FLOODPLAIN GEOMORPHIC SURFACE DEVELOPMENT APPROACH TECHNICAL MEMORANDUM

WHITE RIVER AT COUNTYLINE LEVEE SETBACK PROJECT

Prepared for
King County
Department of Natural Resources and Parks

Prepared by
Herrera Environmental Consultants, Inc.

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Prepared for
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Department of Natural Resources and Parks
Water and Land Resources Division
River and Floodplain Management Section

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INTRODUCTION

This memorandum was prepared for King County's (the County's) proposed White River at Countyline Levee Setback Project (the Project) under contract Amendment #3 as a supplement and update to the initial Model Approach Memo prepared under Task 200.1 in 2011 (Herrera 2011c). King County intends to remove an existing, near-channel levee and revetment and then construct a new setback levee and biorevetment in the project area to improve flood water conveyance, thereby reducing flooding impacts on area residents and public infrastructure while also improving habitat for fish and wildlife.

Flooding in the project area is directly affected by sediment transport and depositional processes inherent to the White River. King County previously retained Herrera to perform hydraulic and sediment transport modeling for the proposed project (Task 200.3 and 200.8) and document the modeling results in a memorandum prepared under Task 200.4 (Herrera 2012). Based upon the model calibration and validation results, it was determined that the sediment transport numerical modeling was not sufficiently accurate to predict future geomorphic changes, particularly considering the degree to which the system is out of equilibrium with respect to sediment supply (Herrera 2012). Thus, a different method of predicting future geomorphic change is necessary to support project effects analysis and design.

This memorandum describes an alternate approach to generate a prediction of future geomorphic changes. Included in this memorandum is a description of the methodology of a process that will be used to develop a series of topographic surfaces that simulate future conditions at the project site. These surfaces and the subsequent hydraulic modeling of them will have direct application to engineering design analyses and will be used to assist the design team in identifying potential project effects. The surfaces include a representation of physical site characteristics for no-project and with-project conditions covering a suite of geomorphic behaviors expected over the short-term (approximately 3 years following construction) and a "fully evolved" state in the long-term. Hence, there are four scenarios simulated in three time periods. Hydraulic modeling methods and results based upon the predicted topographic surfaces will be described in a separate memorandum prepared at a later date under Task 200.9.

Project Site and Study Area

The proposed project site is on the left (east) bank of the White River between river mile (RM) 4.9 and RM 6.1, downstream of the A Street Bridge. The project site lies within incorporated King County, Washington in the City of Pacific and also extends into the City of Sumner in incorporated Pierce County, with a small portion lying in an area of unincorporated Pierce County (Figure 1).

The study area, which in the case of a modeling project is the model domain, extends between approximately RM 4.4 and RM 6.7. A study area larger than the project site is required to properly “spin-up” the numerical hydraulic model and to identify risks to adjacent infrastructure, such as the A Street Bridge, a Burlington Northern and Santa Fe Railway (BNSF) bridge, Stewart Road SE and its bridge crossing over the river, and private development on both sides of the river.

