2.19	1.39
2010	1.27	0.53	1.82	1.22	3.33	2.00	4.53	2.39	1.74	0.91	2.41	1.21
2015	1.40	0.47	1.90	1.17	3.42	1.95	5.15	2.13	8.2	3.11	2.51	1.14
2020	1.58	0.42	1.98	1.12	3.52	1.90	6.72	1.61	2.37	0.9	2.89	1.29
2025	1.82	0.37	2.08	1.07	3.62	1.84	4.09	2.61	1.63	1.06	2.2	1.39
2030	4.31	0.15	2.19	1.02	3.73	1.79	4.56	2.38	1.74	0.91	2.42	1.2
2035	4.99	0.13	2.31	0.96	3.85	1.73	5.16	2.13	8.26	3.09	2.51	1.13
2040	6.19	0.11	8.54	0.26	10.11	0.66	6.72	1.61	2.37	0.9	2.89	1.29
2045	4.00	0.50	4.23	0.53	5.96	1.12	4.07	2.62	1.62	1.05	2.2	1.39
2050	0.10	0.73	0.50	1.43	1.90	1.77	4.53	2.39	1.74	0.91	2.42	1.2
2055	0.10	0.68	0.50	1.38	1.90	2.16	5.13	2.14	8.18	3.11	2.51	1.13
2060	0.10	0.63	0.50	1.33	1.90	2.11	6.72	1.61	2.37	0.9	2.89	1.29
2065	1.15	0.58	1.74	1.28	3.24	2.06	4.07	2.62	1.62	1.06	2.19	1.39
2070	1.27	0.53	1.82	1.22	3.33	2.00	4.53	2.39	1.74	0.92	2.42	1.21
2075	1.40	0.47	1.90	1.17	3.42	1.95	5.14	2.13	8.19	3.11	2.51	1.14
2080	1.58	0.42	1.98	1.12	3.52	1.90	6.71	1.61	2.38	0.91	2.89	1.29
2085	1.82	0.37	2.08	1.07	3.62	1.84	4.09	2.6	1.63	1.06	2.21	1.39
2090	4.31	0.15	2.19	1.02	3.73	1.79	4.54	2.39	1.74	0.91	2.42	1.2
2095	4.99	0.13	2.31	0.96	3.85	1.73	5.12	2.14	8.2	3.11	2.5	1.13
2100	6.19	0.11	8.54	0.26	10.11	0.66	6.71	1.61	2.38	0.91	2.9	1.29
2105	4.00	0.50	4.23	0.53	5.96	1.12	4.07	2.62	1.63	1.05	2.2	1.38

Reach 5 - Hydraulic Data For Energetics Model

	100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
3040	7.02	1.52	7.33	3.01	3.11	1.07
3110	6.98	1.51	7.33	2.98	3.08	1.06
3120	7.05	1.54	7.26	3.01	3.25	0.99
3130	7.11	1.55	7.19	3.01	3.27	1.13
3140	7.08	1.55	7.01	3.03	3.3	1.12
3150	5.78	1.67	2.92	0.84	4.04	1.21
3160	3.69	2.57	2.22	0.89	3.35	1.16
3170	3.94	2.48	2.3	0.83	3.46	1.11
3180	4.24	2.31	6.99	2.84	3.39	1.14
3190	4.66	2.18	6.58	2.89	3.42	1.16
3200	5.12	2.03	6.62	2.85	3.47	1.18
3210	5.03	1.73	3.18	0.88	4.34	1.22
3220	3.49	2.46	2.41	0.96	3.48	1.29
3230	3.81	2.34	2.48	0.83	3.62	1.15
3240	4.28	2.21	2.58	0.82	3.67	1.21
3250	5.04	2.02	2.66	0.82	3.73	1.22
3260	6.13	1.78	2.69	0.83	3.76	1.22
3270	4.98	1.47	3.43	0.9	4.53	1.24
3280	3.94	2.16	2.78	0.86	3.95	1.18
3360	7.08	1.55	2.76	0.86	3.85	1.23

Reach 6 - Hydraulic Data For Energetics Model
Low Flow

	6 cfs		*20 cfs*		*60 cfs*	
Sta	**Vel**	**Depth**	**Vel**	**Depth**	**Vel**	**Depth**
905	4.00	0.50	4.23	0.53	6.04	1.1
910	0.10	0.73	0.20	1.43	1.4	2.15
915	0.10	0.68	0.20	1.38	1.4	2.16
920	0.10	0.63	0.20	1.33	1.4	2.11
925	1.15	0.58	1.74	1.27	3.25	2.05
930	1.27	0.53	1.82	1.22	3.34	2
935	1.41	0.47	1.90	1.17	3.43	1.94
940	1.59	0.42	1.99	1.12	3.53	1.89
945	1.83	0.36	2.09	1.07	3.64	1.83
950	4.37	0.15	2.20	1.01	3.75	1.78
955	5.03	0.13	2.32	0.96	10.04	0.66
960	6.23	0.11	8.57	0.26	10.15	0.66
965	4.00	0.50	4.23	0.53	6.04	1.1
970	0.10	0.73	0.20	1.43	1.4	2.15
975	0.10	0.68	0.20	1.38	1.4	2.16
980	0.10	0.63	0.20	1.33	1.4	2.11
985	1.15	0.58	1.74	1.27	3.25	2.05
990	1.27	0.53	1.82	1.22	3.34	2
995	1.41	0.47	1.90	1.17	3.43	1.94
1000	1.59	0.42	1.99	1.12	3.53	1.89
1005	1.83	0.36	2.09	1.07	3.64	1.83
1010	4.37	0.15	2.20	1.01	3.75	1.78
1015	5.03	0.13	2.32	0.96	10.04	0.66
1020	6.23	0.11	8.57	0.26	10.15	0.66
1025	4.00	0.50	4.23	0.53	6.04	1.1

Reach 6 - Hydraulic Data For Energetics Model
High Flow

	100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
4740	7.09	1.55	2.28	0.86	3.11	1.26
4750	3.75	1.54	2.57	1.24	3.24	1.68
4760	4.99	1.93	2.28	0.86	3.11	1.26
4770	7.05	1.56	2.27	0.86	3.11	1.26
4780	5.43	1.86	2.27	0.86	3.11	1.26
4790	7.1	1.55	2.27	0.86	3.11	1.26
4800	5.44	1.86	2.27	0.85	3.1	1.25
4810	5.07	1.45	2.92	0.92	3.82	1.27
4820	4.24	2.09	2.26	0.85	3.1	1.25
4830	5.37	1.87	2.26	0.85	3.1	1.25
4840	7.1	1.55	2.27	0.85	3.1	1.25
4850	5.44	1.86	2.26	0.85	3.1	1.25
4860	7.09	1.55	2.26	0.85	3.1	1.25
4870	5.07	1.45	2.91	0.92	3.8	1.27
4880	4.24	2.09	2.26	0.85	3.1	1.25
4890	5.35	1.88	2.25	0.86	3.09	1.25
4900	7.09	1.55	2.26	0.85	3.1	1.25
4910	5.42	1.86	2.26	0.85	3.1	1.25
4920	7.09	1.55	2.25	0.85	3.09	1.25
4930	5.07	1.45	2.9	0.91	3.79	1.26
4940	4.21	2.09	2.25	0.86	3.09	1.25
4950	5.29	1.89	2.25	0.84	3.09	1.24
4960	7.09	1.55	2.25	0.84	3.09	1.24
4970	5.43	1.86	2.25	0.84	3.08	1.24
4980	7.09	1.55	2.25	0.84	3.09	1.24
4990	5.07	1.45	2.89	0.91	3.79	1.26
5000	4.23	2.09	2.24	0.84	3.08	1.24
5010	5.35	1.87	2.24	0.85	3.09	1.24
5020	7.09	1.55	2.24	0.84	3.08	1.24
5030	5.42	1.86	2.23	0.85	3.08	1.24
5040	7.08	1.55	2.22	0.85	3.07	1.23
5050	5.07	1.44	2.9	0.91	3.79	1.25
5060	4.23	2.09	2.23	0.85	3.08	1.23
5070	5.33	1.88	2.23	0.85	3.08	1.24
5080	7.08	1.55	2.22	0.85	3.08	1.23
5090	5.43	1.86	2.22	0.85	3.07	1.23
5100	7.08	1.55	2.22	0.85	3.08	1.23

Reach 7 - Hydraulic Data For Energetics Model
Low Flow

	6 cfs		*20 cfs*		*60 cfs*	
Sta	**Vel**	**Depth**	**Vel**	**Depth**	**Vel**	**Depth**
3150	4.00	0.50	4.23	0.53	5.96	1.12
3155	0.10	0.73	0.50	1.43	1.90	1.77
3160	0.10	0.68	0.50	1.38	1.90	2.16
3165	0.10	0.63	0.50	1.33	1.90	2.11
3170	1.15	0.58	1.74	1.28	3.24	2.06
3175	1.27	0.53	1.82	1.22	3.33	2.00
3180	1.40	0.47	1.90	1.17	3.42	1.95
3185	1.58	0.42	1.98	1.12	3.52	1.90
3190	1.82	0.37	2.08	1.07	3.62	1.84
3195	4.31	0.15	2.19	1.02	3.73	1.79
3200	4.99	0.13	2.31	0.96	3.85	1.73
3205	6.19	0.11	8.54	0.26	10.11	0.66
3210	4.00	0.50	4.23	0.53	5.96	1.12
3215	0.10	0.73	0.50	1.43	1.90	1.77
3220	0.10	0.68	0.50	1.38	1.90	2.16
3225	0.10	0.63	0.50	1.33	1.90	2.11
3230	1.15	0.58	1.74	1.28	3.24	2.06
3235	1.27	0.53	1.82	1.22	3.33	2.00
3240	1.40	0.47	1.90	1.17	3.42	1.95
3245	1.58	0.42	1.98	1.12	3.52	1.90
3250	1.82	0.37	2.08	1.07	3.62	1.84
3255	4.31	0.15	2.19	1.02	3.73	1.79
3260	4.99	0.13	2.31	0.96	3.85	1.73
3265	6.19	0.11	8.54	0.26	10.11	0.66
3270	4.00	0.50	4.23	0.53	5.96	1.12

Reach 7 - Hydraulic Data For Energetics Model
High Flow

	100 cfs		250 cfs		400 cfs	
River Sta	Vel (ft/s)	Depth (ft)	Vel (ft/s)	Depth (ft)	Vel (ft/s)	Depth (ft)
4330	7.07	1.54	2.52	0.8	3.66	1.2
4390	5.09	1.73	3.25	0.89	4.42	1.26
4430	5.61	1.93	2.54	0.81	3.68	1.2
4450	5.02	1.77	3.3	0.92	4.43	1.31
4510	5.01	1.76	3.19	0.87	4.38	1.24
4530	3.95	2.39	7.04	2.77	3.68	1.2
4570	5.07	1.72	3.23	0.89	4.38	1.26
4620	5.8	1.84	6.7	3.04	3.42	1.15
4630	4.99	1.78	2.75	1.26	3.6	1.75
4690	4.97	1.76	3.21	0.88	4.35	1.26

Reach 8 - Hydraulic Data For Energetics Model
Low Flow

	6 cfs		*20 cfs*		*60 cfs*	
Sta	**Vel**	**Depth**	**Vel**	**Depth**	**Vel**	**Depth**
3910	3.30	0.34	3.37	0.37	5.00	0.75
3915	0.10	0.49	0.60	1.18	0.90	1.74
3920	0.10	0.44	0.60	1.13	0.90	1.68
3925	0.10	0.39	0.60	1.08	0.90	1.63
3930	0.61	0.35	0.67	1.05	1.28	1.64
3935	1.33	0.28	1.27	0.98	2.42	1.55
3940	1.65	0.23	1.34	0.93	2.50	1.50
3945	3.20	0.12	1.42	0.88	2.60	1.44
3950	3.20	0.12	1.50	0.83	2.70	1.39
3955	3.20	0.12	1.61	0.78	2.81	1.33
3960	3.79	0.10	1.72	0.73	2.93	1.28
3965	5.13	0.07	7.94	0.16	9.25	0.40
3970	3.30	0.34	3.37	0.37	5.00	0.75
3975	0.10	0.49	0.60	1.18	0.90	1.74
3980	0.10	0.44	0.60	1.13	0.90	1.68
3985	0.10	0.39	0.60	1.08	0.90	1.63
3990	0.61	0.35	0.67	1.05	1.28	1.64
3995	1.33	0.28	1.27	0.98	2.42	1.55
4000	1.65	0.23	1.34	0.93	2.50	1.50
4005	3.20	0.12	1.42	0.88	2.60	1.44
4010	3.20	0.12	1.50	0.83	2.70	1.39
4015	3.20	0.12	1.61	0.78	2.81	1.33
4020	3.79	0.10	1.72	0.73	2.93	1.28
4025	5.13	0.07	7.94	0.16	9.25	0.40
4030	3.30	0.34	3.37	0.37	5.00	0.75

Reach 8 - Hydraulic Data For Energetics Model
High Flow

	100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
3859	5.87	1.07	6.76	2.15	2.07	0.96
3909	5.87	1.07	6.76	2.15	2.07	0.96
3910	5.87	1.06	1.93	0.82	2.64	1.23
3970	4.45	1.41	6.76	2.15	2.07	0.96
3970.5	5.86	1.07	6.75	1.87	2.68	1.23
4029	5.82	1.08	6.76	2.15	2.07	0.96
4030.5	5.88	1.06	6.75	1.85	2.69	1.22
4089	4.53	1.38	6.76	2.15	2.06	0.96
4090.5	5.86	1.07	6.78	1.86	2.66	1.23
4130.5	4.5	1.39	6.75	2.15	2.07	0.96
4135	6.83	1.43	2.25	0.86	3.1	1.28
4210	5.07	1.38	2.93	0.94	3.78	1.33
4235	5.24	1.75	2.21	0.83	3.05	1.27

Reach 9 - Hydraulic Data For Energetics Model
High Flow (Note: Low Flow Data Same As Reach 5)

	100 cfs		250 cfs		400 cfs	
River Sta	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
5520	7.01	1.52	2.65	0.81	3.64	1.18
5530	5.12	1.52	2.87	0.91	3.74	1.27
5540	5.21	2.04	2.06	0.83	2.91	1.23
5550	5.97	1.85	6.83	2.91	2.8	1.2
5560	6.64	1.67	6.9	3.03	2.67	1.18
5570	7.13	1.56	7.4	3.02	2.56	1.16
5580	6.11	1.65	2.39	0.82	2.98	1.22
5590	3.87	2.64	7.07	3.22	2.5	1.05
5600	4.18	2.52	7.9	3.05	2.55	1.07
5610	4.49	2.39	8.03	3.05	2.6	1.09
5620	4.79	2.27	8.14	3.05	2.65	1.09
5630	6.56	1.63	2.56	0.89	3.1	1.23
5640	3.93	2.68	1.79	1.01	2.53	1.24

