MILL CREEK PASSAGE DESIGN – UPPER FLUME

BASIS FOR DESIGN REPORT - SRFB PROJECT # 15-1324

Figure 1 - Upstream view of typical channel at low flow.

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1 INTRODUCTION AND BACKGROUND INFORMATION

The report covers the design for fish passage on 5000 feet of Mill Creek in the concrete flume sections from Park Street to Roosevelt Street. The design builds upon a series of projects which have been constructed on Mill Creek. Stationing is in reference to the US Army Corps of Engineers (USCOE) Mill Creek Channel Improvement Projects where STA 0+00 was identified as the Union Pacific Railroad Crossing downstream. See Figure 2 for a site map. There are four bridge crossings within the project area (Table 1). The channel slope changes from 1 percent to 1.2 percent between Park and Otis Street.

STA	Length (ft)	Description
73+07	34	Otis Street Bridge
76+64	34	Merriam Street Bridge
85+35	39	Clinton Street Bridge
94+39	35	Division Street Bridge

Table 1 – Location and Length of Road Crossing and Bridges.

The objective of the Mill Creek Fish Passage Project is to improve fish passage, while not increasing flooding or creating obstructions to maintenance crews which annually clean debris from the channel. This segment of the Mill Creek Flood Control Channel is referenced as a Reach Type 3 (Trapezoidal Flume with 6 foot baffles), per the Mill Creek Fish Passage Assessment (Powers, et.al. 2009) . That study will be referenced throughout this report as The Assessment. Another study, the Mill Creek Fish Passage Conceptual Design Final Report (Powers, 2010) provides detailed conceptual design and cost information on why, for example, the roughened channel design option was selected. That study will be referred to throughout this report as The Conceptual Design Report. Some of the design decisions for the Project were made during Mill Creek Work Group Meetings (MCWG). A detailed physical model of the concrete flume was developed by Northwest Hydraulics in Seattle, WA. Members of the MCWG observed the model and commented on design features (Northwest Hydraulics, 2011). It is important to note when reviewing the Northwest Hydraulics Report that the document is split into a Reach Type 3 and a Reach Type 6 analysis. Reach Type 3 refers to the trapezoidal shape (i.e. sloping overbank areas) which dominates throughout the flume, and Reach Type 6 refers to the sections of flume where the overbank is flat. References to this model study will be noted as Flume Physical Model. Basis of Design Reports have been completed for four other projects on Mill Creek from 2011 to 2013. Also included in Appendix B is design validation information for the Roughness Panels for the recently completed project upstream of N. 9th Avenue. It is not the intent of this report to repeat informatioin which is available in these other studies, but to present new information based on new data. All of these documents can be found at the following FTP site.

Open internet explorer and in the address bar paste the following:
waterfallengineering.com/ppowers/files/TSS/millcreek

When you are prompted for a user name and password:

Username: millcreek
Password: waterfall

2 SITE DESCRIPTION

This project will modify the concrete flume upstream of Park Street to Roosevelt Street. The modified channel length will be 5000 feet. This is a Reach Type 3 channel (per the Assessment).

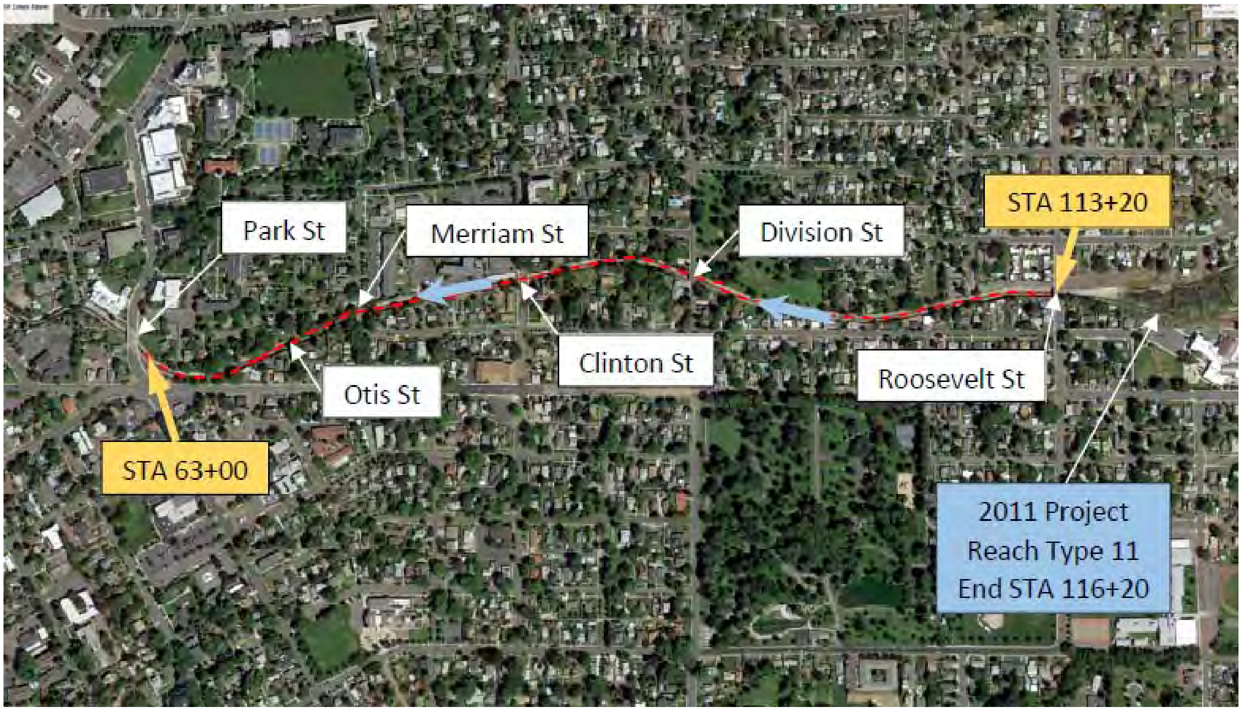

Figure 2 – Project site map. Mill Creek flow is from right to left. The downstream end of this design phase is just above Park Street and extends upstream to just below Roosevelt Street. STA 0+00 is the Union Pacific Railroad (just downstream of N. 9th Avenue).

The trench width is 9 feet with side walls 1.67 feet high. Baffles 12 inches high are spaced at 60 feet on center. The baffles are 6 feet long with a 3 foot low flow slot. The low flow slots alternate back and forth. Currently at low flow fish passage is poor due to shallow depth, and at high flow the velocities in the flume exceed the swimming ability of most fish. At some flows fish can pass. In the 30 to 60 cfs range, the depth is sufficient for passage and the roughness created by the baffles reduces the velocity so some fish can pass.

To calculate the hydraulics for each design flow, a HEC RAS model Version 5.0.3 was developed with Manning's n values which were calculated from the Flume Physical Model and then adjusted for the steeper channel slope of 1.2 percent. The model covers a channel length of 5000 feet. Two segments were modeled with the proposed and existing conditions. From STA 74+60 to STA 78+42 (387 feet), which covers Merriam Street and Bridge and from STA 10+280 to STA 10+780 (500 feet). Detailed output from HEC RAS is provided in Appendix B.

Proposed

Figure 3 - Mill Creek 1:8 Physical Model Reach Type 3. View upstream showing resting pool with cover rocks, baffles and roughened channel.

The baffles in the trench will be removed and replaced with similar concrete baffles, all on the left side. The spacing will vary from 18 to 22 feet based on a 0.2 foot drop. Baffle height will be 0.8 feet. This closer spacing will provide fish passage at low flow as the water depth is increased. In the left overbank area (as viewed downstream), a 7 foot wide section will be removed next to the trench and replaced with a lowered and roughened channel surface, see Figure 3 and **Error! Reference source not found.**. In addition, resting pools (12 feet long by 7 feet wide) will be spaced approximately every 60 feet within the roughened channel. The roughened channel will reduce the velocities so fish can pass, and the resting pools provide a factor of safety and opportunity for fish to rest and recover for a continuous migration pathway. Rocks will be embedded into the resting pool bottoms to provide diverse flow patterns and cover.

To implement this design and still provide access for maintenance trucks to drive up and down the flume the overbank area needs to be a minimum of 9 feet wide. The current vehicle used for maintenance is a One-Ton Truck with Dump Bed. From mirror to mirror the width of the truck is 9.2 feet. The truck width 7.7 feet in the back. Where the overbank width is less than 10 feet after the roughened channel is installed, the roughened channel width will be decreased accordingly unless options can be worked out for a crossing. The calculated overbank width is provided in Table 2.

At two locations (Merriam Bridge and Otis Bridge), concrete extends out into the channel restricting the width to 36 feet. In these areas there isn't enough width for both the 7 foot wide roughness panel and the 9 feet needed for a maintenance vehicle to pass with a minimum vertical clearance of 7 feet. In these two areas the roughened panel width will be reduced to 4 feet and the overbank for truck passage will be 9 feet. The hydraulic model for the 4 foot wide section does not show a significant difference in velocity due to the short length (see Appendix B). For longer lengths the 7 foot wide panels are needed. Resting pools will be spaced at 45 feet at the upstream and downstream ends of this transition from the 4 foot wide to the 7 foot wide roughness panel.

Location - STA	Channel Width (ft)	Left Overbank Width (ft)	Width for Maintenance Truck (ft)
70+00	43	18.6	11.9
72+00	43	17.6	10.9
73+00 Otis Bridge	36	14	7.2
75+00	42	17.6	10.9
76+55 Merriam Bridge	37	14	7.2
81+00	40.6	16.4	9.6
83+00	43.4	16.8	10
85+80 Clinton Bridge	44.4	16.7	9.9
90+20	45.4	19.5	12.7
94+57 Division Bridge	45	18.7	11.9
99+48	46.4	18.1	11.2
105+55	46.1	18.3	11.5
110+43	45	18	11.2
113+43	44.8	19	12.1

Table 2 – Mill Creek channel and overbank widths from Park Street to Roosevelt Street. The last column includes a 7 foot section removed for the roughened channel.

The hydraulic conditions resulting from the design are shown in Table 3. A 500 foot long section of modified channel was modeled for the fish passage calculations. Fish Passage is calculated using the Fish Energetics Model described in The Assessment. The following is a description of passability with the proposed design at the four design flows. This information is summarized in Table 3. These flows represent a range of flows from 90 percent to the 10 percent exceedance flows.

10 cfs: Ten (10) cfs is the low passage design flow. The new baffle spacing at 16 to 22 feet with a 2 foot wide low flow notch will provide a minimum water depth of one foot. The velocity is very low between baffles and fish can rest and recover to pass.

92 cfs: This flow is the 50 percent exceedance flow for passage. The velocities in the roughened channel area vary from 1.3 to 3.9 fps, with a bulk average of 2.7 fps. The fish passage energetics models shown a 26 inch Steelhead can pass 325 feet with 73 percent of their energy left. The results are similar for a 27 inch Chinook. A 12 inch Bull Trout can swim a maximum of 240 feet, and would need the resting pools to pass. The resting pools are spaced at 60 feet. At 60 feet, a 12 inch Bull Trout would have 60% of their energy left.
Note: For the fish passage calculations the actual velocity the fish is assumed to swim against is 0.9 times the average velocity for Steelhead and Spring Chinook and 0.5 times the average velocity for Bull Trout. This is due to fish size and the use of the roughness elements.

