TECHNICAL SERVICE CENTER
DENVER, COLORADO

YAKIMA RIVER HABITAT IMPROVEMENT STUDY:

SCHAAKE REACH, ELLENSBURG, WASHINGTON

INTERIM REPORT TO THE YAKIMA RIVER BASIN WATER ENHANCEMENT PROJECT

U.S. Department of the Interior
Bureau of Reclamation

DECEMBER 22, 2003

U.S. Department of the Interior
Mission Statement

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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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U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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YAKIMA RIVER HABITAT IMPROVEMENT STUDY, SCHAAKE REACH, NEAR ELLENSBURG, WA

EXECUTIVE SUMMARY

This interim report provides conclusions regarding the feasibility of rehabilitating the Schaake Reach of the Yakima River near Ellensburg, Washington, to increase side channel habitat for salmonid fish species. This report concludes Phase II of this study. Phase I of this study took place in August 2003 and consisted of a hydrographic survey of the channel and compilation of the data.

A one-dimensional numerical model was used to evaluate whether or not floods with high frequency and low magnitude will be able to access the floodplain in order to maintain side channels. It has been determined that rehabilitation of the floodplain is possible despite minor incision of the Schaake Reach where levees have limited normal floodplain interaction. The model shows that following levee modification and pilot channel construction, regular inundation of the floodplain can be expected. This allows for increased side channel habitat, similar to historical channel configurations.

This report also contains a discussion of the geomorphic conditions of the Schaake reach relating to past channel changes. Previous locations of the main channel of the Yakima River in the Schaake Reach have been mapped and discussed in order to better understand the tendencies of the river to migrate within the floodplain.

Options for rehabilitation have been presented based on the results of the geomorphic analysis and numerical modeling. These options should be reviewed by the Yakima River Basin Water Enhancement Project (YRBWEP) for feasibility and biological and ecological efficacy. Those options determined feasible by YRBWEP will be evaluated in greater detail with a two-dimensional model during Phase III of this study.

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INTRODUCTION

The Yakima River, in the vicinity of Ellensburg, WA (Figure 1), is being studied to investigate the potential of restoring lost habitat for salmonid fish species. The specific reach of the Yakima River being investigated is approximately 4.3 miles long and is known as the Schaake Reach, named for the owner of the property prior to its sale to the Bureau of Reclamation (Reclamation) on August 7, 2003. This portion of the Yakima River lies south and west of Interstate 90 and flows in a general direction of northwest to southeast before turning south into the Yakima Canyon (Figure 2). The property was purchased 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 added to the potential for a successful rehabilitation and increased public benefit.

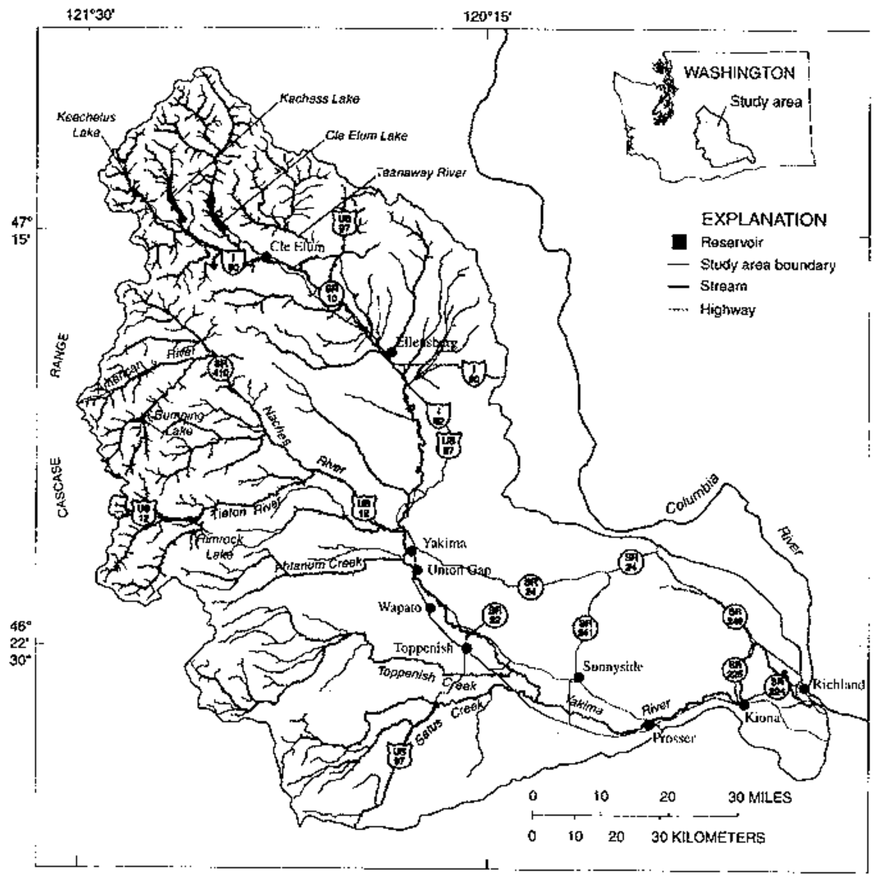

Figure 1: Area map showing the location of the Yakima River basin (from Mastin and Vaccaro, 2002).

The Schaake reach has a series of river training levees on both sides of the river. The construction of these levees has confined the river and prevented regular interaction between the river and the floodplain. The result has been a loss of side channels, critical to the existence of salmonid fish species. 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.

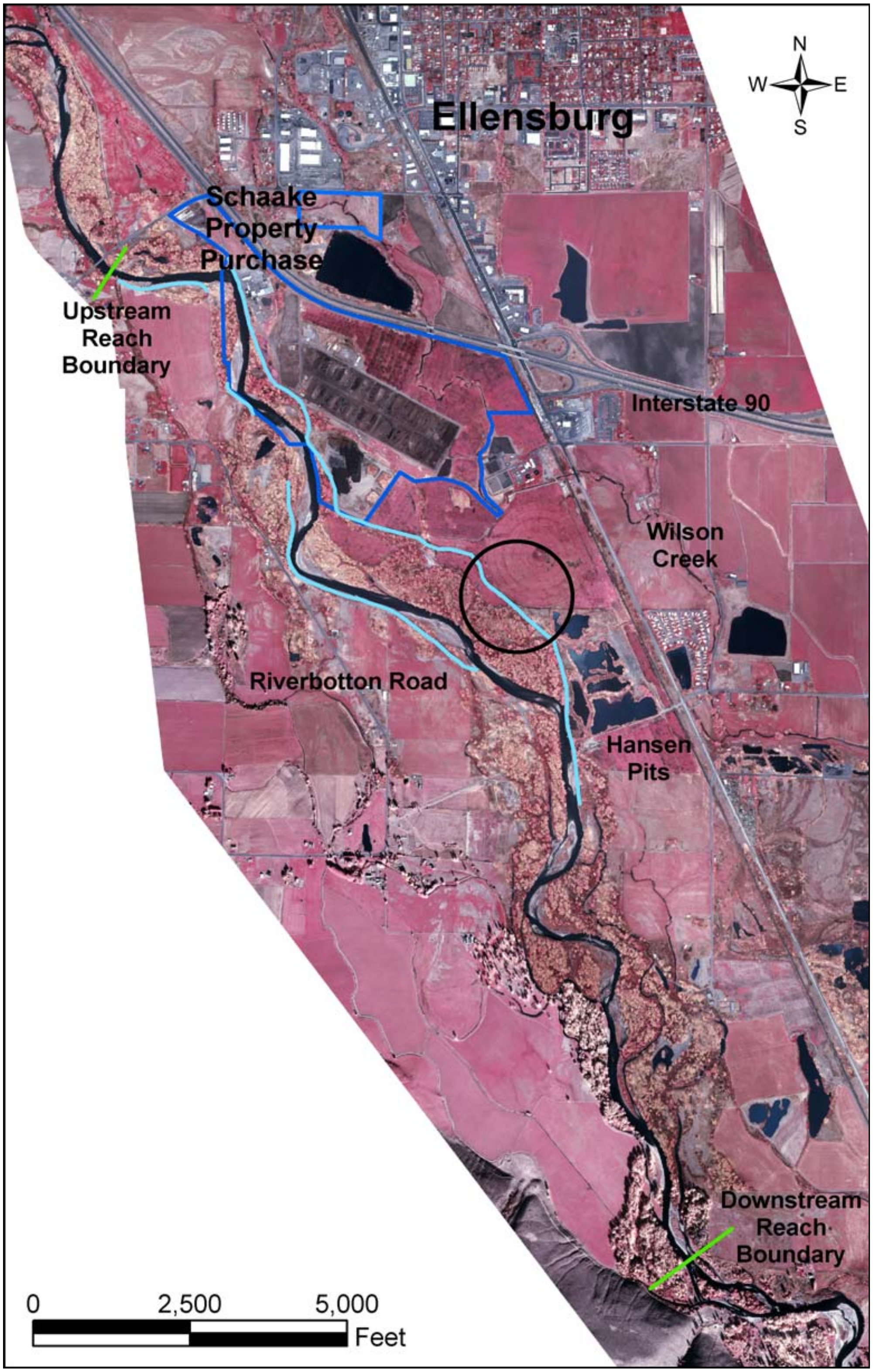

Figure 2: Map of the study reach, Yakima River. Flow is northwest to southeast. Property acquired by the Bureau of Reclamation is indicated within the dark blue outline. Upstream and downstream boundaries of the study reach are indicated with a green line across the river and existing levees are shown in light blue. The circle around the left bank levee shows the portion of the levee that has been constructed to different standards than the rest of the levee.

STATEMENT OF PURPOSE

The purpose of the Schaake Study is to investigate the options available to restore lost side channel habitat due to the construction of levees. The best possible scenario for rehabilitation is that the river be allowed to reclaim historic side channels following the removal or setback of levees with minimal construction of side channels. This will only be possible if historical side channels still exist and frequent and regular inundation of these side channels will occur following levee modification. It is possible that, following removal or setback of the levees, river flows will not interact with the floodplain with normal frequency due to incision of the channel, which limits the ability of the river to access the floodplain. A major part of this phase (Phase II) of the investigation is to determine if frequent return flows will overtop the banks and interact with the floodplain and side channels following levee modification. Minimal construction of side channels will be necessary if the river is able to access the floodplain and form its own channels following removal or setback of the levees. If it is found that flows in the Yakima River will not frequently exceed bankfull stage and inundate the floodplain in the Schaake Reach, it will be necessary to construct the desired side channels. Under either scenario, it will be important to consider the entrapment of fish and the amount of time throughout the year that these side channels are accessible for fish passage.

EXISTING LEVEES, SIDE CHANNELS AND CHANNEL INCISION

There is approximately 18,900 feet of constructed levees within the Schaake Reach, not limited to the Schaake property (Figure 2). Three separate levees exist on the right bank with a total length of approximately 7,400 feet. The left bank levee is assumed continuous and is approximately 11,500 feet long. However, a portion of the left levee (circled in Figure 2) was not constructed to the same design standards as the upstream and downstream portions of the levee. In this portion of the overbank, there is a small build-up of earth, approximately 1 – 3 feet, possibly from spoils removed from the ditch to maintain flow. This portion of the levee is approximately 2 – 3 feet below the elevation of the constructed levee upstream and downstream on the left floodplain. For the purpose of this report the left bank levee will be assumed continuous, even though a portion of it may not provide the same level of protection as the rest of the levee.

