HYDRAULIC AND SEDIMENT TRANSPORT MODELING TECHNICAL MEMORANDUM

WHITE RIVER AT COUNTYLINE LEVEE SETBACK PROJECT

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

Prepared by
Herrera Environmental Consultants, Inc.

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Prepared by
Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206/441-9080

May 29, 2012

CONTENTS

Introduction 1

Project Site and Study Area 1
Objectives 1
RiverFLO-2D Modeling Overview 2

Methodology 5

Topographic Data 5
Hydraulic Modeling Approach 5
Sediment Transport Modeling Approach 7
Hydrodynamic Boundary Conditions 7
Downstream Sediment Transport Boundary Condition 7
Upstream Sediment Transport Boundary Condition 7
Calibration 8
Validation 9

Results 11

Hydraulic Modeling 11
Sediment Transport Modeling 12
Calibration 12
Validation 17
Model Assumptions Affecting Calibration and Validation Results 18

Conclusions 33

References 35

Appendix A Hydraulic Modeling Memoranda from King County

TABLES

Table 1. Summary of Topographic Surfaces Used in the Sediment Transport Modeling. 5

Table 2. Summary Schematic of Breaklines and Improvements to the Hydraulic Model. 6

Table 3. Second-Generation Model Results Compared to Observed High-water Marks for the January 2009 Flood Event. 12

Table 4. Summary of Sediment Transport Re-calibration Results. 17

Table 5. Summary of Sediment Transport Model Validation Results. 18

FIGURES

Figure 1. White River Countyline Levee Setback Project Site and Study Area. 3

Figure 2. Map of Deposition and Erosion from 2007/2008 to 2009 as Predicted by the Model using the County-updated Model Mesh with Volume Polygons Overlaid on the Lower White River Study Area, Pacific, Washington. 13

Figure 3. Map of Topographic Differences (2009 Surface minus the 2007/2008 Surface) in the Lower White River Project Area Used to Calibrate the Sediment Transport Model, Along with the Three Areas of Interest. 19

Figure 4. Map of Deposition and Erosion from 2009 to 2011 as Predicted by the Model with Volume Polygons Overlaid on the Lower White River Study Area, Pacific, Washington. 23

Figure 5. Map of Observed Topographic Differences (2011 Surface minus the 2009 Surface) in the Lower White River Project Area Used to Validate the Sediment Transport Model, Along with the Three Volume Polygons Overlaid..... 27

INTRODUCTION

This Hydraulic and Sediment Transport Modeling Memorandum was prepared for King County's proposed White River at Countyline Levee Setback Project (the project). King County intends to remove a levee in the project area to improve flood water conveyance, thereby reducing flooding impacts on area residents, as well as to improve habitat for resident fish and wildlife.

King County retained Herrera Environmental Consultants, Inc. (Herrera) to perform hydraulic and sediment transport modeling for the proposed project and document the modeling results. The methods and results presented in this memorandum are for the hydraulic and sediment transport modeling performed by the project team prior to a decision to not proceed further with sediment transport modeling and to adapt the approach laid out in Herrera (2011). Therefore, the sediment transport modeling results presented herein are for only the calibration and validation phase of the sediment transport modeling.

Based upon the calibration and validation results, King County determined that the sediment transport model was not suitable to achieve the objectives listed below. Support for this determination is provided in the Model Assumptions Relevant to the Project Site section and Conclusion section of this memorandum. The hydraulic modeling results generated for the project to date are sufficiently accurate to rely upon continuing use of the hydraulic model moving forward in support of the design process.

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.

Objectives

The hydraulic and sediment transport analysis for the project focuses on the determination of geomorphic changes associated with the project and associated effects on flooding characteristics in the study area. It also supports evaluating the consequences of no action

(doing nothing) on the future flooding characteristics in the study area. It is well established that the study area is a locus for sediment deposition (Herrera 2010, 2011; Czuba et al. 2010; Collins and Montgomery 2011). Therefore, the objectives of the hydraulic and sediment transport modeling were to:

1. Estimate the impact of future sediment deposition on the extent of flood inundation under existing and proposed conditions
2. Estimate the amount of sediment stored in the study area and that could be exported farther south (downstream) over 5 years in both existing and proposed conditions
3. Determine the maximum range of probable flow velocities and depths near the proposed setback infrastructure (that is, the biorevetment and floodplain engineered log jams [ELJs]) over the first 5 years following construction
4. Identify possible consequences and mitigation actions necessary to successfully complete the proposed levee setback project

RiverFLO-2D Modeling Overview

The software used to perform sediment transport modeling for this project is RiverFLO-2D. RiverFLO-2D is a hydrodynamic and mobile-bed model specifically developed for rivers. It is a two-dimensional, finite-element model for routing flood flows that enables high-resolution flood hydraulic analysis. A flexible triangular mesh refines the flow field around key river features in complex river environments. RiverFLO-2D has been applied on a number of river projects worldwide. RiverFLO-2D uses the shallow-water equations for depth-averaged free surface flow that allow obtaining water surface elevations, and two components of the velocity (Garcia et al. 2006), resulting in resolution of detailed two-dimensional channel hydraulics and overbank flooding characteristics.

The RiverFLO-2D user interface is based upon the Argus Open Numerical Environment (Argus ONE) platform. This GIS-integrated software system provides interactive functions to generate and refine the finite element mesh representing the topographic and bathymetric surface over which flood flow is routed. It also facilitates assigning boundary conditions and roughness values. Finally, it serves as the means to export model results to GIS-based platforms.

To predict sediment transport and channel bed elevation changes for each time step, RiverFLO-2D uses the output of the hydrodynamics simulation described above and solves the Exner sediment-conservation equation for depth-averaged transport. The Exner equation provides the spatial and temporal evolution of bed elevation, determining areas of erosion and deposition throughout the model domain. Several sediment transport formulas may be used in the RiverFLO-2D model to calculate the sediment flux. Earlier calibration work found that the Ackers and White (1975) sediment transport formula best fits conditions at the project site (Herrera 2011).

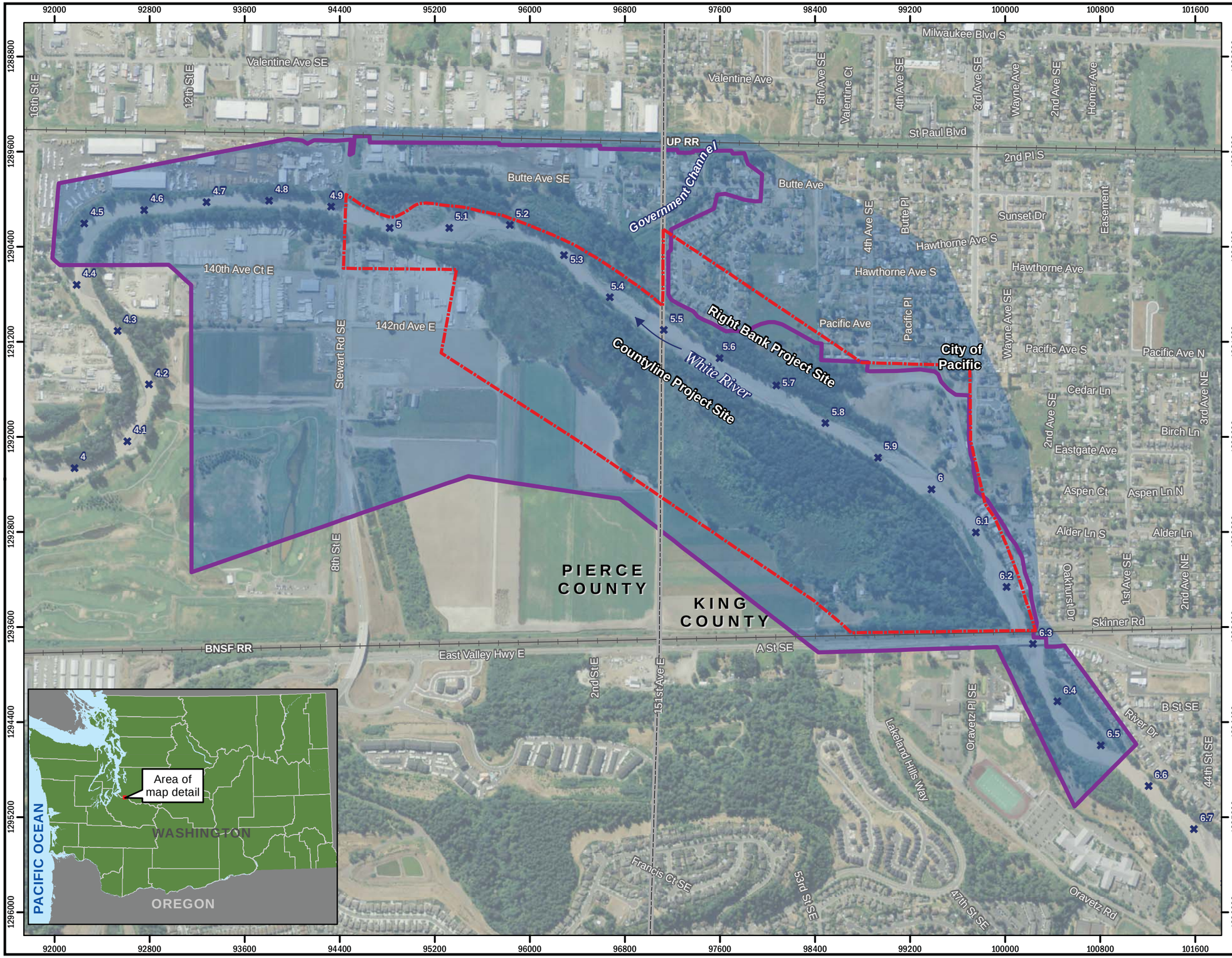

Figure 1.
Vicinity map of the White River at Countyline project site and study area.

Legend

- First- and second-generation modeling domain
- Third-generation model domain
- Project site
- County boundary
- Railroad
- River mile

N

0 400 800 1,600 Feet

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Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\Site_Map.mxd

METHODOLOGY

The background methodology of the modeling work for the project is described in large part in Herrera (2011); however, updates to that approach and cursory background information are summarized here. Numerical models require a set of boundary conditions for each simulation that consist of discharge at the upstream end of the computational mesh, and water surface elevation or a rating curve at the downstream end of the computational mesh. The boundary conditions and other input data developed for the project models are described in this section. Field measurements from the project site were also needed to calibrate the models. Figure 1 shows the RiverFLO-2D model domain, along with many other key locations discussed in the following sections.

Topographic Data

Three different topographic data sets were used in the modeling analysis. Table 1 summarizes a description of these data sets and their sources. They were all derived from three-dimensional surfaces produced by King County and its consultants. Table 1 also summarizes the modeling uses of the different data sets. The following section describes the sequence of modeling work that has been done using these data sets.

Table 1. Summary of Topographic Surfaces Used in the Sediment Transport Modeling.

Name	Constituents	Use
2007/2008	Bathymetric sections (March 2007, April 2008), Photogrammetric analysis (March 2007)	Initial sediment transport calibration geometry, hydraulic calibration geometry (first and second generation hydraulic modeling)
2009	Bathymetric sections (April 2009), Lidar (February 2009), wetland survey (March 2009)	Final sediment transport calibration geometry, initial sediment transport validation geometry, third generation hydraulic modeling
2011	Bathymetric sections (April 2011), Lidar (March 2011)	Final sediment transport validation geometry, fourth (final) generation hydraulic modeling

Hydraulic Modeling Approach

Four "generations" of hydraulic modeling have been run to date for the project. The first generation of modeling was performed by Northwest Hydraulic Consultants (NHC) and is summarized in Herrera (2011). This modeling consisted of calibration runs for existing conditions, comparing simulated results to observations made during the January 2009 flood event. It also used what is called hereafter as the "Build B" version of the RiverFLO-2D model.

Based upon the recommendations of Herrera (2011), King County updated the first-generation model to refine its resolution in selected areas. These refinements were first made on the 2007/2008 surface for calibration purposes. As with original calibration documented by Herrera (2011), the January 2009 flood event was simulated and compared to high-water-mark observations made during that event. The computational mesh was refined to better resolve flood predictions in key locations in the model domain, which required increasing (densifying) the number of elements in the mesh. These refinements are summarized in Table 2. The second-generation modeling also compared different "builds" of RiverFLO-2D. In the time between the first and second generation modeling, the model software was improved by its developers to better handle wetting and drying in the model.

Table 2. Summary Schematic of Breaklines and Improvements to the Hydraulic Model.

Features Common to Project and Existing Model Domains	Features Unique to the Existing Conditions Domain	Features Unique to the Proposed Conditions Domain
Break lines along Butte Avenue, Stewart Road SE, Government Channel (Boeing Ditch), the top of the right bank revetment, and the top of the left bank upstream of the A Street Bridge	Parallel break lines for the HESCO barrier	An outer boundary that follows the HESCO barrier alignment
Parallel break lines along the top of the left bank downstream of the A Street Bridge	Double break lines that are close together and extend along a portion of the forested wetland very near the southern boundary of the wetland	Break line parallel to the proposed biorevetment set back along the terrace
Break line along the edge of the terrace (the proposed bio-revetment alignment)	Parallel break lines along the top of the revetment along the left bank	Single break line along the top of the left bank revetment
Two short break lines to capture the high ground of the BNSF railroad bridge and the A Street Bridge on the north side of the river	An outer domain boundary that includes neighborhoods behind the HESCO barrier	A longer break line along the left bank of the river just upstream of the Stewart Road SE (8th Street E) bridge

With refinements made in the computational mesh and a decision on the best model build to use, the third generation of hydraulic modeling involved simulating flooding with the 2009 topographic surface under the 2-year, 10-year, 50-year, 100-year, and 500-year events. The third generation of modeling included a new proposed (project) conditions surface based upon the 40% design prepared by King County.

The fourth generation of hydraulic modeling completed as of the writing of this memorandum incorporated the same refinements as made in the second and third generation models and applied them to the 2011 topographic surface. Like the third-generation model runs, this included both an existing conditions surface and a proposed (project) conditions surface modeled on the same range of flood hydrographs.

Sediment Transport Modeling Approach

The focus of the sediment transport modeling was, specifically, to estimate the flood flow conveyance lost in both existing and proposed conditions due to sediment deposition and to provide information for analyzing the long-term geomorphic response of the project following construction. The sediment transport modeling was also intended to provide constraints on the immediate response and hydraulic parameters used in the design of engineered logjams (ELJs) proposed in the left bank floodplain that will be restored and reconnected to the mainstem river channel as a part of the proposed project.

The modeling described herein is confined to two model runs: 1) calibration of the sediment transport model to geomorphic changes observed at the project site between 2007 and 2009, and 2) validation of the sediment transport model to geomorphic changes observed at the project site between 2009 and 2011. Like the earlier hydraulic model calibration work, the primary means to evaluate the model results was the volume of sediment deposited in three areas identified as crucial to the effectiveness of the project and the changes with respect to existing conditions. Those three crucial areas are: two channel delineations—one broad, one narrow—and an area of overbank deposits near the jurisdictional county line.

Hydrodynamic Boundary Conditions

The hydrodynamic boundary conditions used in the sediment transport models were the same as described in Herrera (2011). The downstream boundary condition consisted of water surface elevations derived from earlier one-dimensional (HEC-RAS) modeling of the river. In addition, to control flow instabilities over Stewart Road SE, the flow depth over the road was fixed to be non-zero, but extremely shallow. Finally, the input hydrograph for both the calibration and validation model simulations was developed using the methodology described in Herrera (2011).

Downstream Sediment Transport Boundary Condition

There was no specific downstream boundary condition applied for the sediment transport models. Sediment is transported out of the model automatically. The sediment outflux from the model was tallied for each model run and is provided for each model run in the Results section of this memorandum. The predicted outflux numbers were inherently overestimated because eroded areas were included in the calculations (see further discussion in the *Calibration* section, below).

Upstream Sediment Transport Boundary Condition

Sediment influx (i.e., the upstream boundary condition for sediment entering the model) was set by the sediment rating curve described in Herrera (2011) for both the calibration and validation simulations. The rating curve establishes a sediment loading (for the bedload fraction) based upon the water discharge. The loading is spread equally across the upstream boundary nodes in the model. Input hydrographs used a compound hydrograph developed as part of the Lower White River 2D modeling project (Herrera 2011) consisting of flow occurrences greater than 4,000 cubic feet per second (cfs). For smaller flows, wholesale

sediment transport across the river channel does not exceed the critical shear stress, indicating that most of the sediment is not in transport. Since sediment transport is a highly non-linear process that occurs primarily during only the largest flood events, it was assumed that the elimination of smaller flows from the simulation would not affect the predicted bed elevation changes in a significant way. Therefore, those smaller discharges were eliminated from the input hydrograph time series to reduce computation time. If the smaller discharges were not removed, the model would require a much longer period of time to complete (i.e., several times as long). With model runs taking days and sometimes weeks to complete even with exclusion of the smaller discharges, computation time was an important factor to consider in completing this work.

Calibration

Initial calibration of the sediment transport model is summarized in Herrera (2011). However, through the initial calibration process for the modeling effort described in this memorandum, it was determined that several aspects of the model could be modified to improve accuracy and reduce model artifacts. In summary, the modifications that were implemented for model calibration included:

- Refined the left bank levee immediately downstream to eliminate numerical piping through the structure
- Added representation for a naturally occurring log jam approximately 900 feet upstream of the Stewart Road SE bridge on the right bank (this log jam formed recently)
- Refined the topography in the vicinity of Government Channel to direct flow in a more realistic way

A subsequent version of the computational mesh (which had slightly more than 44,000 elements) was developed to incorporate these changes. The re-run of the calibration model is referred to as the "re-calibration run" throughout the remainder of this memorandum.

In addition to re-calibration, an *ad hoc* assumption incorporated in the RiverFLO-2D model was omitted from the discussion of the original calibration (Herrera 2011). To properly account for the reduction in erosion of areas that are either vegetated or hardened (i.e., covered in riprap or concrete), the bed of the model was not allowed to erode. The criterion was: for those areas outside the channel that are represented by Manning's *n* greater than 0.042, the bed was not allowed to erode. While this is an oversimplification, it produced reasonable results in the initial calibration.

One consequence of the assumption of no erosion in these areas was not realistic. Despite preventing adjustment of the bed elevation due to predicted erosion in selected areas, the way the model tracked sediment transport did account for the erosion of sediment and the resetting of the bed elevation at each time step. As a result, the model as a whole did not conserve sediment mass, and typically produced sediment as can be seen in the results below.

