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YAKIMA RIVER HABITAT IMPROVEMENT STUDY

SCHAAKE REACH, ELLENSBURG, WASHINGTON:

FINAL REPORT TO THE YAKIMA RIVER BASIN WATER ENHANCEMENT PROJECT

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TECHNICAL SERVICES CENTER
DENVER, CO

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U.S. Department of the Interior
Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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YAKIMA RIVER HABITAT IMPROVEMENT STUDY,

SCHAAKE REACH, NEAR ELLENSBURG, WA

EXECUTIVE SUMMARY

This study investigates various scenarios related to levee setback and side channel construction along the Schaake reach of the Yakima River near Ellensburg, WA. The property was purchased in August, 2003 so that salmon habitat could be improved and place additional riparian land in public ownership. In December, 2003 an interim report (Hilldale & Klinger, 2003) was presented to the Yakima River Basin Water Enhancement Project (YRBWEP) detailing the results of a one-dimensional model and geomorphic analysis. The general conclusion of the interim report was that some incision has occurred over the time that the levees have been in place however rehabilitation of the site remains a possibility. The interim report also highlighted the contradiction and potential impact of the levees on opposite sides of the river that have a perpendicular orientation to each other.

This report involves a detailed study of two separate rehabilitation schemes, levee rehabilitation and the construction of pilot channels through the floodplain to encourage the creation of side channel habitat. Two separate two-dimensional hydraulic models were constructed and run in order to properly evaluate the proposed rehabilitation schemes, a large model to evaluate the levee modifications and a small model to evaluate the side channels.

The large model first evaluates existing conditions and compares those results with the results from two levee modification scenarios. The model indicates that the water surface elevation and velocity in the main channel would decrease significantly as a result of implementing the first scenario and an even greater improvement if the second scenario is implemented. This improvement will decrease the likelihood of damage from flooding and improve the habitat in the area by reintroducing channel complexity and floodplain interaction.

The small model focuses the study on approximately 4,200 feet of the main channel, the Schaake property and the property that lies just to the south. In this model four proposed side channels are modeled to evaluate their interaction with the main channel and each other. The model results indicate that the channels become inundated at flows greater than 1,000 ft^3/s. This flow rate was chosen in order to maximize the time that the channels are inundated while minimizing the amount of excavation and disturbance. Estimated excavation volumes for the channels as well as for the existing levees are included in the report. Specifications are given regarding the design of the side channels and suggestions made about the new levee construction.

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INTRODUCTION

This report details the results of a study to set back levees and create side channel habitat on the Yakima River, Ellensburg, WA (Figure 1). The Schaake Reach (Figure 2) lies between the interstate and the river south of Damman Road and is named for the former owner of the property. The property was purchased in August, 2003 because of the high potential for habitat improvement outlined in the Reaches Project (Stanford et al., 2002). Public ownership of the adjoining properties upstream and downstream also adds to the potential for a successful rehabilitation and increased public benefit.

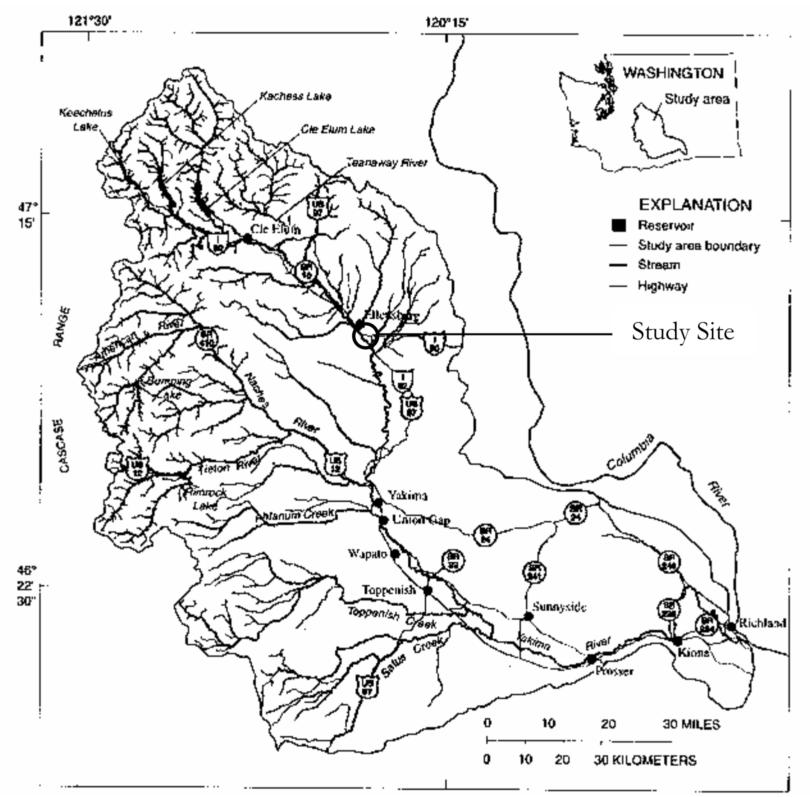

Figure 1: Area map showing the location of the Yakima River basin (from Mastin and Vaccaro, 2002).

The Schaake reach of the Yakima River has a series of levees on both sides of the river, five within the study reach. The construction of these levees has confined the river and prevented regular interaction between the river and the floodplain. This has caused some incision of the river channel and a coarsening of the bed material in this reach (Hilldale and Klinger, 2003). The disconnection of the floodplain from the river has significantly decreased the ability of the river to build and maintain side channel habitat, critical to the existence of salmonid fish species in the Yakima River Basin (Ring and Watson, 1999, Stanford et al., 2002). This type of habitat is needed for fish to escape high velocities during flood events and provides rearing habitat throughout the year for juvenile fish. Food is typically more abundant in side channels due to increased vegetative cover and reduced flow velocities. Temperatures in the side channels are generally cooler in summer and warmer in winter due to groundwater interaction. Throughout this report, references to left and right are made with the perspective of looking downstream.

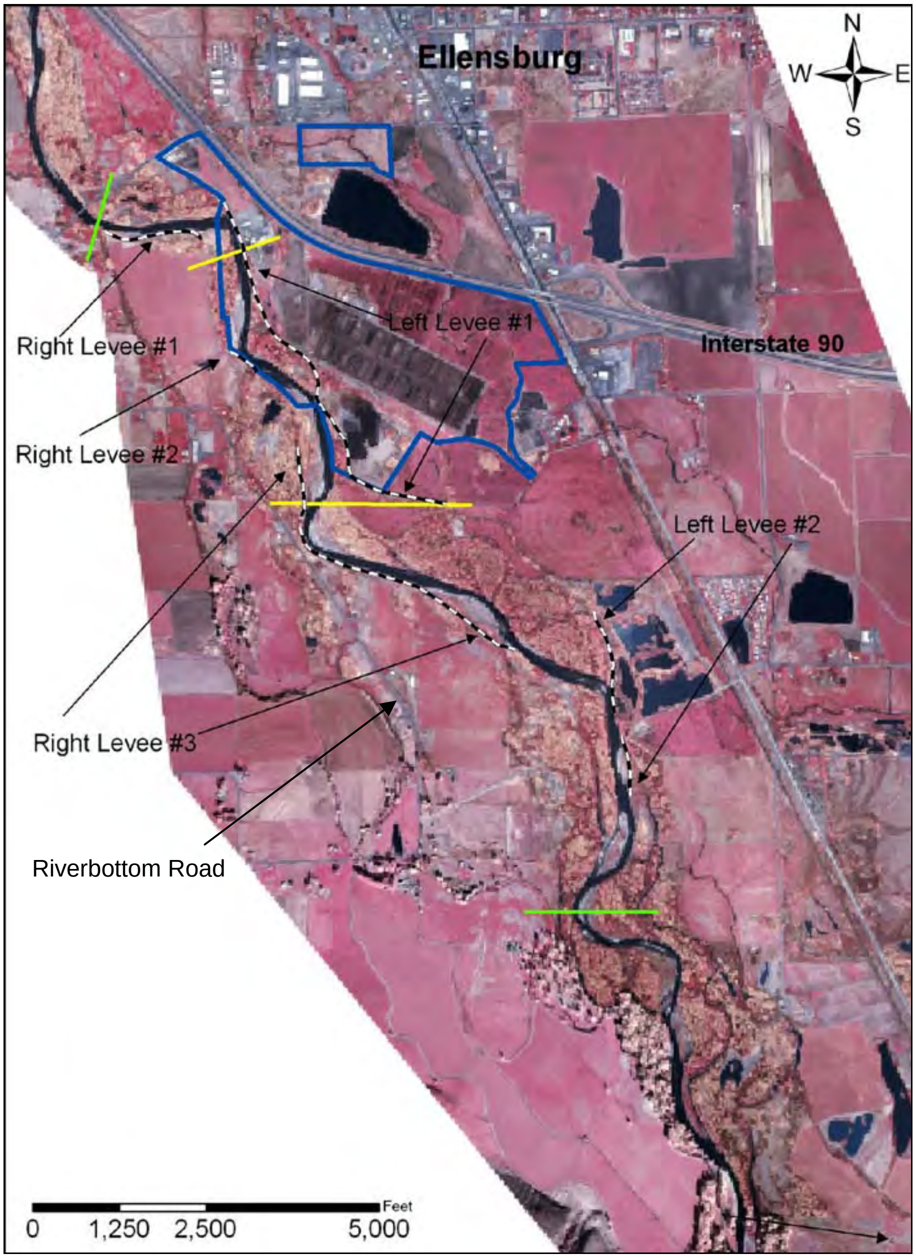

Figure 2: Aerial photograph of the study site showing the existing levees and their naming convention for this report. The Schaake property is outlined in blue. The extent of large reach is shown with green lines and the small reach is shown with the yellow lines. The mouth of the Yakima Canyon lies to the south, just beyond the picture. Flow is from north to south.

Previous to this report, an interim report (Hilldale and Klinger, 2003) was provided to the Yakima River Basin Water Enhancement Project (YRBWEP) detailing the effects of the levee construction in the Schaake Reach and the potential for a successful rehabilitation involving levee setback and the construction of side channels. The interim report stated that, in spite of some channel incision, rehabilitation of the Schaake is expected to achieve some level of river-floodplain interaction. The current study incorporates a two-dimensional (2-D) hydraulic model to simulate channel and floodplain flows following various modifications to the floodplain evaluated over a wide range of flow rates. The construction of pilot channels in the floodplain will more rapidly restore this interaction. The project will improve habitat for fish and restore some of the natural river processes regarding floodplain interaction and channel migration. The potential for flood damage will also decrease due to a wider river corridor, reducing both depth and velocity during high flows. It is expected that over time, the Schaake reach will aggrade slightly, similar to pre-levee condition due to the decreased sediment transport capacity during high flows following levee setback. This effect should also reduce bed material sizes in the Schaake reach to more closely match the sizes in the reach immediately downstream that has experienced much less disturbance.

The two levees on the left side of the river are in disrepair in many locations and do not appear to have been constructed to high standards (Figure 3). Left levee #1 (Figure 2) currently provides limited protection for Interstate 90, Wilson Creek and the Ellensburg waste water treatment plant. Left levee #2 was constructed to prevent avulsion into the Hansen gravel pits. This levee is breached (Figure 3) in the vicinity of the gravel pits, resulting in hydraulic connectivity of the western pit with the river.

Figure 3: Photos of levee damage. The left photo shows the failure of the levee near the Hansen Pits and the material from which it is constructed (local alluvium). The right photo was taken from atop the levee looking away from the river and shows a persistent leak under the levee. Both of these photos are of left levee #2.

STATEMENT OF PURPOSE

The purpose of the Schaake Study is to investigate the options available to restore side channel habitat and river – floodplain interaction lost to the construction of levees. The best possible scenario for rehabilitation is that the river be allowed to form its own side channels or reclaim historical side channels following the setback of levees, with minimal construction. The former Schaake property has few remnant side channels due to past anthropogenic activity in the floodplain, forcing a more aggressive approach if timely rehabilitation is expected. The use of a 2-D model will simulate various floodplain construction options, including levee setback on both sides of the river and the construction of four pilot channels on the left floodplain, totaling an approximate length of 5,200 feet (1585 m).

Communication between YRBWEP and Kittitas County has indicated that frequent repairs have been necessary to Riverbottom Road due to flood damage. Because reconfiguration of the right bank levees would greatly compliment the left bank modifications on Reclamation property, it was decided that modifications to the right bank levees would also be examined. Due to the piecemeal construction of the right bank levees, floodwaters have access to the floodplain behind these levees. Once the flood flows access the floodplain, it is difficult for the water to return to the main channel because of the location of the upstream portion of right bank levee #3 (Figure 2). This exacerbates the effects of the high water, causing damage when Riverbottom Road is overtopped. It was also noted in the interim report that the upstream portion of right bank levee #3 was constructed in an area occupied by the main channel as recently as 1966.

EXISTING CONDITIONS AND PROPOSED FLOODPLAIN MODIFICATIONS

EXISTING CONDITIONS

The existing conditions with respect to levee configuration are shown in Figure 4. The levees were constructed at various times, beginning with a shorter version of right levee #1, which is indicated as a log bulkhead in the 1912 survey (Appendix A, Figure A-1). By 1966 left levee #1 had been constructed and right levee #1 had been extended from what was the log bulkhead in the 1912 survey (Appendix A, Figure A-2 and A-4). It appears likely that right levee #2 and right levee #3 had not been built prior to 1966 (Appendix A, Figure A-2, A-3 and A-4). Sometime after 1966, the upstream portion of right levee #3 was constructed in the former main channel of the river that existed in 1966 (Appendix A, Figure A-2). At all locations in the study reach where the river flows against a levee, a scour hole has developed. This results because the levee prevents the natural erosion and lateral migration of the bank. Instead, the river begins to scour a hole at the toe of the levee. This type of scour hole can erode deep enough that the riprap which is lining the bank falls into the scour hole. Depending on the method of levee construction, this could be the beginning of levee failure. An important conclusion of the interim report was that if any levee modifications are performed, right levee #1 should be removed, as it directs the flow of the river toward Interstate 90, which is less than 500 feet (152.4 m) from the edge of the river.

PROPOSED LEVEE MODIFICATIONS

The first floodplain modification involves modifying levees on both sides of the river and evaluating the scenarios with the large model. This modification is referred to as Mod 1 (Figure 5). In this modification, right levee #1 is removed and left levee #1 is set back. The setback levee on the left bank ties into the interstate embankment at the north end of the property. The proposed levee is approximately 6,800 feet (2,072.7 m) long and terminates in a narrow piece of the southeast portion of the Schaake property. This levee will provide protection for Interstate 90 and the Ellensburg wastewater treatment plant in addition to preventing the Yakima River from migrating into Wilson Creek, which is possibly a relic channel of the Yakima River.

The second floodplain modification involves those changes proposed in Mod 1 in addition to the removal of right levee #2 and right levee #3. This modification is referred to as Mod 2 (Figure 6). A new setback levee is proposed to replace right levee #2 and right levee #3 that borders Riverbottom Road from the location where the river is closest to the existing levee and continues north to tie into the terrace at the western edge of the floodplain. Further recommendations regarding this levee are discussed later in this report.

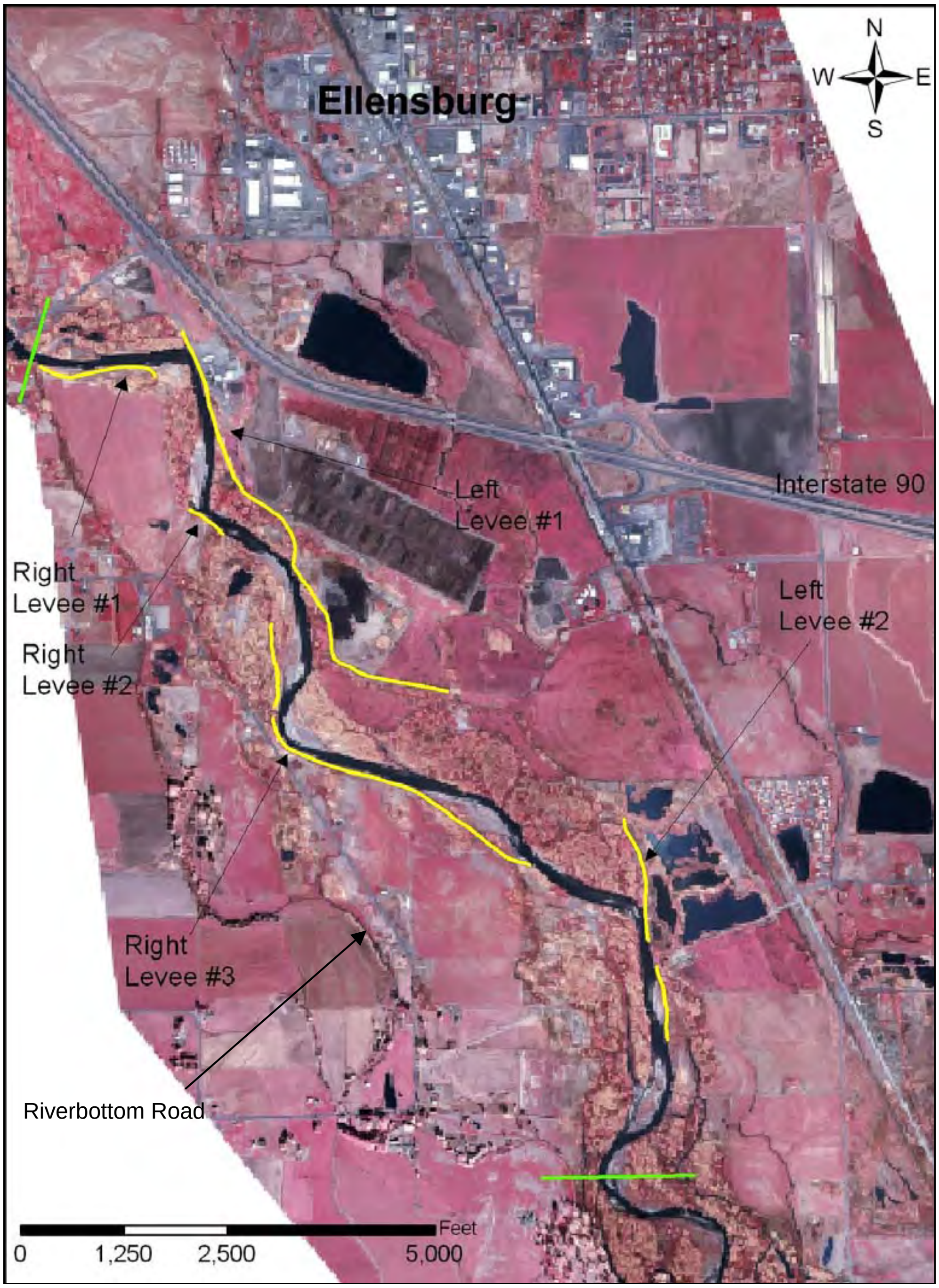

Figure 4: Map showing the existing levee configuration and their respective designations. The green lines across the channel indicate the extents of the large model. Flow is from north to south.

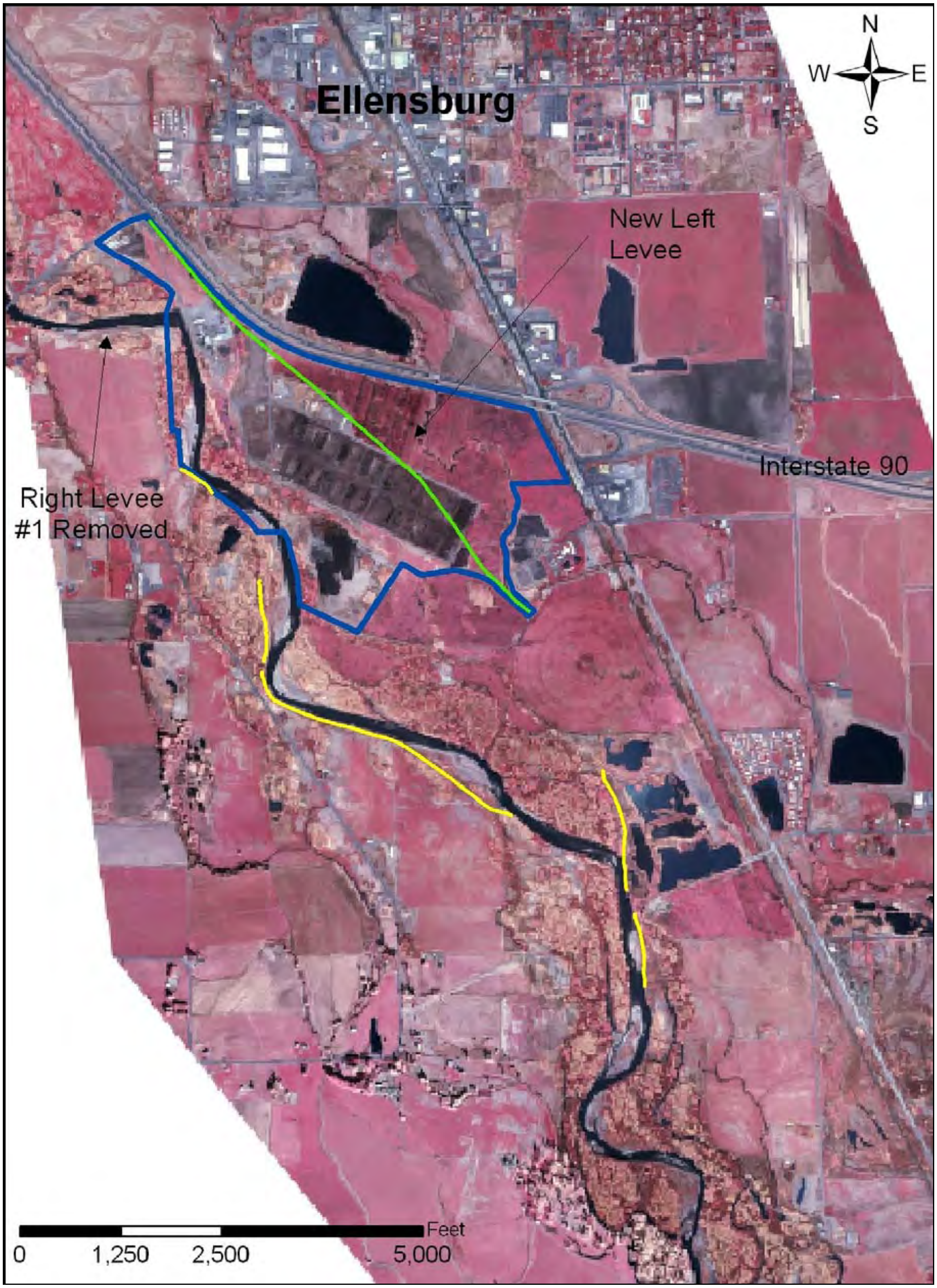

Figure 5: Map showing levee modification scenario 1 (Mod 1). Left levee #1 and right levee #1 have been removed. The proposed new left levee has been added (green line). Flow is from north to south.

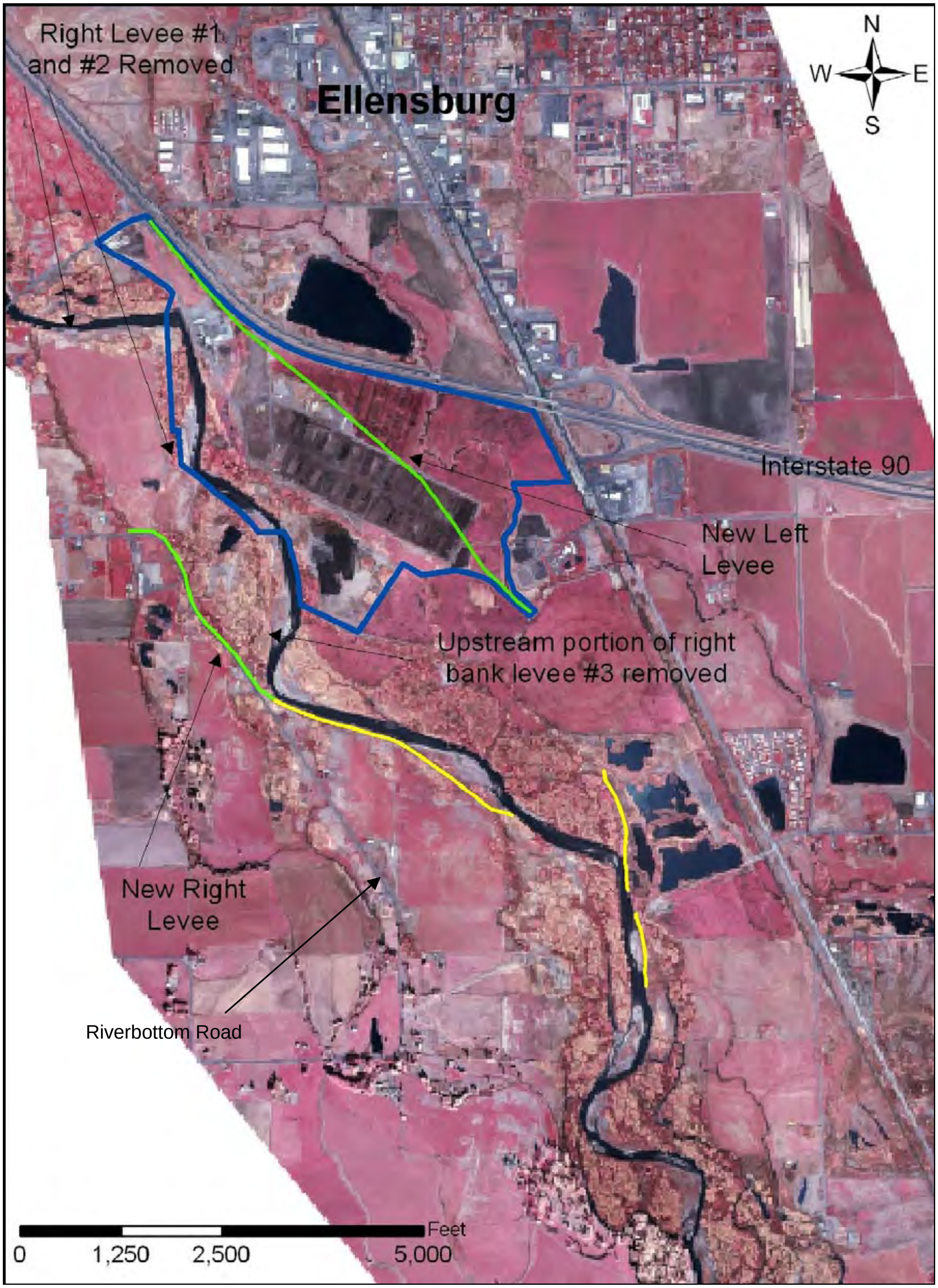

Figure 6: Map showing levee modification scenario 2 (Mod 2). Right levee #2 and the upstream portion of right levee #3 have been removed. The upstream portion of left levee #3 has been replaced with a setback levee shown in green. Flow is north to south.

PROPOSED SIDE CHANNEL CONSTRUCTION

Four separate side channels have been proposed and are shown in Figure 7. The locations of these channels were based on what is expected to be a sustainable location, meaning that access to the main channel will remain open to flow. The flow conditions for the proposed side channels were evaluated with the small model. An attempt was made to provide variable habitat in the side channels, with one still water channel and three flowing channels.

Figure 7: Map showing the locations of the proposed side channels 1 – 4 (green, dark blue, yellow and red, respectively) and the existing Tjossem ditch and its access channel (lt. blue). The existing levee is removed and the proposed levee is built in the model. The pink lines across the channel represent the extent of the small model. Flow is from north to south.

2-D MODEL SPECIFICS

For modeling the hydraulics of the Yakima River, the MIKE 21 two-dimensional (2-D) modeling code, version 2003.0 was used. This software is developed and maintained by the Danish Hydraulic Institute (DHI). MIKE 21 uses a finite difference code with a Cartesian grid and is capable of accurately resolving depths and velocities for riverine environments and associated floodplains, including critical and supercritical flows (McCowan et al., 2001). It is necessary to balance the resolution of the model with the needs of the project and computer processing time. If the grid spacing is too coarse, instabilities can occur and/or the results obtained may not have the resolution needed for the particular evaluation. If the grid spacing is too small, the run times can become extremely long (> 100 hours), adding considerable time to the project.

It was necessary to construct two separate models in order to properly evaluate flow conditions related to the project. The first and longer model (large model) was constructed with a grid spacing of 9.84 feet (3 m) over a reach length of 3.1 miles (5 km). This model was used to evaluate the various levee scenarios so that reach based results could be obtained for high flows. Flows for this scenario ranged from the flow during the survey (3,150 ft^3/s, 89.2 m^3/s) to 25,000 ft^3/s.

For modeling the constructed side channels it was necessary to decrease the grid spacing due to the finer detail required for their analysis. The second and smaller model (small model) has a reach length of 1.1 miles (1.8 km) with a grid spacing of 6.56 feet (2 m). Flows for this model ranged from 500 ft^3/s, (14.2 m^3/s) to the 2-year flood (5,678 ft^3/s, 160.8 m^3/s), including the flow during the survey (3,150 ft^3/s, 89.2 m^3/s).

In order to verify the results of both models, water surface elevations obtained during the survey were compared to modeled water surface elevations for the same flow rate for both the large and small models. Figure 8 compares the modeled and surveyed water surface elevations. Figure 9 and Figure 10 show the true water surface elevations and the thalweg elevation plotted with river station. For the large model, the modeled water surface elevations have a mean error of 0.025 feet (0.0076 m). The median error is -0.021 feet (0.0.0064 m) and the standard deviation is 0.49 feet (0.15 m). Modeled water surface elevations for the small model have a mean error of 0.0053 feet (0.0016 m). The median error is 0.056 feet (0.017 m) and the standard deviation is 0.43 feet (0.13 m).

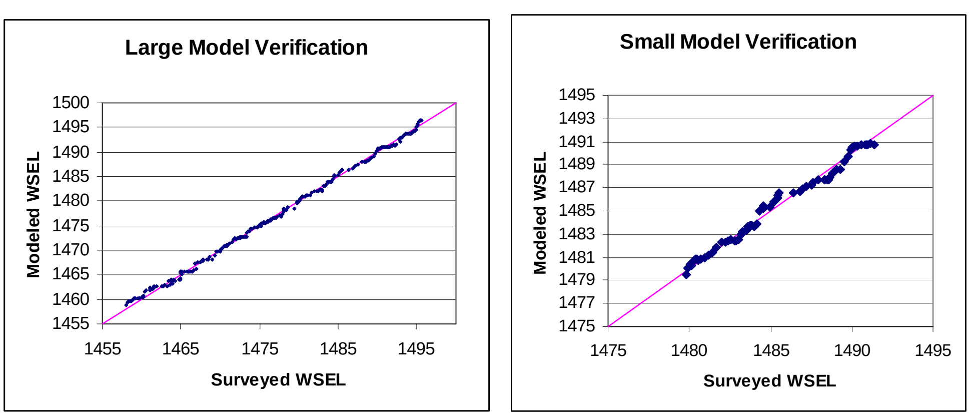

Figure 8: Comparison of surveyed and modeled water surface elevations (WSEL, represented by points) for the large and small models. A perfect match between the data would fall along a 45 degree line (solid line).

