HYDRAULIC MODELING APPROACH AND INITIAL MODELING RESULTS 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.

Note:
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Prepared for
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INTRODUCTION

This memorandum was prepared for Task 200.9 of King County's proposed White River at Countyline Levee Setback Project (the Project). King County intends to remove and set back 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 to perform two-dimensional hydraulic modeling for the proposed project and to document the modeling results. The methods and preliminary results presented in this memorandum were performed by the project team as a part of Task 200.8 (Contract E00187E10). Some results related to the model topographic surface production, completed under Task 300.4, are also presented. This memorandum documents the modeling approach and initial simulation results specific to off-site impacts and the flood reduction benefits of the proposed project. A Geomorphic Assessment memorandum, to be prepared under Task 300.3, will summarize the geomorphic ramifications of the final model results. The model results presented herein are those that specifically relate to off-site impacts and that were used to formulate the remainder of the hydraulic modeling approach for the project.

Project Site and Study Area

The proposed project site is located 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 the City of Pacific and incorporated King County, and also extends into the City of Sumner in Pierce County, with a small portion of the project lying in an unincorporated area of 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 (also referred to as 8th Street E) and its bridge crossing over the river, and private development on both sides of the river.

Objectives

The hydraulic analysis for the proposed project focuses on the determination of likely geomorphic changes that can be expected as a result of constructing the project and associated effects on flooding characteristics in the study area. It also supports evaluating the consequences of no action (i.e., no project implementation) 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, 2011a, 2011b; Czuba et al. 2010; Collins and Montgomery 2011). Therefore, the objectives of the hydraulic modeling were to:

1. Estimate the extent of flood inundation under existing and proposed conditions under a suite of scenarios that simulate both short- and long-term expected changes
2. Determine the maximum range of probable flow velocities and depths near the proposed levee setback infrastructure (i.e., the proposed biorevetment and engineered log jams [ELJs] in the setback floodplain)
3. Identify possible consequences and mitigation actions necessary to successfully complete the proposed levee setback project

A companion memorandum (prepared for Task 200.4.1) will summarize all of the model simulations used to support the project design work. These will include simulations to test the hydraulic stresses on selected design components (i.e., the ELJs and biorevetment), to estimate conditions at the end of the project's service life, and one additional simulation that will be defined once all of the other simulations have been evaluated. This memorandum relies heavily on earlier documentation that describes previous modeling work in the area (Herrera 2011a, 2011b, 2012a, 2012b), particularly as they relate to the way the model was set up and implemented.

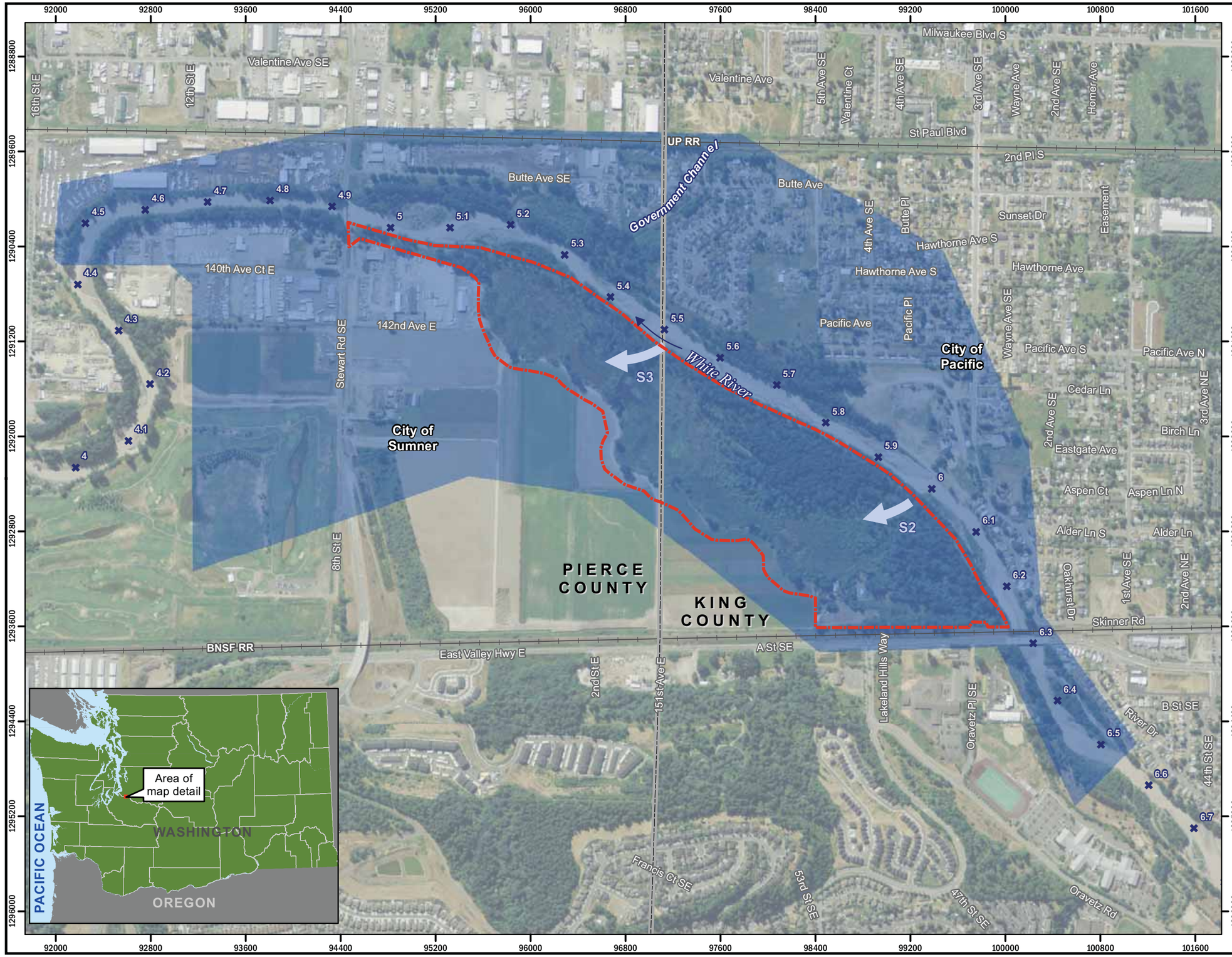

Figure 1.
Vicinity map of the White River at Countyline project site and study area.

Legend

- Project site
- Hydraulic modeling domain boundary and study area
- County boundary
- Railroad
- River mile
- Potential avulsion point for indicated scenario (S3)

N

0 400 800 1,600 Feet

HERRERA

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 a series of previous documents, including Herrera (2011a, 2011b, 2012a, 2012b). Updates to the approach outlined in those documents 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, a water surface elevation or an elevation-discharge rating curve at the downstream end of the computational mesh, and a topographic surface over which the flows are run. The boundary conditions and other input data developed for the project models are described in this section. Figure 1 shows the RiverFLO-2D model domain, along with many other key locations discussed in the following sections.

Modeling Overview

The software used to perform hydraulic modeling for this project is RiverFLO-2D Version 99g. 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 features of interest in complex river environments. RiverFLO-2D has been applied on a number of river projects worldwide, including several in King County. RiverFLO-2D uses the shallow-water equations for depth-averaged free surface flow that allow simulation of 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.

Modeling Approach

To achieve the project objectives described above, Herrera and King County defined a series of scenarios and timeframes that would simulate the range of conditions both due to the project and in the absence of the project. Because of the inherent stochastic nature of river channel development and avulsion, it is impossible to predict accurately and consistently the path of the river beyond a single flood event. Each scenario refers to an assumed set of circumstances that are tracked through time. Because of this, the earlier model results guide the determination of the next surface in time, but necessarily confine the results to the preceding scenario assumptions.

Topographic Surfaces

The hydraulic simulations differed by the topographic surface used. The basic approach to defining the surfaces for the first subset of scenarios (i.e., those intended to simulate existing conditions and conditions immediately following construction of the project – simulations with suffix of "a" in Table 1) is straightforward. In these simulations, a single surface, observed in April 2011, was used for the S4a (existing conditions) simulations. The proposed conditions are based upon an alteration of that surface to reflect the proposed changes represented by the 40% complete project design plans and design refinements that included extending the setback levee north to the BNSF railroad and increasing the levee crest elevation. It is important to note that alterations to the landscape within the model domain, extending approximately from RM 4.4 to 6.7, may have occurred following April 2011, but these were not incorporated into the modeling described herein. Bridges and piers were not included in the topographic surface; only the openings under the bridges were included in the modeling. In the remainder of this report the word "bridge" is used to refer to the opening only.

Table 1. Summary of the Preliminary Hydraulic Modeling to be Performed.

	Year Zero [a]	Short-term [b]	Fully Evolved [c]	Service Life [d]
Existing Without Project (S4)	**S4a**	**S4b**	**S4c**	N/A
Existing With Project (S1)	**S1a**	**S1b**	**S1c**	**S1d**
Full Avulsion (S2)	N/A	**S2b**	N/A	N/A
Avulsion at County Line (S3)	N/A	**S3b**	N/A	N/A

[a] Time immediately following construction for scenarios simulating effects of project construction

[b] Approximately 3 years following construction

[c] 13.8 years following the construction of the project when the main channel under existing conditions is expected to completely fill to the height of the existing levee

[d] Assumes an approximately 30 year service life

N/A = Runs will not be performed because they are not applicable or not appropriate

The next set of simulations (i.e., the simulations with a suffix of "b" in Table 1) are intended to represent conditions 3 years following construction or 3 years of sediment aggradation upon the 2011 surface assumed to occur without the project. These are summarized in detail in Herrera (2012a). All of these topographic surfaces use the same initial surface from the suffix "a" simulations as a base, and were developed using the proposed approach summarized in Herrera (2012a) for this time period shortly following construction.

As mentioned in Herrera (2012a), the scenario S4b simulations assumed that historical sediment accumulation rates would continue to occur in the river channel to a similar extent in the future. In practice this meant the addition of a fixed amount of channel bed elevation increase to simulate future sediment deposition. As mentioned and described in Herrera (2012b), the deposition rate was assumed to be approximately 22,000 cubic yards per year. The addition was ramped down at its edges to ensure a realistic transition to the channel banks, while preserving the total sediment volume added. The same amount was added both upstream of the A Street Bridge and downstream of the Stewart Road SE Bridge to ensure that there were no unrealistic knickpoints formed in the stream profile. In addition to the in-channel sediment accumulation, accumulation was also assumed to occur in the large wetland area east of the existing left bank levee in a similar manner as has been observed in

recent lidar flights (Herrera 2012a). That is, deposition is presumed to occur in classic deltaic style where accumulation rates are greatest at the delta front and diminish to zero on the delta top and at the toe of the delta front. Again, the total volume of accumulation was kept identical to observed accumulation in the past.

For the scenario S1b simulations, the pattern of geomorphic change was predicted as part of a geomorphic assessment (documentation in preparation at the time this memorandum was written). From the geomorphic analysis, it was determined that a partial avulsion of the main channel into the wetland is the most likely scenario following removal of the existing levee. If such an event occurs, the channel complex will form a splay deposit first and then re-incise into that splay to create a new channel network. As described in Herrera (2012a) and observed at a levee setback site along Hansen Creek in Skagit County, Washington (Mostrenko et al. 2011), it is assumed that the splay will capture all of the bedload (both coarse material and a small fraction of the sand load) entering the floodplain immediately following levee removal. It is further assumed that the splay will also include the volume of sediment eroded from up to 2 feet of scour anticipated between the downstream end of the remaining left bank levee and the A Street Bridge.

The scenario S1a model results indicate that approximately half of the flow will leave the channel in all of the flood events (i.e., 2-year, 100-year, and 500-year). Sediment transport is assumed to be partitioned the same as flow. Therefore, the model surface for scenario S1b assumes 10 percent of the sand that enters the left bank wetland will deposit there because much of it will simply pass through the area. It is assumed that sand and coarse bedload will also be trapped at observed historical rates for the proportion of the flow that remains in the existing channel.

Proposed Fully Evolved Simulations

Unlike the suffix “b” scenarios, the methodology to simulate conditions beyond 3 years following construction is not described in Herrera (2012a). The scenario S4c surface was generated assuming a continuation of existing sediment trends documented at the project site (Herrera 2012a). This is defensible because the time period calculated is so short. Typically substantive geomorphic change occurs over much longer time periods (i.e., decades). The time selected (13.8 years) is the length of time for the thalweg elevation to reach the levee height at the current overtopping point at the county line. Once the thalweg elevation is the height of the levee, a full avulsion will have taken place and substantive geomorphic change will occur (Figure 2).

In order to simulate the fully evolved, most likely proposed conditions (scenario S1c), several more assumptions about the dynamics of the system must be made. These were made following review of the results from the scenario S1b simulations. These results helped lead to the following assumptions (Figure 3):

- 70 percent of the coarse sediment reaching the project site will be retained there, both in the new left bank floodplain channel network and in the existing main channel.

- A new splay deposit will form downstream of the location where flow in the existing channel splits into the left bank floodplain wetland (at approximately RM 5.7) based upon the results of the scenario S1b simulations.
- Sediment transport is assumed to partition the same as flow.
- 40 percent of the river flow will enter the new setback floodplain channel network, 50 percent will remain in the existing channel, and 10 percent will flow through the floodplain between the two (existing and new) main channels (taken from the scenario S1b, 2-year event).
- All of the bedload material that enters the setback floodplain will be deposited in the first 3 years following construction.

The proposed conditions, fully evolved simulations (S1c) also used a specially designed method to predict the amount of sand that will deposit in the floodplain. The process to estimate the sand accumulation volume in the wetland is described in detail in a separate memorandum (in preparation at the time this memorandum was prepared). In short, the process estimates the sand delivered to the floodplain based upon the scenario S1b results and historical sand deposition rates in the right bank constructed wetland complex immediately downstream of the King/Pierce county line. Because this approach is fundamentally event-based, the sand flux estimates are also event based. The flood events that were assumed to occur in the 13.8 years following construction are:

- A 48-hour-long, 10-year recurrence event
- A 48-hour-long, 12,000 cfs event, somewhat similar to the January 2009 flood event (which peaked at approximately 12,400 cfs at the project site)
- A 48-hour-long, 2-year recurrence event
- Five days each year with discharge of 8,000 cfs
- Four days each year with discharge of 6,000 cfs

Future Simulations

Because it is assumed that the fully evolved channel and floodplain scenario will be complete in 13.8 years, King County is interested in estimating the levee height needed to contain floodwaters for its entire service life. The County determined that a practical service life, given the design constraints, is approximately 30 years, at which time available levee freeboard above the 100-year flood water surface elevation may begin to decrease. The methodology for assessing the necessary levee height was identical to the fully evolved simulations, meaning that the trends estimated between 3 and 13.8 years were assumed to continue to occur until the service life is complete. The results of this simulation will be summarized in the final hydraulic modeling memorandum to be prepared for the project.