Validation

An important, but often overlooked, part of environmental numerical modeling is validation. Validation is the process of checking that a model meets specifications and that it fulfills its intended purpose. During the sediment transport model calibration process, input and model calculation variables were adjusted to determine the most appropriate, site-specific set of variables to replicate observed conditions in the calibration condition. In the validation phase, the calibration variables are used on an entirely independent data set. Because of the inflexibility of the validation process it is rare for models, particularly those involving highly nonlinear, chaotic physical processes such as sediment transport, to perform well in long-term simulations.

To implement the sediment transport validation, the 2009 post-flood topographic and bathymetric surface (computational mesh) was used as the initial conditions for the validation simulation. A hydrograph for the time period between the post-flood survey (Lidar: February 19, 2009; bathymetry: April 2011) and the 2011 Lidar flight (March 8, 2011) was generated using the methodology described in Herrera (2011). Like the calibration, only those flows exceeding 4,000 cfs were included in the hydrograph. The sediment transport validation model was also evaluated using two different topographic surfaces collected during the course of the project (described in detail above). The initial model surface was the 2009 post-flood surface described in Table 1. As was assumed for model calibration, those areas with roughness exceeding n=0.042 were assumed to be non-erodible.

RESULTS

This section presents the results of the hydraulic and sediment transport modeling completed through January 2012. The discussion of hydraulic modeling results includes the results from four generations of hydraulic models. The discussion of sediment transport modeling results includes both the re-calibration and validation of the sediment transport model.

Hydraulic Modeling

The first generation model runs are summarized in Herrera (2011). Those results found that increasing mesh density lowered water surface elevations and more closely simulated observed conditions. For those computational meshes in excess of 44,000 elements, replication of observed flood conditions was good, and generally less than 1 foot higher than observed values. As a result, all subsequent modeling has used the refined and densified mesh as its basis.

The second-generation model refined the mesh as described previously in the *Methods* section. These refinements increased the total number of elements (increasing run time), but not significantly. Because the refinements created a higher-resolution (much higher resolution than the numerical model itself) topographic surface, the model could more accurately characterize flooding in the study area. When these refinements were added, the differences between observed and simulated water surface elevations remained essentially the same as described by Herrera (2011), although the pattern of inundation simulated was more realistic (Table 3). The improved performance of the model with refinements in topographic accuracy indicates that the model is performing well. This generation of modeling also explored different model "builds". These describe executable routines used in running the model. These executables are constantly updated by the software developers to improve model performance. The results are compared in Table 3. As can be seen in the table, the updated newer build (in this case, Build G) had essentially the same fit between the simulation and the observations, as the original calibration (the Herrera [2011] Build B run). Based upon a qualitative estimate of the extent of inundation from observers and aerial photographs, which was best reflected by the last three observations listed in Table 3, the updated model Build G was selected for ongoing project modeling.

The third generation model simulated both an existing conditions surface and a proposed (post-project construction) surface (see Appendix A). The proposed surface included several unique aspects in its computational mesh. These are summarized in Table 2. One of the key changes was that the mesh was truncated to the existing HESCO barrier alignment on the right bank to conserve on computation time. It is assumed that in the future condition (i.e., 1 percent chance exceedance event), overbank inundation would be limited by a subsequent right bank flood protection project. The third generation modeling will not be used as a basis of design because a more recent topographic surface (the 2011 surface) has been constructed

which more accurately represents existing conditions. The results of the third generation hydraulic model simulations are presented in Appendix A.

Table 3. Second-Generation Model Results Compared to Observed High-water Marks for the January 2009 Flood Event.

Water Level Observation Name	Observation WSE Value	Updated Build G		Updated Build B		Herrera (2011) Build B	
		Computed WSE (feet)	Difference between Observed and Computed (feet)	Computed WSE (feet)	Difference between Observed and Computed (feet)	Computed WSE (feet)	Difference between Observed and Computed (feet)
GW-3	73.7	74.1	0.4	73.8	0.1	73.9	0.2
GW-4	72.7	72.8	0.1	72.6	-0.1	72.6	-0.1
GW-5	75.9	75.5	-0.4	75.1	-0.8	75.4	-0.5
HWM-C	90.4	90.9	0.4	90.7	0.3	90.7	0.3
HWM-A	82.6	83.5	0.9	83.2	0.6	83.3	0.7
HWM-L	71.3	71.6	0.3	71.1	-0.2	71.1	-0.2
HWM-M	71.7	71.8	0.1	71.5	-0.2	71.5	-0.2
HWM-U	71.8	72.9	1.1	72.7	0.9	72.7	0.9
HWM-T	72.9	74.1	1.2	73.5	0.6	73.5	0.6
Photo Obs 1	77.5	77.3	-0.2	77.2	-0.3	77.2	-0.3
Photo Obs 2	78.6	78.7	0.1	78.2	-0.4	78.6	0.0
Photo Obs 3	86.3	87.0	0.7	86.7	0.4	86.9	0.6

WSE - water surface elevation

The fourth generation of hydraulic modeling made the same mesh refinements as described above, but on the 2011 topographic surface (Appendix A). It is important to mention that the meshes described above were designed specifically for flood scenarios when much of the model domain is inundated. As a result, for the mean annual flow simulations where only a few mesh elements are wetted, discretization errors were much greater, particularly near the upstream and downstream boundary conditions in the model. These discretization errors led to input and output flow differences of slightly less than 10 percent for these simulations only. However, a new mesh was generated in the final generation of modeling for the mean annual flow that significantly increased the number of elements in the main channel and provided a small “run-up” channel upstream end of the domain that eliminated nearly all of input and output flow differences.

Sediment Transport Modeling

Calibration

The original calibration, the re-calibration, and the observed bed changes for the same time period (2007 to 2009) are summarized in Table 4 and shown graphically for the re-calibration model in Figure 2 (Sheets A and B). The modeled maps of sediment deposition can be

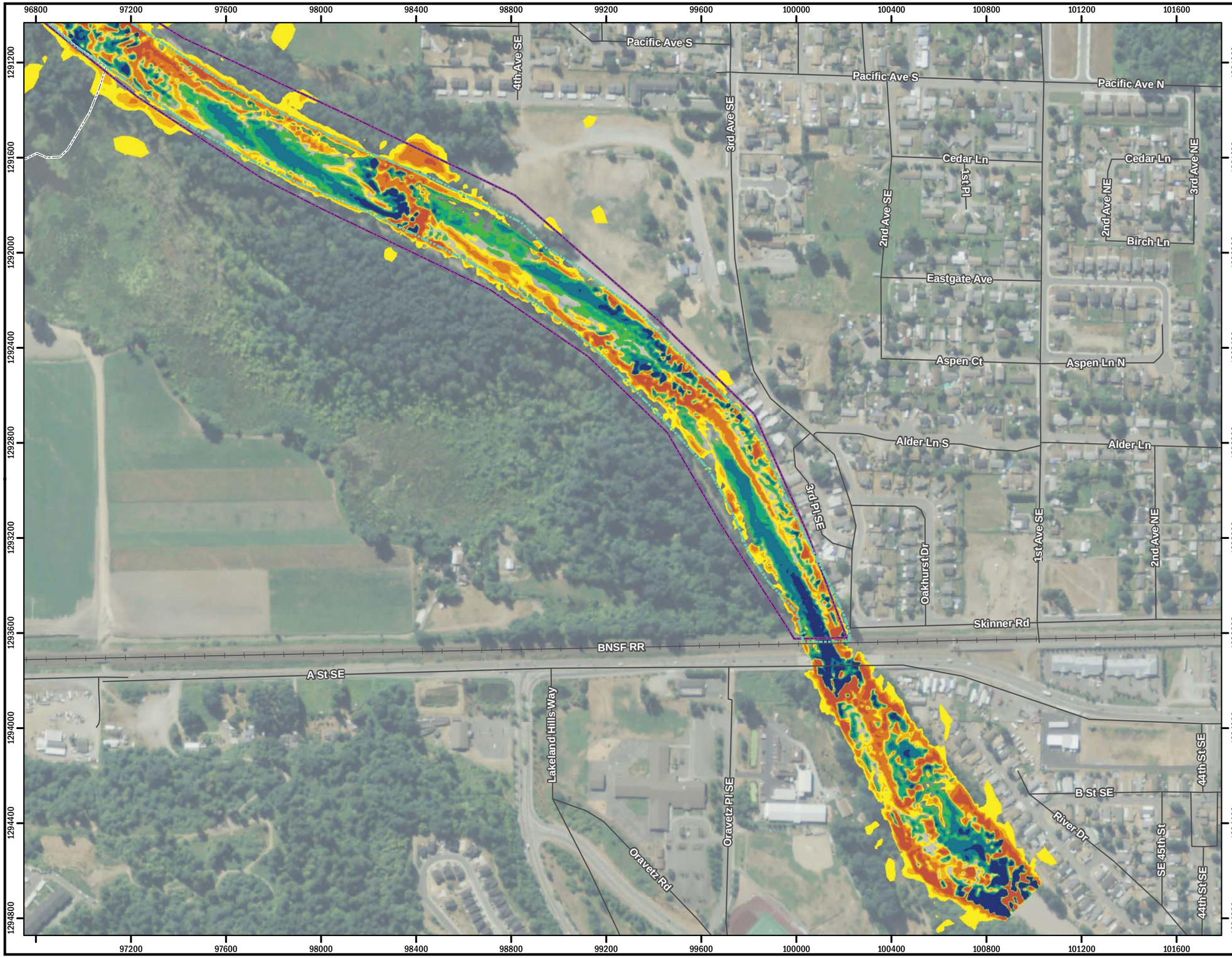

Figure 2, Sheet A
Map of deposition and erosion from 2007/2008 to 2009 as predicted by the model using the County-updated model mesh with volume polygons overlaid on the Lower White River study area.

Legend

Change in bed elevation (ft)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

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Aerial: USDA (2009)

Produced by: GIS (rdr)
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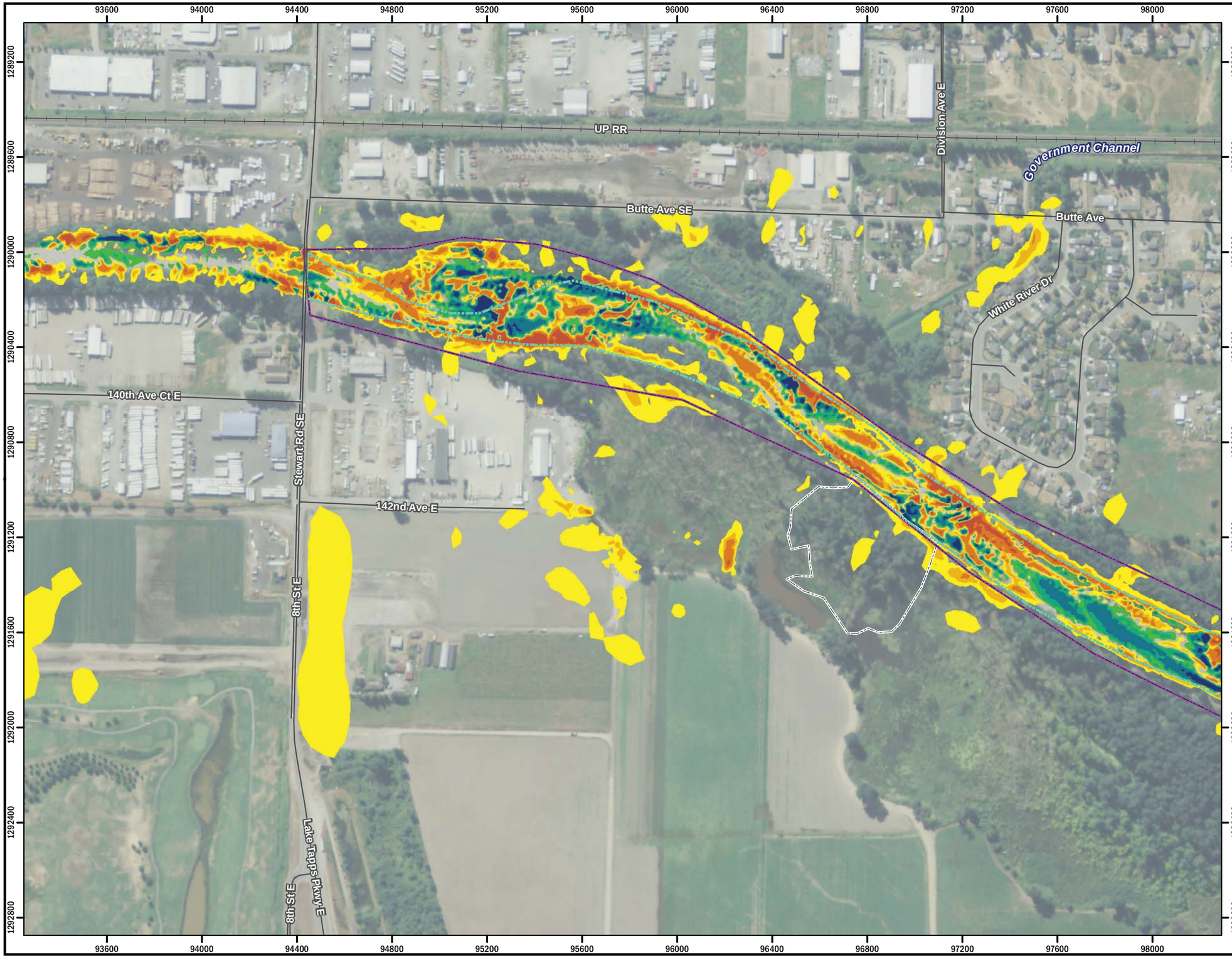

Figure 2, Sheet B
Map of deposition and erosion from 2007/2008 to 2009 as predicted by the model using the County-updated model mesh with volume polygons overlaid on the Lower White River study area.

Legend

Change in bed elevation (ft)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
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compared to the observed changes shown in Figure 3 (Sheets A and B). As can be seen in the re-calibration sediment transport results, the re-calibration model matched observed conditions less accurately than the original calibration. This is likely because the original calibration model under-predicted the sediment stored within the model domain, and the most significant alteration was to confine more flow in the channel in the re-calibration. This resulted in an increase in sediment transport competency of the flow in the main channel, reducing the amount of sediment deposited there.

Table 4. Summary of Sediment Transport Re-calibration Results.

Area of Interest	Original Model Calibration Volume (cubic yards)	Re-calibration Volume (cubic yards)	Observed Volume (cubic yards)
Overbank Area Sediment Deposition	1,762	1,431	4,800
Channel Delineation #1 Sediment Deposition	11,290	6,765	25,800
Channel Delineation #2 Sediment Deposition	28,033	18,899	33,600
Total Model Domain Sediment Deposition	155,677	116,341	Uncertain*
Modeled Sediment Influx	N/A	84,675**	N/A
Modeled Sediment Outflux	N/A	75,490**	N/A

N/A = Not available

* The comparison of the two observed topographic surfaces outside the immediate river channel area were subject to large deviations in the floodplain wetland due to the difference in the survey techniques used to determine the surface, complicating any estimation of the topographic volume difference between the two surfaces.

** The outflux plus the amounted deposited exceeded the influx (i.e., there was a net production of sediment in the model domain). The reason for this apparent discrepancy is the consequence of making some model elements non-erosive, which is discussed in the *Methods* section above.

It is uncertain why the calibration model under-predicted the amount of sediment deposited during the simulation time period. However, it is important to mention that the under-prediction could simply be an artifact of an under-prediction in the sediment influx used to model the January 2009 flood event. It is well known that sediment production rates are highly nonlinear and are generally out-sized for the largest flood events (Syvitski et al. 2003). It is quite possible that, if the influx were known precisely, the model could have better simulated the actual deposition volumes.

The patterns of deposition can be more confounding. For instance, the bar near the City of Pacific Park was eroded away in the calibration model, whereas it has grown in reality. In this case, the dynamics in reality are quite different than what occurred in the simulation. Because the bar near the park is a persistent feature, it has been significantly coarsened over time, such that it now comprises very coarse cobble and boulders. Because the model assumed a single grain-size, it was unable to resolve the armoring that protects the bar from erosion. As a result, the model predicted that the bar would be washed away, when in actuality it was built up, probably from a large armored plug of material deposited during the January 2009 event.

Validation

The results of the sediment transport validation model run are summarized in Table 5 and shown graphically in Figure 4 (Sheets A and B). The modeled maps of deposition can be

compared to the observed changes shown in Figure 5 (Sheets A and B). The validation time period was sedimentologically different than the calibration time period. The validation time period did not include a significant flood event of the magnitude of the January 2009 event. As a result, the total deposition found in both the observed data and the model results is significantly smaller. In contrast, the model results show significantly more sediment deposited, comparable to the modeled deposition in the re-calibration run.

Table 5. Summary of Sediment Transport Model Validation Results.

Area of Interest	Model Validation Volume (cubic yards)	Observed Conditions Volume (cubic yards)
Overbank Area Sediment Deposition	2,260	3,476
Channel Delineation #1 Sediment Deposition	20,713	14,663
Channel Delineation #2 Sediment Deposition	34,570	15,672
Total Model Domain Sediment Deposition	108,125	34,635
Modeled Sediment Influx	27,353*	N/A
Modeled Sediment Outflux	54,314*	N/A

N/A = Not available

* Although the outflux exceeded the influx, there was a net deposition of sediment in the model domain. The reason for this apparent discrepancy is the consequence of making some model elements non-erosive, which is discussed in the *Methods* section above.

The validation model better predicted the sediment deposition volumes in the three key areas of concern for project design. However, the validation model over-predicted the sediment deposited. As described above, the re-calibration model under-predicted sediment deposition, likely because the model assumed an inaccurate sediment influx because of events that occurred during the calibration time period. Similarly, the validation model may have overestimated the sediment input during the relatively quiescent flow conditions in the simulation time period, during which there were no large floods to provide a plug of sediment that is implicitly reflected in the derivation of the modeled sediment influx.

The performance of smaller features in the validation model run was somewhat better than in the re-calibration run, but the model still lacked the ability to accurately and consistently match site-specific observations because of the assumptions mentioned in the following section.

Model Assumptions Affecting Calibration and Validation Results

There are many assumptions made in order to numerically model any physical process. Many of those assumptions are common to any model, regardless of the nature of the process simulated. For instance, the equations of motion (i.e., the equations that constitute the basis of the model) are not solved in a continuous way, but utilize discrete information about the boundaries of the model. Discretization always produces errors, particularly when important "sub-grid" information is lost. This can be seen in the reduction of hydraulic calibration errors with increasing mesh density as reported in Herrera (2011) and described in this memorandum.