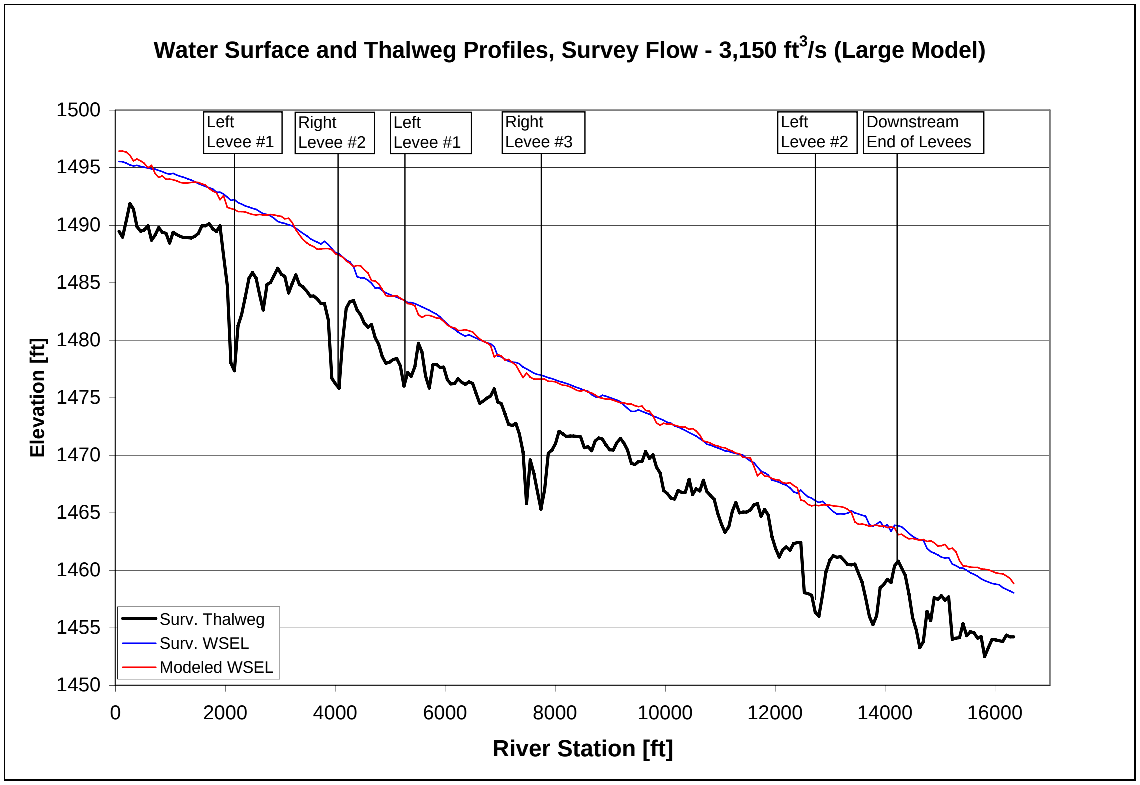

Figure 9: Profiles showing the surveyed river thalweg as well as surveyed and modeled water surface elevations for the large model. The large dips in the thalweg are scour holes where flow is forced against the levee.

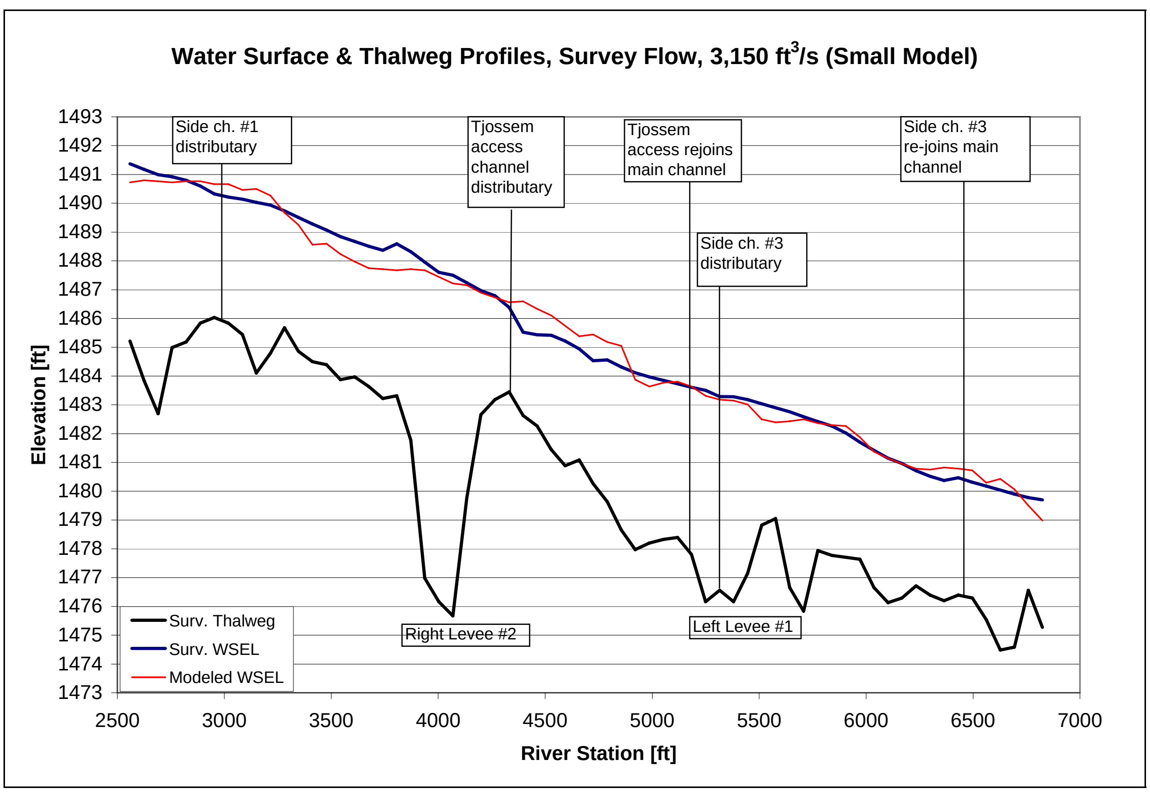

Figure 10: Profiles showing the surveyed river thalweg as well as surveyed and modeled water surface elevations for the small model. The large dips in the thalweg are scour holes where flow is forced against the levee.

BATHYMETRY AND TOPOGRAPHY

The topography used in the model was derived from aerial LiDAR flown in November, 2000. The bathymetry (underwater topography) was surveyed by boat using a single beam depth sounder in conjunction with a Real Time Kinematic (RTK) Global Positioning Satellite (GPS) survey. Bathymetric data was collected during five float trips down the reach and was sufficient to accurately represent the channel bottom for the purpose of 2-D modeling. For more information regarding the survey the reader is referred to the interim report for this study (Hilldale and Klinger, 2003).

TIME STEP

The time step of the large model was 0.5 seconds for all flow rates. In the small model flows greater than 1000 ft^3/s (28.3 m^3/s) had a time step of 0.2 seconds. For the 500 and 1000 ft^3/s (14.2 and 28.3 m^3/s) runs the time step was reduced to 0.1 seconds to maintain a stable solution. The Courant number (the product of maximum velocity and time step divided by the grid spacing) was 0.875 for the large model and less than 0.4 for the small model. DHI recommends that for applications with complicated bathymetry and topography the Courant number is less than or equal to 1.0 to avoid numerical instabilities.

BOUNDARY CONDITIONS

The boundary conditions for both models used a steady inflow for the upstream boundary condition and a constant water surface elevation for the downstream boundary condition. For the large model, the downstream boundary was a pool spanning the wetted width of the river with a bottom elevation of 6.56 feet (2 meters) below the thalweg elevation. The initial water surface elevation in the pool was set to the same value as the downstream boundary condition. All data reported is a minimum of 80 grid cells (787.4 feet, 240 meters) away from the boundaries for the large model and 20 grid cells (131.2 feet, 40 meters) away from the boundaries for the small model. This distance is sufficient to exclude any numerical errors resulting from the presence of the downstream boundary.

ROUGHNESS

The representation of roughness in a 2-D model plays a much lesser role than in a 1-D model. This is because the dissipation of energy in a 1-D model is only accounted for with roughness. A 2-D model accounts for energy dissipation through roughness and turbulence effects. This results in Manning's *n* values being lower for a 2-D model than in the traditional Manning's equation type applications. When a Manning's roughness is specified in MIKE 21, it is converted by the model to a Chezy roughness parameter, based on calculated water depth. For the large model, a set of polygons were made in a Geographic Information System (GIS) that represented heavily vegetated, cultivated, and channel areas of the topography. A background roughness was also used for conditions that were not well represented by these three definitions. The Manning's roughness values used are as follows; background = 0.023, cultivated = 0.018, forested = 0.04 and channel = 0.02. The background roughness value was used for all side channels modeled. These channels generally have a roughness slightly higher than the main channel due to the presence of debris.

For the small model, a similar set of polygons was created, although overbank flows were not as great a concern because modeled flow rates remained in channel and only spilled onto the floodplain during the 2-year flow (5,678 ft^3/s, 160.8 m^3/s). The Manning's equivalent roughness in the main channel was 0.02, constructed side channels had a value of 0.023 and Tjossem ditch was 0.03 due to the presence of trees, dense grass and debris within the channel. These values fall within the typical 2-D modeling applications for riverine and floodplain environments (McCowan et al., 2001).

EDDY VISCOSITY

The eddy viscosity is a term in the momentum equation that can be used to incorporate several effects such as turbulent shear and numerical diffusion. This term has the same dimension as viscosity but is not a fluid property. In most numerical modeling applications this term may be neglected but also may be used to 'calibrate' a model to a desired result, perhaps a measured velocity or depth at a particular location. In the numerical simulations performed for this study, water surface elevations were able to be matched without the use of this term in the momentum equation.

FLOODING AND DRYING PARAMETERS

Flooding and drying parameters are an important part of a multidimensional model, particularly when unsteady flow is being modeled. These parameters form a threshold that represents the depth above or below neighboring cells at which the neighbor cell becomes wet or dries out, respectively. For the steady flow simulations performed in this study, the flooding parameter was set to 0.33 feet (0.1meters) and the drying parameter was set to 0.16 feet (0.05 meters) in the large model. The flooding and drying parameters are 0.16 feet (0.05 m) and 0.08 feet (0.025 m), respectively for the small model.

METHODOLOGY

Once the models were constructed and verified to a known condition, various flow rates were modeled for the existing conditions. This information will be compared to results obtained for the floodplain and levee modification scenarios. To model the various floodplain modification scenarios the grid was manipulated to represent planned changes to the terrain, namely levee setback and removal and side channel construction. These scenarios were then run for all flows of concern to obtain predictions of depth, velocity and inundation area following the modification.

MODELED FLOW RATES

The modeled flow rates for the large model are shown in Table 1. These values, with the exception of the 25,000 ft^3/s flow, were determined with a log-Pearson analysis from historical gage data at the Ellensburg gage (Hilldale and Klinger, 2003). The effectiveness of the levees was evaluated with a 25,000 ft^3/s flow. This discharge was added after initial modeling efforts and comment because it approximates the discharge in this reach during the Winter 1995-96 flood, considering both the Ellensburg gage and the Umtanum gage. The uncertainty of infrequent return flows (50-year and 100-year flood) increases dramatically with limited gage data.

Table 1: Flow rates and return periods modeled in the large model.

Return Period [years]	Survey	2yr	5yr	10yr	20yr	N/A
Flow Rate [ft^3/s]	3,150	5,678	10,066	13,921	18,441	25,000

Table 2 contains the flows used for the small model. Low flows are emphasized in the small model to determine habitat conditions in the side channels at prevailing flows. The constructed side channels are intended to remain wet at all flows greater than 1,000 ft^3/s (28.3 m^3/s). Based on historical gage data at the Ellensburg gage, river flow generally reaches 1,000 ft^3/s (28.3 m^3/s) between February and April and remains above that level for the remainder of the spring and summer. Flow generally drops below 1,000 ft^3/s (28.3 m^3/s) between September and October and remains below that level until spring. Ellensburg gage records indicate that for an average of 249 days per year the flow is greater than 1,000 ft^3/s (28.3 m^3/s) and that late spring and summer flows in the Ellensburg area of the Yakima River are normally between 2,500 ft^3/s (70.8 m^3/s) and 4,000 ft^3/s (113.3 m^3/s). In addition to habitat concerns for fish, a constant water supply is needed during the growing season for the reestablishment of vegetation along newly created riparian zones.

Table 2: Flow rates used for the small model. The two-year flood is 5,678 ft^3/s, all other flows occur frequently in this reach.

500 ft^3/s	1,000 ft^3/s	2,000 ft^3/s	3,150 ft^3/s	5,678 ft^3/s

LARGE MODEL

The large model reach extends from just downstream of the Damman Road Bridge for 3.1 miles (Figure 4). The reach was terminated here in order to include the existing side channels in the floodplain that are downstream of all levee construction to demonstrate the contrast between these two reaches of the river. This also includes the entire length of Riverbottom Road on the right bank. The major side channels in the lower portion of the reach were digitally constructed in the model grid with information gained from a site visit in January, 2004. Because there had not yet been a survey of these channels, they were cut in the model grid to an assumed depth of 3 feet (0.9 meters) below the existing topography indicated by the LiDAR. The same was done for the access to Tjossem ditch, although this channel incorporated the small drop structure at the headworks for Tjossem ditch. Because the flows through the side channels would not significantly affect the results for the large model, assuming side channel geometry based on observation during site visits was sufficient for investigating various levee modification scenarios. A ground survey of Tjossem ditch and its access channel was later completed for the small model, which requires greater resolution and places an emphasis on side channel flow.

Levees are removed from the model grid by matching the terrain values at the levee location to elevations on both sides of the former levee. It is expected that this procedure will most likely mimic the method of the actual levee removal. Levees are added to the grid by adding a fixed value to the existing terrain.

LEVEE MODIFICATION 1 (MOD 1)

Levee modification scenario 1 (Mod 1, Figure 5) includes the removal of the entire length of left levee #1 from the model grid. A proposed new left bank levee was incorporated in the model grid by adding 6.56 feet (2 m) to the existing terrain. This scenario also incorporates the removal of right bank levee #1. This was included in the scenario because of the easterly direction that it forces the flow. The levee height chosen in this model was based on the greatest height of the existing levee. Much of the existing levee is approximately four feet above the ground surface.

LEVEE MODIFICATION 2 (MOD 2)

Levee modification scenario 2 (Mod 2, Figure 6) includes all modifications made for Mod 1 in addition to the removal of right levee #2 and the upstream portion of right levee #3. The proposed right bank setback levee was incorporated by adding 4 feet (1.22 m) to the existing terrain beginning at the location where the north end of Riverbottom Road leaves the terrace and drops onto the floodplain. The proposed levee follows the river side of the road to right bank levee #3, where it joins with the downstream portion of the existing levee. The levee height chosen in this model was based on the greatest height of the existing levee.

SMALL MODEL

The small model was constructed to specifically study the interaction of the river with the constructed side channels and the flow within the side channels. The existing channels and ditches, namely Tjossem ditch and its access channel, were surveyed to determine the channel bottom, water surface elevations and geometry. Existing channels and proposed side channels were created in the small model in addition to the setback of left levee #1 (Mod 1, Figure 7). The results of the small model are valid whether or not Mod 2 is incorporated. The small model uses the same stationing as the large model for discussion purposes. The assumed cross section geometry of the constructed channels in the model is a trapezoid with a 4:1 (H:V) side slope. The bottom width is 13.1 feet (4 m) and the top width is 26.2 feet (8 m). These widths are mostly representative of the dimensions of natural side channels that exist downstream of the Schaake property where artificial constrictions are nonexistent. Beyond the modeled top width of 26.2 feet (8m), the natural topography was used. The channel dimensions used in the model were based on observation of existing side channels and a request to have 4:1 side slopes to accommodate efforts to start riparian vegetation. Since the model was constructed, discussions have taken place that removed the requirement for 4:1 side slopes, instead opting for a more natural 1:1 side slope and a bottom width of 8 – 10 feet. The only effect this may have on the results of the model is that initial flows in the side channels may be less than indicated in the model, however once the channels become established they are expected to have widths similar to what was modeled. Stable channel design methods were not used in the determination of channel geometry. Details regarding side channel geometry and how it applies to this project will be discussed later in this report.

Because the terrain representation in the hydraulic model is rectilinear, flow paths that are not orthogonal to the North-South or East-West orientation are not as accurately represented when channel widths are narrow with respect to the grid cell size. This does not affect flows in the main channel because it is large with respect to the grid size. However, the side channels have a width of four cells, which can have an effect on the numerical representation of depth and velocity. The overall effectiveness of modeling the side channels is not impacted, although some detail related to the water surface is necessarily sacrificed depending on the final constructed geometry of the channels. Water surface elevations in the main channel, bottom width, invert elevation and slope of the side channels are the most critical factors in the determination of whether or not the side channels will be effective at a given flow. An effective side channel in this case is one that remains wet at flow rates greater than 1000 ft^3/s (28.3 m^3/s), flows in the desired direction and does not disrupt the current status of the 4 ft^3/s (0.11 m^3/s) water right of the Tjossem ditch. This has been accomplished in the hydraulic model.

SIDE CHANNEL #1

This proposed channel has an upstream connection with the river near river station 2,800 and terminates at the Tjossem ditch access channel (Figure 7 and Figure 11). The channel is 1,526 feet (465.1 m) long with a slope of 0.00235 ft/ft (0.235%). Much of the proposed channel passes through an existing depression in the topography, which was likely dug by the previous owner and is not a remnant channel (Figure 11). After the proposed channel crosses the existing levee, a remnant channel exists (circled in Figure 11) that connects with the Tjossem access channel. Using existing channels or depressions in the topography minimizes excavation cost.

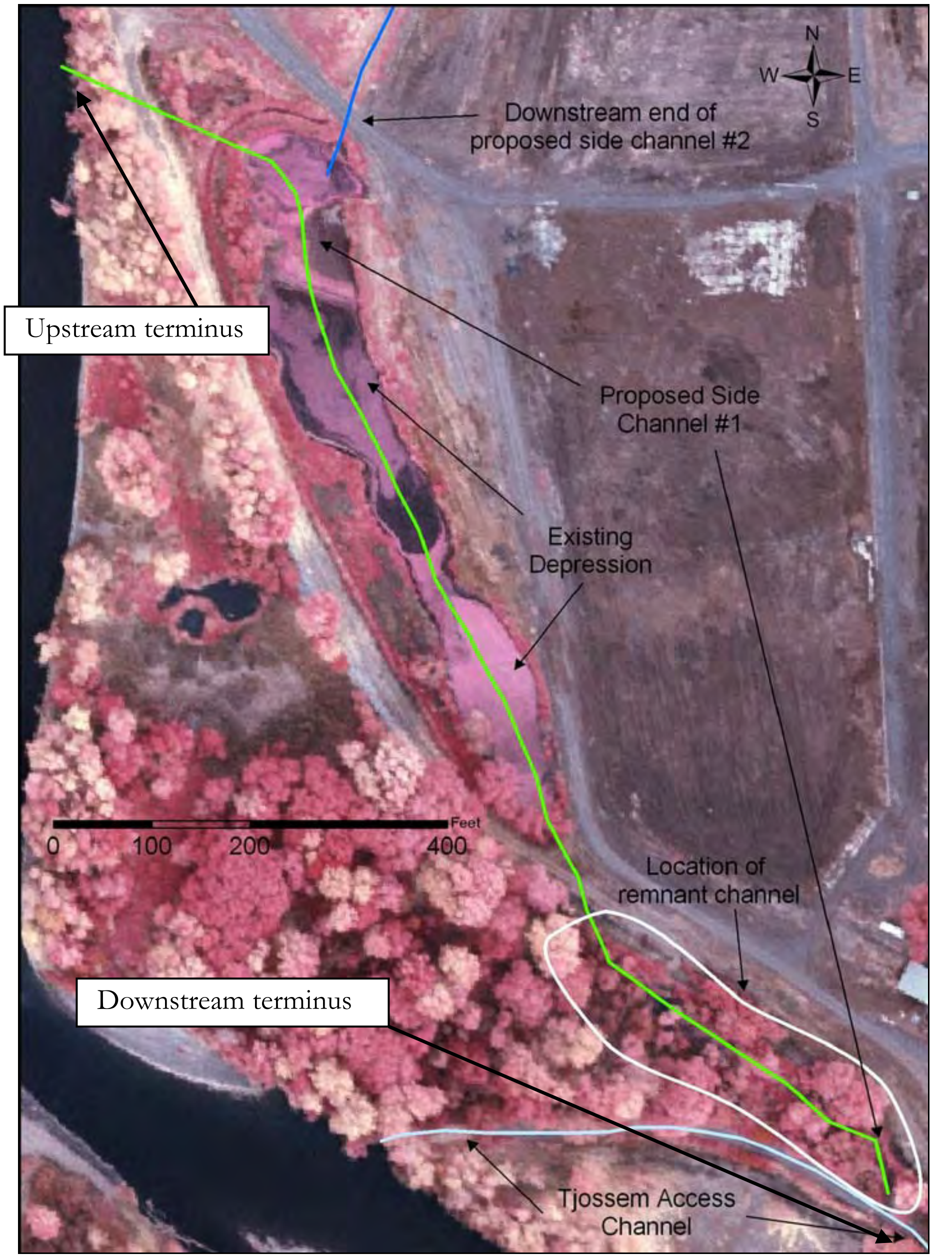

Figure 11: Photograph showing side channel #1. The white circle indicates a remnant channel utilized in the design. The upstream and downstream ends of the channel are indicated. Flow is from north to south.

SIDE CHANNEL #2

Proposed side channel #2 (Figure 7 and Figure 12) has no direct connection to the river. The northern half of this channel takes advantage of another existing depression in the topography. The depression can be seen in Figure 12 as the bright pink area under the line indicating the proposed side channel. An interesting possibility exists with this side channel because somewhere near the upper end of this channel there used to be a connection to a 4 ft^3/s (0.11 m^3/s) surface water right now controlled by the Bureau of Reclamation. This water right could be fed into this channel and then routed to side channel #1. This may aid efforts to improve water quality in the area.

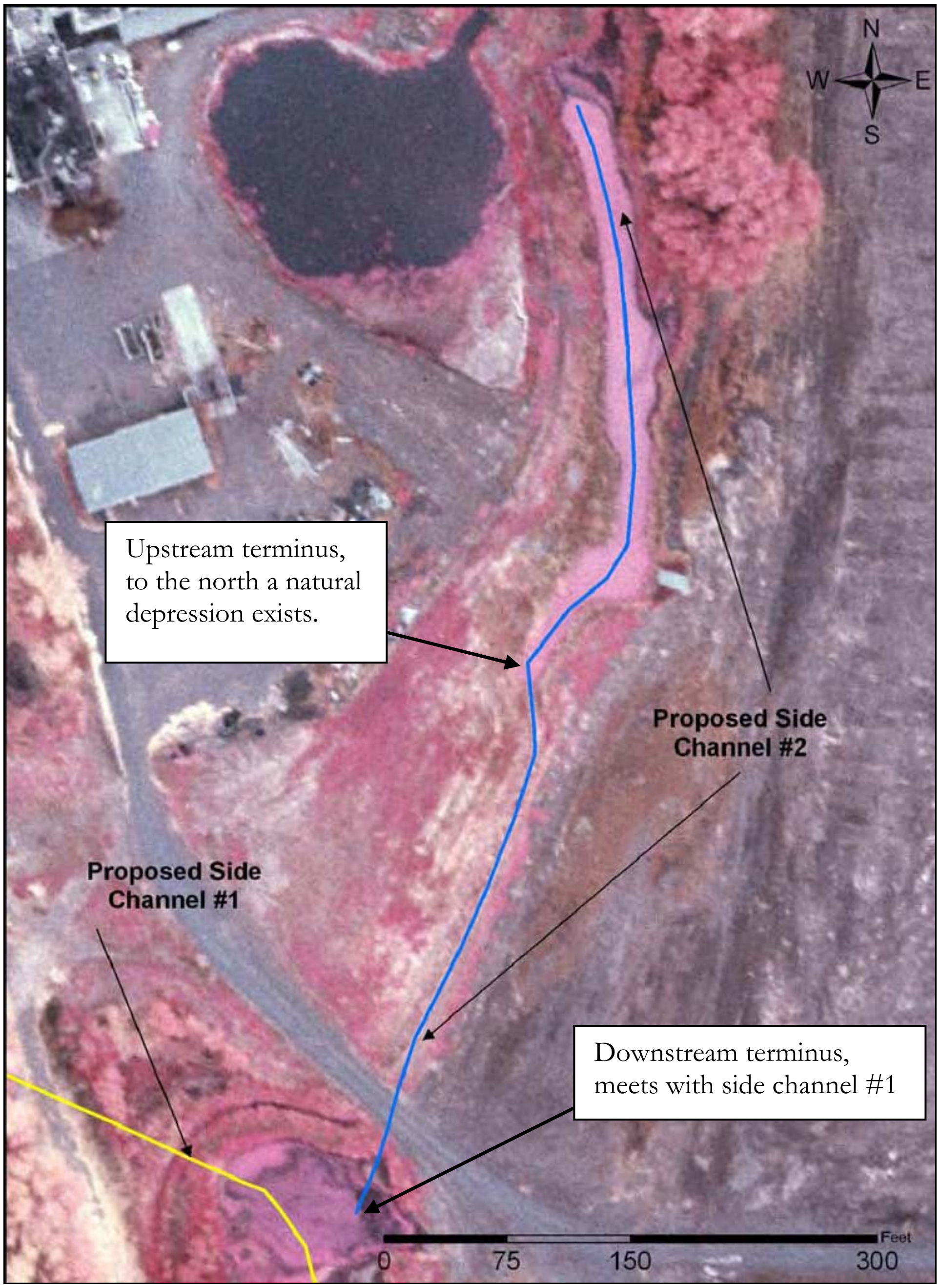

Figure 12: Aerial photograph showing proposed side channel #2. Note the existing depression in the northern half of the proposed channel (light pink). The beginning and end of the excavation is indicated.

SIDE CHANNEL #3

The upstream connection of proposed side channel #3 is near station 5,174 and reconnects to the river near station 6,280 (Figure 7 and Figure 13). This channel is approximately 1,450 feet (137.2 m) long with a slope of 0.00178 ft/ft (0.178%). There are no existing channels or depressions in the vicinity of this channel, however the area northeast of the levee was previously referred to as a lagoon. This area was one of the lowest portions of the floodplain on the east side of the river, although much of this area has been reworked since the topography was flown. Mature woody vegetation grows on the west side of this channel while the east side is void of vegetation. The last 250 feet (76.2 m) of this channel lies outside of Reclamation property.

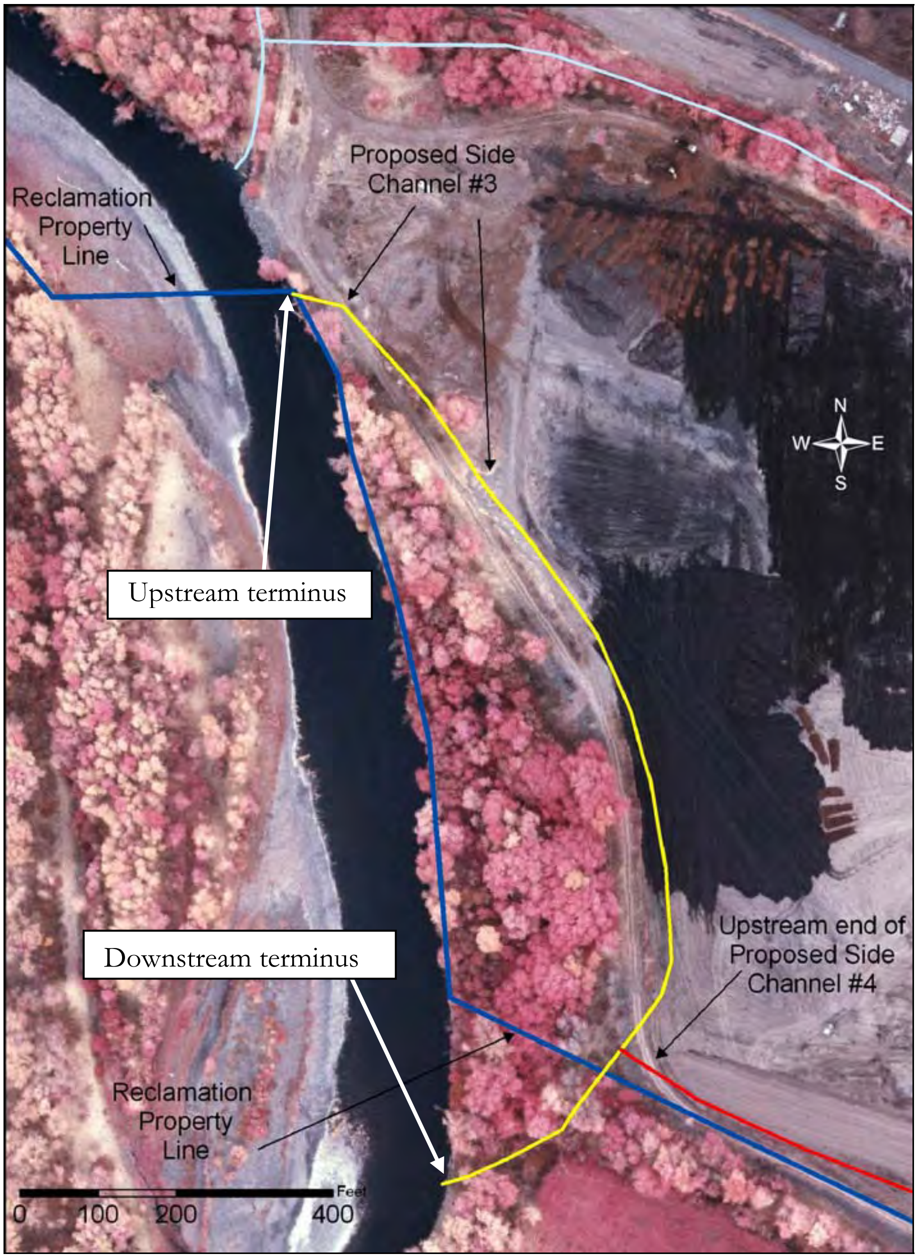

Figure 13: Aerial photograph showing the location of the proposed side channel #3 (yellow). Side channel #4 (red) feeds from this channel. Note the property line in blue. The beginning and end of the excavation is indicated. Flow is from north to south.