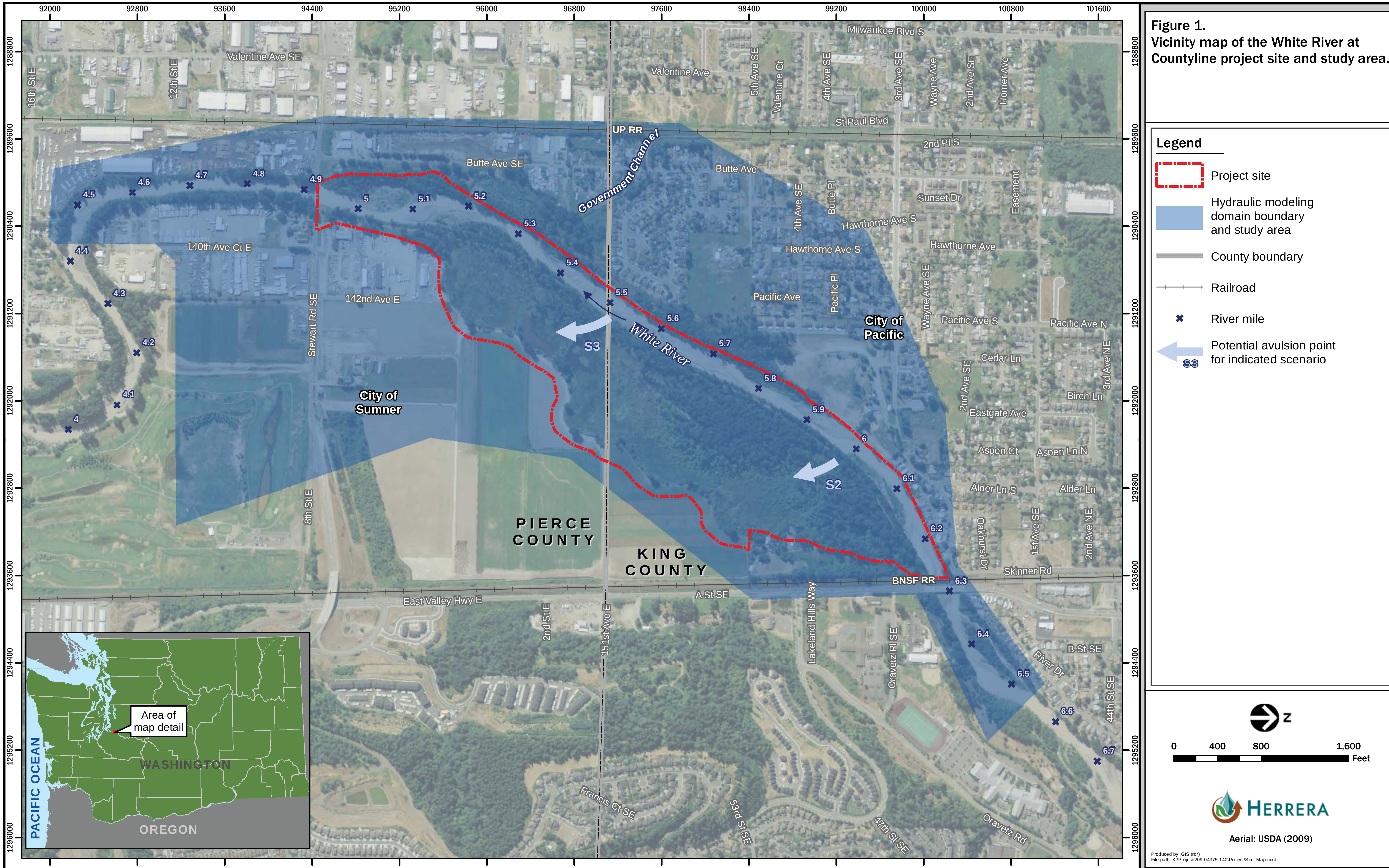

Figure 1.
Vicinity map of the White River at Countyline project site and study area.

SCENARIO DEVELOPMENT METHODOLOGY

The methodology of the numerical modeling component of the Project has already been described in large part in the Model Approach Memo prepared under Task 200.1 (Herrera 2011c) and the subsequent 2012 technical memorandum prepared under Task 200.4 (Herrera 2012); however, updates to that approach and a cursory background are summarized here. RiverFLO-2D is the hydraulic and sediment transport modeling software that has been used to date for the Project, and that will continue to be used for numerical hydraulic modeling in support of the design and impacts assessment. Figure 1 shows the RiverFLO-2D model domain, along with many other key locations discussed in the following sections.

The numerical hydraulic modeling to estimate future impacts from the Project requires the establishment of some basic terminology. To fully vet the range of possible outcomes that the Project may produce, several scenarios (i.e., possible outcomes) are investigated. These correspond to the scenario number (e.g., S1, where the 1 corresponds to the most-likely, with-project scenario). Because the site is dynamic from a geomorphic point of view, these scenarios need to be analyzed at different periods of time in the future. The result is that several surfaces will need to be constructed and used as the geometry for the individual hydraulic model runs, called simulations. They are called simulations because they are intended to simulate most likely future conditions, and do not represent a definitive calculation because there is inherent unpredictability to the alignment of the river over time. The time period of interest is denoted with a suffix in the simulation number (e.g., S1c, where c corresponds to the fully evolved, most likely, with-project simulation).