Reach 10 - Hydraulic Data For Energetics Model

	10 cfs		20 cfs		40 cfs		100 cfs		250 cfs		400 cfs	
River Sta	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth	Vel	Depth
11360	1.16	0.95	1.67	1.33	2.53	1.76	4.05	2.63	1.79	1.03	2.43	1.35
11370	1.28	0.86	1.78	1.24	2.66	1.65	4.36	2.5	7.24	3.49	2.56	0.99
11380	1.02	0.73	1.32	1.12	1.87	1.57	2.84	2.55	1.11	1.03	1.48	1.5
11390	1.93	0.57	2.3	0.94	3.15	1.36	4.65	2.25	2.37	0.99	2.99	1.48
11400	2.17	0.49	2.44	0.87	3.26	1.29	4.76	2.16	2.42	0.91	3.13	1.39
11410	3.31	0.33	3.18	0.7	3.96	1.11	5.57	1.97	8.11	3.12	2.66	1.19
11420	3.32	0.34	4.2	0.53	4.71	0.95	6.18	1.79	8.47	3.02	2.74	1.12
11430	3.28	0.34	4.17	0.53	5.23	0.85	6.98	1.58	8.48	3.02	2.75	1.12
11440	3.29	0.34	4.16	0.54	5.24	0.85	7.12	1.56	8.48	3.02	2.75	1.13

Reach 11 - Transition Fishway

Drop, Velocity, Pool Depth and EDF

	Weir Elevation			**WSEL**				**Floor Elevation**			**Drop**			**Velocity**			**Plunge Pool Depth**			**Flow Area**			EDF			Pool Velocity			Depth Over Weir		
Flow	Weir 1	Weir 2	Weir 3	Weir 1	Weir 2	Weir 3	Channel	Pool 1	Pool 2	Pool 3	Weir 1	Weir 2	Weir 3	Weir 1	Weir 2	Weir 3	Pool 1	Pool 2	Pool 3	Pool 1	Pool 2	Pool 3	Pool 1	Pool 2	Pool 3	Pool 1	Pool 2	Pool 3	Weir 1	Weir 2	Weir 3
cfs																															
6	1032.7	1031.1	1030.3	1032.85	1031.94	1030.5	1028	1028	1027.8	1027.7	0.9	1.4	2.5	7.6	9.6	12.6	3.9	2.7	0.3	39	24	2	0.1	0.3	6.7	0.2	0.3	3.0	0.1	0.8	0.2
20	1032.7	1031.1	1030.3	1033	1032.1	1030.65	1028.6	1028	1027.8	1027.7	0.9	1.45	2.05	7.6	9.6	11.5	4.1	2.9	0.9	41	26	8	0.4	1.0	4.6	0.5	0.8	2.5	0.3	1.0	0.4
60	1032.7	1031.1	1030.3	1033.3	1032.4	1031	1029.3	1028	1027.8	1027.7	0.9	1.4	1.7	7.6	9.5	10.4	4.4	3.2	1.6	45	30	14	1.1	2.5	6.5	1.3	2.0	4.3	0.6	1.3	0.7
100	1032.7	1031.1	1030.3	1033.5	1032.6	1031.2	1029.7	1028	1027.8	1027.7	0.9	1.4	1.5	7.6	9.5	9.8	4.6	3.4	2.0	48	32	21	1.7	3.9	6.3	2.1	3.1	4.8	0.8	1.5	0.9
200	1032.7	1031.1	1030.3	1033.9	1033.1	1031.7	1030.2	1028	1027.8	1027.7	0.8	1.4	1.5	7.2	9.5	9.8	5.1	3.9	2.5	56	39	23	2.5	6.4	11.6	3.6	5.1	8.7	1.2	2.0	1.4
400	1032.7	1031.1	1030.3	1034.4	1033.7	1032.4	1031	1028	1027.8	1027.7	0.7	1.3	1.4	6.7	9.1	9.5	5.7	4.6	3.3	66	48	39	3.8	9.6	12.8	6.1	8.3	10.3	1.7	2.6	2.1

Reach 12 Division Dam And Fishway

Station, Velocity, Depth Fish Path Data

Flows

	Mill Creek cfs	Division Dam cfs	Fishway cfs	Yellowhawk Slot cfs	Yellowhawk Radial Gate cfs	Yellowhawk cfs
6" Fishway Exit Slot	6	0	6	15	18	33
6" Fishway Exit Slot	20	13	7	17	18	35
6" Fishway Exit Slot	60	52	8	19	19	38
18" Fishway Exit Slot	20	12	8	15	17	33
18" Fishway Exit Slot	60	43	17	18	19	37
18" Fishway Exit Slot	100	81	19	17	17	34
18" Fishway Exit Slot	200	178	22	18	16	33
18" Fishway Exit Slot	400	374	26	23	18	41
Center Two Gates Open	400					

Hydraulic Drop

	Fishway Exit	Fishway Weir 1	Fishway Weir 2	Fishway Ent	Division Dam	Yellowhawk Slot
6" Fishway Exit Slot	1.3	0.4	0.2	0.3	2.2	0.8
6" Fishway Exit Slot	1.3	0.4	0.2	0.3	2.2	0.8
6" Fishway Exit Slot	1.4	0.3	0.2	0.3	2.2	0.9
18" Fishway Exit Slot	0.2	0.6	0.6	0.7	2.2	0.8
18" Fishway Exit Slot	0.7	0.4	0.1	1.0	2.2	0.9
18" Fishway Exit Slot	0.7	0.4	0.2	0.8	2.2	0.7
18" Fishway Exit Slot	0.9	0.3	0.0	1.0	2.2	0.6
18" Fishway Exit Slot	1.2	0.0	0.1	0.9	2.2	0.8
Center Two Gates Open					0.0	

Pool Depth

	Fishway Exit	Fishway Pool 1	Fishway Pool 2	Fishway Pool 3	Fishway Entrance	Fishway Apron	Dam Apron	Yellowhawk Apron
6" Fishway Exit Slot	2.0	1.5	1.7	1.6	1.1	0.4	-0.2	1.4
6" Fishway Exit Slot	2.1	1.6	1.8	1.7	1.2	0.5	-0.1	1.5
6" Fishway Exit Slot	2.3	1.7	2.0	1.9	1.4	0.7	0.1	1.6
18" Fishway Exit Slot	2.0	2.6	2.6	2.1	1.6	0.5	-0.1	1.5
18" Fishway Exit Slot	2.3	2.4	2.6	2.6	2.1	0.7	0.1	1.6
18" Fishway Exit Slot	2.4	2.5	2.7	2.6	2.1	0.9	0.3	1.9
18" Fishway Exit Slot	2.7	2.6	3.0	3.0	2.5	1.1	0.5	2.3
18" Fishway Exit Slot	3.1	2.7	3.3	3.3	2.8	1.5	0.9	2.5
Center Two Gates Open							0.9	

EDF

	Fishway Pool 1	Fishway Pool 2	Fishway Pool 3	Fishway Entrance
6" Fishway Exit Slot	8.7	3.5	2.4	9.2
6" Fishway Exit Slot	8.9	3.5	2.4	7.9
6" Fishway Exit Slot	9.8	2.6	2.4	6.0
18" Fishway Exit Slot	0.9	4.5	6.6	8.8
18" Fishway Exit Slot	7.4	5.3	1.8	12.6
18" Fishway Exit Slot	7.8	5.9	4.0	11.1
18" Fishway Exit Slot	11.7	4.2	1.1	10.7
18" Fishway Exit Slot	19.8	0.0	2.6	10.7
Center Two Gates Open				

Velocity

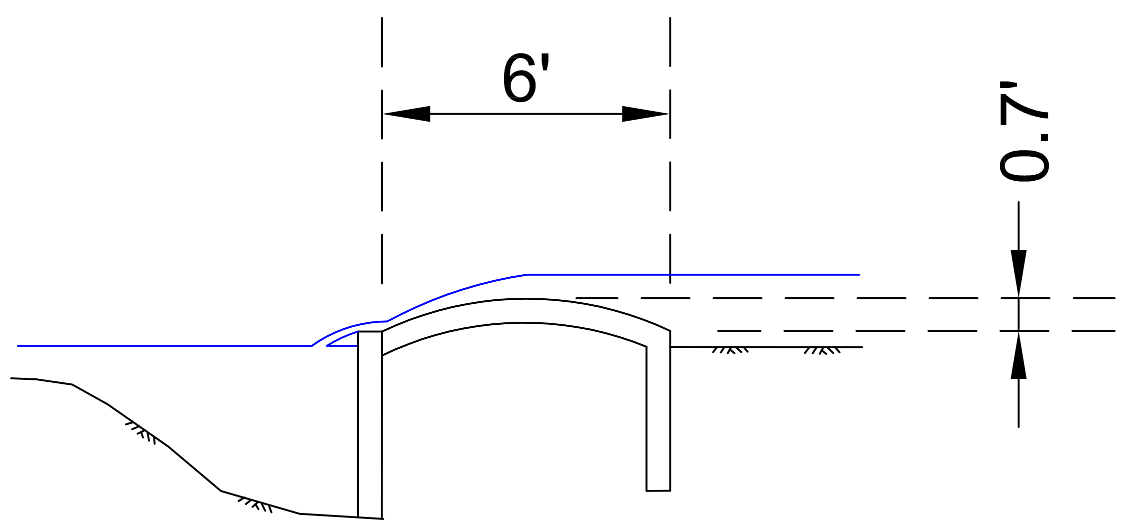
	Fishway Exit *fps*	Fishway Weir 1 *fps*	Fishway Weir 2 *fps*	Fishway Ent *fps*	Fishway Apron *fps*	Division Dam *fps*	Yellowhawk Slot *fps*
6" Fishway Exit Slot	9.1	5.1	3.6	4.5	1.6	11.9	7.2
6" Fishway Exit Slot	9.3	5.1	3.6	4.5	1.4	12.0	7.3
6" Fishway Exit Slot	9.5	4.4	3.6	4.4	1.1	11.9	7.6
18" Fishway Exit Slot	3.6	6.5	6.2	6.8	2.8	11.8	6.9
18" Fishway Exit Slot	6.7	4.9	2.5	8.0	4.2	11.8	7.5
18" Fishway Exit Slot	6.8	5.1	3.6	7.3	3.1	11.8	6.8
18" Fishway Exit Slot	7.6	4.0	1.8	7.9	3.5	11.8	6.2
18" Fishway Exit Slot	8.8	0.0	2.5	7.7		11.9	7.2
Center Two Gates Open						9.3	

Appendix A6 – Conceptual Design Drawings and Cost Estimates

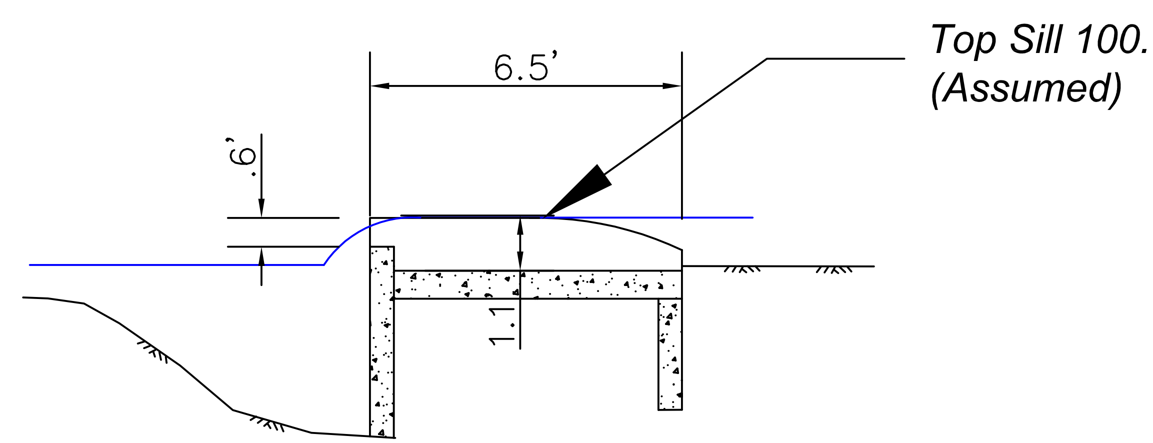
Reach Type 1

Reach Type 7

Reach Type 8

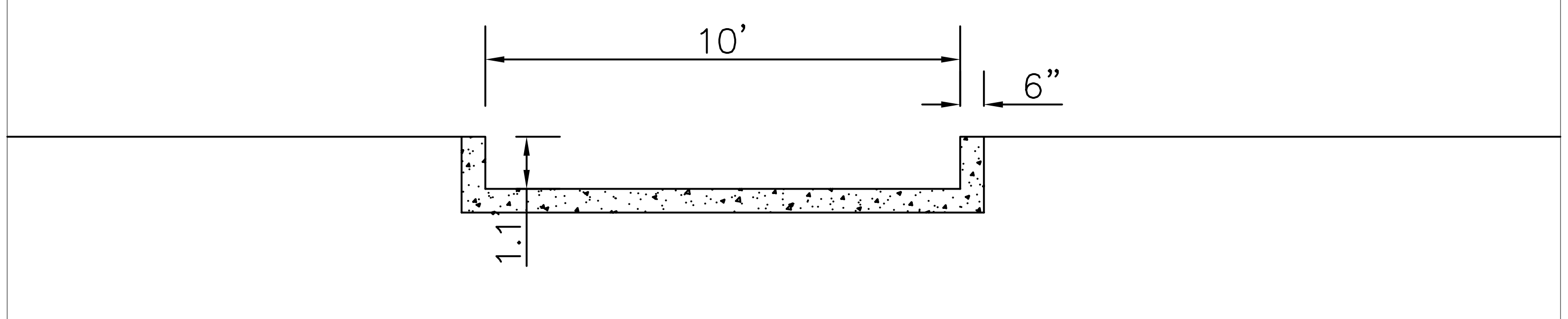


Existing
Profile
Scale 1" = 4'

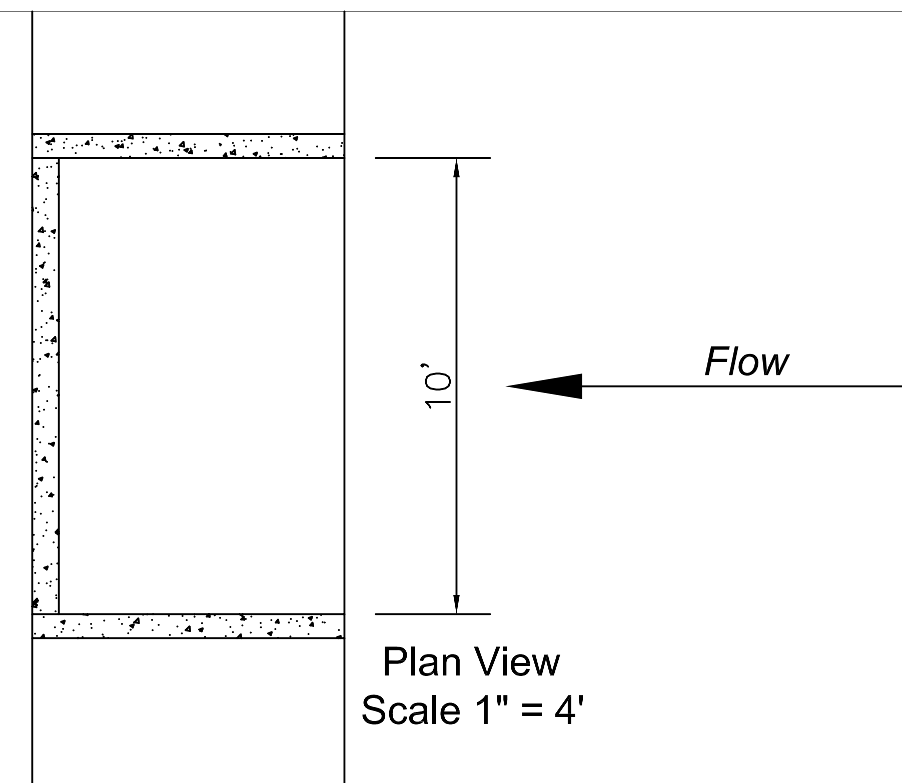


Profile
Scale 1" = 4'