SIDE CHANNEL #4

Proposed side channel #4 has an upstream connection with side channel #3 and a downstream connection with Tjossem ditch (Figure 7 and Figure 14). The channel is approximately 1,570 feet (478.5 m) long with a slope of 0.0015 ft/ft (0.15%). Both sides of this proposed channel lack mature vegetation, although the channel alignment could be moved to the south to take advantage of the existing mature vegetation.

It is not necessary for this channel to drain into Tjossem ditch as shown here. The alignment could be changed such that the channel terminates south of its current terminus where side channels currently exist that are wet at less frequent return flows (5-year to 10-year return period). The flow directed through this area would likely create its own channel to the river.

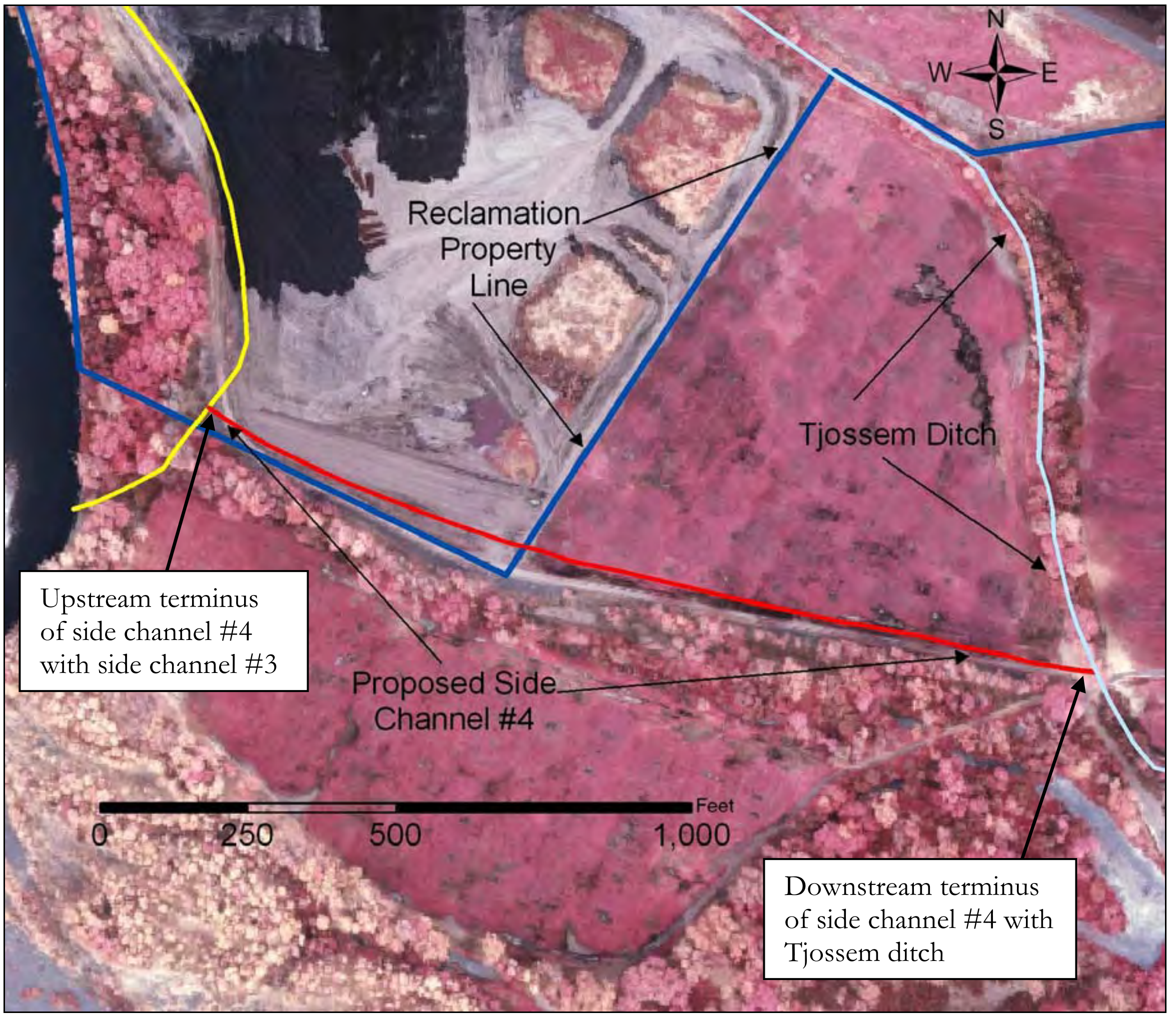

Figure 14: Aerial photograph showing side channel #4 (red) and it's upstream connection with side channel #3 (yellow) and downstream connection with Tjossem ditch (lt. blue).

FLOODPLAIN SOIL COMPOSITION

The proposed channels exist in three different soil types as identified by the Kittitas County Soil Survey (USDA, 2003). The engineering properties have been reproduced from the soil survey and are shown in Appendix B. Soil groups 806 and 706 are primarily composed of coarse alluvial gravel and sand throughout the depth of the measured soil column. Soil group 598 has a finer composition in its upper strata and appears to be an older portion of the floodplain, as evidenced by the lack of gravel near the surface and the loam and silt composition down to 51 inches (floodplain deposits). Below 51 inches the composition is coarse, similar to soil groups 806 and 706. The coarse alluvial sediment will provide an excellent medium for creating side channels. The coarser materials, while tending to be more stable than silt and loam, also provide a good medium for groundwater exchange. Proposed side channels #1, #2 and #3 lie entirely within the 706 or 806 soil groups (very gravelly soil). Side channel #4 lies partially within the 598 soil group. This channel could be less stable than the other proposed side channels cut through gravel, depending on whether the excavation depth is great enough to reach the gravel reported in the soil survey. The flows will more easily rework the finer bed and bank material. However, the soils here may be more conducive to vegetal growth, which will aid in reinforcing the banks.

RESULTS

Among other means, the results of both the large and small models are represented by inundation depth in the appendices. Additionally, digital results of the models have been placed on the CD that accompanies this report. These files are Arc GIS files that can be displayed over the color infra-red photography. The naming convention along with other information is contained in a 'Read Me' file on the CD. In addition to the model results that show computed depth, velocity and water surface elevation are shape files, grids and Triangulated Irregular Networks (TINs) used to develop the model and interpret the results.

LARGE MODEL RESULTS

The results of the modeling will be shown with overlays of the modeled data on top of the aerial photo. This best demonstrates the effects of the changes made to the levee configurations and differences in spatial extent of the modeled flows. These figures are contained in Appendix C. Table 3 details the figures that are contained in Appendix C. The results will be discussed in terms of river stationing in feet, beginning at the upstream end of the reach (Sta. 0) and increasing downstream (Sta. 16,000). Appendix C, Figure C-1 shows the river stationing referred to throughout this report. This stationing is used only for reference in the discussion. Cross sections were not used in the modeling.

Table 3: Table indicating the information contained in the Figures in Appendix C.

Figure Number	Data Shown in Figure	Levee Configuration	Modeled Flow Rate [ft^3/s] and Return Period
Figure B-1	River Stationing	-N/A-	-N/A-
Figure B -2	Depth	Existing	3,150 (Surv.)
Figure B -3	Depth	Existing	5,678 (2yr)
Figure B -4	Depth	Existing	10,065 (5yr)
Figure B -5	Depth	Existing	13,921 (10yr)
Figure B -6	Depth	Existing	18,441 (20yr)
Figure B - 7	Depth	Existing	25,000 (N/A)
Figure B -8	Depth	Mod 1	5,678 (2yr)
Figure B -9	Depth	Mod 1	10,065 (5yr)
Figure B -10	Depth	Mod 1	13,921 (10yr)
Figure B - 11	Depth	Mod 1	18,441 (20yr)
Figure B -12	Depth	Mod 1	25,000 (N/A)
Figure B -13	Depth	Mod 2	5,678 (2yr)
Figure B -14	Depth	Mod 2	10,065 (5yr)
Figure B -15	Depth	Mod 2	13,921 (10yr)
Figure B -16	Depth	Mod 2	18,441 (20yr)
Figure B - 17	Depth	Mod 2	25,000 (N/A)

EXISTING CONDITIONS

The model results of the existing conditions show how the river is artificially constricted at some locations. This is particularly evident when viewing the results of the 20-yr flow (Appendix C, Figure C-6). The modeling results for the existing conditions can be seen in Appendix C on Figures C-2 through C-6. In the upstream portions of the reach, right levee #1 (Sta. 0 – 1,500) restricts the river width and directs flow perpendicular to left levee #1 near station 2,000, creating a 90 degree bend. The interim report recommended that right levee #1 be removed to reduce the stream power through the 90 degree bend. This location has historically had a sharp bend, with a split channel configuration (Appendix A, Figure A-4), however levee construction has forced a single thread channel 400 feet to the east and decreased the bend radius. A significant scour hole currently exists in the vicinity of station 2,000 due to the position of left levee #1, which currently prevents lateral migration.

Right levee #2 (station 3,870 to 4,200) is a short 'river training' levee preventing lateral migration on the right bank. Floodwaters in this location flow onto the floodplain upstream and downstream of the levee, making the levee ineffective at containing flood flows. During high flows, the river is able to access the floodplain on the left side of the river in this location because left levee #1 is positioned approximately 430 feet (131 m) from the river bank.

At station 5,250 the river flows against left levee #1 for a short distance, where a scour hole has formed. Just downstream, at station 5,900 is the upstream end of right levee #3. This levee prevents floodwaters that have accessed the right floodplain at upstream locations from returning to the main channel. There is a small breach in the bend of this levee, which allows some of the flood water back to the main channel. The rest of the water is forced to remain on the floodplain. Where the river flows along this levee a significant scour hole has formed from station 7,400 to 7,800. The highest velocities in the study reach exist at the downstream end of this levee at station 8,924. Just beyond this location the levee moves away from the channel and out onto the floodplain.

The next location where the river flows against a levee is at Hansen Pits and left levee #2. There is a scour hole at this location between stations 12,470 to 12,860. Velocities in this reach are also high. Left levee #2 is breached between stations 12,860 and 13,150. One of the Hansen Pits is currently connected with the river during flows greater than or equal to the 2-year flow (5,678 ft^3/s, 160.8 m^3/s).

Left levee #2 ends at station 14,000. From this point downstream to the end of the model, velocity and depth is reduced due to the more natural geomorphic conditions in the absence of levees. In this section more natural river processes prevail. It was noted during the survey that the bed material sizes and bank heights decreased in this section of the river. The river braids and interacts with the floodplain at a higher frequency. Side channels, bars and islands are numerous and large woody debris is common.

It is important to notice the stark contrast between the wetted widths of the river at the 20-year flood where the river has levees (near station 2,000) and where the river has no levees (near station 14,000). These widths become more similar following the levee modifications.

LEFT LEVEE SETBACK AND REMOVAL OF RIGHT LEVEE #1 – MOD 1

The results of the modeling for Mod 1 can be seen in Appendix C, Figures C-7 through C-10. The only location where the 2-year flow accesses the floodplain (without side channel construction) is at station 2,500. Here a small pool fills on the left bank (Appendix C, Figure C-7). With increasing flows, it becomes evident that the left floodplain experiences more inundation (Appendix C, Figures C-8 through C-10). Greater floodplain inundation results in reduced depth and velocity in the main channel. Figure 15 shows the water surface profile before and after Mod 1. It can be seen that there is approximately 1 foot (0.3 m) of reduction in the water surface elevation from station 0 to 1,850 and approximately 0.5 feet (0.15 m) of reduction from station 1,850 to 3,670 during the 20-year flood. The reduction in velocity for the same return flow is shown in Figure 16. Velocity decreased in the same locations where the depth decreased.

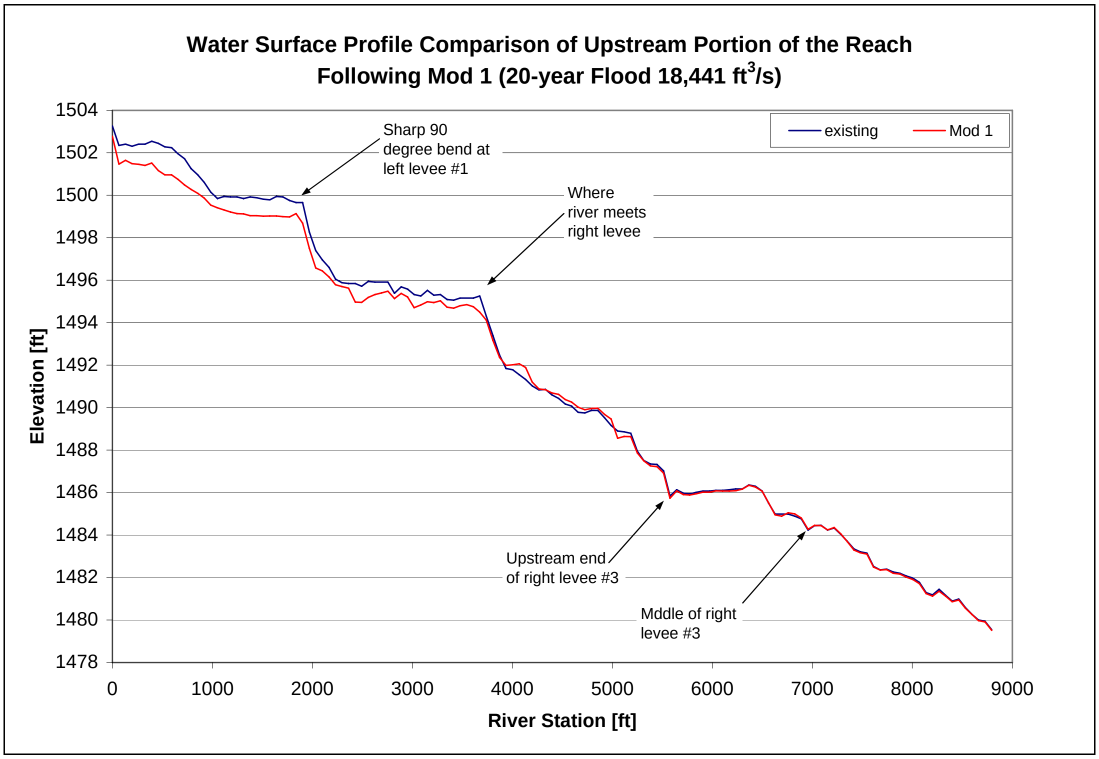

Figure 15: Profiles of the water surface before and after mod 1. Note the significant reduction from the upstream end of the model to approximately station 3500. The entire profile is not shown because there is no change downstream of station 7,000. River stationing corresponds with that shown in Figure C-1.

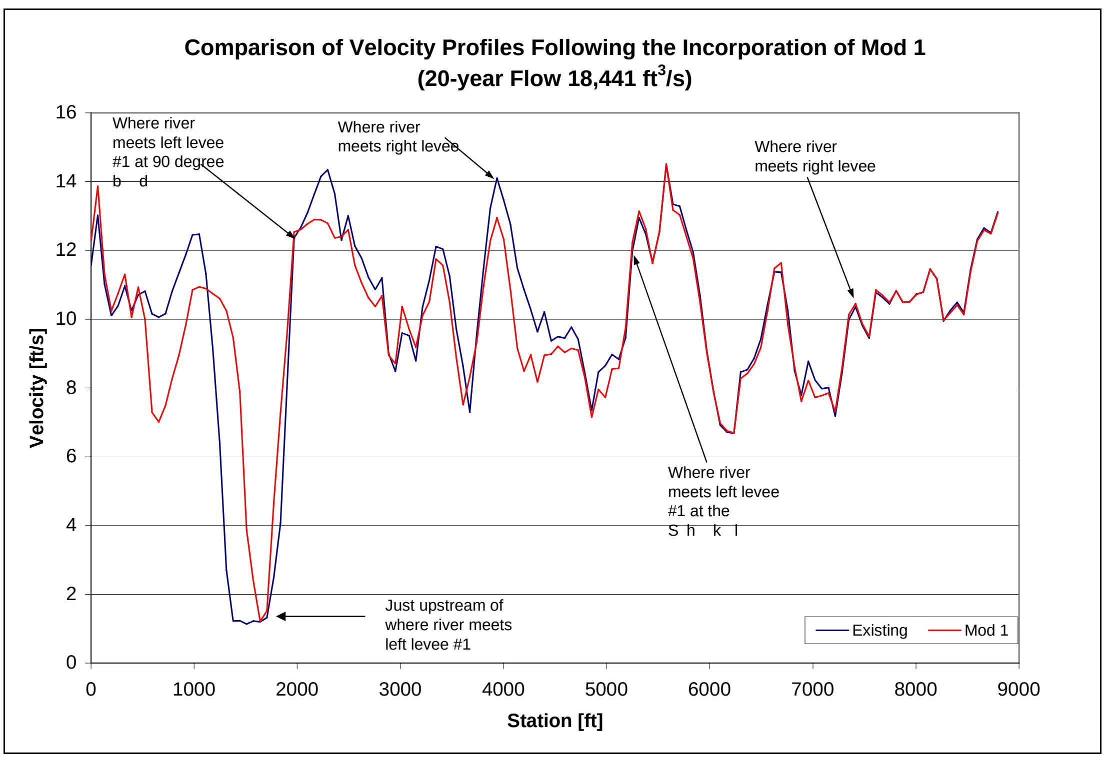

Figure 16: Graph of centerline velocity. Note the reduction through station 5,000. The entire reach is not shown because there is no change downstream of the levee modification. River stationing corresponds with that shown in Appendix C, Figure C-1.

During the 20-year flow (Appendix C, Figure C-10), water flows against the proposed levee near the upstream end for approximately 1,000 feet (304.8 m). Modeled water depths at the levee do not exceed 3.5 feet (1.1 m) and modeled velocities are between 3 and 5 ft/s (0.9 and 1.5 m/s). The remaining portion of the proposed levee is untouched for the 20-year flow. In the vicinity of station 2,500 wetted widths increase from 575 feet to 1,181 feet (175.3 to 360 m). Improved floodplain interaction is also evident from stations 5,000 to 6,000 when wetted widths on the left floodplain in the vicinity of the proposed levee setback increase from a maximum of 1,150 feet to 1,640 feet (350.5 to 499.9 m) near river stations 7,500 to 9,000.

On the right bank, the removal of right levee #1 results in the inundation of Fogarty Ditch during the 20-year flow. This may cause some concern for the ditch if it is still used. The possibility exists that measures may need to be taken to maintain the integrity of this ditch through maintenance or leaving the existing levee in place around the headworks of the ditch. It is expected that a simple field investigation would indicate the necessary action, if any.

The water accessing the right floodplain as a result of the removal of right levee #1 flows down valley and over Riverbottom Road. However this does not appear to exacerbate the existing condition where flood flows accessing the right floodplain near right levee #2 also inundate Riverbottom Road. The inundation of the wooded section and part of the cultivated field near right levee #1 provides a wider flow path for water that is directed toward the former location of left levee #1. This reduces the likelihood of the river migrating to the east near station 2,000.

LEFT AND RIGHT LEVEE SETBACK WITH REMOVAL OF RIGHT LEVEE #1 – MOD 2

Modeling results of Mod 2 are shown in Appendix C, Figures C-11 through C-14. There is further reduction of the depth and velocity with the setback of the right levees. Figure 17 shows the water surface elevation profile for Mod 2 at the 20-year flood. Further reduction in water surface elevation is realized with Mod 2 from stations 2,100 through 4,400. Velocities are also reduced, as shown in Figure 18.

The most important difference in the results of Mod 2 is that Riverbottom Road is not inundated because of the placement of the proposed right levee. This was cited by representatives of Kittitas County as an important consideration.

When the entire modeled reach for the large model is considered, there is a 15% increase in wetted surface area for the 20-year flood following the incorporation of Mod 1. This wetted surface area is gained primarily on the Schaake property and in the vicinity of right levee #1. Under the Mod 2 scenario, the total increase of wetted surface area from existing conditions only increases by approximately 2%. The reason for this difference is the addition of the setback levee on the right bank, which prevents water from flowing over Riverbottom Road. Under existing conditions and the Mod 1 scenario, water flows over Riverbottom Road and inundates much of the area behind the road. In other words, Mod 2 exchanges wetted surface behind Riverbottom Road for wetted surface area at the north end of the reach in the vicinity of right levee #1 and on the Schaake property behind left levee #1.

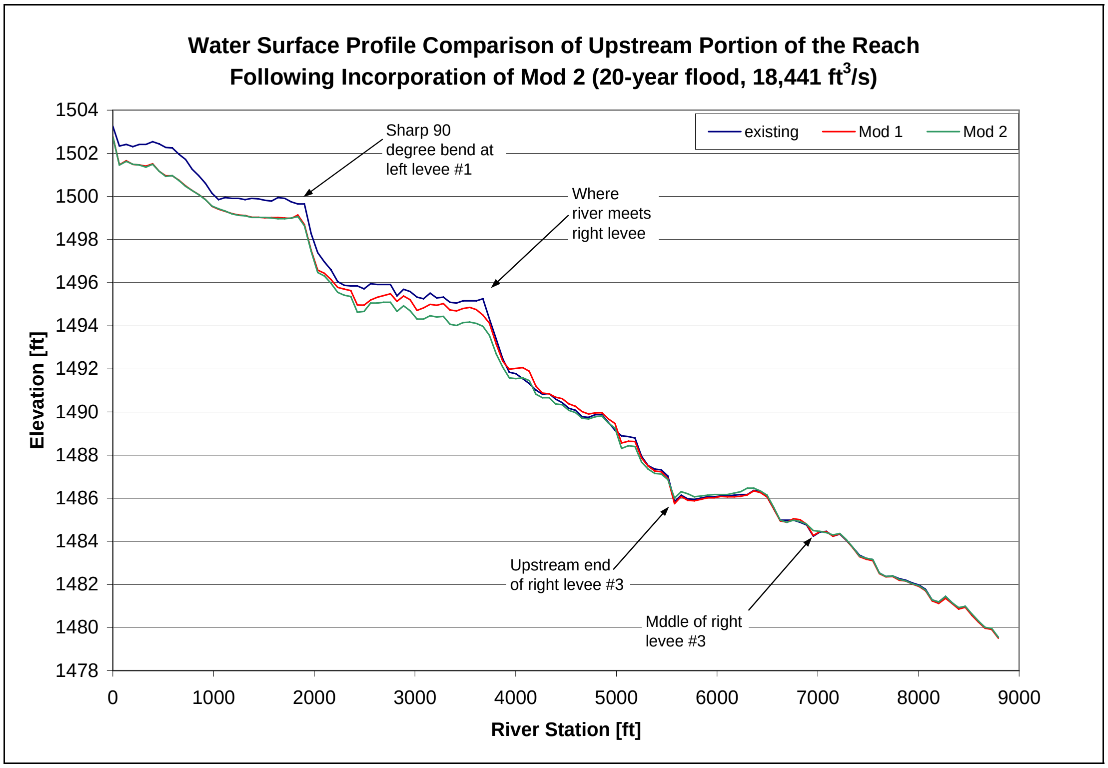

Figure 17: Profile of predicted water surface elevation following the setback of levees on both sides of the river and the removal of right levee #2 (Mod 2). Note the further reduction of depth from stations 2,100 through 4,400. River stationing corresponds with that shown in Appendix C, Figure C- 1.

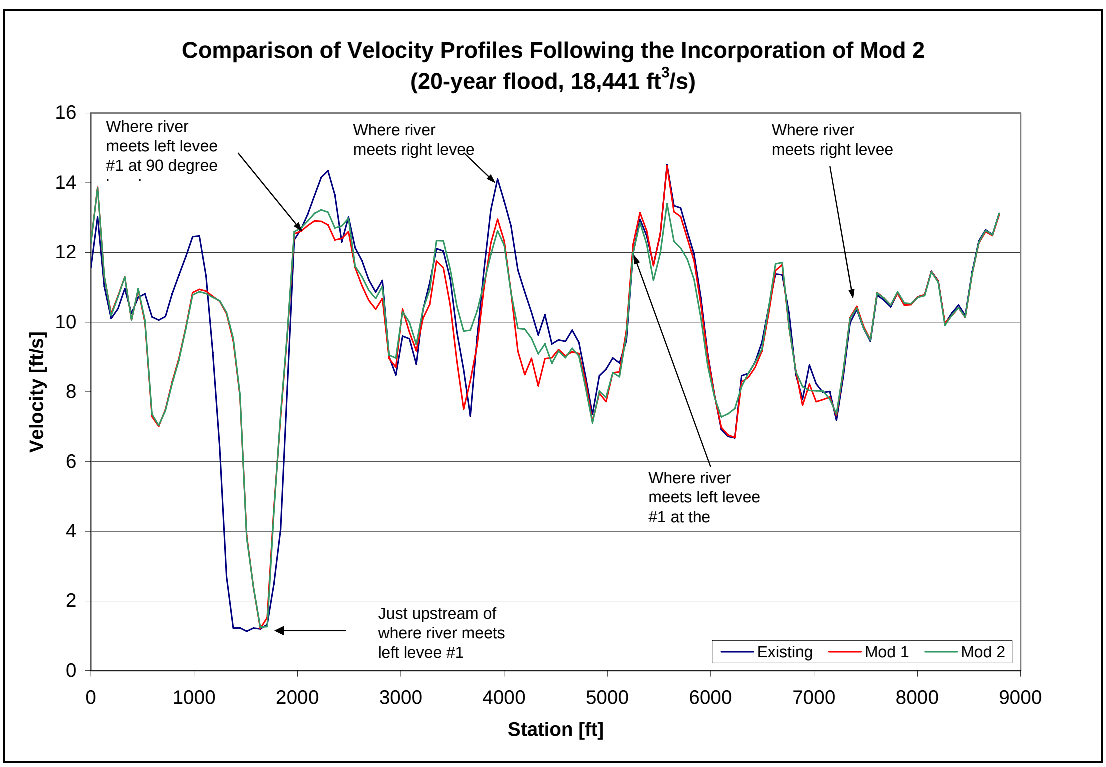

Figure 18: Chart showing the velocity over the thalweg. Note further reductions in velocity near stations 4,000 and 5,600. The entire reach is not plotted because there is no change downstream of the levee modifications. River stationing corresponds with that shown in Appendix C, Figure C-1.

LEVEE EXCAVATION

During the removal of levee material for left levee #1 near station 2000, the riprap below the natural grade should remain in place. This will slow the migration efforts of the river during the time it is adjusting to the levee modifications. Following the removal of left levee #1 and right levee #1 the river will have a broader flow path during high flows. The broader flow path decreases the stream power of the river in this location which will decrease the tendency of the river to migrate. Because of the wider flow path and decreased stream power, this portion of the river is expected to eventually become similar to the 1966 alignment (Appendix A, Figure A-4).

Levees removed in the hydraulic model were removed completely along their entire length so that locations where the levees once existed match the surrounding topography. The estimated volumes for levee removal are shown in Table 4. These volumes were obtained by comparing 'before' and 'after' grid surfaces in a GIS. Questions were raised at the presentation of the preliminary study whether it was necessary to remove the entire levee or if portions could remain in place and still have the removal be effective. There may be portions of the existing left levee #1 that could remain in place without jeopardizing the flow of floodwater back to the main channel. Figure 19 shows some areas of left levee #1 that could remain in place without jeopardizing the effectiveness of the project. This reduces the excavation length of left levee #1 by approximately 1000 feet (304.8 m). These locations were determined by areas that are not expected to be inundated during a 20-year flood. It may be possible to leave more of the levee in place or create strategic breaches in the levees, however portions of left levee #1 that remain in place should not impede floodplain flows from returning to the main channel.

Table 4: Table showing excavation volumes for each proposed levee removal.

Levee	**Estimated Excavation Volume [yd3]**
Left Levee #1	27,000
Right Levee #1	18,000
Right Levee #2	2,000
Right levee #3 (upstream portion)	5,000
TOTAL	***52,000***

Figure 19: Aerial view showing the locations where the levee can remain in place (Red blocks) without preventing floodplain flows from returning to the main channel.

SMALL MODEL RESULTS

The interaction of the river channel with the floodplain and proposed side channels is the primary concern of the small model. The invert elevation of the side channels was chosen to optimize a balance between excavation volume and the flow rate in the main channel at which the side channels are inundated. The target flow rate of the main channel above which side channels will be flowing was chosen to be 1,000 ft^3/s (28.3 m^3/s). Inundation maps showing the modeled depth for the side channels is shown in Appendix D. Table 5 categorizes the data contained in Appendix D.

Table 5: Table showing the contents of Appendix D where the results of the small model are shown.

Figure Number	Data Shown in Figure	Side Channel	Modeled Flow Rate [ft³/s]
Figure C-1	Depth	Entire Model	500
Figure C-2	Depth	Entire Model	1000
Figure C-3	Depth	Entire Model	2000
Figure C-4	Depth	Entire Model	3,150
Figure C-5	Depth	Entire Model	5,678
Figure C-6	Depth	Side Channel #1 & #2	3,150
Figure C-7	Depth	Side Channel #3	3,150
Figure C-8	Depth	Side Channel #4	3,150
Figure C-9	Depth	Side Channel #1 & #2	5,678
Figure C-10	Depth	Side Channel #3	5,678
Figure C-11	Depth	Side Channel #4	5,678

Flow rates within the side channels are only estimates of what may actually flow within them should they be constructed. The more important relationship is the proportion of the flow in one channel compared to another and the direction of flow. The flow values for the side channels provided in the following paragraphs are based on a flow of 3,150 ft^3/s (89.2 m^3/s) in the main channel, which can be considered a typical summer flow. The results of the small model are summarized in Table 6.

Table 6: Table showing the modeling results of the side channels for a main channel flow of 3,150 ft^3/s at the upstream end of the reach.

Channel #	ApproximateLength [ft]	Slope [ft/ft]	Average Velocity [ft/s]	Anticipated Water Depth [ft]
1	1,520	0.00235	2.5-3.5	2.2-2.7
2	700	N/A	0	2-3
3	1,460	0.00178	2-3	2.0-2.6
4	1,570	0.0015	2.0-2.5	2.0-2.3

It is anticipated that there will be regular groundwater interaction with the proposed side channels. This effect will be entirely dependant upon the elevation of the groundwater table. In the 2000 color infra-red photography some shallow topographical depressions in the vicinity of the Schaake property contain groundwater. The flow rate in the main channel during this photo was 585 ft^3/s (16.6 m^3/s), as indicated by the Ellensburg gage. This flow rate is near the lower end of the normal low flow throughout the year, indicating that the groundwater table on the Schaake property is likely at an elevation such that shallow channels (2 – 4 feet below the ground surface) will remain wet throughout most or all of the year. The presence of groundwater in the side channels was not part of the numerical model. This causes the modeling results to be conservative in the estimates of the amount of time throughout the year that the channels will remain wet.