194 cfs: This flow is the high fish passage design flow for Spring Chinook and Bull Trout. The velocities in the roughened channel area vary from 3.5 to 4.7 fps, with a bulk average of 4.0 fps. A 26 inch Steelhead can pass 240 feet before they need to use the resting pools. The results are similar for a 27 inch Chinook. A 12 inch Bull Trout can swim a maximum of 154 feet, and would need the resting pools to pass.

320 cfs: This flow is the high fish passage design flow for Steelhead. The velocities in the roughened channel area vary from 3.2 to 6.1 fps, with a bulk average of 4.9 fps. A 26 inch Steelhead can swim a maximum distance of 180 feet, and would need the resting pools to pass. The resting pools are spaced at 60 feet. For a channel length of 60 feet, a 26 inch Steelhead would use only 20% of their energy left. After a series of pools and migrating upstream, fish energy would vary from 50 to 20%. An assumption from the energetics model calculations is that fish only recover 50 percent of their energy in the resting pools (Powers, et.al. 2009).

These calculations are based on average velocity and do not take into account the lateral and vertical variation of point velocities within the roughened channel (Powers, 2014). Design validation of the roughness panels has documented that at an average velocity of 3.1 fps, lateral velocities in the boundary layer where the depth is less can be as low as 2.0 fps, and in the vertical direction velocities can be less than one fps near the top and behind the 6 inch high roughness elements. These lower velocities could be used by fish to hold and recover on a more frequent basis to pass, therefore not needing the resting pools to recover.

			Percent Energy Left After Swimming 325 Feet or Maximum Swimming Distance		
Flow (cfs)	Average Velocity Range (fps)	Roughened Channel Bulk Average Velocity (fps)	26″ Steelhead	27″ Chinook	12″ Bull Trout
92	1.9 to 3.3	2.7	73%	71%	260 feet
194	3.5 to 4.7	4.0	240 feet	240 feet	80 feet
320	3.2 to 6.1	4.9	180 feet	N/A	N/A

Table 3 – Summary of Fish Passage Conditions Modeled with 325 feet of modified Reach Type 3 Channel.

3 OTHER DESIGN INFORMATION

Mannings n

The Manning coefficient, *n*, is an empirically derived coefficient, which is dependent on many factors. Values were developed from the Flume Physical Model (NHC, 2011) for the design flows used in this study and modified based on the increased slope from 1.0 to 1.2 percent. This requires some explanation. On December 16, 2015 model calibration measurements and observations were made in the flume downstream of Roosevelt Street. The flow was 104 cfs. The depth and velocity measured was less and more, respectively compared to the one percent reach. Based on variables in the Manning's equation this change in slope may result in a 25 percent decrease in roughness for the existing conditions. For the proposed conditions with the roughness panels it was estimated to be a 9 percent reduction in roughness. Based on these reductions the roughness values were modified as a percentage and a new table of roughness created for the 1.2 percent slope portion on the flume. This resulted in higher existing velocities for each design flow analyzed. This was the calculation which lead to the design change of reducing the pool spacing from 80 to 60 feet.

The entire concept of providing passage in the Mill Creek Channel relies on roughness providing a reduced velocity boundary layer in a newly constructed portion of channel. This segmentation of flow areas within the cross section of the channel and the Manning's n derived for each section is an important design variable. Recent design validation monitoring of the channel section above N. 9th Avenue, design validation on the completed project from Spokane to Colville and the Physical Model Study all contribute to "fine tuning" the roughness values.

Physical Model Results						
Flow		**Existing**			**Proposd**	
	Left	Center	Right	Left	Center	Right
92	0.022	0.044	0.018	0.062	0.052	0.018
194	0.023	0.033	0.022	0.052	0.048	0.015
320	0.017	0.027	0.02	0.044	0.047	0.016
3500		0.015			0.019	
Proposed for Upper Flume				Channel Reduction		0.25
				LOB/RC Reduction		0.09
Flow		**Existing**			**Proposd**	
	Left	Center	Right	Left /RC	Center	Right
92	0.017	0.033	0.014	0.056	0.039	0.014
194	0.017	0.025	0.017	0.047	0.036	0.011
320	0.013	0.020	0.015	0.040	0.035	0.012
3500		0.011			0.014	

Figure 4 – Manning's Roughness for the Original Physical Model Studies and the Proposed Values to be used for the Modeling in this section of the flume.

Energetics Model Passage Compared to WDFW Culvert Criteria

Figure 5 is a comparison of the maximum swimming distance obtained based on calculations using the fish energetics model to the recommended culvert length criteria from Bates (2003). For example if the water velocity is 4 fps the energetics model calculations result in a maximum distance a 26 inch Steelhead can swim to be about 310 feet. At 310 feet the fish has zero energy left. At this same velocity the maximum length of a culvert per the WDFW Culvert criteria would be about 100 feet. This figure also shows a blue dashed line for the distance a Steelhead could swim to a point where 60 percent of their energy is left (160 feet). At 40 percent energy left the distance would be 210 feet.

This is a difficult comparison to make as the roughness panels provide a wide range of velocities for fish to pass. If fish swim or attempt to rest near the bottom of the panels the velocities are in the 1 to 2 fps or less range. At these velocities Steelhead can actually rest and recover energy. In either case, the resting pools are spaced at 60 feet, based on the requirement to pass smaller sized Bull Trout.

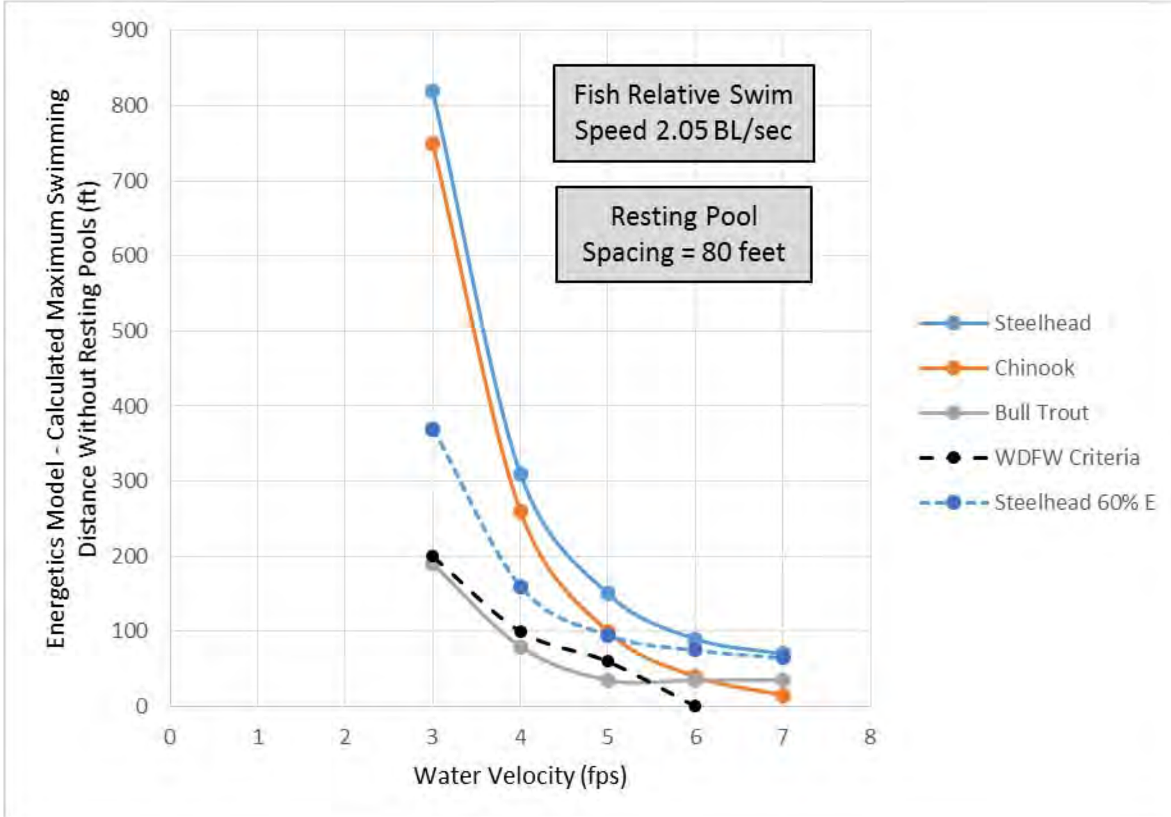

Figure 5 – Maximum calculated swimming distance based on Fish Energetics Model. The blue dashed line represents the distance a Steelhead could swim with 60 percent of their energy left. The black dashed line represents the maximum allowable culvert length per WDFW guidelines.

Resting Pools

The resting pool spacing used for the one percent channel slope is 80 feet. For the 1.2 percent slope portion a spacing of 60 feet is proposed. The spacing is based on passing Bull Trout at 194 cfs and using average velocities. At this flow, Bull Trout have 60 percent of their energy left after swimming 60 feet, and therefore should be able to rest and recover in the pools. The size of the effective resting area varies with flow. Near the bottom of the pools, the velocities are much lower as compared to the surface. At 92 cfs, the entire area of the resting pool has low velocities. As the flow increases to 194 and 320 cfs, the resting area moves to the left bank and within one foot of the bottom (see Figure 6). Three cover rocks are provided in each resting pool for cover.