Head	WSEL US	Flow Slot	Flow Sill	Total Flow	Depth US	Velocity US
0.5	99.9	11	0	11	1.0	1.1
0.7	100.1	19	6	25	1.2	1.6
1	100.4	32	47	79	1.5	2.1
1.5	100.9	59	159	218	2.0	2.9
2	101.4	91	308	399	2.5	3.6



Section View
Scale 1" = 4'



Plan View
Scale 1" = 4'

TRI-STATE STEELHEADERS

Mill Creek Fish Passage Assessment

Conceptual Design

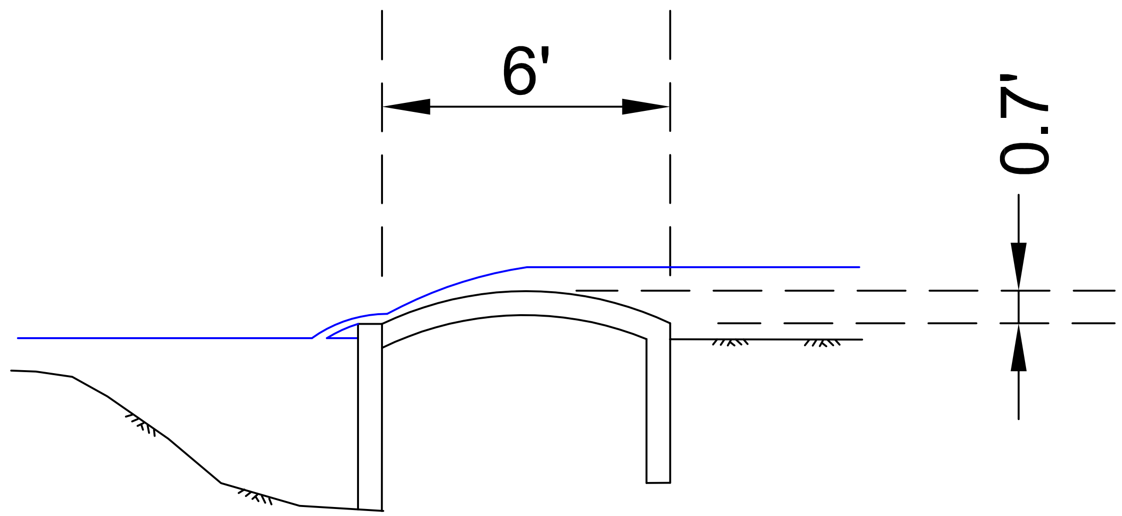
REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: Waterfall Engineering
DRAWN BY: Waterfall Engineering
CHECKED BY:
APPROVED BY:
FILE:
DATE: 7/31/09

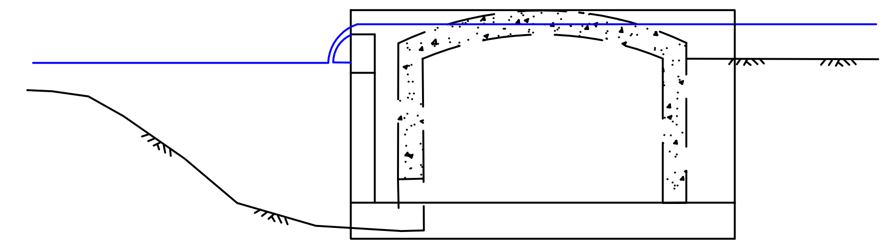
Reach 1

Slot Cut Into Sill

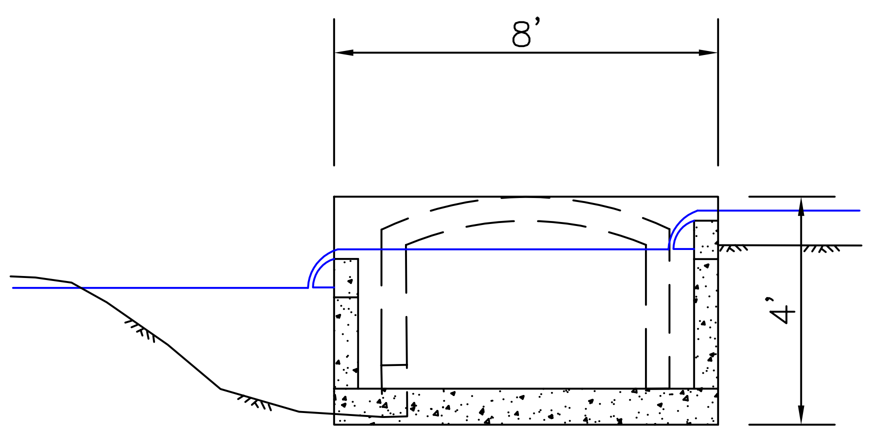
SHEET NO. 1 OF 3



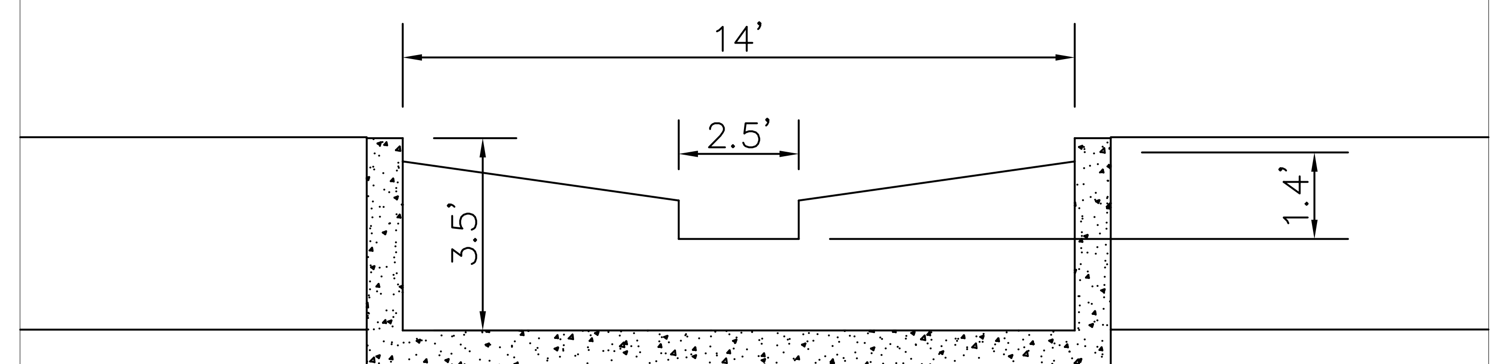
Existing
Profile
Scale 1" = 4'



Single Drop
Profile
Scale 1" = 4'



Two Drops
Profile
Scale 1" = 4'



Weir Detail
Section
Scale 1" = 4'

TRI-STATE STEELHEADERS

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

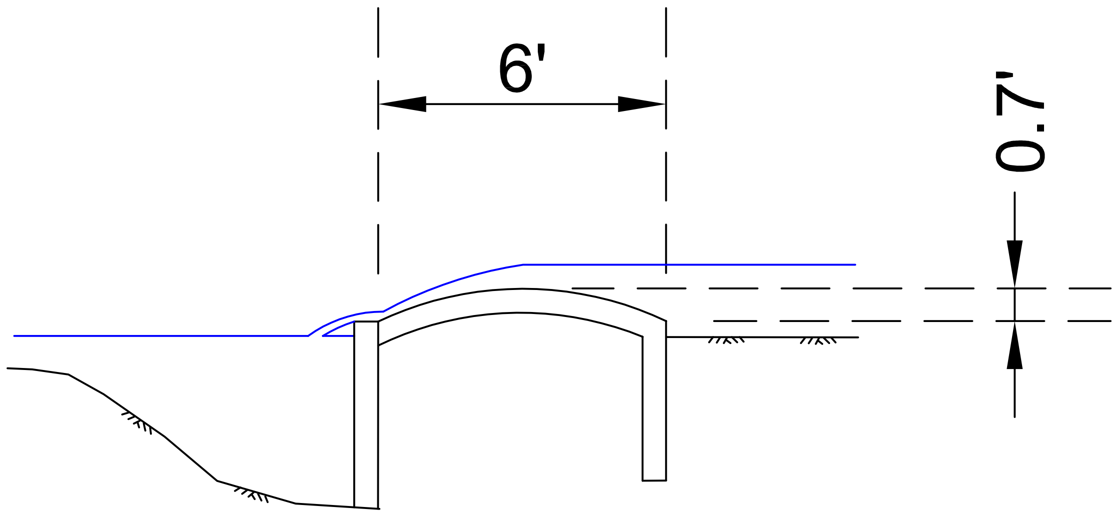
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: Waterfall Engineering
DRAWN BY: Waterfall Engineering
CHECKED BY:
APPROVED BY:
FILE:
DATE: 7/31/09

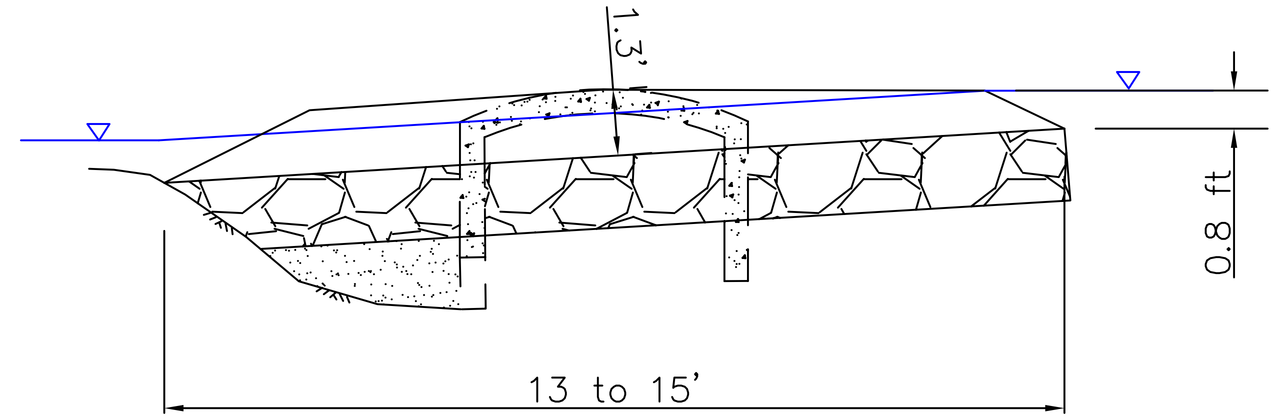
Reach 1

Pool and Weir Fishway Design

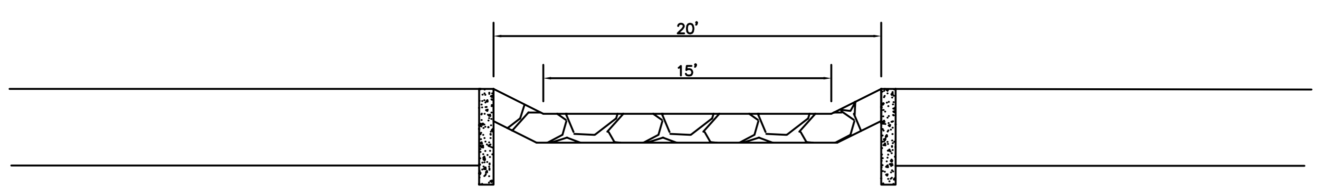
SHEET NO. 2 OF 3



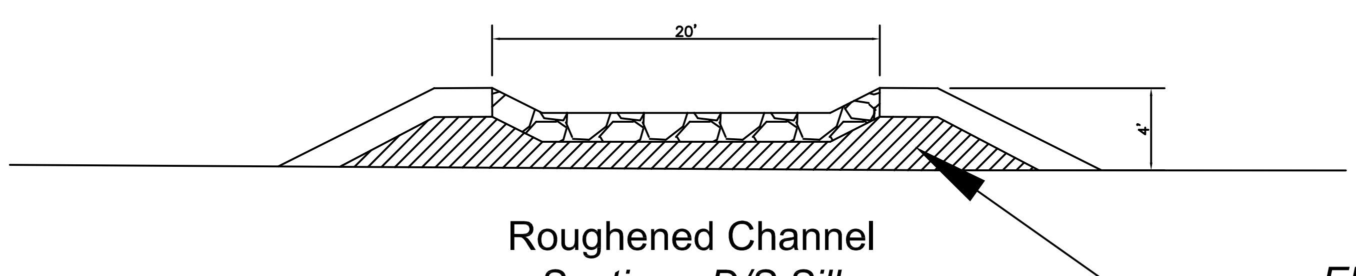
Existing
Profile
Scale 1" = 4'



Roughened Channel
Profile
Scale 1" = 4'



Roughened Channel
Section - Through Sill
Scale 1" = 10'



Roughened Channel
Section - D/S Sill
Scale 1" = 10'

Note: Preferred Design is to Eliminate Fill in Channel and Extend Concrete Wall Downstream

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: Waterfall Engineering
DRAWN BY: Waterfall Engineering
CHECKED BY:
APPROVED BY:
FILE:
DATE: 7/31/09

Reach 1

Roughened Channel Design

SHEET NO. 3 OF 3

Mill Creek Fish Passage Assessment - Cost Estimate

Date:	3/6/2009
Reach:	1
Number Sills	4
Design Level:	30%
Cost Per Sill	**$9,225**

Project Description: Reach 1 is the channel sills. They are rock filled wire baskets capped with concrete, 70 ft long by 6 feet wide. The design plan is to cut out a 10 foot section down about 1 foot, remove the wire basket and rock, prepare the foundation, form and pour a weir/sill and slab. Any voids will be grouted to seal to the existing weirs.