The locations at which the side channels connect with the main channel were chosen based on what is determined to be either a stable or slightly eroding bank. If the bank where the connection is made is stable or slightly eroding, it is more likely that the connection will remain open to allow flow into the side channels. An aggrading bank or one that may tend to migrate toward the opposite bank may experience aggradational conditions that could cause the channel to aggrade closed. It is intended that these channels will be maintenance free however, natural channel processes may to eventually cause these channels to no longer function as intended. Following the levee setbacks proposed in this report, the channel is expected to aggrade slightly over time, creating a condition where more frequent floodplain inundation occurs. In this case, natural fluvial processes may or may not form additional side channels or cause morphological changes to the constructed channels. In either situation the desired habitat will likely be created if natural processes are allowed to occur in this reach of the river.

SIDE CHANNEL#1

This channel has a slope of 0.00235 ft/ft and is expected to carry approximately 100 ft^3/s (2.83 m^3/s) of flow when there is 3150 ft^3/s (89.2 m^3/s) in the main channel at the upstream end of the modeled reach. Modeled centerline velocities in this channel range from 2.5 to 3.5 ft/s (0.76 to 1.1 m/s) during a flow of 3,150 ft^3/s (89.2 m^3/s) in the main channel. Side channel #1 terminates at the Tjossem access channel, where one third of its flow returns to the river via the upstream portion of the Tjossem ditch. The remaining two thirds of the flow continues down the Tjossem access channel to the head works for Tjossem ditch, where approximately one fourth of that flow is diverted into Tjossem ditch, with the remaining flow continuing downstream in the access channel to return to the river near station 1570. The most important consideration for implementing this side channel is the possibility of reversing the direction of flow in the upstream half of the Tjossem access channel. The model indicates that this will occur because flow has been added to the Tjossem access channel. This reversal of flow presents no major concern because 2/3 of the flow entering the Tjossem access channel from side channel #1 flows in the direction of the Tjossem head works, providing the necessary flow for the 4 ft^3/s (0.11 m^3/s) diversion. Figure 20 shows the flow direction within the Tjossem access channel before and after implementation of side channel #1. Velocity vectors for this junction are also shown in Appendix E, Figure E-1.

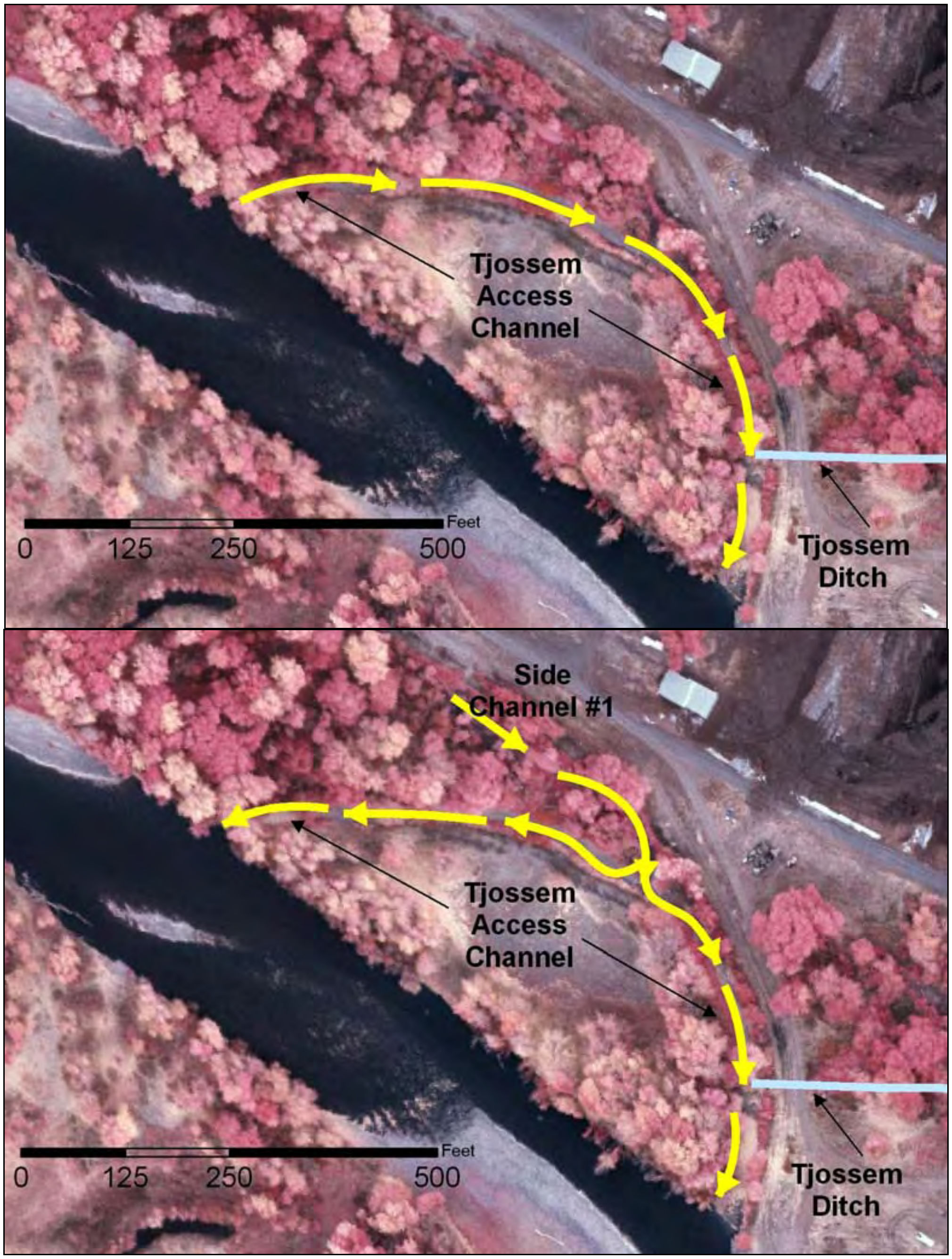

Figure 20: Diagrams indicating the direction of flow in the Tjossem access channel in the vicinity of the proposed side channel #1. The top diagram shows the existing conditions and the bottom picture shows the anticipated flow direction after implementing side channel #1.

SIDE CHANNEL #2

Side channel #2 (Appendix D) is designed to be a backwater channel with little or no velocity. This channel will increase the complexity of the proposed floodplain channel network due to the reduced velocity. The channel terminates near the northwest corner of the property where a 4 ft^3/s (0.11 m^3/s) water right once entered. This water right was not modeled because the flow is not significant enough to change any modeling results and at this time it is not certain what role this water right will play in the development of the property. Excavation is minimal for this channel, as it takes advantage of an existing depression in the topography (Figure 12). The model results indicate that this channel is wet at main channel flows of 2,000 ft^3/s ($56.6\ m^3/s$) or greater, however groundwater is likely to keep this channel wet through most of the year. Water quality may be an issue in this side channel due to the lack of velocity, allowing pollutants to concentrate. The introduction of the 4 ft^3/s ($0.11\ m^3/s$) water right at the head of this channel may prevent the pollutant concentrations from becoming excessive. The water depth in the area of the existing depression shown in Appendix D, Figure 12 is the depth above the existing groundwater because no channel depth was cut in the model.

SIDE CHANNEL #3

This channel has a slope of 0.00178 ft/ft and carries approximately 75 ft^3/s ($2.1\ m^3/s$) to its junction with side channel #4, at which point approximately two thirds of the flow enters side channel #4, with the remaining flow returning to the main channel. Modeled centerline velocities in side channel #3 range from 2 to 3 ft/s (0.6 to 0.9 m/s) when the flow in the main channel is 3,150 ft^3/s ($89.2\ m^3/s$). Downstream of the junction with side channel #4 modeled velocities decrease to approximately 1 ft/s. An important consideration for this channel is that the model indicates that flows in side channel #3 escape the channel and flow over the floodplain during a 2-year flood (5,678 ft^3/s, $160.8\ m^3/s$). This is a desirable result however the topography of this area has changed since the LiDAR was flown. The modeled depths can be seen in Appendix D, Figure D-5.

SIDE CHANNEL #4

Side channel #4 is fed entirely from side channel #3. It has a slope of 0.0015 ft/ft and is expected to carry approximately 50 ft^3/s ($1.4\ m^3/s$) when 3,150 ft^3/s ($89.2\ m^3/s$) flows in the main channel. Modeled centerline velocities in the side channel range from 2.0 to 2.5 ft/s (0.6 to 0.76 m/s) when there is 3,150 ft^3/s ($89.2\ m^3/s$) in the main channel. The amount of flow in this channel may be an excessive amount considering that it is being fed into Tjossem ditch. It may be possible to direct the flow of this channel in such a way that less flow enters Tjossem ditch, or to not connect with Tjossem ditch in any way. There are existing low spots in the floodplain where the flow might be able to drain back to the main channel. A short side channel to direct the flow of side channel #4 could be investigated further and it is not likely that more modeling would be needed.

DESIGN OF SIDE CHANNELS

CHANNNEL GEOMETRY

Previous discussions between the TSC and YRBWEP regarding channel construction indicated that the channel construction on the Schaake property will be performed with a bulldozer. Channel construction with this type of equipment can create more impact than is necessary, particularly when removing the spoils from the newly cut channel or clearing existing channels of forest litter and debris. While much of the construction could take place with a bulldozer, other equipment could create less of an impact to the property and existing vegetation. These discussions also indicated that a 4:1 (H:V) side slope is desirable for the growth of riparian vegetation where none currently exists. The drawback to constructing a channel with low side slopes is that it forces a wide channel, which is more costly to construct and creates more impact to the floodplain. Additionally, it is not likely that the side channels will be able to maintain that geometry throughout its length. The design of the side channels for this project will call for a pilot channel dug to a specified elevation while maintaining a minimum bottom width. The angle of repose of the earth material on the Schaake property is expected to result in a side slope of approximately 1:1. If the natural angle of repose is capable of maintaining a slope steeper than 1:1 then the channel should be cut so that an approximate 1:1 side slope is achieved. Spoils from the pilot channels should not be staged at the channel margins, as this will prevent the side channels from accessing the floodplain on a regular basis and possibly cause the side channels to incise.

Investigations were made of existing, naturally formed side channels in the floodplain of the Yakima River just downstream of left levee #2 near station 14,000 (Appendix C, Figure C-1). The natural side channels had varying bank slopes from near vertical to near horizontal above the water surface. Near vertical slopes did not dominate the channel geometry and usually existed near the base of large trees or at the outside of bends in the channel. Reed Canary Grass (*Phalaris arundinacea*) on the banks of the side channels also creates a steeper side slope than might otherwise exist. The low sloped areas are often limited to the inside of bends on gravel bars, but occasionally existed in straighter stretches of the channels in some locations. Channel top widths varied from 15 to 40 feet (4.6 to 12.2 m), with wider widths being more common. These factors were taken into consideration during the study. The numerical model assumed a channel top width of 26.2 feet (8 m) with a bottom width of 13.1 feet (4 m). Beyond the specified top width, the natural topography remained unchanged.

It is the conclusion of the author that a specific and consistent channel geometry for the constructed side channels should not be given. Stable channel and regime analysis methods are empirical in nature and were derived for straight, low sloping canals where steady flows are to be expected. The proposed side channels will have a large variability in flow rate and duration of peak flows that are routed through them, further complicated with groundwater flows. The channel geometry and to some degree, the planform will be determined by the flow within the channel, their slope and the size of available bed material. A better method for constructing the side channels is to specify a general slope and a range of bottom and top widths, which will provide some variability in channel width and bank slope and allow operators to adapt the channel to specific situations, such as stands of mature vegetation. Where healthy riparian vegetation exists there should be minimal disturbance to the area due to the difficulty in regenerating healthy, native flora. In these areas only the determined bottom channel width should be cleared, with the side slopes determined by the angle of repose of the bank material. Where possible, side slopes should be .approximately 1:1.

Modeled side channel flow depth for the 2-year flood ranges between 3.5 to 4 feet (1.1 to 1.2 m). When the depth exceeds 4 feet in the side channels it flows onto the floodplain, as shown in side channels 3 and 4 in Appendix D, Figure D-5. Channel depths should be approximately 4 feet (1.2 m) deep, however in many locations, the natural topography will be at least 4 feet (1.2 m) above the channel bottom, in which case the bottom elevation should be the major criterion.

Recommended bottom widths should fall between 8 and 16 feet (2.4 and 4.9 m). Top widths should be between 16 and 24 feet (4.9 and 7.3 m). Side slopes should be shaped to 1:1 where the natural angle of repose does not form a similar side slope. Around channel bends, the inside of the bend should have a flatter slope than the outside of the bend and the channel bottom may be narrower (Figure 22). The most critical guideline is the invert elevation of the channels, particularly at their connections to the main channel. Channel elevations, slopes and anticipated depths are summarized in Table 7.

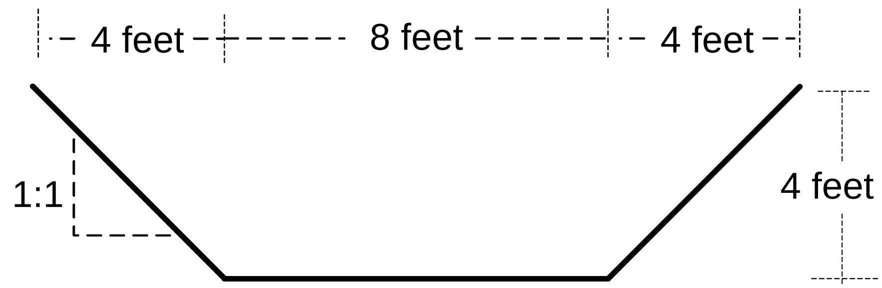

Figure 21: Typical cross section showing a 1:1 side slope on both banks. This would be a typical cross section shape for the pilot channel. Not all channels will be 4 feet deep.

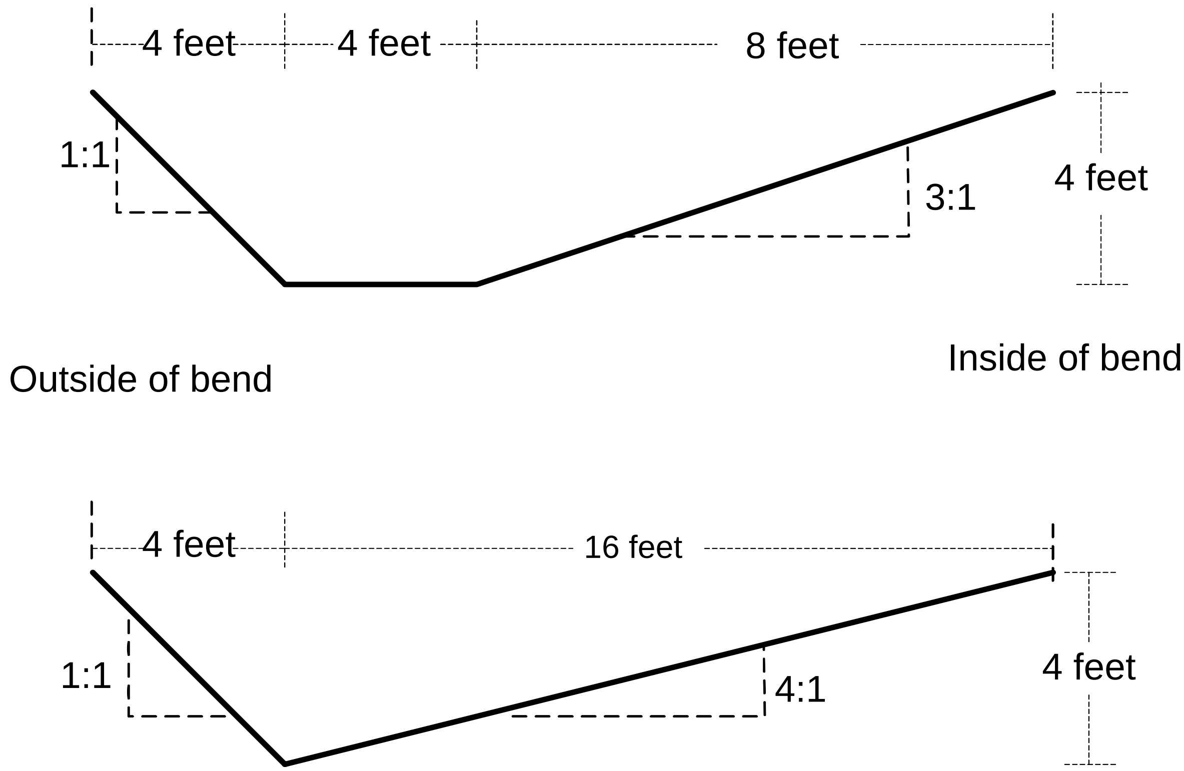

Figure 22: Example cross sections of a side channel in a bend. The upper cross section is perhaps how the channel might be constructed. The bottom channel is what might be expected to form over time depending on the radius of curvature, bed material, depth and velocity. Channel bends can be constructed similar to the shape of the either cross section. Not all channels will be 4 feet deep.

Table 7: Table of channel design specifics. Elevations are given in NGVD88. Upstream and downstream terminus locations are shown in Figures 10 – 13.

	Bed elevation @ upstream terminus [ft]	**Bed elevation @ downstream terminus [ft]**	**Minimum Channel Depth [ft]**	**Channel slope [ft/ft]**
Side channel #1	1488.2	1484.6	3.5	0.00235
Side channel #2	1489.0	1487.3	3.5	N/A
Side channel #3	1480.9	1478.3	4	0.00178
Side channel #4	1478.8	1476.2	4	0.0015

To carry out these guidelines, it will be necessary to stake the alignment of the pilot channels. The stakes should be placed at regular intervals or where channel dimensions or direction will change and include the required excavation depth and top and bottom width for the equipment operator.

ESTIMATED CHANNEL EXCAVATION VOLUMES

Estimates of excavation volumes were made for the four proposed side channels. The results are shown in Table 8. The depth of excavation was calculated by subtracting the two surface grids in a GIS. This results in a separate grid with excavation depth for each channel (Appendix F). Excavation volumes will increase from estimated values if 4:1 side slopes are carried out to meet with existing terrain throughout the channel length.

Table 8: Table of estimated excavation volumes for the four proposed side channels. The assumed cross section used to determine these volumes is the cross section used in the model grid, a bottom width of 13.1 feet and a top width of 26.2 feet.

Channel	Estimated Excavation Volume (yd^3)
Side Channel #1	1,400
Side Channel #2	660
Side Channel #3	4,600
Side Channel #4	3,200
TOTAL	***9,860***

DISCUSSION

LEVEE MODIFICATIONS

The modeling results indicate a significant reduction of the water depth and velocity in the main channel from approximately stations 1,500 to 5,000 with both levee modifications implemented (Mod 2). When depth and velocity are reduced, the erosive power of the river is also decreased. This reduces the opportunity for flood damage, particularly due to sudden planform changes. The wider river corridor allows the river to naturally migrate and/or braid and create and maintain a floodplain. It is expected that the river will change its position somewhat following the removal of the levees and seek an equilibrium configuration. The equilibrium slope of the study reach is likely to be similar to the current slope, which translates to minimal change to the current channel length. This conclusion is based on information taken from the downstream portion of the study reach that has not been subjected to artificial constriction and historical photographs that do not indicate a change in channel length in over approximately 90 years (Appendix A). The largest change to the current river configuration is expected to be the width of the active channel and to a lesser degree changes in planform and bed material. Following the construction of the existing levee #1, the main channel became single thread and moved 400 feet to the east, where the left bank levee currently exists. There used to be a slough at this location, visible in the 1912 survey (Appendix A, Figure A-1 and A-4). Following the removal of right levee #1 and left levee #1 the river will likely widen at the ninety degree bend, with the expectation that in planform, it will resemble the 1966 channel (Appendix A, Figure A-2) with an island. There is a possibility that the remaining riprap on the left bank will eventually be flanked by the river and form the beginning of an island, with a channel to the east of the existing riprap bank. This is not likely to be detrimental because of the reduced stream power at this location due to the levee reconfiguration and would increase channel complexity.

Another consideration for right bank levee modification is that the downstream portion of right bank levee #3 (river stations 7,200 through 10,800; Figure 6 and Appendix C, Figure C-1) be set back to Riverbottom Rd., similar to the upstream levee setback proposed in Mod 2. This would compliment the results of the proposed levee reconfiguration and further widen the river corridor. Following the proposed Mod 2 (levee modifications on both sides of the river), this becomes the most constricted portion of the reach, resulting in the highest velocities in the study reach, near river station 9,000. As can be seen in Figure 4, the downstream portion of right bank levee #3 is directing flow into left levee #2, similar to the current situation upstream with right levee #1 and left levee #1 near station 1,500 to 2,000 (Figure C-1 and Figure 6),

LEVEE DESIGN SUGGESTIONS

Because of the distance from the levee to the main channel, most of the levee is not expected to have water at its toe during the 20-year flood event with the river in its current alignment (Appendix C, Figures C-10 and C-14). As measured from Damman Road along the proposed levee alignment, the first 800 feet (243.8 m) of the levee will only experience backwater flows and will not likely require heavy reinforcement. Historical river alignment suggests that the river is not likely to migrate in this direction. For the remaining length of the levee there is one portion that is wet at a 20-year flow. With either levee modification incorporated, modeled velocities along this wetted portion of the levee are as high as 3 to 5 ft/s (0.9 to 1.5 m/s) at the toe (Figure 23) for a 20-year flood event. This location will need to be reinforced in the event of an unplanned avulsion to isolate the river from Interstate 90. The remaining portion of the levee is not likely to experience high velocities at the toe with the current river alignment but levee designs should anticipate the worst case scenario and plan for the river migrating to the east.

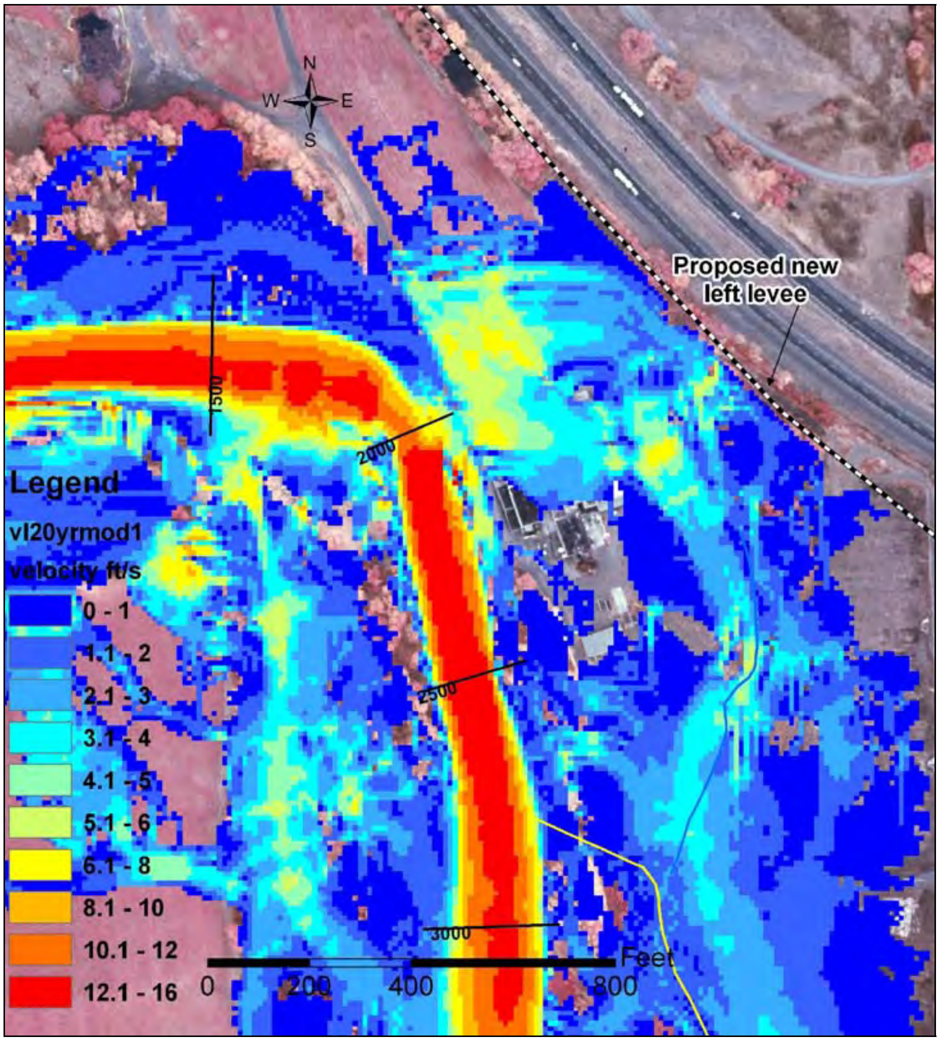

Figure 23: Plot of velocity at the 90 degree bend following levee modification.

SIDE CHANNELS

The construction of the pilot channels in the floodplain provides a means by which the main channel flows can interact with the floodplain on a regular and sustained basis. Following levee setback, the main channel is expected to aggrade somewhat, with a decrease in bed material size, creating a condition where the floodplain is accessed more frequently. This will take many flood cycles over many years before this effect is realized. Construction of pilot channels in the floodplain provides the desired habitat in a much shorter time scale and does not require adjustment of the main channel.

The dimensions of existing, natural side channels were taken into consideration during the hydraulic modeling and in determining the dimensions that are suggested in this report. Numerous side channels exist immediately downstream of the leveed reach near the Hansen Pits, some of which were visited during the study. Figures 24 through 27 show the variation of habitat types with respect to water depth and velocity and channels width.

Figure 24: Photograph of a still water side channel. The photographs are taken from the same location, one looking toward the main channel (left) and one looking away from the main channel (right).

Discussions took place during this study regarding the revegetation of the site, particularly along channel margins. It was requested that the side slopes of the channel be kept at 4:1 or less. While it is possible to construct the channels this way, it is not likely that the side slopes will remain at that slope. The erosive action of the water and the angle of repose of the soil will ultimately determine the side slopes. In some locations, particularly on the inside of bends, a low side slope is sustainable. It was decided that the side channels will be cut as pilot channels with an approximate 1:1 side slope and the planting of the riparian vegetation will be done after the pilot channels have had time to adjust and determine their own geometry. A 1:1 side slope was chosen because this is the anticipated angle of repose of the soils on the floodplain and similar to what will be the dominant bank slope. Because the revegetation of the channel margins will likely take the form of seeding, it may be best to seed all the banks and those that are eroded away will be left alone. It will be unlikely that the flows through the side channels will be predictable unless a stage-discharge record can be obtained before the vegetation effort. This may be advisable depending on plans for vegetation. Automated data collection systems are available. Even then predicting the river flows may be challenging if the work is done in the spring.

One existing side channel downstream of the Schaake reach has a log jam at its upstream junction with the main channel (Figure 26). It is evident that this structure is stabilizing the entrance of the side channel as well as providing increased habitat complexity. It would be advisable to retain any large trees removed during channel construction or levee deconstruction. The debris can be placed in the channel to encourage a specific flow direction, create a pool, reduce or increase flow into another channel at a junction or to stabilize a specific area.

Figure 25: Side channel downstream of Hansen Pits. Note the steep bank angle on the left side of the photograph while there is a low bank angle on the right side, which corresponds to the inside of the bend. This is currently a low velocity channel but was once actively migrating right to left, building a bar on the right and eroding the bank on the left.

Figure 26: Photo showing a log jam at the entrance of a naturally formed side channel. The main channel flows from right to left in the photo and the side channel is flowing toward the reader.

Figure 27: Photo showing a natural side channel with a top width of approximately 15 to 20 feet, a thalweg depth of about 3 feet and velocities in the range of 2 to 3 ft/s. Note the reed canary grass supporting what appears to be a 1:1 or 2:1 side slope.

WATER QUALITY

There is cause for concern regarding the quality of the surface and groundwater flows on the Schaake property, creating concerns for the quality of water that will be routed to the main channel as well as providing new habitat where nutrient concentrations and oxygen demand may be elevated. As of this writing, a water and soil quality study is being performed. Some of the proposed side channels take advantage of the existing depressions on the property, which currently hold groundwater and aquatic vegetation. These areas may also need to be investigated before utilizing them as habitat. The moving water introduced to these existing depressions will be cooler and contain more oxygen than the stagnant water, which will improve the quality to some extent. Side channel #2 is the only proposed channel that has little or no velocity. This could change if the 4 ft^3/s (0.11 m^3/s) water right is routed through this channel. Regardless of the initial conditions regarding water quality following floodplain improvements, it will be an improvement over what currently exists

CONCLUSION

The Schaake property was purchased in order to improve salmonid habitat. The procedures outlined in this report are expected to meet that goal, in addition to improving the flood protection in the vicinity of the Schaake property on both sides of the river. Recommendations and guidelines have been given on the pilot channel dimensions and can be used for their construction. Recommendations have also been made regarding levee construction, however further consultation will be required for levee design.

