Technical Memorandum

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Date: 10/19/2017

Subject: Zackuse Creek Bed Material Stability

Project No.: 032794

The purpose of this memo is to summarize hydraulic model results and stability calculations, specifically focusing on the evaluation of the proposed channel profile for Reach 2A. These results illustrate and guide the appropriate choice of proposed material and channel geometry. This memo builds on the previous Otak geomorphic memo which described and detailed existing conditions and proposed alternatives.

Proposed Channel Design Profile and Dimensions

The current selected profile is a step-pool-run sequence. The average gradient of the reach is 3.78%. The gradient of the run was 1.6% based on previous equilibrium analyses when using a gravel mix gradation appropriate for kokanee spawning with a length of 20 ft and a step height of 0.8 ft, and a pool length of 8 ft and depth of 0.4 ft. The proposed profile for a step-pool-run sequence was created using Civil 3D grading tools.

Table 1. Proposed Channel Geometry

	Proposed Geometry
Bankfull Width (ft)	8.0
Bed Width (ft)	5.0
Bankfull Depth (ft)	0.75
Channel Side Slope (1:Z)	3.0
Run Length (ft)	20
Run bed slope (%)	1.6
Pool depth (ft)	0.4
Pool Length (ft)	7
Step height (ft)	0.8

Hydraulic Analysis

A 1-D hydraulic analysis of Zackuse Creek in the project vicinity was performed using the USACE HEC-RAS v5.0 computer software (USACE, 2016). Results of the hydraulic modeling were used to provide hydraulic input to hydraulic design calculations and provide input to sediment transport and channel stability calculations. Manning's roughness value was based on existing conditions upstream of the proposed reach and would reflect post restoration conditions with the vegetation fully restored to natural conditions. A constant n value of 0.1 was used for floodplain for both overbanks to represent average conditions and a value of 0.045 was used for the channel. The downstream boundary condition is a rating curve from the proposed hydraulic model for reach 1 with the preferred culvert option. Hydrology was based on results from a WWHM model. For simplicity of comparison of stability data it was assumed that the discharge remained constant throughout the proposed reach.

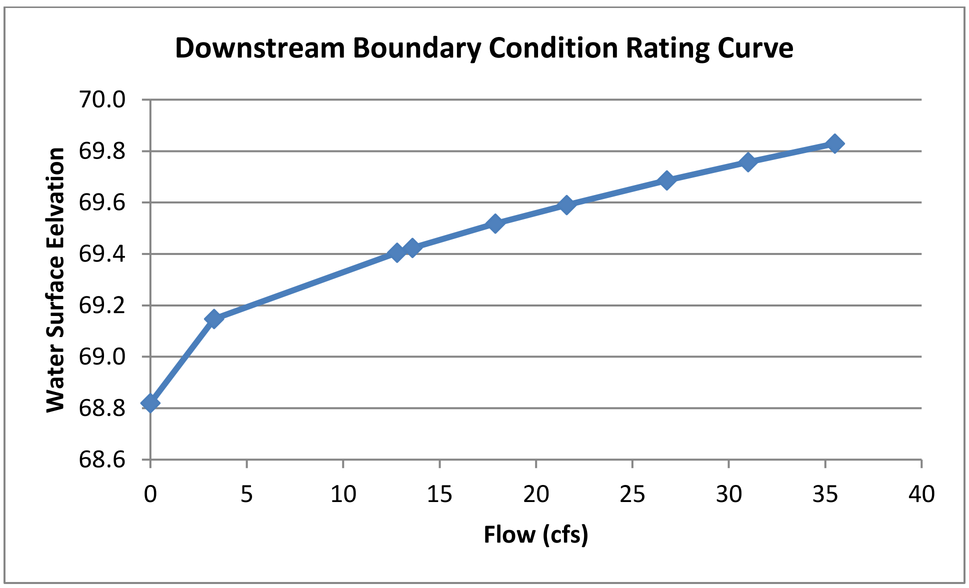

Figure 1. Boundary Condition Rating Curve

Hydraulic Model results

Table 2 presents the reach average hydraulic values for the entire reach 2 and for the proposed channel reach 2A and existing channel reach 2B upstream of the project area at the 2-year flow (12.8 cfs). Generally, reach average values for width (W_2), shear stress (τ_2), energy slope ($S_{e,2}$) and velocity (v_2) decrease from reach 2B to reach 2A while depth and hydraulic radius (R_2) increases.

Table 2. Reach Average Values for Q_2

Variable	Units	Reach Average Value	Reach 2A	Reach 2B
Q_2	cfs		12.8	11.7
W_2	ft	7.7	7.3	9.8
R_2	ft	0.6	0.631	0.428
τ_2	lb/ft^2	0.764	0.736	0.899
$S_{e,2}$	ft/ft	0.0247	0.0225	0.0355
y_2	ft	0.83	0.87	0.64
v_2	ft/s	2.85	2.82	3.02

The upstream average bed slope is 3.58% which is slightly less than the proposed reach bed slope (3.78%). The reduction in velocity and shear stress and increase in depth is due to the proposed bed form and lower gradient run sections included in the proposed design.