The development of the methodology for the scenarios and surfaces was synthesized and discussed in a series of three meetings involving Herrera and County staff. These meetings chronologically addressed increasing specificity in the methodology documented in this memorandum. The first meeting, held on March 15, 2012, determined the type of simulations (i.e., existing without-project, with-project most probable, and two avulsion scenarios) to be performed and the basic methodology to be used to develop the future floodplain topography scenarios. The second meeting, held on April 4, 2012, developed the details (e.g., the types of channels to be developed, major assumptions associated with future actions, etc.) of the scenarios. The final meeting, held on April 12, 2012, established a procedure to define the estimated quantities of sediment to be eroded and deposited in the identified future conditions scenarios.

Finally, it is important to mention that data of all sorts (e.g., hydraulic, sediment concentration, survey, etc.) is being collected continuously on geomorphic changes occurring throughout the study area. Therefore, the methodology may be refined based upon these new observations as appropriate.

Background Information

There have been a number of studies completed to characterize sediment transport through the Project site and downstream to Commencement Bay. These studies provide the scientific basis for the model scenarios originally developed and described in Herrera (2011a), particularly as the system evolves following project implementation. Similar studies of other fluvial systems are relevant for context and for understanding how researchers have addressed predictions of sediment transport and deposition in those systems. Additionally, there have been several studies and investigations at the project site during the course of project development. The studies and data sets include:

Project-specific work contracted or performed by the County

- A sediment trends report for the White River between RM 4.44 to RM 10.60 (Herrera 2010)
- Previous modeling reports regarding the project, including topographic comparisons between 2007, 2009, and 2011 (Herrera 2011a, 2011b, 2011c and 2012)
- An exploration by the County of the left bank levee composition at the project site (King County 2011)
- An earlier survey of hand-augered boreholes in the left bank floodplain within the project site provided by King County (Shannon & Wilson 2009)
- An analysis of topographic data collected by the County and several recent lidar flights (King County 2012b)
- An archeological investigation of the project site, which included 90 shovel probes of shallow subsurface conditions provided by King County (Paragon Research Associates 2011)
- A radiocarbon analysis of soil borings in the project site provided by King County (Beta Analytic 2010)
- Oblique aerial photographs taken during the January 2009 and February 2012 flood events (U.S. Army Corps of Engineers 2009; King County 2012a)

Site-specific work developed for other purposes

- A U.S. Geological Survey (USGS) study that sought to characterize and model sediment transport in the greater lower Puyallup River system, including the project site (Czuba et al. 2010; Czuba et al. 2011), and a subsequent study to develop a sediment budget for the White-Puyallup basin (public release date expected in later 2012).
- USGS sediment sampling (bedload and suspended load) of the White River at R Street in Auburn (USGS 2010)

- A sediment rating curve constructed by USGS staff of the White River in the 1980s (Sikonia 1990)
- Washington State Department of Ecology well logs for wells and borings drilled by others within the project site (Ecology 2012)

Historical resources

- Several early investigations of sediment removal and channel conveyance in the greater lower Puyallup River system, including the project site (Borland 1984; Prych 1988)
- A series of Inter-County River Improvement (ICRI) maps that pre-date some of the human alterations to the river (ICRI 1914 and 1922, Undated)
- Historical aerial photographs provided by King County (King County 1936, 2008)
- An analysis and description of historical channel locations of the White River (Collins and Sheikh 2004)

Analyses of potential analog sites and projects

- Upper Puyallup River geomorphic assessment (Cardno-Entrix 2010)
- Recent analysis of performance monitoring at the Hansen Creek levee setback project site (Mostrenko et al. 2011)
- A geomorphic analysis of the lower Tolt River (Herrera 2007)
- An analysis of the ramifications of maintaining status quo levees in the lower Puyallup River on flooding and channel aggradation (TetraTech 2009)

General scientific literature related to the physical processes active at the project

- A recent peer-reviewed journal article describing the long-term geomorphic evolution of the study area (Collins and Montgomery 2011)
- Recent theoretical developments in the characterization of floodplain sedimentation (Lauer and Parker 2008a, 2008b)
- A series of recent publications from around the world that describe the geomorphic evolution of channel cutoff events and the alluviation of former floodplain channels (Hooke 1995; Piegay et al. 2000; Hooke 2003; Citterio and Piegay 2009; Constantine et al. 2010; Le Coz et al. 2010; Zinger et al. 2011)