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APPENDIX A

Historical River Planform (1912 & 1966 over 2000)

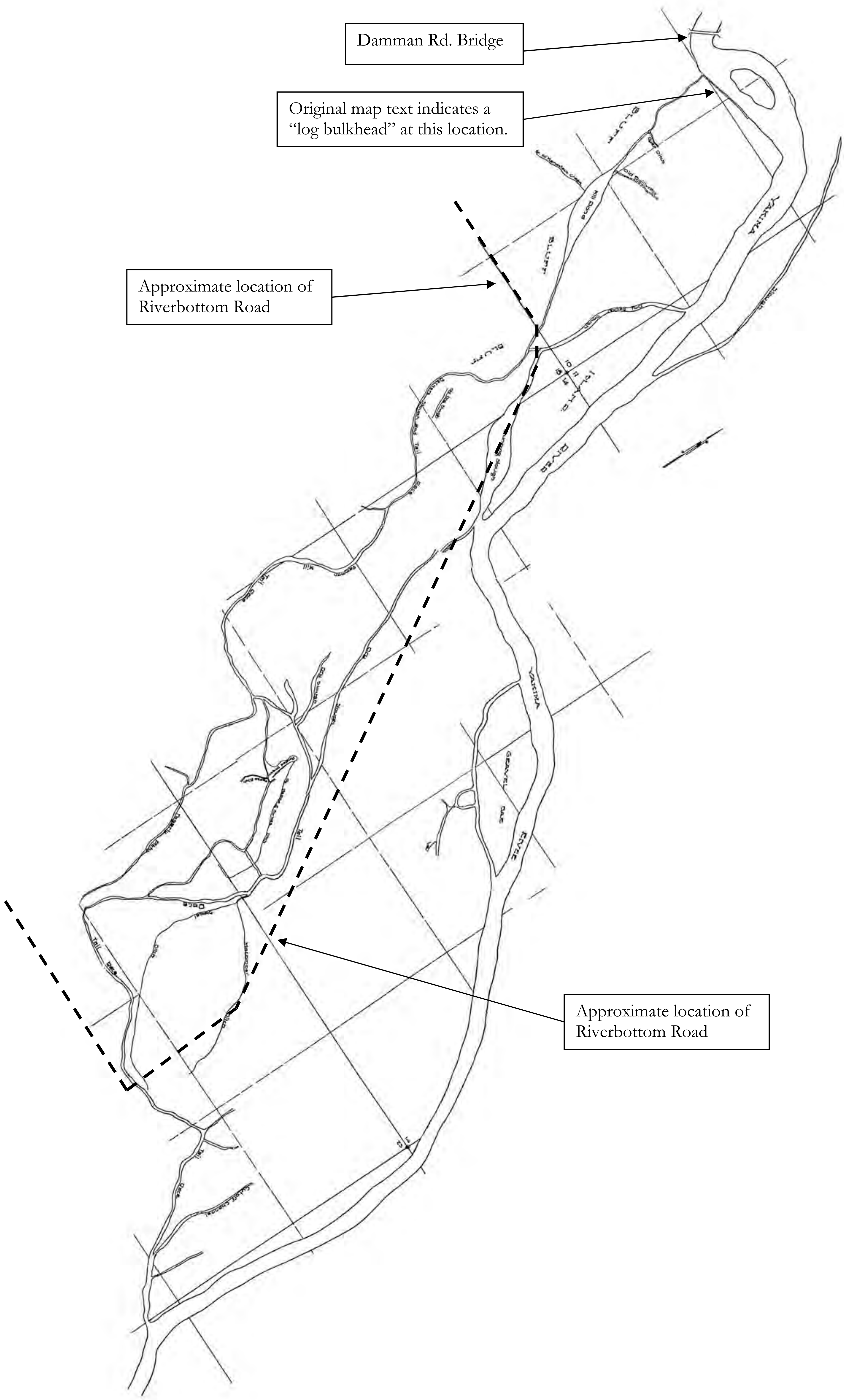

Figure A-1: Composite map of the 1912 Yakima River ditch survey. The length of the river shown in this diagram is approximately the same length as the large model. The approximate scale is one inch equals 1,056 feet. The map is divided into quarter sections, which means that each division on the map is 1,320 feet. Flow is from top to bottom on the page.

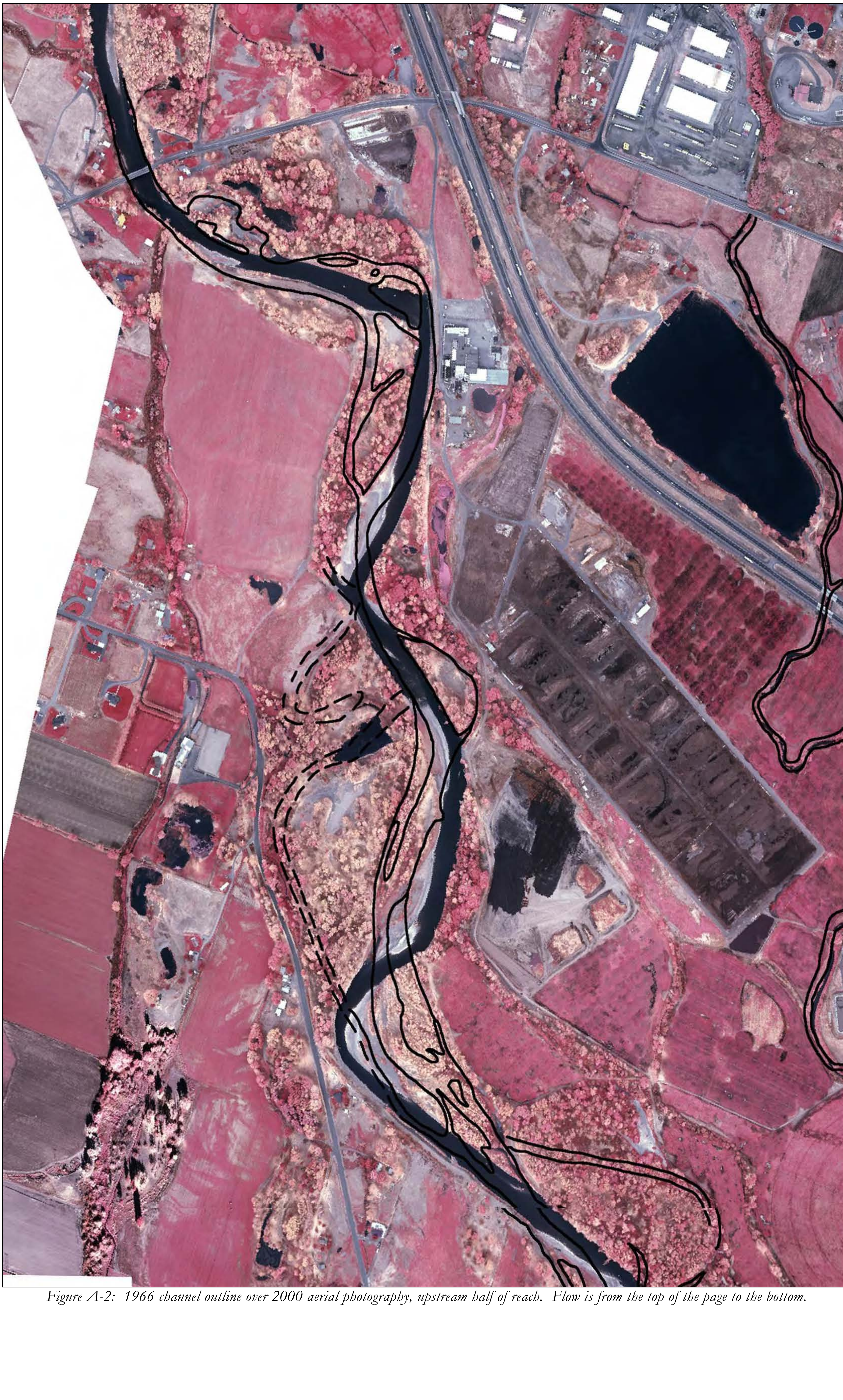

Figure A-2: 1966 channel outline over 2000 aerial photography, upstream half of reach. Flow is from the top of the page to the bottom.

Figure A-3: 1966 channel outline over 2000 aerial photography, downstream half of reach. Flow is from the top of the page to the bottom.

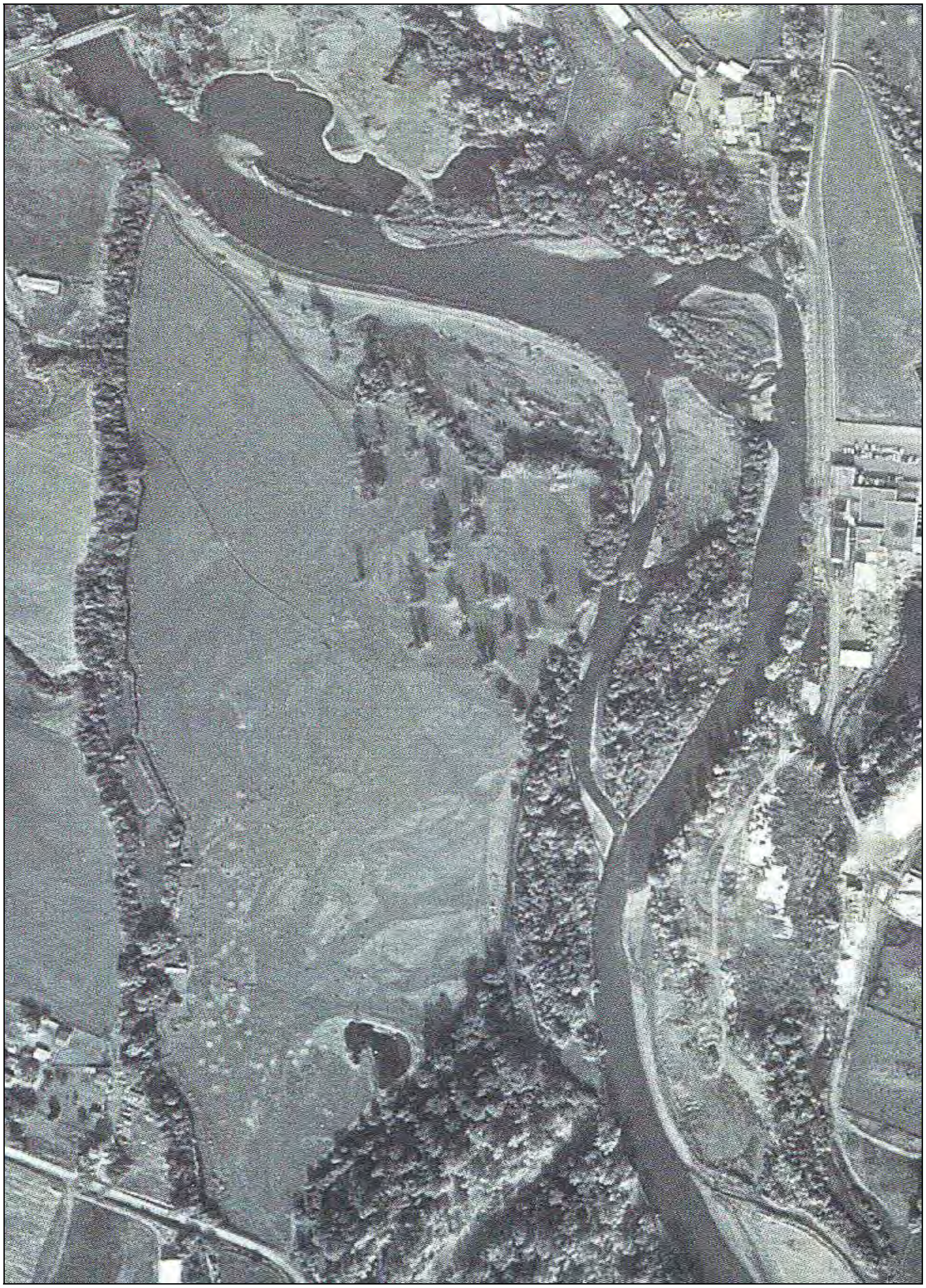

Figure A-4: 1966 photograph of the 90 degree bend at the western border of the Schaake property. The portion of river shown in this photograph is station 0 through 4000. Notice that the alignment in this photograph is in line with the property line (Figure 2) on the inside of the 90 degree bend.

APPENDIX B

Soil Composition of Floodplain Material in the Vicinity of the Proposed Side Channels (Reproduced from the Kittitas County Soil Survey, USDA 2003)

The information in this table was reproduced from the Kittitas County Soil Survey (USDA, 2003).

Map symbol		USDA	Classification		Fragments		Percent passing sieve number				Liquid	Plasticity
& Soil Name	**Depth**	**Texture**	**Unified**	**AASHTO**	**>10**	**3-10 in**	**4**	**10**	**40**	**200**	**Limit**	**Index**
	[in]				[Pct]	[pct]	[pct]	[pct]	[pct]	[pct]	[Pct]	
598-Zillah	0–7	Silt loam	ML	A4	0	0	100	100	95-100	80-90	20-30	5-10
	–15	Silt loam	ML	A4	0	0	100	100	95-100	80-90	20-30	5-10
	15-39	Very fine sandy loam	ML	A4	0	0	100	100	95-100	75-100	20-30	5-10
		Silt loam			0	0						
	39-51	Fine sandy loam	----	----	----	----	----	----	----	----	----	----
		Sandy Loam	----	----	0	0	----	----	----	----	----	----
7		Very Gravelly Loamy	GM	A1	0	0	50-100	45-100	40-75	15-30	0-10	NP
		Gravelly loamy sand	SM	A2	0	0	----	----	----	----	----	----
706-Kayak	0-6	Ashy Loam	CL	A6	0	0-5	90-100	80-100	65-95	55-75	20-35	5-15
	6-18	Gravelly Ashy Loam	CL	A6	0	0-5	75-100	65-90	55-80	45-70	20-35	5-15
51-60		Ashy Loam	CL-ML	----	----	----	----	----	----	----	----	----
		Ashy Fine Sandy Loam	CL	A4	0	0-10	75-100	65-90	50-80	40-65	20-35	5-15
		Gravelly Ashy Sandy	CL-ML	A6	----	----	----	----	----	----	----	----
		Gravelly Sandy Loam	CL	A4	0	0	75-100	65-90	50-80	40-65	20-35	5-15
		Gravelly Ashy Sandy	CL-ML	A6	----	----	----	----	----	----	----	----
		Fine Sandy Loam	SC	----	----	----	----	----	----	----	----	----
18-27		Very Gravelly Loamy	GP	A1	0-10	10-30	30-50	20-40	15-30	0-10	0-14	NP
27-38		Extremely Gravelly Loamy Sand	GP-GM	----	----	----	----	----	----	----	----	----
806-Weirman	0-5	Very Gravelly Sandy	GM	A1	0-5	0-5	40-60	30-50	15-35	5-25	15-20	NP-5
	5-15	Very Gravelly Loamy	GM	A1	0-5	0-15	40-60	30-50	5-25	0-5	0-10	NP
38-60	15-60	Very Gravelly Sand	GP	A1	0-5	10-40	30-50	10-45	5-20	0-10		NP

APPENDIX C

Figures of Modeled Water Depth – Large Model Results

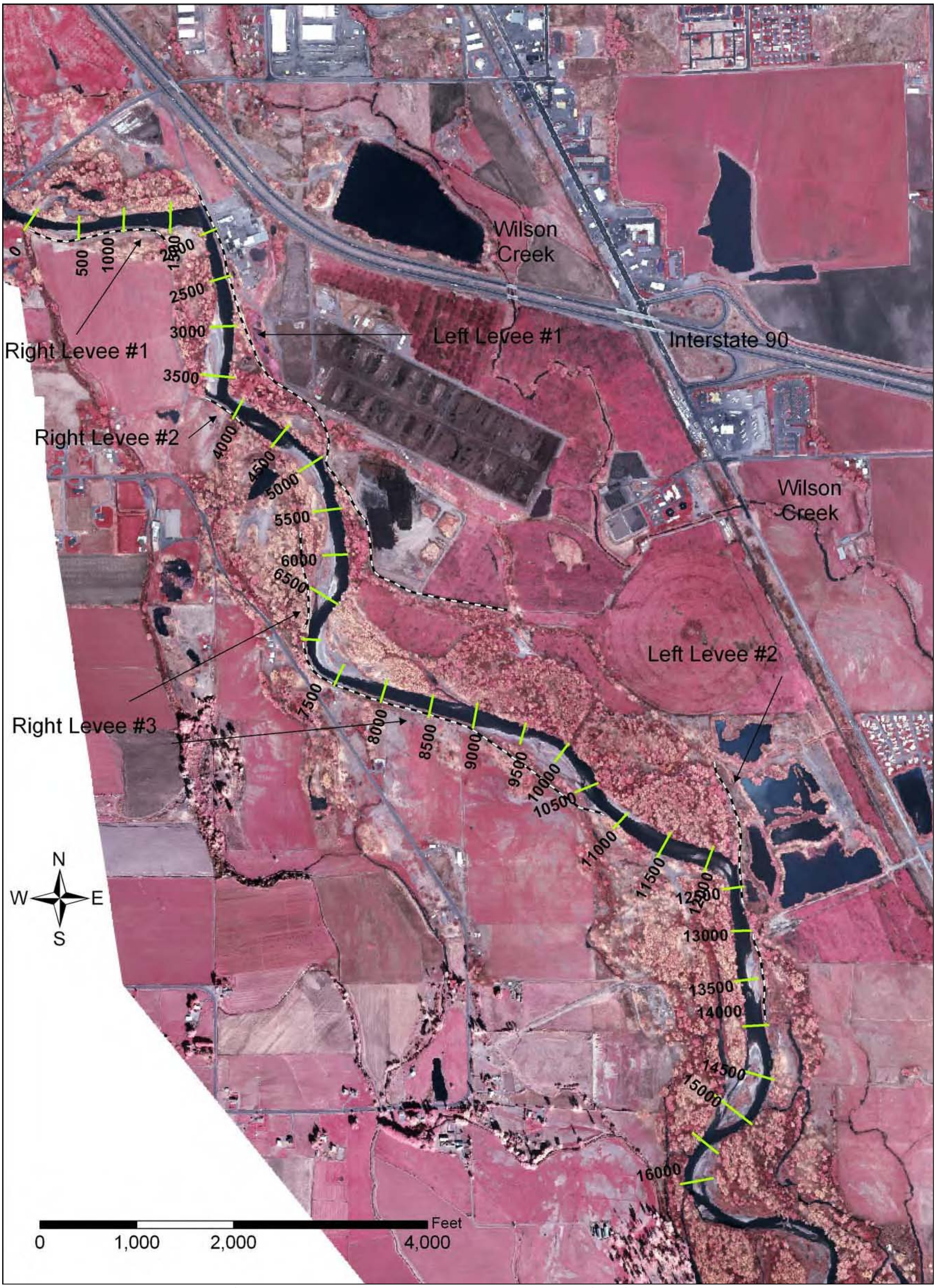

Figure C-1: Photograph of entire study reach showing the river stationing. The stationing is used for discussion purposes only. Flow is from the top of the page to the bottom.

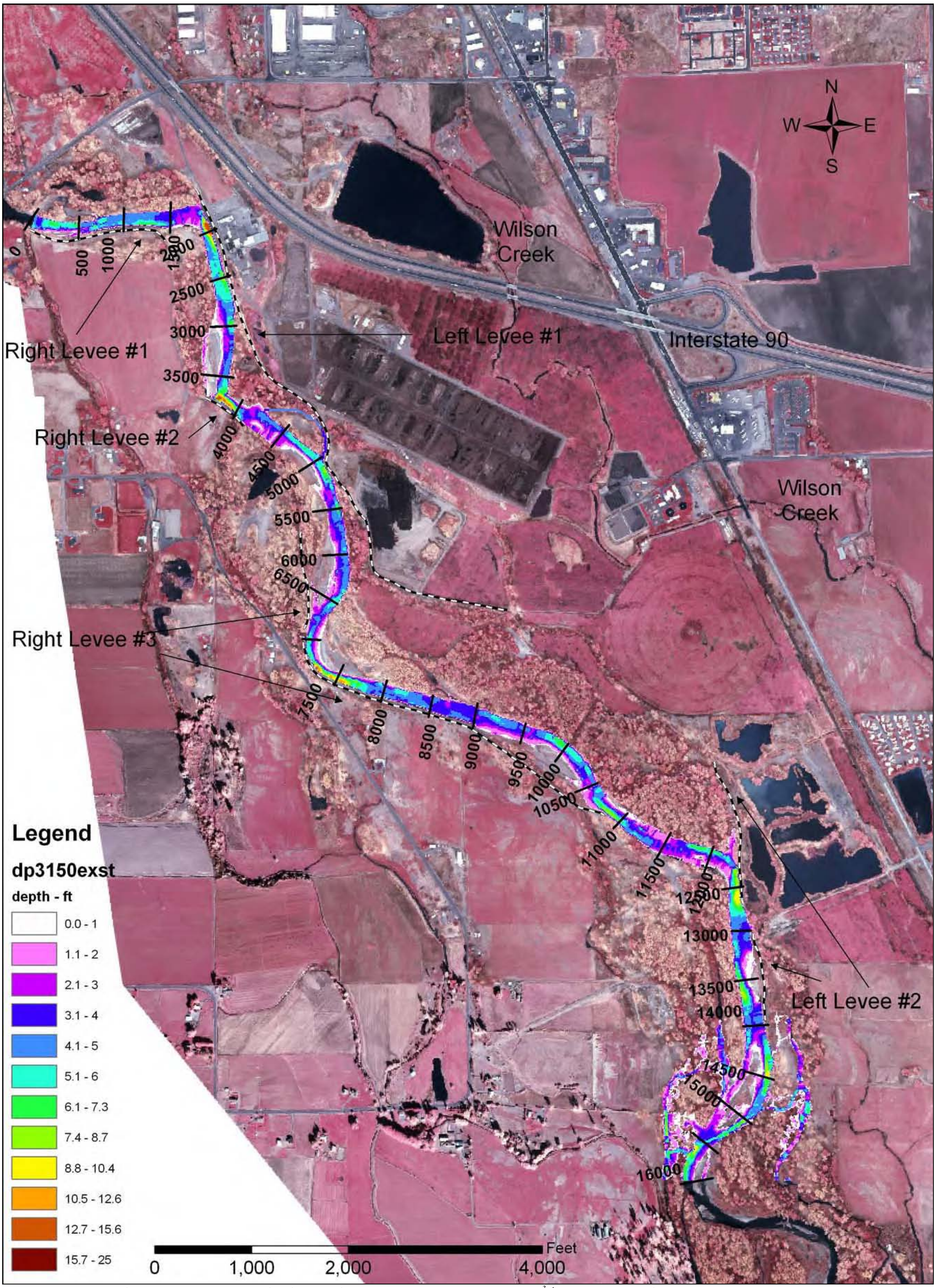

Figure C-2: Inundation map showing modeled water depth for the survey flow (3,150 ft^3/s), existing conditions. Flow is from the top of the page to the bottom.

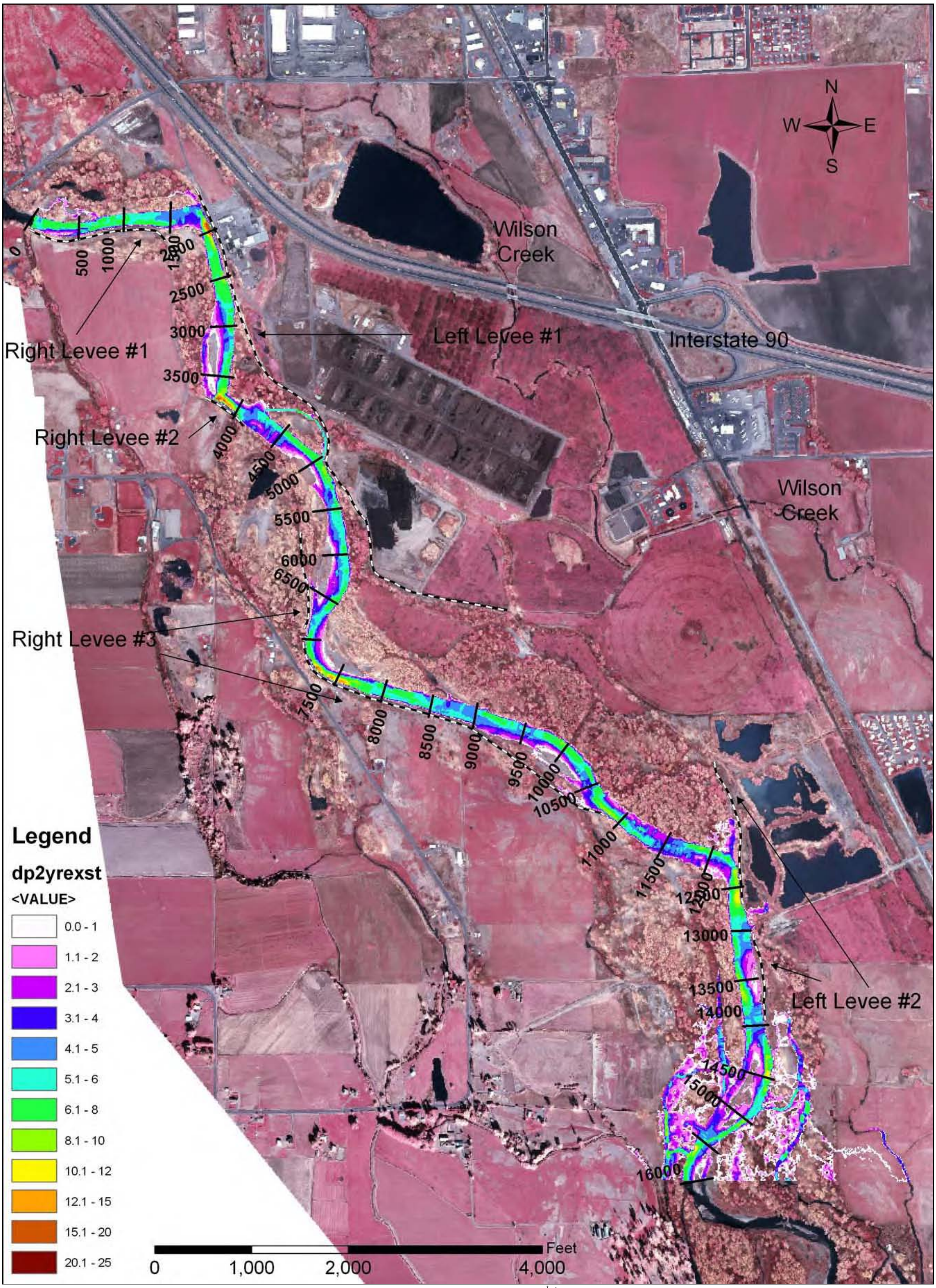

Figure C-3: Inundation map showing modeled water depth for the 2-year flood (5,678 ft^3/s), existing conditions. Flow is from the top of the page to the bottom.

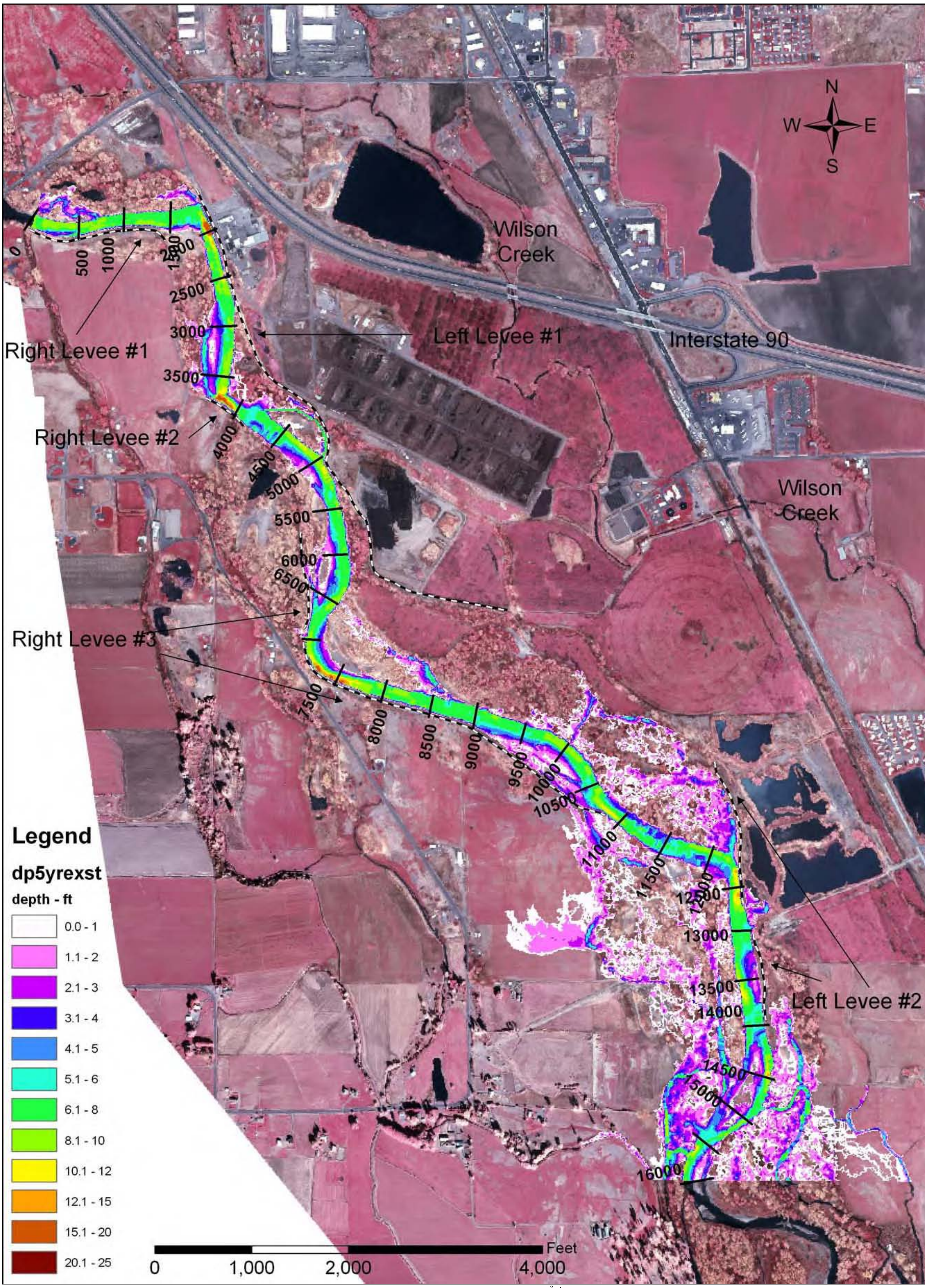

Figure C-4: Inundation map showing modeled water depth for the 5-year flood (10,066 ft^3/s), existing conditions. Flow is from the top of the page to the bottom.