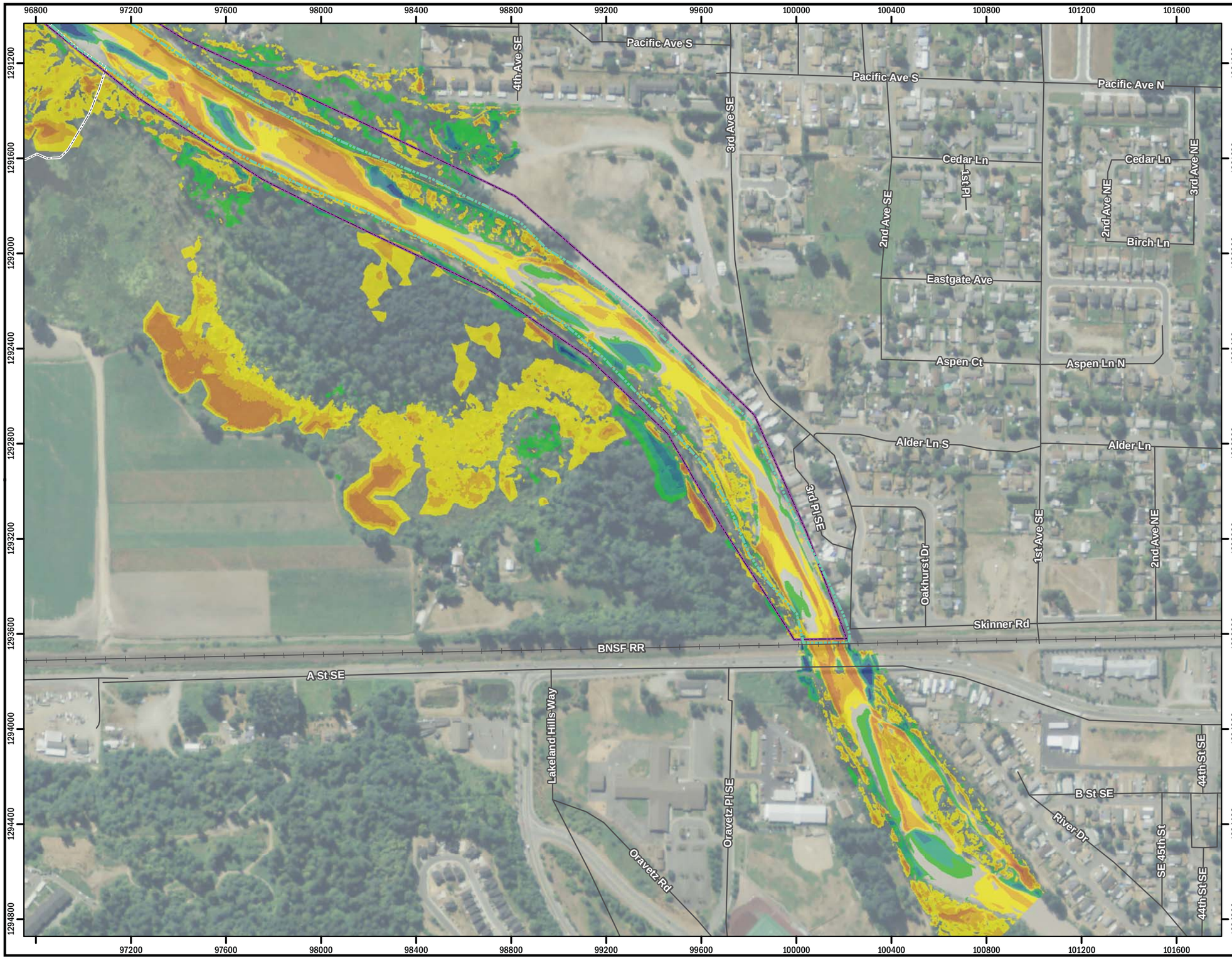

Figure 3, Sheet A
Map of topographic differences (2009 surface minus the 2007/2008 surface) in the Lower White River project area used to calibrate the sediment transport model, along with the three areas of interest.

Legend

Change in volume (ft³)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\topo_2007_8_to_2009.mxd

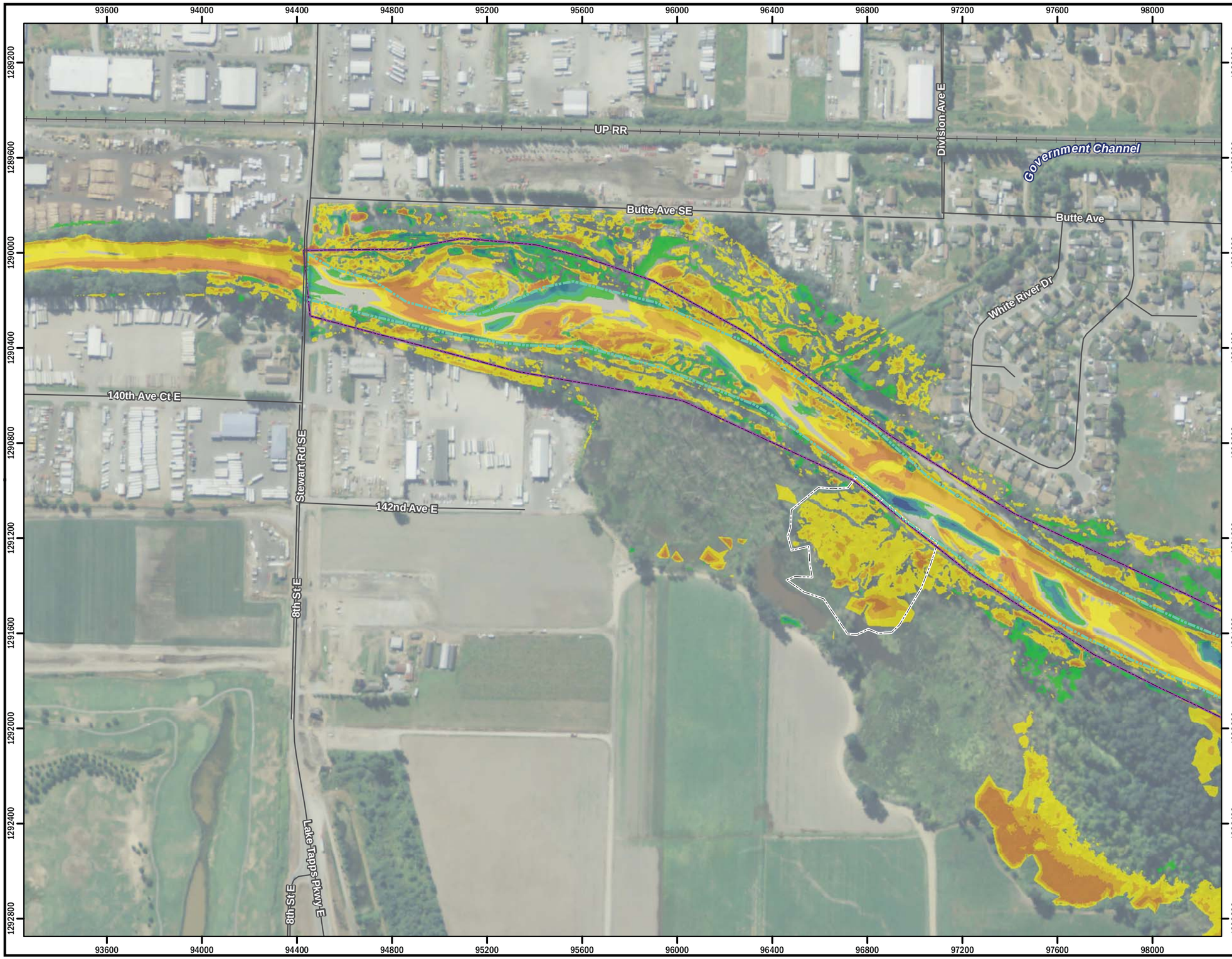

Figure 3, Sheet B
Map of topographic differences (2009 surface minus the 2007/2008 surface) in the Lower White River project area used to calibrate the sediment transport model, along with the three areas of interest.

Legend

Change in volume (ft³)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\topo_2007_8_to_2009.mxd

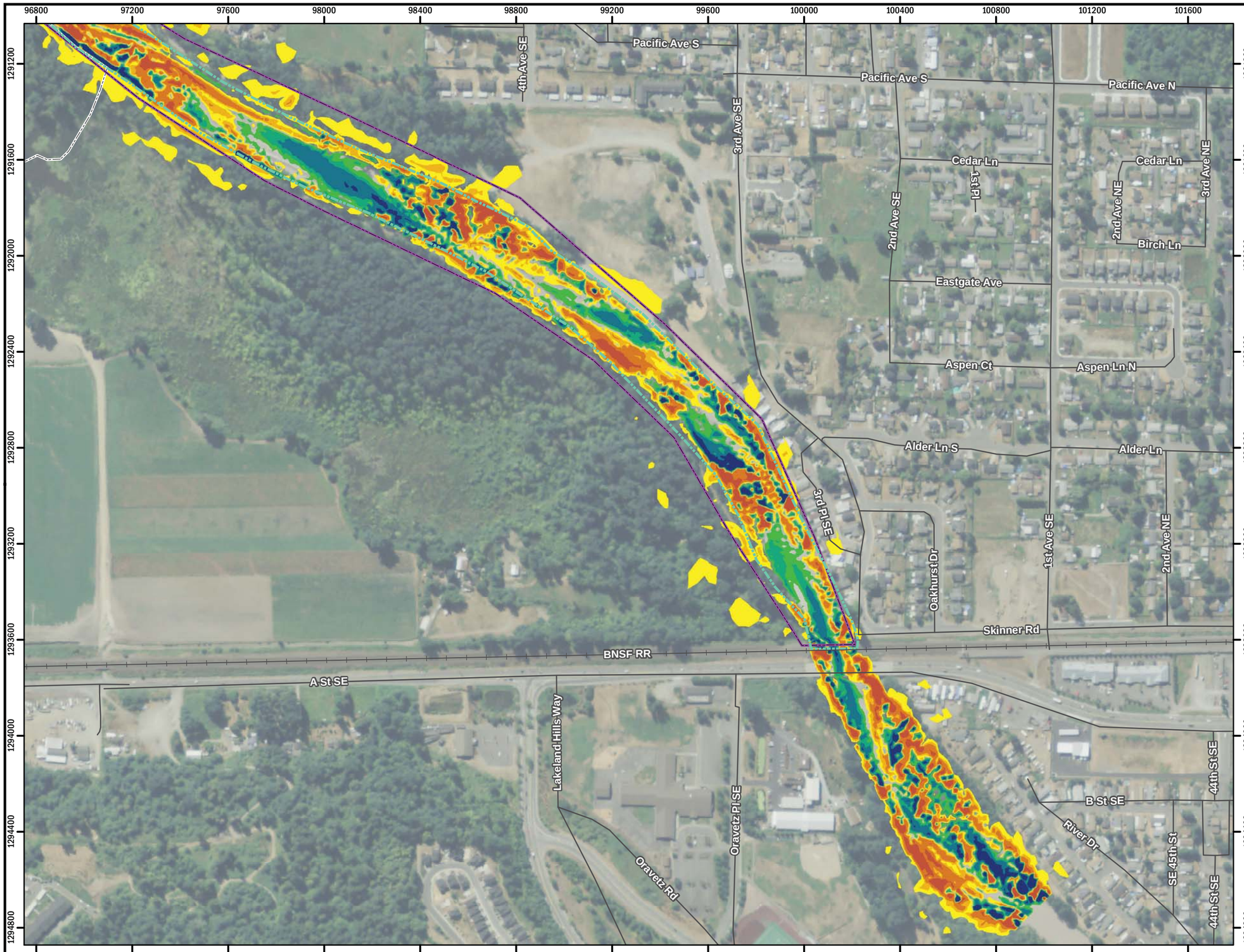

Figure 4, Sheet A
Map of deposition and erosion from 2009 to 2011 as predicted by the model with volume polygons overlaid on the Lower White River study area.

Legend

Change in bed elevation (ft)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\sediment_2009_to_2011.mxd

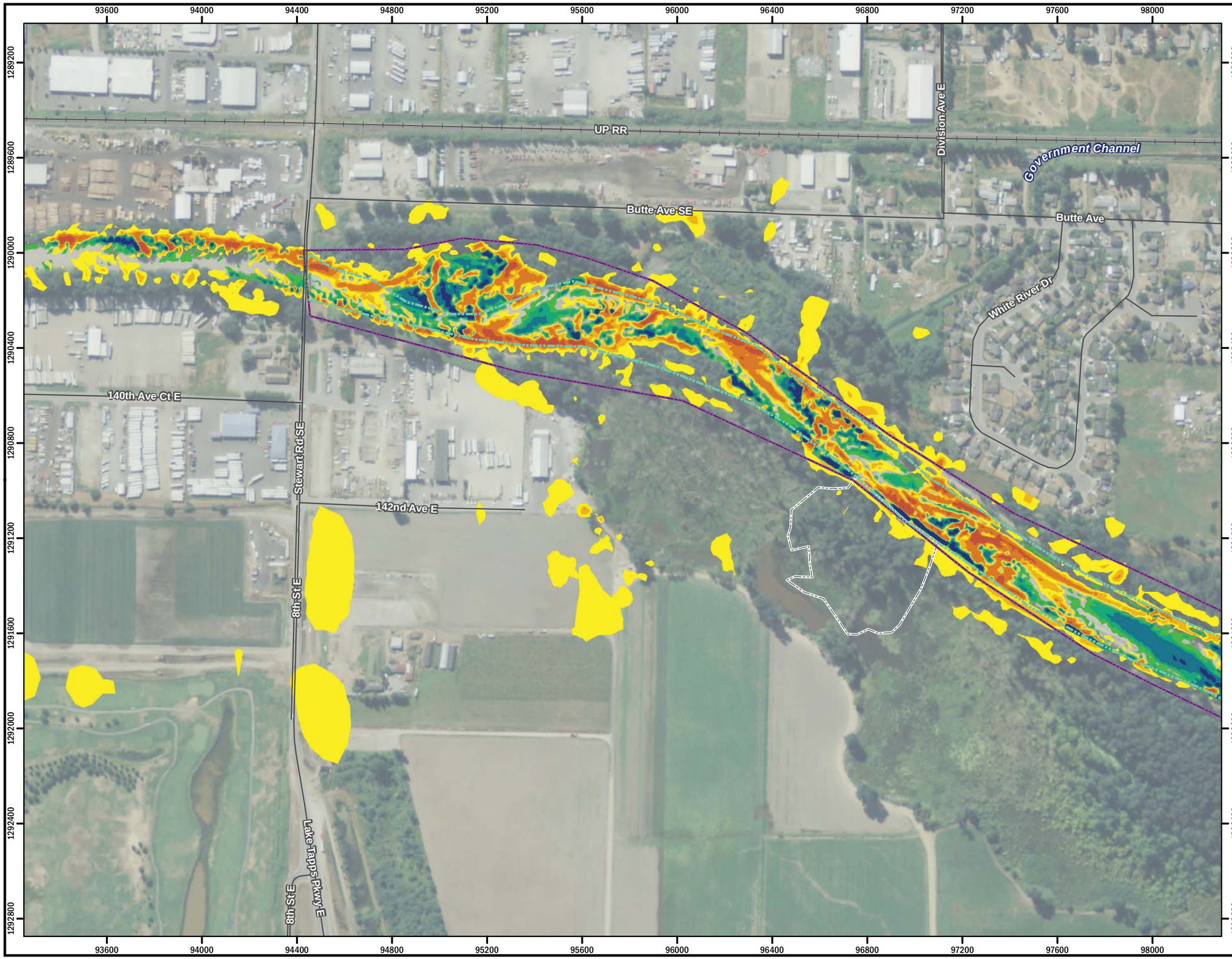

Figure 4, Sheet B
Map of deposition and erosion from 2009 to 2011 as predicted by the model with volume polygons overlaid on the Lower White River study area.

Legend

Change in bed elevation (ft)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\sediment_2009_to_2011.mxd

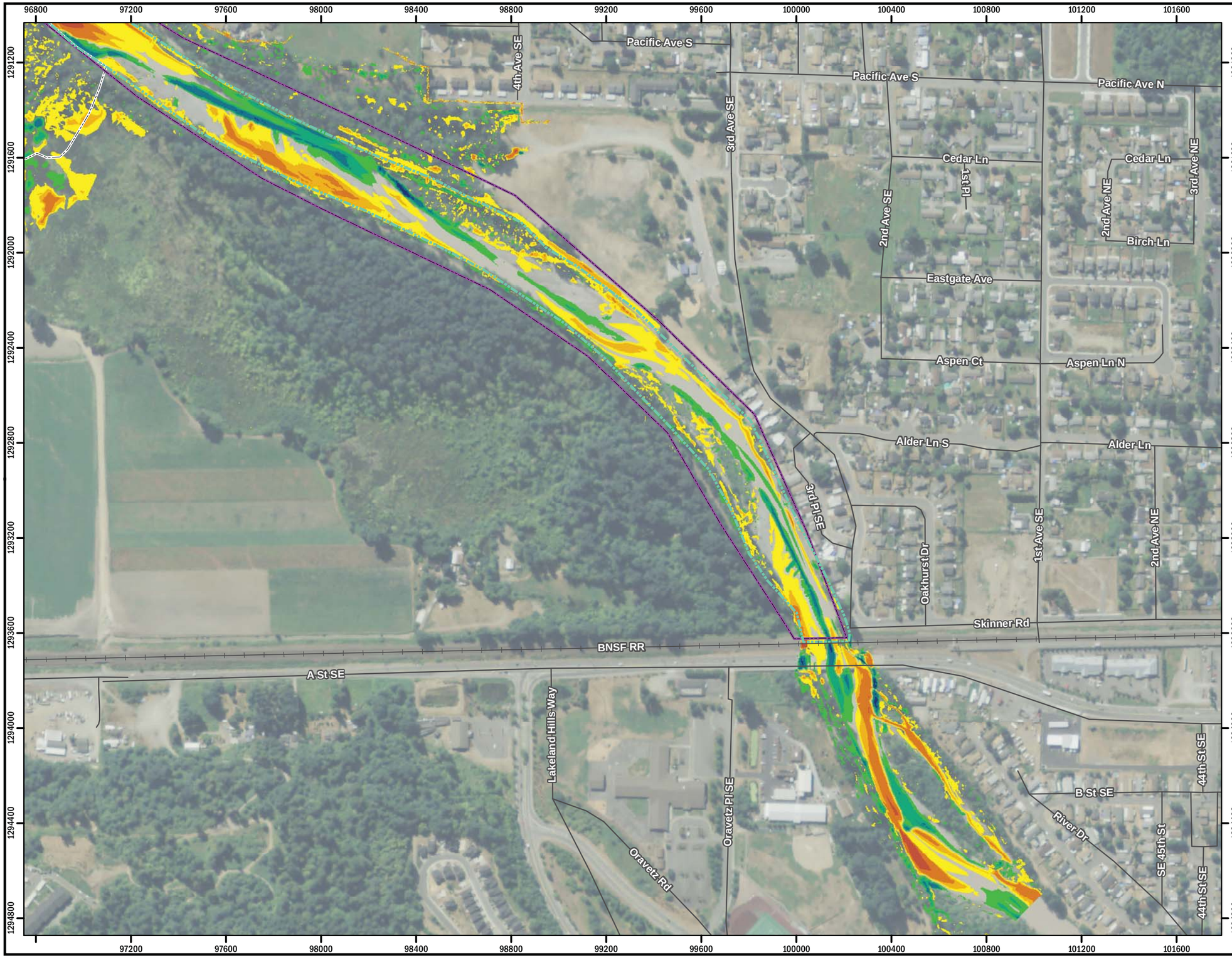

Figure 5, Sheet A
Map of observed topographic differences (2011 surface minus the 2009 surface) in the Lower White River project area used to validate the sediment transport model, along with the three volume polygons overlaid.