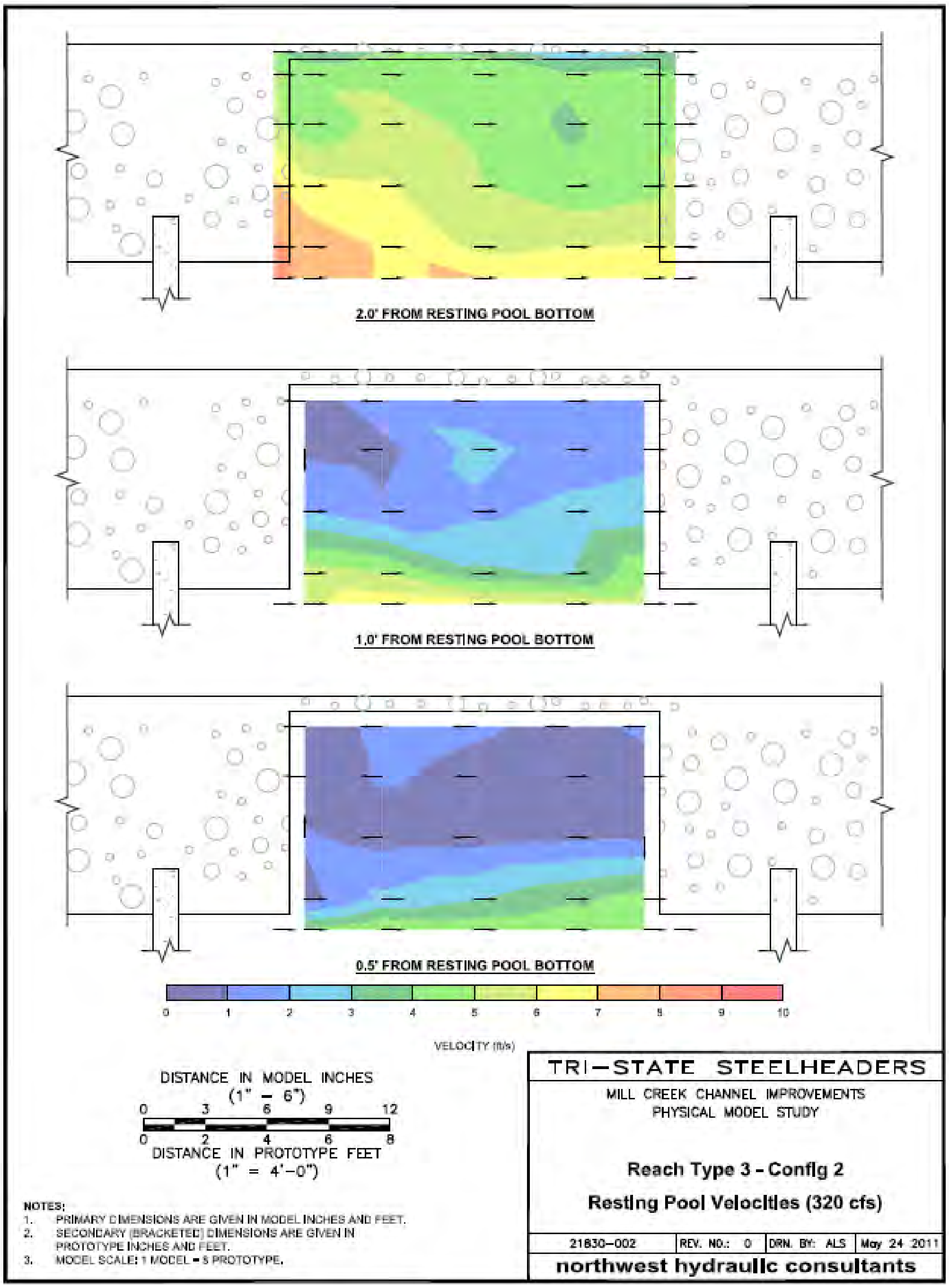

Figure 6 – Resting Pool Velocities at 320 cfs Without Cover Rocks.

Roughness Panels

The roughness panel details are provided in the project plans and have not changed from the N. 9th Avenue project (see Figure 7).

Figure 7 - Left Photo is the Steel Form Flipped Upside down, and the Right Photo is the Final Poured Panel. The Overall Roughness Height, Density and Spacing within the Values Used in the Physical Model Study.

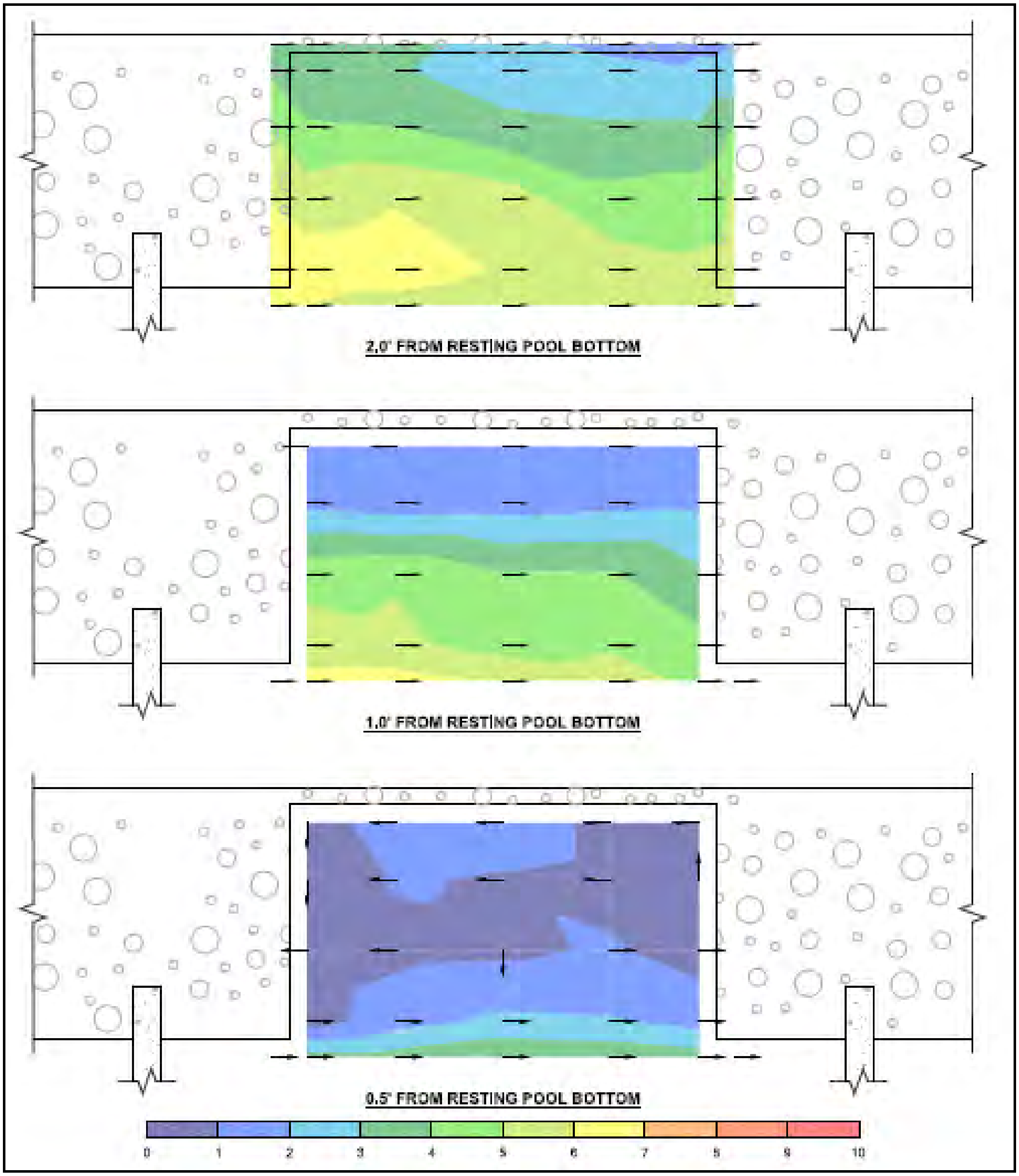

Figure 8 - Resting pool velocities at 194 cfs for the Reach Type 3 Channel Retrofit.

4 FLOOD FLOW ANALYSIS

Water Surface Elevations

One goal of the Mill Creek Fish Passage Project is make sure the fish passage designs do not increase flooding. The criteria provided by the Mill Creek Work Group are no rise in water elevation at the 100 year flood of 3500 cfs. The Flume Physical Model Study (Northwest Hydraulics, 2011) developed composite roughness values for 92, 194, 320 and 1000 cfs for the one percent channel. These composite values were then modified and used in HEC RAS to calculate the before and after conditions for select areas of the project. For the section through the Merriam Street Bridge see Figure 9. For the section from STA 10280 to 10780 see Figure 10. In both cases the calculated water surface elevation for the proposed condition is slightly lower than the existing.

Figure 9 – Existing versus proposed water surface elevations from STA 7460 to 7847 (Merriam Bridge) at 3500 cfs. The blue line with triangles is the existing condition.

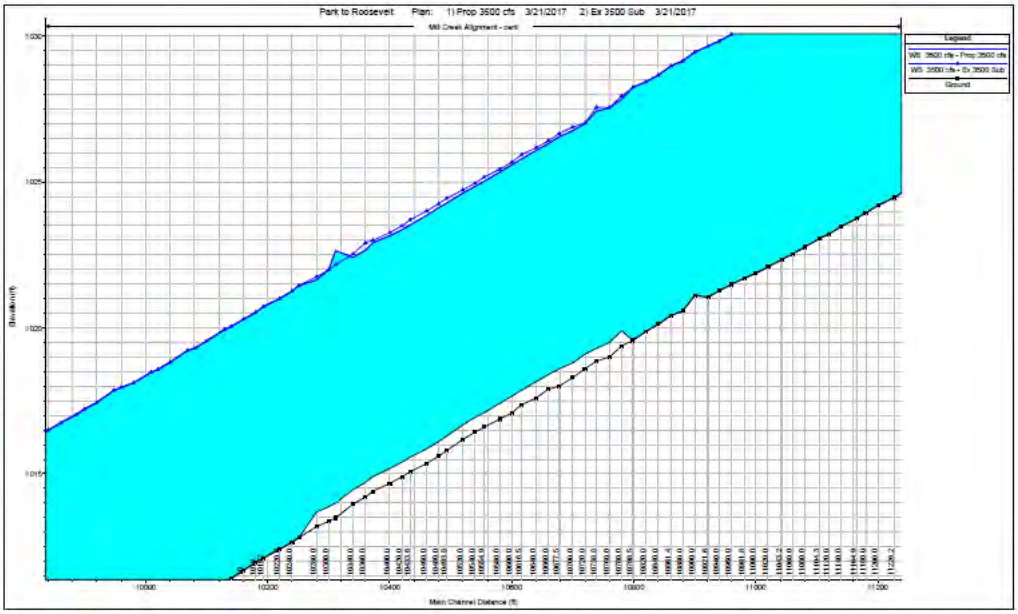

Figure 10 - Existing versus proposed water surface elevations from STA 10280 to 10780 at 3500 cfs. The blue line with triangles is the existing condition.

Analyzing flood flows in the flume above 500 cfs with HEC RAS becomes very complex due to the standing waves and transition to supercritical flow. Based on results from the Flume Physical Model, the flow at 1000 cfs was near critical for both the baseline and proposed conditions. The baffles in the flume are effective at controlling the depth at low to medium flows, but at some point they become submerged enough and are less effective. In the Steady Flow Analysis selection from HEC RAS the Subcritical Flow Regime was selected for the calculations. This is likley a conservative approach in terms of water depth as it gives the greatest depth. The Mixed flow regime was tested and the results show a lowering of the water depth by about two feet at 3500 cfs. Ultimateley the results of the Flume Physical Model, which did not show a flood rise provide the highest level of certainty.

Superelevation

One dimensional Steady State models (HEC RAS), assume a constant water surface elevation across the cross section. When water flows around a bend a mass of water concentrates to the outside resulting in higher elevations on the outside and lower elevations on the inside. This difference in elevation across the channel can be estimated by the following equation:

$$\Delta y = CV^2W/gR$$

where; Δy = difference between channel centerline and outside of bend, C = coefficient based on channel shape, flow regime, etc, V is the average channel velocity, W is the water surface width, g is the gravitational constant and R is the radius of curvature at the channel centerline. Figure 11 is a summary table of the calculations. In the worse case scenario, there is 0.95 feet of superelevation at STA 67+44 at 3500 cfs, assuming supercritical flow. The overall effect of the proposed project design is to slightly lower velocities with similar hydraulic properties. The result is likley a decrease in superelevation, but for all practical purposes the difference is within the error range of the calculations.

							STA 67+44	STA 90+26
							Radius of Curvature	
							395.4	982.7
	Q	d	A (sq ft)	V (fps)	Width (ft)	Froude	Superelevation (ft)	
Mixed	3500	6.6	180.9	19.3	43	1.3	0.63	0.25
		6.4	169.5	20.7	43	1.4	0.72	0.29
		6.2	158.4	22.1	43	1.6	0.82	0.33
		6	147.7	23.7	43	1.7	0.95	0.38
		6.3		**21.4**		**1.5**		
Subcritical	3500	9	349.6	10.0	46	0.6	0.18	0.07
		8.8	333.4	10.5	46	0.6	0.20	0.08
		8.6	317.5	11.0	46	0.7	0.22	0.09
		8.4	302.1	11.6	46	0.7	0.24	0.10
				10.8		**0.6**		

Figure 11 – Superelevation calculations for the Mill Creek channel at two bends at STA 67+44 and STA 90+26.