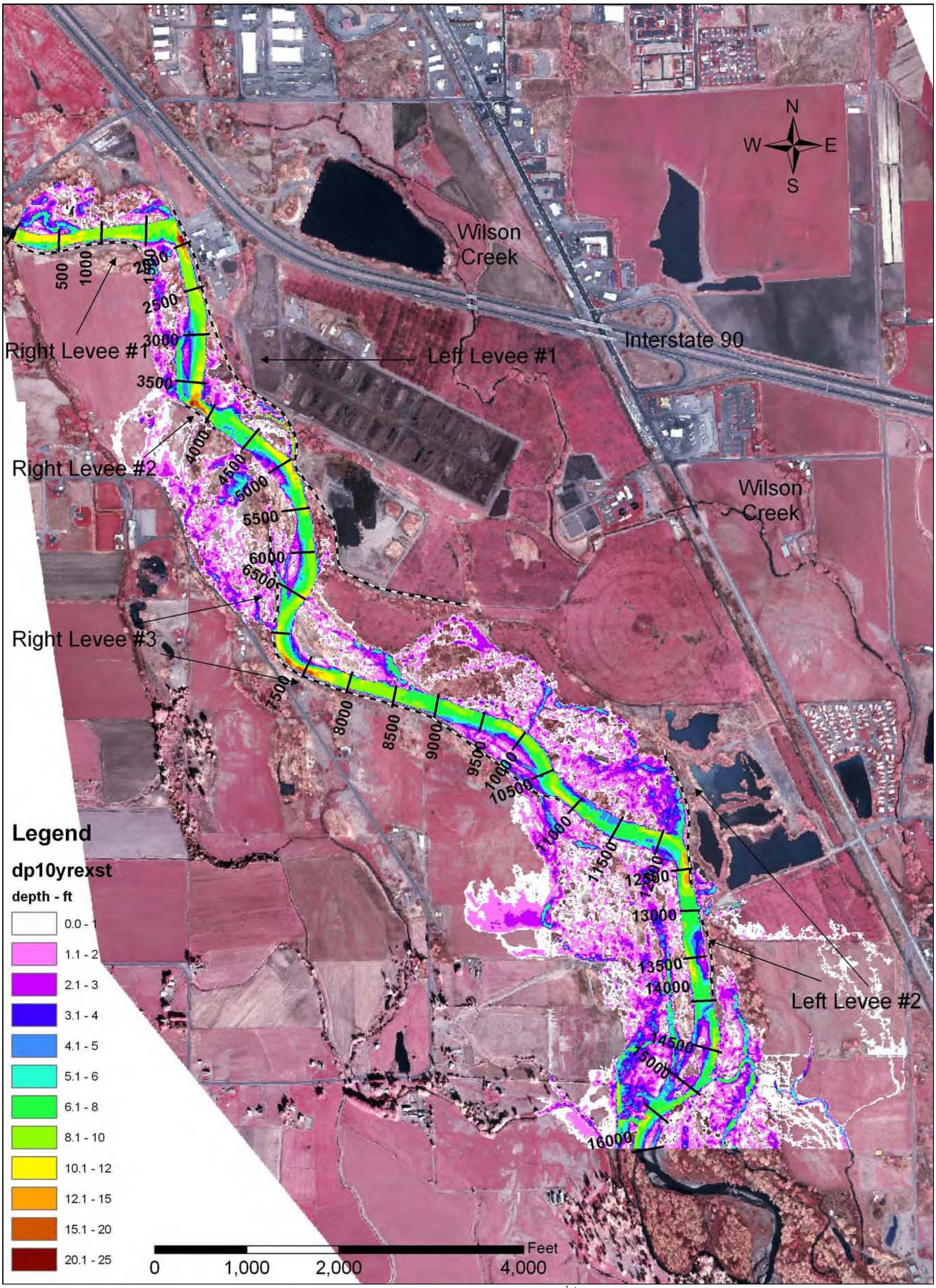

Figure C-5: Inundation map showing modeled water depth for the 10-year flood (13,922 ft^3/s), existing conditions. Flow is from the top of the page to the bottom.

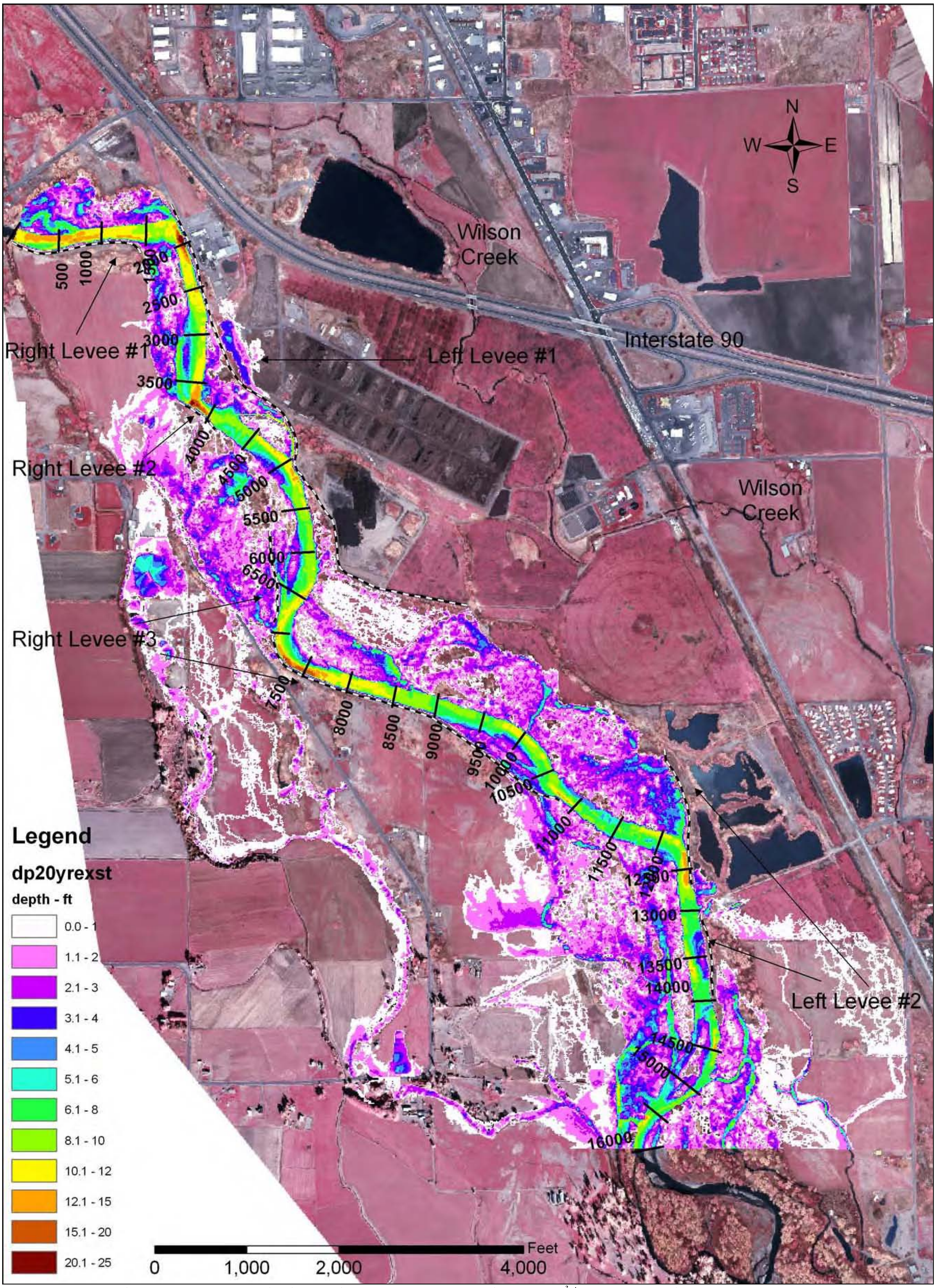

Figure C-6: Inundation map showing modeled water depth for the 20-year flood (18,441 ft^3/s), existing conditions. Flow is from the top of the page to the bottom.

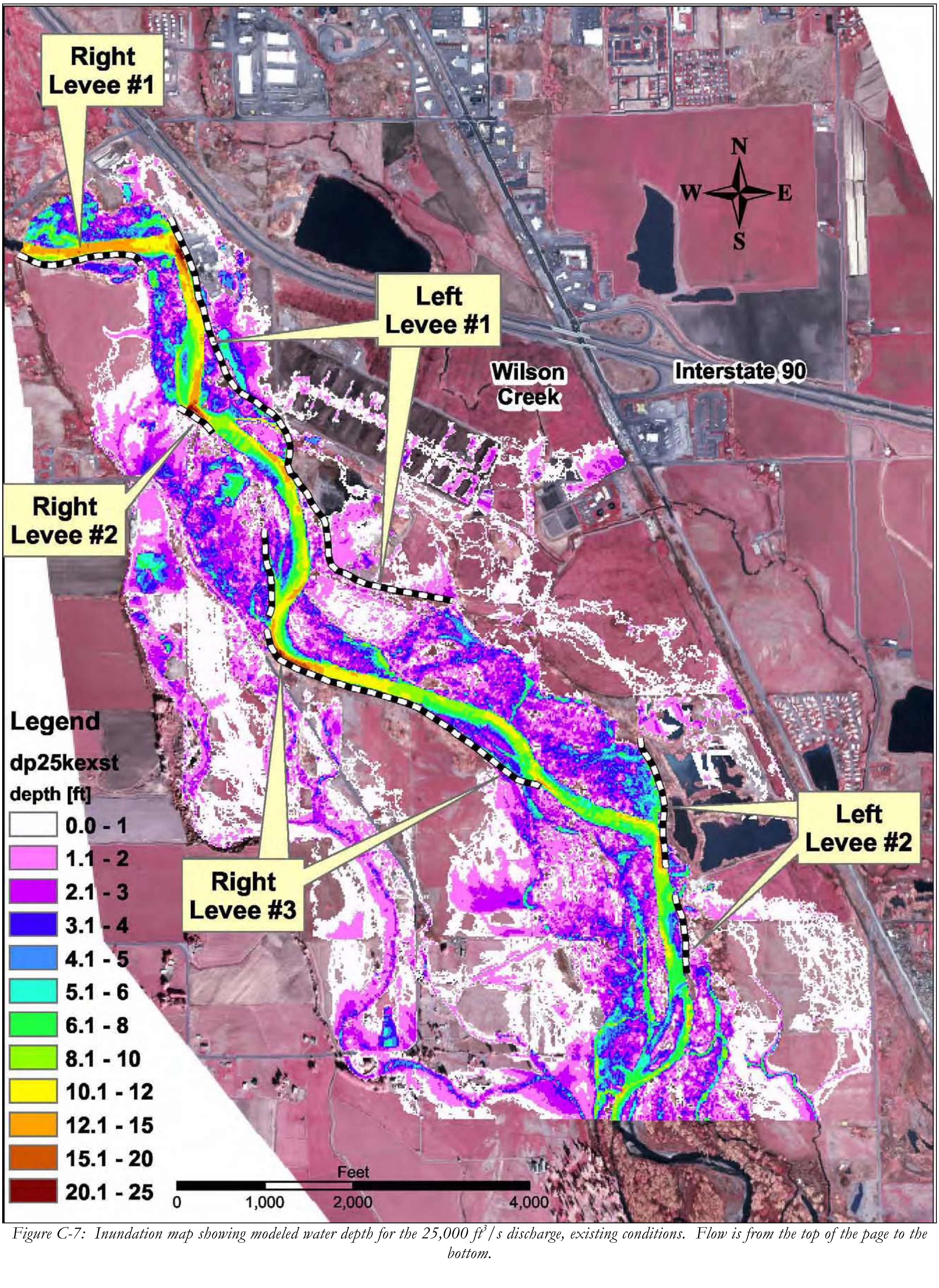

Figure C-7: Inundation map showing modeled water depth for the 25,000 ft^3/s discharge, existing conditions. Flow is from the top of the page to the bottom.

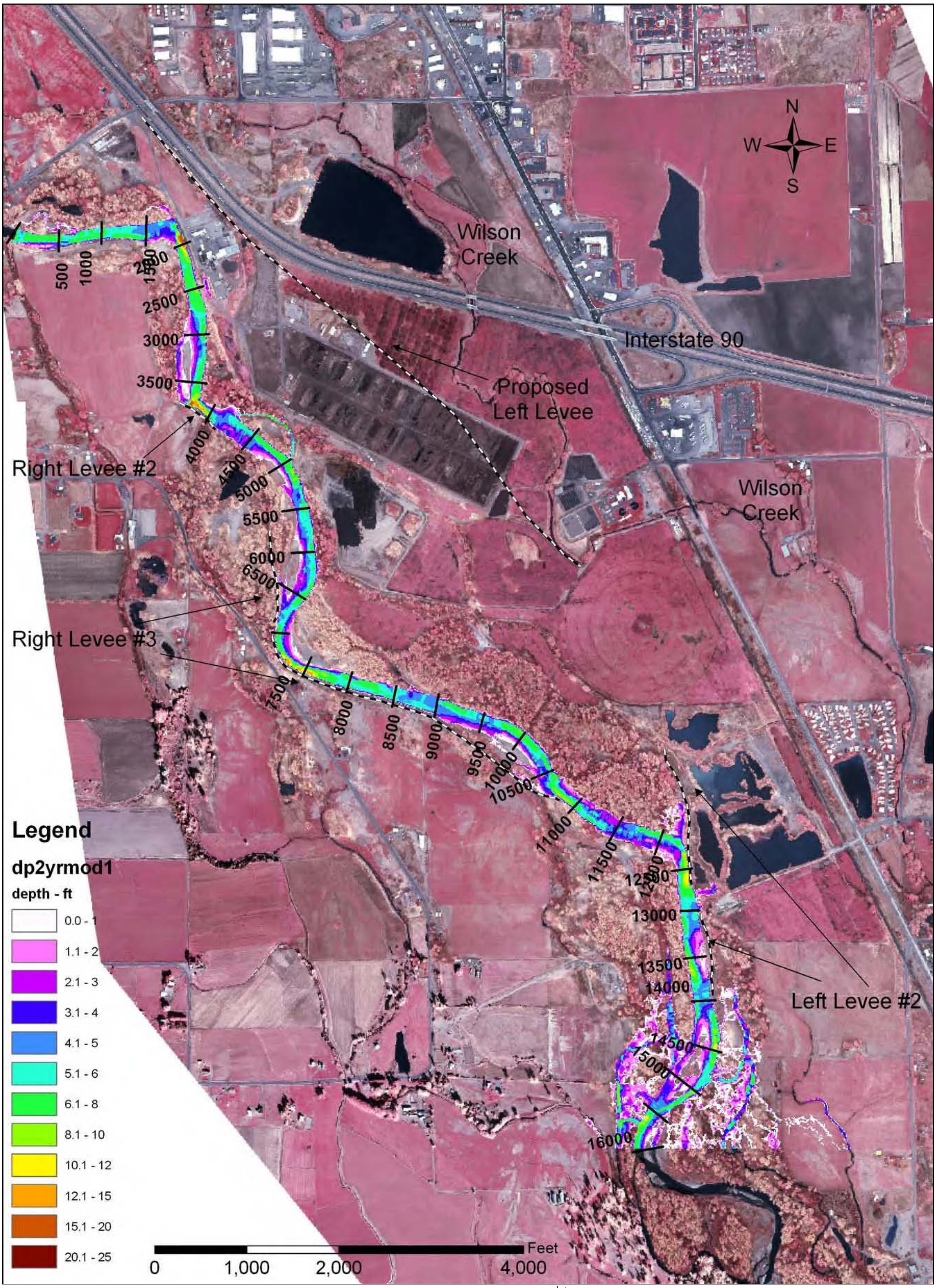

Figure C-8: Inundation map showing modeled water depth for the 2-year flood (5,678 ft^3/s), Mod 1. Flow is from the top of the page to the bottom.

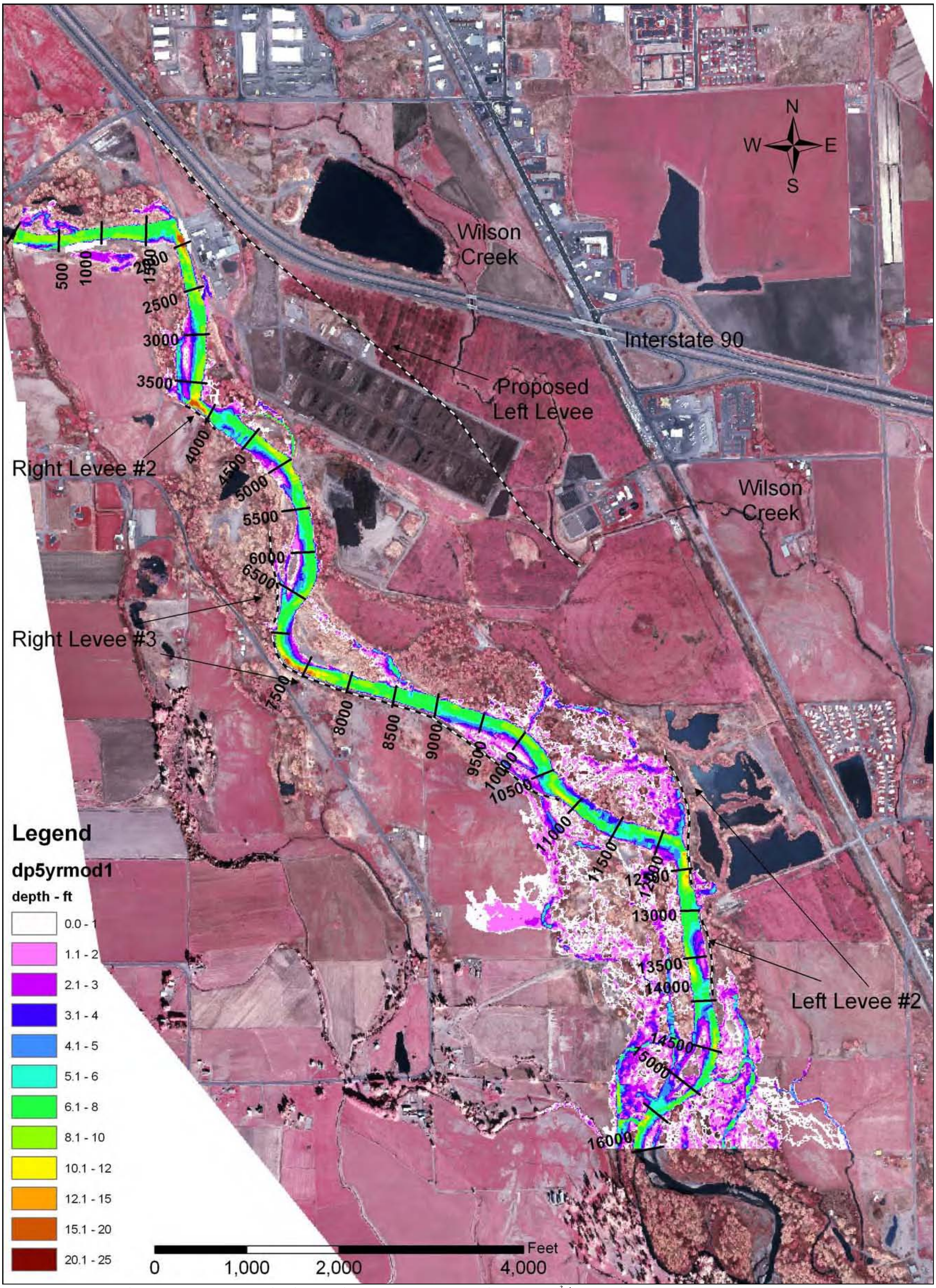

Figure C-9: Inundation map showing modeled water depth for the 5-year flood (10,066 ft^3/s), Mod 1. Flow is from the top of the page to the bottom.

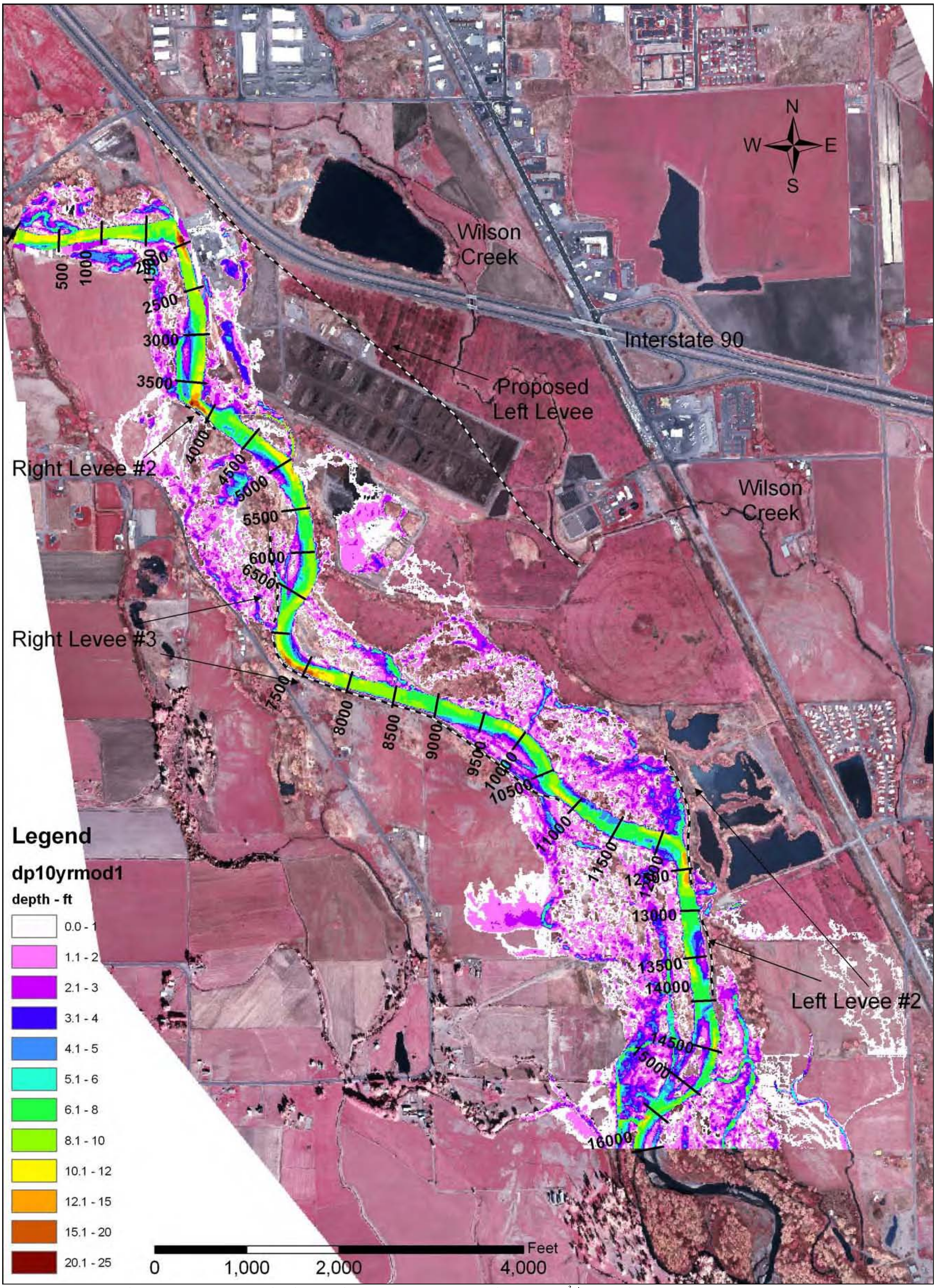

Figure C-10: Inundation map showing modeled water depth for the 10-year flood (13,922 ft^3/s), Mod 1. Flow is from the top of the page to the bottom.

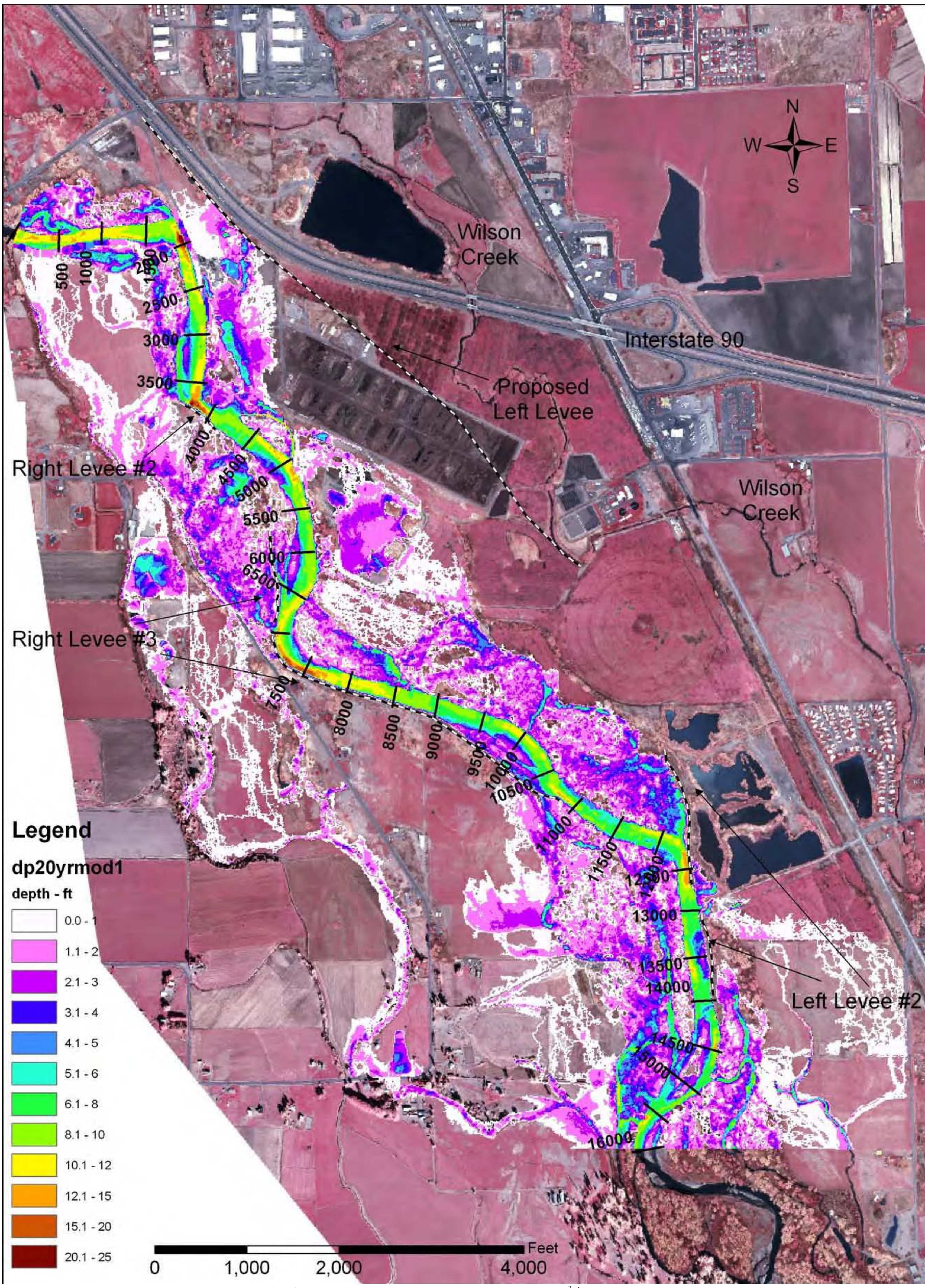

Figure C-11: Inundation map showing modeled water depth for the 20-year flood (18,441 ft^3/s), Mod 1. Flow is from the top of the page to the bottom.

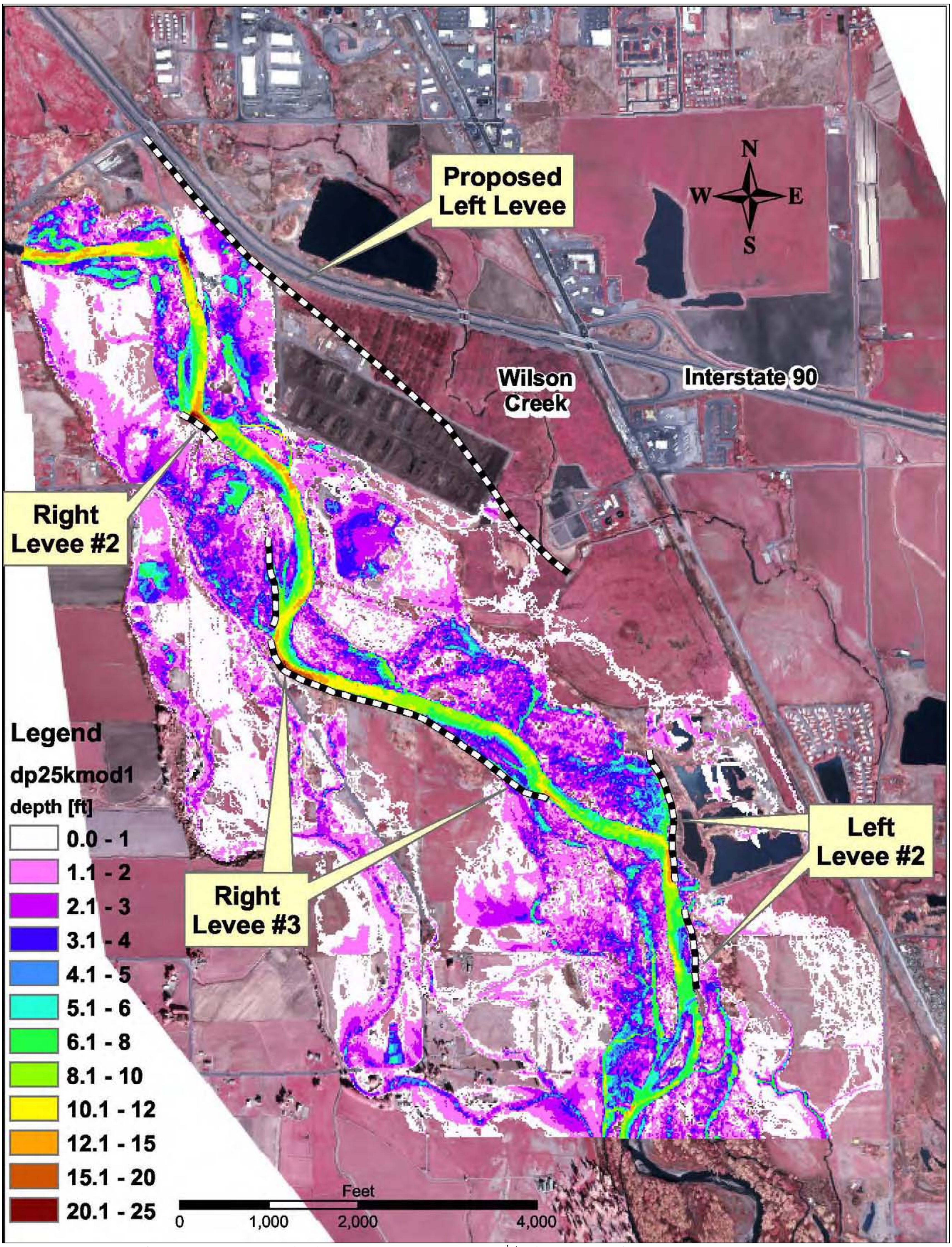

Figure C-12: Inundation map showing modeled water depth for the 25,000 ft^3/s discharge, Mod 1. Flow is from the top of the page to the bottom.