In addition to the service life simulation, two design scenarios will also be performed that maximize the velocities at the proposed engineered logjams in the left bank floodplain. Because these scenarios are for design purposes, they will not necessarily follow the same

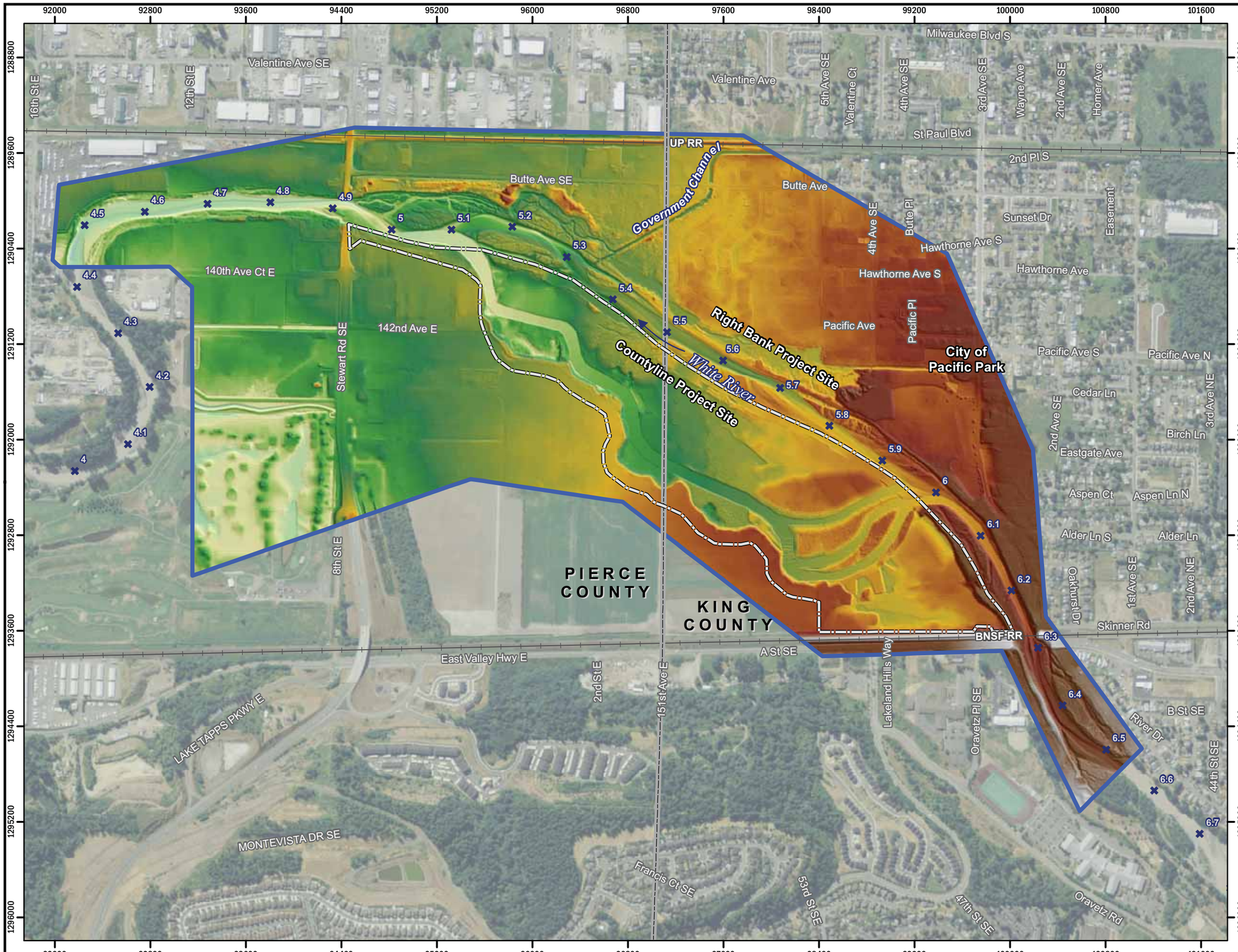

Figure 2.
Channel network assumed to form in the three years following construction of the project

Legend

- Project area
- Hydraulic modeling domain boundary and study area
- County boundary
- Railroad
- River mile

Elevation (ft)

- High : 104.836
- Low : 54.3561

N

0 400 800 1,600 Feet

HERRERA

Aerial: USDA (2009)

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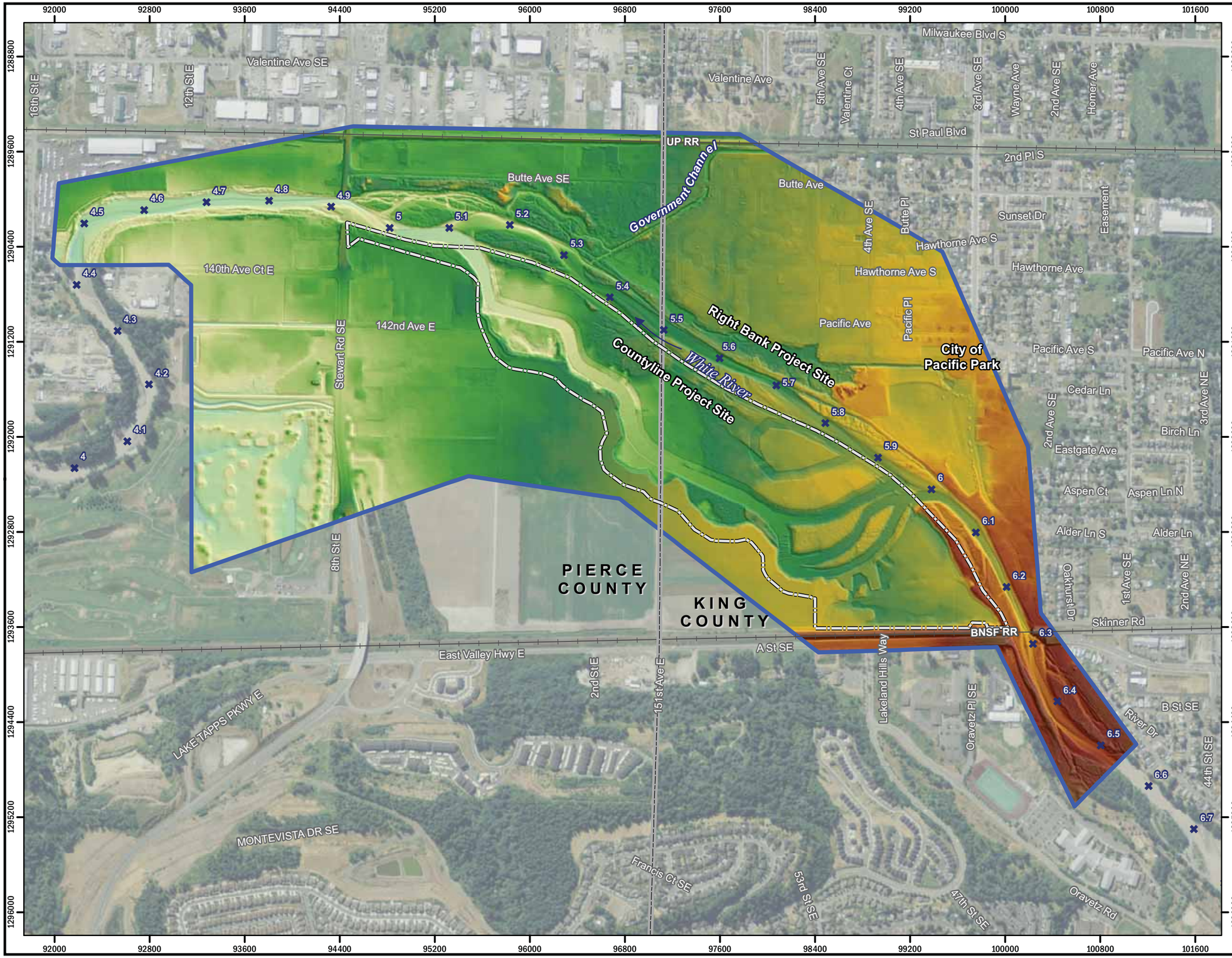

Figure 3.
Channel network and deposition assumed to occur in 13.8 years following construction of the project

Legend

- Project area
- Hydraulic modeling domain boundary and study area
- County boundary
- Railroad
- River mile

Elevation (ft)

High : 120

Low : 55.0456

N

0 400 800 1,600 Feet

HERRERA

Aerial: USDA (2009)

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strict procedures to calculate the time required for the associated surface to form following construction. Rather, it is assumed that the altered channel and floodplain surface will be formed due to large woody accumulations that are much more stochastic in nature.

Boundary Roughness

Roughness that slows flood flows is a key component to any hydraulic model, although changes in roughness manifest as changes in water surface elevations to a lesser extent in two-dimensional models than they do in simpler one-dimensional models such as HEC-RAS. For all of the scenario S4 simulations, the roughness was delineated in the same manner as in earlier hydraulic model calibration work (Herrera 2011a). For the scenario S1 simulations, all of those areas that were delineated as channel features were assigned a Manning's "n" value of 0.025. The Manning's "n" values in areas of assumed splay deposits and in other overbank floodplain areas were not changed compared to existing conditions in the scenario S4 simulations.

Upstream Boundary Condition

The upstream boundary condition is set by hydrographs developed in earlier phases of the project. For the purposes of permit application submittals and determination of basic project design geometry, a subset of simulations was performed. It was determined that simulation of the mean annual flow (1,740 cubic feet per second), 2-year, 100-year, and 500-year recurrence flood events would sufficiently reveal all of the off-site impacts that may occur due to the project construction for environmental documentation and permitting purposes, while also identifying basic design constraints (e.g., the height of the setback levee). All of the simulations are unsteady. The hydrograph used for mean annual flow is held constant through time. The hydrographs for the other flood events (i.e., 2-year, 100-year, and 500-year recurrence events) are based upon historical events described in detail in Herrera (2011a). Hydraulic modeling of the 10- and 50-year recurrence events will eventually be performed for the project. These results will be summarized in a future memorandum.

Downstream Boundary Conditions

There are two separate downstream boundary conditions for the model. The first and primary (for most of the simulations) downstream boundary condition is in the main channel at RM 4.4. This boundary condition is a rating curve derived from HEC-RAS model simulations at this location, which were performed for updated floodplain mapping purposes. The rating curve is described in depth in Herrera (2011a). In sum, it is capable of accurately depicting high water marks across the project site under existing conditions. Very close to this boundary condition care should be taken to not over-interpret the model results since the existing conditions HEC-RAS model is not capable of simulating dynamic hydraulic conditions where flow has a component that is parallel to the downstream boundary, as occurs there during times of high flow.

Flow over Stewart Road SE leaves the model domain outside of the channel. As a result, it was necessary to establish a new downstream boundary condition to regulate flow in this area. Because very little is known about how flow will leave and reenter the main channel in

this area, the boundary condition in this area was kept simple. It assumes a fixed water surface elevation along the boundary that increases for the size of the event (e.g., 63 feet in the 2-year event, 65 feet in the 100-year event, and 66 feet in the 500-year event). This boundary condition, and the need for it, is described in detail in Herrera (2011a).

Many of the simulations are intended to predict conditions where sediment deposition will not be uniform across the downstream boundary. Presumably this altered topographic surface will alter the fraction of flow remaining in the channel. As a result, a sensitivity analysis was performed on both the water surface elevation adjacent to the left bank levee and other key design variables. The results of this sensitivity analysis are summarized in the Quality Control subsection of this memorandum.

Lateral Boundary Conditions

Though the model domains in all of the scenarios are identical, the right bank protection was modeled differently in different scenarios. The without project scenario (S1) only had the existing HESCO revetment included, while the with-project scenarios (S2, S3, S4) had an extremely high levee that precluded all flow over it.

Initial Modeling Results

This section presents the results of the hydraulic modeling completed through July 2012, using the methods described above. The discussion of hydraulic modeling results includes the results from 6 of the 10 scenarios described in Herrera (2012a) and summarized in Table 1. The six scenarios represent existing conditions and most likely (based on expert interpretation) proposed conditions immediately following construction, 3 years following construction, and fully evolved conditions, which are forecasted to be in effect about 13.8 years following project construction. They also represent the most probable conditions without the project for the same timeframes (S4b and S4c).

Previous model simulations on earlier topographic surfaces and for earlier engineering design plan configurations are summarized in Herrera (2011b, 2012b). Those results found that increasing topographic surface mesh density lowered the modeled water surface elevations and more closely simulated observed conditions. That documentation also recommended several model mesh refinements:

- Greater mesh resolution and two closely spaced breaklines on the left bank levee to prevent short circuiting of water to the wetland
- Greater mesh resolution and the placement of a series of single breaklines in the vicinity of the Butte Avenue SE crossing of Government Channel
- Greater mesh resolution along the eastern edge of the left bank wetland
- A breakline and greater mesh resolution along Stewart Road SE on both sides of the bridge over the White River
- Two closely spaced breaklines on the BNSF railway alignment
- A breakline on the top of the Auburn Riverside High School revetment on the left bank upstream of the A Street Bridge

All of these recommendations were implemented and broadly improved the performance of the model and the accuracy of the original model calibration.