These materials were used to synthesize and provide analogs for the development of several future topographic surfaces at the project site that are discussed below. In particular, these references were used to estimate the quantity and location of sediment that may deposit or erode in the project site to generate the surface to simulate future conditions. It is expected, however, that the scenario surfaces may each indicate that sediment deposition occurs in the study area, including the without-project alternative. It is clear from the referenced studies that without extensive, ongoing sediment removal (i.e., dredging) the river channel within the project site will continue to aggrade over time (Herrera 2010; Czuba et al. 2010; Collins and Montgomery 2011).

General Surface Development Procedure

The development of the surfaces will be a coordinated effort between the County and Herrera. The procedure will be dependent on the surface in question. In those instances where a surface is already prepared for another purpose (e.g., the post-construction surface, S1a; and the without-project existing conditions simulation, S4a), those surfaces will be constructed by the County and delivered to Herrera. For the S4b surface, which is relatively straightforward to produce, a map .pdf (using the same format as previous maps produced for the Project: Herrera [2011c]) of the topographic differences between the April 2011 lidar surface and the S4b surface will be delivered to the County for their approval. The S4b surface will then be used as the surface, or topographic basis, for hydraulic modeling to be completed as part of Task 200.8.

For all other surfaces, a hand sketch of the deposition and erosion present for the given scenario and time frame will be produced by the County, which details the distribution of sediment volumes calculated according to the analysis described in the next section. The sketch will be delivered to Herrera, who will modify the April 2011 lidar surface to reflect the modifications in the sketch. Once the surface is created, it will be used to generate a map .pdf of the differences between that surface and the April 2011 lidar surface. Once approved by the County, the surface will be used for the hydraulic model simulations.

SURFACE DEVELOPMENT

Basis of Topographic Surfaces

The topographic surface of the floodplain for the scenarios described in the calibration report (Herrera 2011a) can be readily developed using the data sets and various methods described above. In the meeting on March 15, 2012, it was agreed upon that the pending hydraulic model runs will emulate the same four scenarios described in Herrera (2011a). These scenarios are summarized in Table 1, along with each set of simulations and the order in which they will be performed. All of the original scenarios developed in the production of the sediment transport numerical modeling approach can be attained through the four scenarios (S1-S4) listed below (Herrera 2011c).

The order of simulations follows with each successive time frame building on earlier ones. As a result, the simulations should occur in the order listed in Table 1 (numbers in parentheses following each scenario). A specific sequence is needed because some of the earlier model results indicating conditions immediately following construction (i.e. Year 0 and Short Term) will inform the patterns of sediment deposition and erosion that should be used to develop future surface topography for subsequent model runs. The need to change the sequence of the model simulations will be evaluated as preliminary modeling results become available. Finally, to ensure that individual locations within the project site can be evaluated in a strict way (i.e., so that one point in the with-project model corresponds to the same exact point in the no-project model), the final model domain and mesh for all runs must be the same. This necessitates a “reckoning” of all model runs once the densest topographic/bathymetric mesh is determined because it cannot be known at the outset of these model simulations where the model mesh needs to be dense to accurately model the flow until all of the runs have been completed. Each model run will be replicated as necessary following the reckoning of the mesh. It was determined that the mean annual flow runs will be reckoned separately from the flood runs because of the propensity of those runs to produce highly resolved grids in the main channel that are unnecessary for and would significantly slow the flood event modeling.

The study area is under continual change from both natural processes (e.g., deposition from incoming sediment input) and human modifications (e.g., development of adjacent land and associated infrastructure and the maintenance of flood facilities). Some of these types of changes have occurred in the study area since the latest model was developed, as documented in Herrera (2012). The “Year Zero” time will be set to coincide with the time of the 2011 lidar flight (April 2011). It is acknowledged that landscape and infrastructure alterations that may have an impact on the flood flow patterns have occurred since April 2011. These include the placement of fill materials as related to land development south of Stewart Road SE. Lidar topographic data collected in spring 2012 is not yet available to incorporate into an update of the surface model in this area. Updating the surface model with topographic changes unrelated to the project could also pose a problem rectifying whether the cause of any changes in flood elevations were caused by the project or by the surface update. In order to assess changes in flood flow patterns and flood elevations resulting only from the project, recent landscape changes will not be included in the future model simulations.