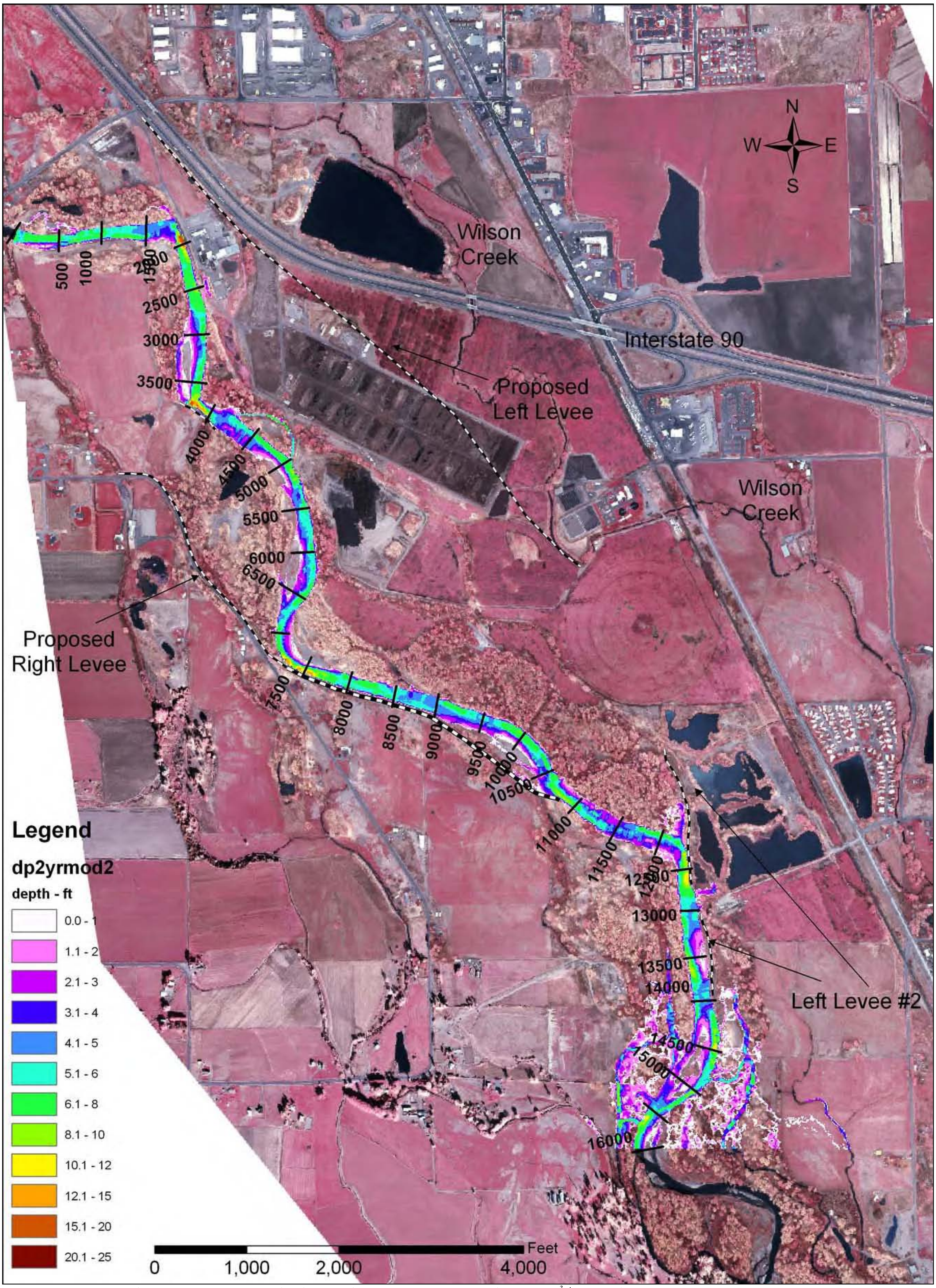

Figure C-13: Inundation map showing modeled water depth for the 2-year flood (,5678 ft^3/s), Mod 2. Flow is from the top of the page to the bottom.

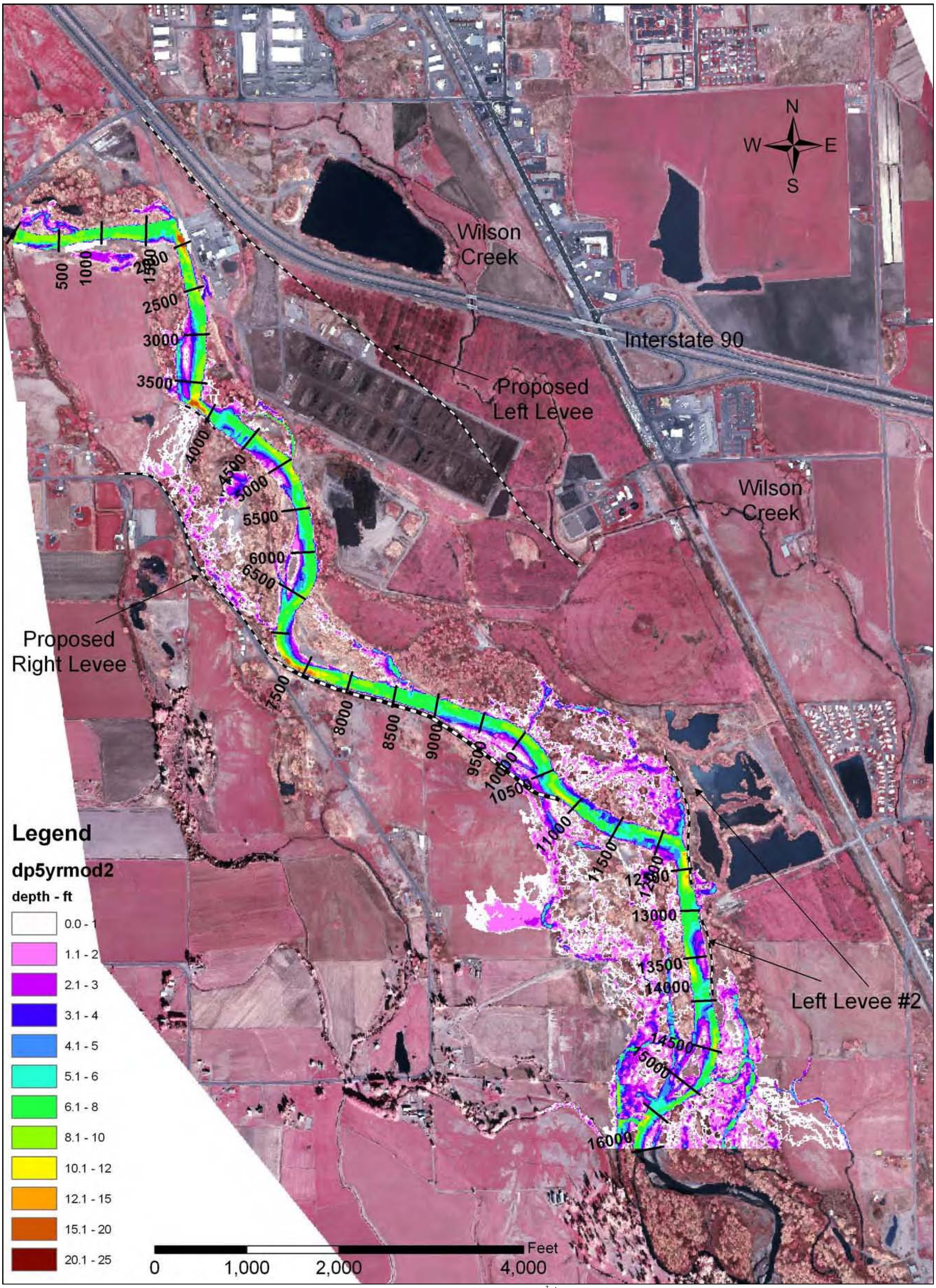

Figure C-14: Inundation map showing modeled depth for the 5-year flood (10,066 ft^3/s), Mod 2. Flow is from the top of the page to the bottom.

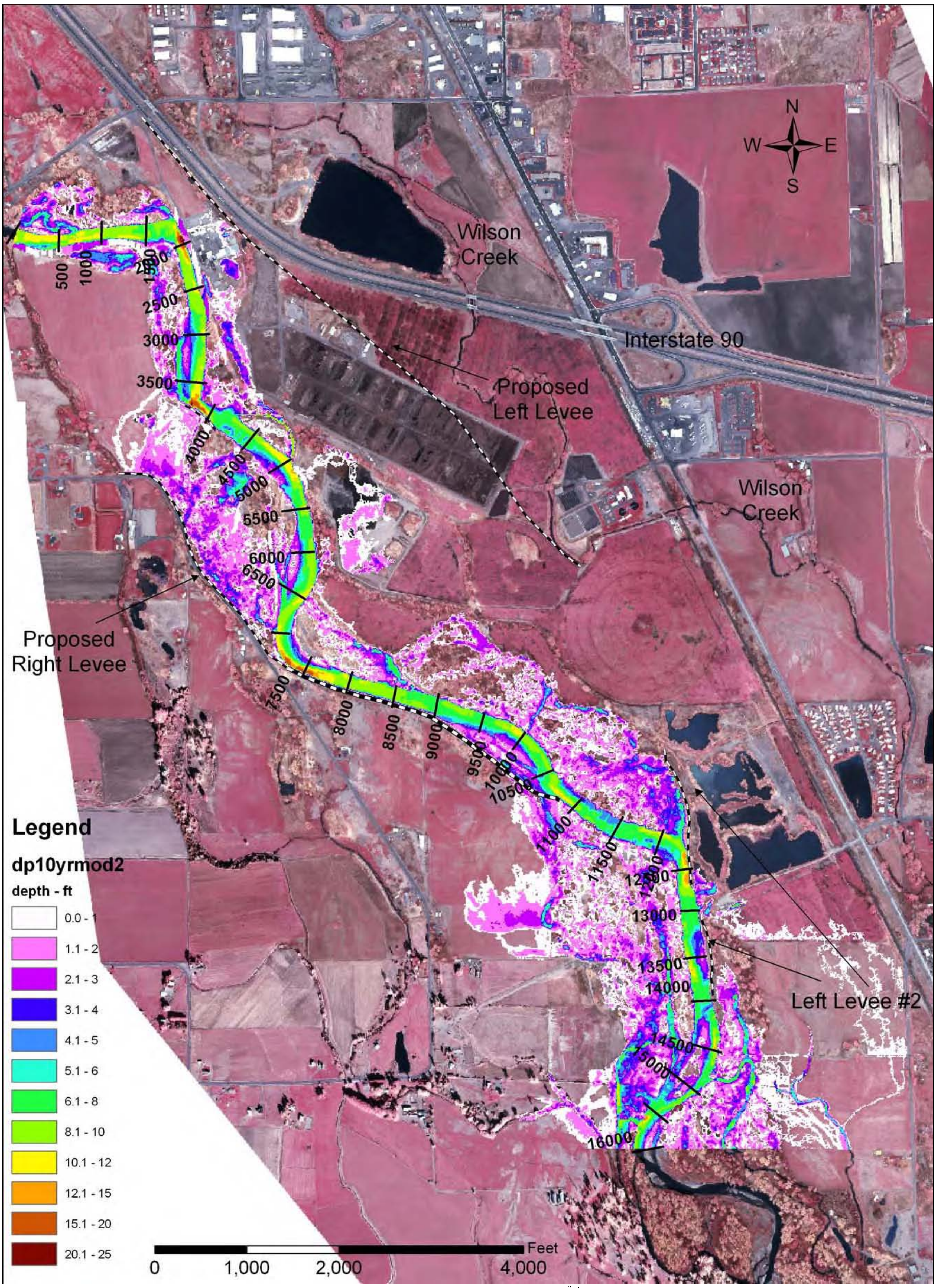

Figure C-15: Inundation map showing modeled water depth for the 10-year flood (13,922 ft^3/s), Mod 2. Flow is from the top of the page to the bottom.

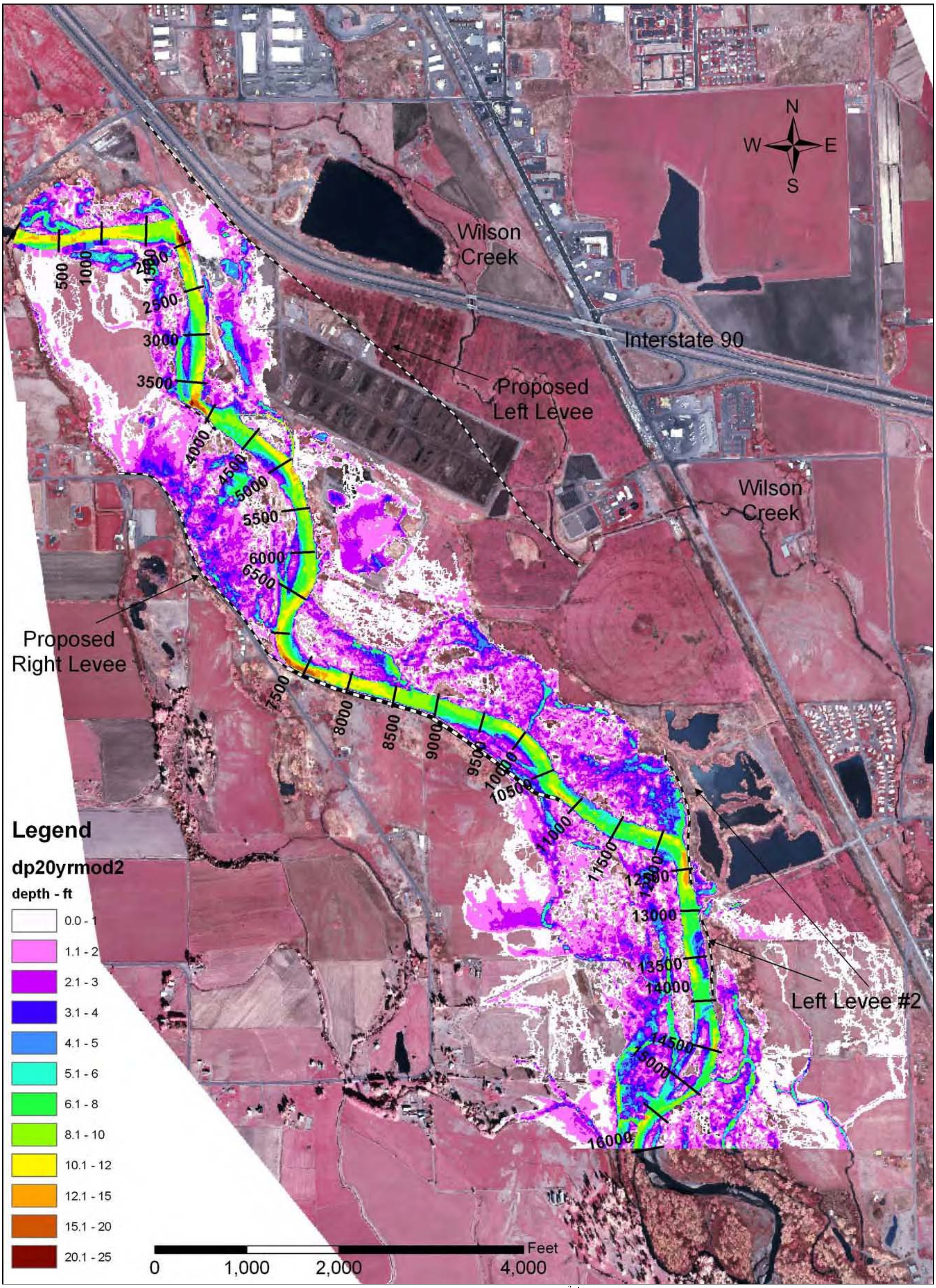

Figure C-16: Inundation map showing modeled water depth for the 20-year flood (18,441 ft^3/s), Mod 2. Flow is from the top of the page to the bottom.

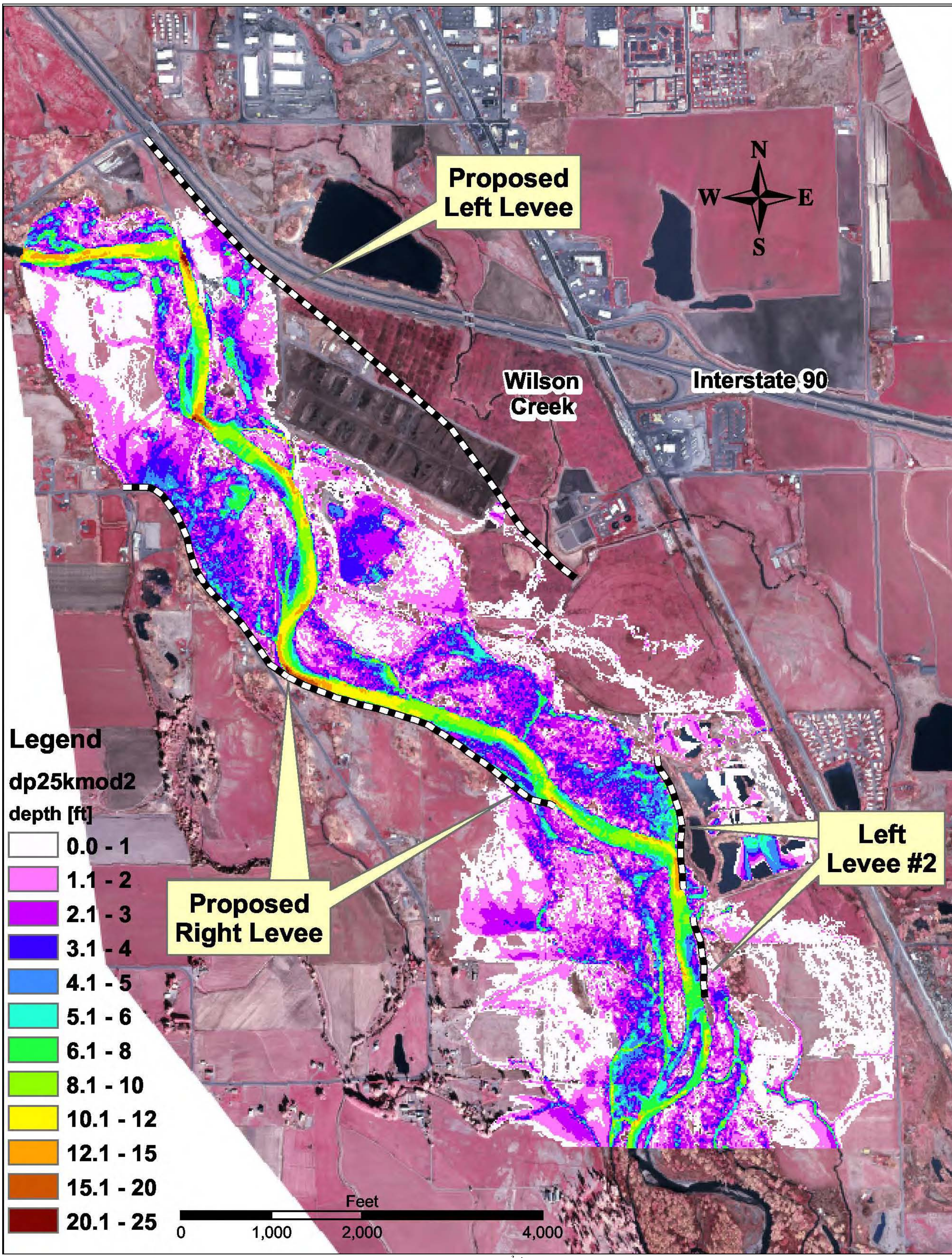

Figure C-17: Inundation map showing modeled water depth for the 25,000 ft^3/s discharge, Mod 2. Flow is from the top of the page to the bottom.

APPENDIX D

Figures of Modeled Water Depth - Small Model Results

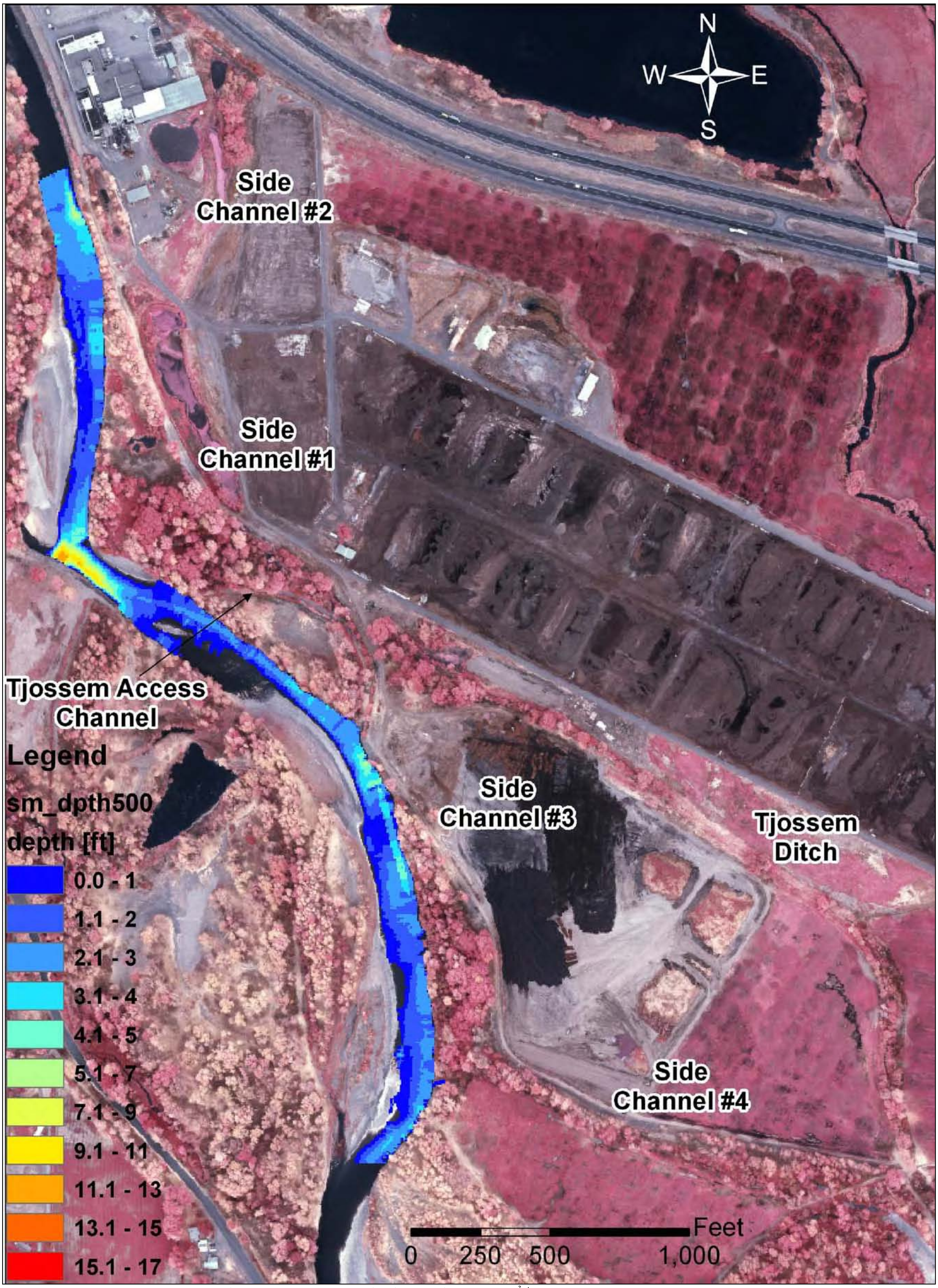

Figure D-1: Inundation map showing modeled water depth, 500 ft^3/s. Flow is from the top of the page to the bottom.

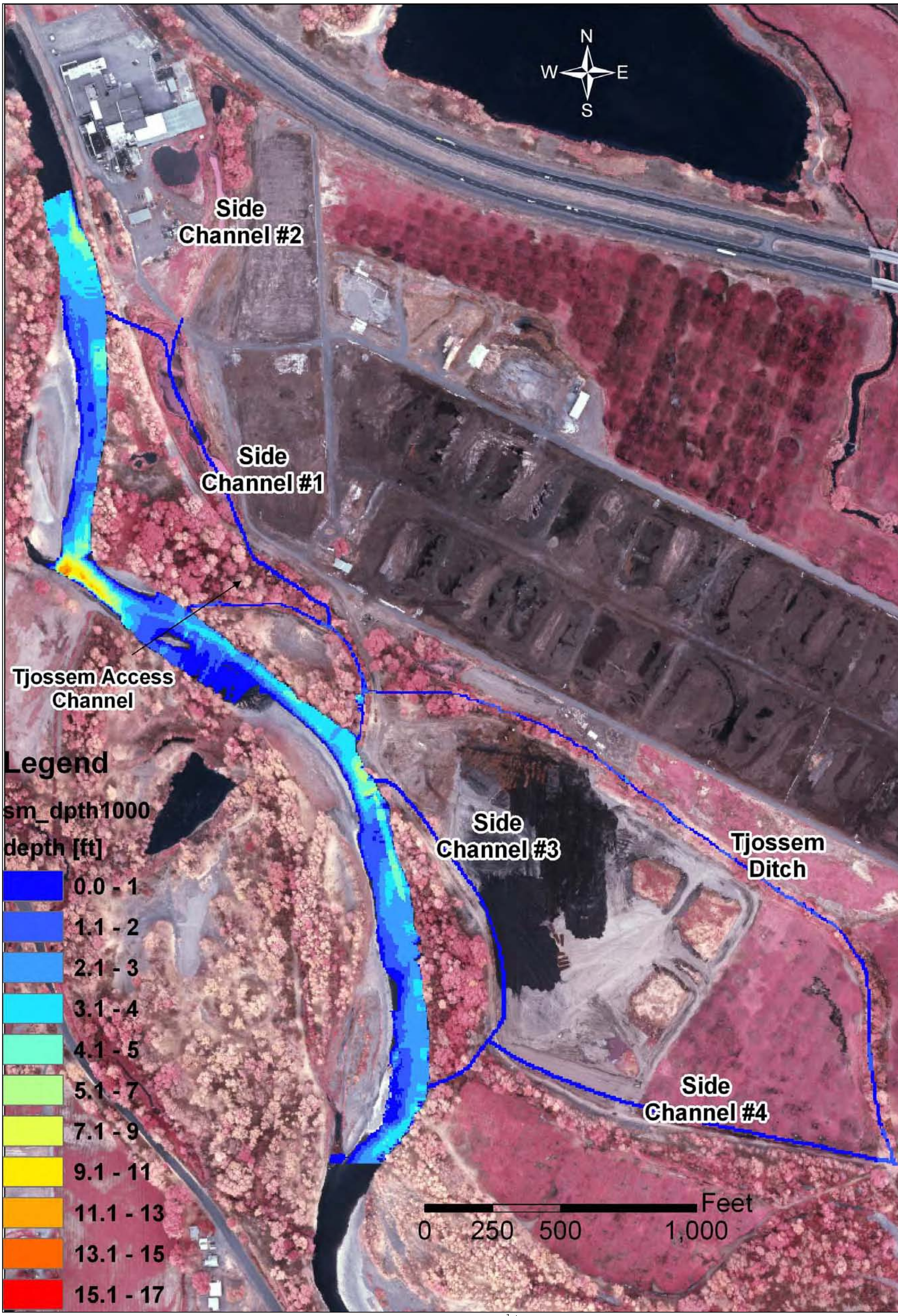

Figure D-2: Inundation map showing modeled water depth, 1000 ft^3/s. Flow is from the top of the page to the bottom.

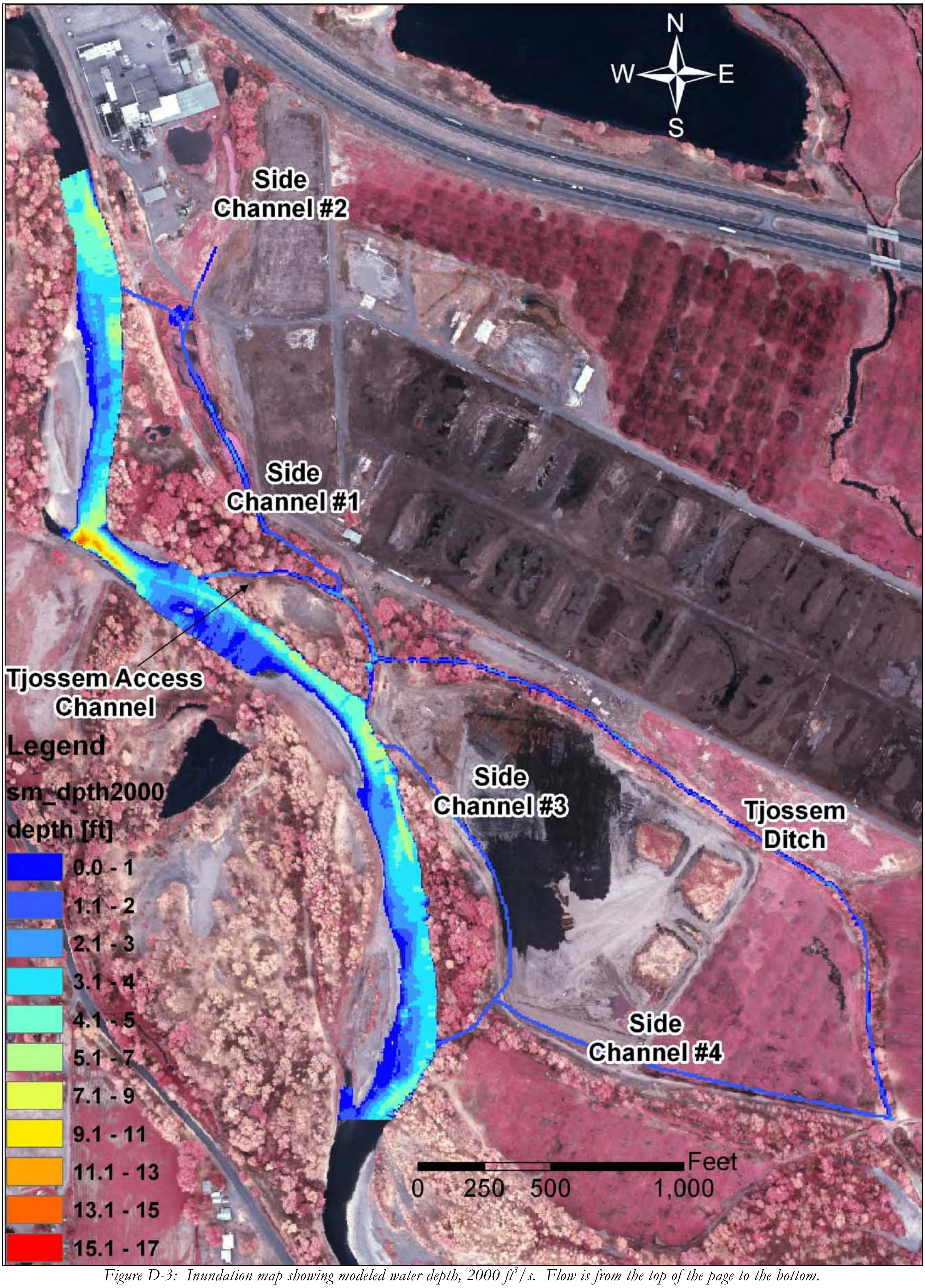

Figure D-3: Inundation map showing modeled water depth, 2000 ft^3/s. Flow is from the top of the page to the bottom.