Year-0 ("a") Simulations

The existing conditions simulations without the project are summarized in Figure 4. These simulations can be compared to the simulated conditions immediately following construction based upon the topographic information extracted from the 40% complete design plans and the design refinements described earlier in this memo (Figure 5). Figure 6 provides a detailed map of the differences between existing (scenario S4a) and proposed conditions (scenario S1a) for the 100-year flood event. Large areas behind the proposed levees that are outside of the proposed-conditions model domain show a reduction in depth differences

(negative values in Figure 6) but are actually simulated as dry under proposed conditions following construction because they are isolated by the proposed facilities. These areas depicted in Figure 6 (and in forthcoming figures showing inundation differences) include residential, commercial and light industrial areas in the City of Pacific outside of Pacific City Park and agricultural and light industrial areas south of the wetland restoration property in Pierce County.

As can be seen in Figures 4, 5, and 6, the model indicates that the primary impact of the project will be lowered flood water surface elevations along the right bank in the City of Pacific. Localized flood height reductions are predicted to be up to 5 feet for the 100-year event in the vicinity of Pacific City Park immediately following construction of the project. Similarly, the model predicts lowered water surface elevations in these same locations in the 2-year flood event, but to a lesser magnitude.

Downstream of the westward turn in the proposed new levee just south of the county boundary line (i.e., 1,200 feet upstream from the Stewart Road SE Bridge), the model predicts an increase in flood water surface elevations primarily because the setback levee will prevent flow from overtopping the left bank wetland area and Stewart Road SE. The additional flow contained by the setback levee relative to existing conditions (which allows overland flow to leave the wetland area) will also increase flow velocities in this area. These increased water surface elevations are localized in the vicinity of the Stewart Road SE Bridge, and the increases vary, though on average they are predicted to be about 1 foot upstream of the Stewart Road SE Bridge and less than 0.5 feet downstream of the bridge in the timeframe immediately following construction compared to existing conditions. Local perturbations in the proposed model output (and the mottled appearance seen in Figure 6) are a modeling artifact associated with numerical stability, which can lead to larger (greater than 1 foot) single-point differences. Increases in flow velocity in this area will also likely mean that there will be increased scour at the bridge during large floods. It is important to note that this scour effect was not included in the channel/floodplain topographic surfaces used for later simulations (i.e., suffix “b” and “c” simulations).

As noted previously the proposed conditions simulation (scenario S1a) did not alter the Manning’s “n” values used to represent hydraulic roughness in the left bank floodplain wetland. Therefore, the left bank wetland serves as passive storage and the model results indicate very small flow velocities throughout the wetland area. A full discussion of the sensitivity of the model to boundary conditions and other input parameters in provided in the *Quality Control* section below.

Year-3 (“b”) Simulations

The existing conditions simulations without the project and assuming historical sediment accumulation patterns over the course of 3 years (scenario S4b) are summarized in Figure 7. These simulations can be compared to the most likely proposed conditions (scenario S1b), assuming a partial avulsion of the main channel network to the lowest area of the left bank floodplain wetland (Figure 8). Figure 9 provides a detailed map of the simulated differences between existing conditions (without project) and the most likely proposed conditions for the 100-year flood event.

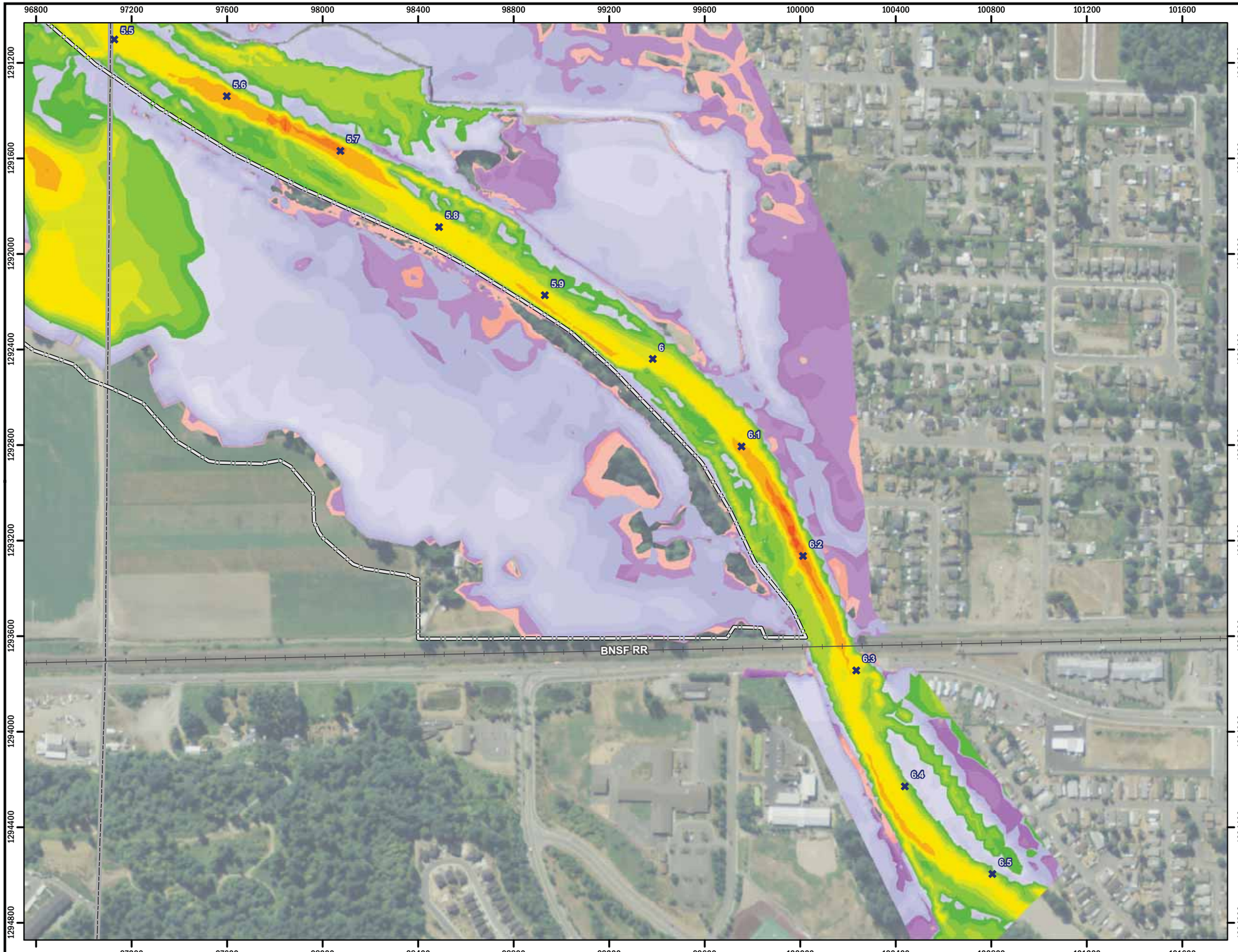

Figure 4. Sheet A.
Existing conditions depth of inundation and flooding extent without the project (S4a).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

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Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\existing_s4a.mxd (10/4/2012)

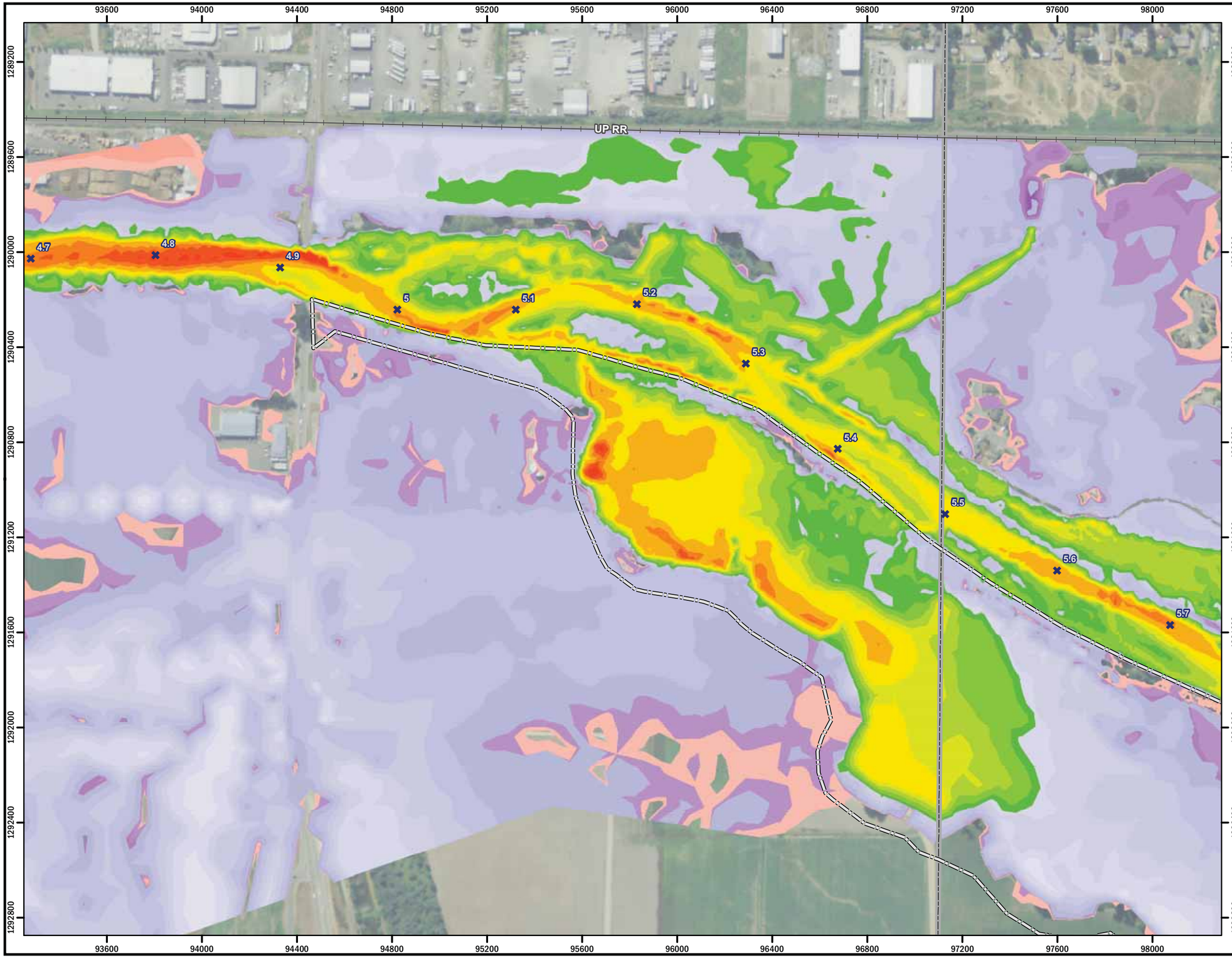

Figure 4. Sheet B.
Existing conditions depth of inundation and flooding extent without the project (S4a).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\existing_s4a.mxd (10/4/2012)