Assumed Sediment Deposition within the Study Area

Numerous studies of sediment production, transport and deposition have been prepared for the White River basin which includes estimates of bed material deposited in the study area (Prych 1988; Herrera 2010, 2011a, 2012; Czuba et al. 2011; King County 2012b). Bed material is distinguished from sediment size classifications (i.e., gravel/cobble, sand, silt/clay) because it includes sediment of a range of sizes. The estimates of deposited sediment in these studies were derived using a variety of methods, from quasi-analytical methods to topographic comparisons and dredge contract records. For those sediment studies developed prior to the 1990s (Borland 1984; Prych 1988), the volumes are strongly influenced by the effects of the extensive and ongoing dredging that was occurring at that time. The results of all of the bed material sediment budgets vary between roughly 1,100 and slightly less than 110,000 cubic yards per year, based upon the bedload flux into the project site. These estimates depend on the approach by which they were obtained and the time-frame of the measurements. The highest (post-dredge) estimates come from a quasi-analytical approach (Syvitski et al. [2003] used in Herrera [2010]). This method implicitly incorporates a relatively long time frame and the largest sedimentation events. Likewise, the smallest estimates from King County (2012b) are from years in which no significant flood events (i.e., events exceeding 10,000 cfs) occurred.

Table 1. Description of surfaces to be constructed and modeled, with order of sequence indicated

Scenario	Scenario Intent	Time Frame		
		Year Zero *	Short-term **	Fully Evolved ***
S4: Existing Conditions Without Project	To simulate conditions in the absence of the project	**S4a** – Existing conditions based on the April 2011 lidar topography. (Sequence #1)	**S4b (3)** - Aggrade channel and floodplain at site of overtopping at the county line at the average deposition rate since intensive monitoring has begun. (Sequence #3)	**S4c (5)** - Aggrade channel and floodplain at site of overtopping at the county line per existing sediment trends until thalweg reaches levee height at the King-Pierce county boundary line. The time for this to occur is determined and used to estimate the fully evolved conditions for subsequent project concept scenarios (S1c, S2c, and S3c). (Sequence #5)
		Assumptions: • The left bank levee/revetment will remain intact (i.e., it will not erode) due to the expected repair work completed by Pierce County. • The right bank levee (HESCO or other means) will be maintained to prevent overtopping into the City of Pacific. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • Most of the bedload (coarse material) entering the project reach deposits in the study area under existing conditions, and this will continue to be the case. • The existing left bank levee will be maintained and remain intact.	**Assumptions:** • The left bank levee/revetment will remain intact (i.e., it will not erode) due to the expected repair work completed by Pierce County. • The left overbank splay deposit near the county boundary line will not change in character over time (i.e., sand will continue to be completely sequestered at existing rates and silt/clay deposition will continue to be negligible). • No avulsion of the White River through Stewart Road SE will be allowed to occur due to the likelihood of flood fighting measures in this area. • The right bank levee (HESCO or other means) will be maintained to prevent overtopping into the City of Pacific. • Silt and clay deposition is assumed to be negligible. • Sand will continue to be completely sequestered in floodplain areas. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • The existing left bank levee will be maintained and remain intact.	**Assumptions:** • The left bank levee/revetment will remain intact (i.e., it will not erode) due to the expected repair work completed by Pierce County. • The left overbank splay deposit near the county boundary line will not change in character over time (i.e., sand will continue to be completely sequestered at existing rates and silt/clay deposition will continue to be negligible). • No avulsion of the White River through Stewart Road SE will be allowed to occur due to the likelihood of flood fighting measures in this area. • The right bank levee (HESCO or other means) will be maintained to prevent overtopping into the City of Pacific. • Deposition rates of gravel/cobble, sand, and silt/clay will be revisited once the short term (suffix b) simulations are completed. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • Climate change will be accounted for by increasing volumes by 10%. • The existing left bank levee will be maintained and remain intact.

Table 1 (continued). Description of surfaces to be constructed and modeled, with order of sequence indicated.