5 CONSTRUCTION ACCESS

The following potential construction access areas have been identified and are shown on the plans. The sites are:

- On the left bank of the flume wall just upstream of Park Street, address is 175 Alder St. There is a 6 foot high channel wall which could be cut out and a ramp built down into the flume.
- At Merriam Bridge upstream on left bank, there is a house which has been vacated.
- S. Clinton Street there is a low wall downstream to the left, house rentals address 42 S. Clinton Street.
- At Division Street upstream on the right at Wildwood Park. The wall is low upstream, could have two access points here.
- Between Division and Roosevelt 1023 Hobson St and 1048 Hobson Street (in between).
- End of Blue Street 500′ downstream of Roosevelt on the right bank might be City Property.
- Downstream of Blue Street, 1068 Francis Ave on right bank, big open field.

6 GROUNDWATER SEEPAGE

On April 14, 2016 the channel was investigated from Roosevelt Street downstream. At Roosevelt the flow was less than 0.5 cfs and the water temperature was 83.8°F. Just downstream STA 104+00 there are numerous springs flowing into the channel through cracks in the concrete and under drains. The water temperature of these springs is 56°F. The as-built drawings of the channel denote 102 feet of 8″ concrete drain pipe in the reach (see Table 5). Dewatering sumps will be required in the resting pools to pump and lower the water a minimum of one foot below the work area. Past efforts to capture this water has been challenging as often the water seeps into the work area from a flowing spring source and lowering the local groundwater doesn't help. A ditch to collect seepage will likely be needed.

STA	Drains
64+75	3′ x 8″ Perf Conc Pipe (Left and Right)
67+01	6′ x 8″ Perf Conc Pipe (Right)
67+05	Same
70+80	3′ x 8″ Perf Conc Pipe (Right)
70+85	2′ x 8″ Perf Conc Pipe (Left)
73+50	6′ x 8″ Perf Conc Pipe (Right)
81+85	6′ x 8″ Perf Conc Pipe (Left and Right)

85+30	5 – 2″ Diam Holes in Trench Wall
89+00	6′ x 8″ Perf Conc Pipe (Left and Right)
92+00	7 – 2″ Diam Holes in Trench Wall
94+50	6′ x 8″ Perf Conc Pipe (Left and Right)
98+00	18′ x 12″ Perf Conc Pipe (Left)
101+32	6′ x 8″ Perf Conc Pipe (Left and Right)
114+25	6′ x 8″ Perf Conc Pipe (Left and Right)

Table 5 – Location and description of drain pipes.

7 POROUS OPENINGS IN RESTING POOLS

If approved by the CORP, the plan drawings provide a provision to leave an opening in the floor of the resting pools to encourage additional groundwater seepage into the channel. The opening would be a maximum of 2 feet. After the concrete is poured for the resting pool floor, the sump hole would be backfilled with angular rock. At the 100 year flood the velocity is 15 fps, the depth 8.5 feet and the channel shear stress is 0.73 lbs/sq ft. Using the Shields Diagram (Trend line develop by Leopold, Wolman and Miller 1964), for the relationship between grain diameter for entrainment and shear stress a grain diameter size of 40 mm (or 1.6 inches) would be required to be stable. Based on observations of cobbles moving within the channel flume it is suggested a minimum size of 6 to 9 inches be used. These should be angular rock and compacted to interlock within the sump hole.

8 MAINTENANCE CONSIDERATIONS

During construction the contractor will be required to provide access as needed for maintenance vehicles to move up and down the channel during mid-September. The construction access points and flow diversion has not yet been designed but the layout will be similar to the layout for the N. 9th Avenue Fish Passage Project with a 36 inch diameter bypass pipe. Due to the cost of the pipe, the contractor may select to build a partial plywood polyethylene lined flume along the toe of the wall.

9 COST ESTIMATE

This will be the fourth project constructed in Mill Creek of similar design. The cost estimates are based on actual costs and bids received. The highest level of uncertainty involves two items, 1) construction access and staging and 2) pumping groundwater from the excavated areas, especially the pools. Each design has improved incrementally with regards to these two items. For this site, the potential for two access points and the development of an infiltration pond for sediment contaminated water is very encouraging. Coordination with landowners and the City will be required to further develop the details of this in the final design and bid documents. The estimated construction cost is $4,121,500 (Figure 12).

Mill Creek Fish Passage - Park Street to Roosevelt Street									
Date:	12/1/2017								
By:	Chinook Engineering and Waterfall Engineering								
Design Level:	90%								
Project Length (ft):	4904								
Resting Pools:	90								
Roughness Panels:	408								
Baffles:	306								
Bridge Ramps	4								
Description	**Unit**	**CAD Quantity**	**t (in)**	**Mult**	**Bid Quantity**	**Cost**	**Amount**	**Sub Total**	***Comments***
Mob, Access and Water Management								**$690,000**	
Mobilization	L.S.	1		1	1	$60,000.00	$60,000		*Average 11% of construction costs minus panel prefab*
Access to Flume	L.S.	1		1	1	$140,000.00	$140,000		*Site to be Identified*
Water Management	L.S.	1		1	1	$490,000.00	$490,000		*2013 Low Bid Unit Cost $34,000, Average Bid $41,000 for 350 feet*
Concrete Demolition								**$410,168**	
Concrete Slab cutting	L.F.	9849		1	9849	$10.00	$98,492		*2013 Low Bid Unit Cost $8, Average Bid $12*
Concrete Wall cutting (plain)	L.F.	0	8			$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.	0		1		$625.00	$0		*12" = $625, 36" = $1750*
Concrete Removal	C.Y.	1181		1.1	1299	$240.00	$311,676		*2013 Low Bid Unit Cost $210, Average Bid $277*
Remove Whole Pieces	ea.	0				$140.00	$0		*1 to 2.5 cubic yards in size*
Loading Concrete	C.Y.	109				$200.00	$0		
Hauling	C.Y.	109				$7.00	$0		
Concrete Disposal	C.Y.	109				$10.00	$0		
Reinforced Concrete Form and Pour								**$1,740,005**	
Excavation and Disposal	C.Y.	2332		1.1	2565	$65.00	$166,736		*2013 Low Bid Unit Cost $44, Average Bid $84*
Disposal	C.Y.	0				$30.00	$0		*High cost for getting out of flume area*
Gravel Backfill	C.Y.	110		1.2	132	$140.00	$18,480		*2013 Low Bid Unit Cost $80, Average Bid $153*
Concrete Underpining	C.Y.	0				$2,100.00	$0		
CIP	C.Y.	0				$1,300.00	$0		
Grouting	S.F.	0				$2.76	$0		
Roughness Panels (Form and Pour)	C.Y.	962		1.02	982	$1,015.00	$996,346		*Actual Bid Amount*
Install Roughness Panels	ea.	408		1.02	416	$300.00	$124,848		*2013 Low Bid Unit Cost $270, Average Bid $1311*
CIP Concrete	C.Y.	308		1.1	339	$1,000.00	$339,095		*2013 Low Bid Unit Cost $740, Average Bid $1240*
Enclosure Curbs	C.Y.	132				$0.00	$0		
Baffles	C.Y.	70				$0.00	$0		
Resting Pools	C.Y.	106				$0.00	$0		
Habitat Boulders	L.S.	270		1	270	$350.00	$94,500		*2013 Low Bid Unit Cost $150, Average Bid $300*
Bridge Pass Ramps								**$157,390**	
Concrete Cutting	L.F.	960		1	960	$10.00	$9,600		
Concrete Removal	C.Y.	95		1.1	104	$230.00	$23,988		
Excavation and Disposal	C.Y.	190		1.1	209	$55.00	$11,473		
Gravel Backfill	C.Y.	47		1.2	57	$120.00	$6,827		
CIP Concrete	C.Y.	96		1.1	106	$1,000.00	$105,502		
Construction Subtotal								$2,997,563	
Contingency	18%							$539,561	
Sales Tax	8.9%							$314,800	
Construction Total								**$3,851,900**	
Construction Management	7.0%							$269,600	
Project Total								**$4,121,500**	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Chinook Engineering) has no control over the cost or availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction cost.

Figure 12 – Detailed Cost Estimate.

10 REFERENCES

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P. Powers, B. Burns, K. Bates, J. Kidder. *Mill Creek Fish Passage Assessment.* Walla Walla, WA: Tri State Steelheaders Fisheries Enhancement Group, 2009.

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Northwest Hydraulic Consultants (NHC). *Mill Creek Channel Improvement Physical Model Study.* Final Report, 2011.

APPENDIX A – SITE PHOTOS

Photo 1 – View downstream of Park Street Bridge.

Photo 2 – Stormwater outlet upstream of Park Street.

Photo 3 – Pedestrian Foot Bridge at STA 68+00.

Photo 4 – Upstream View of Otis Street Bridge (104 cfs).

Photo 5 – Channel Downstream of Otis Street

Photo 6 – Upstream view towards Merriam Road Bridge.

Photo 7 – Upstream View under Merriam Bridge

Photo 8 – View downstream towards Otis Street Bridge.

Photo 9 – View upstream towards Clinton Street Bridge (104 cfs).

Photo 10 – Clinton Street Bridge (104 cfs).

Photo 11 – View downstream towards Merriam Street Bridge.

Photo 12 – View downstream towards Clinton Street Bridge.

Photo 13 – View upstream of Division Street Bridge.

Photo 14 – 12" Drain Pipe

Photo 15 – Division Street Bridge

Photo 16 – Under Division Street Bridge

Photo 17 – 2" Galvanized stand pipe and 15" Concrete Drain Pipe.

Photo 18 – View downstream of Roosevelt Street.

Photo 19 – Roosevelt Street Bridge

Photo 20 – Spring/Groundwater enters the channel from STA 104+00 to STA 73+00. Flow increases from 0.2 cfs to approximately 2 cfs.