Legend

Change in volume (ft³)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\topo_2009_to_2011.mxd

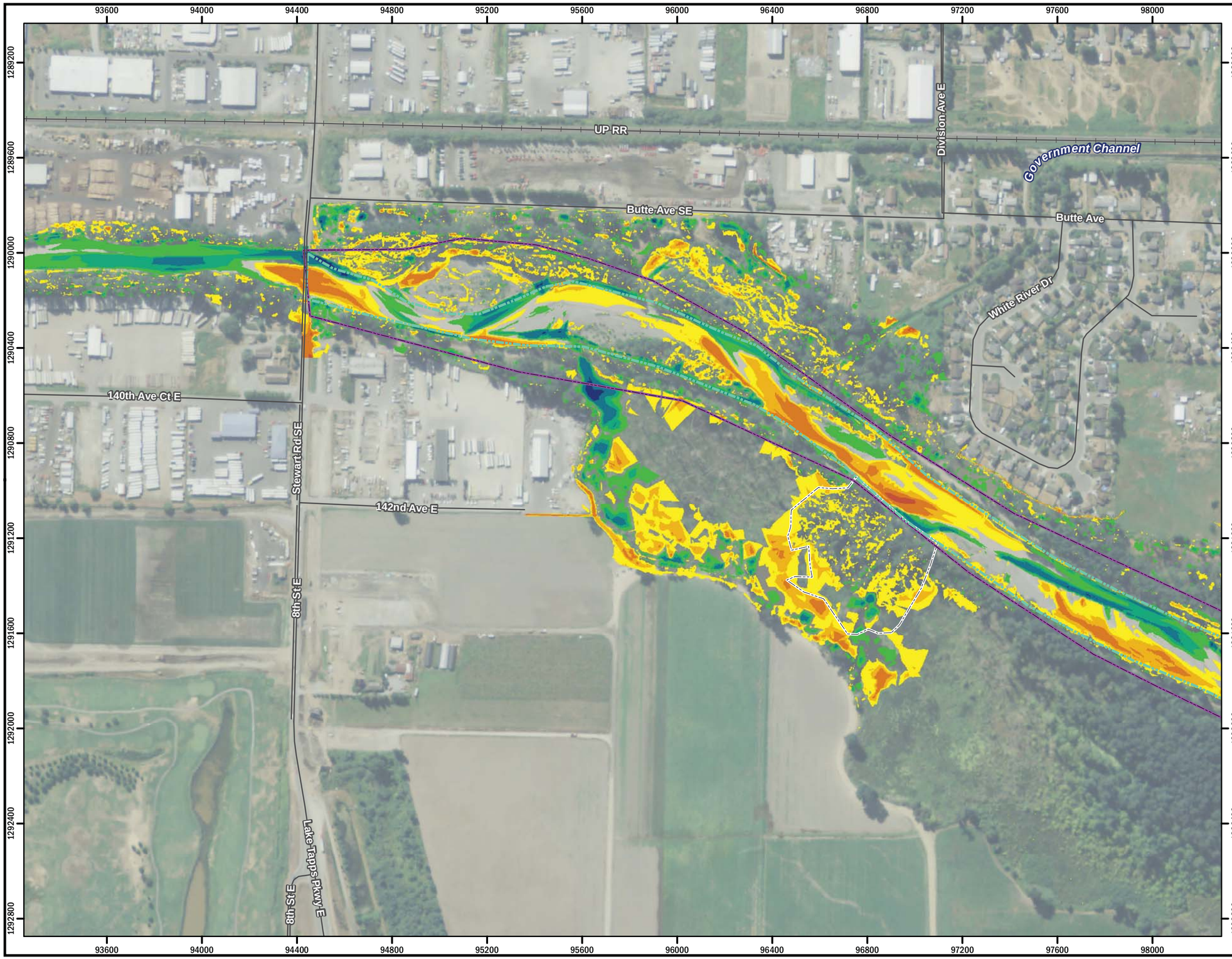

Figure 5, Sheet B
Map of observed topographic differences (2011 surface minus the 2009 surface) in the Lower White River project area used to validate the sediment transport model, along with the three volume polygons overlaid.

Legend

Change in volume (ft³)

- < -5
- -5 to -2.5
- -2.5 to -1.5
- -1.5 to -0.5
- -0.5 to 0.5
- 0.5 to 1.5
- 1.5 to 2.5
- 2.5 to 5
- > 5
- Channel delineation #1
- Channel delineation #2
- Overbank area

Note:
Represents conceptual model results from "Hydraulic and sediment transport modeling technical memorandum" 05/24/2012

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\09-04375-140\Project\sediment_transport_memo\topo_2009_to_2011.mxd

However, there are several assumptions particular to this sediment transport modeling effort that warrant further discussion as they limit the accuracy of the modeled conditions in specific ways. They are:

- Erosion capacity of vegetated areas – Currently there is no well-established method to estimate the reduction in erosion rate in vegetated areas, particularly one that would be relevant to the plant species found at the project site. As a result, it was necessary to assume that vegetated areas would not erode at all, although they could accumulate sediment. While this assumption produced reasonable results with regard to the sediment deposition volume estimates, it could result in significant deviations from observed conditions, particularly for a long-term simulation.

- Single grain size – The Ackers and White (1975) equation used to predict sediment transport in the model did not have the capability to transport different-sized material differently. Therefore, it was not possible to simulate the armoring of surficial sediments. The project site is highly armored, particularly in key areas, like the right bank bar at the City of Pacific Park. As mentioned in the validation section above, the bar at the city park denudes in smaller flood events and accumulates material in larger flood events. This bar has coarsened considerably in recent years as each successive denuding of finer material has been followed by deposition of large cobble in a subsequent flood event, ultimately resulting in it becoming a persistent feature. Since the model equations do not represent this process, the model is incapable of resolving bar armoring, and as a result the bar at the city park was obliterated over time in the re-calibration and validation model runs, although the models did initiate a significant amount of deposition around it. The result is that the pattern of deposition in the model is significantly different than that in the observations, even though the overall deposition and loss of conveyance in the channel is predicted reasonably accurately.

- Sediment input – The method of importing sediment into the model is always a key consideration in any sediment transport model because the typical approach implicitly assumes some form of sediment transport equilibrium. Variability of sediment supply is notoriously difficult to assess even in systems where significant sediment transport observations have been made. It is well known that sediment input into a river system like the White River has hysteretic behavior (i.e., the sediment concentrations are significantly higher on the rising limb of the hydrograph than the falling limb for a given discharge). The past history of sediment loading and the hysteresis of sediment concentration were not possible to incorporate into the model input rating curve because of a lack of data. This likely had numerous impacts on the ability of the model to predict sediment transport, not the least of which was that deposition on the rising limb was underestimated, but overestimated on the falling limb.

The collective effect of these assumptions resulted in the inability of the sediment transport model to precisely match the geomorphic response of the river system, particularly over long time periods.

CONCLUSIONS

The hydraulic modeling results indicate that the model performs well when up-to-date topography is used along with a detailed accounting of critical flow dispersal points, provided that the mesh density is appropriate to the flows modeled (low flows need a much finer mesh to accurately simulate depths and velocities).However, the rapid sediment deposition in the project area can cause significant errors to develop if significant geomorphic change has occurred, as found by Herrera (2011). Increasing resolution of the model, particularly around key flow dispersal points, such as the left bank levee immediately downstream of the A Street bridge, did not impair the calibration, indicating that the physical processes responsible for flooding are well simulated by the model.

The sediment transport model did not perform as well as the hydraulic model in replicating observed conditions. While the sediment transport validation model results matched observations within the error established during the re-calibration effort, the model did not adequately match important geomorphic features seen throughout the project site. It is suggested that this is due to the model limitations to account for river bed armoring and the sediment input rate uncertainty. Continuing with the sediment transport modeling effort could provide unreliable estimates of geomorphic changes in specific areas that are difficult to defend. Explaining the nuances of the modeling approach and assumptions described in this memorandum to a lay audience would also be extremely challenging. As a result, the sediment transport modeling work was concluded after the re-calibration and validation model runs documented in this memorandum, and will not be carried farther in project design. The challenges in accurately simulating sediment transport at the project site with the RiverFLO-2D model do not affect the ability of the same model program to accurately simulate hydraulic characteristics, as long as a reasonable depiction of existing and future floodplain topography and channel bathymetry is reflected in the computational mesh in the hydraulic model for any given scenario.

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Syvitski, J.P.M., S.D. Peckham, R. Hilberman, and T. Mulder. 2003. Predicting the terrestrial flux of sediment to the global ocean: a planetary perspective. *Sedimentary Geology* 162(1-2):5-24.

APPENDIX A

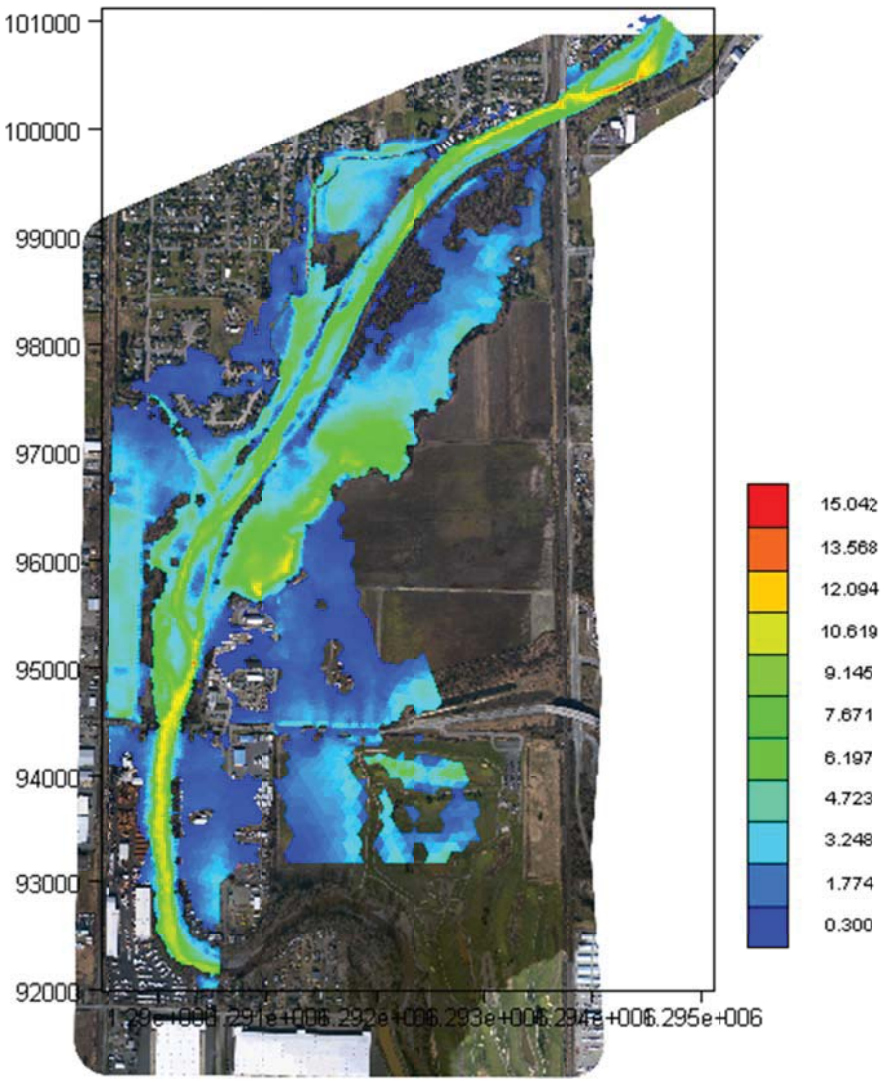
Hydraulic Modeling Memoranda from King County

King County

Memorandum

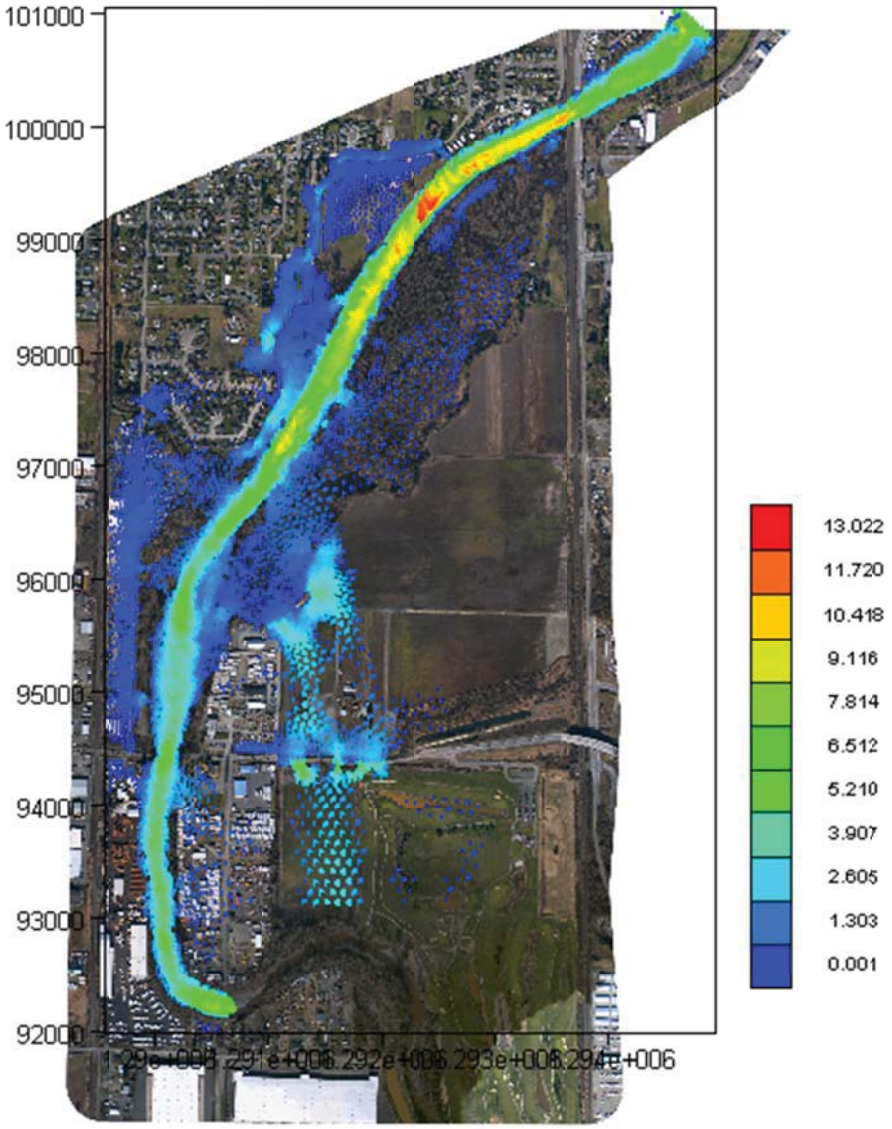
Date:	January 27, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 2yr/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 2-yr hydrograph and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 2-yr, ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



