Memorandum

16300 Christensen Road, Suite 350
Seattle, WA 98188-3418
Phone: 206-241-6000
Fax: 206-439-2420

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To: Steve Foley and Jeff Burkey, King County Water and Land Resources Division

From: David Hartley, Peter Brooks, Derek Booth (Stillwater Sciences)

Subject: Addendum to Draft Incipient Motion Analysis for Priority Reaches in Juanita Creek

Pages: 5

Introduction

Since submission of the original incipient motion analysis memorandum (NHC, January 11, 2010) followed by the project report (NHC and Stillwater Sciences, February, 2010) which included a summary of the results of the incipient motion analysis, it has come to NHC's attention that recent research (Wilcock et al, 2009) on gravel mobility suggests that a far more mobile condition for bedload sediment in Juanita Creek might exist than previously described by project documents. A key conclusion of this recent research is that the presence of relatively small percentages of sand (i.e., 10% to no more than 30%) on the bed of a flume or stream mixed with coarser gravel material causes the gravel particles to mobilize at shear stresses that are up to 4 times smaller than the critical shear stress calculated using the typical value of the Shields parameter for mixed gravel-sized sediment (0.045). Given that fine sediment at such levels are pervasive within the Juanita Creek stream system, this theory of mixed sediment mobility would suggest that gravels throughout Juanita begin to move at discharges that are considerably lower than previously reported in the aforementioned report and memorandum. This addendum provides guidance and recommendations to the County for re-interpretation of previously presented results as well as for further analysis of sediment transport in Juanita Creek.

Bed Material Movement of Gravel in the Presence of Sand

Initiation of motion, sediment transport, and the evolution of the grain mixture and form of the stream bed in a hydrologically and geomorphically dynamic system like Juanita Creek involves extremely complex, three-dimensional, temporally and spatially variable processes that defy precise numerical analysis, simulation or quantification. Given these complexities, earlier project work related to sediment mobility took a well-established, simplified approach of using a standard and constant value for the dimensionless critical shear stress (Shields Parameter) equal to 0.045. This parameter is central to the determination of sediment mobility, because it is directly proportional to the shear stress needed to mobilize the bed but is the only parameter that cannot be directly measured.

Calculation of the critical shear stress required to move each size class (sands, D_{50}, and D_{90}) was made separately for Tier-1 sites where a pebble count was taken, using a single value for Shields Parameter. While this simplified approach has the virtue of being understandable and unpretentious in its objectives, it should also be the best feasible approach possible and convey reasonably conservative estimates. Our reconsideration of the Juanita Creek incipient motion situation suggests that these caveats have not been sufficiently met in our earlier work products.

The reasoning behind this change is as follows: the method we applied to identify the critical shear stress, corresponding discharges, and flow quantiles at which the different sized particles would move at the Tier-1 sites would have been approximately valid for plain stream beds with mixed gravel sediment having the measured median particle sizes. As mentioned in the introduction, an increasing body of new data and research indicates that the presence of sand in a gravel-dominated bed significantly reduces the shear stress necessary to move that gravel. As shown in Figure 1a (after Wilcock et al., 2009), the dimensionless critical shear for gravel movement decreases from above 0.040 down to less the 0.010 as the sand percentage on the surface increases from 10% to 30%. This empirical result may be viewed as a kind of "reverse hiding factor". The logic behind the hiding factor is that finer particles "hide" behind or are shielded from flow forces by larger particles and therefore do not move as readily as they would if only their size made up the bed. This phenomenon has been postulated and observed by sedimentologists since the early 1950s. The effect of the hiding factor is illustrated by the curves shown in Figure 1b for bimodal sediment mixtures of sand and gravel in which the gravel-to-sand size ratio varies from 10 to 50, going from the lowest curve in the figure to the highest.

One way to view the *reverse-hiding factor* and *hiding factor* data summarized by these figures is in terms of an *effective grain size*—or, alternatively, an *equivalent critical shear stress* since these are linearly related for sediment of a given density. The *effective size* is the size that is equivalent to what has been observed for stream beds with uniform sediment. Figure 1a indicates that sand fractions on the bed that are greater than 30% reduce the effective size of the co-existing gravels by a factor of four compared to a bed composed solely of that gravel size. Conversely, as indicated by Figure 1b, when sand makes up only 10% of a bed, the effective size of that sand increases by as much as a factor of eight (based on the lowest curve corresponding to gravel size to sand size ratio of 10) compared to a plain sand bed composed of that size sand.