APPENDIX B – EXISTING AND PROPOSED VELOCITY AND DEPTH

	92 cfs Existing			194 cfs Existing			320 cfs Existing			3500 cfs Existing		
STA	**WSEL**	**Max Depth[a]**	**Ave Velocity[a]**	**WSEL**	**Max Depth**	**Ave Velocity**	**WSEL**	**Max Depth**	**Ave Velocity**	**WSEL**	**Max Depth**	**Ave Velocity**
	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)
7489	981.5	2.2	6.0	982.3	3.0	7.0	982.9	3.6	7.6	988.1	8.8	15.9
7500	982.0	2.7	3.4	982.8	3.4	4.9	983.3	3.9	6.1	988.7	9.3	14.8
7520	982.1	2.5	3.7	982.8	3.1	5.4	983.2	3.6	7.1	988.6	8.9	15.4
7548	982.2	2.2	6.0	983.0	3.0	6.9	983.6	3.6	7.6	988.6	8.7	15.7
7560	982.7	2.6	3.4	983.4	3.3	5.0	983.9	3.8	6.3	988.7	8.7	15.9
7580	982.7	2.4	3.9	983.4	3.0	5.8	983.7	3.3	7.9	989.0	8.6	15.9
7609	982.9	2.2	6.1	983.7	3.0	7.0	984.3	3.7	7.7	989.5	8.9	15.8
7620	983.4	2.6	3.6	984.1	3.3	5.1	984.6	3.8	6.3	989.6	8.8	16.1
7640	983.5	2.4	4.0	984.1	3.1	5.8	984.5	3.4	7.9	990.0	8.9	16.5
7646	983.6	2.2	6.1	984.4	3.0	6.9	985.0	3.6	7.6	990.0	8.9	18.6
7669	984.1	2.6	3.5	984.8	3.3	5.0	985.3	3.8	6.2	990.3	8.9	18.7
7680	984.2	2.4	3.9	984.8	3.1	5.7	985.2	3.4	7.9	990.4	8.9	19.1
7700	984.4	2.2	6.0	985.2	3.0	6.9	985.8	3.6	7.6	993.5	11.8	11.2
7730	984.9	2.6	3.6	985.6	3.3	5.2	986.0	3.7	6.7	993.4	11.2	11.8
7740	985.0	2.4	3.9	985.6	3.1	5.8	985.9	3.4	8.0	993.4	11.1	11.7
7760	985.1	2.2	6.1	985.9	3.0	7.0	986.5	3.6	7.7	993.2	10.6	12.8
7789	985.6	2.6	3.6	986.3	3.4	5.1	986.9	3.9	6.4	992.8	9.9	14.2
7800	985.7	2.4	4.0	986.3	3.1	5.8	986.7	3.4	7.9	992.8	9.8	14.6
7820	985.8	2.2	6.1	986.6	3.0	7.0	987.2	3.6	7.7	992.6	9.3	15.7
7847	986.4	2.6	3.4							992.6	9.0	16.2
10280	1015.7	2.5	3.7	1016.3	3.1	5.5	1016.5	3.3	7.9	1021.6	8.5	15.3
10300	1015.8	2.4	4.0	1016.3	2.9	6.3	1016.8	3.4	7.9	1022.0	8.6	15.2
10311	1015.7	2.3	6.0	1016.5	3.0	6.9	1017.1	3.6	7.6	1022.6	9.1	13.8
10340	1016.4	2.5	3.7	1017.0	3.0	5.7	1017.3	3.3	7.9	1022.4	8.5	15.3
10360	1016.5	2.3	4.3	1016.9	2.7	7.0	1017.6	3.4	8.0	1022.7	8.5	15.3
10372	1016.6	2.2	6.0	1017.4	3.0	6.9	1018.0	3.6	7.6	1022.9	8.5	15.4
10400	1017.2	2.6	3.6	1017.8	3.2	5.5	1018.1	3.4	7.9	1023.2	8.5	15.4
10420	1017.3	2.4	4.0	1017.9	3.0	6.2	1018.3	3.4	7.9	1023.4	8.5	15.3
10434	1017.3	2.2	6.1	1018.1	3.0	6.9	1018.7	3.6	7.6	1023.5	8.5	15.3
10460	1017.9	2.6	3.6	1018.6	3.2	5.5	1018.8	3.4	7.9	1023.8	8.5	15.4
10480	1018.0	2.4	4.0	1018.6	3.0	6.1	1019.0	3.4	8.0	1024.1	8.5	15.4
10494	1018.1	2.3	6.0	1018.8	3.0	6.9	1019.4	3.6	7.5	1024.3	8.5	15.3
10520	1018.7	2.5	3.7	1019.3	3.1	5.6	1019.6	3.4	7.9	1024.6	8.4	15.3
10540	1018.8	2.4	4.1	1019.3	2.9	6.3	1019.8	3.4	7.9	1024.9	8.4	15.3
10555	1018.8	2.2	6.0	1019.6	3.0	6.9	1020.2	3.6	7.5	1025.0	8.4	15.3
10580	1019.4	2.6	3.6	1020.1	3.2	5.4	1020.3	3.4	7.9	1025.3	8.4	15.3
10600	1019.5	2.4	4.0	1020.1	3.0	6.1	1020.5	3.4	7.9	1025.6	8.4	15.3
10617	1019.5	2.2	6.0	1020.3	3.0	6.9	1020.9	3.6	7.6	1025.8	8.4	15.3
10640	1020.2	2.6	3.6	1020.8	3.2	5.4	1021.0	3.4	7.9	1026.1	8.4	15.3
10660	1020.2	2.3	4.1	1020.8	2.9	6.3	1021.3	3.4	7.9	1026.3	8.4	15.3
10678	1020.3	2.3	6.0	1021.1	3.1	6.9	1021.7	3.7	7.6	1026.5	8.4	15.3
10700	1020.9	2.6	3.5	1021.5	3.2	5.3	1021.7	3.4	7.9	1026.8	8.5	15.3
10720	1021.0	2.4	4.1	1021.5	2.9	6.2	1022.0	3.4	7.9	1027.0	8.4	15.4
10739	1021.1	2.2	6.0	1021.8	3.0	7.0	1022.4	3.6	7.6	1027.4	8.6	14.7
10760	1021.6	2.6	3.5	1022.3	3.3	5.2	1022.5	3.5	7.7	1027.5	8.5	15.2
10780	1021.7	2.3	4.2	1022.3	2.9	6.4	1022.8	3.4	7.9	1027.8	8.4	15.3
Average		**2.4**	**4.5**		**3.1**	**6.1**		**3.5**	**7.6**		**8.9**	**15.3**
Notes:	a) Depth and Velocity for all values are in the center trench (or channel)											

	92 cfs Proposed			194 cfs Proposed			320 cfs Proposed			3500 cfs Proposed		
STA	**WSEL**	**Ave Depth[b]**	**Ave Velocity[b]**	**WSEL**	**Ave Depth**	**Ave Velocity**	**WSEL**	**Ave Depth**	**Ave Velocity**	**WSEL**	**Ave Depth**	**Ave Velocity**
	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)	(ft)	(ft)	(fps)
7489	981.3	0.8	3.3	981.9	1.4	4.7	982.4	1.9	6.2	988.0	5.7	12.6
7500	981.7	1.1	2.7	982.3	1.7	3.9	982.8	1.8	4.7	988.1	5.7	12.6
7520	981.9	1.1	2.6	982.5	1.7	3.8	983.1	1.8	4.6	988.2	5.7	12.5
7548	982.2	1.1	2.6	982.7	1.6	3.9	983.3	1.8	4.8	988.5	5.6	12.5
7560	982.3	1.0	2.8	982.8	1.5	4.3	983.3	1.9	5.6	988.7	5.6	12.5
7580	982.5	0.9	2.9	983.1	1.5	4.4	983.5	1.9	6.0	989.0	5.6	12.5
7609	983.0	1.1	2.6	983.6	1.7	3.9	984.1	1.8	4.8	989.4	5.7	12.6
7620	983.1	1.0	2.8	983.6	1.5	4.3	984.1	1.9	5.5	989.6	5.7	12.5
7640	983.3	1.3	3.0	984.0	0.8	3.9	984.9	1.6	5.3	989.7	6.5	12.6
7646	983.3	1.3	3.2	984.1	0.8	3.9	984.8	1.5	5.5	990.0	6.7	13.6
7669	983.7	1.4	2.7	984.3	2.0	4.0	985.0	1.2	4.9	990.0	6.5	14.0
7680	983.8	1.5	2.7	984.7	1.0	3.7	985.4	1.7	5.1	990.0	6.4	16.2
7700	984.1	1.2	2.4	984.7	1.8	3.4	985.2	1.9	4.4	992.9	5.9	7.9
7730	984.3	0.9	3.0	984.9	1.5	4.4	985.3	1.9	6.0	992.9	7.5	9.4
7740	984.5	1.0	2.7	985.1	1.6	4.1	985.6	1.9	5.3	992.8	7.3	9.9
7760	984.7	1.0	2.9	985.3	1.5	4.4	985.8	1.9	5.9	992.5	7.0	10.9
7789	985.2	1.1	2.7	985.7	1.7	4.0	986.3	1.9	5.0	992.1	6.5	12.2
7800	985.3	1.1	2.6	985.9	1.7	3.9	986.4	1.9	4.9	992.0	6.3	12.6
7820	985.5	1.1	2.6	986.1	1.7	3.9	986.6	1.9	4.9	992.1	6.1	12.9
7847	985.8	1.0	2.9	986.3	1.5	4.3	986.8	1.9	5.7	992.4	6.1	12.9
10280	1015.6	1.3	2.3									
10300	1015.8	1.2	2.2	1016.1	1.8	3.5	1016.4	1.9	5.2	1021.7	5.5	12.3
10311	1015.8	1.1	2.5	1016.3	1.8	3.3	1016.9	2.0	4.2	1022.2	5.4	11.6
10340	1016.1	0.9	2.9	1016.3	1.6	3.9	1016.8	1.8	4.9	1023.2	6.6	10.2
10360	1016.4	1.0	2.7	1016.6	1.4	4.5	1017.0	1.9	6.0	1022.9	5.9	11.5
10372	1016.5	0.9	2.9	1016.9	1.5	4.0	1017.4	1.9	5.2	1022.7	5.5	12.3
10400	1017.0	1.1	2.6	1017.0	1.5	4.5	1017.5	1.9	6.2	1022.9	5.4	12.4
10420	1017.2	1.1	2.6	1017.5	1.7	3.9	1018.1	1.6	4.4	1023.2	5.5	12.5
10434	1017.3	1.0	2.7	1017.7	1.6	3.9	1018.3	1.8	4.5	1023.4	5.5	12.3
10460	1017.6	1.1	2.7	1017.9	1.6	4.0	1018.4	1.8	4.9	1023.6	5.5	12.3
10480	1017.8	1.0	2.7	1018.1	1.6	4.0	1018.7	1.8	5.0	1023.9	5.5	12.4
10494	1018.0	1.0	2.8	1018.4	1.6	4.1	1018.8	1.9	5.4	1024.2	5.5	12.4
10520	1018.3	0.9	2.9	1018.5	1.5	4.3	1019.0	1.9	5.7	1024.3	5.5	12.3
10540	1018.6	1.0	2.8	1018.8	1.5	4.4	1019.3	1.9	5.8	1024.6	5.5	12.4
10555	1018.8	1.0	2.7	1019.1	1.5	4.2	1019.6	1.9	5.6	1024.9	5.4	12.4
10580	1019.1	1.0	2.7	1019.4	1.6	4.0	1019.9	1.8	5.1	1025.1	5.4	12.4
10600	1019.4	1.0	2.8	1019.6	1.5	4.1	1020.1	1.9	5.4	1025.4	5.4	12.4
10617	1019.6	1.0	2.8	1019.9	1.5	4.2	1020.4	1.9	5.4	1025.6	5.4	12.3
10640	1019.9	1.0	2.8	1020.1	1.5	4.2	1020.6	1.9	5.5	1025.8	5.4	12.3
10660	1020.1	1.0	2.7	1020.4	1.5	4.2	1020.9	1.9	5.5	1026.1	5.4	12.4
10678	1020.3	1.0	2.7	1020.6	1.5	4.1	1021.1	1.8	5.4	1026.3	5.4	12.4
10700	1020.6	1.1	2.6	1020.9	1.6	4.1	1021.3	1.8	5.3	1026.6	5.4	12.4
10720	1020.8	1.0	2.8	1021.2	1.7	3.8	1021.7	1.8	4.7	1026.8	5.4	12.4
10739	1021.0	1.0	2.7	1021.3	1.5	4.2	1021.8	1.9	5.5	1027.1	5.4	12.4
10760	1021.3	1.1	2.6	1021.6	1.6	4.0	1022.1	1.8	5.0	1027.4	4.4	11.0
10780	1021.5	0.9	3.1	1021.8	1.6	3.9	1022.3	1.8	4.9	1027.6	5.0	12.2
Average		**1.1**	**2.7**		**1.5**	**4.1**		**1.8**	**5.2**		**5.8**	**12.2**
Notes:	b) Depth and Velocity for all values are in the left overbank or roughened channel portion											