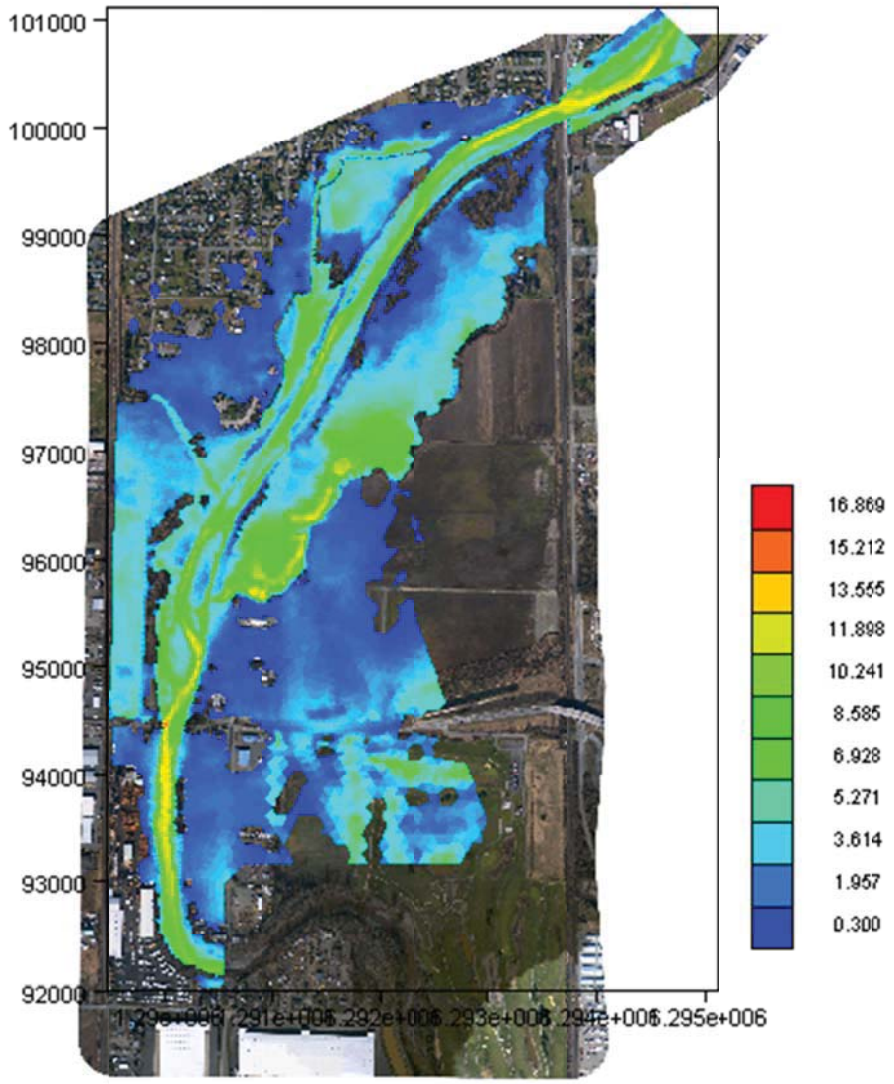
Vel. at Peak, 2-yr, ExCond

King County

Memorandum

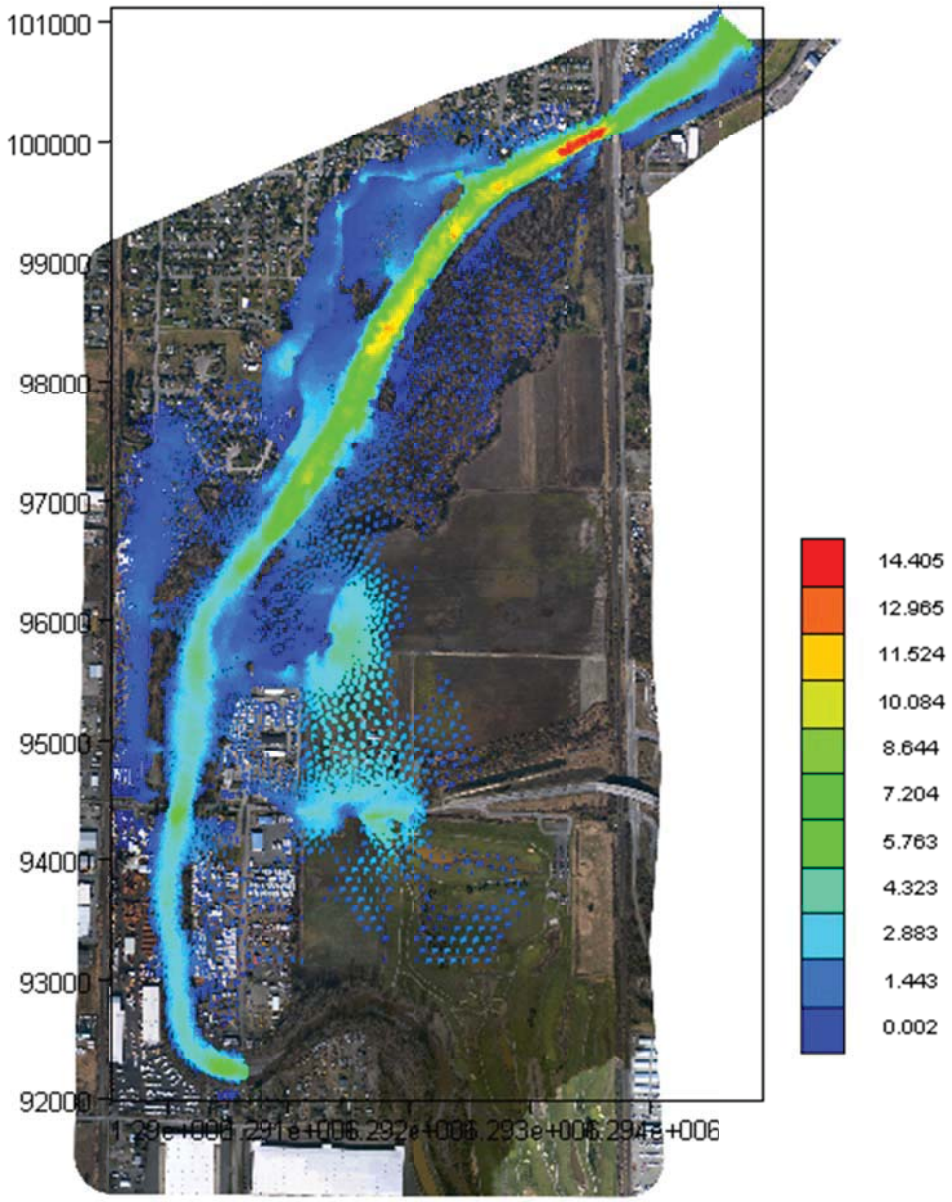
Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 10yr/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 10-yr hydrograph and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 10-yr, ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



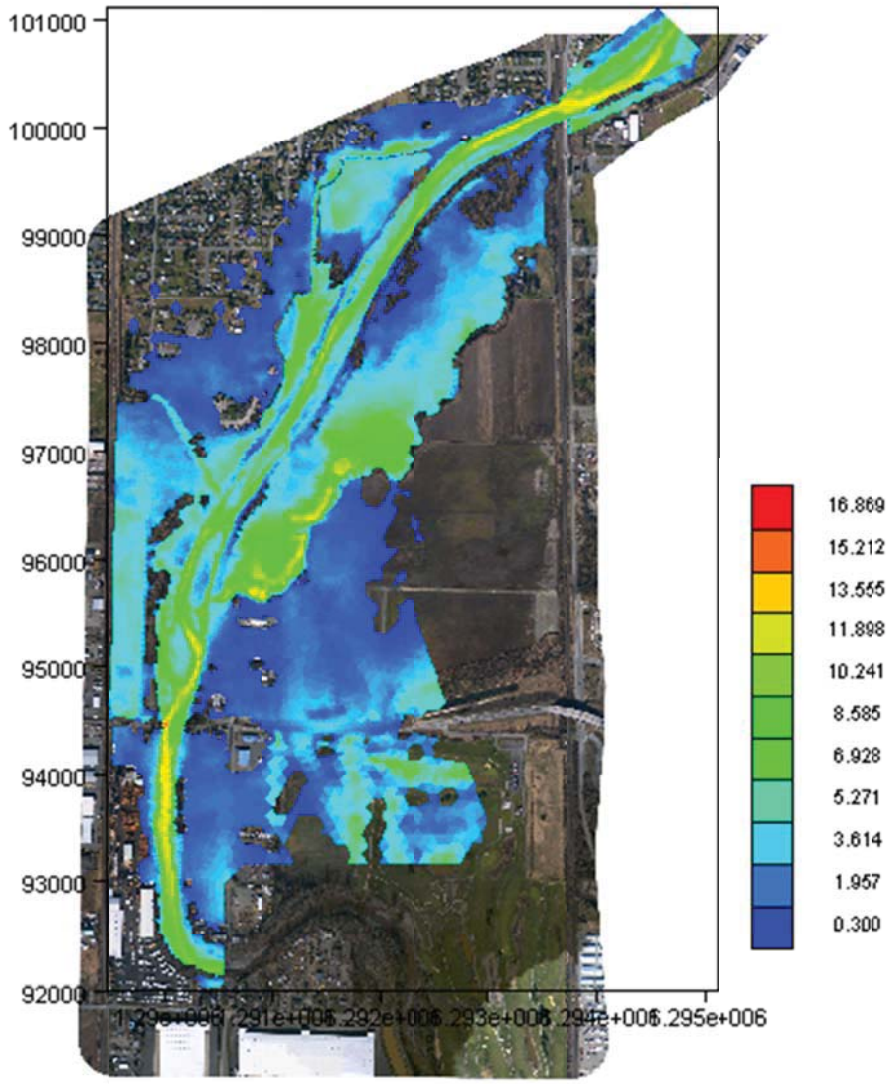
Vel. at Peak, 10-yr, ExCond

King County

Memorandum

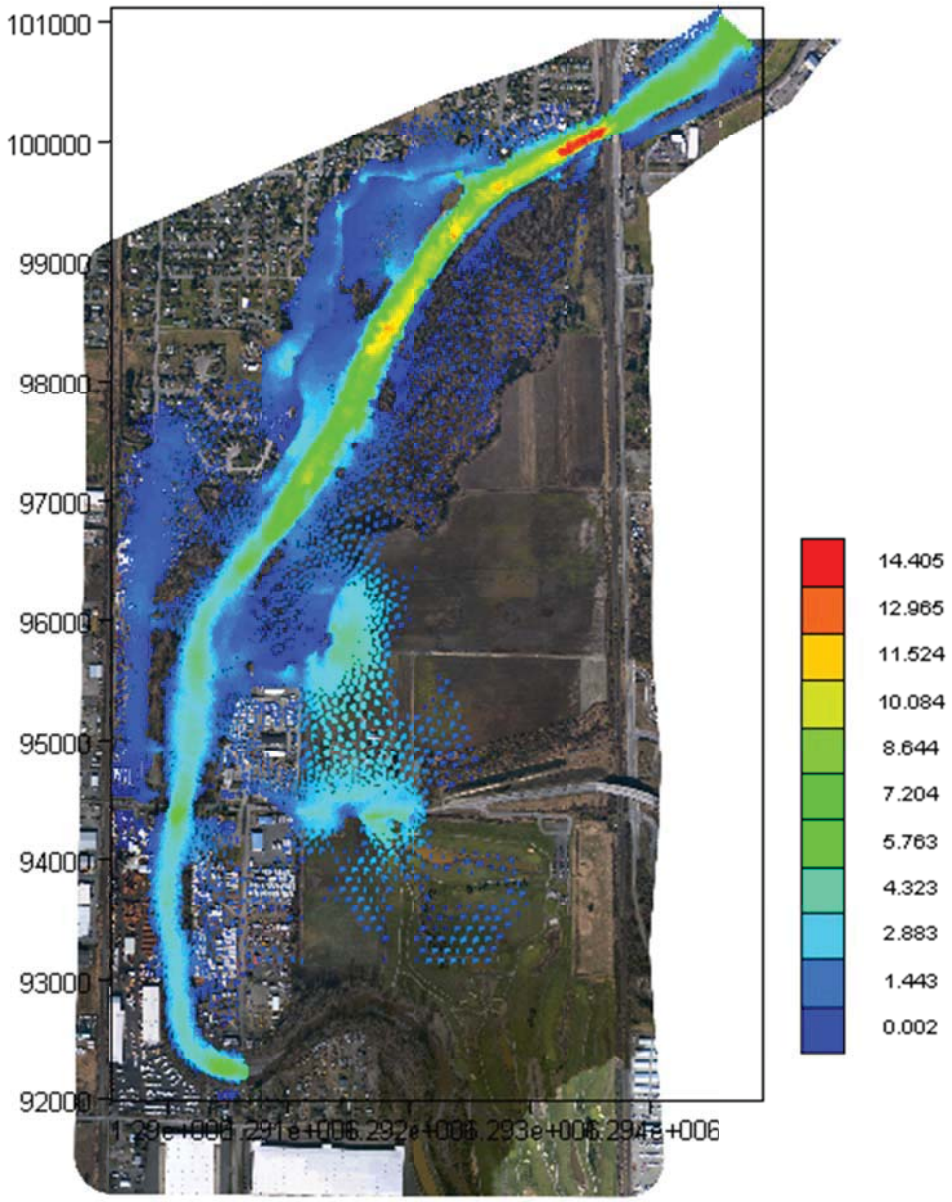
Date:	January 27, 2012
To:	Deb Pessoa – NOTE RUNNING AGAIN
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 50yr/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 50-yr hydrograph and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 50-yr, ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



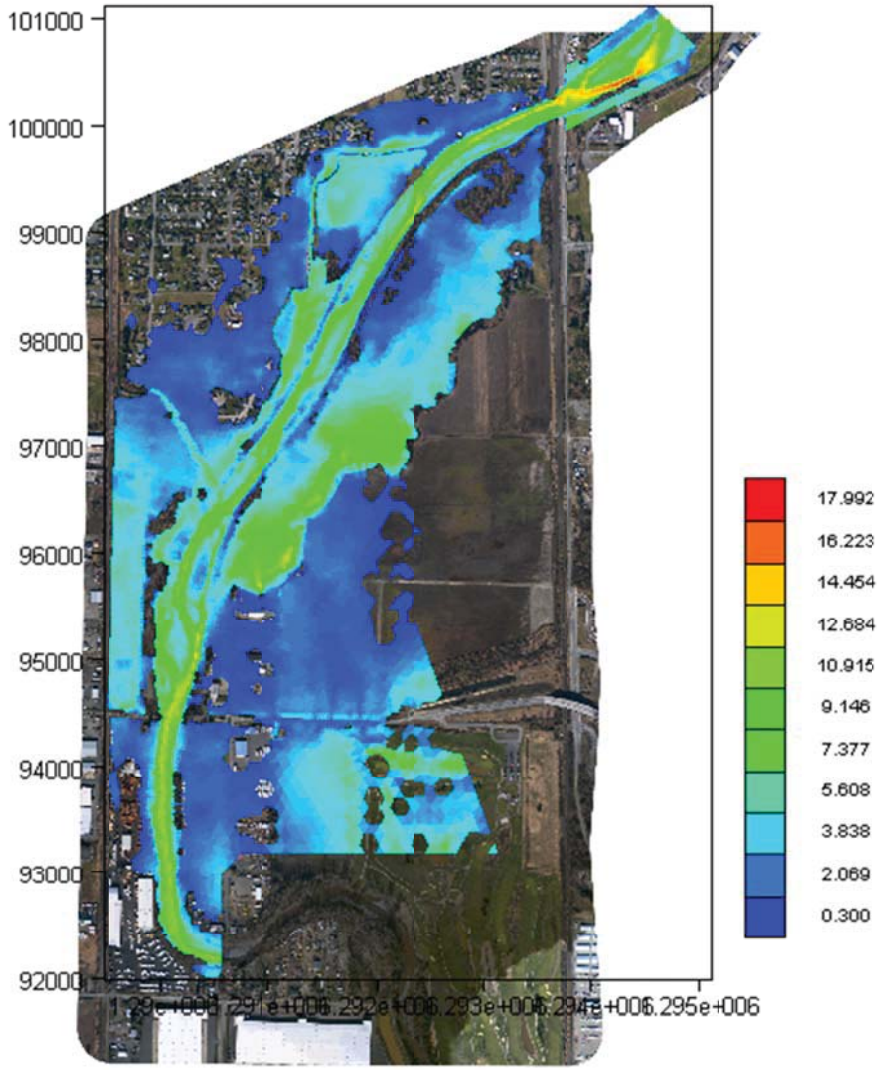
Vel. at Peak, 50-yr, ExCond

King County

Memorandum

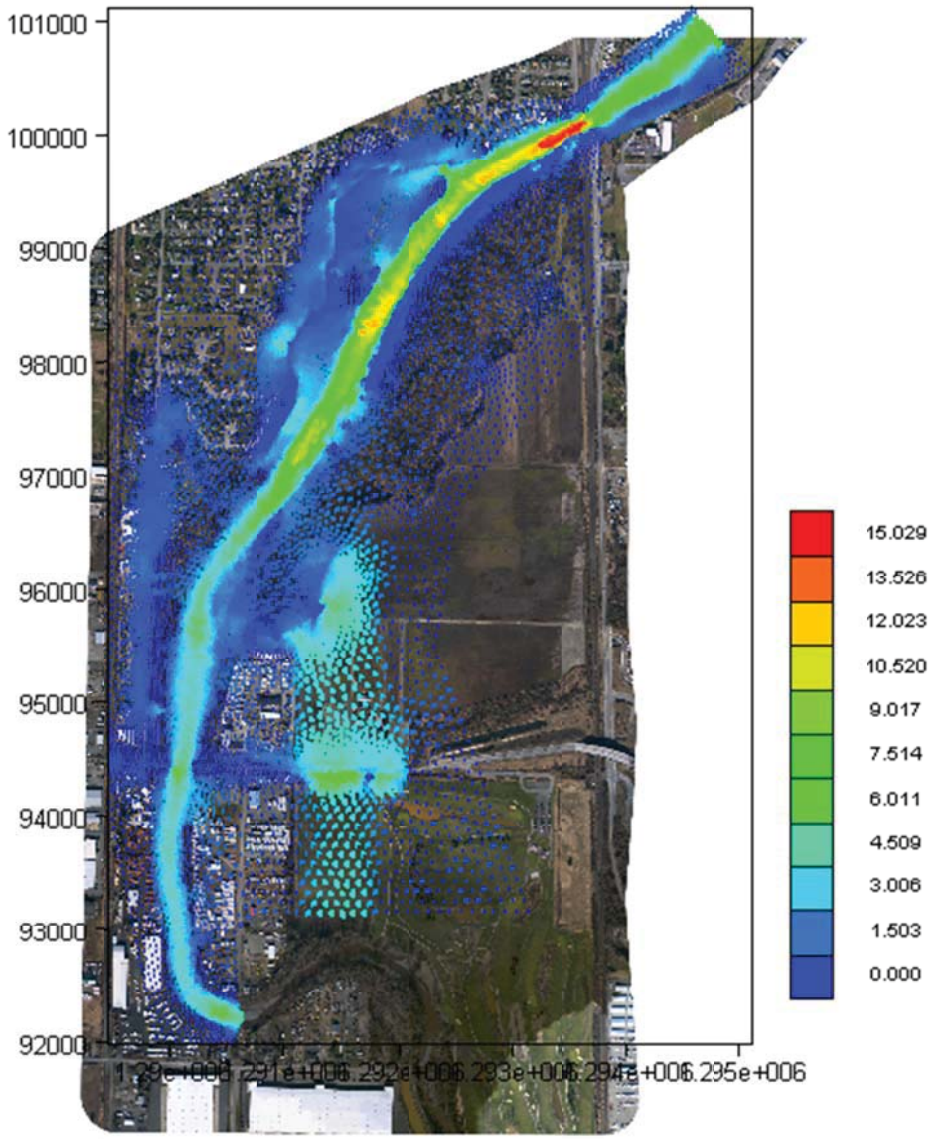
Date:	January 27, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 100yr/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 100-yr hydrograph and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 100-yr,ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