Scenario	Scenario Intent	Time Frame		
		Year Zero *	Short-term **	Fully Evolved ***
S1: Project Concept, Most-likely Response	To simulate the most likely conditions if the project is constructed	**S1a -** "As-built" conditions immediately after construction, per 40% design plans (dated March 2012) and refined ELJ and biorevetment locations. (Sequence #2)	**S1b (4)** - Scour channel upstream toward A Street bridge. Deposit scoured sediment in splay at upstream inlet to reconnected floodplain, in mainstem downstream of RM 5.9, and in splay at the King – Pierce county boundary line. Scour small channels at outlet of reconnected floodplain and at bar near RM 5.1. (Sequence #4)	**S1c (6)** - Deposit incoming sediment in splay at upstream inlet to reconnected floodplain. Scour channels through splay at inlet. Deposit in mainstem downstream of RM 5.9. Deposit in splay at County line. Scour channels through splay, floodplain outlet, and bar near RM 5.1. Deposit some of this sediment downstream of floodplain outlet (RM 5.1) and in main channel in project site. (Sequence #6)
		Assumptions: • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • The existing left bank levee will remain intact where it is not removed.	**Assumptions:** • Silt and clay deposition is assumed to be negligible. • Sand will continue to be completely sequestered in floodplain areas. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • All of the coarse material and the same fraction of sand stored in existing conditions in the White River will be retained in the project site following the removal of the existing levee based upon the analog at Hansen Creek (Mostrenko et al. 2011). • The existing left bank levee will remain intact where it is not removed.	**Assumptions:** • Deposition rates of gravel/cobble, sand, and silt/clay will be revisited once the short term (suffix b) simulations are completed. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • Climate change will be accounted for by increasing volumes by 10%. • The existing left bank levee will remain intact where it is not removed.
S2: Project Concept, Full Avulsion	To simulate a condition that would produce the maximum velocities and inundation in the northern portion of the site if the project constructed	N/A	**S2b (7)** - Block mainstem at RM 5.9. Scour channel upstream toward A Street bridge. Deposit scoured sediment and 3 years of incoming sediment in splay at upstream inlet to reconnected floodplain. Scour channels in splay deposit and floodplain outlet; scour bars near RM 5.1; deposit some of this sediment downstream of floodplain outlet (RM 5.1). (Sequence #7)	TBD
			Assumptions: • Silt and clay deposition is assumed to be negligible. • Sand will continue to be completely sequestered in floodplain areas. • Flow will be completed blocked in the main channel to an elevation comparable to the height of the existing left bank levee near Pacific City Park and will extend into the left bank floodplain as necessary to fully direct flow into the overbank. • This scenario is intended primarily for design purposes (i.e., to estimate maximum erosion, deposition, and flow velocity at and near the engineered log jams, biorevetment and setback levee) and are not necessarily intended to be a direct interpretation of future conditions. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road	

Table 1. Description of surfaces to be constructed and modeled, with order of sequence indicated

Scenario	Scenario Intent	Time Frame		
		Year Zero *	Short-term **	Fully Evolved ***
			in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • All of the coarse material and the same fraction of sand stored in existing conditions in the White River will be retained in the project site following the removal of the existing levee based upon the analog at Hansen Creek (Mostrenko et al. 2011). • The existing left bank levee will remain intact where it is not removed.	
S3: Project Concept, Avulsion at County Line	To simulate a condition that would produce the maximum velocities and inundation in the southern portion of the site if the project constructed	N/A	**S3b (8)** - Block floodplain inlet near RM 5.9. Deposit some of the 3 years of overbank suspended sediment landward of blockage at upstream inlet. Block mainstem at ~RM 5.4. Deposit incoming sediment in splay at the King –Pierce county boundary line. Scour channels in splay deposit to floodplain outlet; scour bars near RM 5.1; deposit some of this sediment downstream of floodplain outlet (RM 5.1). (Sequence #8)	TBD
			Assumptions: • Silt and clay deposition is assumed to be negligible. • Sand will continue to be completely sequestered in floodplain area. • Flow will continue to be concentrated flow in the existing channel (as the existing levee currently does) and the main channel will be blocked near the county boundary line, forcing all flow out of the existing channel at that location. • This scenario is intended primarily for design purposes (i.e., to estimate maximum erosion, deposition, and flow velocity at and near the engineered log jams, biorevetment and setback levee) and are not necessarily intended to be a direct interpretation of future conditions. • All other stormwater infrastructure crossing Stewart Road SE is insignificant as related to modeling the flood events and is disassociated as related to lower flow event modeling (i.e., mean annual flow). Existing conditions modeling shows thousands of cubic feet per second flow toward the road in large (100-year) flood events. • The recent land development work association with the construction of a fill pad and accompanying channel feature in the pathway of floodwaters south of Stewart Road SE are acknowledged but will not be accounted for by changing the topography in future simulations. • All of the coarse material and the same fraction of sand stored in existing conditions in the White River will be retained in the project site following the removal of the existing levee based upon the analog at Hansen Creek (Mostrenko et al. 2011). • The existing left bank levee will remain intact where it is not removed.	