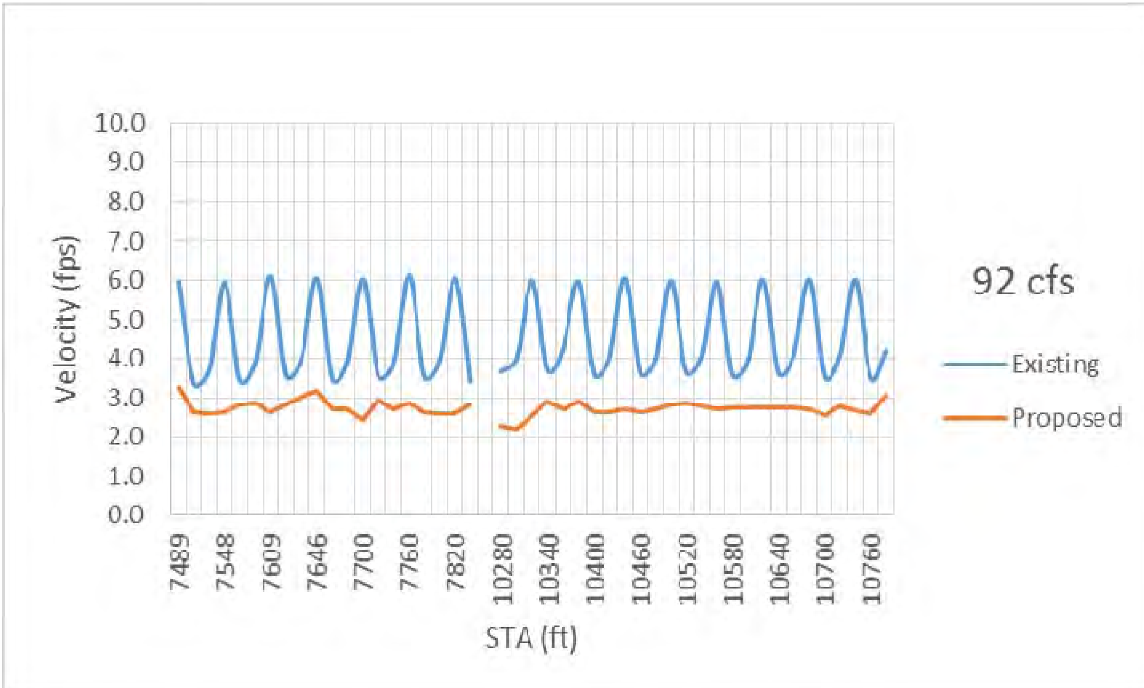

Figure 13 – Existing and Proposed velocities for the modeled areas. These are average velocities for the cross section. Existing velocities are in the channel or trench, and proposed are in the left overbank or roughened channel. The existing is a smooth concrete surface and the proposed has roughness with a velocity boundary layer.

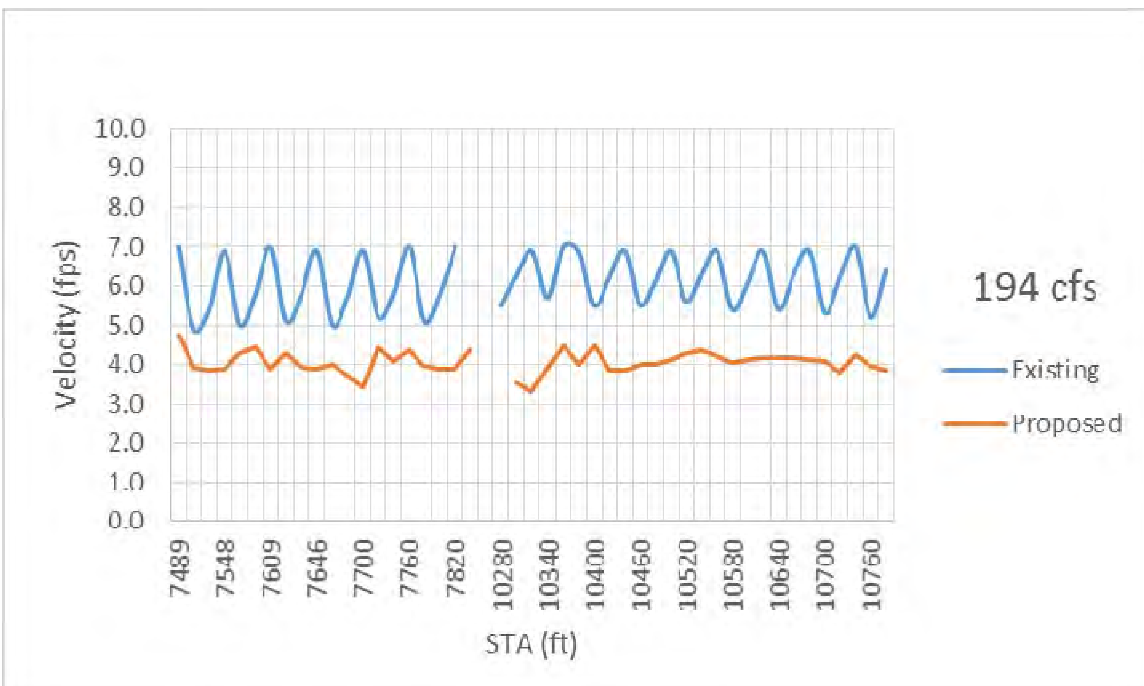

Figure 14 – Same as Figure 13 except flow is 194 cfs.

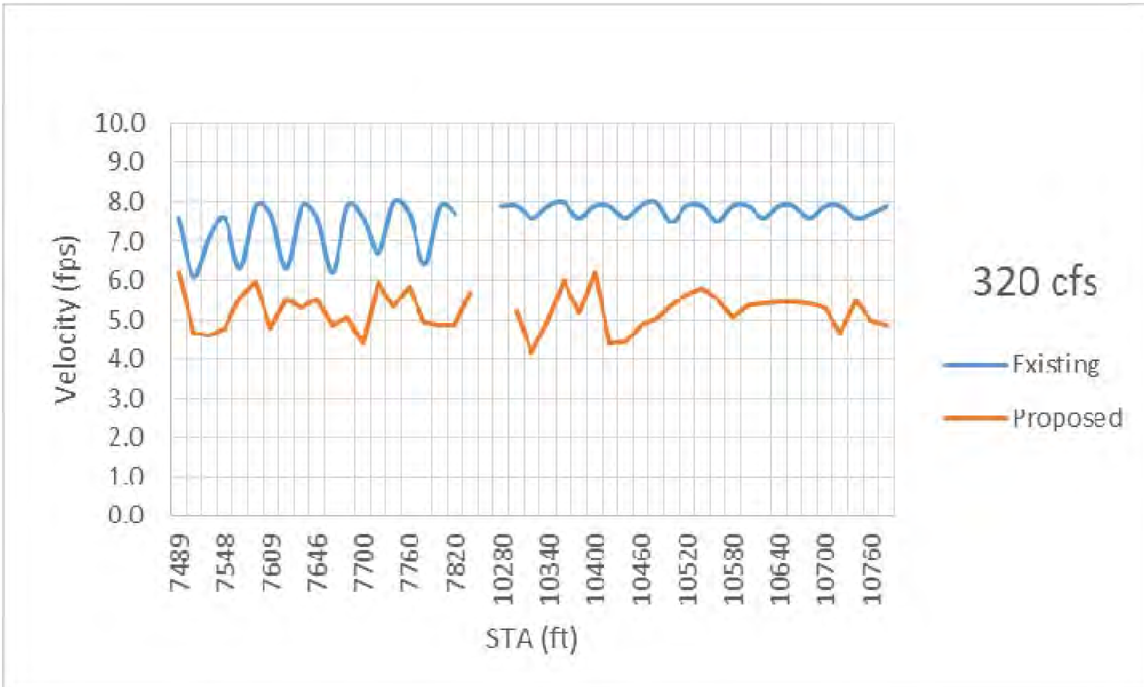

Figure 15 – Same as Figure 13 except flow is 320 cfs.

APPENDIX C: REACH TYPE 3 DESIGN VALIDATION – ROUGHNESS PANELS AND RESTING POOLS

Field measurements were made to validate the prototype water velocities within the fish passage corridor for the recently completed fish passage project on Mill Creek between 9th Avenue and to just above 6th Street. The Stationing location of this new construction is from STA 9+81 to Sta 23+19.7, USCOE. This is a Reach Type 3 channel, and the roughness panels are side sloped 1:5.1. Measurements were made on April 20, 2017, from 12:00 p.m. to 5:00 p.m. As was previously performed in the Reach Type 6 area, the objective was to 1) observe and document overall flow patterns relative to fish passage, and 2) measure velocities in locations where fish are assumed to pass, "passage pathways", and rest (resting pools, roughness panels, and fish resting pocket). The fish resting pockets were a completed design feature added for the 2013 construction and again constructed in this reach because the pre-casting forms are the same as used in earlier construction, so particular attention was again paid to the hydraulics around these elements. The stream flow varied during the day from 190 to 197 cfs (USGS gage 14015000 Mill Creek at Walla Walla); see Figure 16. The flow rates were consistent for this day which is known to vary at the 14013000 USGS gage, (Mill Creek near Walla Walla). The gage is located 14 miles upstream of the 14015000 gage.

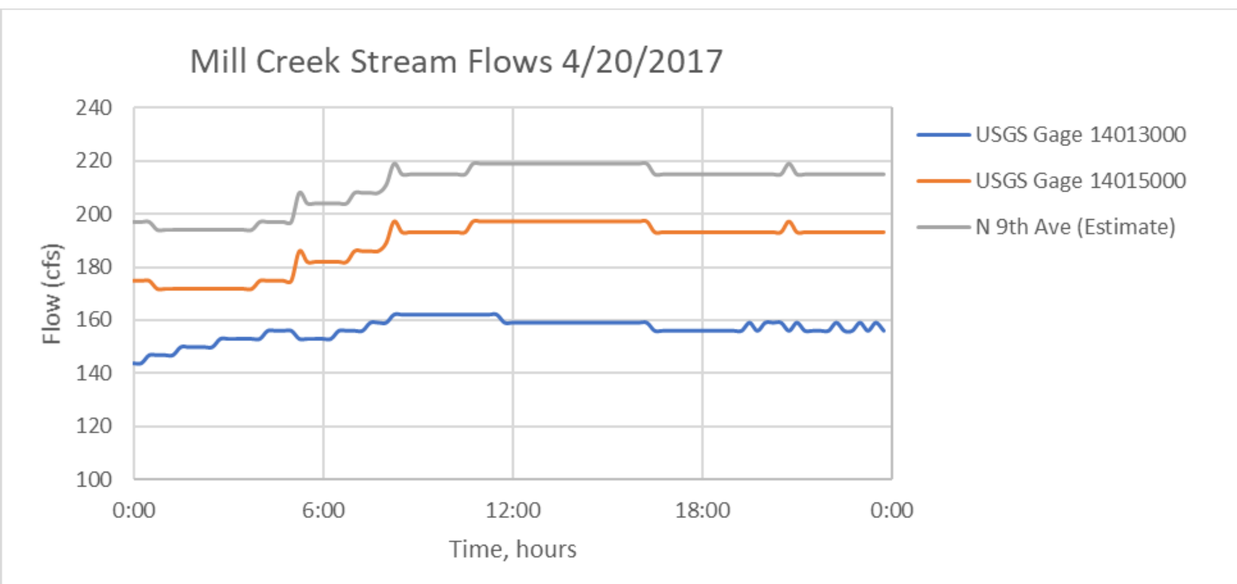

Figure 16 - Mill Creek stream flows during design validation on 4/20/2017. The increase in flow from STA 14015000 to N 9th Avenue is based on measurements taken the N 9th Avenue site.