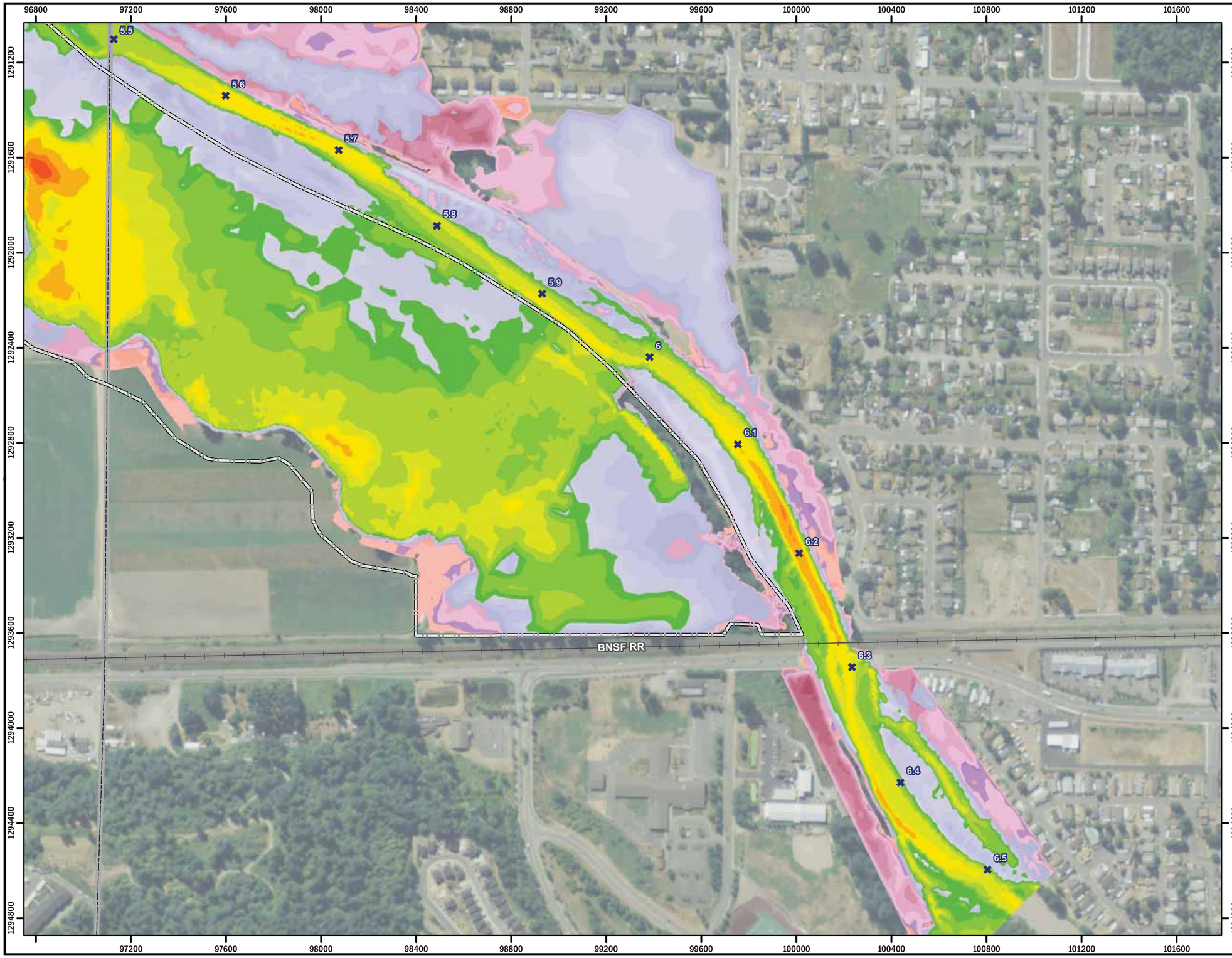

Figure 5. Sheet A.
Proposed conditions depth of inundation immediately following construction (S1a).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 10-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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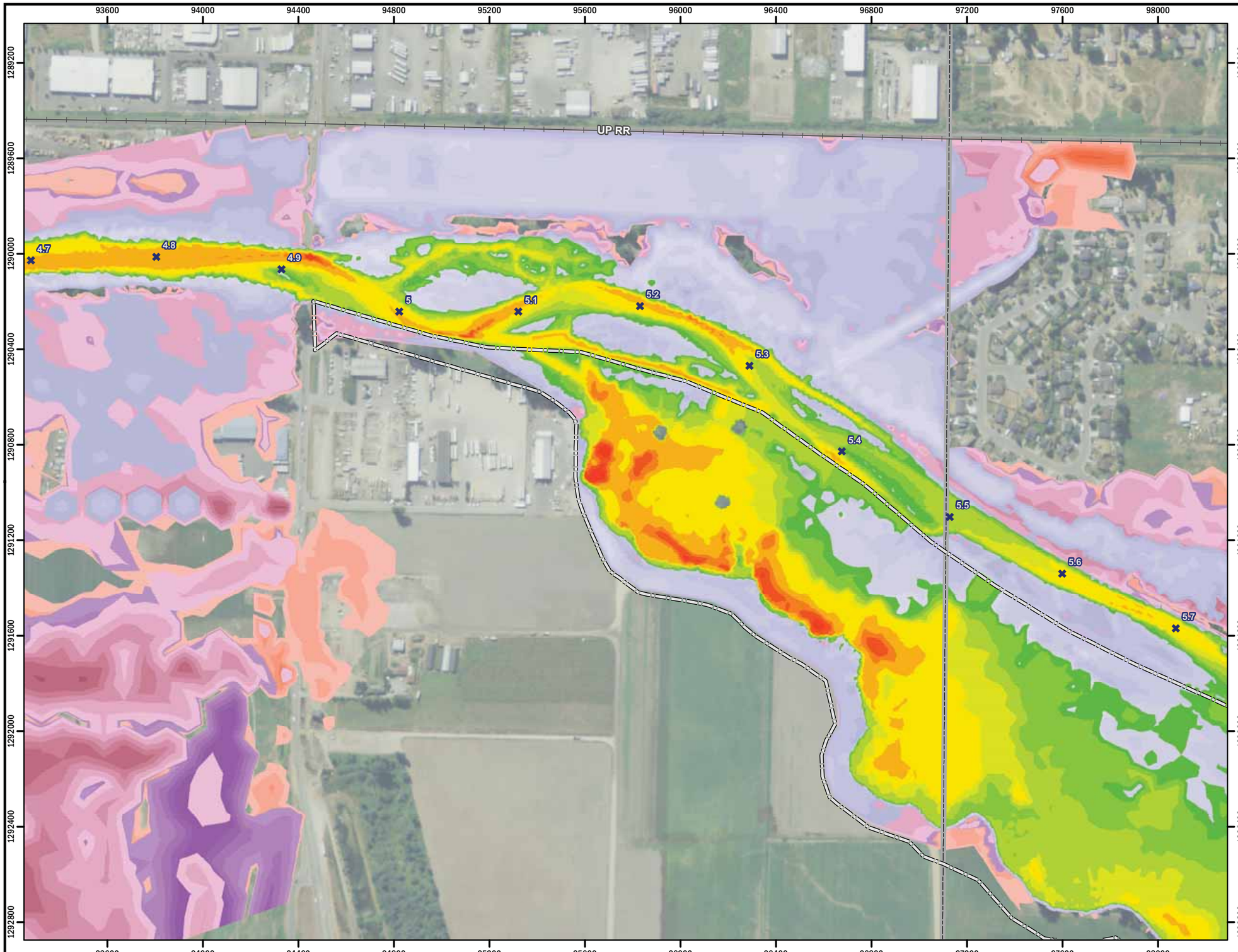

Figure 5. Sheet B.
Proposed conditions depth of inundation immediately following construction (S1a).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 10-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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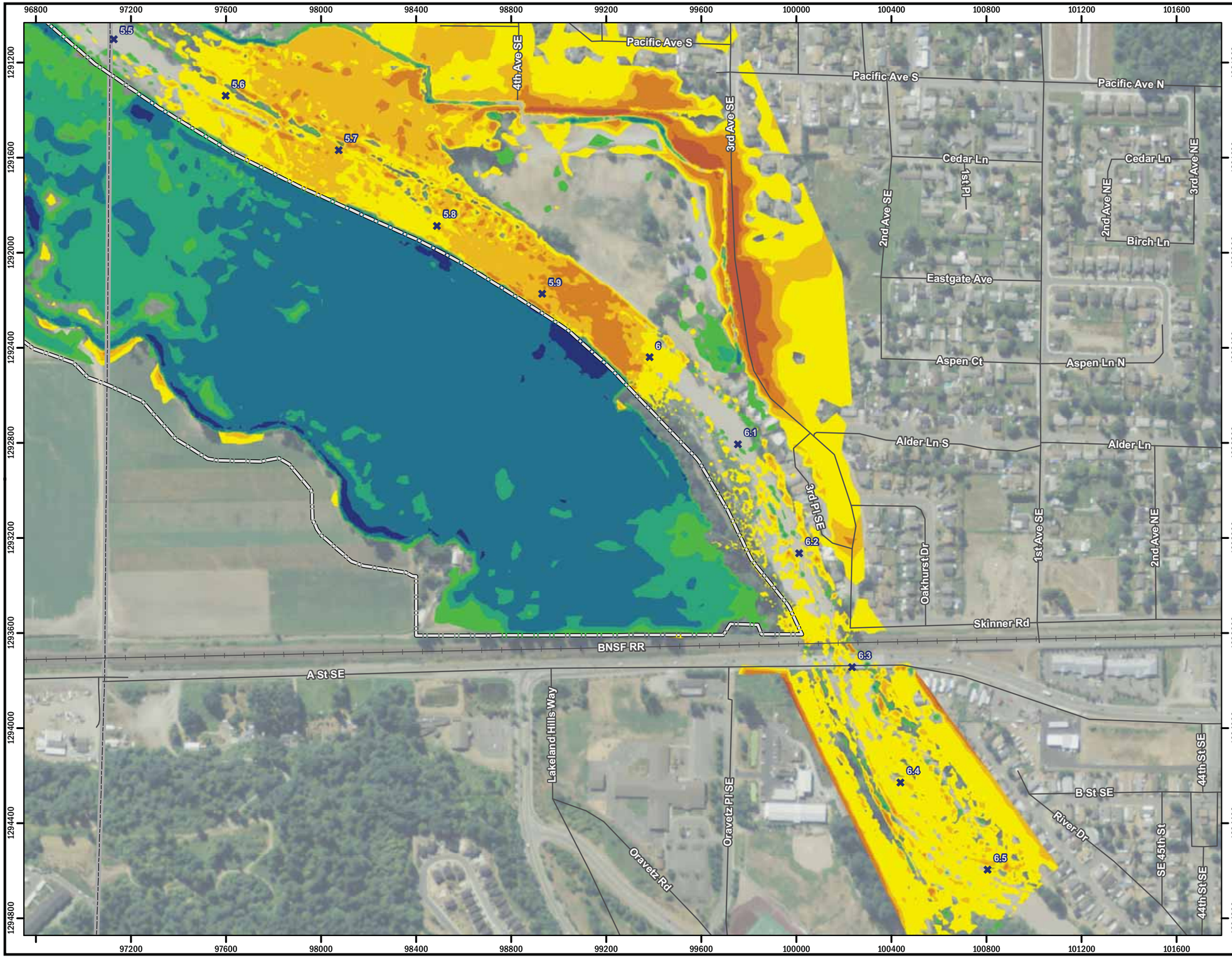

Figure 6. Sheet A.
Inundation difference for the 100-year flood event between existing and proposed conditions immediately following construction (S4a-S1a).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
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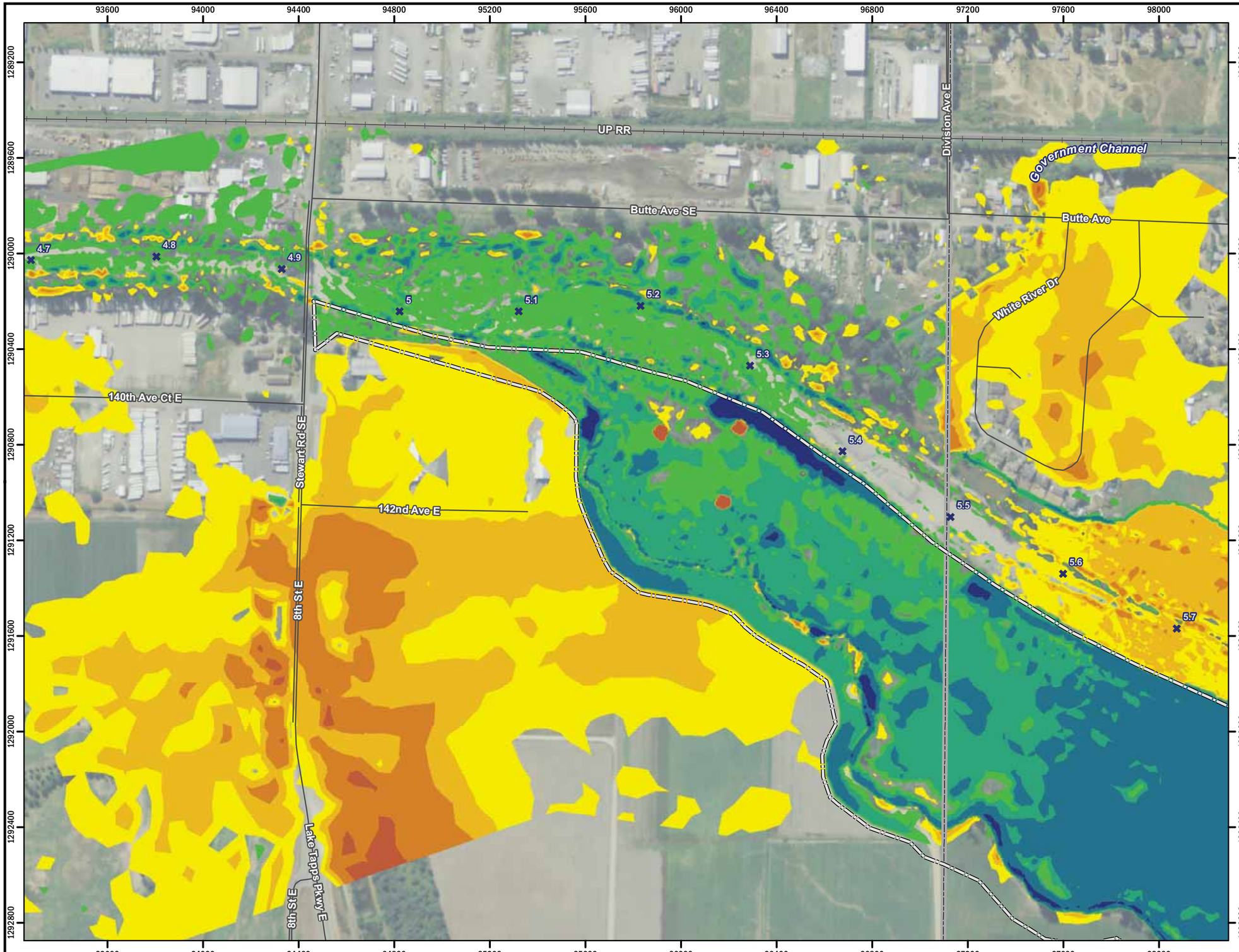

Figure 6. Sheet B.
Inundation difference for the 100-year flood event between existing and proposed conditions immediately following construction (S4a-S1a).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
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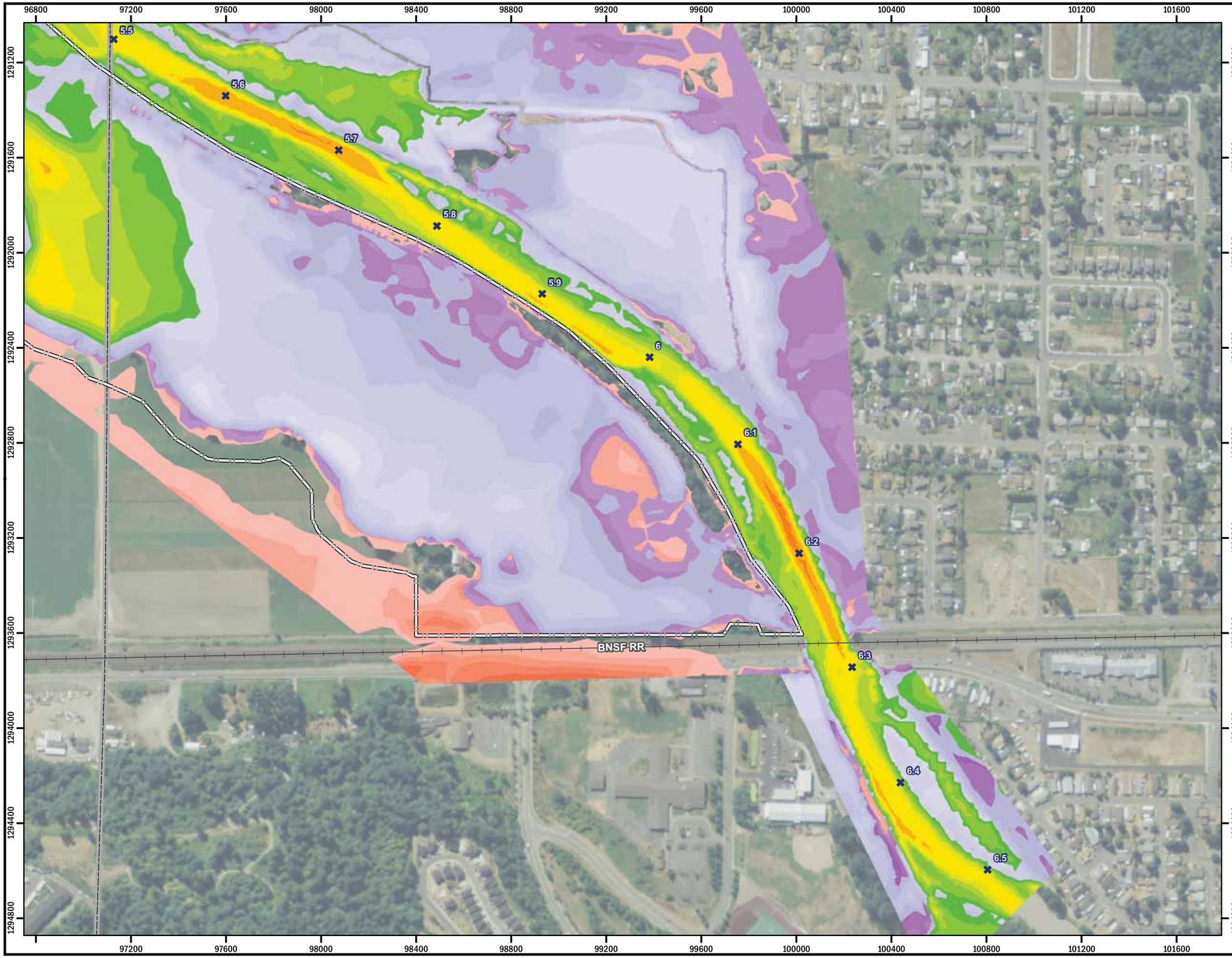