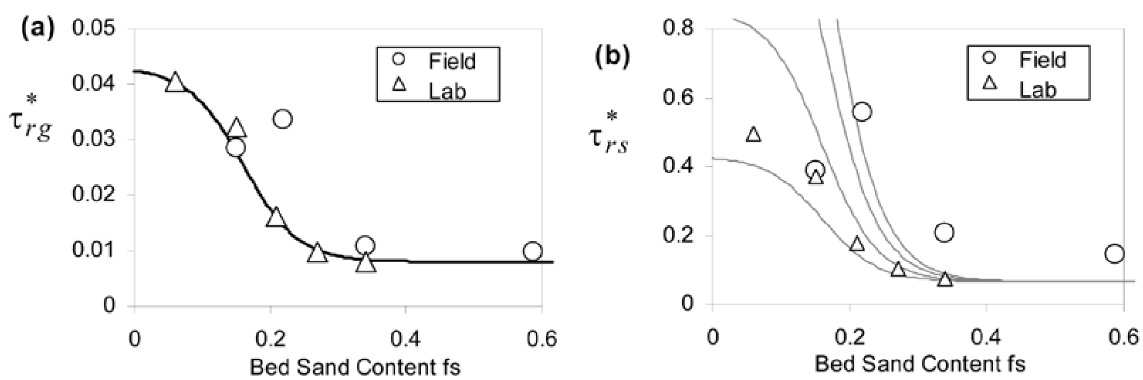

Figure 1. Change in the critical shear stress (τ^*) as a consequence of changing sand fractions (from Wilcock et al., 2009).

In effect, based on these data and concepts, approximately ***the same shear stress and corresponding stream discharge*** would be expected to initiate both gravel and sand motion for a mixed bed surface composed of 85% gravel of 20-mm size and 15% sand of 2-mm size. This critical shear stress would be only about half of the critical shear stress needed to mobilize a bed composed 100% of 20-mm gravel bed—in other words, adding sand makes the bed much easier to mobilize. It is also approximately five times the critical shear stress required to mobilize a uniform bed composed of 2 mm sand.

Re-Interpretation of Incipient Motion Calculations

During field data collection for this project, varying amounts of sand were observed on the surface of the bed of Juanita Creek at all sites; however, the sand percentage was characterized only semi-quantitatively in bins of 0-33%, 34-66% and 67%-100%. At all sites, including the Tier-1 sites where pebble counts were taken to establish gravel size distribution, stream bed patches reflecting all three sand percentage bins were typically observed. Given the high critical shear sensitivity to relatively low percentages of sand in the bed noted above, it is recommended that the critical shear values previously calculated for gravels be *reduced by a factor of two* corresponding to a bed sandiness of approximately 15%. The resultant critical shears and discharges should be regarded as reflective of conditions under which sediments of the specified size and smaller would be set in motion throughout the length of the Tier-1 site in question. A comparative summary of results of this recommendation is shown in Figure 2a and 2b below. Figure 2a is the original figure from the February, 2010 Geomorphic Assessment report based on the constant dimensionless critical shear stress value of 0.045, while Figure 2b provides the same information based on the revised approach for mixtures of gravels and fines discussed above.

In contrast to the original analysis, the revised analysis indicates that with a couple of exceptions, the D_{50} gravel mobility is expected to occur at discharge values as low as 50% of the 1.01-year peak which is typically exceeded over 20 times per year in the Juanita system. Exceptions include the lower portions of the Totem Lake tributary and the lower mainstem just above NE Juanita Dr. Additionally, in the original analysis there was virtually no D_{90} mobility predicted (an unusual outcome, as discussed at the time), while in the revised analysis the D_{90} is expected to be mobile at approximately bankfull discharges on lower Cedar Creek (site 104) and also on the upper mainstem of Juanita Creek (site 205). As originally noted, culverts within Juanita Creek cause backwater at extreme flood discharges and suppress upstream sediment mobility and bed scour at several locations; however, this is not as constraining to overall gravel transport as originally reported.