The location and methods used for data collection are shown in Figure 17. Figure 18**Error! Reference source not found.** is a photo—for comparison purposes—of the baseline channel to the modified channel; Figure 19 shows the completed fish passage elements. Velocities were measured with a Swoffer 2100 flow meter. The display averaging feature was used, which averages the velocities over a 20-second time period.

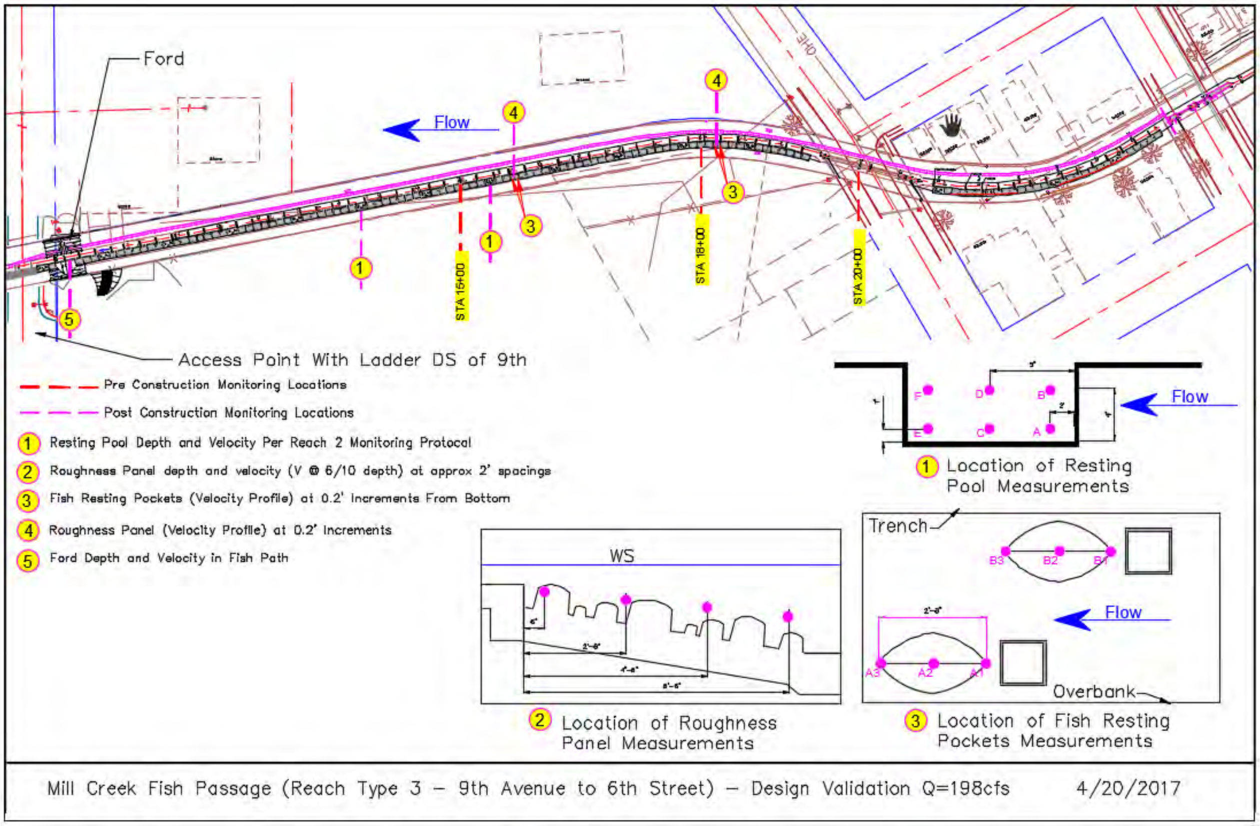

Figure 17. Design validation locations in the Mill Creek channel downstream of 6th Street in Walla Walla, WA.

Figure 18 - Photo of baseline and modified Mill Creek channel downstream of 6th Street. The red lines in the photo are of the modified channel (right) denote the 5- to 6-foot wide fish passage corridor created by the roughness panels, V-occupied of the fish passage pathway.

Figure 19 - View from 9th Avenue of the during construction fish passage elements (baffles, roughness panels, and resting pools). The ramp in the left foreground is the ford to allow county maintenance vehicles to cross the channel.

General Observations

Access to the Type 3 channel on foot is limited to flows less than 210 cfs. At this flow, the velocity and depth in the overbank area varies from 0′ to 1′ and tends to oscillate with waves forming a scalloped water's edge and velocities of ~1 fps. Walking outside of the Type 3 channel on the roughness panels is possible and best done with a wading staff and wading boots with cleats. In the deepest portion of the channel during this water flow rate and between the baffles, water depths are approximately 3′ deep and water velocities are greater than 10.0 fps. To measure velocities at higher flows would require a cable system across the top of the concrete flume walls. Also, at 180 cfs, one cannot wade across the channel, so access for measuring flows is limited to one bank and the roughened channel. The depth and velocity combination on the roughened channel is wadable.

As was noted in the Type 6 channel geometry, the Type 3 geometry exhibits a continuous reduced velocity boundary layer observed along the path of the roughness panels (Figure 28). The width of this boundary layer varies from 4 to 6 feet depending on the location in relation to the baffles and resting pools and is a continuous fish passage pathway. A "sweet spot" is apparent at a water depth of 1.5 feet (defined by a location where the velocities are good for fish passage and there is adequate cover, consistent flow patterns, and an area of low velocity immediately towards the left bank). A fly fisherman might recognize this as a good place to drift a dry fly. The center channel velocity is too high, and the overbank too shallow for fish passage.

Figure 20. Photo showing the "sweet spot" for fish passage as a continuous pathway for fish to swim upstream along the left side of the channel. The "V-occupied" fish passage pathway area is clear along the left margin of the streamlines where the water depth varies from ~1' to 3' over the roughness panels and resting pools. Flat flow is a little more nuanced where the resting pools exist but can be seen at the arrow and the resting pool downstream.

As also seen in the Type 6 channel resting pools, the Type 3 channel resting pools exhibit a water flow regime that does not fully dissipate the energy in the resting pools. Most of the flow streams over the top of the resting pool. No difference could be observed in the hydraulics of the fish resting pockets in the Type 3 channel. The fish resting pockets are small trenched out areas located downstream of 12-inch wide roughness elements (Figure 21).

Figure 21 - Photo of fish passage elements: baffles, resting pools, and fish resting pockets within roughness panels.

Measured Velocities Type 3 Channel Geometry

Resting Pools

Velocities were measured in the resting pools six inches from the bottoms of the pools and six inches below the surface of the water at six different plan view locations (see Figure 22 and Figure 23). Target resting water velocities are one body length per second (1BL/sec). For a 26-inch steelhead trout, this would be 2.2 fps and for a 12-inch bull trout, 1.0 fps. All of the velocities below the invert elevation of the adjacent roughness panels exhibit areas and spaces that are below the target velocities for both species. The highest velocities occur near point B, which is the furthest upstream and furthest out towards the center of the channel. The lowest velocities occur downstream near the bottom and furthest left near the outward wall of the resting pool. The main role of the cover rocks in the pools is to provide cover for fish. The results compare very well to the physical model test results for Reach Type 3 Figure 24 and (NHC, 2011: Figures 5–3).

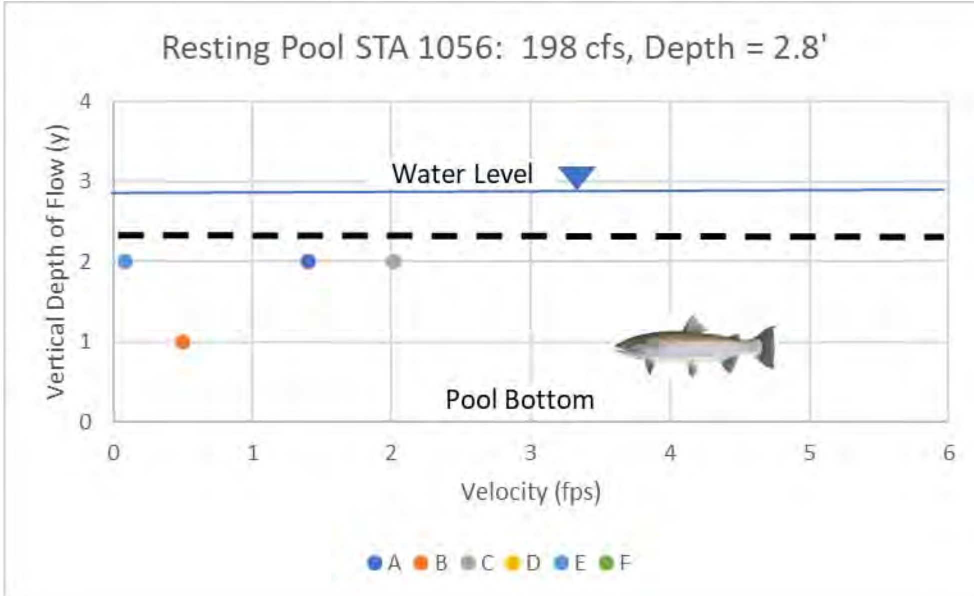

Figure 22 - Resting pool velocities at STA 1056. The black dashed line is the location of the roughness panel invert elevation. Points A to F correspond to the depth and velocity of points 1-5 shown in Figure 17. Data collected 4-20-17, 1100am, Q=198cfs