Description	Unit	Qty	t (in)	Cost	Amount	Sub Total	*Comments*
Mob, Access and Water Management						$13,000	
Mobilization	L.S.	1		$6,000.00	$6,000		*Typically 10% of construction costs*
Access	L.S.	1		$2,000.00	$2,000		
Water Management	L.S.	1		$5,000.00	$5,000		
Removal of Weir Section	**4**					$13,308	
Concrete Slab cutting	L.F.	22		$4.84	$106		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Excavation	C.Y.	0		$15.00	$0		
Wire Basket Cutting	L.S.	1		$2,000.00	$2,000		
Rock Removal	C.Y.	4		$15.00	$60		
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*spoil on site*
Concrete Wall cutting (with rebar)	L.F.	0	12	$11.45	$0		*per inch of depth*
Blades	ea.	1		$625.00	$625		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	1.5		$140.00	$210		
Remove Whole Pieces	ea.	0		$140.00	$0		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	1.5		$200.00	$300		
Hauling	C.Y.	1.5		$7.00	$11		
Concrete Disposal	C.Y.	1.5		$10.00	$15		
Precast Concrete Fishway	**4**					$10,594	
Excavation	C.Y.	0		$15.00	$0		
Disposal	C.Y.	0		$6.00	$0		
Subgrade	C.Y.	0		$60.00	$0		*Use Existing*
Concrete Underpining	C.Y.	0		$2,100.00	$0		
Concrete Slabs	C.Y.	2		$700.00	$1,400		
Concrete Walls	C.Y.	0.5		$900.00	$450		
Concrete Weirs	C.Y.	0		$900.00	$0		
Grouting	S.F.	90		$2.76	$248		*Holes in walls pump into sills*
Concrete Seal to Weirs	C.Y.	0.5		$1,100.00	$550		
Construction Total						**$36,902**	
Contingency	15%					$5,535	
Sales Tax	7.7%					$3,300	
Engineering	10%					$4,200	
Project Management	5%					$2,100	
Project Total						**$52,000**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate

Date:	2/17/2009
Reach:	1
Number Sills	4
Design Level:	30%
Cost Per Sill	**$29,490**

Project Description: Reach 1 is the channel sills. They are rock filled wire baskets capped with concrete, 70 ft long by 6 feet wide. The design plan is to cut out a section, remove the wire basket and rock, prepare the foundation, place a rock fill 6% slope roughened channel, 15 feet wide by 15 feet long. The ends of the existing weir sills will be sealed with a grouted concrete wall after they are cut.

Description	**Unit**	**Qty**	**t (in)**	**Cost**	**Amount**	**Sub Total**	***Comments***
Mob, Access and Water Management						$37,000	
Mobilization	L.S.	1		$17,000.00	$17,000		*Typically 10% of construction costs*
Access	L.S.	1		$10,000.00	$10,000		
Water Management	L.S.	1		$10,000.00	$10,000		
Removal of Weir Section	**4**					$40,299	
Concrete Slab cutting	L.F.	20		$4.84	$97		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Excavation	C.Y.	25		$15.00	$375		
Wire Basket Cutting	L.S.	1		$7,000.00	$7,000		
Rock Removal	C.Y.	18		$15.00	$270		
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*spoil on site*
Concrete Wall cutting (with rebar)	L.F.	0	12	$11.45	$0		*per inch of depth*
Blades	ea.	1		$625.00	$625		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	4		$140.00	$560		
Remove Whole Pieces	ea.	2		$140.00	$280		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	4		$200.00	$800		
Hauling	C.Y.	4		$7.00	$28		
Concrete Disposal	C.Y.	4		$10.00	$40		
Roughened Channel	**4**					$40,660	
Prepare Subgrade	C.Y.	5		$15.00	$75		
Disposal	C.Y.	5		$6.00	$30		
Subgrade	C.Y.	35		$60.00	$2,100		*Crushed Rock*
Rock Riprap	C.Y.	30		$80.00	$2,400		
Channel Mix	C.Y.	22		$90.00	$1,980		
Concrete Walls	C.Y.	0		$900.00	$0		
Concrete Weirs	C.Y.	0		$900.00	$0		
Grouting	S.F.	500		$2.76	$1,380		*Holes in walls pump into sills*
Concrete Seal to Weirs	C.Y.	2		$1,100.00	$2,200		
Construction Total						**$117,959**	
Contingency	15%					$17,694	
Sales Tax	7.7%					$10,400	
Engineering	10%					$13,600	
Project Management	5%					$6,800	
Project Total						**$166,500**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate

Date:	2/17/2009
Reach:	1
Number Sills	4
Design Level:	30%
Cost Per Sill	**$28,758**

Project Description: Reach 1 is the channel sills. They are rock filled wire baskets capped with concrete, 70 ft long by 6 feet wide. The design plan is to cut out a section, remove the wire basket and rock, prepare the foundation, place a precast fishway 14 feet wide by 8 feet long in the new opening and then pour concrete and grout to seal to the existing weirs.

Description	**Unit**	**Qty**	**t (in)**	**Cost**	**Amount**	**Sub Total**	***Comments***
Mob, Access and Water Management						$40,000	
Mobilization	L.S.	1		$20,000.00	$20,000		*Typically 10% of construction costs*
Access	L.S.	1		$10,000.00	$10,000		
Water Management	L.S.	1		$10,000.00	$10,000		
Removal of Weir Section	**4**					$29,891	
Concrete Slab cutting	L.F.	20		$4.84	$97		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Excavation	C.Y.	20		$15.00	$300		
Wire Basket Cutting	L.S.	1		$5,000.00	$5,000		
Rock Removal	C.Y.	16		$15.00	$240		
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*spoil on site*
Concrete Wall cutting (with rebar)	L.F.	0	12	$11.45	$0		*per inch of depth*
Blades	ea.	1		$625.00	$625		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	3		$140.00	$420		
Remove Whole Pieces	ea.	1		$140.00	$140		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	3		$200.00	$600		
Hauling	C.Y.	3		$7.00	$21		
Concrete Disposal	C.Y.	3		$10.00	$30		
Precast Concrete Fishway	**4**					$45,140	
Excavation	C.Y.	5		$15.00	$75		
Disposal	C.Y.	5		$6.00	$30		
Subgrade	C.Y.	5		$60.00	$300		*Crushed Rock*
Concrete Underpining	C.Y.	0		$2,100.00	$0		
Concrete Slabs	C.Y.	4		$700.00	$2,800		
Concrete Walls	C.Y.	2		$900.00	$1,800		
Concrete Weirs	C.Y.	3		$900.00	$2,700		
Grouting	S.F.	500		$2.76	$1,380		*Holes in walls pump into sills*
Concrete Seal to Weirs	C.Y.	2		$1,100.00	$2,200		
Construction Total						**$115,031**	
Contingency	15%					$17,255	
Sales Tax	7.7%					$10,200	
Engineering	10%					$13,200	
Project Management	5%					$6,600	
Project Total						**$162,300**	

Opinions of Probable Construction Cost

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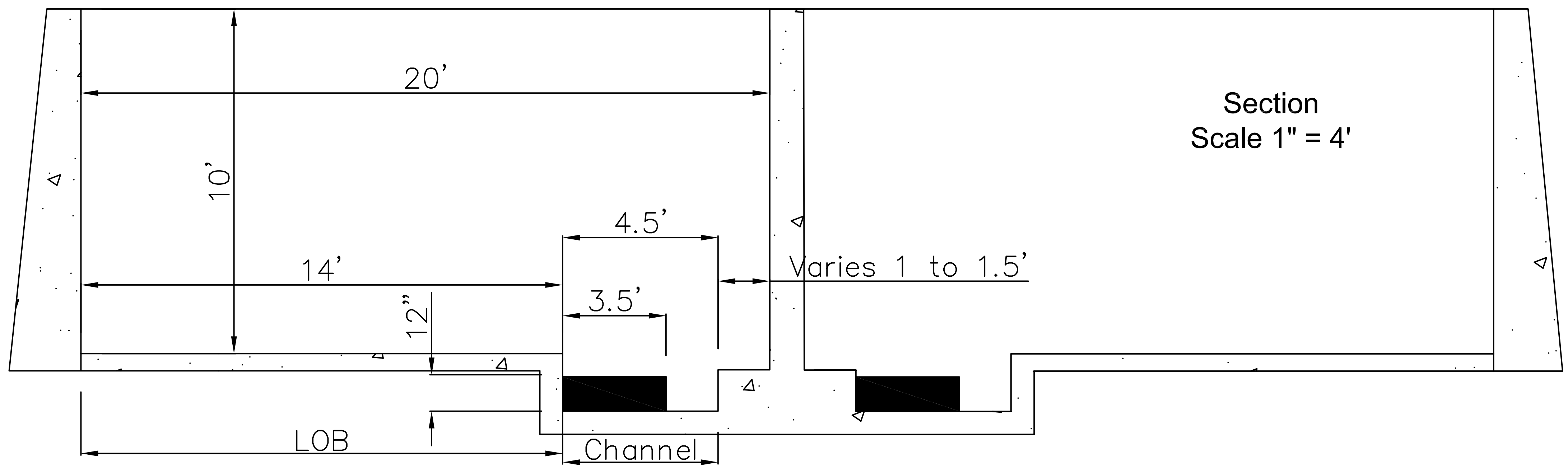
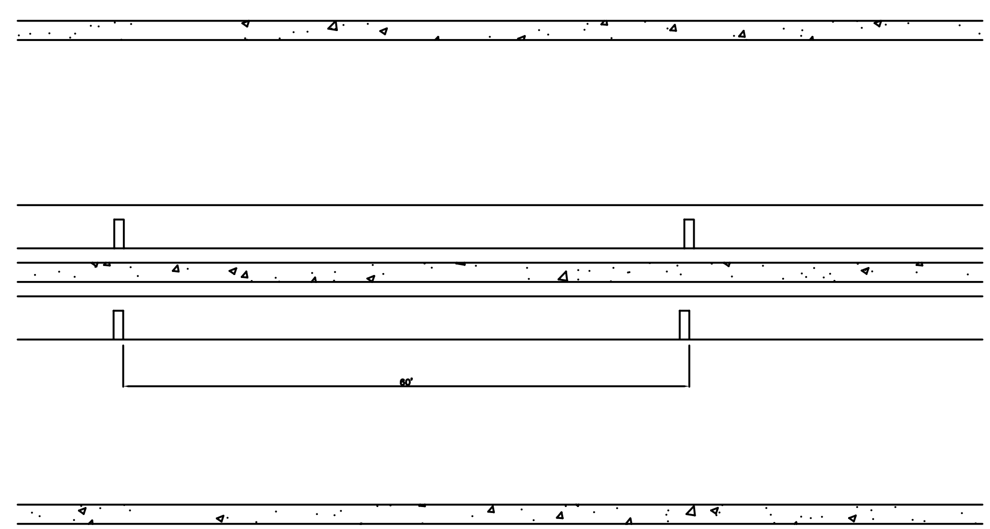


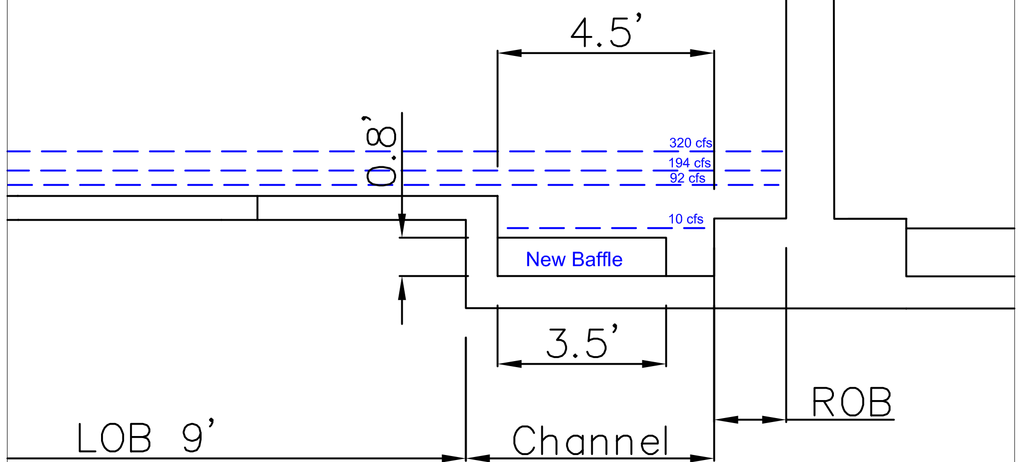
Section
Scale 1" = 4'



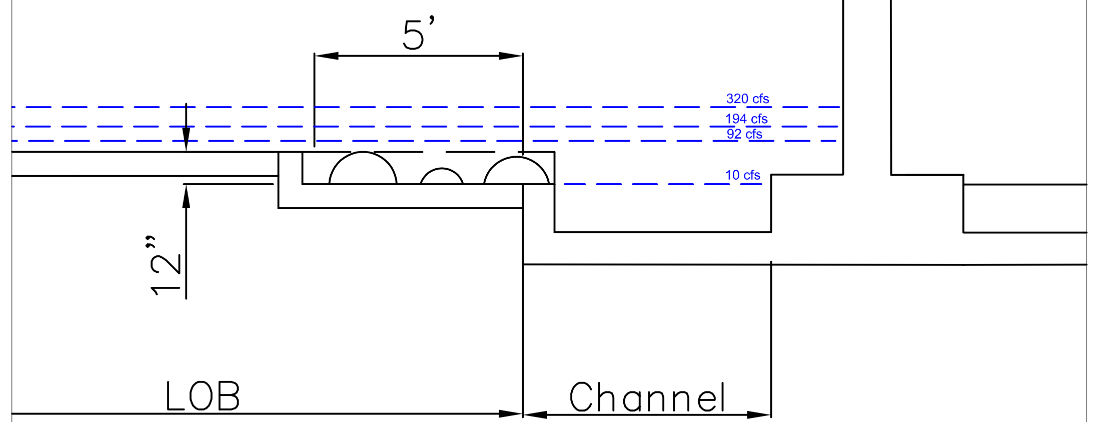
Plan View
Scale 1" = 20'

Mill Creek Fish Passage Assessment	Conceptual Design	REVISIONS	DESIGNED BY: DRAWN BY: CHECKED BY: APPROVED BY: FILE: DATE:	Reach 7 Existing	SHEET NO. 1 OF 4