* Time immediately following construction for scenarios simulating effects of project construction.
** After the first few annual flood events, assumed to occur approximately 3 years following construction.
*** Future time at which the channel will avulse into the floodplain if the project is not implemented, assuming no erosion of the left bank levee. This time is similarly applied to the Project concept scenarios.
TBD = To be determined following completion of the preceding simulations. The characteristics (i.e., topography) of these surfaces will be dependent on the inundation and velocity distribution of preceding simulations.
N/A = Scenarios will not be developed and modeled for these timeframes because avulsions require some time in which to occur.

Table 2 summarizes the estimates of sediment input, output, and change in storage from repeated surveys of the study area between 2001 and 2009. The change in storage (ΔS) is equivalent to deposition of bed material. As mentioned above, bed material includes all sediment size classes (i.e., gravel/cobble, sand and silt/clay). The bed material is assumed to be comprised of 70% gravel/cobble and 30% sand. This was the approximate size distribution found in earlier subsurface sampling of the bars within with the project site (Herrera 2011).

Table 2. Historical channel sediment deposition estimates from King County (2012b) in 1000s of cubic yards per year (2001-2009)

		IN	Δ S	OUT
R Street to A Street	Gravel/cobble	30	8	22
	Sand	150	2	148
	Bed Material		10	
A Street to 8th Street (Project Reach)	Gravel/cobble	22	16	6
	Sand	148	6	142
	Bed Material		22	
8th Street to RM 3.0	Gravel/cobble	6	6	0
	Sand	142	2	140
	Bed Material		8	

Note: Numbers in shaded boxes indicate values used to construct the surfaces for scenario S4. Silt/clay fractions are assumed negligible.

From this analysis, a value of 22,000 cubic yards of deposition per year will be used as the assumed rate of average annual bed material deposited in the project reach under existing conditions in the short-term following project construction. This value necessitates several assumptions. This value is based on the assumption that moderate-sized floods will likely occur in the near future as controlled by current U.S. Army Corps of Engineers authorized operation guidelines at Mud Mountain Dam (C. Brummer, personal communication, April 30, 2012).It is slightly less than the preliminary value calculated by Czuba et al. (2011) for the study area because these preliminary results were based on the wettest portion of the 2011 water year (C. Brummer, personal communication, April 30, 2012). It is important to mention that the volumes in Table 2 are for in-channel deposition only. They do not include the volume of sand in the left overbank splay deposit, which was approximately 4,800 cubic yards between 2007 and 2009 and 3,500 cubic yards between 2009 and 2011.

For suspended load, Czuba et al. (2011) provides a preliminary estimate of suspended load discharge (680,000 tons per year) in the White River through the project area based upon suspended sediment measurements at the R Street Bridge in Auburn (approximately 1 mile upstream of the study area). This equates to approximately 450,000 cubic yards, assuming a unit weight of 1.5 tons per cubic yard of sediment. The same anecdotal evidence mentioned above (i.e., that the preliminary results were obtained for only the wettest portion of the year) suggests that the preliminary sediment supply figures derived by Czuba et al. (2011) may also be high (C. Brummer, personal communication, April 30, 2012). Also, there is some storage of fine sediment upstream of the A Street Bridge (Herrera 2010). Therefore, the

County estimated the average annual suspended load entering the project site would likely be about 290,000 cubic yards per year based upon an analysis of storage and transport through the project site (Table 2) and the most recent USGS estimates (King County 2012b). This estimate of annual suspended load agrees with the relative estimate provided by Czuba et al. (2011) indicating that the suspended load in the White River is approximately ten times as large as the coarse sediment transported as bedload. Finally, this value is significantly less than the value calculated by Herrera (2010) using the methodology of Syvitski et al. (2003). Again this difference is because the Syvitski et al. (2003) method implicitly includes large events from unregulated basins, which do not currently occur on the White River because of the operation of Mud Mountain Dam.