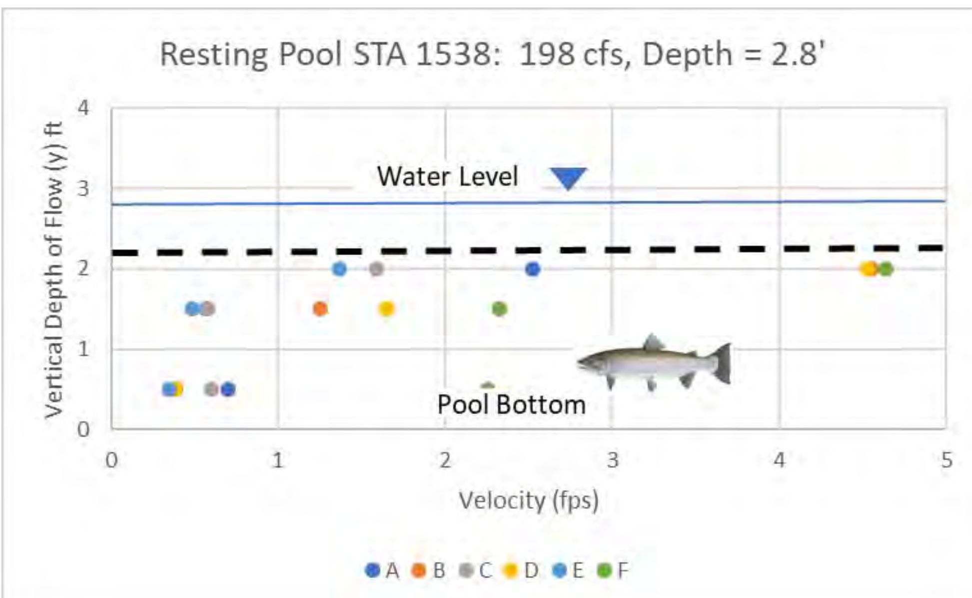

Figure 23 - Resting pool velocities at STA 1538. The black dashed line is the location of the roughness panel invert elevation. Points A to F correspond to the depth and velocity of points 1-5 shown in Figure 17. Data collected 4-20-17, 1100am, Q=198cfs

Roughness Panel Velocities

Velocities within the roughness panels were measured at two different cross sections. Measurements were taken at 6/10 of the depth at approximately every 2 feet across the panel at 12 locations. The water flow rate in the reach was 198 cfs. The average velocity measured over the roughened channel area was 2.9 fps, but ranged from 0.5 to 6.2 fps, for each roughness panel. The depth averaged 1.6 feet. The average velocity calculated from the HEC RAS model at 194 cfs (which was used in the fish energetics calculations) was 3.2 fps, but ranged from 2.7 to 4.2 fps. The velocity measurements at each location and depth are shown in Figure 24. Velocities increase as depth increases. The average velocities in the physical model study were 0.8 fps higher than the velocities measured in the prototype in the field. The roughness height and spacing have not changed from previous construction.

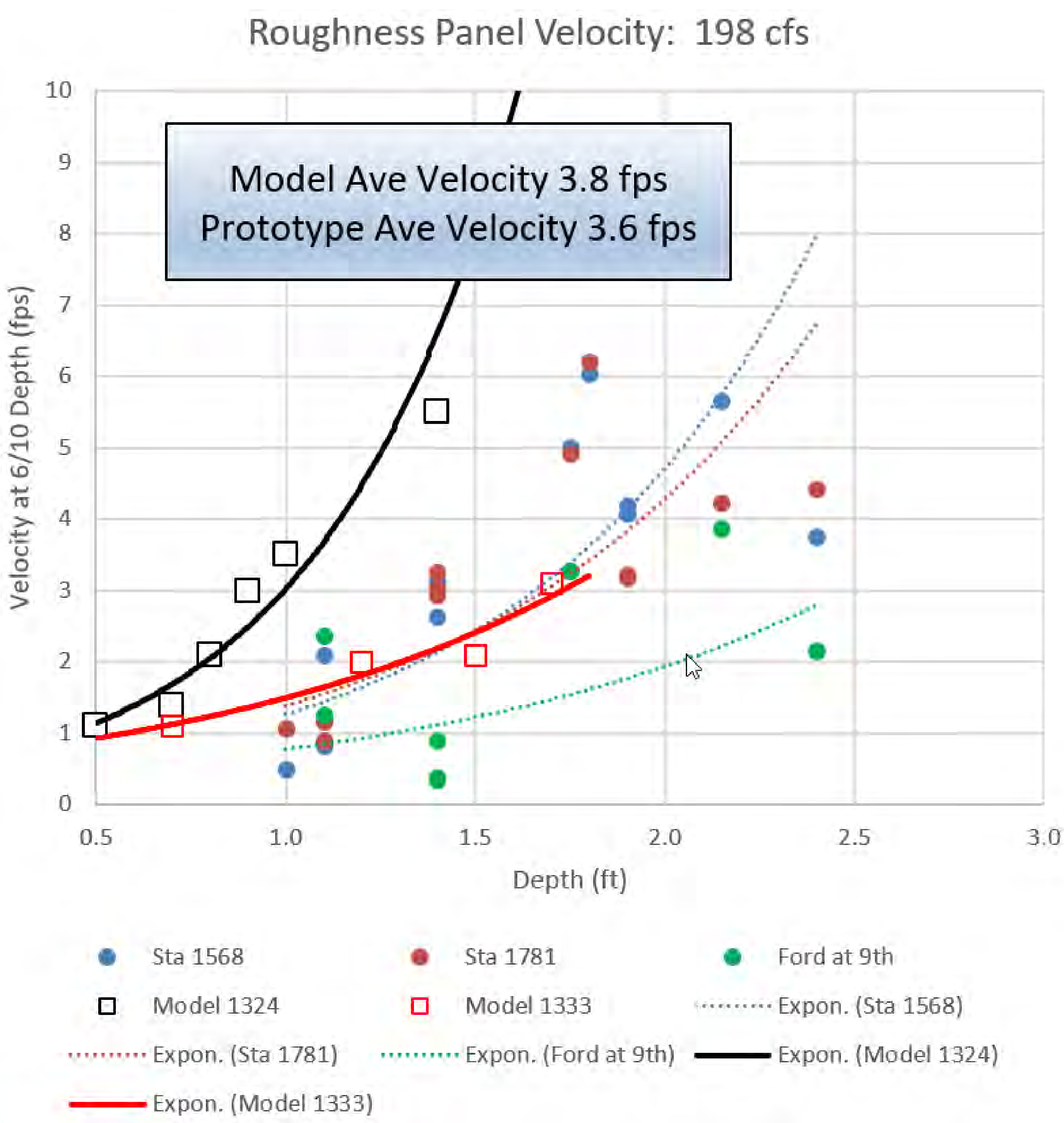

Figure 24 - Type 3 channel geometry velocities measured in the roughness panels at 198 cfs for two roughness panels. The dots are the prototype, and the boxes represent data from the physical model study. The dotted green line and points represent a section through the ford.

Fish Resting Pockets, Validation Measurements Type 3 Channel

Velocities were measured in the fish resting pocket areas of the roughness panels as shown in Figure 17 at the 0.6depth in the water column at Sta 1568 and Sta 1820. The football-shaped areas were intended for adult steelhead to rest in behind roughness elements, which were 12 inches wide by 6.5 inches high. There are two fish resting pockets per roughness panel. Locations A and B are designated by shallower and deeper water respectively and correspond to the upstream and downstream pockets. Points 1, 2, and 3 indicate where the velocity was measured relative to a distance downstream of the roughness element (Point 1 is immediately behind, Point 2 in the middle of the football-shaped resting area, and Point 3 at the downstream end of the resting area. The total length of this resting area is 27 inches. The resting area is countersunk two inches below the invert of the roughness panel. Velocities measured in the 0.6depth position in all pockets averaged 2.7 fps. Water velocities below the upstream roughness element was found to be similar to the Reach Type 6 measurements and was not elaborated on during this Type 3 measurement. Water velocities above the roughness element increase quickly as seen in the Type 6 channel (Figure 25) and were similar in the Type 3 measurements.

Measured water velocities in the resting pockets are shown in Figure 26 for Sta 1568.

Figure 25 - Fish resting pocket velocities at Point 1, immediately downstream of the roughness element. The dashed red box is representative of the height of the roughness element.

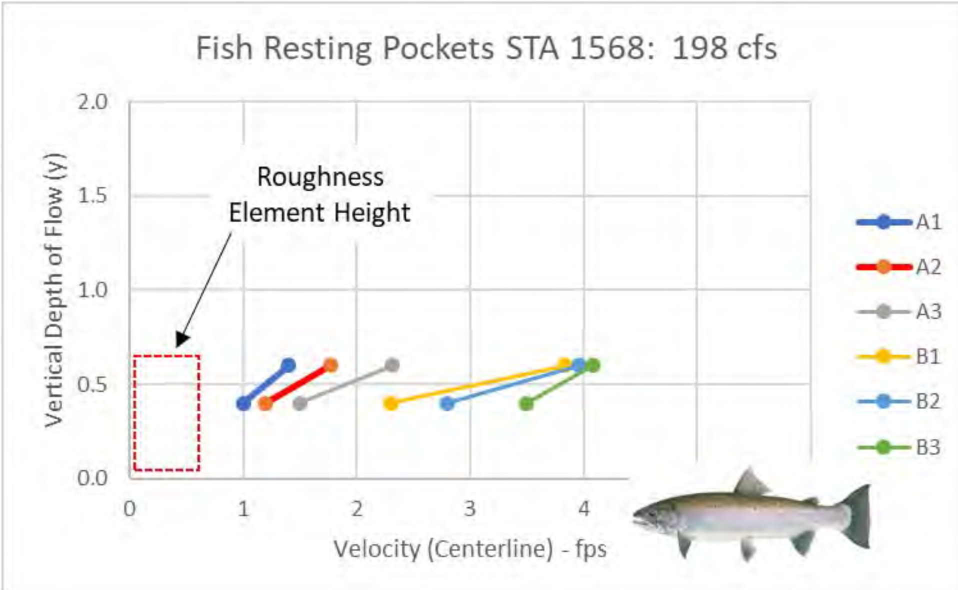

Figure 26 - Fish resting pocket velocities at Point 3 (downstream end of the resting pocket). The dashed red box is representative of the height of the roughness element.

Summary

Velocities were measured within and over the roughness panels and resting pools in the recently constructed Mill Creek Fish Passage Project from above the 9th Avenue Bridge upstream to approximately 260′ above the 6th Street Bridge. Stream flows varied from 190 to 198 cfs during the time of measurement. Observations and recommendations are provided below. This information was presented to the Mill Creek Work Group (MCWG) on September 12, 2017. The MCWG has been instrumental in driving the design and may have other recommendations in the future.

- Target resting pool velocities are one body length per second (1BL/sec). For a 26-inch steelhead, this would be 2.2 fps and for a 12-inch bull trout, 1.0 fps. As was found in the Reach Type 6 channel, all of the velocities measured below the invert elevation of the roughness panels were below these values in the Reach Type 3 channel.

- The average velocity over the roughness panels and in the roughened channel fish passage pathway at 198 cfs is 3.6 fps. The average velocity calculated from the HEC RAS model was 3.8 fps. On average, velocities are 0.9 fps less than was measured in the physical model.

- Type 3 channel fish resting pockets exhibit a very similar water velocity distribution as those located on the Type 6 channel.

- Within the average velocities in the roughened channel (3.6 fps), there exists a range of velocities (from 0.5 to 6 fps) in the vertical water column that fish could occupy. This velocity varies with the water depth.

- When observing the roughened channel area from above on the bridges the location of the fish passage pathway in the water flow is very obvious from the surface and indicates that below the water surface there is a marked boundary layer. These water velocities and depths have now been measured and the water velocities that exist are fish passable water velocities, and by design, indicate distances that match the anticipated energetics of the target species. All this together as measured, suggests that the target species are physically able to pass upstream.

- Further study is required to determine if actual target species are ascending upstream and that their behavior and physical ability allow them to proceed upstream as the project goals have intended.