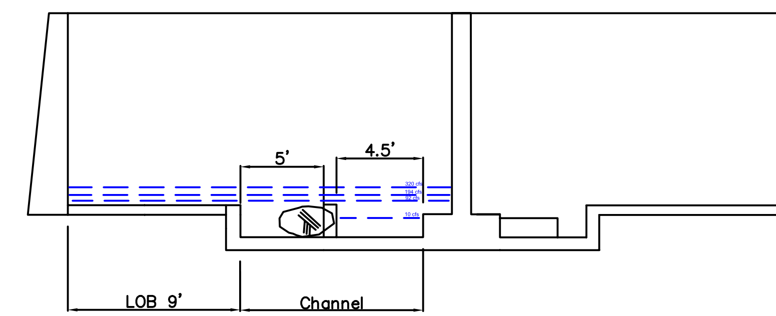
REV	DATE	BY	APP'D	DESCRIPTION



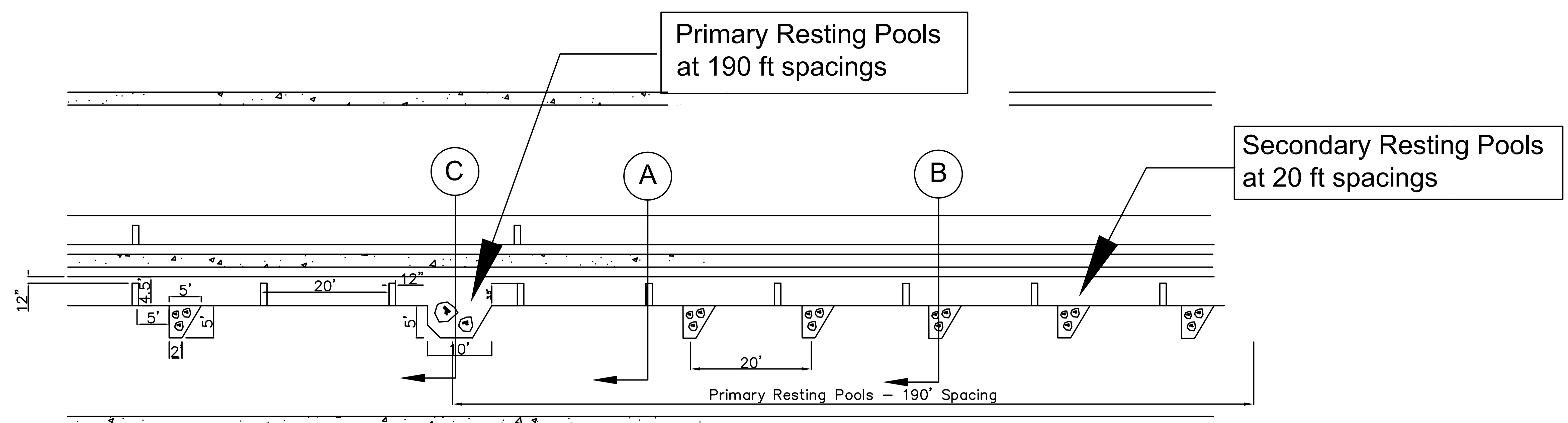
Section A - Section at Baffle
Scale 1" = 4'



Section Showing Secondary Resting Pool
Scale 1" = 4'



Section Showing Primary Resting Pool
Scale 1" = 10'



Plan View
Scale 1" = 20'

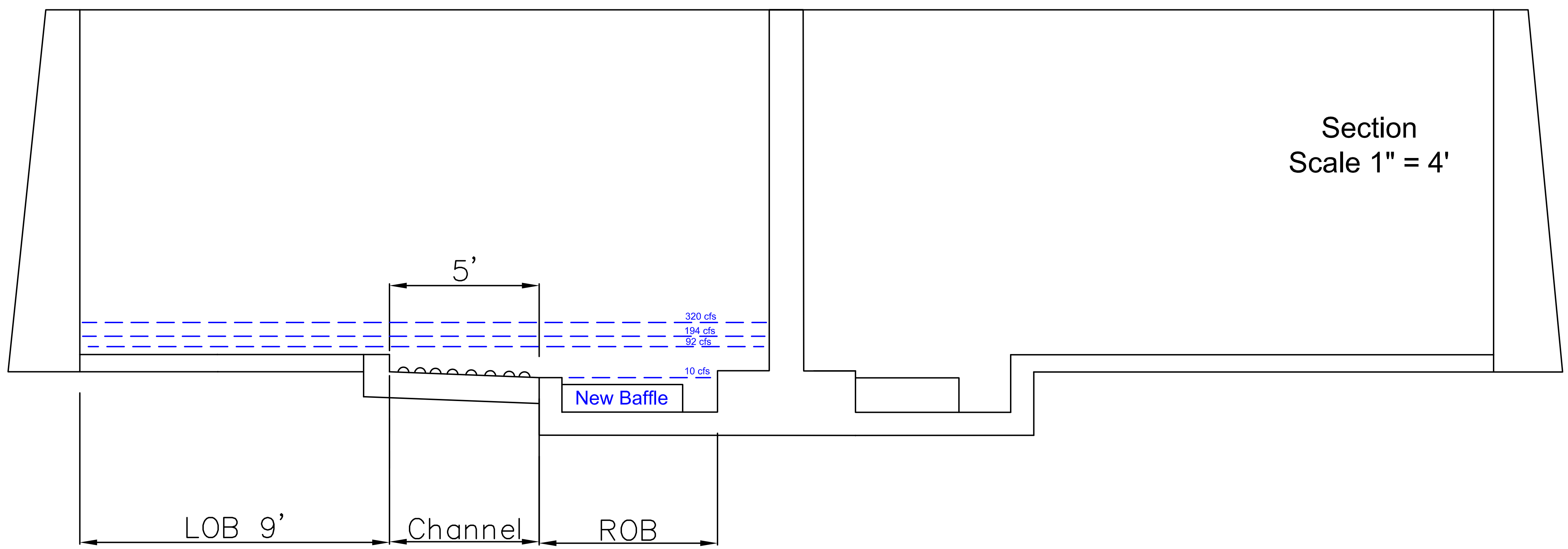
TRI-STATE STEELHEADERS	Mill Creek Fish Passage Assessment	Conceptual Design	Reach 7 / Design A

REVISIONS

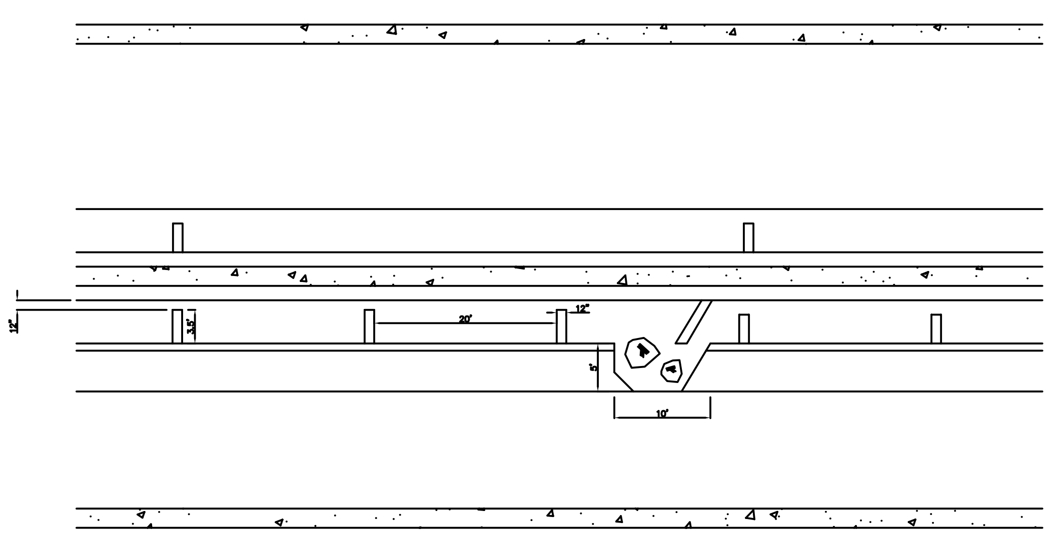
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

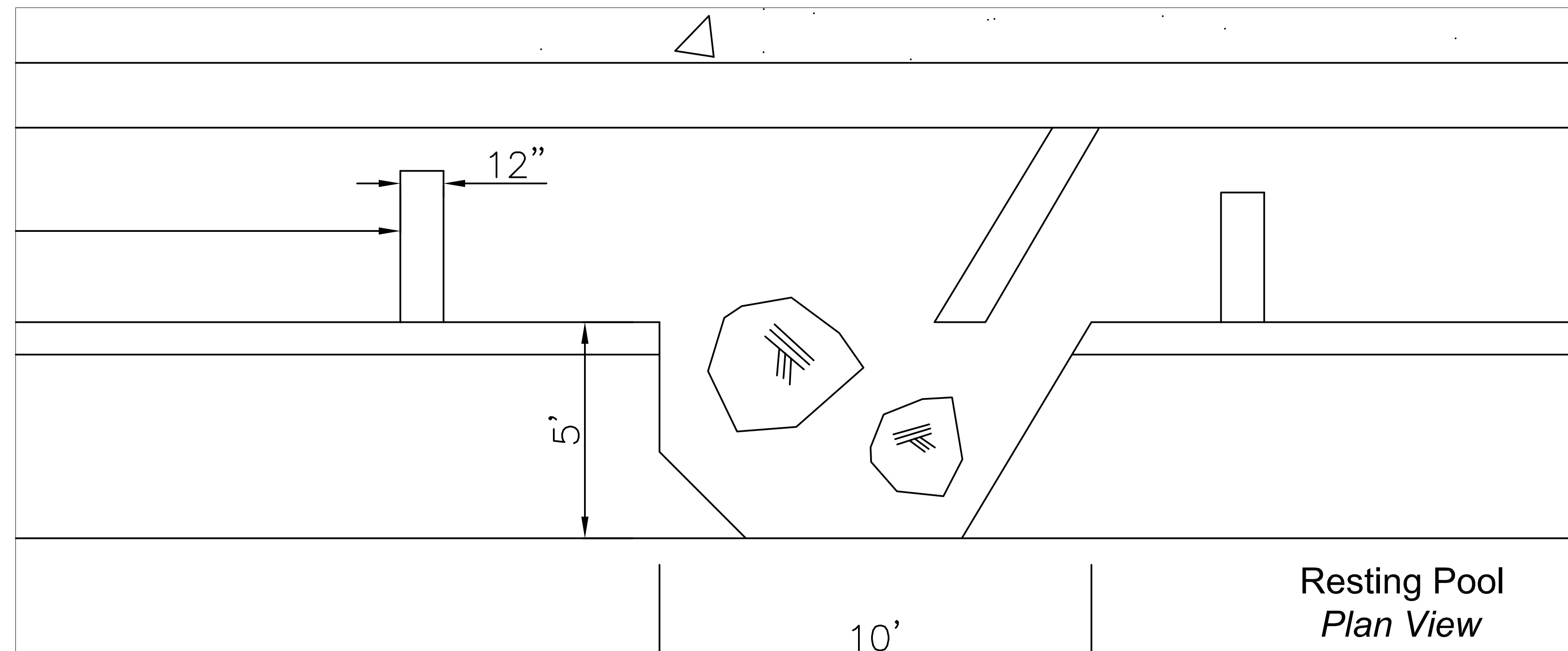
SHEET NO. 2 OF 4



Section
Scale 1" = 4'



Plan View
Scale 1" = 20'



Resting Pool
Plan View
Scale 1" = 4'

Mill Creek Fish Passage Assessment

Conceptual Design

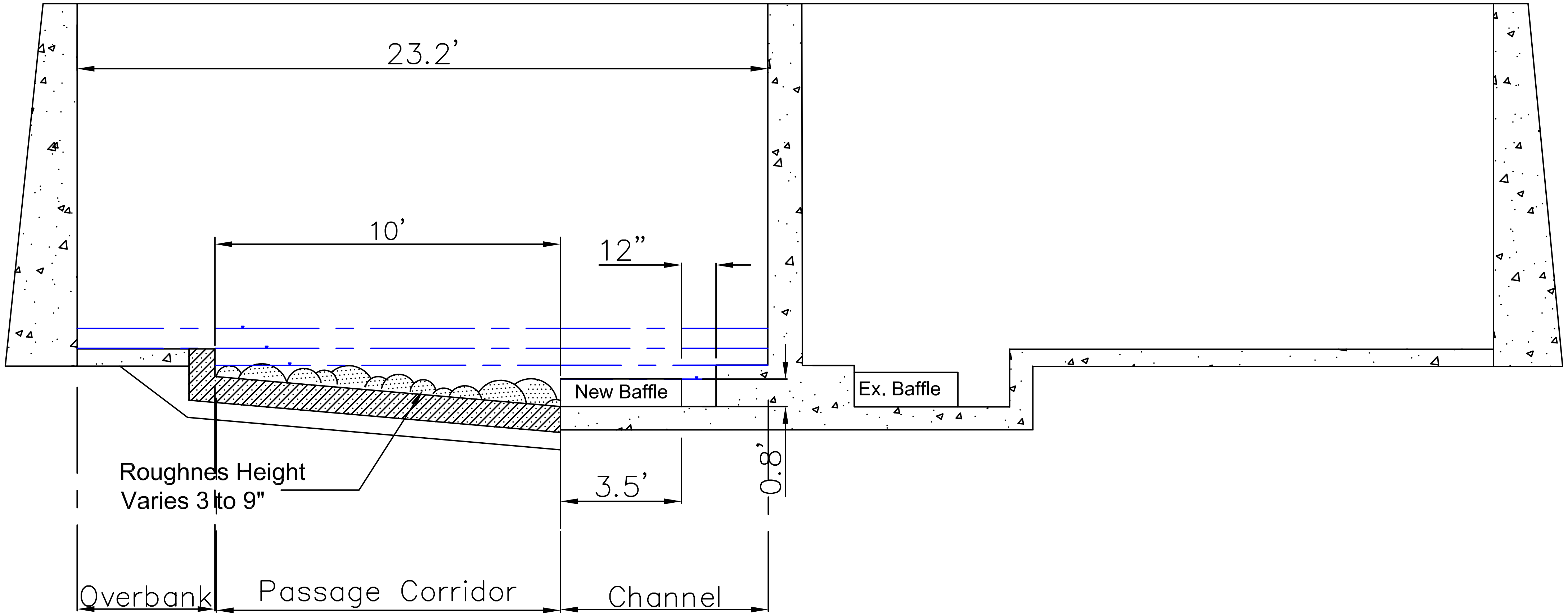
REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