These levees exist in the upstream portion of the reach being studied, which is approximately 60% of the overall reach. In the upstream section of the reach, the existence of side channels is minimal. The levees have confined the river and isolated frequent, small magnitude floods from the floodplain. The river in the upstream portion of the reach largely consists of a single channel with little complexity in the manner of islands, side channels and woody debris. In the downstream portion of the reach, no levees exist and the river freely interacts with the floodplain. Many side channels exist in this portion of the reach, usually two on each side of the main channel. Some have upstream and downstream connectivity with the main channel, some do not. Islands and woody debris also add to the complexity of the channel in the downstream portion of the reach. The side channels in the lower reach are generally remnants of the main channel. Geomorphic analysis indicates that channel avulsions are common in this reach and are as common a migration mechanism as meander migration. When the river abandons its primary channel to create a new one, the old channel may remain connected to the newly formed main channel and becomes a side channel. This type of migration activity is prevented when levees are built too near the river on the floodplain. The downstream portion of this reach will be used to compare with the upstream portion to indicate whether the upstream portion has become incised and which flows will be sufficient to maintain side channels.

The Yakima River may have become incised in the upstream reach due to the presence of the levees. Without proper historical channel surveys to make a direct comparison, geomorphic evidence of the riverbed elevation relative to the floodplain and the particle size distribution can be evaluated to determine if the river has become incised. For example, the top of bank elevation relative to the water surface can be used as an indicator if a relatively undisturbed reach exists nearby with which to make a comparison, which is applicable in the Schaake Reach. Figure 3 shows a photo typical of the upstream portion of the river, where the top of the banks are 2 – 4 feet above the water surface during normal summer flows on the river (approximately 2,000 to 4,000 ft^3/s) while the downstream portion has banks less than 2 feet above the water surface for the same flow (Figure 4). Another indicator of channel incision is armoring of the bed. Visual observation during the bathymetric survey indicated that the upstream portion of the Schaake Reach has a larger bed material composition than the downstream portion. Large cobbles are less frequent in the bed material in the downstream portion. It was also noted that at some locations in the downstream portion of the reach, the bed has a high sand content as opposed to the upstream portion, where no sand was visible. These areas of sand were largely found in slack-water portions of the main channel.

Figure 3: Photo showing bank height in the upstream portion of the Schaake Reach. Here the bank is approximately four feet above the water surface. Photo taken 8/20/2003, flow approximately 3,150 ft^3/s.

Figure 4: Photo showing the bank height of the lower portion of the Schaake Reach. Here the banks are two feet or less above the water surface. Photo taken 8/20/2003, flow approximately 3,150 ft^3/s.

GEOMORPHIC ANALYSIS

A geomorphic analysis of the Yakima River through the study reach was undertaken primarily to outline current river characteristics relative to these same historical characteristics. This analysis was undertaken by utilizing hydrographic survey maps compiled by the U.S. Reclamation Service (USRS) in 1912, topographic mapping by the U.S. Geological Survey (USGS), and historical aerial photography (Table 1). Over the 88-year period between the mapping by the USRS in 1912 and the 2000 imagery utilized for the hydraulic modeling in this study, significant geomorphic changes in the Yakima River can be recognized.

Table 1. Inventory of Historical Data

Date	Type	Sheets/Frames	Agency	Scale
1912	Hydrologic map	14-17	USRS	1:2,400
July 19, 1965	B&W photography	E-139-1-2/6	WDOT	1:12,000
October 14, 1966	B&W photography	E-206-2-7/12	WDOT	1:12,000
1975 (1956)	Topographic map	Ellensburg South	USGS	1:24,000
November 11, 2000	Color IR photography	N/A	USBR	1:4,800

The principle aspect of the geomorphology along the Yakima River that is of interest to this study is the channel planform and the nature of the side channels formed on the floodplain. This was due to an interest by Reclamation at rehabilitating areas of the Yakima River to enhance salmonid habitat. These side channels form the habitat utilized by salmonid fish species. Within the study reach, the most readily recognized changes to the river historically have been changes in the channel planform and the decline in formation and maintenance of side channels on the floodplain associated with anthropogenic modification, principally the construction of levees along the river. Modification of the river is evident as early as 1912 with the construction of levees and irrigation ditches. The primary objective of the geomorphic analysis was to document historical change in channel and floodplain conditions within the study reach, and identify those parts of the study reach that have experienced minimal modification that could be utilized as "reference conditions" in the rehabilitation of the river. These reference conditions could then be physically replicated in the Schaake Reach to enhance the habitat conditions for salmonid fish along this part of the Yakima River. It is assumed that these reference conditions represent a near-natural state of the river and that the river would be capable of maintaining these conditions.

In addition to changes in the channel planform, other physical characteristics of the river were analyzed. Channel width, sinuosity, and general morphology could be developed from the historical maps and photography. Physical aspects of the river that could not be developed from this historical data include channel depth as well as sediment characteristics, but this information was not considered important to the objectives of the geomorphic analysis undertaken for this study. However, the current channel thalweg profile (channel depth) developed from data collected specifically for the hydraulic analysis can be analyzed and an interpretation of past hydraulic conditions made based on the current state of associated river conditions. Significant departures of the current thalweg profile and channel slope from an average may indicate either some external influence on the channel morphology or a reach of the river that may have undergone recent changes. The physical and engineering properties of the sediment in the floodplain through the study reach are described in the most recent soil survey (NRCS, 2003 Draft) and may prove useful in any future rehabilitation efforts.

METHODOLOGY

For this analysis, five sets of historical data including hydrologic and topographic maps and aerial photography were utilized (see Table 1). While only a cursory analysis of the historical channel change was described for this study, a more detailed analysis including geomorphic mapping of the river corridor, developing stratigraphic data on the chronology of the alluvium and an inventory of stored sediment could be possible. Analyzing historical aerial photography and comparing the channel position to the mapped position of the river in the 1912 USRS hydrologic survey relative to common landmarks determined the extent of channel change. The position of the river was first mapped on historical black and white aerial photography, and then overlaid on the imagery acquired in 2000 (Appendix A) and compared with a map of the channel form taken from the 1912 USRS hydrologic survey (Appendix A). The extent of channel change was also compared to channel changes mapped by the USGS. The 1:24,000 scale topographic maps for the Ellensburg area were compiled from two different sets of aerial photography. The maps used for this study reach were compiled from aerial photography flown in 1956 and revisions were made based on changes apparent in aerial photography flown in 1975.

The term river channel, as used in this report, includes that part of the river channel covered by water in the photography and presumably represented as the river on the USGS topographic maps and in the older USRS maps. Hence, the width and to a certain degree the position of the river would be dependent on the discharge in the river at the time the photography was flown or the map surveyed. While it is unknown what discharge is represented on the Yakima River in the USGS or USRS maps, the mean daily discharge in the 1966 and 2000 photographs was similar, approximately 1,250 ft^3/s and 840 ft^3/s respectively. The mean daily discharge in the 1965 photographs is 3,340 ft^3/s, significantly greater than the other photography; but the 1965 photography covers primarily the southern most part of the study reach. These discharges were measured at the Umtanum gage, which is located several miles downstream of the study reach and has been recording stream flow for more than 95 years (1906; 1908-2003).

In addition to the channel position, other physical characteristics of the floodplain that are easily delineated on aerial photography that are clearly associated with fluvial deposition or modification by the Yakima River include bars and islands, relict bar-and-swale morphology, scars of abandoned meanders, side channels, and abrupt changes in elevation that may result from channel migration, aggradation, or incision. As stated above, many of these characteristics of the river are directly influenced in the historical data by anthropogenic modification and their appearance in aerial photography or depiction on maps may in part be dependent on the discharge in the river at the time the photography was flown and the objectives for each map compilation.

For the purpose of this analysis, the Yakima River in the Schaake Reach was subdivided into sub-reaches based on specific physical characteristics (summarized in Table 2). These characteristics include the presence of bars and islands and large meanders in the main channel, relict bar-and-swale morphology or scars of abandoned meanders on the floodplain that, the occurrence of side channels, abrupt changes in elevation representative of preserved terraces that may result from channel migration, aggradation, or incision, and levees. All are visible on the aerial photography and to a certain degree may be shown on the maps. It should be understood that the criteria used to subdivide the river in this area are relatively arbitrary, and that these sub-reaches were defined primarily to ease the description of channel and floodplain characteristics and changes. Because the focus of this study is on the Schaake Reach, more emphasis was placed on the historical changes within this reach. Dramatic differences or changes noted between these sub-reaches may or may not be due to natural or anthropogenic influences. Due to the limited scope and the reconnaissance nature of the geomorphic analysis, it was not always possible to precisely determine the source of changes in the system. However, an effort has been made to document significant changes and note possible influences on the change where the information was available.

CHANNEL CHANGE AND FLOODPLAIN CHARACTERISTICS

In a qualitative and quantitative sense, the sinuosity, channel width, and the multiple tread character of the river can be categorized as increasing in a downstream direction (Table 2; Appendix A). This change appears to be directly related to those reaches of the river where levees have limited the ability of the river to migrate laterally or where they restrict direct connectivity of the river with its floodplain. The extent of this change is best illustrated in sub-reaches 1 and 2 (see Appendix A) where the channel has moved about 400 feet east from its position in 1912 and 1966. This change in the position of the channel appears to be the direct result of the levee along the right bank or artificial narrowing of the channel. In 1912, the river through this reach consisted of two channels separated by a large mid-channel island. By 1966, the river in the upper part of the reach flowed in a single channel and the second channel had been filled in and the multi-tread character of the channel migrated to the downstream end of the reach. It is unclear based on historical data used in this analysis what caused this change, but there is some evidence that it may have been induced by human modifications to the channel and floodplain. In addition to some form of bank protection or levee along the right bank, there was a head gate located near RM 4.2 on the right bank to divert flow to the Dammon Mill in 1912.

Table 2: Summary of Channel Change and Floodplain Characteristics

Reach	River Mile	Channel Change and Floodplain Characteristics
1	4.3-3.9 (0.37)	Current reach is flanked along the right bank by levee present in some form since before 1912. An abandoned meander scar that served as a secondary channel for flow in 1912 currently marks the left bank of the river. By 1966, the multi-thread character of the river had migrated to the downstream end of the reach. The lower end of the reach is marked by a sharp 90° right bend and a levee on the left bank.
2	3.9-3.5 (0.35)	The upstream half of the reach is flanked along left bank by levee. In the upper part of the reach, the channel has migrated approximately 400 ft east to its current position into a side channel from 1912. Similarly, the lower part of the reach has migrated to the east from its position in 1966.
3	3.5-2.9 (0.70)	Long arcuate reach consists of a single thread flanked by levees on both sides of the river. In 1966, abandoned meander scars, narrow side channels, and broad, gravel bars mark the floodplain in this reach. By 2000, the arcuate character of the reach has decreased slightly and the gravel bars have narrowed. The main channel in the lower part of the reach has migrated east approximately 200 feet resulting in overall straighter channel.
4	2.9-1.5 (1.45)	This reach is located downstream of the Schaake property. The relatively linear reach is marked by two gentle right bends. Again, the river is flanked by levees on both banks along a majority of its length. As in the upstream reaches, this reach shows a decrease in the number of well-developed side channels and mid-channel islands, the gravel bars have narrowed, and the multi-tread character has changed to a narrow, single channel. The channel sinuosity has increased slightly from 1966.
5	1.5-0.0 (1.50)	This reach is at the downstream end of the study and the entire length of the reach currently contains no levees. While the main channel is narrower than in the upstream reaches, side channels that are conveying flow are much more numerous and the channel sinuosity is significantly greater than upstream reaches. The position of the main channel has changed frequently, but has generally moved into a previously existing side channels. This reach is assumed to represent reference conditions.

A 90° right bend in the current channel forms the dividing point between sub-reaches 1 and 2 (Appendix A). At this point in the river, a levee forms the left bank of the river and the main channel flows in what was once a back channel on the floodplain. The shift of the main channel into this back channel can be observed in the 1966 aerial photographs where the flow is split between two channels; the original main stem and the back channel depicted in 1912 maps. By 2000, the channel is limited to a single tread flowing through the back channel and the original channel has been completely abandoned. It is apparent that the original main channel became an area of deposition in the area downstream of the levee on the right bank. Since 1966, the channel in the lower part of sub-reach 2 has continued to migrate to the east and a large bar has formed in the area of the main channel.