In our judgment, these analytical results correspond much more closely to both observed conditions along the Juanita Creek channel network and our expectations from other measurements on alluvial stream systems in humid regions. The benefit to the County of

Figure 2a. Original Figure 4 from February, 2010 Report

Priority Reach	NHC Site	Sand %	D_{50} (mm)	D_{90} (mm)	Largest Size Class Mobilized at Flow Quantile†							
					½ of 1.01	1.01	1.5	2	5	10	25	100
Upper Juanita	205	33-67%	19	69	Olive	Olive	Olive	Gray	Gray	Gray	Gray	Gray
Upper Juanita	204	0-33%	24	44	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Gray
Upper Juanita	203	33-67%	15	33			Olive	Olive	Olive	Olive	Olive	Olive
Gage 6 Trib	208	0-33%	43	101	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive
Gage 6 Trib	207	0-33%	33	79	Olive	Olive	Olive	Olive				Olive
Cedar Creek	202	0-33%	21	39		Olive	Olive	Olive	Olive	Olive	Olive	Gray
Cedar Creek	104	33-67%	19	32	Olive	Olive	Olive	Olive	Gray	Gray	Gray	Gray
Totem Lk Trib	110	0-33%	25	50				Olive	Olive	Olive	Olive	Olive
Totem Lk Trib	108	0-33%	15	36			Olive	Olive	Olive	Gray	Gray	Gray
Lower Juanita	106	33-67%	15	128	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Lower Juanita	107	33-67%	12	35	Yellow	Gray	Gray	Yellow	Yellow	Yellow	Yellow	Yellow
Lower Juanita	102	0-33%	19	38	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

† Return interval (years), annual series.
Yellow = All sand (D=5 mm); Olive = Small gravels (D=10 mm); Gray = D_{50}; Purple = D_{90}

Figure 2b. Revised Mobility Summary per this Addendum.

Priority Reach	NHC Site	Sand %	D_{50} (mm)	D_{90} (mm)	Largest Size Class Mobilized at Flow Quantile†							
					½ of 1.01	1.01	1.5	2	5	10	25	100
Upper Juanita	205	33-67%	19	69	Gray	Gray	Purple	Purple	Purple	Purple	Purple	Purple
Upper Juanita	204	0-33%	24	44	Gray	Gray	Gray	Gray	Gray	Gray	Purple	Purple
Upper Juanita	203	33-67%	15	33	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Gage 6 Trib	208	0-33%	43	101	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Gage 6 Trib	207	0-33%	33	79	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Cedar Creek	202	0-33%	21	39	Olive	Gray	Gray	Gray	Gray	Gray	Purple	Purple
Cedar Creek	104	33-67%	19	32	Gray	Gray	Purple	Purple	Purple	Purple	Purple	Purple
Totem Lk Trib	110	0-33%	25	50					Gray	Gray	Gray	Gray
Totem Lk Trib	108	0-33%	15	36			Gray	Gray	Gray	Gray	Gray	Gray
Lower Juanita	106	33-67%	15	128	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Lower Juanita	107	33-67%	12	35	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Lower Juanita	102	0-33%	19	38		Olive	Olive	Olive	Olive	Olive	Olive	Olive

† Return interval (years), annual series. Olive = Small gravels (D=10 mm); Gray = D_{50}; Purple = $D_{90,}$ Sands will generally mobilize when D50 of gravel is mobilized.

having a more reliable and credible analytical framework is that alternative future scenarios can now be evaluated with respect to their sediment-transport consequences with greater confidence. Although the predictions of sediment-transport modeling must always be treated judiciously, particularly when executed under significant constraints of time and budget, they can provide broadly useful guidance notwithstanding the high imprecision involved. This modification to our original results does not alter the fundamental patterns of sediment mobility previously recognized, but the quantitative results should allow a more functional evaluation of alternatives.

Summary and Recommendations

The County should consider the impact of fine sediment (sand) on gravel mobility in evaluating and refining restoration alternatives for Juanita Creek. As demonstrated by Wilcock et al (2009), the introduction of fine sediment to the stream bed increases gravel mobility with consequences for stream biota (e.g., salmon redd scour and fine sediment intrusion), downstream sedimentation, and channel stability. The pervasive instability of channel banks throughout the Juanita system is surely a significant source of fine sediment to the stream bed and likely causes further instability associated with enhanced bed material mobility. If the County intends to calculate sediment transport rates as part of its restoration design, it may be prudent to consider the application of the two fraction model developed by Wilcock and Crowe (2003) and further documented in the BAGS report (Pitlick et al, 2009). Application of this method would be significantly enhanced by the collection of additional pebble counts that track both gravel sizes and the percentage of the bed occupied by sand for reaches of particular concern.

References

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