Estimating future storage of sediment in the floodplain requires making several assumptions, detailed in the following section. First, it is assumed that all of the sand that currently overtops the left bank levee is sequestered in the left bank floodplain in the short term following construction. This is consistent with the distinct edge of the splay deposition in the 2009 and 2011 lidar data. It is also consistent with direct observations of the splay deposit in the field. Because the channels that develop shortly after the levee is removed will be immature (i.e. within the assumed 3-year timeframe), like the existing left overbank splay, it is expected that the sand transported into the floodplain will continue to be completely sequestered, at least for a few years following construction.

While some amount of the finer-grained materials (i.e., silt/clay) are delivered to floodplains in the study area under existing conditions, as can be seen in recent flood aerial photographs (King County 2012a), the percentage of silt/clay in bed material is extremely small (2 percent silt/clay found in hand auger sample HA-4 in Shannon & Wilson [2009]). There is also a thin veneer of fine sediment in areas beyond the primary splay deposit. It is assumed that this veneer, because of how thin it is (generally less than a few inches), has negligible influence on flood storage or conveyance over relatively short time periods (years, not decades). Therefore, it is assumed that for the short-term simulations (suffix b of each scenario in Table 1) the contribution to overbank deposition from silt- and clay-sized material will be negligible. This assumption will be reevaluated for the fully evolved simulations (suffix c) after the short-term simulations are completed.

Potential Effects of Climate Change

Climate change is an important factor to consider in any analysis of future geomorphic change in western Washington. It has been shown that basins like the White River are transitioning from mixed snowmelt/rainfall basins to becoming rainfall-dominated basins (Mantua and Binder 2011). From this same work, it is estimated that peak flows in the Puyallup River Basin will increase by 10 to 20 percent, indicating that sediment load may increase in the future because sediment transport is a highly non-linear physical process where the largest events disproportionally transport more sediment. Also, since the White River is supply limited with respect to sediment (i.e., there is more sediment available than can be transported by the existing flows), an increase in peak flows means there could be an increase in the average annual quantity of sediment transport to the project site.

However, it is expected that the White River will not be as susceptible to these changes as the Puyallup River because the Puyallup River flow is largely unregulated, while the White River is greatly influenced by the flood control operations at Mud Mountain Dam. The regulation of flow releases from the dam decreases the amount of sediment transported during peak flow events by reducing peak shear stress and flow rate, even though the dam does not specifically prevent any bedload from being transported through the dam outlets during these events.

Two other factors are important to consider in assessing whether future climate change could increase sediment supply to the project site beyond the estimate of 290,000 cubic yards per year (on average) described above. First, the period of time selected for the estimation of sediment input to the project site could have still been under the influence of the gravel removal that occurred in the late twentieth century, causing estimates to be higher than they will be in the future without accounting for climate change. It is clear in the draft channel monitoring data assembled by the County that the highest sediment accumulation rates occurred immediately following cessation of channel dredging (King County 2012b). Second, the time period used to construct the sediment supply estimates coincides with a period of time in which the U.S. Army Corps of Engineers used a maximum flow release target of 12,000 cfs for Mud Mountain Dam discharge, which is lower than the formal maximum operational release of 17,600 cfs. Operations at the dam are expected to continue with the lower flow releases, when feasible per the Corps' operational requirements, thereby potentially supplying less sediment than was supplied during the period of project site sediment supply estimation described above (C. Brummer, personal communication). Therefore, for the short-term simulations (i.e., 3 years in the future), no adjustment to sediment volumes listed in Table 2 will be made. However, for the fully evolved simulations, the average annual sediment influx will be increased by 10 percent after the first 3 years to account for potential increases in sediment flux due to climate change.

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