Currently, a long arcuate channel flanked by a broad vegetated floodplain forms sub-reach 3 (Appendix A). The overall character of the main channel appears to have changed very little between 1966 and 2000 with the exception that the gravel bars flanking the main channel appear narrower than in 1966. Also, a shift in the channel position in the lower part of the reach between 1966 and 2000 by about 200 feet to the east has also resulted in a slightly straighter channel. The current straighter nature of the channel more closely approximates the channel planform depicted in the 1912 maps at this location. However, in 1912 a relatively large side channel existed on the floodplain west of the main channel. Remnants of this channel can be identified on both the 1966 and 2000 photography.

It is important to note that Wilson Creek currently flows across the floodplain east of the Yakima River (Figure 2 and Appendix A). The closest approach of Wilson Creek to the main stem of the Yakima River upstream of its confluence is in the area of sub-reach 4 (about 2000 feet). There is a low spot in the floodplain in the vicinity of Wilson Creek (Figure 5, RM 3.55 – 3.02) and the floodplain in this location is at approximately the same elevation as the channel. It is expected that here Wilson creek is flowing in what used to be the main channel of the Yakima River. Any levee modifications should separate the main flow of the Yakima River from Wilson Creek and the Ellensburg wastewater treatment plant to prevent complete migration of the Yakima River into these portions of the floodplain. It is likely that the Yakima River will tend to migrate toward Interstate 90 without reinforcement on the left bank near the former location of the meat packing plant. This will be discussed in greater detail later in this report.

Based on the geometry of the cross-sections used in the hydraulic analysis, it appears that Wilson Creek occupies an abandoned course of the main stem of the Yakima River. Because Wilson Creek is flowing in an abandoned course of the river suggests that channel avulsions on the Yakima River are essentially instantaneous. Due to the much smaller flows in the tributary, Wilson Creek was unable to maintain the position of its confluence with the main stem. The present confluence of Wilson Creek with the Yakima River is at the head of Yakima Canyon. The presence of numerous abandoned channels and meander scars on the floodplain in the historical photography with channel widths comparable to current channel widths provides evidence that the Yakima River has migrated extensively across the valley floor in recent geologic history (i.e., within the last 10,000 years).

Sub-reach 4 represents the longest and straightest section of the river in the study (Appendix A). The right bank of the river through much of this reach is flanked by a levee that limits overbank flow onto the floodplain. Historically, the river has been in much the same position with the exception of a shift of the main channel in the upper-most part of the reach almost 300 feet to the southwest. In 1966, the river in this area flowed in a multi-tread channel with broad bars and islands and numerous side channels marked the floodplain on both sides of the river. The lower end of this reach of river is located at the Hansen pits and the downstream extent of levees along the river (see Figure 2).

Sub-reach 5 is marked by a noticeable increase in the channel complexity including multi-tread character, tighter bends, broader bars, and greater connectivity of the side and back channels with the main stem of the river (Appendix A). While this reach of the river has experienced as many changes in the channel position as upstream reaches, the channel complexity following any shift in position has remained fairly consistent. The main channel has remained largely multi-tread with bars and islands and numerous side channels mark the floodplain. In many cases, the main channel appears to have migrated into a previously smaller side channel and the main channel is either completely abandoned or becomes a side channel.

The river in the downstream half of the study area (sub-reaches 4 and 5) does not appear to have been impacted to the same extent by anthropogenic modifications as the upstream part of the study reach, hence it appears to have undergone less dramatic channel changes since 1966. This

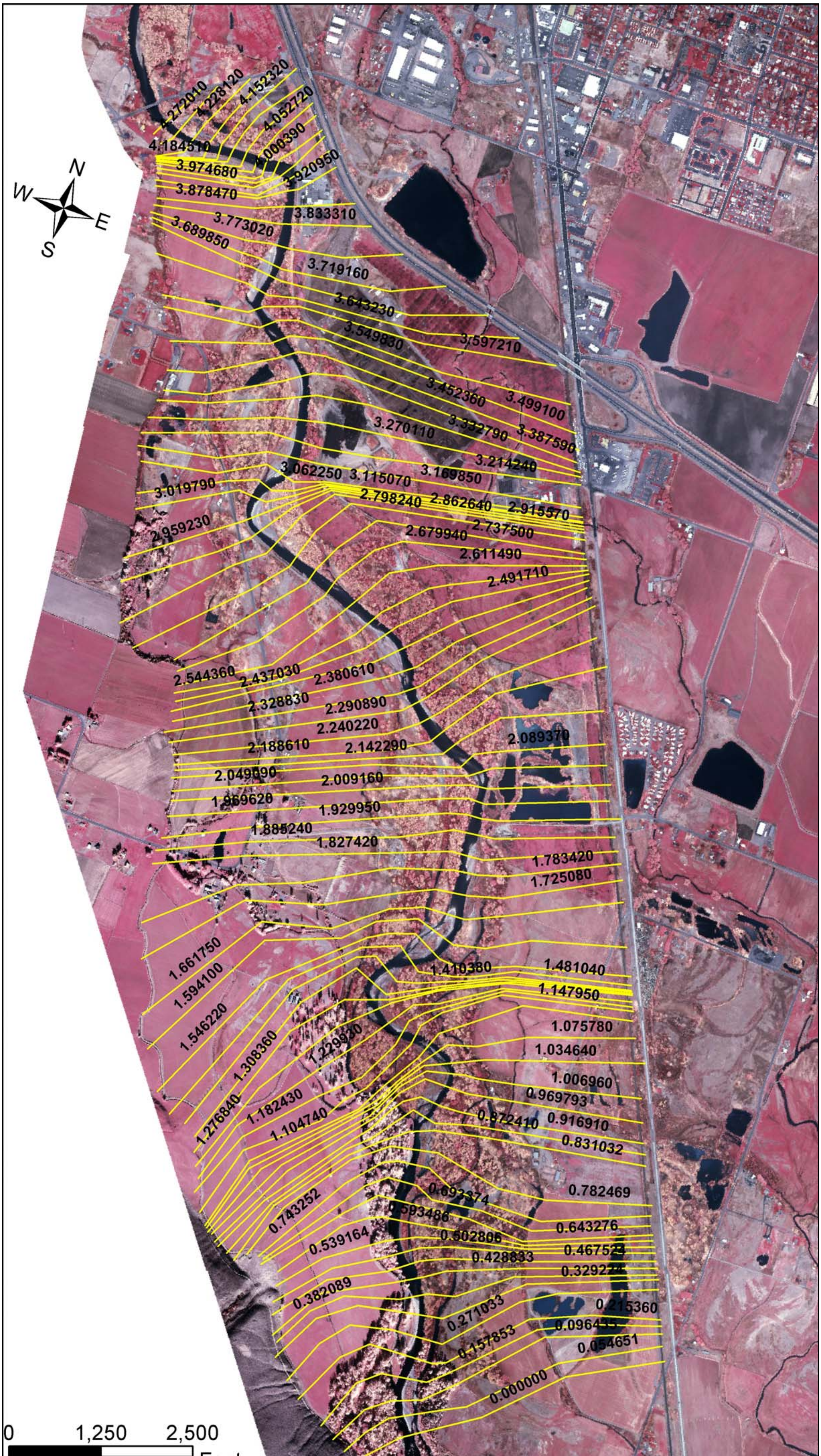

Figure 5: This figure shows the cross sections and stationing used in the model. Stationing is in river mile and increases upstream.

is supported by 1:24,000 scale USGS topographic mapping. For this reason, the lower part of the study reach is viewed as being more representative of natural conditions and will be cited as the control or reference reach. It is evident from the 1912 USRS survey of the Yakima River that the river has also changed dramatically to its current position. However, because the datum for the 1912 maps is unclear and there appears to be some errors in the mapping of the main stem, location and configuration, the actual extent of the change is unknown. There are also factors controlling the geomorphology in this reach that have not been thoroughly analyzed and are not present in the upstream portion of the study area. Some of these factors include tributary channels, localized changes in slope and sinuosity, the occurrence of older river terraces in the reach, and bedrock control.

NUMERICAL HYDRAULIC MODEL OF THE SCHAAKE REACH

A one-dimensional (1-D) hydraulic model (HEC-RAS, ver. 3.1.1, Brunner, 2002) was utilized in order to assess the frequency with which flows in the Yakima River are expected to exceed bankfull stage and access the floodplain to determine if the upstream portion of the reach has become incised. The most critical components of this model are geometry and flow input data. All components of the model specific to this project application are explained in detail below.

FLOOD FREQUENCY ANALYSIS

Flows on the Yakima River are partially regulated by reservoirs within the basin. The largest flow events are typically associated with spring runoff or rain-on-snow events during the winter. A flood frequency curve containing seasonal peaks for a 27-year record was obtained from the YRBWEP team that provided return frequencies for summer and winter. Because this study is not concerned with the season in which the peak exists, the annual peaks were used instead of seasonal peaks. The flows were taken from the Ellensburg gage, located on the Yakima River just upstream of the Schaake Road Bridge which is located at the upstream end of the study reach. This gage was discontinued after 1948 and a new gage was constructed in 1977 just upstream of the previous location (Steve Fanciullo, pers. communication). Using annual peaks from 1941 – 1948 and 1977 – 1998 a frequency curve was determined with a program (FREQY; Carson, 1989) written to perform a log-Pearson Type III distribution of annual peaks following methods outlined in Bulletin 17-B (Interagency Advisory Committee on Water Data (IACWD) (1982)). No regional skew was applied to the calculated values. Because the period of record for the analysis is short, a return flow of 20 years is all that can be reasonably predicted from this data set. This does not present a problem for this analysis because frequent return flows are the major concern, not large flow events.

Values obtained from the flood frequency analysis were compared to return frequencies at other locations on the Yakima River with longer records (Williams and Pearson, 1984). This was done in order to insure reasonable values were obtained for the return flows used at Ellensburg in this report. The USGS gages used to compare return flow values were Umtanum (downstream) and Cle Elum (upstream). This comparison indicated that the return flows used are reasonable because they fall within the range of the upstream and downstream return flows. The flood frequency data used in this report is shown in Appendix B. Flow input to the model is shown in Table 3.

Table 3: Table showing the flow rates modeled for the project.

Flow Rate (ft^3/s)	Return Period	Comments
585	-N/A-	Flow rate during 2000 aerial survey
3150	-N/A-	Flow rate during 2003 hydrographic survey
5,678	2-year	-N/A-
10,066	5-year	-N/A-
13,922	10-year	-N/A-
18,441	20-year	-N/A-

MODEL GEOMETRY

Aerial photography and Light Detection and Ranging (LiDAR) flown November 1, 2000 was used to obtain overbank topography. Discussions with the YRBWEP team and gage records indicate that there has not been a large flow event since this data was gathered, indicating that the overbank information is still reasonably accurate. Because the underwater portion of the topography can not be obtained with commercially available photogrammetry or LiDAR, it was necessary to survey the river channel to obtain accurate bathymetry. This was performed on August 19 and 20, 2003 using Global Positioning System (GPS) survey methods and a single beam depth sounder mounted to a raft. Five float trips were made through the reach, with an emphasis on obtaining bathymetry on as much of the river width as possible. These float trips began at the Ellensburg boat launch just upstream of the Schaake Road Bridge. The take out location was the U.S. Fish and Wildlife boat launch on Ringer Road. In certain locations it was not possible to obtain survey information for part of the river usually due to swift currents, lack of proper GPS coverage or obstructions preventing the raft from accessing all portions of the river. At these locations interpolations were made based on known topography and bathymetry and notes taken during the data collection.