Sediment Data

Sediment data collected during previous field visits (described in the previous Otak geomorphic memo) was used for the stability analysis. In order to understand the downstream change in sediment gradation, a total of four pebble counts were conducted along Zackuse creek, with at least one pebble count per geomorphic reach. Two pebble counts were conducted in the alluvial fan reach ("Reach 2"), one downstream (Reach 2a between Sta. 8+75 to 9+25) and one upstream near the ditch line (Reach 2b, between Sta. 11+25 to 11+75), based on observations that the grain sizes increased from downstream to upstream within the reach. The Reach 3 pebble count was conducted from approximately Sta. 16+30 to 17+00, below a grade break immediately downstream of the previous stream restoration work and upstream of the wooden footbridge. The Reach 5 pebble count was conducted from approximately Sta. 19+25 to 20+00, above the 206th Street culvert. The results of the pebble count are summarized in 2 below.

Table 3. Pebble Count Data

	Reach 2a		Reach 2b		Reach 3		Reach 5	
Percentile	**Dia (mm)**	**Dia (in)**	**Dia (mm)**	**Dia (in)**	**Dia (mm)**	**Dia (in)**	**Dia (mm)**	**Dia (in)**
DMIN	2	0.1	2	0.1	2	0.1	2	0.1
D10	6.6	0.3	11.0	0.4	8.9	0.4	11.9	0.5
D16	8.2	0.3	14.1	0.6	13.0	0.5	14.0	0.6
D25	10.2	0.4	18.2	0.7	17.4	0.7	17.4	0.7
D50	16.0	0.6	29.0	1.1	27.1	1.1	28.3	1.1
D75	22.0	0.9	41.5	1.6	43.0	1.7	45.0	1.8
D84	26.6	1.0	48.1	1.9	57.6	2.3	57.4	2.3
D90	30.5	1.2	54.9	2.2	74.1	2.9	80.3	3.2
DMAX	64	2.5	128	5.0	180	7.1	Bedrock	Bedrock
Class	**% Total**		**% Total**		**% Total**		**% Total**	
Sand	5%		1%		3%		1%	
Fine Gravel	10%		5%		6%		4%	
Coarse Gravel	85%		91%		78%		83%	
Cobble	0%		3%		13%		11%	
Boulder	0%		0%		0%		0%	
Bedrock	0%		0%		0%		1%	

Equilibrium Bed Slope Calculations

Equilibrium bed slope calculations (NRCS, 2007) were performed for Reach 2A proposed conditions using hydraulic data from HEC-RAS and the Reach 2A pebble count data. The results indicate that for the existing hydraulics, the required stable D50 particle may be higher than existing (0.15 ft compared to existing 0.09 ft from the pebble count). Using the Manning and Shields equation, the calculated equilibrium bed slope is 1.3%. For the purposes of this preliminary analysis, a critical shear stress of 0.047 was assumed, after Gessler, 1971.

The equilibrium bed slope calculations were performed based on hydraulic results for the cross sections representing the run profile within the reach. This was done to eliminate the variability of the hydraulics due to the step and pool sequence and evaluate the stability of the run using a proposed gradation for spawning gravel.

A mix similar to the WDOT 4" streambed cobble mix is proposed (Table 4). Note that the WSDOT 4" mix is similar to the gradations required for adult kokanee spawning. The WSDOT 4" mix is also similar to the pebble count data from Reach 3 and upstream Reach 2 (Reach 2B), which may represent future sediment supply.

The results for the analysis using just the run cross sections indicate that for the existing hydraulics the required stable D50 particle is very close to the proposed 1.6 inches compared to the proposed gradation of 1.4 inches. Using the Manning and Shields equation, the calculated equilibrium bed slope is 1.7%. This indicates the reach will be slightly degradational and the bed material may coarsen over time. Given the fear that the reach will be depositional in nature due to the upstream sediment supply and the uncertainty involved with these calculations it is a favorable result.

Table 4. Initial Proposed Sediment Mix

Percentile	Dia (inches)
D10	0.7
D16	0.8
D25	0.9
D50	1.4
D75	1.9
D84	2.4
D90	3
DMAX	4

Incipient motion Analysis

The relationship between the driving forces of water flow and resisting forces of gravity and friction are summarized in the Shields dimensionless shear stress parameter (τ^*). Values of this parameter, which scales with bed grain size and shear stress at a given discharge, can be compared to standard values of critical dimensionless shear stress which tend to range from 0.03 to 0.07 (Buffington and Montgomery 1997). The Shields parameter represents a ratio of the shear stress acting on the bed to the weight of the grain, and is calculated as follows:

$$\tau^* = \frac{\tau_0}{(\rho_s - \rho)gD}$$

Where:
τ^* = Shields shear stress
τ_0 = boundary shear stress (N/m^2)
ρ_s = density of sediment (2650 kg/m^3)
ρ = density of water (1000 kg/m^3)
g = gravity (9.81 m/s^2)
D = diameter of sediment (m)