Figure 7. Sheet A.
Existing conditions depth of inundation, three years in the future without the project (S4b).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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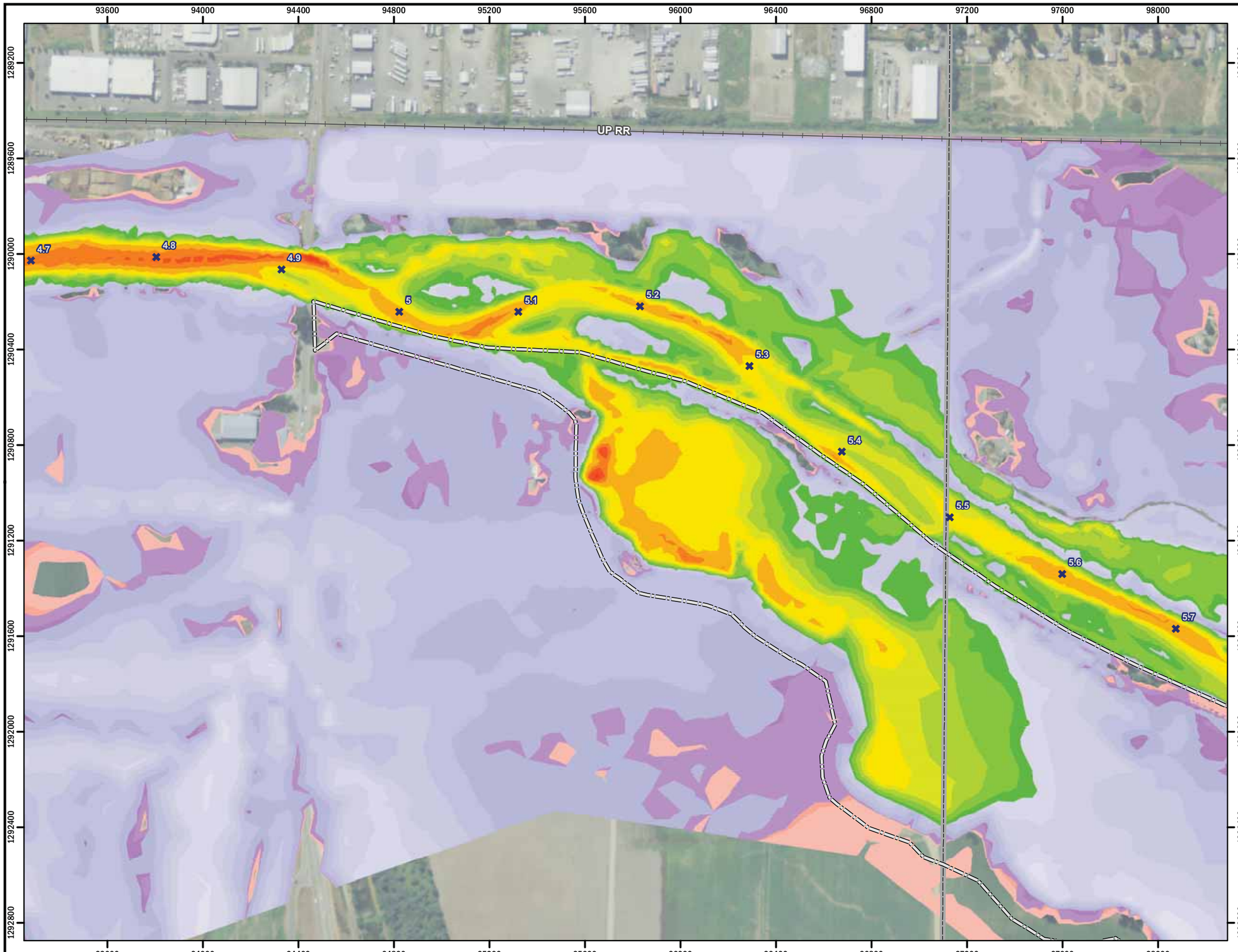

Figure 7. Sheet B.
Existing conditions depth of inundation, three years in the future without the project (S4b).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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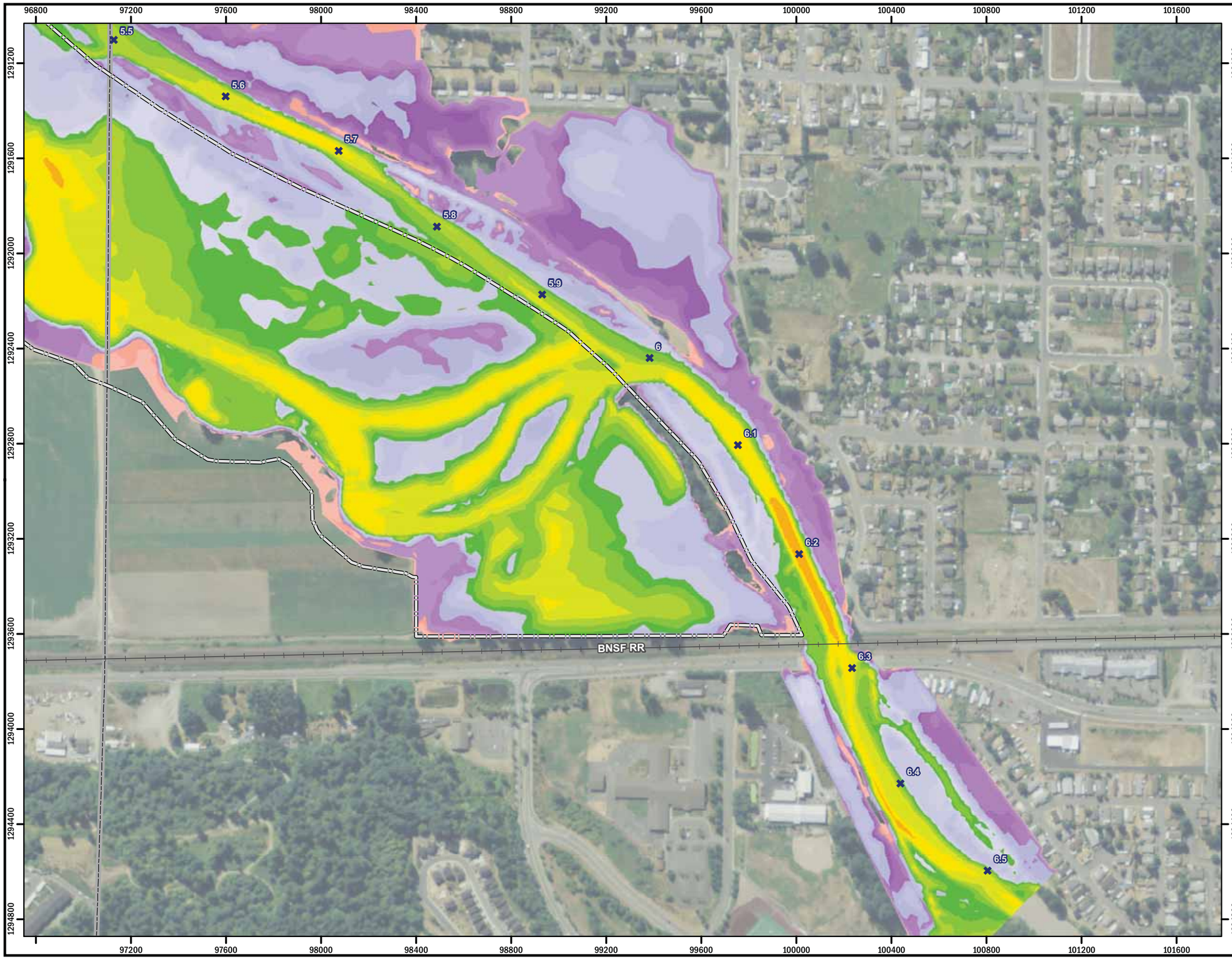

Figure 8. Sheet A.
Proposed conditions depth of inundation 3 years following construction (S1b).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\proposed_s1y3.mxd (10/4/2012)

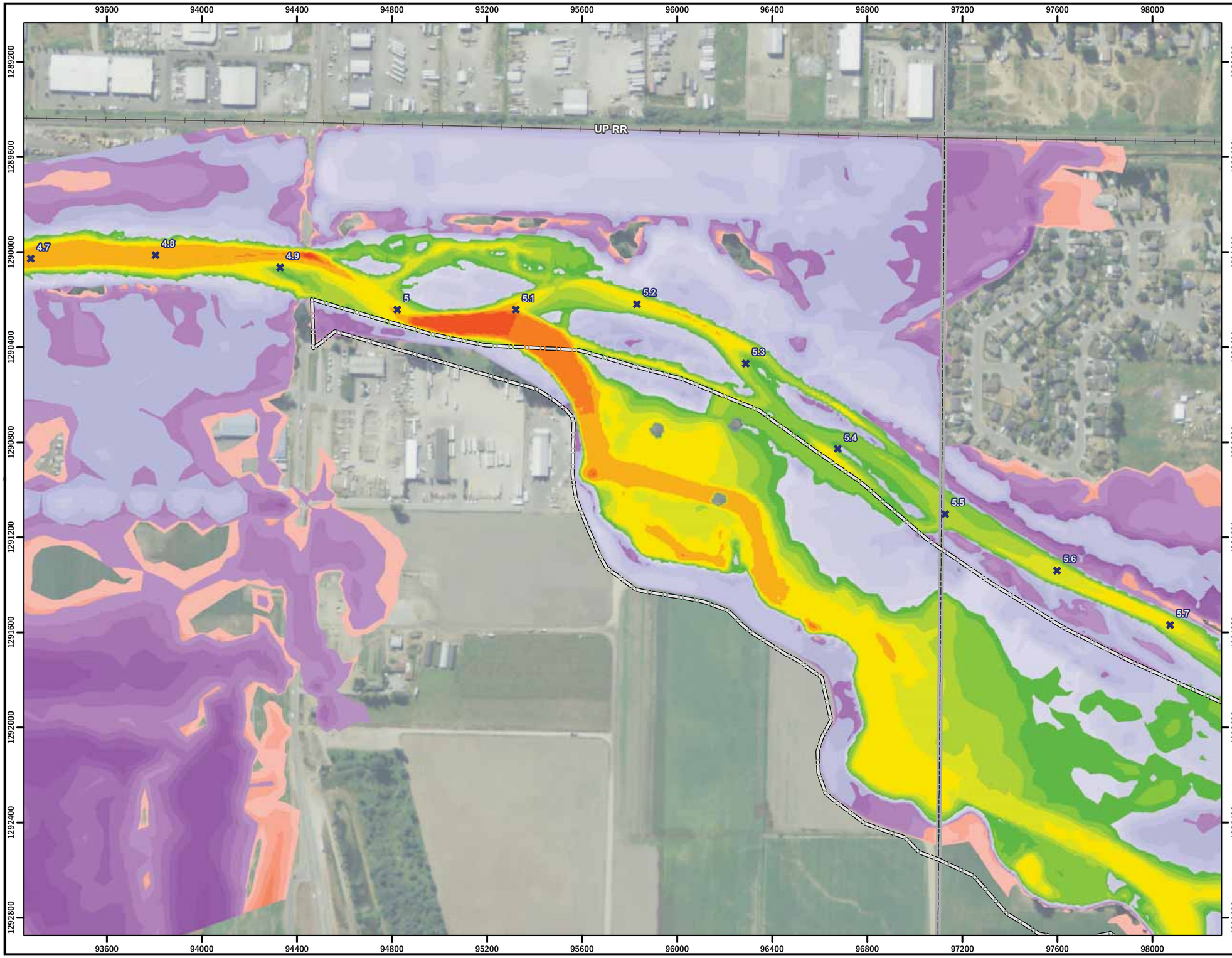

Figure 8. Sheet B.
Proposed conditions depth of inundation 3 years following construction (S1b).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\proposed_s1y3.mxd (10/4/2012)