Once the survey information was obtained, it was reviewed for consistency and processed into a database. This database was then used to make a geographic information system (GIS) shape file and combined with the LiDAR data. This provided a fairly dense, continuous representation of the topography so that a Triangulated Irregular Network (TIN) could be made from the data. Using the TIN, cross sections were cut using HEC-GeoRAS, version 3.1.1 (Ackerman, 2000) with ArcView (ver. 3.3, 2002). These cross sections were then imported into HEC-RAS to create the geometry for the 1-D model.

The locations of the cross sections used in the model can be seen in Figure 5. The river stationing used in the hydraulic model corresponds with river mile and increases in the upstream direction. The cross sections were cut in such a way that the lines remain perpendicular to the direction of flow. Some of the cross section alignments may look awkward. This is due to the complexity of the floodplain and, in some locations, the artificial alignment of the river due to the levees.

ACCURACY AND ERROR ASSOCIATED WITH BATHYMETRY DATA

The accuracy of the GPS survey equipment when used in Real Time Kinematic (RTK) mode is ± 0.0328 feet (1 cm) for the horizontal plane and ± 0.0565 feet (2 cm) in the vertical plane under ideal conditions. The accuracy should be expected to be somewhat less while on a moving platform (raft) when radio link and satellite reception varies. The depth sounder is accurate to ± 0.5 feet for deep water applications. For shallow water such as the Yakima River, the accuracy is ± 0.2 feet. Surface disturbance on the river may also contribute to error in the survey. The bathymetry resulting from the survey is within the error of the LiDAR data (± 1 foot).

ROUGHNESS AND SENSITIVITY ANALYSIS

Following the construction of the geometry, roughness values were assigned to the overbank and main channel. A Manning's n of 0.036 was used for the main channel. This value was taken from calibrated values on the Yakima River near the Umtanum gage (Barnes, 1967). The Manning's n value chosen for the forested regions of the overbanks and cultivated fields was 0.075 and 0.03, respectively (J. F. Sato and Assoc. et al., 1981). Where side channels were visible in the photograph and evident in the cross section geometry, a Manning's n of 0.04 was used. For those cross sections with woody debris present in the main channel, the Manning's n was increased to 0.04. A sensitivity analysis of the Manning's n value for the main channel was performed. It was found that adjusting the Manning's n to 0.03 from 0.036 made an average change in the water surface elevations of 0.3 feet, which is less than the error for the survey data. Therefore, the chosen Manning's n value of 0.036 appears to be reasonable.

MODEL VERIFICATION

The model results were verified by comparing water surface elevations obtained during the survey and water surface elevations predicted by the model. Results from this comparison are shown in Figure 6. It can be seen in this figure that modeled water surface elevations during the survey are well represented by the model. There was no need to adjust or 'calibrate' the model to obtain the water surface elevations shown in Figure 6. The downstream boundary condition was set to normal depth with a slope of 0.002267, the slope of the energy grade line at the downstream end of the model.

Flows during the survey, obtained from the Ellensburg gage, are shown in Figures 7 and 8. There was a variation of no greater than 132 ft^3/s during data collection on the first day (8/19/03) and a 110 ft^3/s variation on the second day (8/20/03). There was an overall variation of 195 ft^3/s over the two day period during data collection times, about 6% of the total flow. Average flow during data collection was approximately 3150 ft^3/s, which was used in the model to verify the predicted values with those obtained during the survey.

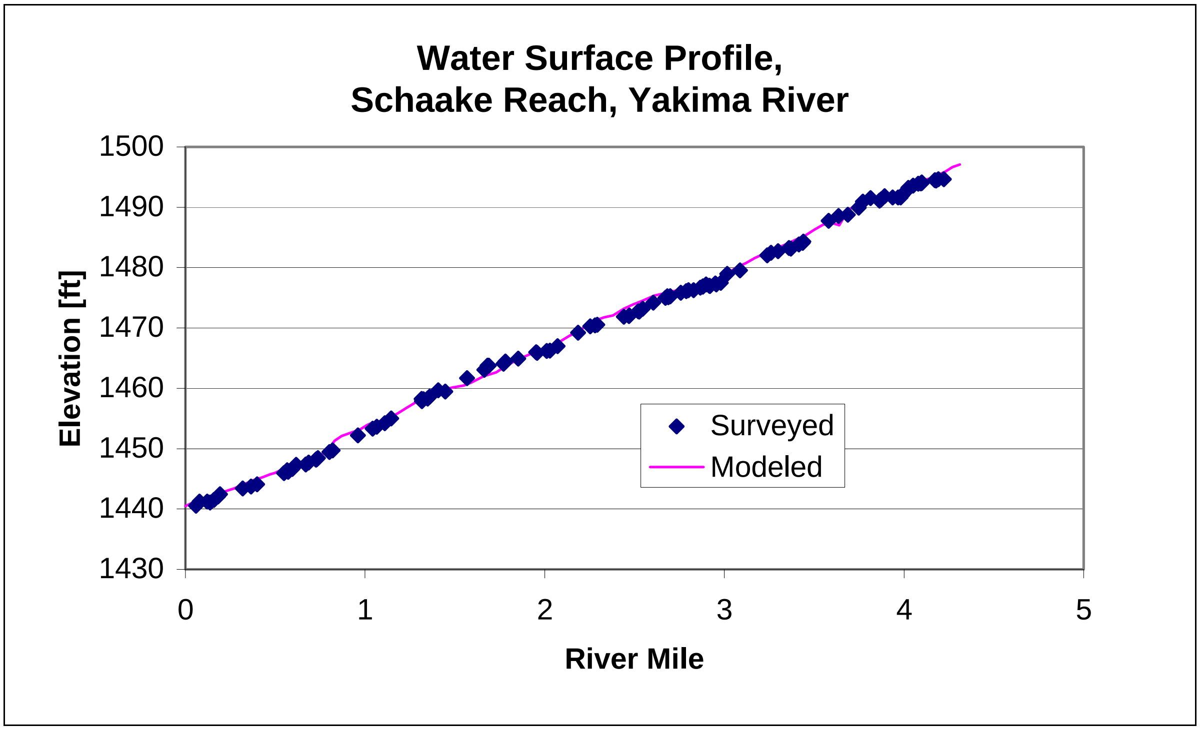

Figure 6: Profile comparing model predicted water surface elevations and those obtained from the survey. Flow in the model was 3150 ft^3/s.

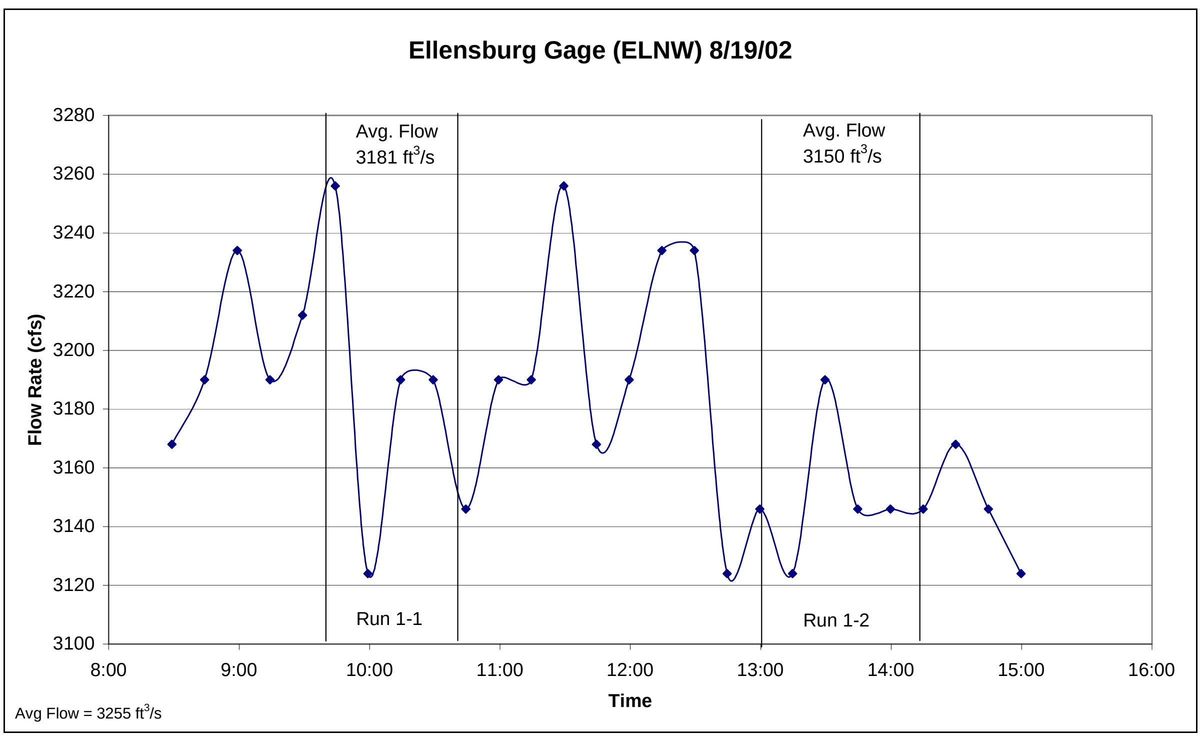

Figure 7: Graph of flows recorded on the Ellensburg gage during data collection on August 19, 2003.

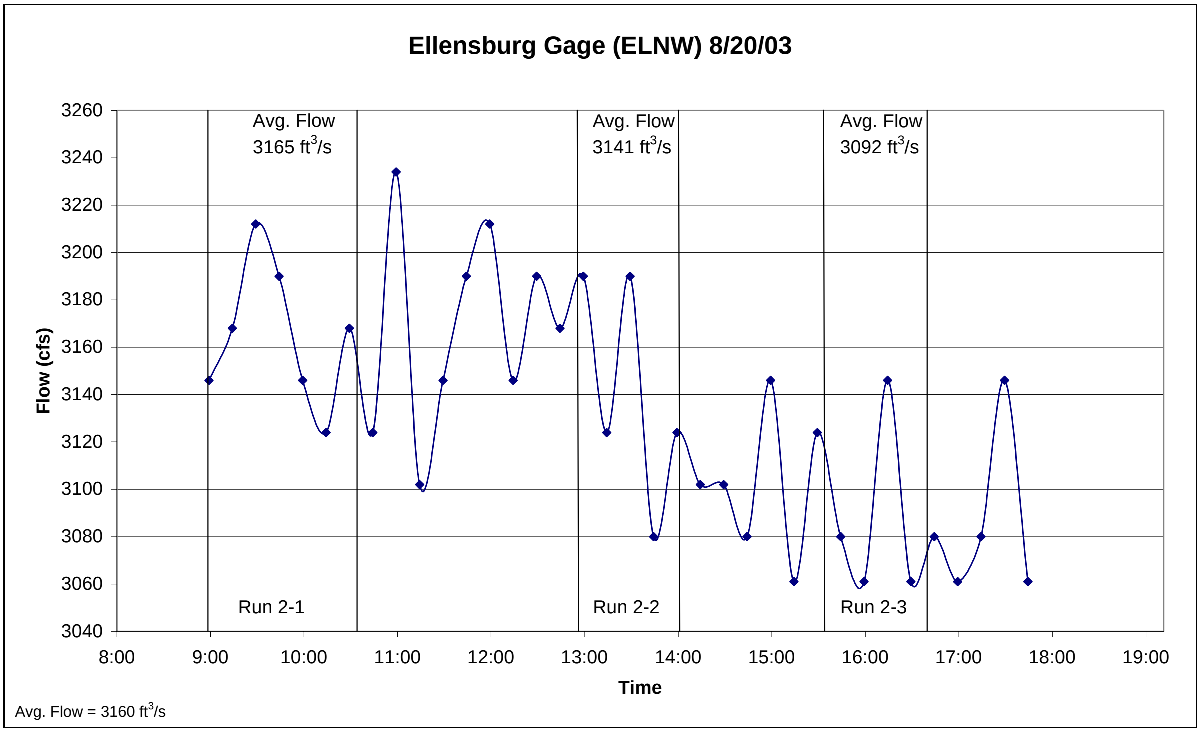

Figure 8: Graph of flows recorded on the Ellensburg gage during data collection on August 20, 2003.