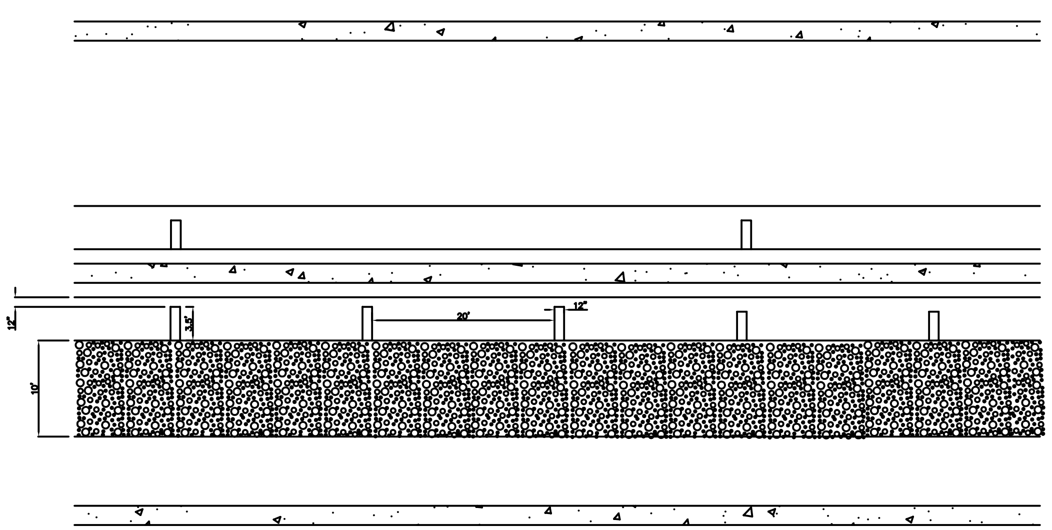
Reach 7

Design B

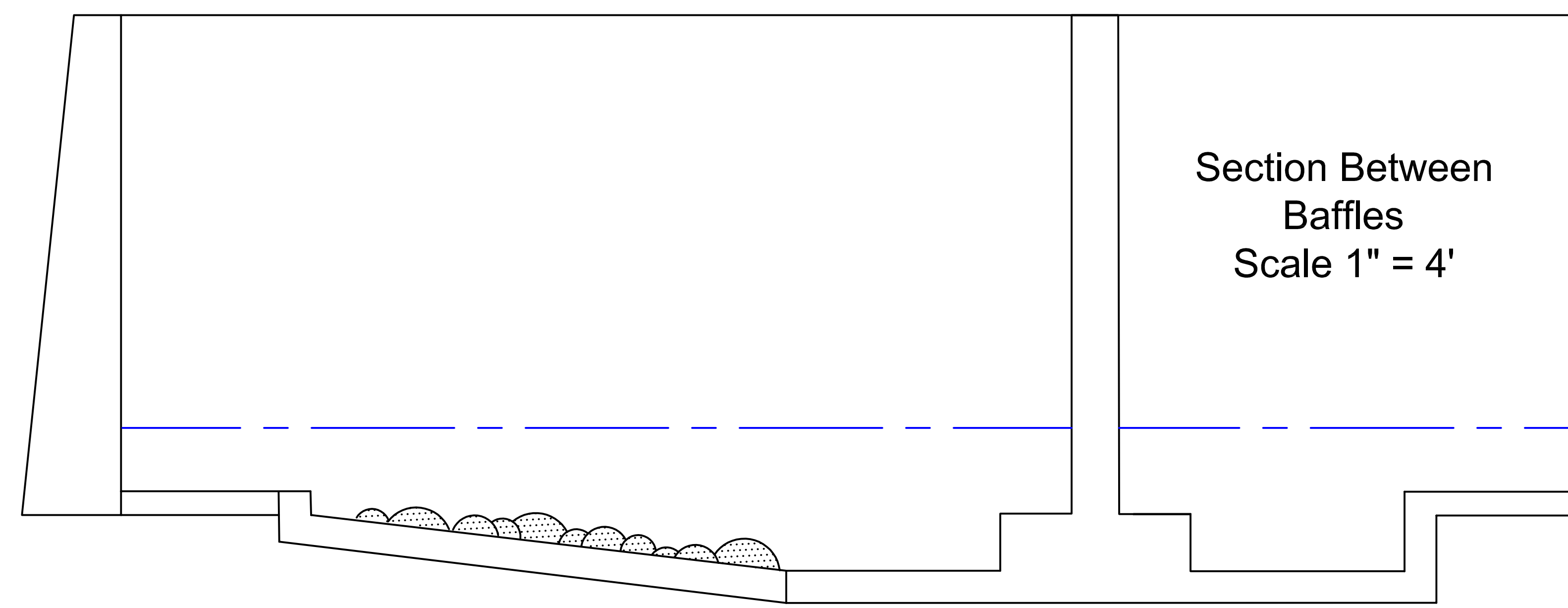
SHEET NO. 3 OF 4



Section At Baffle
Scale 1" = 4'



Plan View
Scale 1" = 20'



Section Between Baffles
Scale 1" = 4'

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

Reach 7

Design C

SHEET NO. 4 OF 4

Mill Creek Fish Passage Assessment - Cost Estimate

Mill Creek Fish Passage Assessment - Cost Estimate					Reach 7a	120
Date:	5/3/2009				Reach 7b	180
Reach:	7				Reach 7c	420
Reach Length:	1140	ft	Note: Total Reach 7 Length = 1140			
Design:	**A**	**Revised baffles with resting pools**				
Design Level:	30%					
Cost Per Foot:	**$536**					

Description	**Unit**	**Qty**	**t (in)**	**Cost**	**Amount**	**Sub Total**	***Comments***
Mob, Access and Water Management						$95,000	
Mobilization	L.S.	1		$60,000.00	$60,000		*Typically 10% of construction costs*
Access	L.S.	1		$20,000.00	$20,000		
Water Management	L.S.	1		$15,000.00	$15,000		
Concrete Demolition						$2,372	
Concrete Slab cutting	L.F.	0		$4.84	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*per inch of depth*
Concrete Wall cutting (with rebar)	L.F.	0	8	$11.45	$0		*per inch of depth*
Blades	ea.	3		$625.00	$1,875		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	1		$140.00	$140		
Remove Whole Pieces	ea.	1		$140.00	$140		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	1		$200.00	$200		
Hauling	C.Y.	1		$7.00	$7		
Concrete Disposal	C.Y.	1		$10.00	$10		
Rienforced Concrete Form and Pour						$0	
Excavation	C.Y.	0		$15.00	$0		
Disposal	C.Y.	0		$20.00	$0		*High cost for getting out of flume area*
Subgrade	C.Y.	0		$60.00	$0		*Crushed Rock*
Concrete Underpining	C.Y.	0		$2,100.00	$0		
Precast	S.F.	0		$9.20	$0		*4 to 5" thickness*
Concrete Slabs	C.Y.	0		$700.00	$0		
Concrete Walls	C.Y.	0		$900.00	$0		
Grouting	S.F.	0		$2.76	$0		*Assumes 1/4 C.Y. per foot*
Cobble/Roughness Finish	S.F.	0		$1.73	$0		*$1.73 for exposed agg finish*
Baffles						$26,514	
Concrete Slab cutting	L.F.	57		$10.78	$614		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	37		$700.00	$25,900		
Resting Pools						$309,333	
Primary	ea.	6		$10,126.00	$60,756		
Secondary	ea.	57		$4,361.00	$248,577		
Construction Total						**$433,219**	
Contingency	15%					$64,983	
Sales Tax	7.7%					$38,400	
Engineering	10%					$49,800	
Project Management	5%					$24,900	
Project Total						**$611,300**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate

Date:	5/3/2009		
Reach:	7		
Reach Length:	1140	ft	Note: Total Reach 7 Length = 1140
Design:	**B**	**5 ft cut out section with roughness**	
Design Level:	30%		
Cost Per Foot:	**$352**		

Reach 7a	120
Reach 7b	180
Reach 7c	420

Description	Unit	Qty	t (in)	Cost	Amount	Sub Total	*Comments*
Mob, Access and Water Management						$65,000	
Mobilization	L.S.	1		$30,000.00	$30,000		*Typically 10% of construction costs*
Access	L.S.	1		$20,000.00	$20,000		
Water Management	L.S.	1		$15,000.00	$15,000		
Concrete Demolition						$150,909	
Concrete Slab cutting	L.F.	1140		$4.84	$5,518		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*per inch of depth*
Concrete Wall cutting (with rebar)	L.F.	1140	8	$11.45	$104,424		*per inch of depth*
Blades	ea.	5		$625.00	$3,125		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	106		$140.00	$14,840		
Remove Whole Pieces	ea.	0		$140.00	$0		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	106		$200.00	$21,200		
Hauling	C.Y.	106		$7.00	$742		
Concrete Disposal	C.Y.	106		$10.00	$1,060		
Rienforced Concrete Form and Pour						$68,739	
Excavation	C.Y.	158		$15.00	$2,370		
Disposal	C.Y.	158		$20.00	$3,160		*High cost for getting out of flume area*
Subgrade	C.Y.	169		$60.00	$10,140		*Crushed Rock*
Concrete Underpining	C.Y.	0		$2,100.00	$0		
Precast	S.F.	5700		$9.20	$52,440		*4 to 5" thickness*
Concrete Slabs	C.Y.	0		$700.00	$0		
Concrete Walls	C.Y.	0		$900.00	$0		
Grouting	S.F.	228		$2.76	$629		*Assumes 1/4 C.Y. per foot*
Cobble/Roughness Finish	S.F.	0		$1.73	$0		*$1.73 for exposed agg finish*
Baffles						$0	
Concrete Slab cutting	L.F.	0		$10.78	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	0		$700.00	$0		
Resting Pools						$0	
	ea.	0		$10,126.00	$0		
Construction Total						**$284,648**	
Contingency	15%					$42,697	
Sales Tax	7.7%					$25,200	
Engineering	10%					$32,700	
Project Management	5%					$16,400	
Project Total						**$401,600**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate							Reach 7a	120
Date:	2/7/2009						Reach 7b	180
Reach:	7						Reach 7c	420
Reach Length:	1140	ft	Note: Total Reach 7 Length = 1140					
Design:	**C**	**10 ft cut out section with roughness**						
Design Level:	30%							
Cost Per Foot:	**$897**							

Description	**Unit**	**Qty**	**t (in)**	**Cost**	**Amount**	**Sub Total**	***Comments***
Mob, Access and Water Management						$125,000	
Mobilization	L.S.	1		$90,000.00	$90,000		*Typically 10% of construction costs*
Access	L.S.	1		$20,000.00	$20,000		
Water Management	L.S.	1		$15,000.00	$15,000		
Concrete Demolition						$257,573	
Concrete Slab cutting	L.F.	4000		$4.84	$19,360		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*per inch of depth*
Concrete Wall cutting (with rebar)	L.F.	1140	12	$11.45	$156,636		*per inch of depth*
Blades	ea.	10		$625.00	$6,250		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	211		$140.00	$29,540		
Remove Whole Pieces	ea.	0		$140.00	$0		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	211		$200.00	$42,200		
Hauling	C.Y.	211		$7.00	$1,477		
Concrete Disposal	C.Y.	211		$10.00	$2,110		
Rienforced Concrete Form and Pour						$342,292	
Excavation	C.Y.	970		$15.00	$14,550		
Disposal	C.Y.	970		$20.00	$19,400		*High cost for getting out of flume area*
Subgrade	C.Y.	300		$60.00	$18,000		*Crushed Rock*
Concrete Underpining	C.Y.	0		$2,100.00	$0		
Concrete Slabs	C.Y.	317		$700.00	$221,900		
Concrete Walls	C.Y.	48		$900.00	$43,200		
Grouting	S.F.	2000		$2.76	$5,520		*Assumes 1/4 C.Y. per foot*
Cobble/Roughness Finish	S.F.	####		$1.73	$19,722		*$1.73 for exposed agg finish*
Baffles						$0	
Concrete Slab cutting	L.F.	0		$10.78	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	0		$700.00	$0		
Resting Pools						$0	
	ea.	0		$10,126.00	$0		
Construction Total						**$724,865**	
Contingency	15%					$108,730	
Sales Tax	7.7%					$64,200	
Engineering	10%					$83,400	
Project Management	5%					$41,700	
Project Total						**$1,022,900**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate

Date:	5/3/2009
Reach:	Primanry Resting Pool
Design Level:	30%

Description	Unit	Qty	t (in)	Cost	Amount	Sub Total	Comments
Resting Pools	**1**					$10,126	*10 long by 5 wide*
Concrete Slab cutting	L.F.	0		$10.78	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	0		$900.00	$0		
Concrete Wall cutting (with rebar)	L.F.	33	9	$11.45	$3,401		*per inch of depth*
Excavation	C.Y.	5		$15.00	$75		
Subgrade	C.Y.	1.5		$60.00	$90		*Crushed Rock*
Disposal	C.Y.	1.5		$20.00	$30		*High cost for getting out of flume area*
Concrete Underpining	C.Y.	1.8		$2,100.00	$3,780		
Concrete Slabs	C.Y.	2		$700.00	$1,400		
Concrete Walls	C.Y.	1.5		$900.00	$1,350		*Includes Weirs*
Construction Total						**$10,126**	

Opinions of Probable Construction Cost

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Mill Creek Fish Passage Assessment - Cost Estimate

Date: 5/3/2009

Reach: Secondary Resting Pool

Design Level: 30%

Description	Unit	Qty	t (in)	Cost	Amount	Sub Total	Comments
Resting Pools	**1**					$4,361	*5 by 5 wide*
Concrete Slab cutting	L.F.	0		$10.78	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	0		$900.00	$0		
Concrete Wall cutting (with rebar)	L.F.	20	9	$11.45	$2,061		*per inch of depth*
Excavation	C.Y.	2		$15.00	$30		
Subgrade	C.Y.	0.5		$60.00	$30		*Crushed Rock*
Disposal	C.Y.	1		$20.00	$20		*High cost for getting out of flume area*
Concrete Underpining	C.Y.	0.5		$2,100.00	$1,050		
Concrete Slabs	C.Y.	0.9		$700.00	$630		
Concrete Walls	C.Y.	0.6		$900.00	$540		*Includes Weirs*
Construction Total						**$4,361**	

Opinions of Probable Construction Cost

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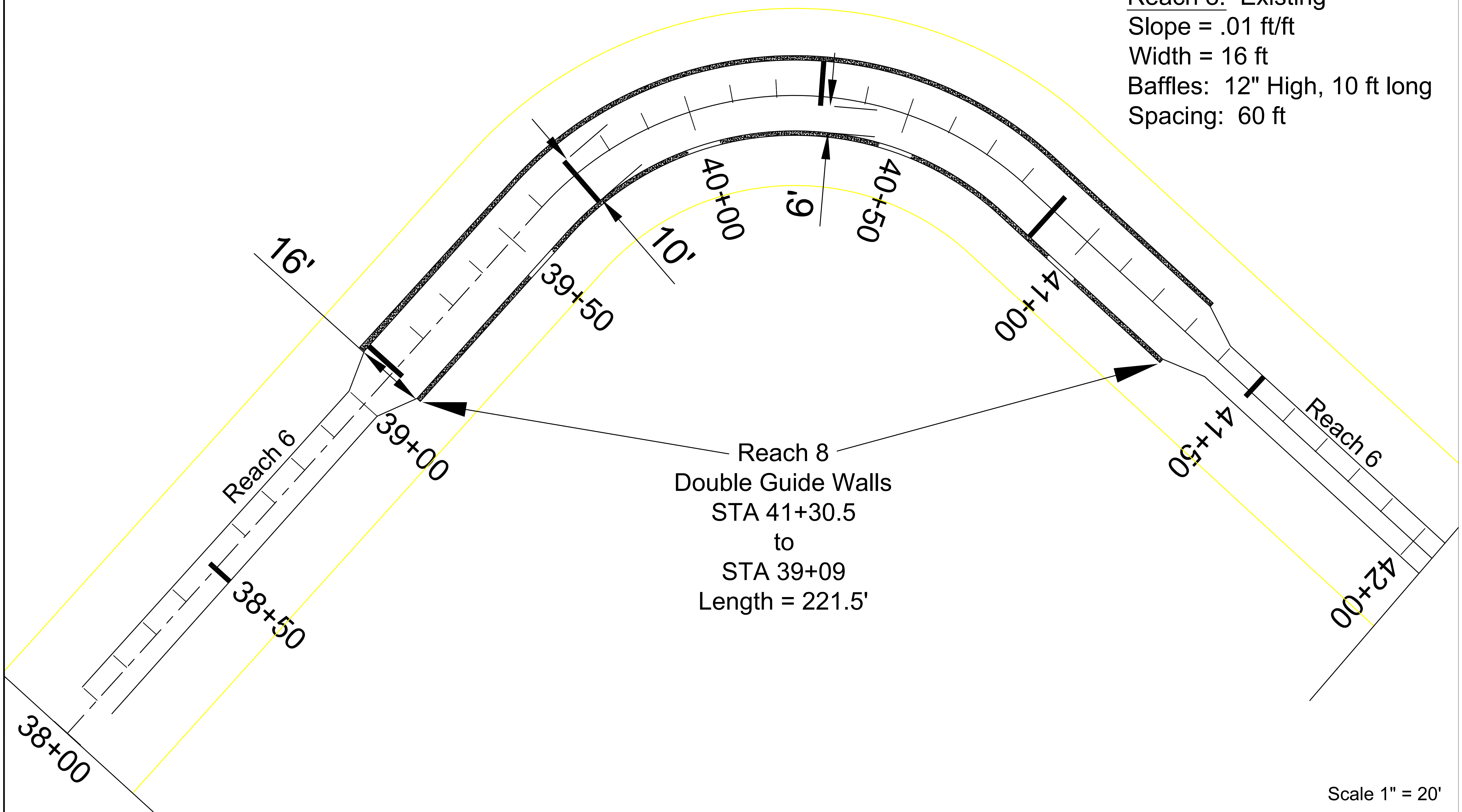
Reach 8: Existing
Slope = .01 ft/ft
Width = 16 ft
Baffles: 12" High, 10 ft long
Spacing: 60 ft