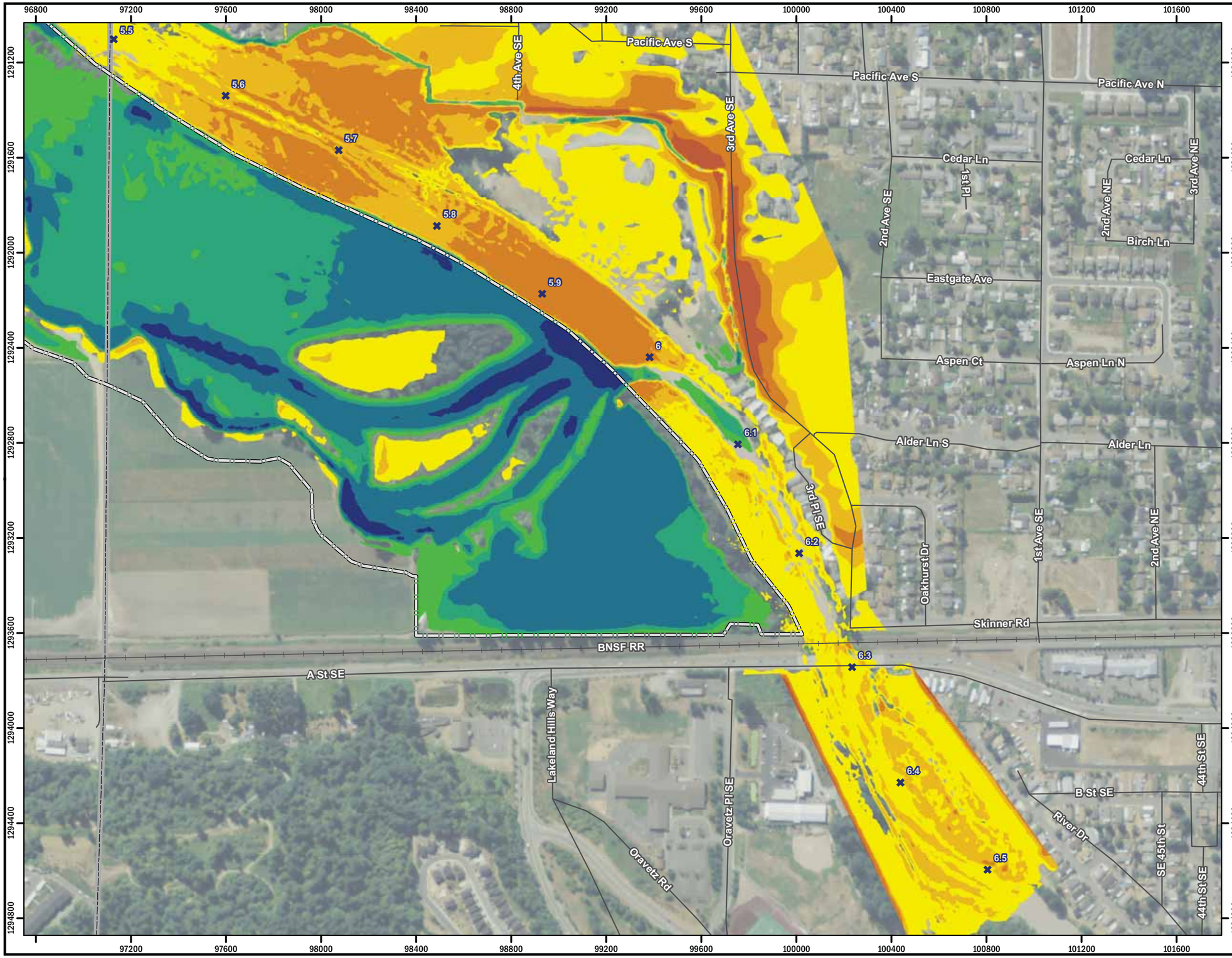

Figure 9. Sheet A.
Inundation difference for the 100-year flood event between existing and proposed conditions 3 years following construction (S4b-S1b).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\100-year_difference.mxd

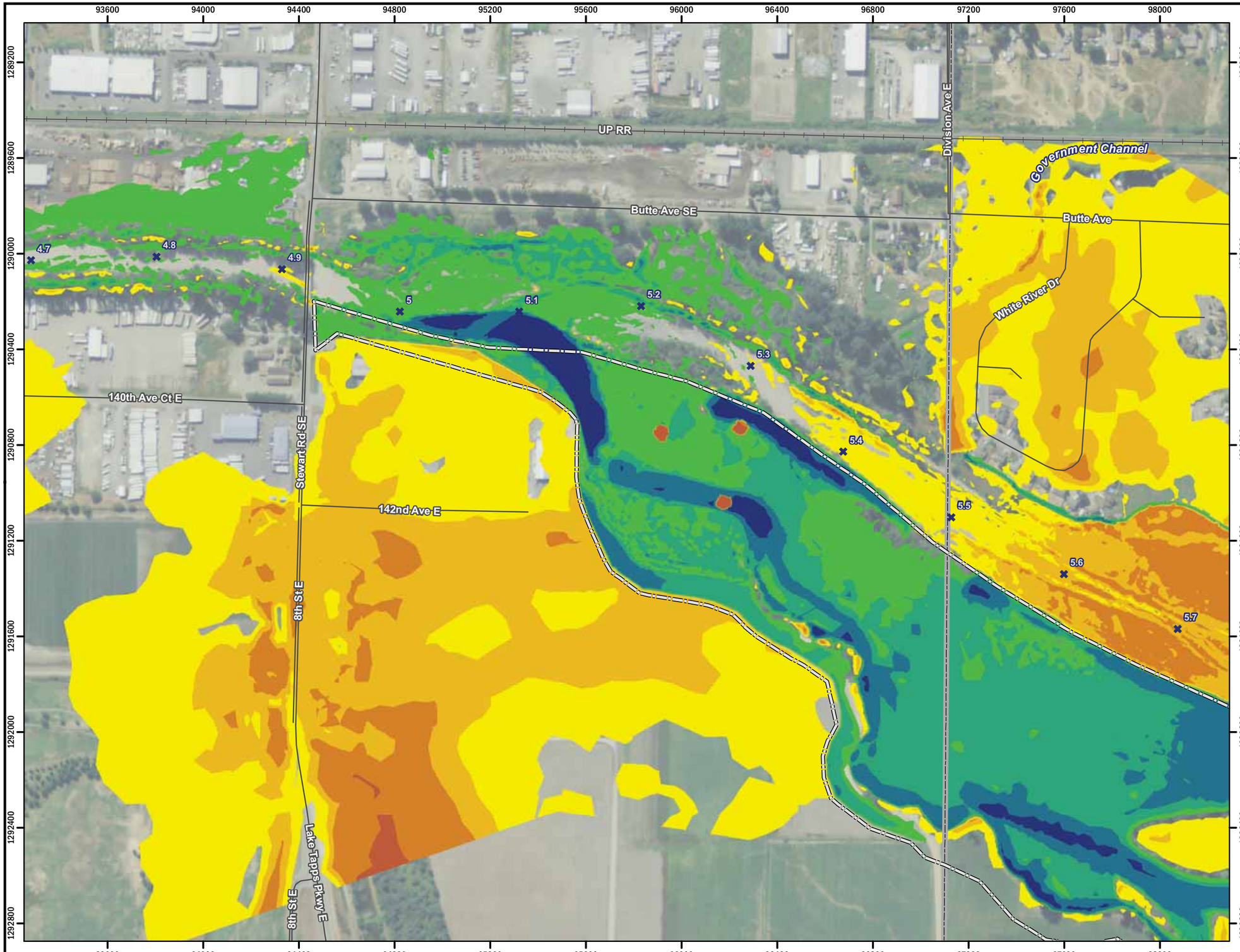

Figure 9. Sheet B.
Inundation difference for the 100-year flood event between existing and proposed conditions 3 years following construction (S4b-S1b).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\100-year_difference.mxd

Like the Year 0 ("a") simulations, the model predicts decreased water surface elevations for the 100-year flood event on the right bank in the City of Pacific, increased water surface elevations in the left bank floodplain wetland, and increased water surface elevations in the vicinity of the Stewart Road SE Bridge (roughly the same area as described in the *Year-0 ("a") Simulations* section above though the peak was shifted downstream somewhat). The reasons for these differences are similar to the reasons described above for the changes seen in the "a" simulations. Although the simulated flood elevations in the wetland restoration area between the river and Butte Avenue SE are projected to increase relative to future conditions without the project, this relative increase is less than the relative increase for the year 0 simulations.

Fully Evolved Channel and Floodplain ("c") Simulations

The existing conditions simulations for the "fully evolved" time period (scenario S4c) are summarized in Figure 10. The existing conditions fully evolved time period assumes complete filling of the existing river channel near the county boundary line. As expected these simulations indicate that a majority of the flow would leave the main channel, flow through the wetland and agricultural fields to the south, and overtop Stewart Road SE, even during mean annual flow conditions. These simulations can be compared to the equivalent conditions with the constructed project (scenario S1c) shown in Figure 11. As described in the methodology section above, the modeled topographic surface in scenario S1c includes a number of active channels and splays based upon the model results from the scenario S1a and S1b simulations. Finally, Figure 12 provides a detailed map of the differences between existing and proposed conditions for the 100-year flood event in the fully evolved channel and floodplain configuration.

The most significant impact predicted for the fully evolved floodplain under conditions without the project is that most of the flow, even for smaller flow rates like the mean annual flow, would continue over the left bank of the wetland, overtop Stewart Road SE, and exit the model domain in the left bank floodplain in the vicinity of the Sumner Meadows Golf Course. This presents significant geomorphic and flood emergency management risks. A partial or full avulsion of the White River along 142nd Avenue SE could occur rapidly in flood conditions and would likely cause substantial property damage to existing and future proposed development. The avulsion could also result in the loss of life, and would temporarily close Stewart Road SE until the river was diverted back under the Stewart Road SE Bridge and repairs to Stewart Road SE could be completed. Flood fighting actions to curtail overtopping or that route overbank waters away from left bank existing infrastructure would increase flood risks elsewhere, upriver or on the right bank. These flood fighting actions would have their own ramifications that would present a risk to all areas downstream of Stewart Road SE, even those properties on the right bank. A full discussion of the geomorphic ramifications of these results will be presented in a separate memorandum (Herrera 2012c).

Like the Year 0 and Year 3 simulations for proposed conditions (i.e., the S1a and S1b simulations), the model for fully evolved conditions predicts flood water surface reductions in developed areas along the right bank through the project site. The greatest reduction in 100-year flood water surface elevation is simulated (i.e., immediately post construction) to be over 5 feet near Pacific City Park. These reduced water surface elevations would be

compensated by water surface elevation increases in the left bank floodplain wetland. The model results for scenario S1c indicate that the wetland will be inundated almost completely even during mean annual flows. Flood height increases are also predicted in the vicinity of the Stewart Road SE Bridge, particularly 500 to 1,000 feet downstream of the bridge. It is important to mention that the existing results do not account for scour effects at the bridge. Model results indicate that the largest water surface elevation increases downstream of Stewart Road SE (absent other landscape or flood protection measures not modeled) will be in the river channel, with somewhat smaller increases in the overbank areas within existing flood hazard areas. As mentioned above, these effects are a direct result of prohibiting flow over Stewart Road SE in the proposed conditions, whereas for future conditions without the project, the majority of the river flow is predicted to overtop the road.

Quality Control

One of the fundamental tests of any hydraulic model is whether the model conserves mass (i.e., the mass of water entering the model domain equals the change in water storage and the mass of water leaving the model domain). There are many ways to assess mass conservation. The manner employed for this modeling effort calculated all fluxes along the domain boundary and then accounting for storage within the model. A summary of those calculations for all simulations presented in this memorandum is provided in Table 2. These results show that continuity degrades for larger flood events and for simulation time periods further in the future. The without-project simulations performed worse than the most likely proposed conditions simulations in terms of conservation of mass. The lack of continuity (generally less than 3 percent) for those simulations where the 2-year flood does not inundate the left bank floodplain indicates that the fixed water surface elevation in the left bank floodplain is the source of the continuity error.

The conservation of mass analysis summarized in Table 2 indicates that there is an imbalance between the imposed boundary condition and flow entering the left bank floodplain near the downstream boundary condition south of Stewart Road SE. Although the model is technically capable of solving for the flow exiting the model and rectifying this balance, previous results indicate that a free boundary condition (i.e., without a fixed water surface elevation) does not generate a numerically stable solution in most cases (Herrera 2011a). Therefore, modeling for this project should continue to employ a fixed boundary condition in the area where the mass conservation error occurs, but it is important to understand the extent of these errors.

It is known that the constriction at the Stewart Road SE Bridge could serve to hydraulically isolate much of the project site from the downstream boundary condition by serving as an independent hydraulic control point. For instance, the model results indicate a head loss of 3 to 4 feet at the bridge due to this construction. To test this hypothesis, a number of additional simulations were performed to determine the variability in water surface elevations associated with a change in downstream boundary condition for those simulations where the continuity error is the largest (i.e., scenarios S4c and S1c). Because one of the key design parameters is the water surface elevation along the setback levee (extending from the Stewart Road SE Bridge to the junction of the setback levee with the BNSF railroad embankment), the maximum water surface elevation was solved for in a number of simulations with varying downstream boundary conditions.