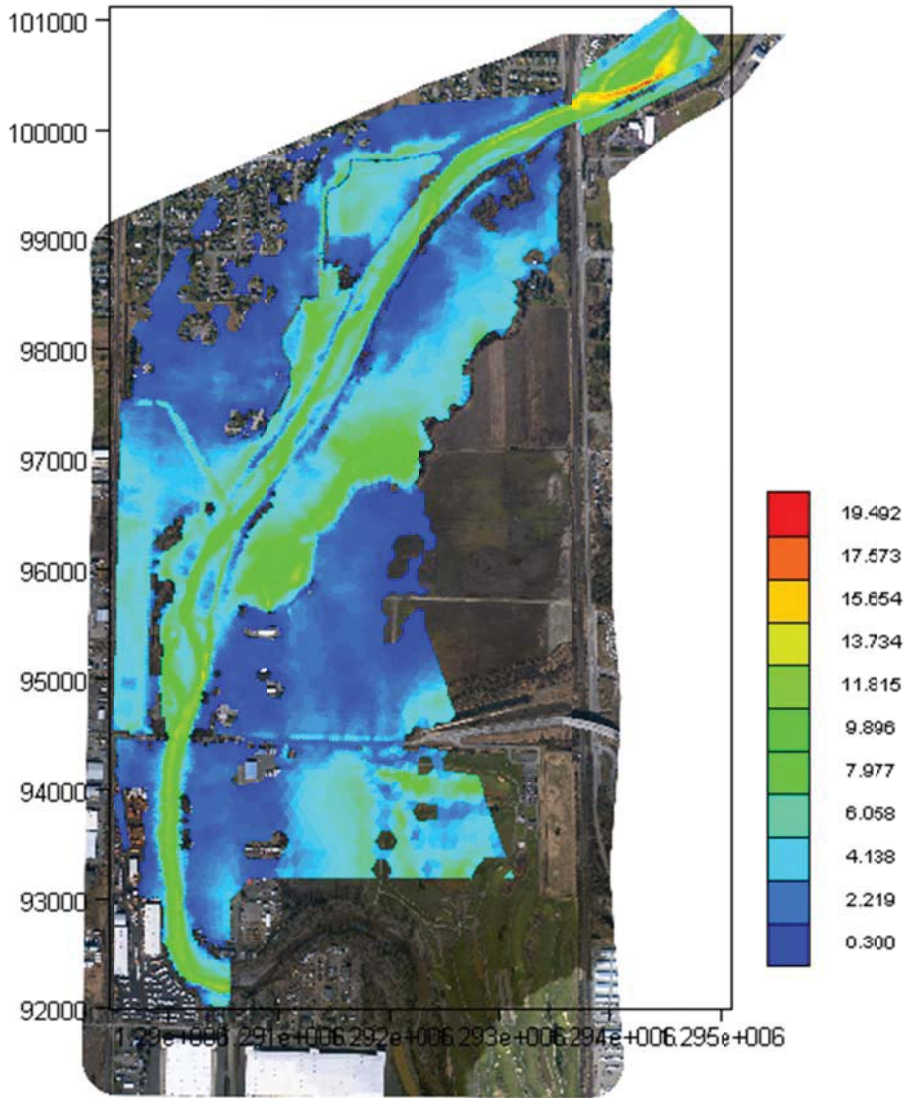
Vel. at Peak 100-yr,ExCond

King County

Memorandum

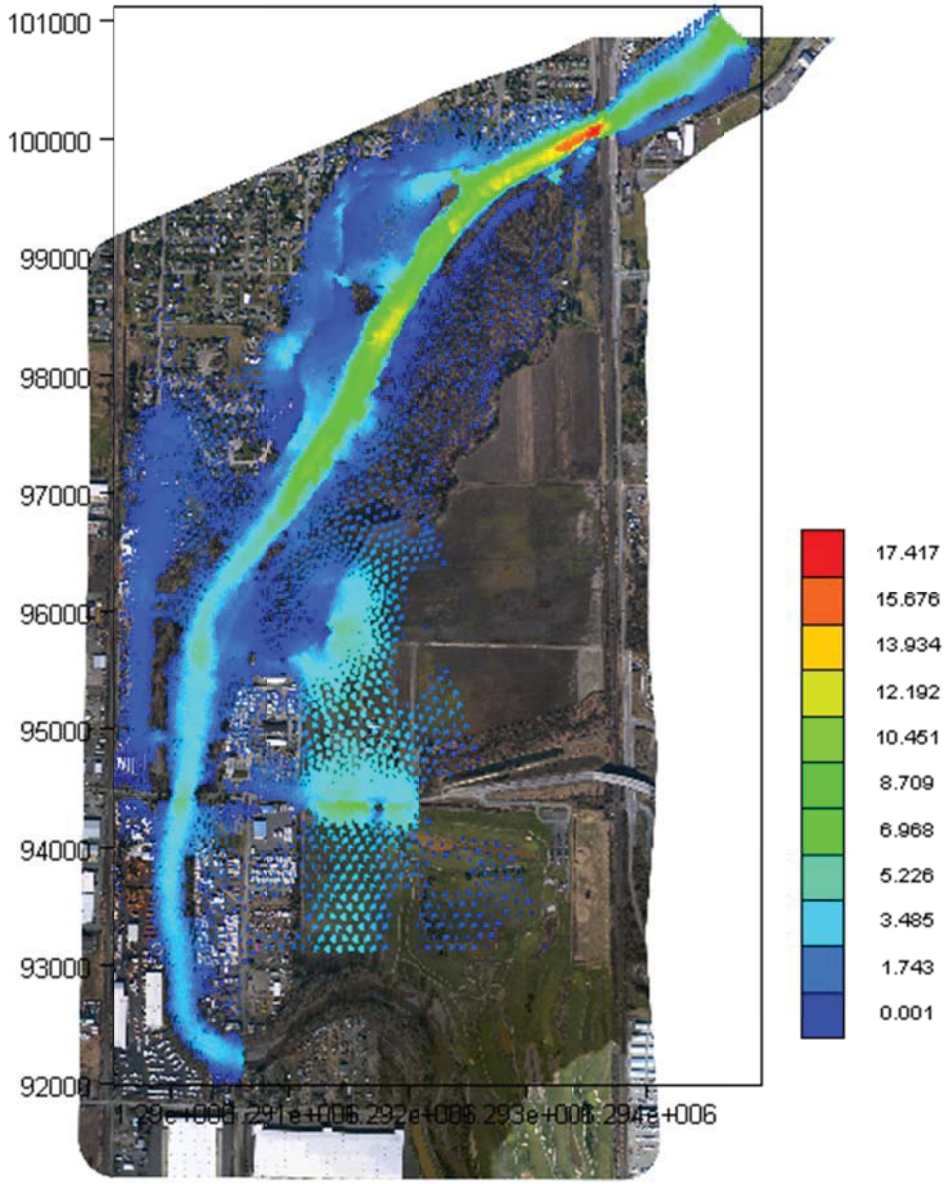
Date:	January 27, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 500yr/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 500-yr hydrograph and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 500-yr,ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



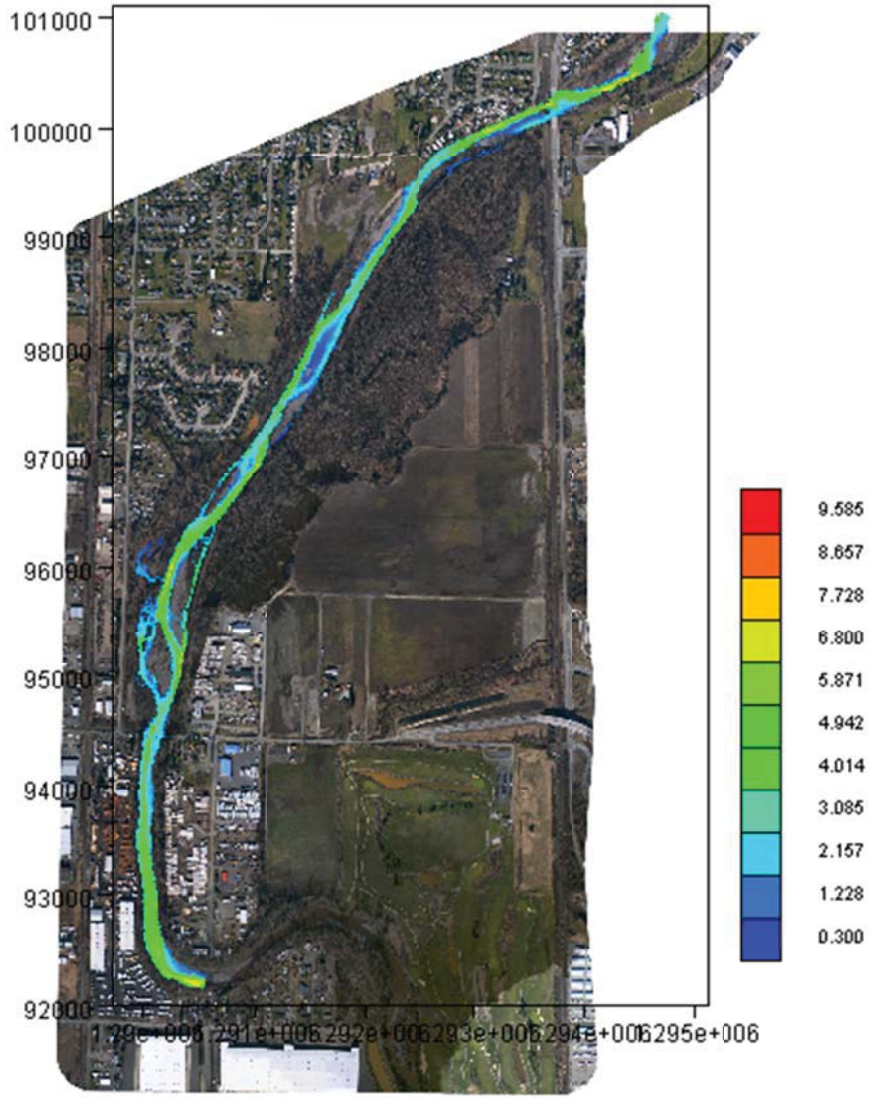
Vel. at Peak 500-yr,ExCond

King County

Memorandum

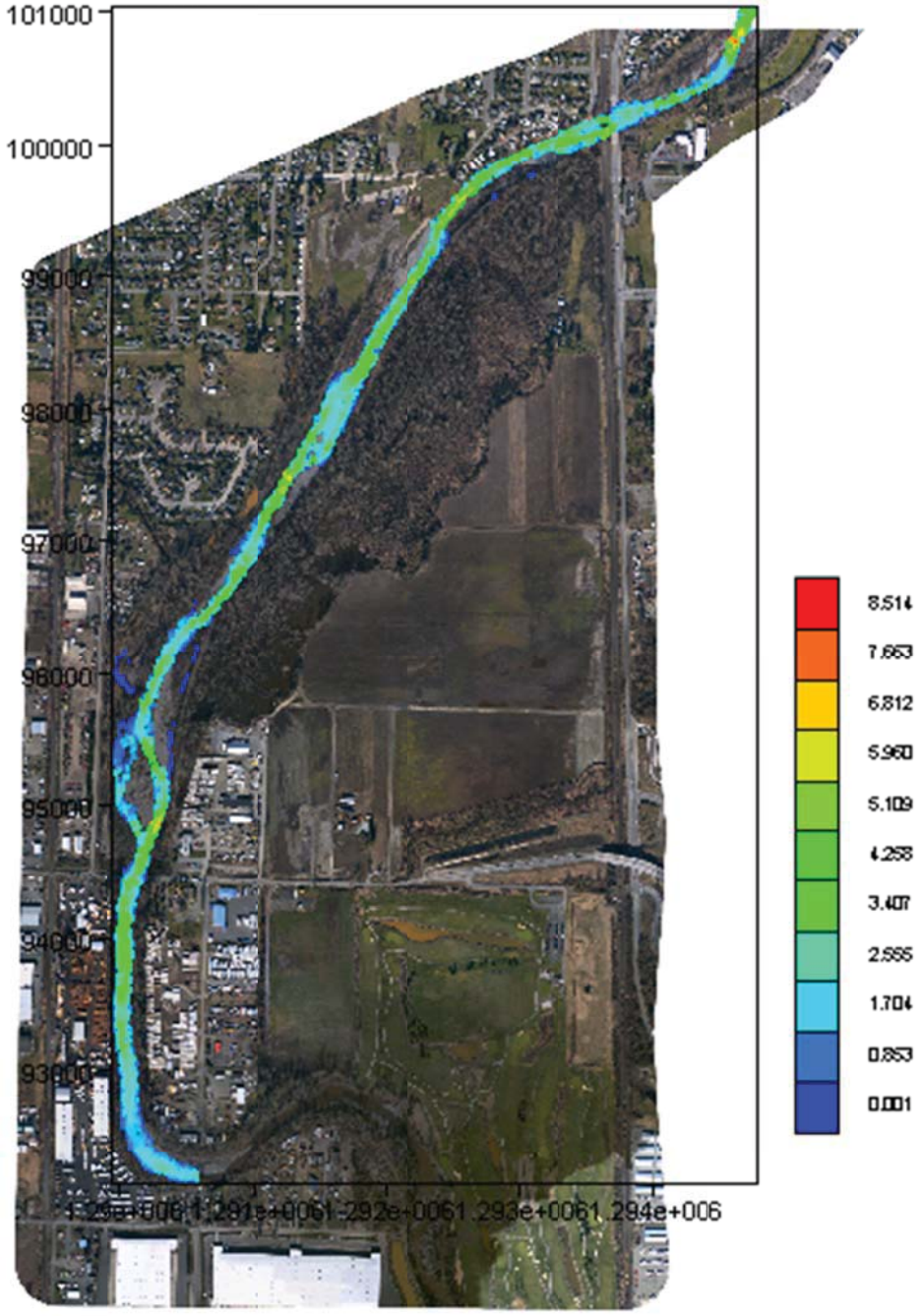
Date:	January 27, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – MAF/ExCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the Mean Annual Flow (MAF) and the existing conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the MAF and the velocity field at the MAF. The mesh used for the MAF is finer than that used for the other flows.



Depth at Peak, MAF, ExCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



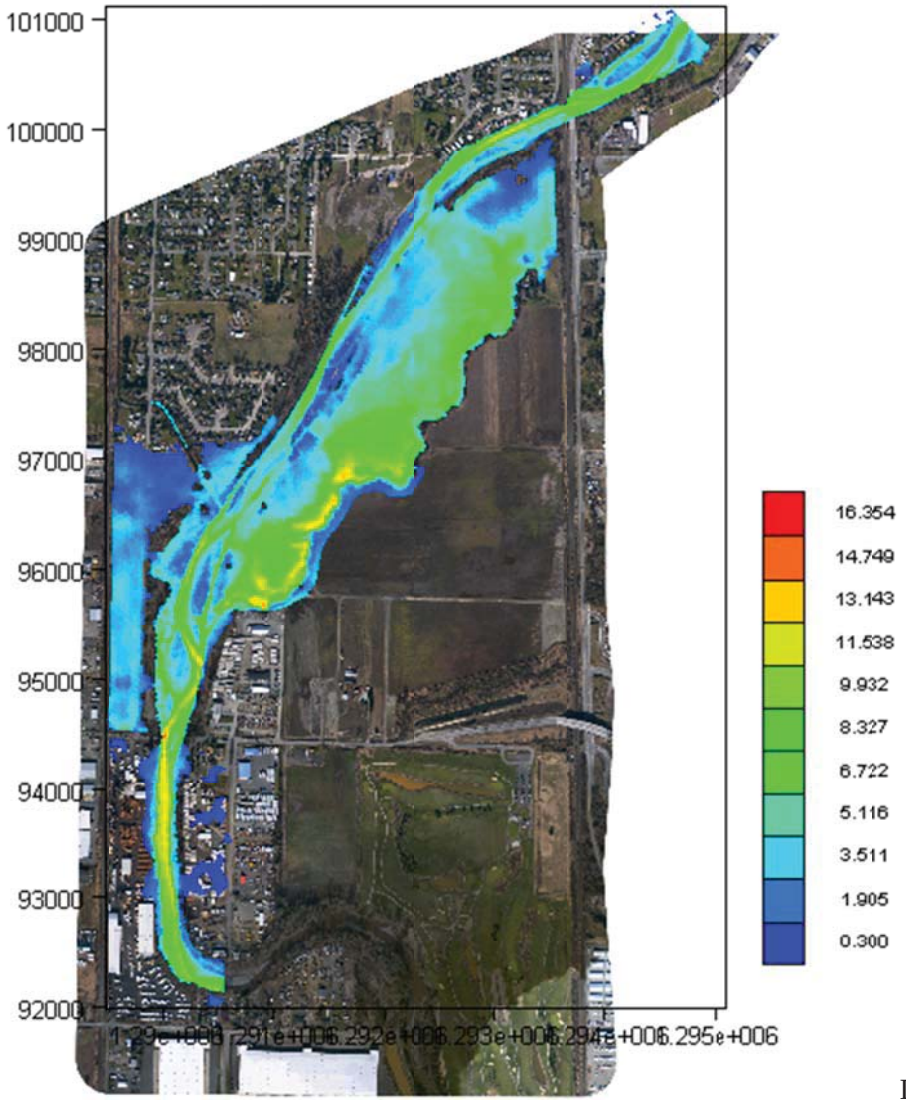
Vel. at Peak MAF, ExCond

King County

Memorandum

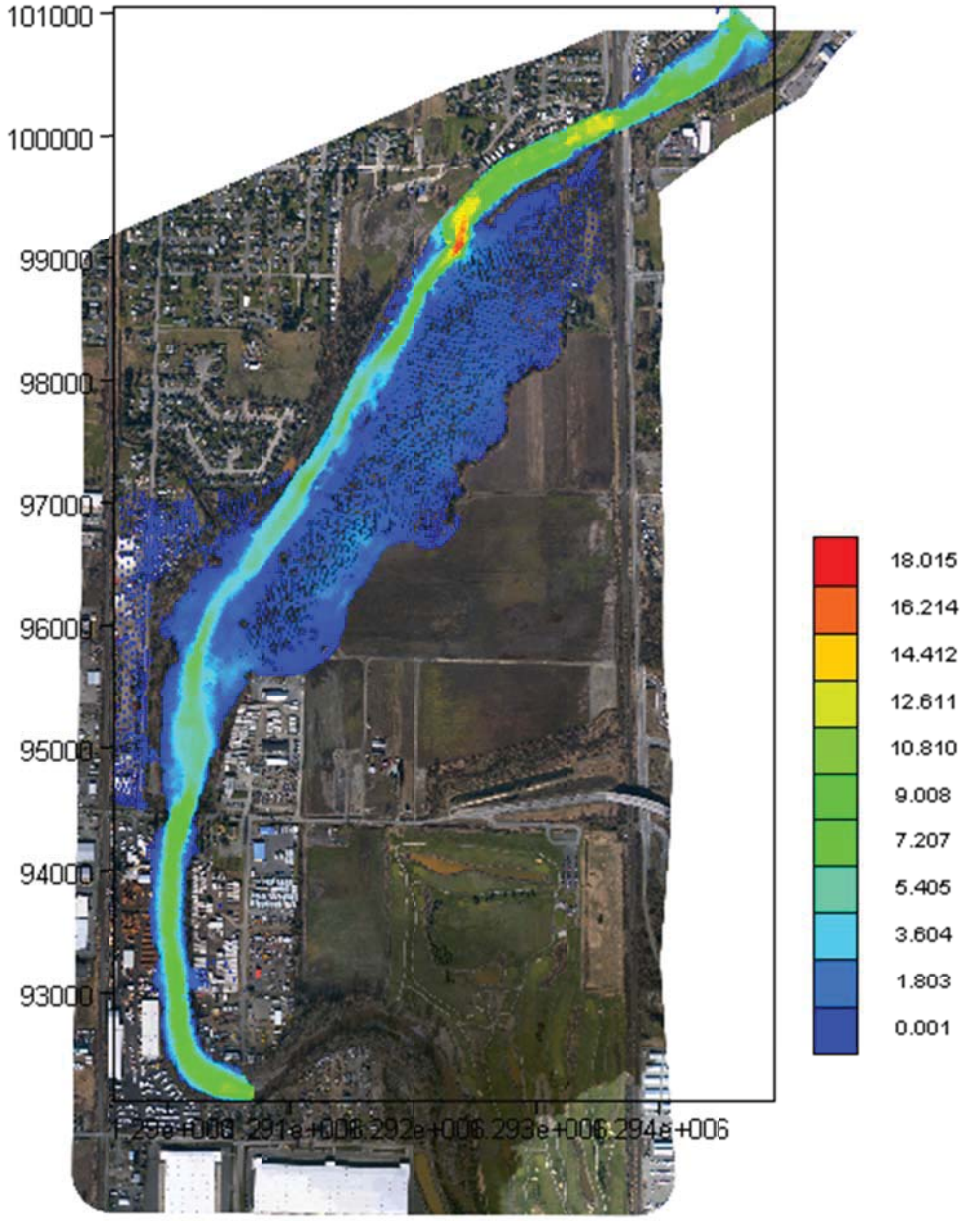
Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 2yr/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 2-yr hydrograph and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 2-yr, PrCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