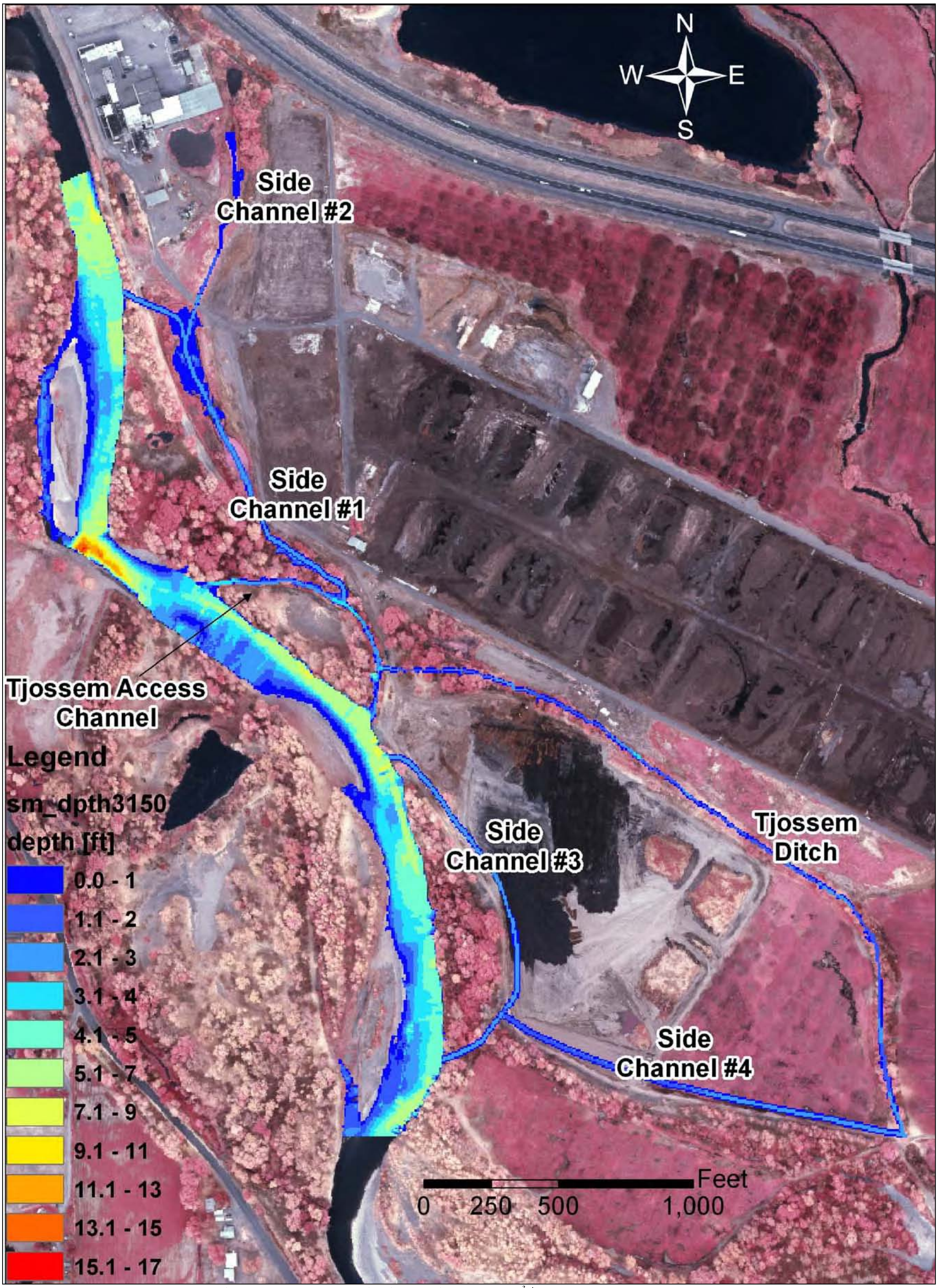

Figure D-4: Inundation map showing modeled water depth, 3150 ft^3/s. Flow is from the top of the page to the bottom.

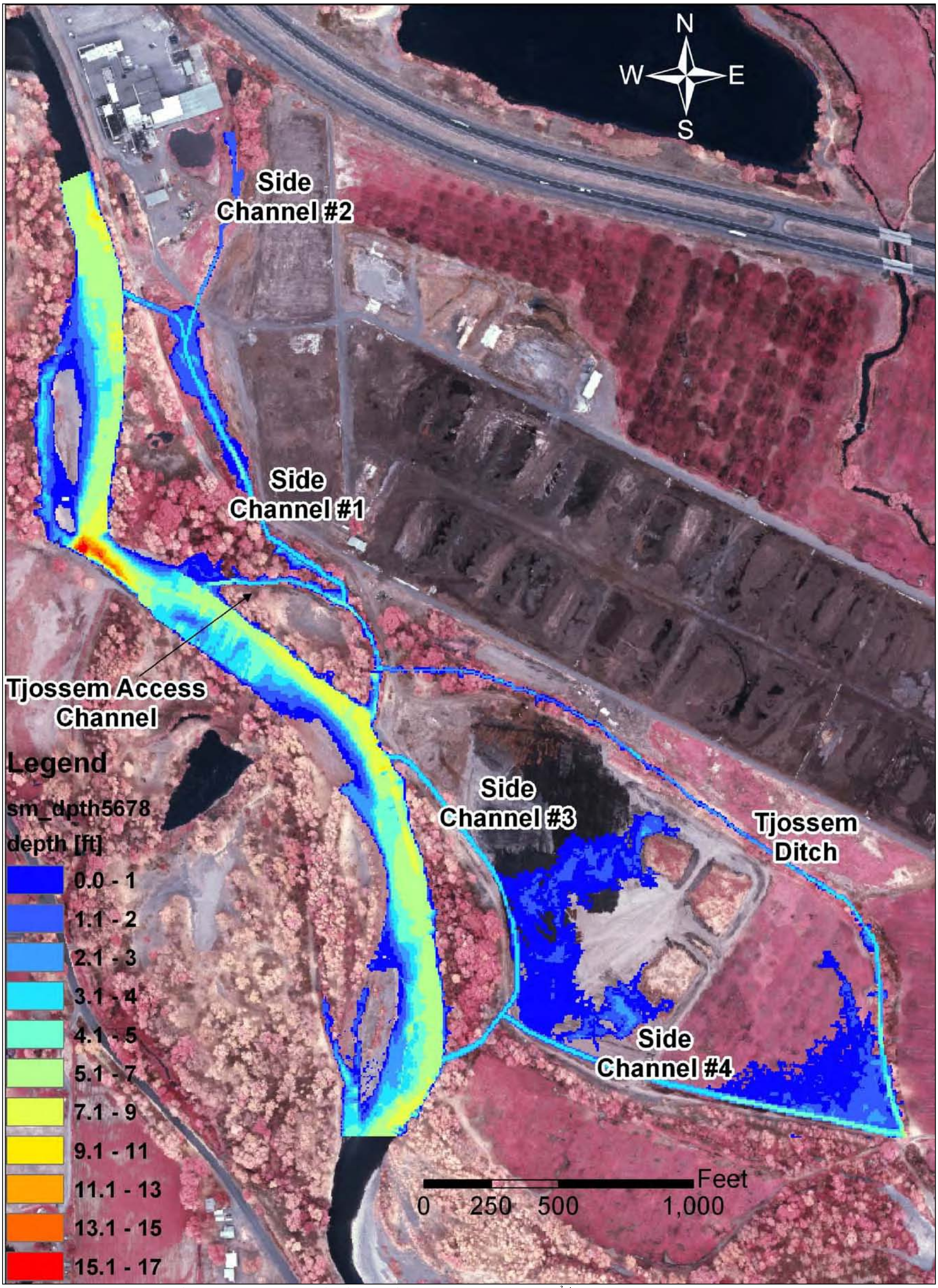

Figure D-5: Inundation map showing modeled water depth, 2-year flow (5,678 ft^3/s). Flow is from the top of the page to the bottom.

APPENDIX E

Velocity Vector Plots of Side Channel Junctions

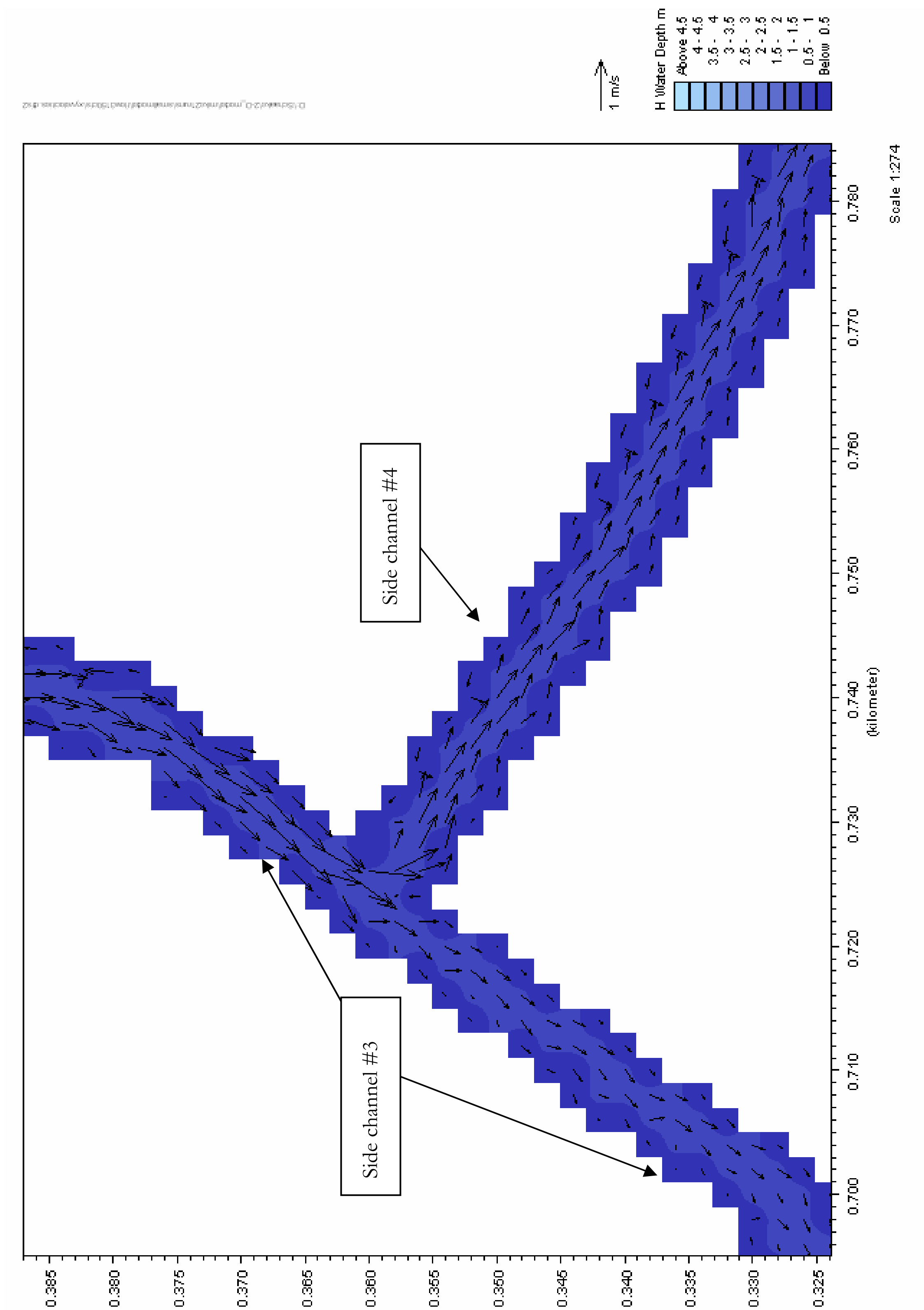

Figure E-2: Velocity vector plot of the junction of side channels 3 and 4.

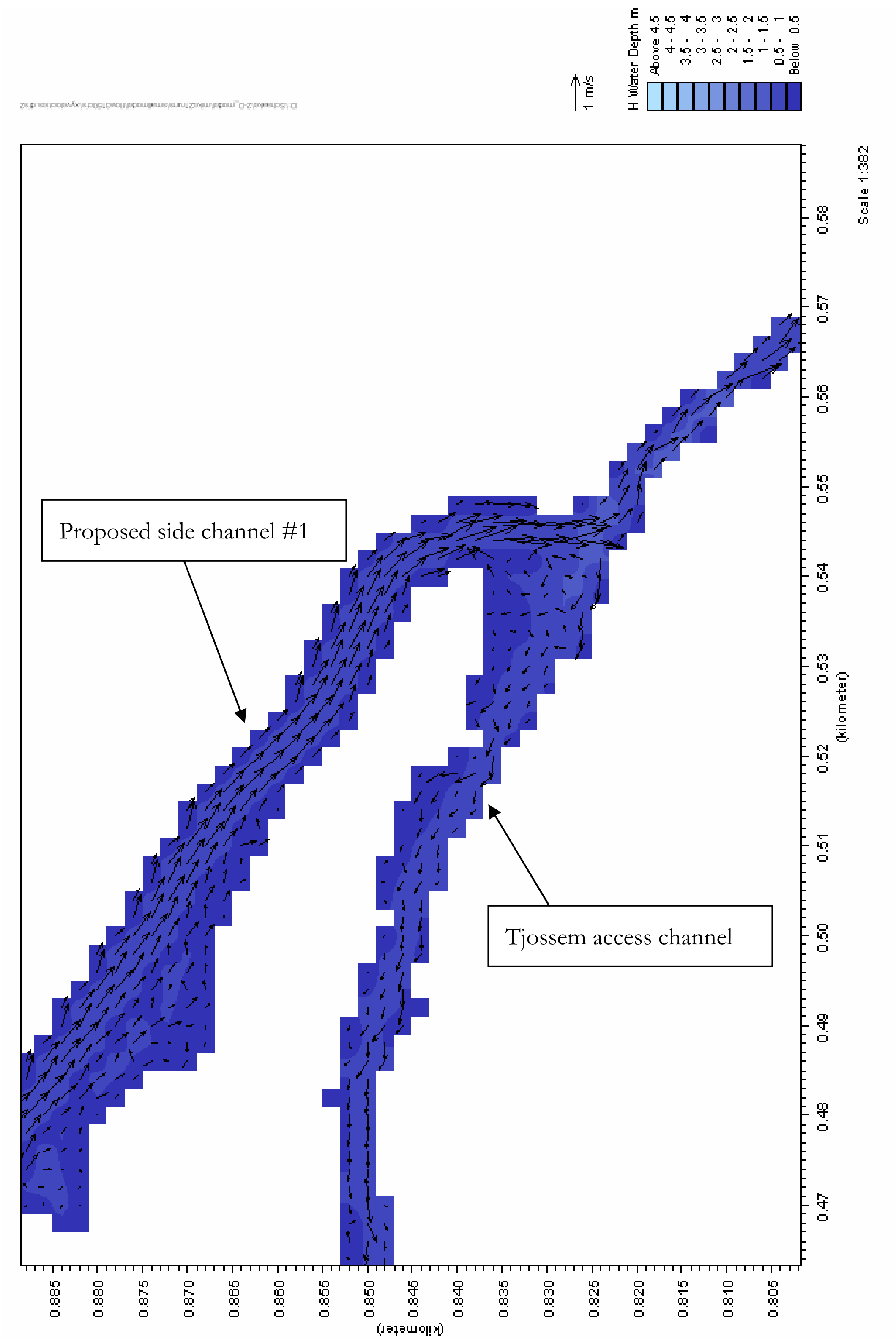

Figure D-1: Velocity vector plot of the junction of side channel #1 and the Tjossem ditch access channel. Flow is 3,150 ft^3/s.

APPENDIX F

Grid Representation of Side Channel Excavation Depths

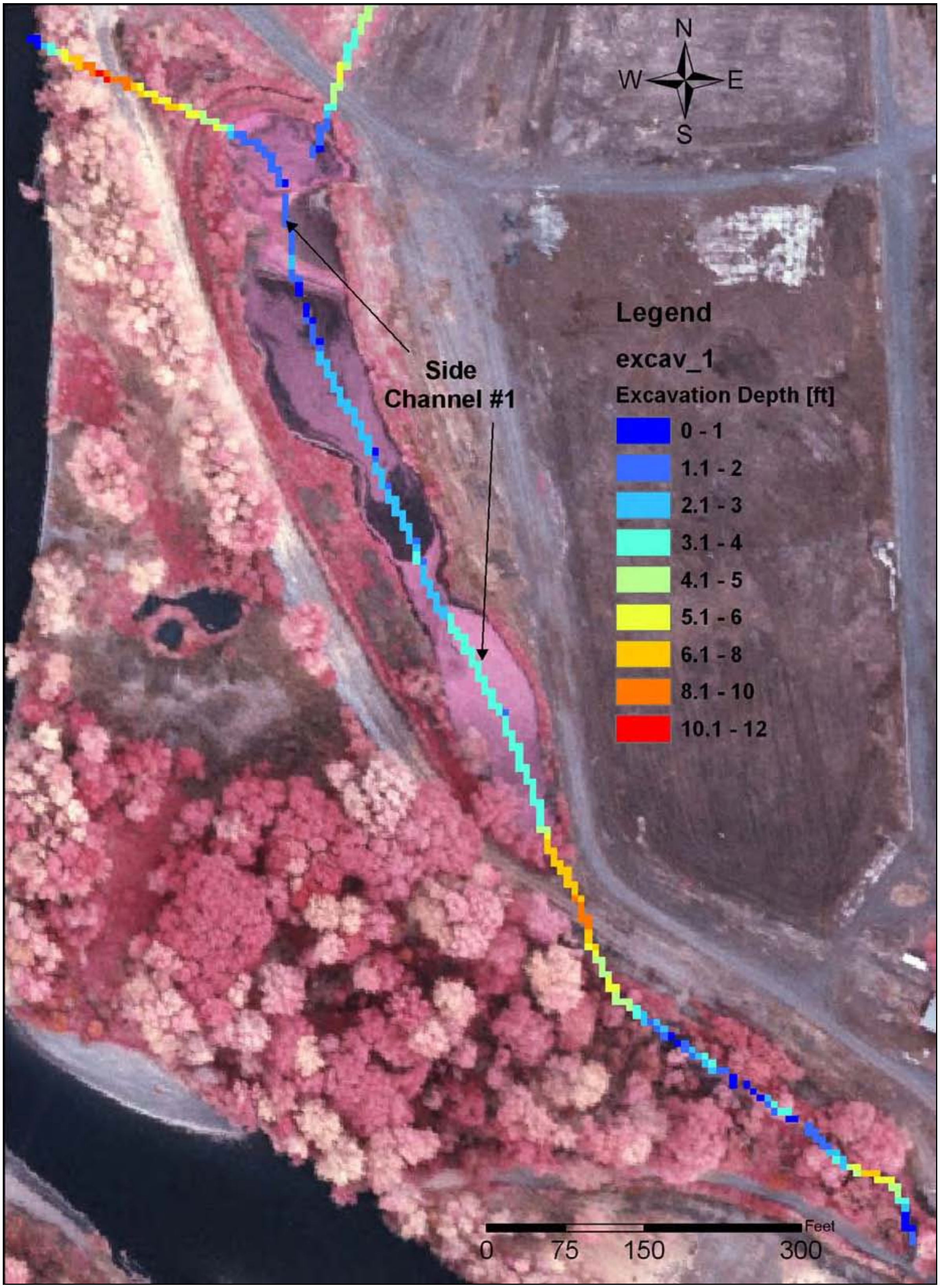

Figure F-1: Estimated excavation depth, side channel #1.

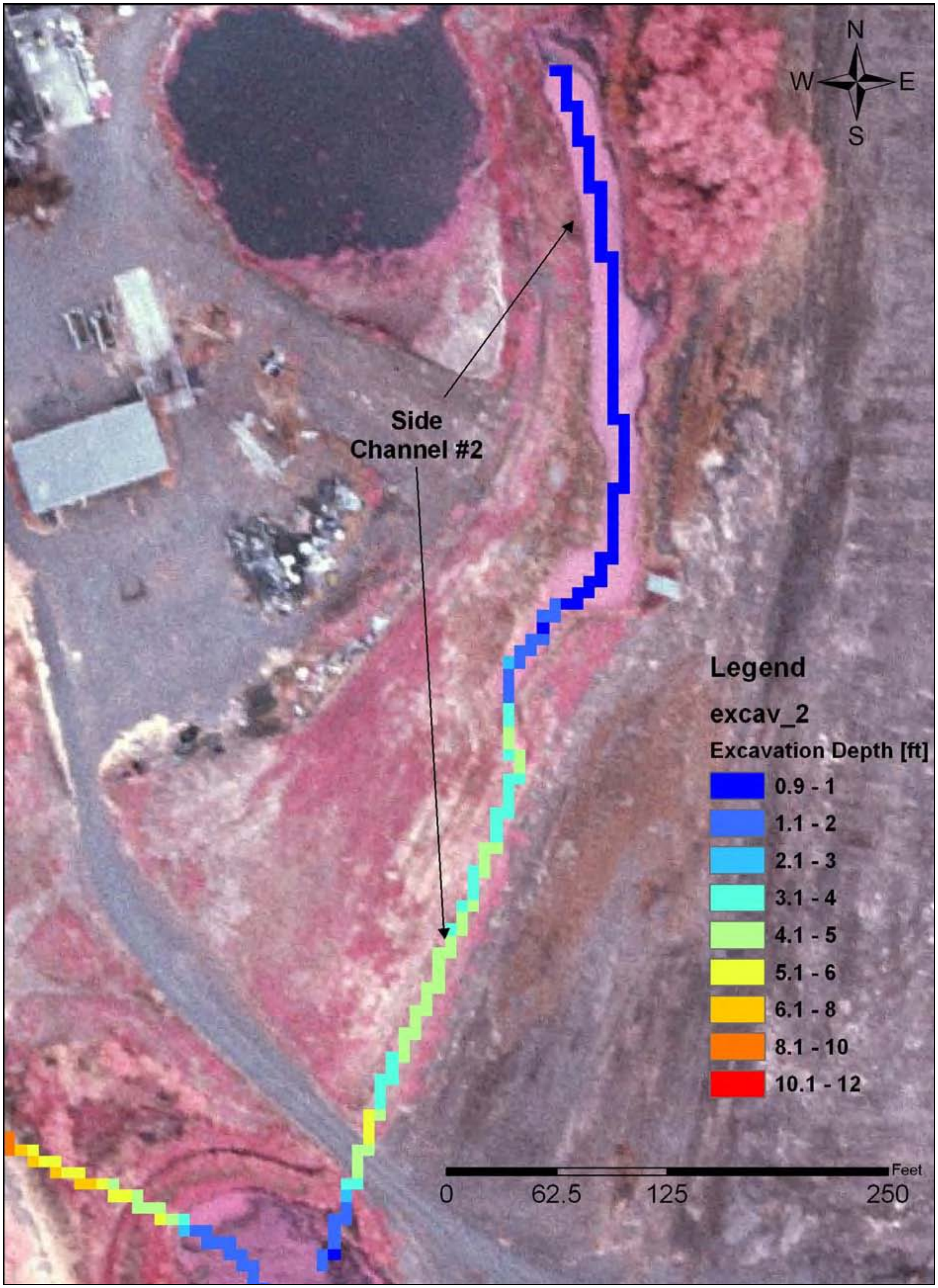

Figure F-2: Estimated excavation depth for side channel #2.

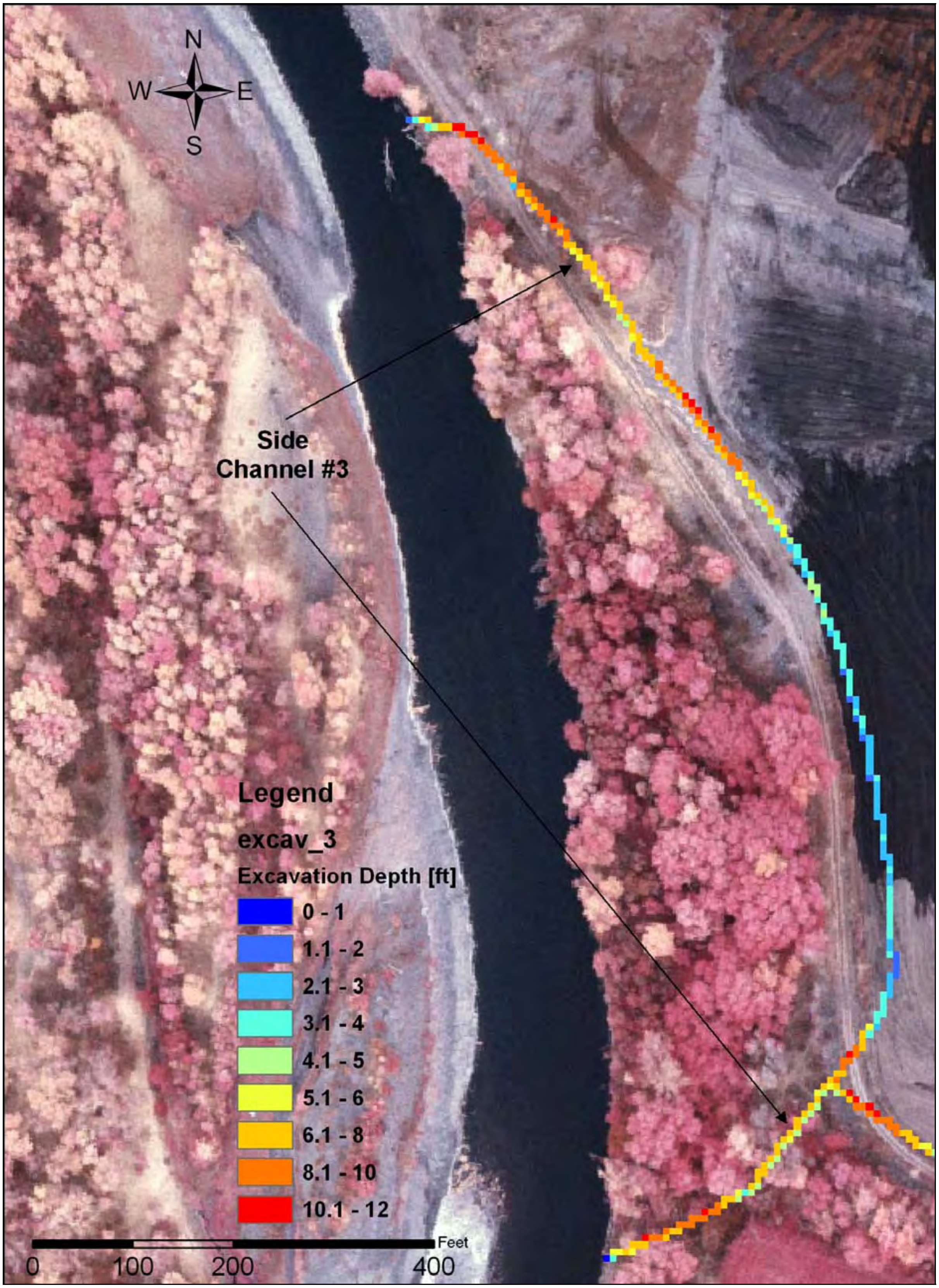

Figure F-3: Estimated excavation depth, side channel #3.

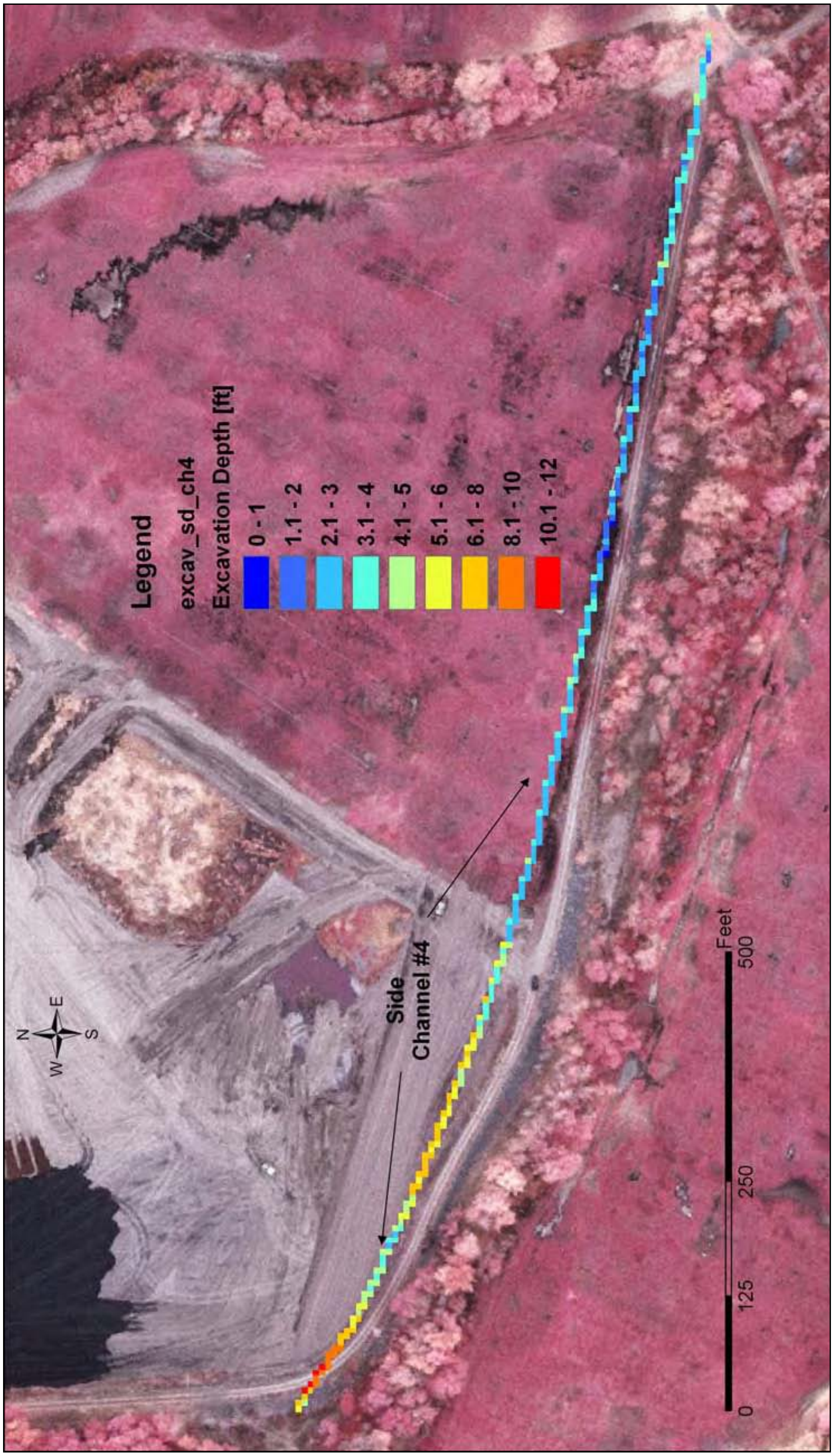

Figure F-4: Estimated Excavation depth, side channel #4.