The boundary shear stress, obtained from HEC-RAS, is averaged for a given cross section, but considering only a portion of this shear stress acts directly on the stream bed to initiate sediment movement, shear stress partitioning is more appropriate to estimate grain size mobility. Shear stress available to mobilize bed grains was calculated following Pitlick, et al. (2009), and replaces τ_0 in the above equation with τ', defined as follows:

$$\tau' = \rho g (0.013)^{1.5} (SD)^{0.25} U^{1.5}$$

Where:
τ' = Bed grain shear stress (N/m2)
S = Friction slope
U = flow velocity (m/s)
D = grain size, D_{90} (mm)

Particle mobility was determined for each bed sediment size class by comparing τ^* against a critical dimensionless shear stress value (τ_c^*). When $\tau^* > \tau_c^*$, the particle is considered mobile at the representative critical dimensionless shear and associated discharge value. Values of τ_c^*=0.03 and 0.047 were used to characterize mobility at each cross section. The 2 and 25-year return flows were evaluated for stability. For final design the full range of flows could be evaluated to determine crest rock sizes. Table 5 shows the results for incipient motion at the step crest, the pool and run cross sections. These are the predicted size of rock that could mobilize for the given flow and design sizes should be increased for a safety of factor and stability.

Critical Sediment Size (inches)				
	Q_2		Q_{25}	
	t*c= 0.03	t*c= 0.047	t*c= 0.03	t*c= 0.047
Step Crest	5.6	3.6	7.2	4.6
Pool	0.9	0.6	0.9	1.26
Run	2.0	1.3	2.0	2.20

Alternative Alignment and Bedform Analysis

A constant equilibrium bed slope of 1.6% without bedforms or grade breaks would require a very long proposed channel (>900 feet) to connect the proposed tie-in elevations at the East Lake Sammamish Parkway culvert. This length of channel would necessitate an alternative upstream tie in on private land much farther upstream or an unnaturally meandering channel to achieve the needed length. However, since the equilibrium bed slope applies only to the channel gradient between the top of a downstream grade control and the base of an upstream grade control (e.g., step, riffle), using grade control structures means that the proposed shorter channel reach within the project boundaries can be achieved. The crests of the grade breaks will maintain higher velocities and the pools will scour and fill depending on flows.

The proposed tie in point for the channel which dictates the elevation drop was designed to meet multiple project constraints. The proposed tie in point takes advantage of an existing overflow path in the floodplain that currently has flow at wet times of year. This alignment also stays within the project boundaries (property rights, budget and scope) and maintains existing appropriate spawning habitat described in Otak's initial geomorphic memo.

A repeating pattern of rock chutes or log drops and pools were considered to provide bedform complexity and habitat with spawning habitat provided in the runs and pool tailouts. Grade control structures in both the form of boulder bands or rock chutes were evaluated and for this project site boulder bands were the chosen alternative. Due to the amount of elevation needed along the proposed channel rock chutes would need to be long or steep, resulting in sections of channel > 10% or longer lower gradient sections that reduce the length of spawning habitat. The grain size distribution for these proposed rock chutes would also be higher than the grain size distribution required for adult kokanee spawning. Boulder bands were chosen as the step form for the grade control design and are designed to meet applicable stability and fish passage requirements. They maximize equilibrium slope sections as well as have the ability to make up grade within the project limitations and provide habitat features for returning fish. Log features are incorporated for these structures as well.

Conclusions and Future Work

Both the proposed channel geometry (equilibrium run lengths and channel cross section) and bed material were evaluated for design suitability and stability. Slopes and bed material for the proposed channel realignment seem to be appropriately sized for the purpose of stability and spawning habitat. Within the range of uncertainty of current analysis, the proposed reach may have the energy and transport capacity to become slightly degradational. This, however, does not take into account velocity variability due to step-pool structures and added large wood structures designed to provide added roughness and habitat diversity. These design elements will reduce velocities in the vicinity of the structures and therefore also reduce scour and transport potential. Additionally, the amount of sediment supply delivered to the reach is currently unquantified. The slopes and bed material gradations will likely fluctuate over time depending on the variable nature of sediment supply.

Instabilities exist above the project reach where upstream of the realignment channel is a steep incised/unstable channel. The two 90 degree bends upstream of the project site, in particular, have very steep non-cohesive banks that are likely a large source of sediment for downstream. One option for additional work at the ditch line is grading back the steep banks or making the bends less severe. A second option is extending the proposed channel grading upstream further to connect above the ditch line bypassing the bends entirely. However, since neither of these options addresses the channel instabilities upstream of the two 90 degree bends the stream those instabilities will remain and the stream is likely to continue to headcut. An alternative consideration for work at the 90 degree bends is adding wood structures into the channel or adding roughness to increase stability temporarily. While this may help the situation in the short term the tradeoff is an increased likelihood of avulsion at this location.

References:

1. Gessler, J., Beginning and ceasing of sediment motion, in *River Mechanics,* edited by H.W. Shen, pp.7:1-7:22, H.W. Shen, Fort Collins, Colo., 1971.
2. NRCS (Natural Resources Conservation Service). 2007. National Engineering Handbook 654 Technical Supplement 14B. Scour Calculations. 210-VI-NEH. August 2007.