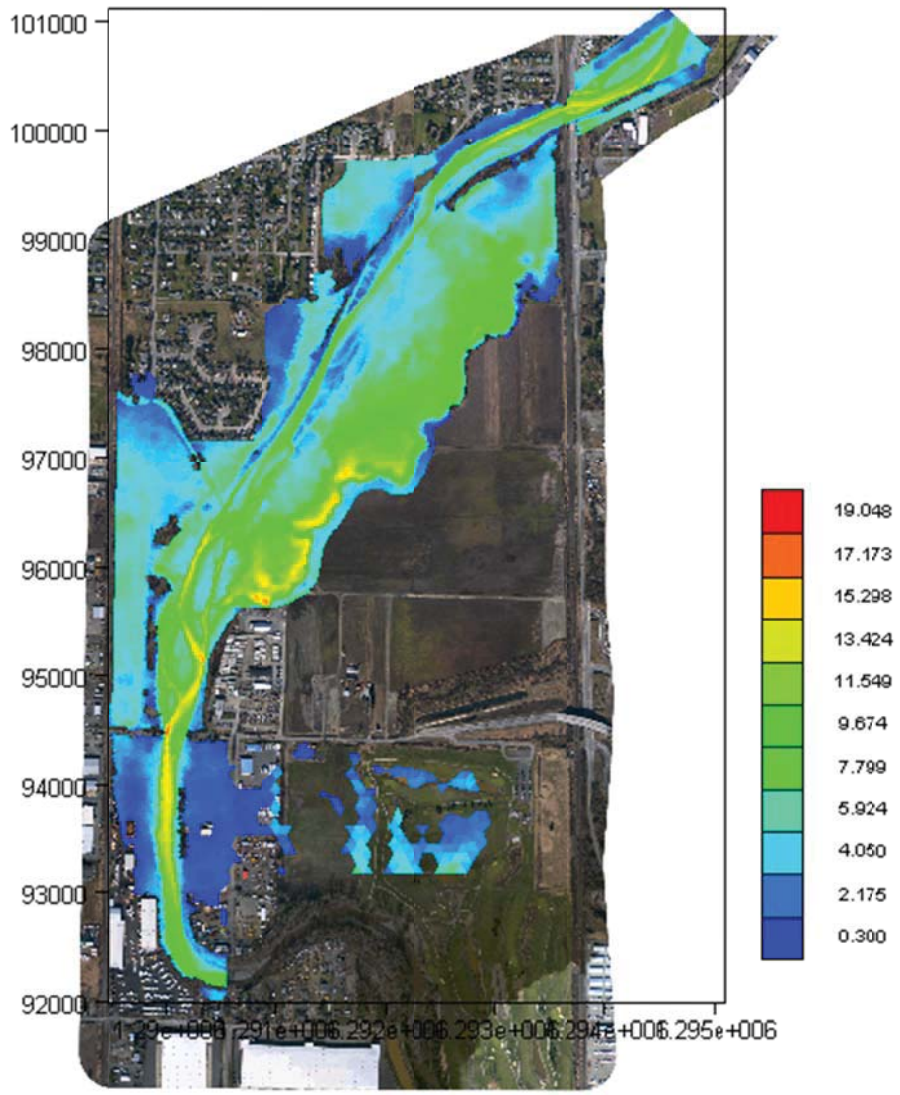
Vel. at Peak, 2-yr, PrCond

King County

Memorandum

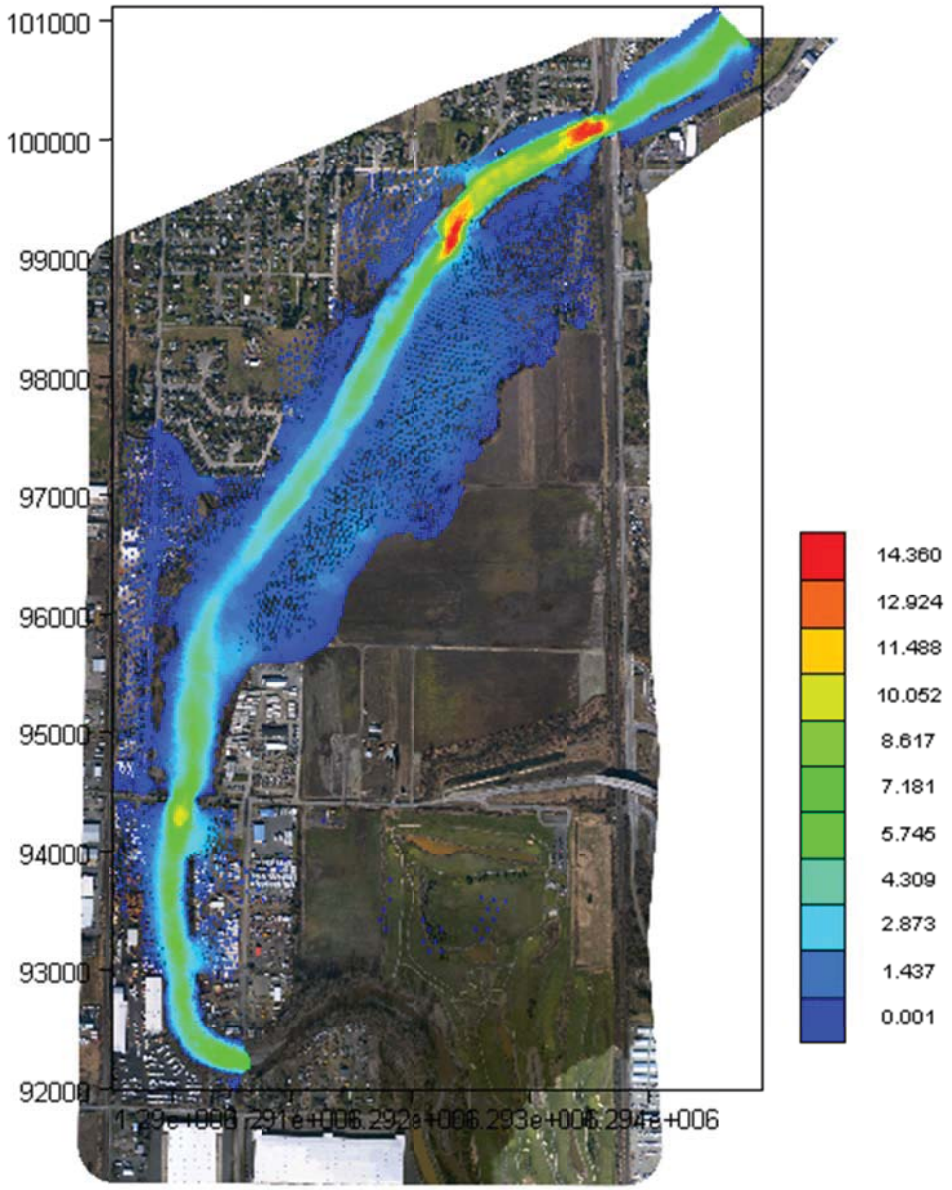
Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 10yr/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 10-yr hydrograph and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 10-yr, PrCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



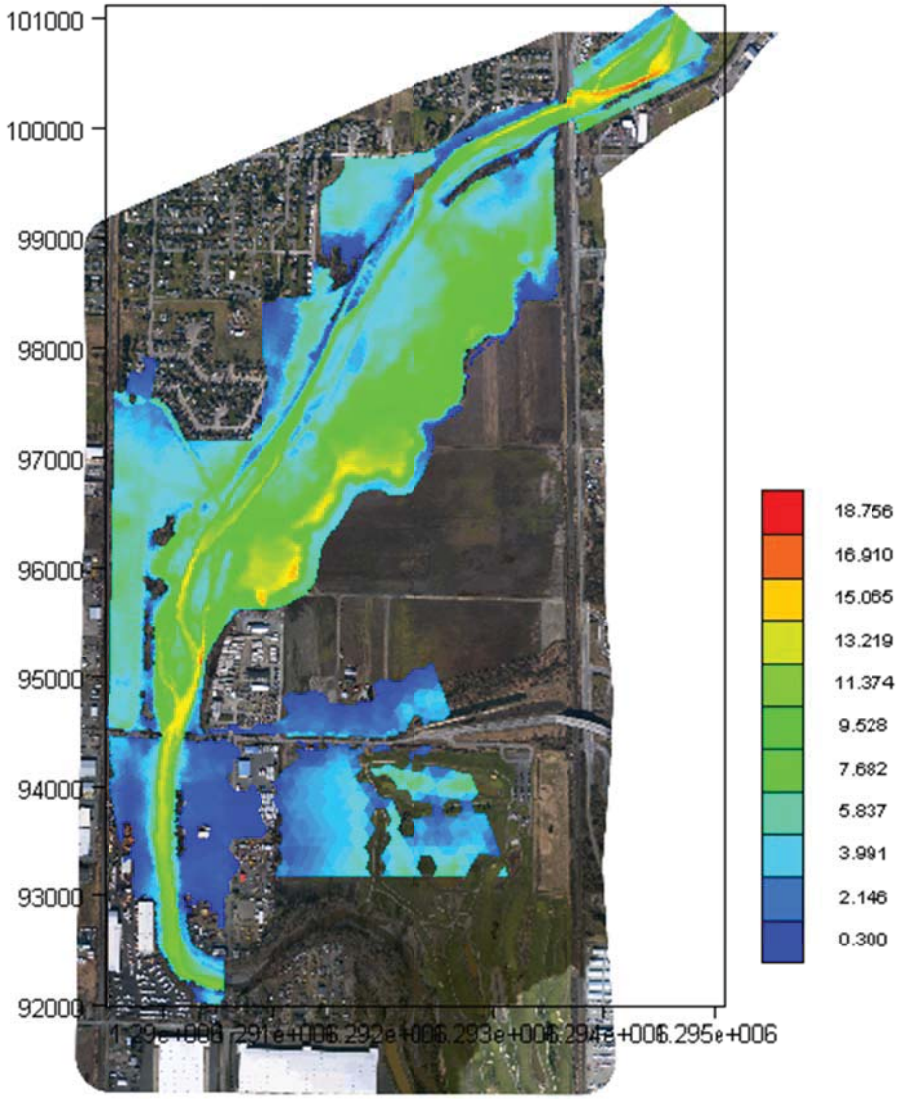
Vel. at Peak, 10-yr, PrCond

King County

Memorandum

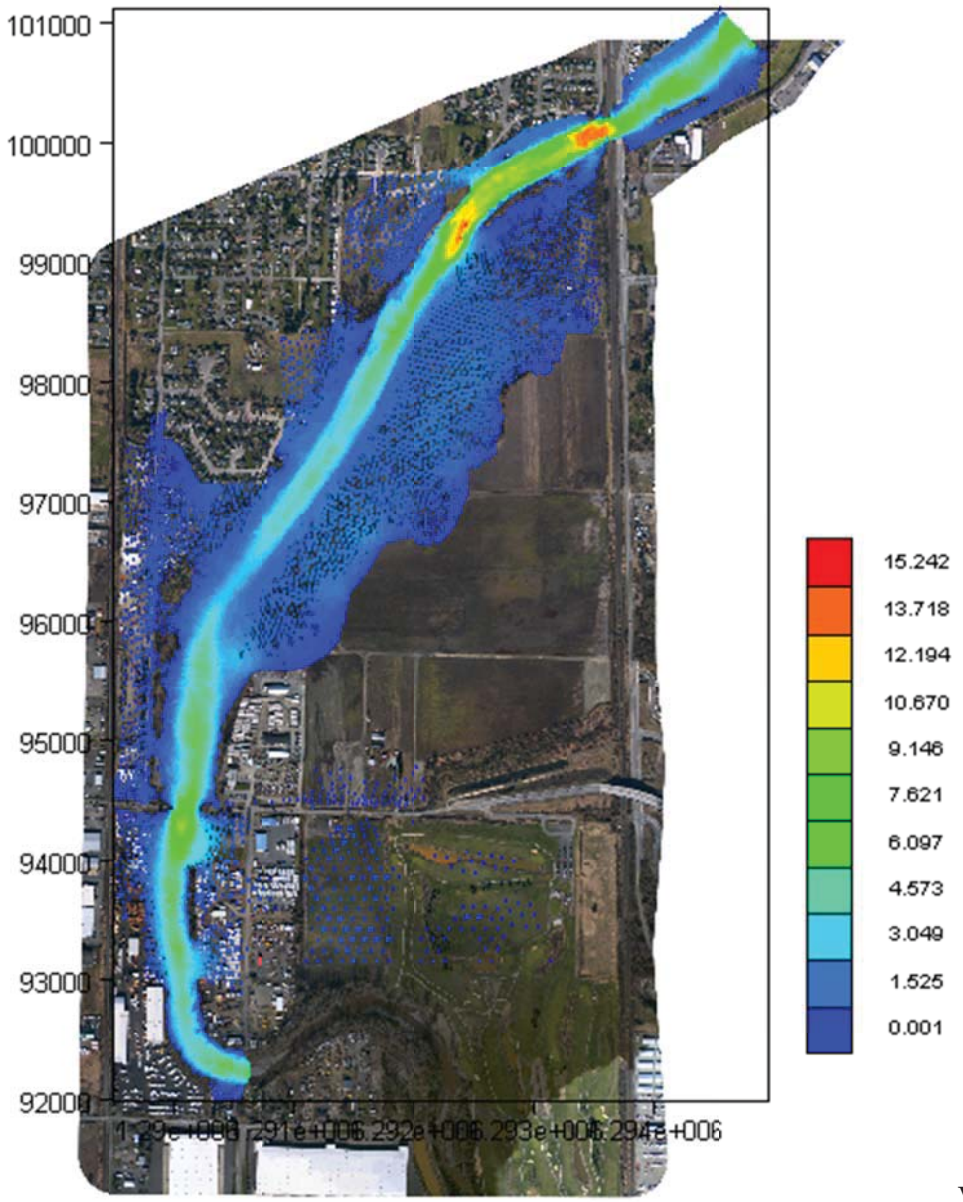
Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 50yr/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 50-yr hydrograph and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 50-yr, PrCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