Scale 1" = 20'

TRI-STATE STEELHEADERS

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

REV	DATE	BY	APP'D	DESCRIPTION

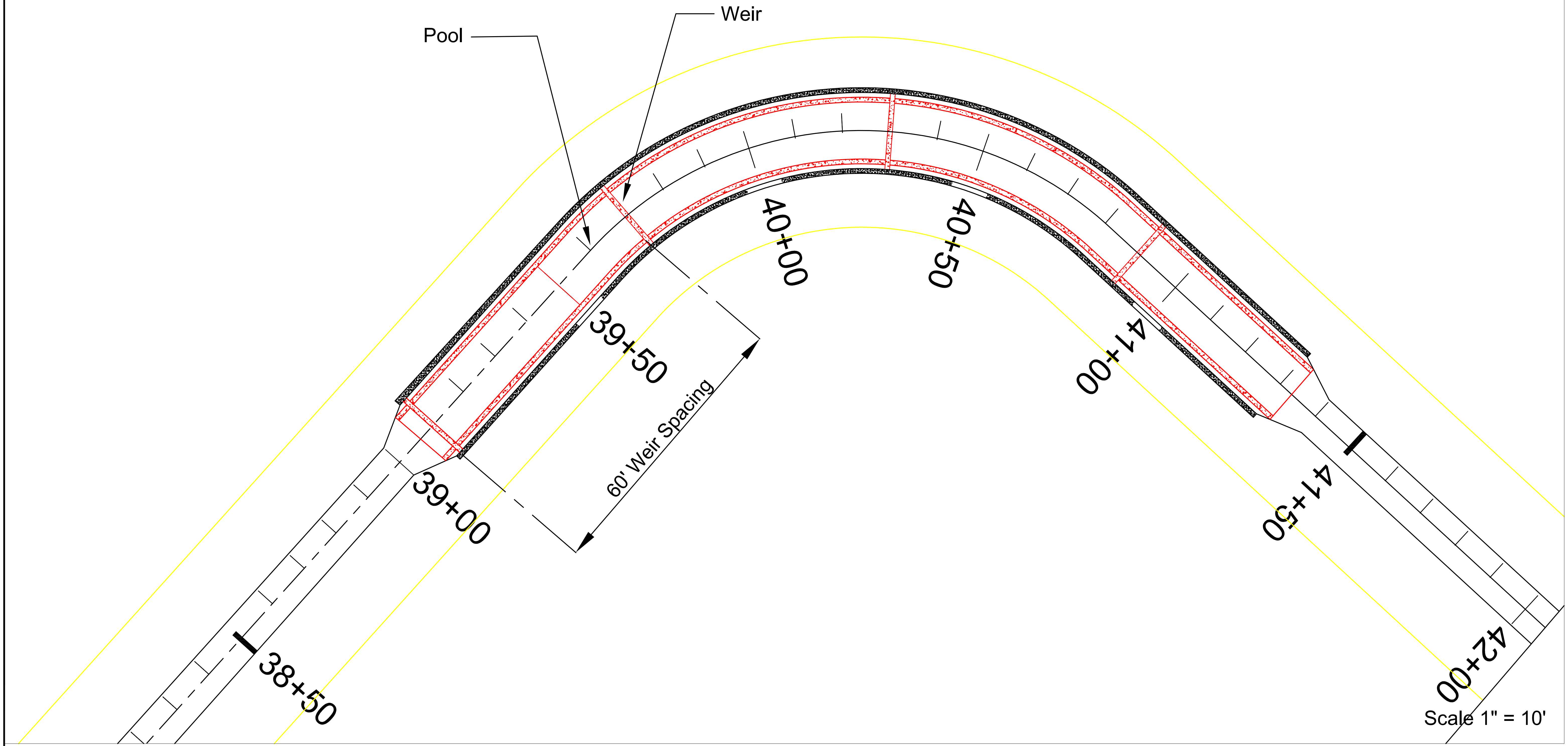
DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

Reach 8

Existing

SHEET NO. 1 OF 4

Reach 8: Proposed
Width = 16 ft
Weirs: 3' High, 14 ft long
Pool Depth: 3 to 6 ft



Mill Creek Fish Passage Assessment

Conceptual Design

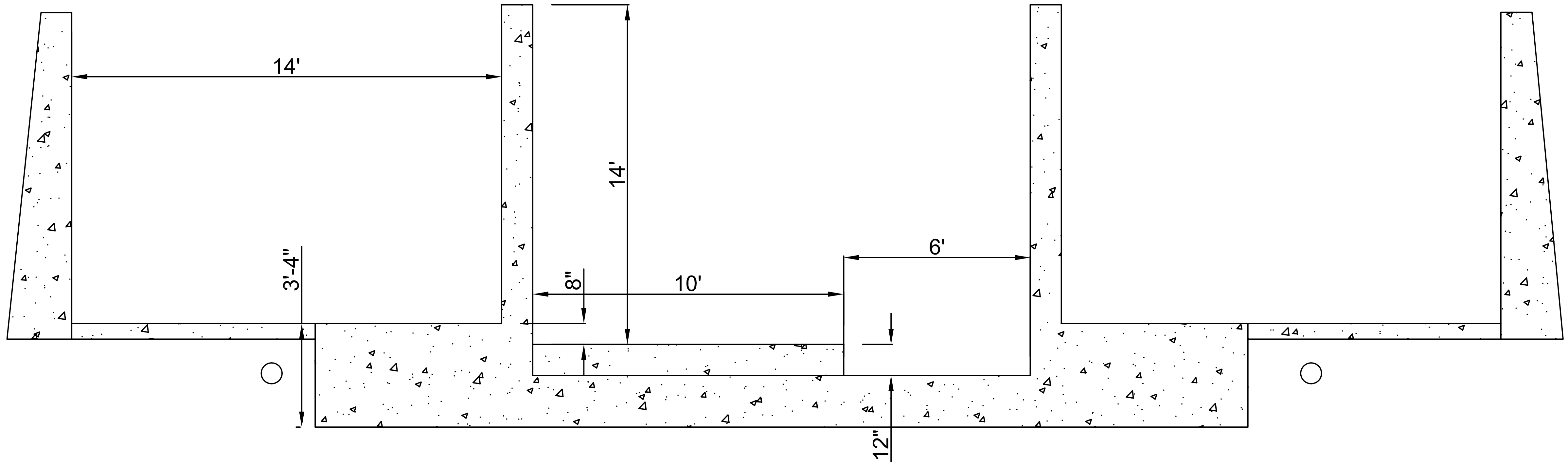
REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

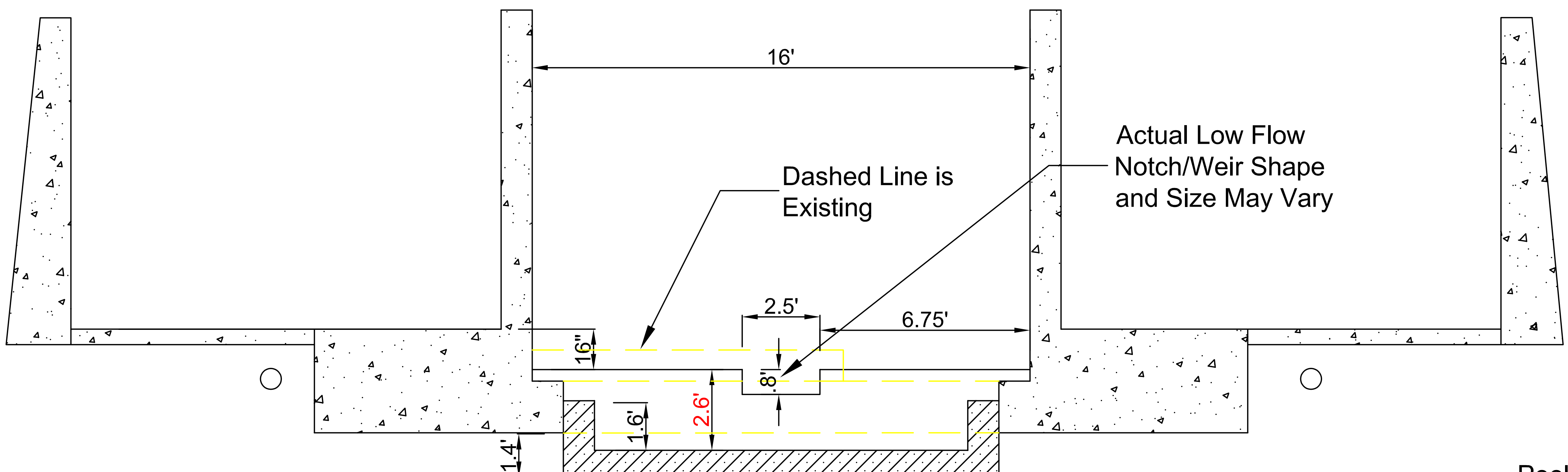
Reach 8

Proposed

SHEET NO. 2 OF 4



Existing
Section
Scale 1" = 4'



Pool and Weir - Proposed
Section
Scale 1" = 4'

TRI-STATE STEELHEADERS

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

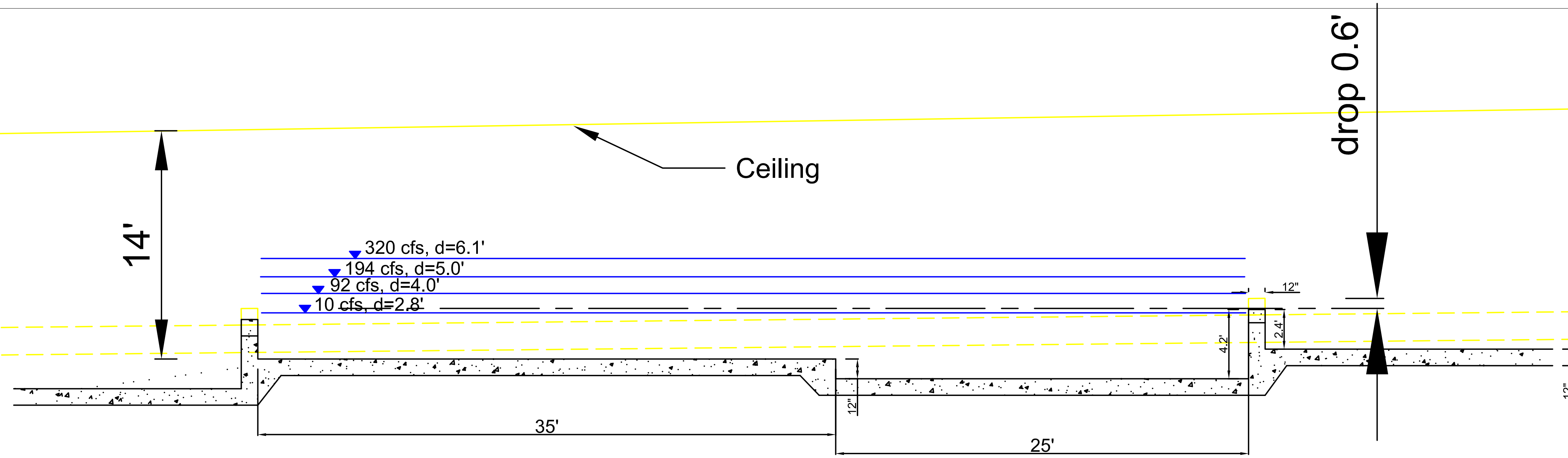
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

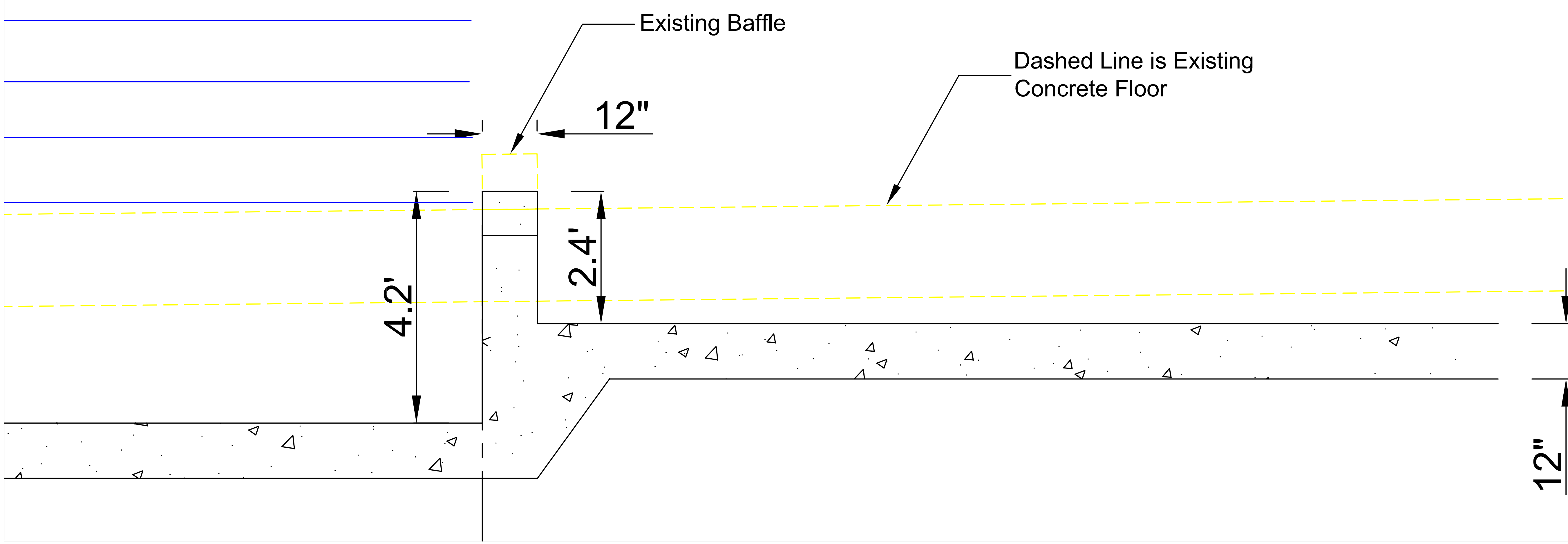
Reach 8

Section

SHEET NO. 3 OF 4



Pool and Weir
Profile
Scale 1" = 8'



Pool and Weir
Profile Detail
Scale 1" = 2'

TRI-STATE STEELHEADERS

Mill Creek Fish Passage Assessment

Conceptual Design

REVISIONS

REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
FILE:
DATE:

Reach 8 - Pool and Weir

Profile

SHEET NO. 4 OF 4

Mill Creek Fish Passage Assessment - Cost Estimate

Date:	2/11/2009		
Reach:	8		
Reach Length:	222 ft		
Design Level:	30%	$3,204	Cost Per Foot

Project Description: Reach 8 is a rectangular shaped channel split into three channels by divider walls. The reach turns to the left 90 degrees and is 222 feet long. The center (or channel section) is 16 feet wide, has baffles spaced 60 feet apart. Baffles are 10 feet long and 1 foot high. The design proposal is to cut out the floor and modify the weirs to create a pool and weir fishway. The fishway would function up to 140 cfs (195 cfs in Mill Creek, with drops of 0.6 feet and EDF less than 4. Above 140 cfs, the fishway would transition to streaming flow. The Fish Passage Energetics Model calculates Steelhead would be by swimming through the center section and pass through with 60% of their energy left. Resting pools at the upstream and downstream end are recommended.