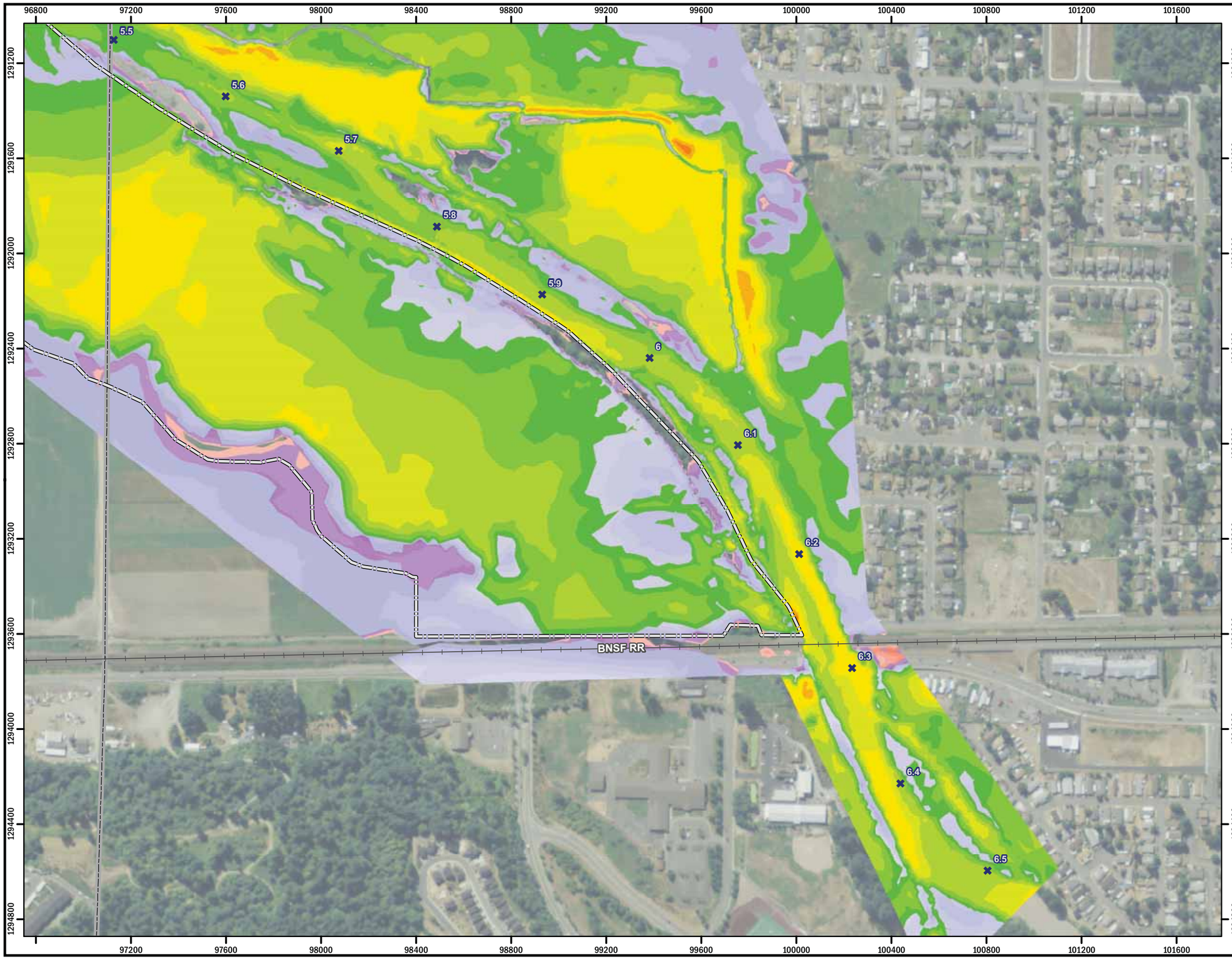

Figure 10. Sheet A.
Existing conditions depth of inundation 13.8 years in the future without the project (S4c).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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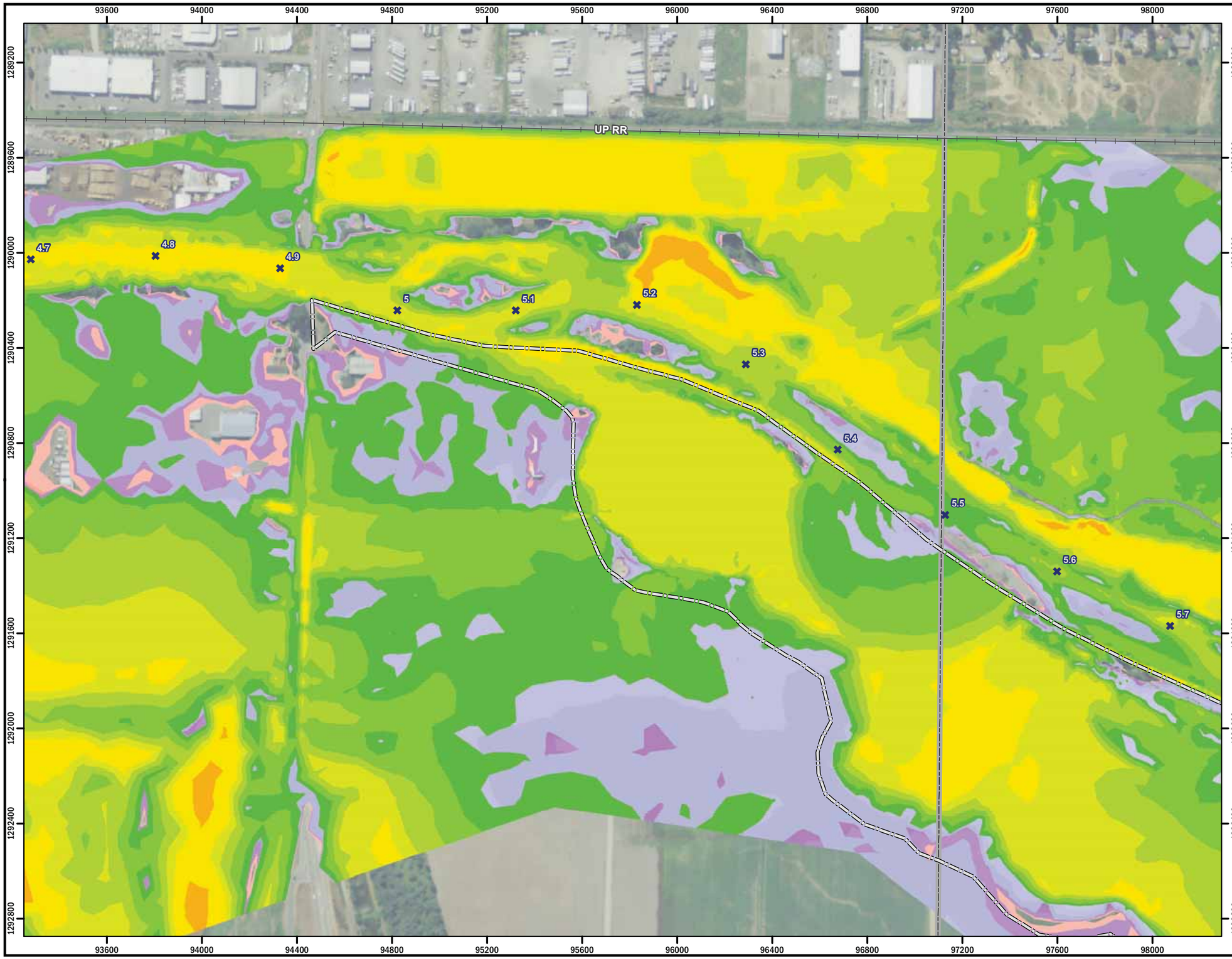

Figure 10. Sheet B.
Existing conditions depth of inundation, Year 13.8 without project (S4c).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\existing_s4b.mxd (10/4/2012)

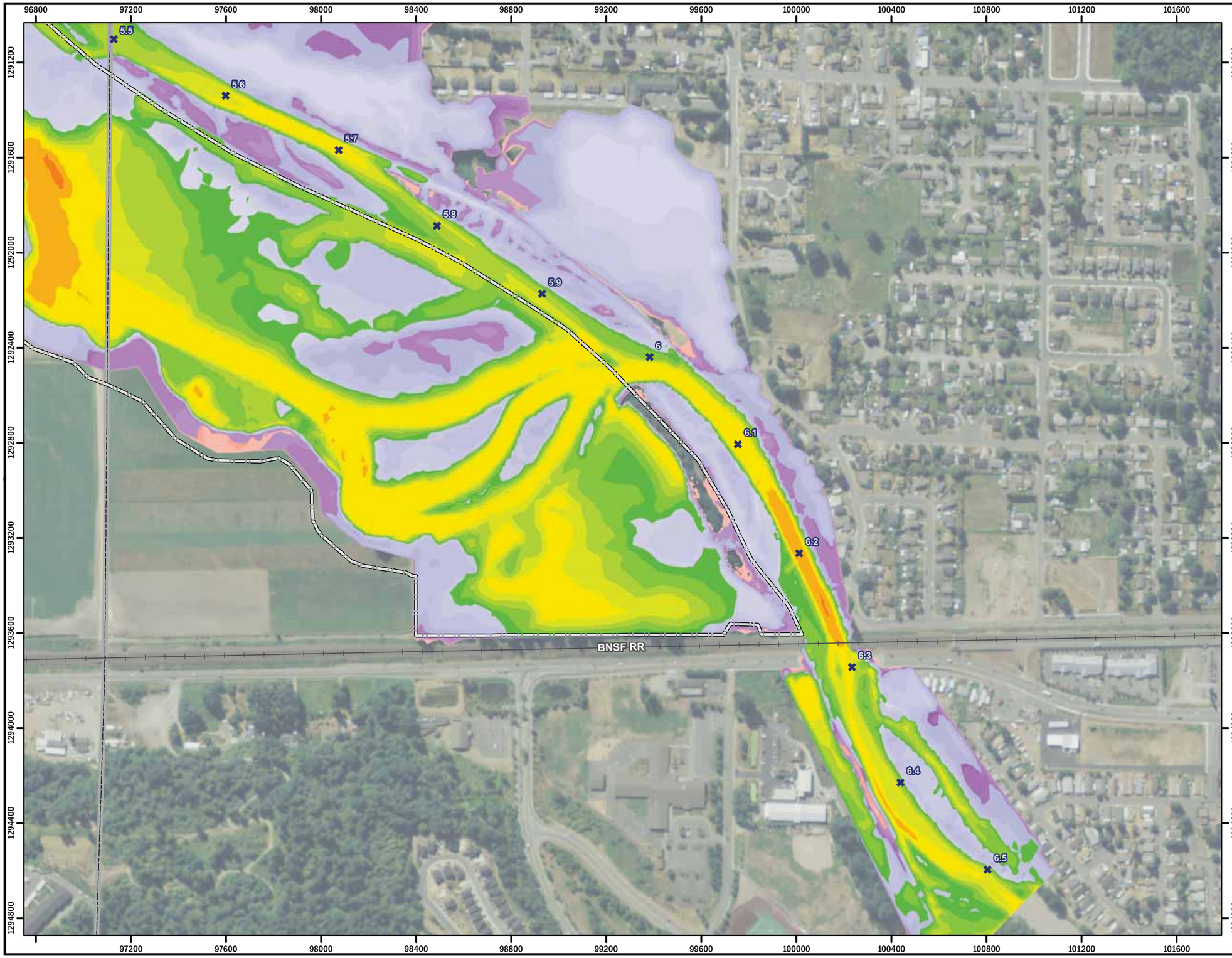

Figure 11. Sheet A.
Proposed conditions depth of inundation 13.8 years following construction (S1c).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
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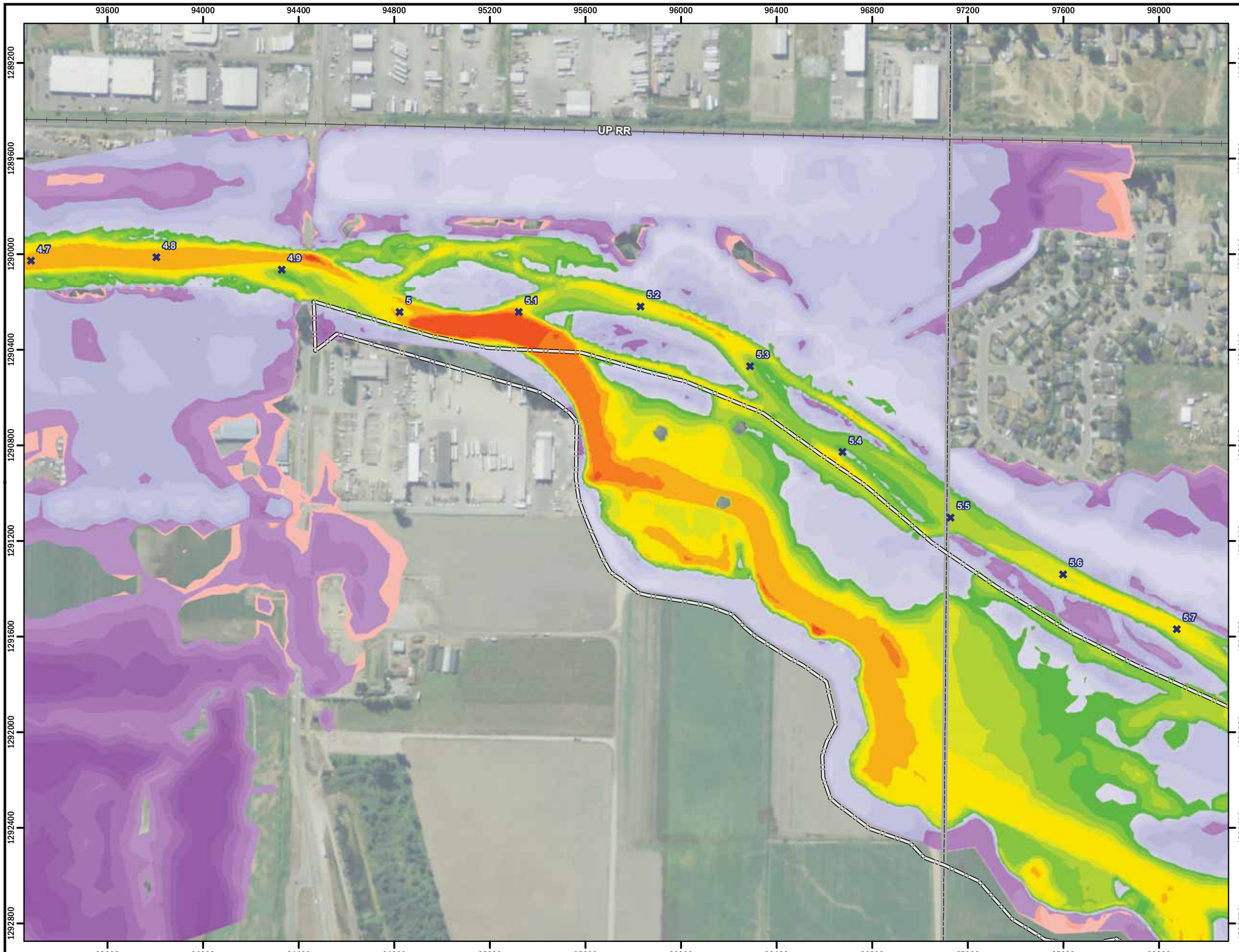

Figure 11. Sheet B.
Proposed conditions depth of inundation 13.8 years following construction (S1c).

Legend

- River mile
- Project area
- County boundary

Mean annual flow (1740 cfs) extent and depth of inundation (ft)

- 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 6
- 6 to 8
- 8 to 9
- 9 to 10
- > 10
- 2-year extent
- 100-year extent
- 500-year extent

Note:
Flow events are layered with the 500-year extent at the base and the mean annual extent at the surface (see legend order).