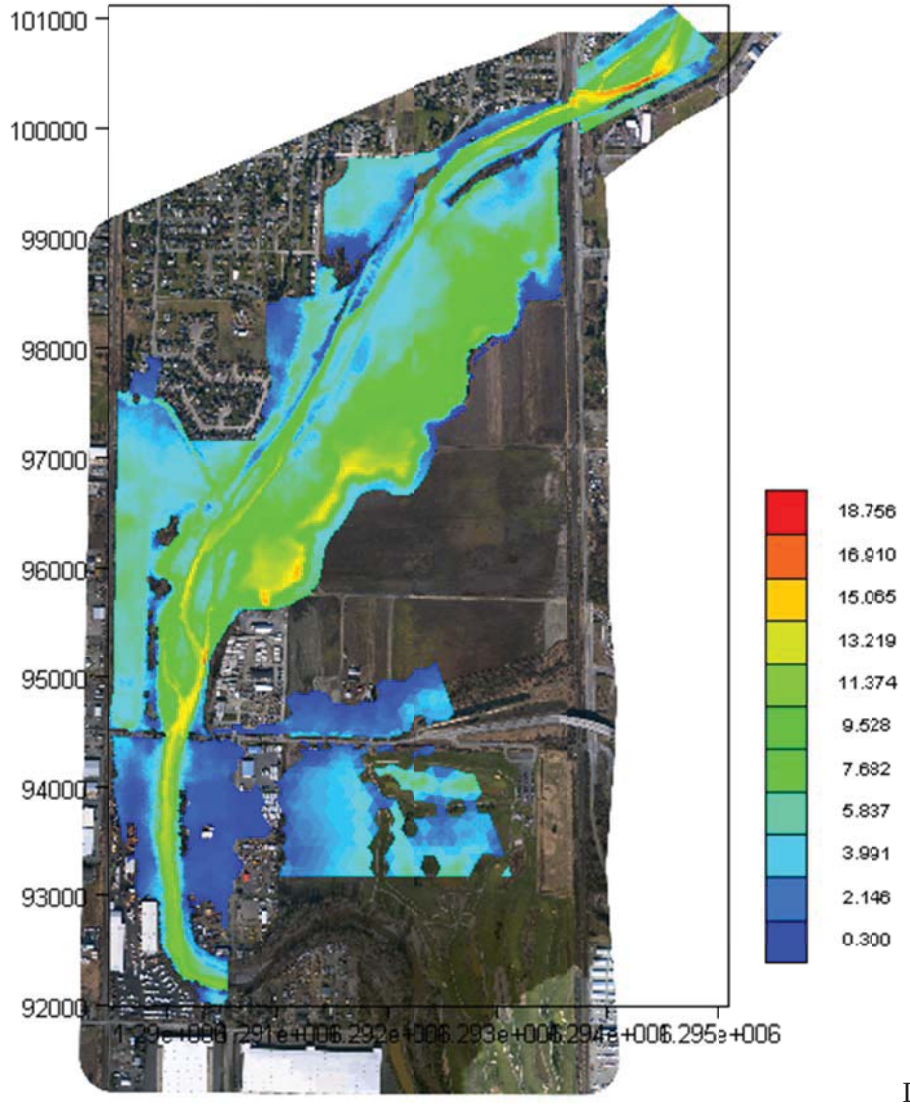
Vel. at Peak, 50-yr, PrCond

King County

Memorandum

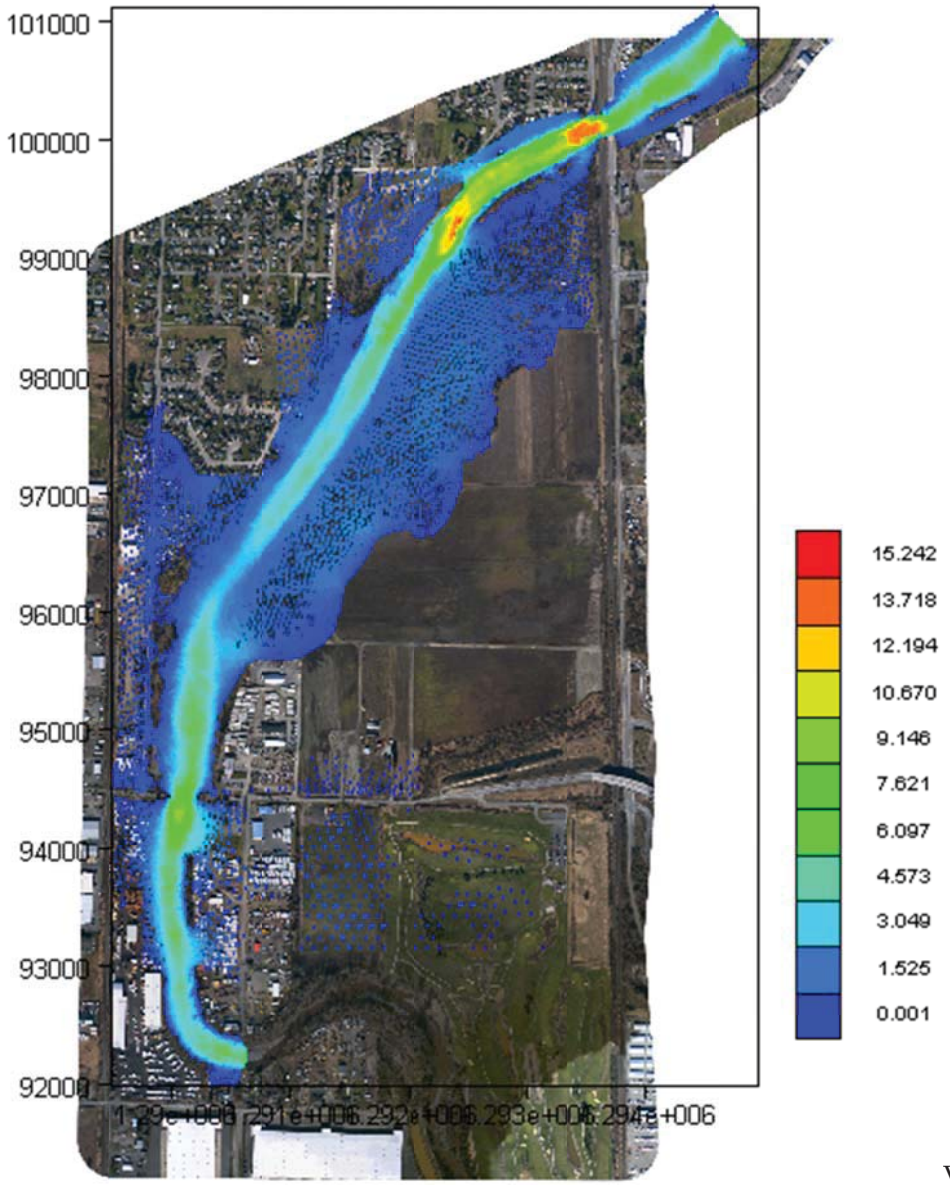
Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 100yr/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 100-yr hydrograph and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 100-yr, PrCond

Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600 Seattle, WA 98104-3855



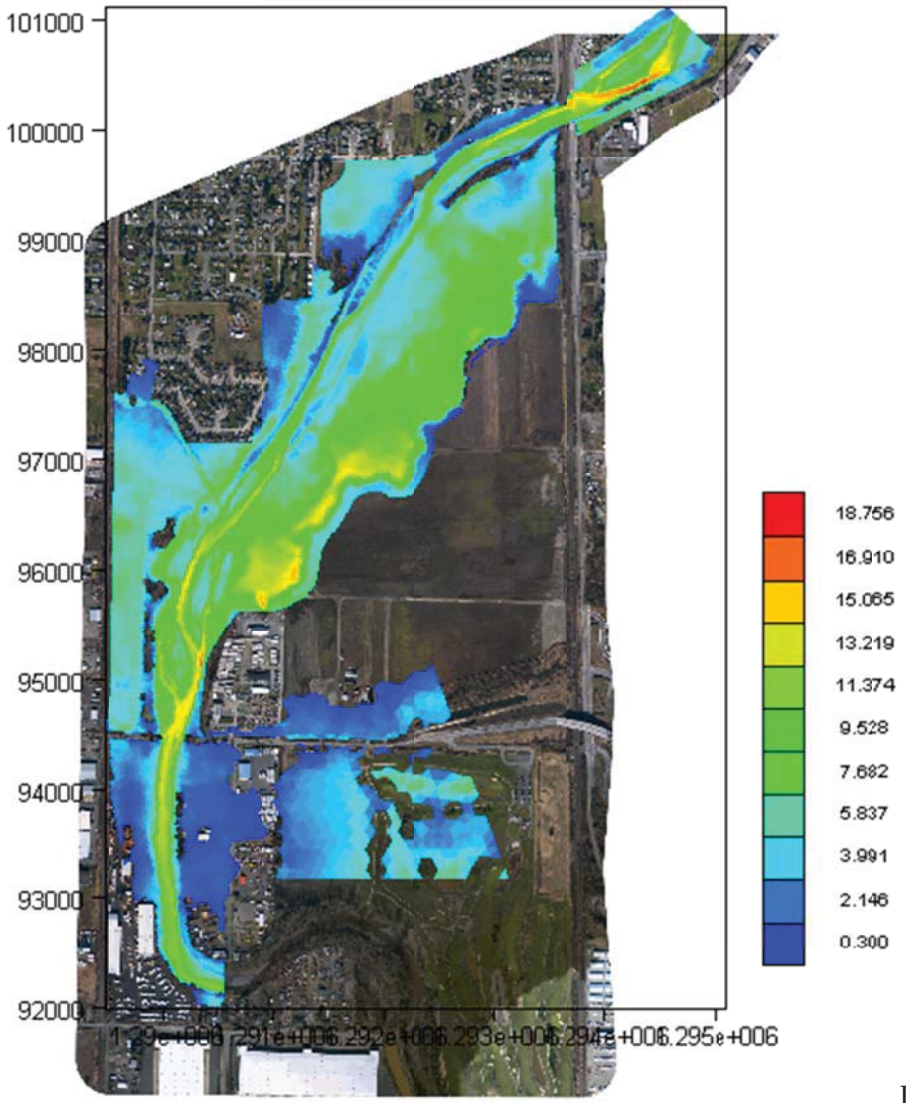
Vel. at Peak, 100-yr, PrCond

King County

Memorandum

Date:	January 30, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – 500yr/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the 500-yr hydrograph and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the peak of the hydrograph and the velocity field at the peak.



Depth at Peak, 500-yr, PrCond

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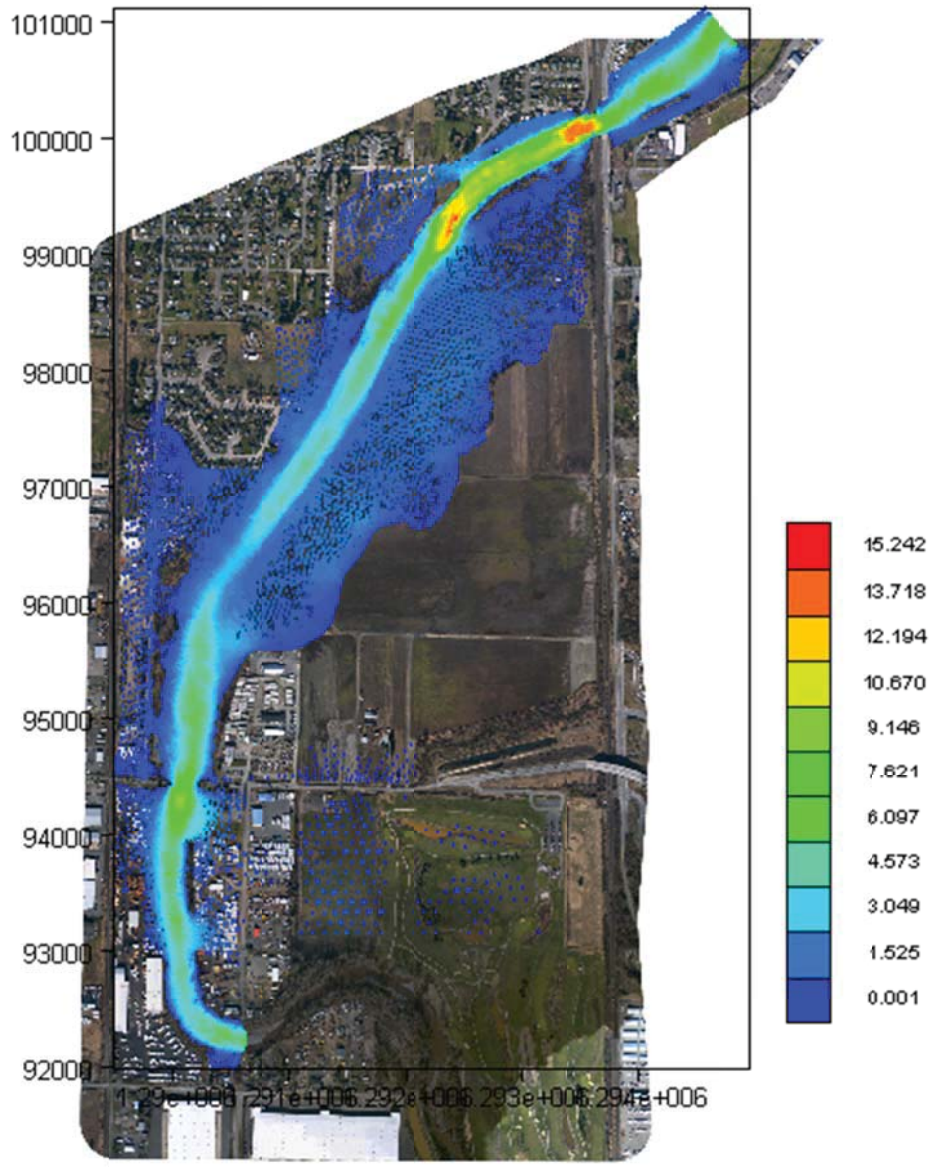


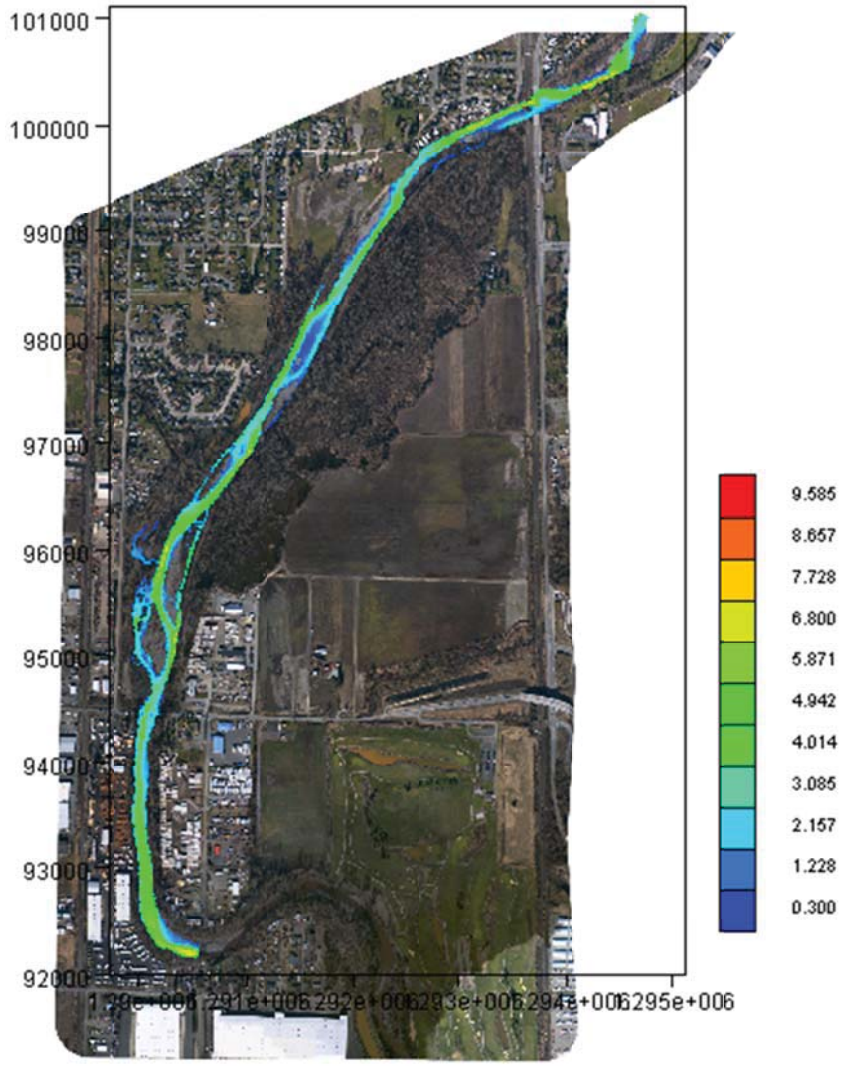
Vel. at Peak, 500-yr, PrCond

King County

Memorandum

Date:	January 27, 2012
To:	Deb Pessoa
Cc:	Project File
From:	Kyle Comanor
Project No./Name:	FL9007 / County Line
Subject:	King County RiverFlo-2D Model Summary – MAF/PrCond DRAFT

This memo describes a RiverFLO2D model created to support the County Line project. The model described here uses the Mean Annual Flow (MAF) and the proposed conditions mesh file representing the surface depicted by the April 2011 LiDAR. Included here are the flow depths at the MAF and the velocity field at the MAF. The mesh used for the MAF is finer than that used for the other flows. These are the same as the ExCond Model runs, as the flows are entirely within channel for the MAF.



Depth at Peak, MAF, PrCond

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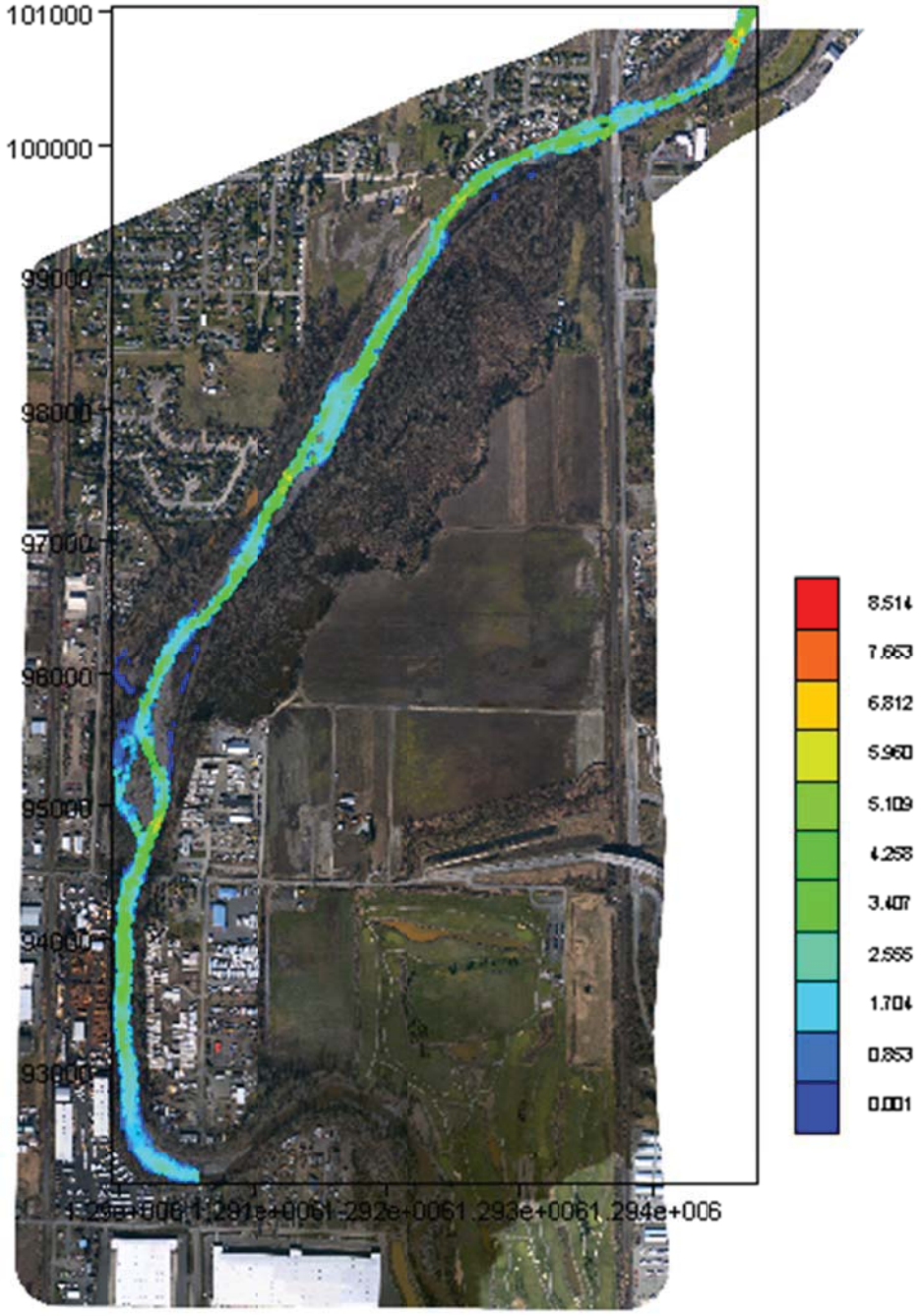

Vel. at Peak MAF, PrCond