RESULTS AND DISCUSSION

1-D MODELING RESULTS

After the model was verified with water surface elevations obtained during the survey, flows determined by the flood frequency analysis were modeled. There are two major objectives to the 1-D modeling: to determine if the channel in the upstream portion of the reach has become incised, and if so, how much; and to determine how often overbank flows can be expected. These are important factors in determining the potential for rehabilitation of the Schaake Reach.

CHANNEL INCISION AND FREQUENCY OF INUNDATION

In addition to the geomorphic factors evaluated, the model was used to determine if the channel in the upstream portion has become incised. The model was used so that a comparison of top width and hydraulic depth could be made of the upstream and downstream portions of the reach (with and without levees, respectively). As mentioned previously, an assumption was made that the downstream portion of the reach is a more natural and desired system and was used as a reference reach.

It was expected that a simple comparison could be made using the 2-year flow to determine if that flow exceeded bankful stage in either the upstream or downstream portions of the reach, or both. Due to the complex floodplain topography and the lack of a well defined, consistent top-of-bank, this type comparison could not be utilized to obtain the desired results. In some locations, the 2-year flow accesses the floodplain through side channel interaction and not by overtopping the banks. In other locations, the 2-year flow does exceed the bank height and spills onto the floodplain. This situation made it necessary to compare other parameters throughout the reach such as top width of the wetted surface, hydraulic depth (flow area divided by water surface width) and slope to determine the level of impact to the upstream portion of the reach.

Along with a comparison of the upstream and downstream portions of the Schaake Reach, three separate geometries were used in the analysis. The geometries are: the existing geometry, including levees; removing the three right bank levees and assuming that Riverbottom Road will act as a levee through a portion of the reach; and setting back the left bank levee away from its current alignment. The scenario of modifying the left and right bank levees together was not evaluated because the information needed to make a conclusion for this report was able to be determined without doing so.

Removing the right bank levees will require at least a flood easement and perhaps property purchase. The left bank levee setback is mostly on Reclamation property and is meant to serve as a tool to indicate areas of the floodplain that may become inundated should the levee be modified. The exact location of this levee setback will need to be more closely reviewed should this option be exercised. The location of the existing levees and the left levee setback is highlighted in Figure 9. A more detailed discussion of the options regarding levee modification will be discussed later in this report.

Hydraulic Depth

The model was run for existing conditions and each of the two levee modification scenarios mentioned above. A direct comparison of hydraulic depth was made for the entire reach and plotted with river mile for the 2 and 5-year return flows (Figures 10 and 11). The 2 and 5-year flows are examined because these are channel forming discharges and are capable of maintaining side channel geometry. The reason for plotting hydraulic depth with river mile is to compare values in the upstream and downstream portions of the reach and to indicate the effects of the levees and their modification. For existing conditions in the downstream portions of the reach the hydraulic depth is generally between 2 and 5 feet for the 2-year return flow with an average of about 4 feet. In the upstream portion of the reach existing hydraulic depths range between 3 and 9 feet with 5 to 6 feet being the average. This may indicate that the channel has incised by 1 or 2 feet or it may simply be an indication of the narrowing affects of the levees. However, the regions with the greatest hydraulic depth are coincident with those portions of the river flowing against the levees. Because the river is not allowed to erode the banks, these areas are subject to localized scouring of the channel bed.

The model results for the two levee modification scenarios provide additional indication that the river is slightly incised through some of the upstream portion of the reach. Because historical aerial photography indicates this section of river regularly flowed into side channels, it would be expected that setting back or removing the levees would allow water to spill into the floodplain and reduce hydraulic depths. Instead, when the results are examined in Figures 10 and 11 (left levee setback or right levees removed), it can be seen that the hydraulic depth in some locations of the upstream portion does not decrease to depths calculated for the downstream portions of the reach as a result of either of the two levee modifications. The channel incision prevents the water from getting out of bank and flowing onto the floodplain in the most constricted locations where scour has lowered the channel elevations. This situation can be corrected following levee modification by constructing access from the main channel to existing side channels or constructing pilot channels in those portions of the floodplain that are low enough to become inundated with less than a 2-year flow.

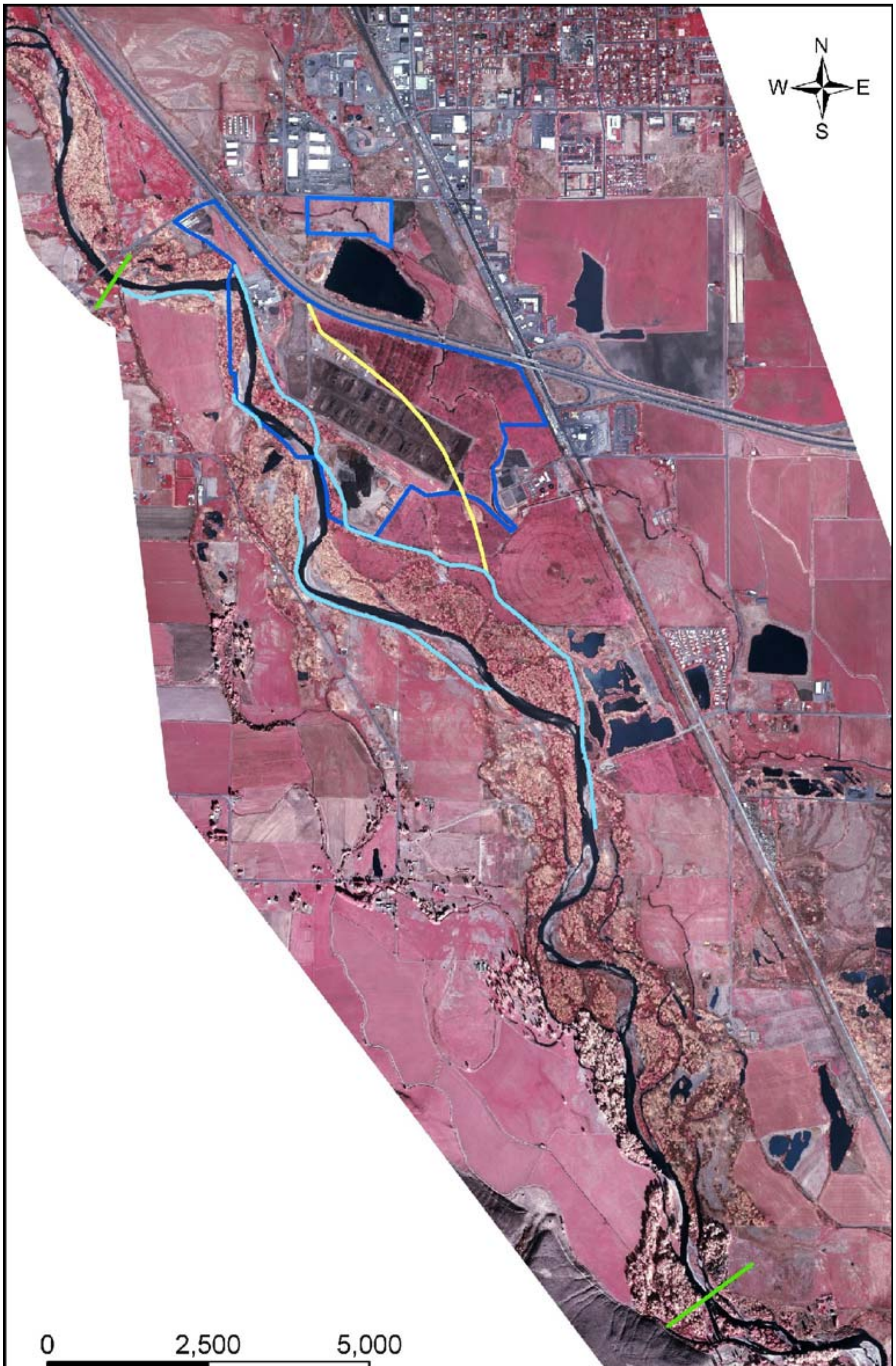

Figure 9: Photo showing existing levees (light blue) and location of left bank levee setback (yellow). Schaake property is shown within a dark blue outline. Riverbottom Road is visible on the right floodplain through much of the reach. Flow is from top to bottom of the page.

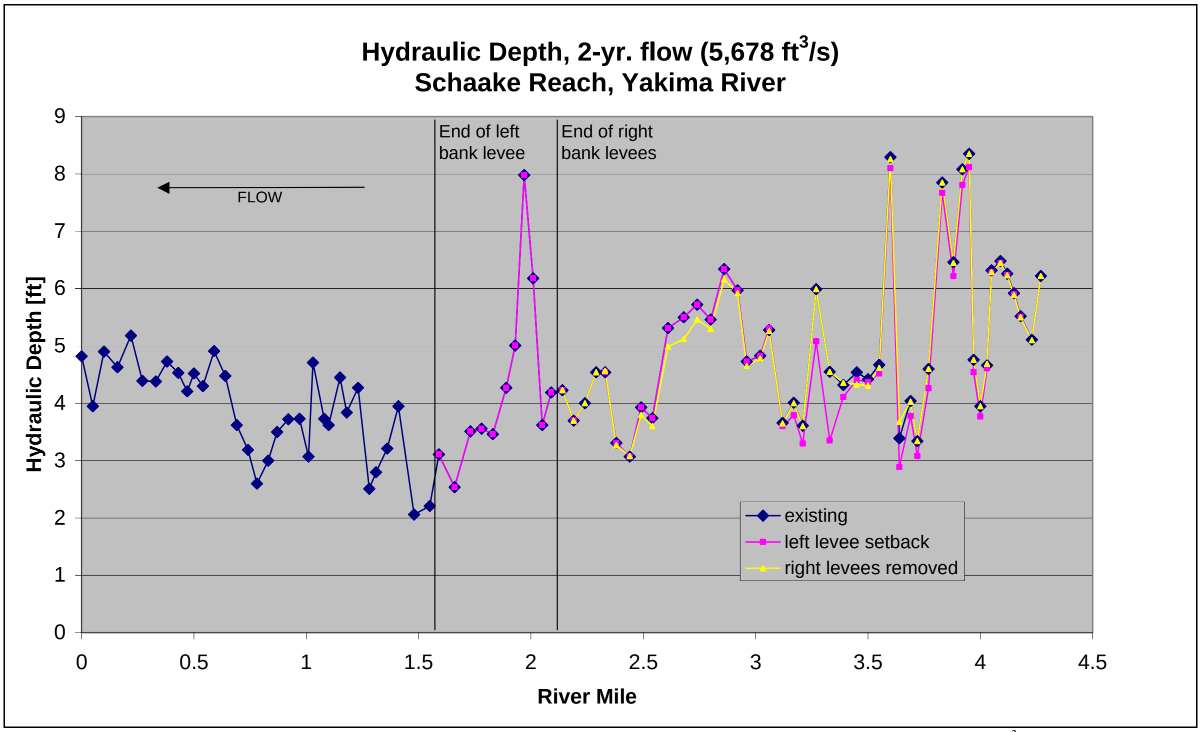

Figure 10: Graph of hydraulic depth with river mile using the 2-year return flow (5,678 ft^3/s).