N

0 200 400 800
Feet

HERRERA

Aerial: USDA (2009)
Coordinates: NAD 1983 Washington State Plane North (ft)

Produced By: GIS
Project: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\proposed_s1c.mxd (10/4/2012)

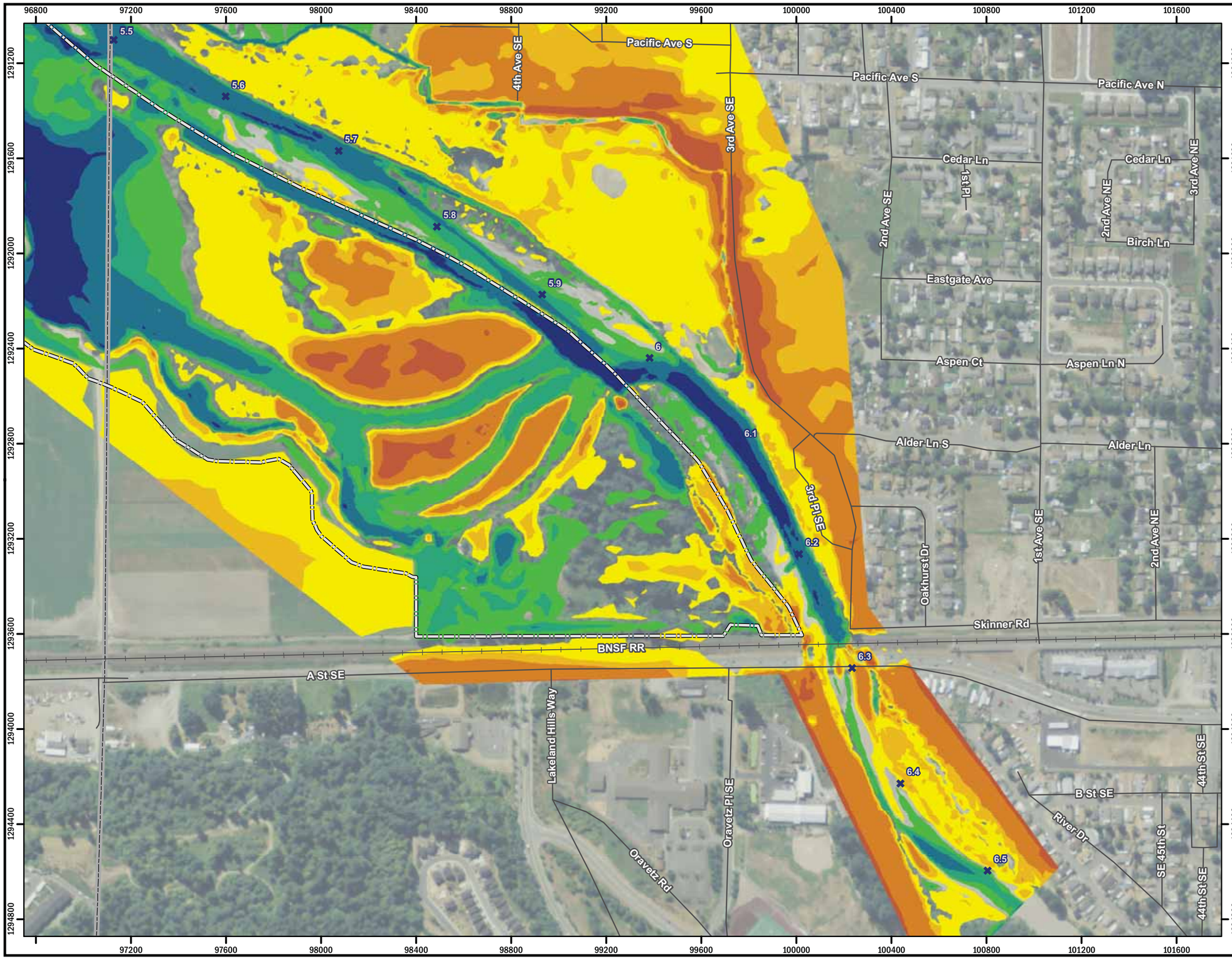

Figure 12. Sheet A.
Inundation difference for the 100-year flood event between existing and proposed conditions 13.8 years following construction (S4c-S1c).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
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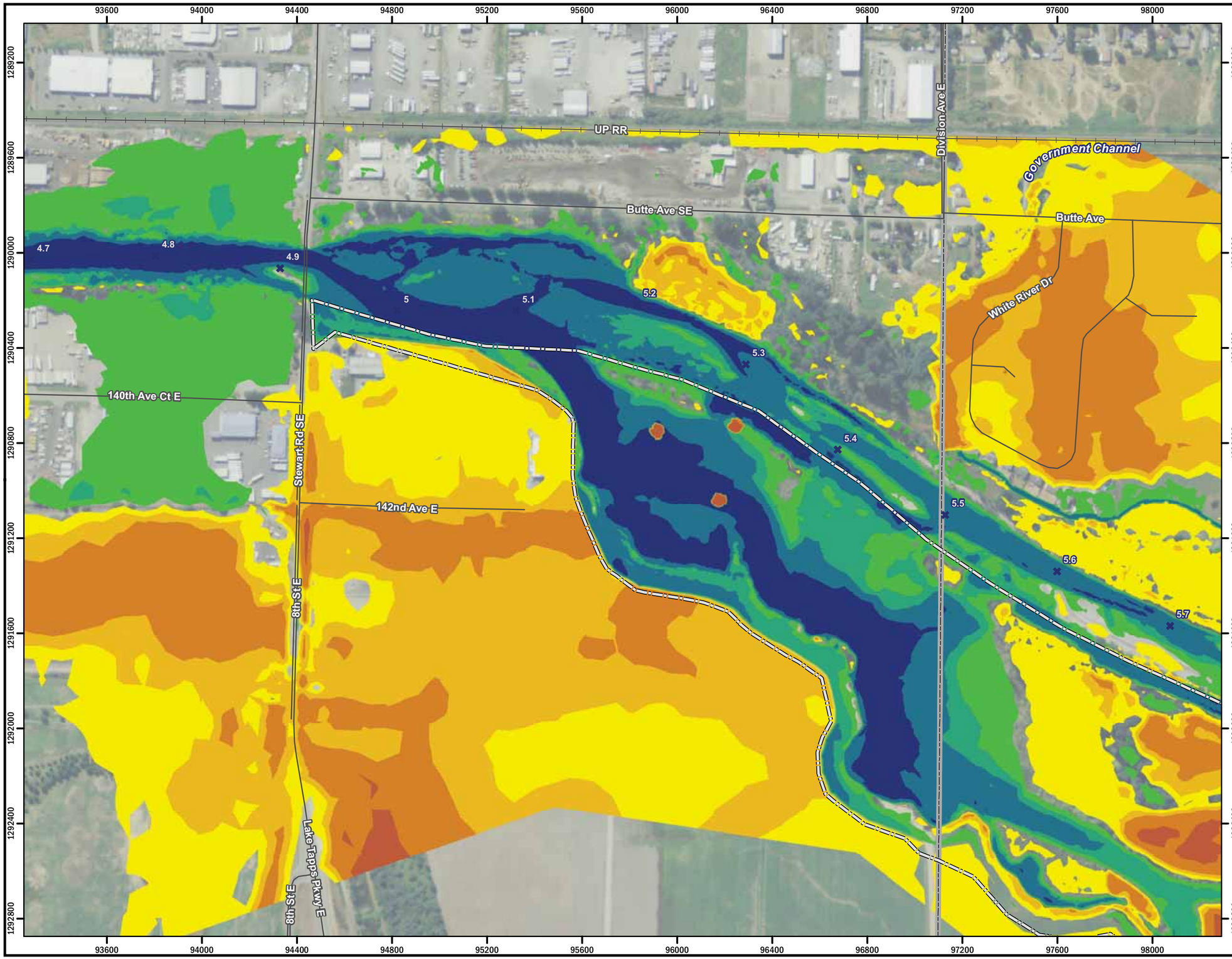

Figure 12. Sheet B.
Inundation difference for the 100-year flood event between existing and proposed conditions 13.8 years following construction (S4c-S1c).

Legend

- River mile
- Project area
- County boundary

Depth difference (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

N

0 200 400 800 Feet

HERRERA

Aerial: USDA (2009)

Produced by: GIS (rdr)
File path: K:\Projects\10-04770-000\Project\Hydraulic_modeling_approach_memo\100-year_difference_13.mxd

Table 2. Continuity Errors Calculated at the Edge of the Model Domain Accounting for Internal Storage.		
Scenario	**Simulation**	**Continuity Error (%)**
S4a	MAF [a]	2.3
	2-year	1.2
	100-year	-17.3
	500-year	-24.7
S1a	MAF	-20.3
	2-year	0.5
	100-year	11.4
	500-year	15.8
S4b	MAF	15.9
	2-year	-9.5
	100-year	-27.4
	500-year	-29.7
S1b	MAF	-2.7
	2-year	-2.8
	100-year	8.4
	500-year	14.1
S4c	MAF	-177.6
	2-year	30.9
	100-year	-52.8
	500-year	-51.1
S1c	MAF	-18.1
	2-year	-2.8
	100-year	17.7
	500-year	30.9

[a] MAF = Mean Annual Flow

The results of the analysis of boundary conditions are summarized in Table 3, which shows the maximum and average variability in water surface elevations between the base case (i.e., with the original HEC-RAS-generated rating curve and a fixed left bank floodplain water surface elevation of 65 feet) and the other sensitivity runs. Each simulation of a combination of boundary conditions is called a draft. With the exception of Drafts B, E, and G of scenario S4c, all of the simulations indicate less than 1-inch variability in the largest deviation of the maximum water surface elevations along the proposed levee alignment, despite changing the downstream boundary condition (water surface elevation) by several feet. Based on these results, it is obvious that hydraulic control is provided at Stewart Road SE. Ironically, the greatest deviations do not occur near Stewart Road SE; they are at the north end of the project site near the BNSF railroad. In these simulations there is a small bump in the topography near the railroad alignment that is barely overtopped in the base

case. The bump controls the flow of water into a small low lying area adjacent to and bounded by the railroad. Reducing the left bank floodplain boundary water surface condition (as was done in Drafts E and G), results in the bump not being overtopped, which indicates that flooding would not occur in the small low lying area, and makes the water surface elevations in the low lying area quite different for different drafts.

Table 3. Results of Sensitivity Analysis.

Simulation	Main Channel Boundary Condition	Floodplain Boundary Condition Elevation	Maximum Deviation in WSE from Base	Average Deviation in WSE
S4c 100 year				
Draft A	*original*	*65*	N/A	N/A
Draft B	original	66	1.668	0.026
Draft C	original	67	0.019	0.001
Draft D	original	64	0.027	0.001
Draft E	original	63	1.059	0.017
Draft F	original	64.5	0.090	0.001
Draft G	original	63.5	1.491	0.009
Draft H	original +4	68	0.307	0.007
S1c 100 year				
Draft A	original	61	0.162	0.024
Draft B	original	63	0.162	0.025
Draft C	original	64	0.007	0.001
Draft D	*original*	*65*	N/A	N/A
Draft E	original +1	65	0.009	0.001
Draft F	original +2	65	0.011	0.000
Draft G	original +3	65	0.008	0.000

Base simulation in *italics*
WSE = Water Surface Elevation
N/A = Not applicable
All units in feet

To further validate the model results for scenarios S1 and S4, the flow across Stewart Road SE (both the flow that goes under the bridge and over the road surface) was calculated and compared to the inflow hydrograph. In nearly all cases, these calculations indicate that the flow at and upstream of Stewart Road SE is modeled as accurately as is possible and that the roadway and bridge effectively act as hydraulic controls.

In summary, the results of the sensitivity analyses indicate that Stewart Road SE acts as an independent hydraulic control on the model, effectively isolating most of the model domain from the downstream boundary condition. While domain boundary continuity checks do not perform well for simulations where there is significant flow over Stewart Road SE, these imbalances do not adversely affect the results in the model at and upstream of Stewart Road SE. However, the model was found to be dependent on the downstream boundary

condition (and likely in error) more than 1,000 feet downstream of Stewart Road SE in those simulations where flow into and out of the left bank floodplain south of Stewart Road SE is significant.

SUMMARY OF PRELIMINARY FINDINGS

The following statements are based upon the model results discussed herein:

- These preliminary findings are based on the projection of recent trends in sediment deposition within the project reach and assume that both the Countyline (left bank) project and the right bank project (or temporary flood protection measures) are constructed to provide 100-year flood protection.
- The model produced reasonable results for all of the conditions simulated to date (for scenarios S1 and S4) at and upstream of Stewart Road SE (i.e., reasonable water depths, flow velocities and hydraulic patterns).
- Mass was typically not conserved when it was calculated along the model domain boundary because of the imprecise imposition of the downstream boundary condition, particularly in the left bank floodplain. Therefore, it is expected that the model results are not necessarily reliable very near the model domain boundary for simulations where the left bank floodplain is engaged south of Stewart Road SE.
- Based upon the sensitivity analysis and careful evaluation of simulated flows across Stewart Road SE, the model was found to be dependent on the downstream boundary condition (and likely in error) only more than 1,000 feet downstream of Stewart Road SE.
- Nearly all areas between the UP and BNSF railroads will be within the 100-year floodplain within 14 years if the project is not constructed.
- The required elevation of the top of the setback levee increases depending on the time period examined because of ongoing sediment accumulation expected to occur in the left bank floodplain wetland.
- By far, the highest portion of the levee needs to be in the vicinity of the Fairweather property.
- The project will lower flood water surface elevations by several feet along the right bank in the City of Pacific for all time periods examined. The greatest flood reduction benefit appears to be in the vicinity of Pacific City Park, where modeled flood water surface elevation reductions of up to 5 feet are common.
- Because the project will eliminate flow over Stewart Road SE (a major arterial) for all flow ranges including the 100-year event, water surface elevations immediately after construction are expected to increase in the right bank floodplain along Butte Avenue upstream of the Stewart Road SE Bridge due to the backwater effects from the bridge. Increases are also expected in the right bank floodplain downstream of the bridge. The model results indicate that water surface elevations in these areas are expected increase by approximately one foot upstream from the bridge and by less than 0.5 feet

downstream of the bridge. Both areas of estimated water surface elevation increase are within the present-day, 100-year flood zone. These increases in water surface elevations might be an artifact of the model because they occur near the edge of the model domain. Additional modeling, with the model domain extending farther downstream should be conducted to address this effect.

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