Description	Unit	Qty	t (in)	Cost	Amount	Sub Total	*Comments*
Mob, Access and Water Management						$86,000	
Mobilization	L.S.	1		$50,000.00	$50,000		*Typically 10% of construction costs*
Access	L.S.	1		$20,000.00	$20,000		*Needs Discussion With City For Concept*
Water Management	L.S.	1		$8,000.00	$8,000		
Utilities	L.S.	1		$8,000.00	$8,000		
Concrete Demolition						$93,505	
Concrete Slab cutting	L.F.	1500		$16.72	$25,080		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Wall cutting (plain)	L.F.	0	0	$7.00	$0		*per inch of depth*
Concrete Wall cutting (with rebar)	L.F.	0	12	$11.45	$0		*per inch of depth*
Blades	ea.	5		$1,750.00	$8,750		*12" = $625, 36" = $1750*
Breaking up for Removal	C.Y.	0		$140.00	$0		
Remove Whole Pieces	ea.	124		$140.00	$17,360		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	195		$200.00	$39,000		
Hauling	C.Y.	195		$7.00	$1,365		
Concrete Disposal	C.Y.	195		$10.00	$1,950		
Rienforced Concrete Form and Pour						$197,540	
Excavation	C.Y.	460		$25.00	$11,500		
Disposal	C.Y.	460		$25.00	$11,500		*High cost for getting out of flume area*
Subgrade	C.Y.	58		$80.00	$4,640		*Crushed Rock*
Concrete Underpining	C.Y.	16		$2,100.00	$33,600		
Concrete Slabs	C.Y.	115		$700.00	$80,500		
Concrete Walls	C.Y.	62		$900.00	$55,800		*Includes Weirs*
Grouting	S.F.	0		$2.76	$0		*Assumes 1/4 C.Y. per foot*
Cobble/Roughness Finish	S.F.	0		$1.73	$0		*$1.73 for exposed agg finish*
Resting Pools	**2**					$20,251	*10 long by 5 wide*
Concrete Slab cutting	L.F.	0		$10.78	$0		*Overbank Area, 6" slab, 12" = $10.78, 18" = $16.72*
Concrete Walls	C.Y.	0		$900.00	$0		
Concrete Wall cutting (with rebar)	L.F.	33	9	$11.45	$3,401		*per inch of depth*
Excavation	C.Y.	5		$15.00	$75		
Subgrade	C.Y.	1.5		$60.00	$90		*Crushed Rock*
Disposal	C.Y.	1.5		$20.00	$30		*High cost for getting out of flume area*
Concrete Underpining	C.Y.	1.8		$2,100.00	$3,780		
Concrete Slabs	C.Y.	2		$700.00	$1,400		
Concrete Walls	C.Y.	1.5		$900.00	$1,350		*Includes Weirs*
Construction Total						**$397,296**	
Contingency	30%					$119,189	
Sales Tax	7.7%					$39,800	
Engineering	20%					$103,300	
Project Management	10%					$51,600	
Project Total						**$711,200**	

Opinions of Probable Construction Cost

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Appendix A7 – Fish Passage Summary Sheets

Mill Creek Fish Passability Detail Spreadsheet

Mill Creek Fish Passability Summary Spreadsheet

Mill Creek Fish Pasability Detail Spreadsheet

Run Date 10/27/2008

	Flow	6 cfs									20 cfs									60 cfs								
		Steelhead			Chinook			Bull Trout			Sthd			Chnk			BT			Sthd			Chnk			BT		
Reach definition		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	Channel sills	0	0	D	0	0	D	0.2	12	RD	0	0	D	0	0	D	1	70	RD	0	0	D	0	0	D	1	84	R
2	Transition to flume	1	81	RD	1	82	RD	0	28	D	1	56	D	1	56	D	0	32	SR	0	70	S	0	68	S	0	28	S
3	Flume - trapezoidal, 6-ft baffles	0	45	SD	0	45	SD	0	96	SR	1	38	R	1	39	R	0	75	SR	1	23	R	1	7	R	0	45	S
4	Flume split - trapezoidal, 3-ft baffles	0	45	SDR	0	45	SDR	0	98	SDR	1	64	D	1	68	RD	0	76	SR	1	21	R	1	23	R	0	42	S
5	Flume transition to flat (#4)	0	45	SDR	0	45	SDR	0	98	SDR	1	64	D	1	68	RD	0	76	SR	1	21	R	1	23	R	0	42	S
6	Flume - flat, 6-ft baffles (#3)	0	45	SD	0	45	SD	0	96	SR	1	38	R	1	39	R	0	75	SR	1	23	R	1	7	R	0	45	S
7	Flume split - flat, 3-ft baffles (#4)	0	45	SDR	0	45	SDR	0	98	SDR	1	64	D	1	68	RD	0	76	SR	1	21	R	1	23	R	0	42	S
8	Flume split - 10-ft baffles	0	33	D	0	32	D	0	49	SDR	1	44	RD	1	42	RD	0.4	137	0	1	37	D	1	41	R	0	49	S
9	Flume transition to trapezoidal (#3)	0	45	SD	0	45	SD	0	96	SR	1	38	R	1	39	R	0	75	SR	1	23	R	1	7	R	0	45	S
10	Roosevelt Bridge	1	80	DR	1	81	DR	0	58	S	1	72	R	1	73	R	0	44	S	1	27		1	29		0	34	S
11	Transition fishway	0		D	0		D	0		HDT	0.7			0.7			0.2		H	1			1			0.3		HT
12	Division Dam and Fishway 6" exit	0		D	0		D	0.1	fw	HDT	0		D	0		D	0.1	fw	T	0.3	fw	DT	0.3	fw	D	0		HT
	Division Dam and Fishway 18" exit										0		D	0		D	0.5	fw	HDT	0.3	fw	DT	0.3	fw	DT	0.2	fw	DTV

	Flow	100 cfs									200 cfs									400 cfs								
		Sthd			Chnk			BT			Sthd			Chnk			BT			Sthd			Chnk			BT		
Reach definition		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	Channel sills	1	90	RD	1	89	RD	1	81	R	1	94	RD	1	92	RD	1	51		1	89		1	89		0.8	16	S
2	Transition to flume	0	34	S	0	20	S	0	22	S	1	88		1	88		0	28	S	1	74		1	74		0	28	S
3	Flume - trapezoidal, 6-ft baffles	0	40	S	0	75	S	0	20	S	1	62		1	66		0	30	S	1	88		1	88		0	30	S
4	Flume split - trapezoidal, 3-ft baffles	0	63	S	0	83	S	0	20	S	1	62		1	67		0	46	S	1	88		1	88		0	38	S
5	Flume transition to flat (#3)	0	74	S	0	90	S	0	0	S	0	64	S	0	72	S	0	0	S	0	236	S	0	238	S	0	0	S
6	Flume - flat, 6-ft baffles (#3)	0	56	S	0	58	S	0	24	S	1	70		1	70		0	42	S	0.8	352		1	9		0	20	S
7	Flume split - flat, 3-ft baffles (#4)	0	0	S	0	0	S	0	0	S	0	240	S	0	240	S	0	0	S	0	116	S	0	116	S	0	0	S
8	Flume split - 10-ft baffles	0	10	S	0	0	S	0	0	S	0	31	S	0	51	S	0	0	S	1	43	R	1	42	R	0	20	S
9	Flume transition to trapezoidal (#3)	0	36	S	0	46	S	0	22	S	0.4	82	SR	1	50	R	0	28	S	1	80		1	81		0	28	S
10	Roosevelt Bridge	0	54	S	0	54	S	0	30	S	1	31	R	1	41	R	0	32	S	1	89	R	1	89	R	0	34	S
11	Transition fishway	1			1			0.4		HT	0.3		T	0.3		T	0		HT	0.1		T	0.1		T	0		HT
12	Division Dam and Fishway 6" exit																											
	Division Dam and Fishway 18" exit	0.6	fw	T	0.6	fw	T	0.3	fw	VT	0.3	fw	T	0.3	fw	T	0.1	dm	VT	0.7	dm	T	0.6	dm	T	0.1	dm	HTV

NOTES

Flume reaches 1-10

A Passability.
- 1 = passable for 100% of species. Blue font when passability >= 0.5
- 0 = impassable. Red font when passability < 0.5
- Example: 0.4 = 40% of species can pass.

B If A=1, B is weighted average energy left at end of reach.
If A<1, B is weighted average distance swum through reach.

C Notes
- S Stamina failure
- D Depth diminished stamina
- SR Stamina failure; fish were able to rest
- SD Stamina failure; stamina was reduced by low depth
- SDR Stamina failure; stamina was reduced by low depth and fish were able to rest

Fishways 11-12

A Passability.
- 1 = passable for 100% of species. Blue font when passability >= 0.5
- 0 = impassable. Red font when passability < 0.5
- Example: 0.4 = 40% of species can pass.

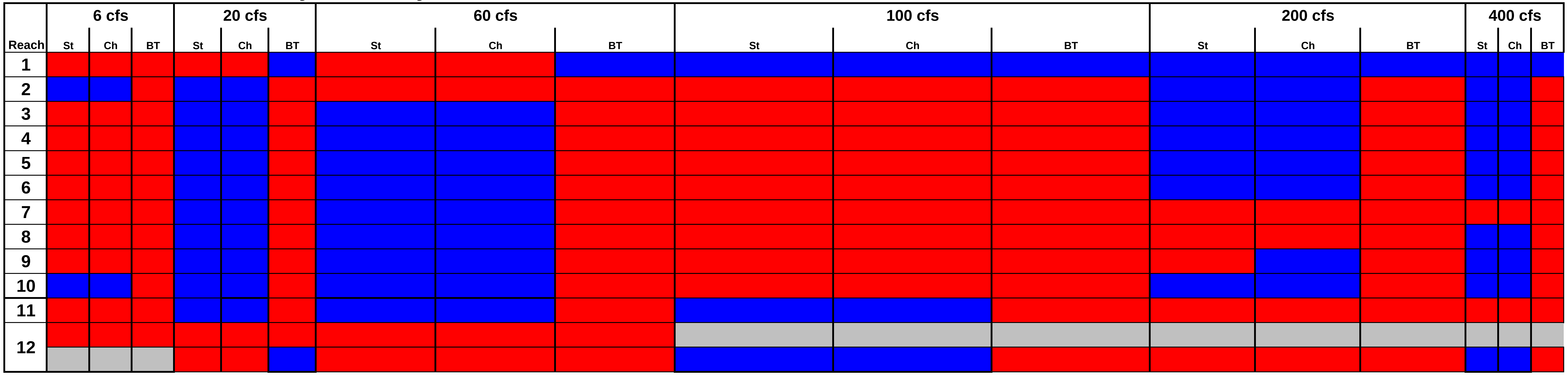
B At Division Dam, passage route reported is the best offered at the flow.
- Fw Passage at fishway
- Dm Passage over dam

C Primary barrier characteristics at fishway (parameter value is <0.5)
- H Height barrier
- D Depth barrier
- T Turbulence barrier
- V Velocity at entrance

The following is an explanation of the detailed fish passage spreadsheet in Appendix A8. The spreadsheet is separated into two blocks (6, 20 and 60 cfs), and (100, 200 and 400 cfs). Each block is separated into three segments, which represent each flow. Within each segment are three species. For each species of fish there are three additional columns that provide information about passability (A), energy left or distance swam (B) and notes about what the failure mechanism was (C). If a fish did not pass through the reach, it is recorded as "0" passage and the station at which the fish was exhausted is recorded. If a fish was able to pass through the reach, the remaining energy of the fish was recorded.
In the notes column the letters represent the following:
S = stamina (energy) failure
R = the fish was able to rest within the reach

The rows represent the reaches. Reach 12 has two rows for the two fishway slot widths. Also, Reaches 11 and 12 are analyzed as fishways so the A, B and C columns represent different numbers as was described in Section 4.3. The notes column is described as:
H = height barrier
D = depth barrier
T = turbulence barrier (EDF)
V = velocity barrier
Fw = passage best at fishway
Dm = passage best at dam
For Example:
Reach 1, 20 cfs: Steelhead and Chinook were not able to pass due to depth, but Bull Trout were able to pass with 70% of their energy left, but the depth diminished their stamina.
Reach 2, 100 cfs: All fish failed to pass due to stamina failure. Steelhead swam 34 feet, Chinook 20 feet and Bull Trout 22 feet.
Reach 3, 60 cfs: Steelhead were able to pass with 23% of their energy left and they rested to pass. Chinook were able to pass with only 7% of their energy left and they rested to pass. Bull Trout failed due to stamina and were able to swim 45 feet. Reach 3 lengths are given in Table 2.1.
Note: It is important to remember that "23% of the Steelhead", is the weighted average of the three size ranges analyzed. The actual remaining energy for the steelhead sizes of 22, 26 and 28 inches were 13%, 24% and 26% respectively.
Reach 11, 200 cfs: 30% of Steelhead and Chinook can pass and are limited by turbulence. Bull Trout cannot pass due to height and turbulence barrier.
Reach 12, 100 cfs: 60% of the Steelhead and Chinook can pass with turbulence affecting passage. 30% of the Bull Trout can pass with passage affected by velocity and turbulence.

Mill Creek Fish Passability Summary



Barrier

Passable

Note: The larger cell sizes represent the flow frequency. For example: 100 cfs occurs 32% of the time as compared to 6 cfs which only occurs 8% of the time.