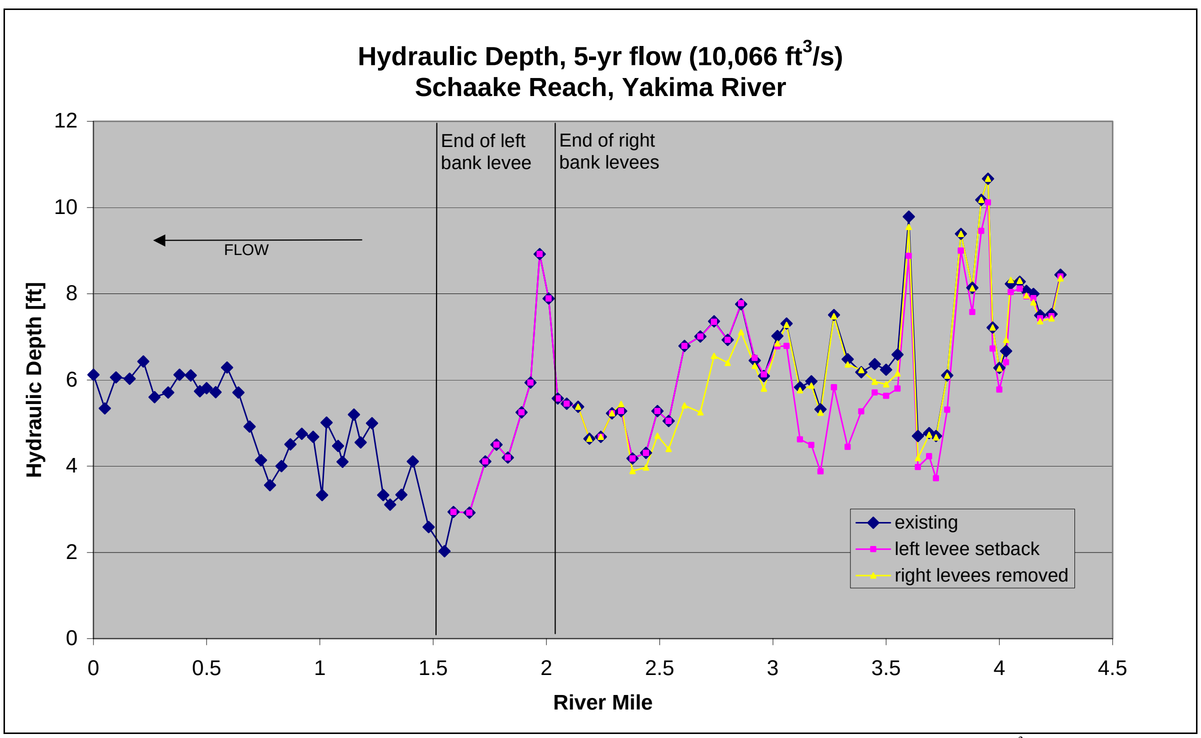

Figure 11: Graph of hydraulic depth with river mile using the 5-year return flow (10,066 ft^3/s).

Top Width of the Wetted Surface

Another comparison that can be made between the upstream and downstream portions of the reach is the top width of the wetted surface. Figures 12 and 13 show the top width plotted with river mile for the 2 and 5-year flows. Hydraulic depth is a function of top width; therefore, the location of changes in hydraulic depth throughout the reach is similar to the location of changes in top width. For example, from river mile 0.7 through 1.7 there is a reduction in hydraulic depth and an increase in top width in that portion of the river compared to the reach immediately upstream of RM 1.7. It is at this location that side channels in the floodplain are accessed by the river at most flow rates, which is an indication of what the upstream portion of the river might look like if the levees had not been constructed.

Also shown in Figures 12 and 13 are the results of the model with the left levee setback and the removal of the right bank levees. It can be seen that there is a greater change in top width than hydraulic depth in the upstream portion of the river following levee modification. It may be necessary to construct a connection from the river to portions of the floodplain to realize the increased top width shown in Figures 12 and 13 because an assumption was made that water that exits the main channel has access to all portions of the floodplain.

Inundation Area

Water surface TINs were created for 3,150 ft^3/s (considered a normal summer flow), 2-year (5,678 ft^3/s) and 5-year (10,066 ft^3/s) return flows for the various levee configurations (Appendix C). These inundation maps help to determine low spots in the floodplain and existing side channels. The 3,150 ft^3/s TIN was made to indicate surfaces in the floodplain that are low enough to become inundated during normal summer flows following levee modification, therefore potentially being the best locations for digging pilot channels. The 2-year and 5-year flows are channel forming flows that will be expected to help form and maintain newly created side channels.

The accuracy of each water surface TIN is limited to the location of individual cross sections with an assumption that water has a path to the inundated area. Because the data was obtained using a 1-D model, only a straight line interpolation if the water surface can be made for the areas that lie between the cross sections. However, these inundation maps serve to indicate regions that are low enough in the floodplain to become inundated following levee modification. It is likely that some pilot channel construction will need to take place before the inundation area indicated in Appendix C is realized. A two-dimensional (2-D) model will more accurately predict interaction between the main channel and the floodplain and is therefore recommended for a more detailed analysis of flows on the floodplain.

It is important to note that side channels were not part of the river survey and only the water surface elevation appears in the floodplain topography when these channels contain water.

Thalweg Profile and Bed Slope

The slope of the bed profile for the entire Schaake Reach is 0.0024. It is expected that if the upstream portion of the reach has become significantly incised its slope would be different from the downstream portion. This is not the case in the Schaake Reach, where the downstream portion has only a slightly greater slope (0.0026) than the upstream portion (0.0024) (Figure 14). This concurs with previously mentioned evidence pointing to some channel incision in the upstream portion of the reach but not to any great extent. Those portions of the channel that are more severely scoured are coincident with locations where the river flows against the levee, as mentioned previously. Those areas can also be seen in the bed profile where the elevation drops significantly.

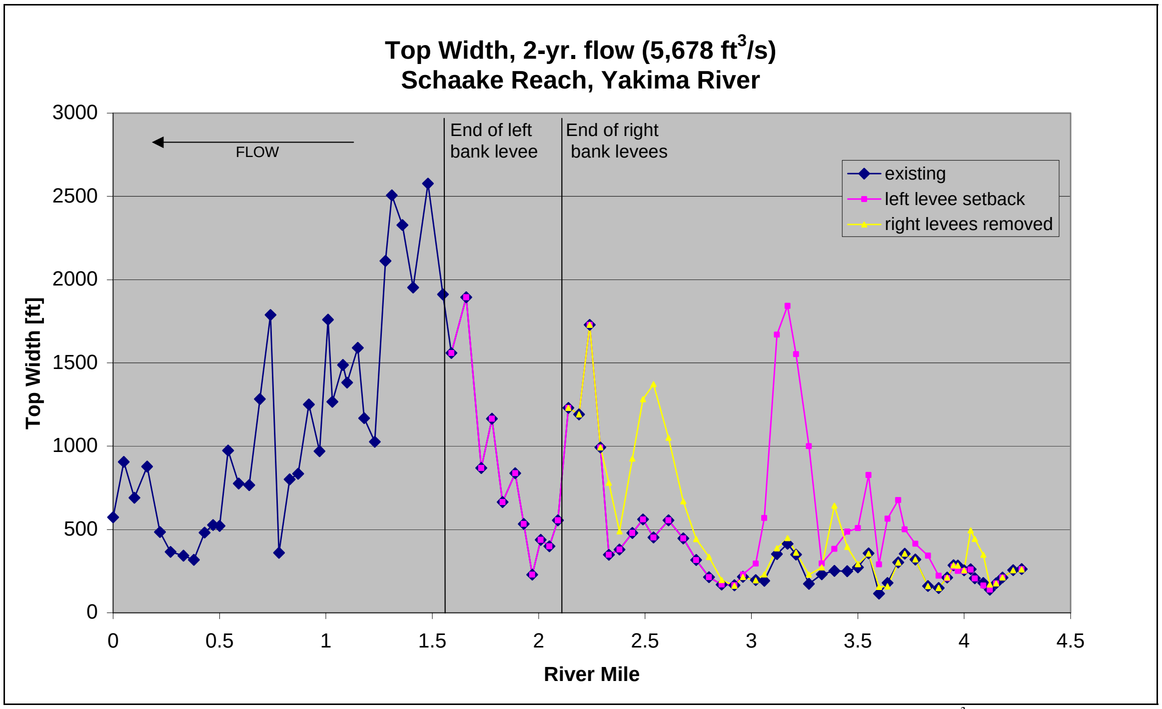

Figure 12: Chart of top width with river mile using the 2-year return flow (5,678 ft^3/s).

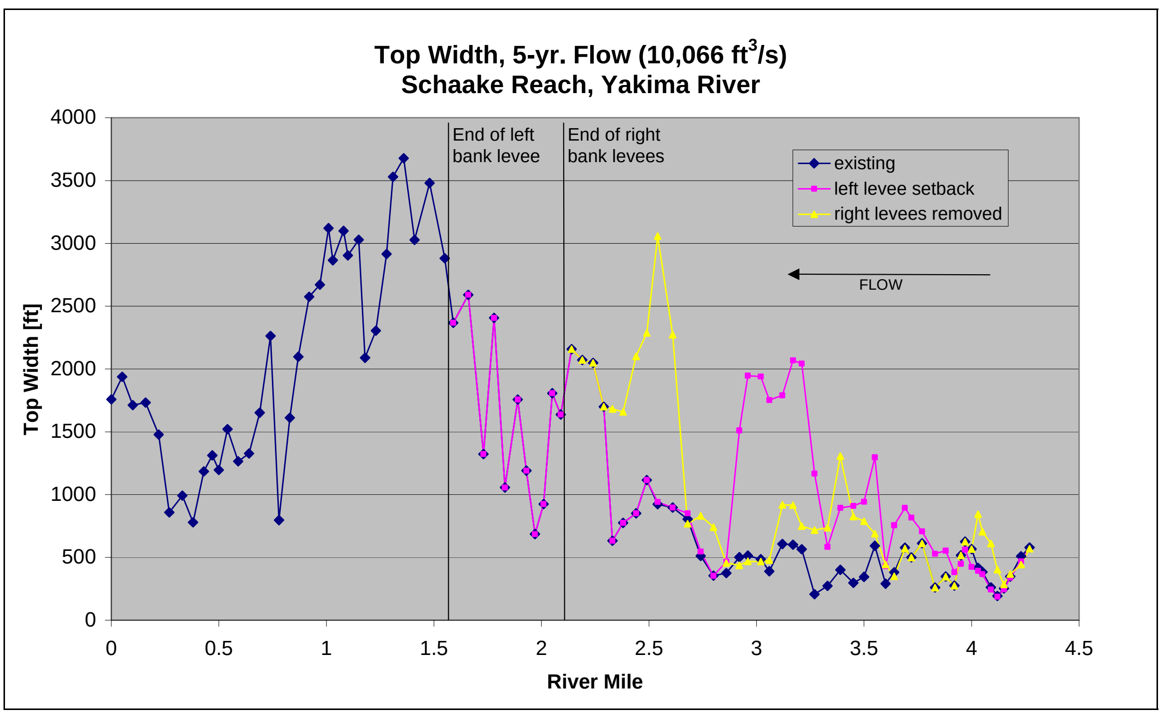

Figure 13: Chart of top width with river mild using the 5-year return flow (10,066 ft^3/s).

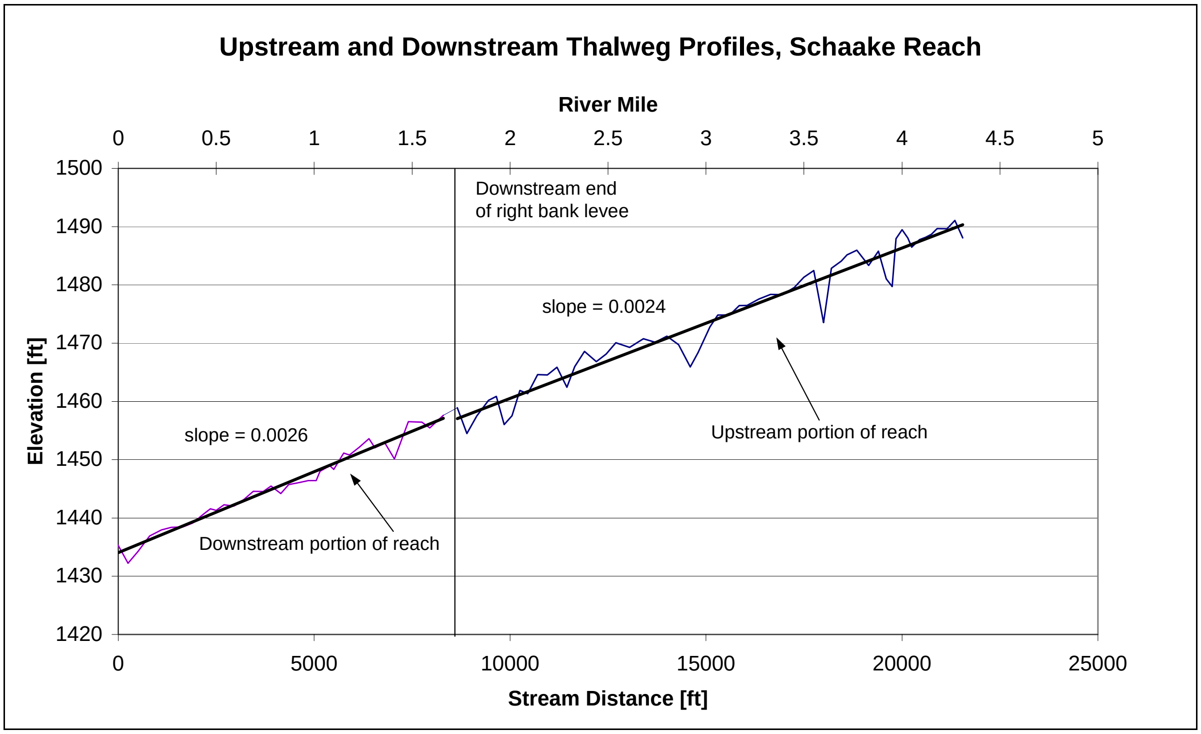

Figure 14: Thalweg profiles of the upstream and downstream portions of the Schaake Reach and associated bed slopes. The bed slope of the entire profile is 0.0024.

Conclusion of Modeling Results

The overall conclusion from the 1-D modeling is that the Schaake Reach has become somewhat incised in the entire upstream portion of the reach, with local scour in some locations exacerbating this condition. However, the overall reach does not seem to be incised to the point that rehabilitation of the adjacent floodplains can not be successful. Pilot channels can be dug to provide access to existing side channels by normal river flows. In those portions of the floodplain where anthropogenic activity has done away with former side channels, pilot channels can be dug to encourage the formation of new side channels. It is expected that when these pilot channels are constructed, the river flows will determine the eventual course of the side channels. Further evaluation of the Schaake Reach using a 2-D hydraulic model will provide a more detailed analysis of flow interaction with the floodplain so that existing channels and low lying portions of the floodplain can be analyzed for locating new side channels.

Some aggradation might be expected in the upstream portion of the reach following levee setback or removal and the resulting increase in flow through side channels. This would result from decreased flow in the main channel, decreasing the sediment transport capacity of the main channel. Significant aggradation is not anticipated in the upstream portion of the Schaake Reach because other reaches on the Yakima River with similar hydraulic conditions (width, depth and slope) are not subject to excessive deposition.

OPTIONS FOR REHABILITATION

At this stage in the study, options available for rehabilitation should be discussed and reviewed for feasibility by YRBWEP. Following discussions with the TSC and YRBWEP, a 2-D model could be developed to evaluate scenarios determined feasible or otherwise of interest to the YRBWEP team. This would be Phase III of the study. The scenarios to be evaluated in Phase III are not necessarily limited to those options mentioned in this report.

REMOVAL OF THE RIGHT BANK LEVEES

The right bank levee just downstream of the Schaake Road Bridge (Figure 15, RM 4.27 – 4.03) has existed in some form since 1912, and is shown as a log bulkhead in the 1912 hydrographic survey. Because this levee directs flow in the direction of Interstate 90, removal of this levee should be considered to allow other flow paths to develop. If this levee is removed, the old Dammon Mill Heading (located at the junction of the bluff and the right bank levee midway between RM 4.31 and 4.27, Figure 15) may need to be blocked off to prevent the river from avulsing into the ditch that runs along the bluff leading to Riverbottom Road. If this ditch is still used, any modifications to the levee may need to investigate the stability of the heading and insure that proper flow into the ditch is maintained. This levee has blocked river access to the vegetated portion of the right floodplain between the cultivated field and the river. The cultivated portion of the floodplain from RM 4.27 – 3.64 lies completely above the 10-year flood stage and only portions of it are inundated with the 20-year flood. It is not likely that the levee in this reach provides protection to the cultivated portion of the floodplain because the river has access to the floodplain downstream of the levee where the river makes the 90° bend to the right. This limits the possible impact from flooding if this levee is to be removed.

Should this levee be removed, the river will potentially have access to the vegetated portion of the floodplain at the 90° bend, which seems to be the natural flow path of the river in this location. Since 1912, the river has migrated approximately 400 feet to the east toward Interstate 90. This is in spite of efforts to reinforce the left bank. By allowing the river to flow through the abandoned channel in the vegetated portion of the right bank (Figure 15), the potential for the river to continue migrating toward Interstate 90 will be decreased and a more complex channel configuration is likely to form. A portion of the western property boundary of the Schaake Property runs along the former channel (Figure 9).

The right levee from RM 3.64 – 3.55 (Figure 16) is blocking migration of the river westward toward Riverbottom Road, which is currently 900 feet from the river. If this levee is removed, the river will be expected to migrate in this direction. Portions of the floodplain adjacent and downstream of this levee may be subject to increased flooding if the levee is removed. The 2-D model will indicate if this property is currently flooded due to the river's access to the floodplain upstream of the levee from RM 3.64 – 3.55. The possibility exists that riprap from the existing levee could be moved and laid against Riverbottom Road to protect the embankment from erosion. There is a gravel pit of unknown depth in the floodplain at RM 3.39 (Figure 5) that will also need to be considered should this levee be removed.

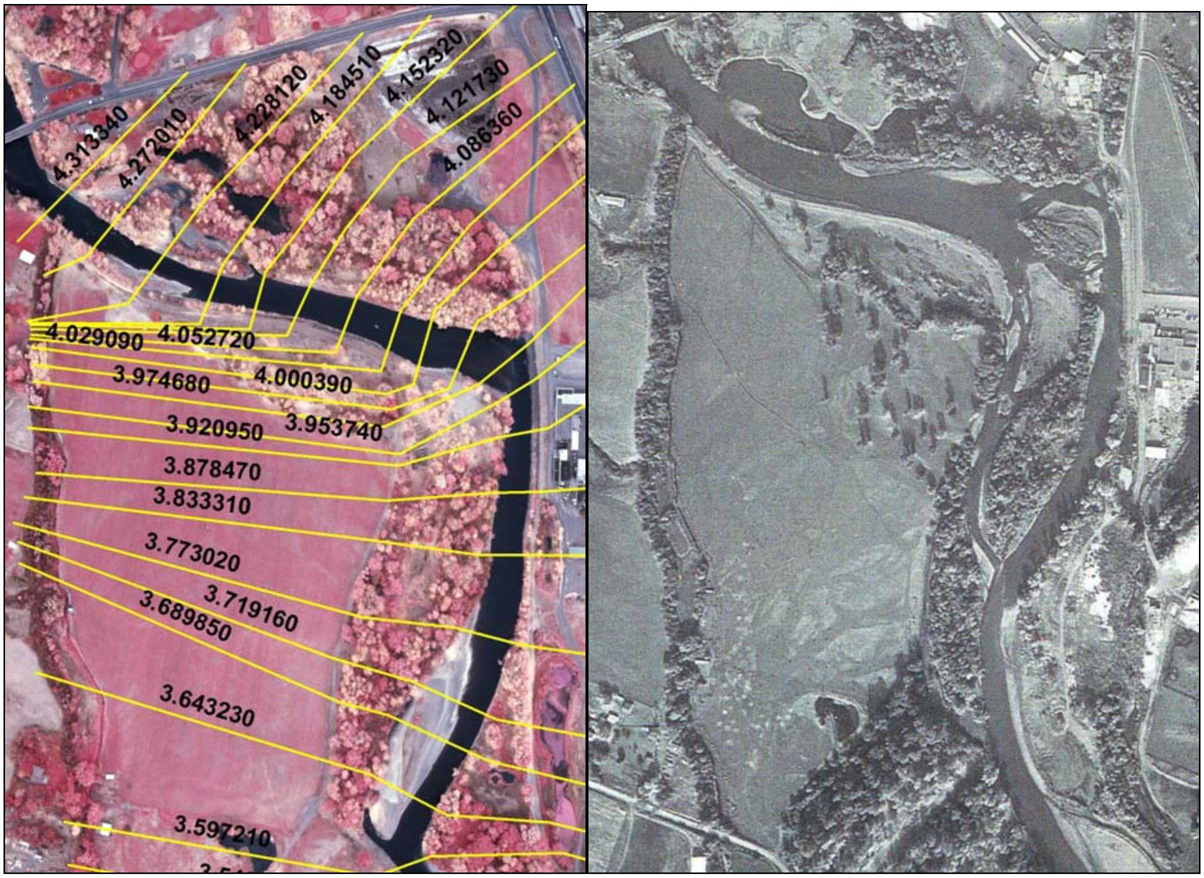

Figure 15: The left photo is dated 2000 and the right photo is dated 1966. The location is just downstream of the Schaake Road Bridge. The cultivated portion of the floodplain from RM 4.23 - 3.64 is higher than the vegetated portion. Note the change in channel location from 1966 – 2000. The scale and orientation of the two photos is similar but not exact.

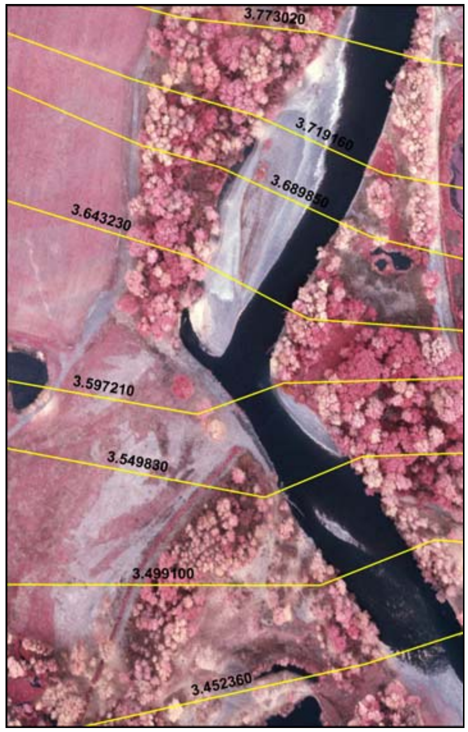

Figure 16: Photo of the middle right bank levee between RM 3.64 – 3.55

Removal of the right bank levee from RM 3.27 – 2.29 (Figure 17) is likely to result in river migration in the direction of Riverbottom Road. The 1966 photos indicate that the river has migrated approximately 250 feet to the west toward Riverbottom Road since that date. The road is currently 130 feet from the river and flow is directed toward it. Much of the right floodplain along this levee lies below the 5-year flood stage and some of it is low enough to be accessed by the 2-year flow.

Farming activity on the right floodplain may be able to continue as it currently does following levee modification depending on the tolerance for flooding. It may be that these farms are currently flooded with a 5-year return flow or less and removing the right bank levees may make little difference. Obtaining flood easements may be an appropriate alternative to property purchase, especially if a property is currently subject to frequent flooding. It is also important to note that if the levee is set back on the left bank, water surface elevations will be expected to additionally decrease during flood events.

Because the right bank levees are not one continuous levee, the possibility exists that the main channel could migrate to portions of the floodplain behind the levees. There is currently no data to suggest that this occurrence is eminent, although future migration could take place that could create this situation. In 1966 the channel ran through the portion of the right floodplain containing the gravel pit and the existing levee beginning at RM 3.27. This levee appears to have been constructed in the 1966 channel (Appendix A). By removing one of the upstream levees on the right bank, there is an increased risk of the main channel migrating behind the next downstream levee, although this could be prevented if the project determines that removing one or both of the upstream right bank levees is feasible.

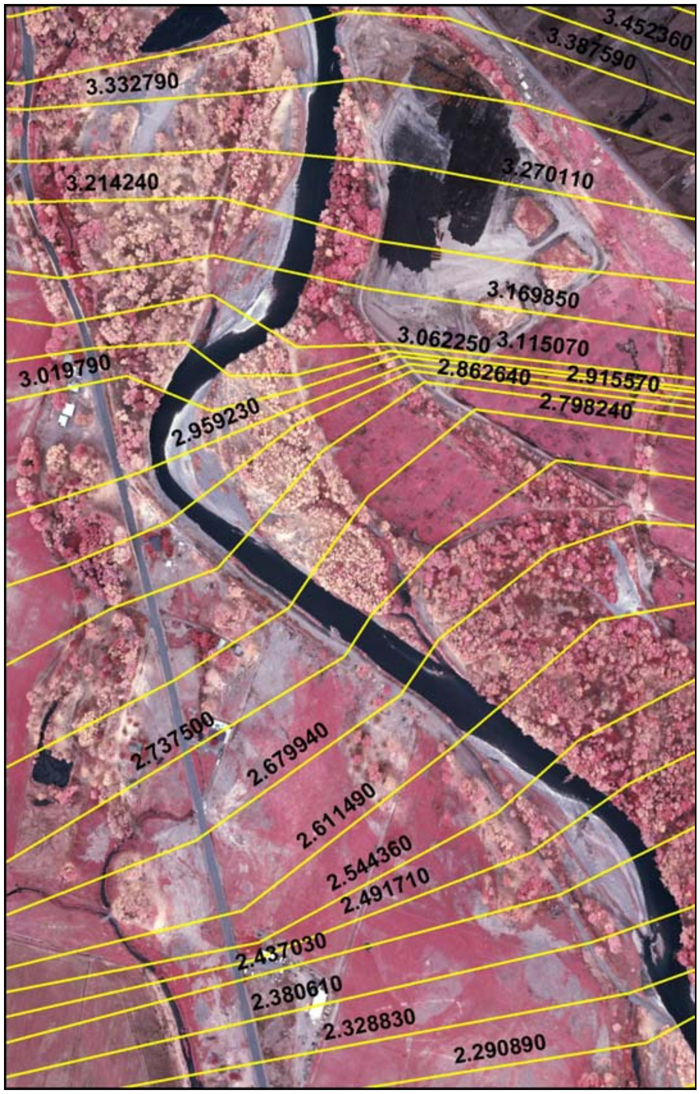

Figure 17: Photo showing right bank levee from RM 3.27 – 2.29. Flow is from top to bottom of page.

SETBACK OF THE LEFT BANK LEVEE

Because of the presence of existing infrastructure on the left floodplain, the presence of Wilson Creek and private property, it is not feasible to completely remove the left bank levee. An acceptable scenario would be to setback the levee similar to the alignment shown in Figure 9. With a configuration similar to this, the river may be able to access portions of the left floodplain without jeopardizing existing infrastructure or risking complete migration into Wilson Creek.

The portion of the left bank levee from RM 3.97 – 3.88 (Figure 18) is preventing migration of the Yakima River eastward into Interstate 90. For this reason it is recommended that the existing bank protection remain in place. It may be feasible to remove the portion of this levee that lies above the current floodplain elevation if another levee is constructed between the river and Interstate 90. However, it is expected that the river will migrate eastward if all protection is removed from this bank, especially if the right bank levee just upstream of this location is left in place. It is likely that, following levee modification, the existing bank protection will eventually fail, especially if the top portion of the existing levee is removed. This might be expected to occur because the high energy flow against the riprap will scour under the protection, causing it to fall into the river. These large boulders may form the beginning of an island if the flow gets behind the riprap. This may create a planform similar to what existed in 1966 (Appendix A), although it will likely move eastward from its current alignment. This situation may take many years to occur, depending on the age and condition of the existing riprap. If this does occur, the channel width will increase and velocities will decrease. This situation will be favorable because stream power will be decreased, lessening the likelihood of continued eastward migration.

A possible scenario for providing access to the left floodplain is to construct a pilot channel connecting the river to the floodplain in the vicinity of RM 3.77 (Figure 18, marked with a red oval), immediately behind the existing levee. An existing channel, low enough for frequent and regular inundation, runs from RM 3.77 to RM 3.60 just behind the levee. Another pilot channel can be constructed for a downstream connection if that is desired.

Some of the floodplain outside of the existing left bank levee is low enough to become inundated during a 2-year return flow or less but because of the extensive reworking of the floodplain by human activity, few old channels remain. If side channels in this area are desired, it will be necessary to construct pilot channels and allow the river to create its own system of side channels over time. This will require significant earthwork because of the distances from the river and resulting channel length, although if a new levee is to be constructed, significant earth work will already be anticipated.

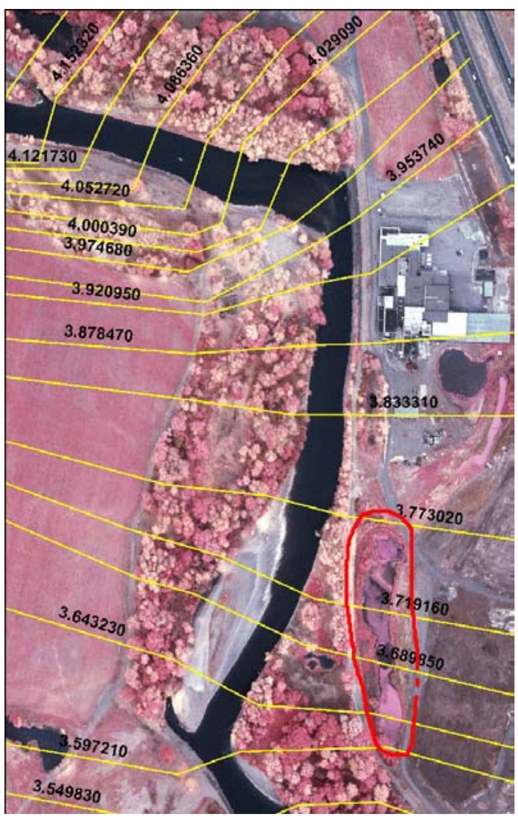

Figure 18: Photo showing the upstream portion of the left bank levee. The oval highlights an old channel in the floodplain.

OPPORTUNITIES FOR IMPROVING SIDE CHANNEL HABITAT WITHOUT LEVEE MODIFICATION

Few opportunities, if any, exist for enhancing side channel habitat without levee modification. Because the levees have been in place for some time, the river has come into equilibrium concerning the formation and the ability to maintain side channels. Existing flow conditions are such that the river is not likely to maintain any newly constructed side channels within the confinement of the existing levees. If that were possible, the river would likely have created and maintained side channels on its own.

STABILITY OF FLOODPLAIN SIDE CHANNELS

If pilot channels are to be cut in the reworked portions of the floodplain, the project will benefit from vegetation that has had an opportunity to mature for some time before the area is expected or allowed to become inundated. The more mature vegetation will aid in stabilizing the side channels and is more likely to survive inundation. The vegetation could be planted in advance of the levee setback, during the construction of the new levee and any pilot channels to be cut.

The Kittitas County Soil Survey (USDA, 2003) indicates that the soils in the floodplain of the Schaake Reach have a high content of gravel and cobbles. This will provide good substrate for side channel formation because the finer sediment will quickly be eroded and a gravel bed will be expected to form.

The possibility exists that the main channel of the Yakima River could eventually take over side channels created by levee modification. This should not present a problem on the left floodplain, assuming that a new levee is constructed in the vicinity of the proposed location to prevent migration into existing infrastructure or Wilson Creek. Channel migration on the right floodplain should be investigated further if either one or both of the two downstream levees are to be removed. Placement of woody debris or other measures can be taken to discourage avulsion of the main channel into regions where that might be a concern.

SUMMARY

This study indicates that levee modification and pilot channel construction within the Schaake Reach of the Yakima River will be expected to be successful in providing increased habitat for salmonid fish species. Because the left floodplain is currently in public ownership, modifications to this portion of the reach could be performed first. If it is feasible to do so, the right bank levee just downstream of the Schaake Road Bridge could be considered for removal because of its tendency to direct flow toward Interstate 90, although removal of this levee should not be considered necessary for implementing the levee setback on the left floodplain.

Prior to allowing flow onto the left floodplain, revegetation of the Schaake property should take place so that it has an opportunity to mature. This will improve the chances for a successful rehabilitation of the Schaake property. During this time, a new levee can be constructed between the existing levee and Interstate 90.

It is expected that water surface elevations during flood events will be decreased through the Schaake Reach following the proposed actions to the left floodplain on the Schaake property. It may then be feasible to review the options for modification or removal of the right bank levees.

Phase III of this study will involve a 2-D hydraulic numerical model of the Schaake Reach. This model will more accurately indicate flow conditions, both prior to and following any levee modifications. Specific scenarios determined feasible by YRBWEP will be modeled including levee modifications and pilot channels to be cut into the floodplain.

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APPENDIX A

GEOMORPHIC MAPS OF CHANNEL CHANGE – 1966 TO 2000 AND 1912 CHANNEL MAP

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Figure A-1: 2000 photography of the Schaake Reach with the 1966 channel outline superimposed.

Figure A-2: Composite map of the Schaake Reach from USRS 1912survey.

APPENDIX B

Flood Frequency Analysis Used as Flow Input for 1-D Model

Mean of Logs	Std. Dev	Data Skew	Reg. Skew	Final Skew
3.7729	0.2817	0.3976	0	0.3976

RANK	m-.4/N+.2	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.02206	1996	21191	0.99	1588	1009	2161
2	0.05882	1991	20112	0.98	1803	1183	2410
3	0.09559	1981	14790	0.975	1886	1252	2506
4	0.13235	1978	14410	0.96	2091	1423	2740
5	0.16912	1998	11031	0.95	2205	1520	2871
6	0.20588	1983	10982	0.9	2667	1919	3395
7	0.24265	1997	9988	0.8	3404	2573	4238
8	0.27941	1984	8773	0.7	4100	3196	5050
9	0.31618	1982	8708	0.6	4837	3852	5940
10	0.35294	1980	7309	0.5704	5073	4060	6231
11	0.38971	1986	6835	0.5	5678	4587	6997
12	0.42647	1990	6347	0.4296	6374	5179	7907
13	0.46324	1995	5997	0.4	6703	5454	8350
14	0.5	1987	5890	0.3	8053	6550	10241
15	0.53676	1989	5435	0.2	10066	8100	13259
16	0.57353	1985	4606	0.1	13922	10869	19586
17	0.61029	1988	4082	0.05	18441	13899	27715
18	0.64706	1977	3714	0.04	20060	14945	30784
19	0.68382	1979	3622	0.025	23765	17276	38078
20	0.72059	1993	3507	0.02	25675	18449	41972
21	0.75735	1992	3484	0.01	32293	22391	56102
22	0.79412	1946	3310	0.005	40081	26838	73835
23	0.83088	1994	3129	0.002	52495	33609	104179
24	0.86765	1940	3040	0.001	63766	39499	133617
25	0.90441	1942	2720	0.0005	76933	46143	169962
26	0.94118	1941	2580	0.0001	116482	64986	289540
27	0.97794	1948	2110				

APPENDIX C

Water Surface TINs Showing Inundation for 3,150 FT^3/S, 2 and 5-year Return Flows

NOTE: The cross sections have been intentionally omitted from the maps in this appendix due to increased clutter. For reference regarding river mile or river station, refer to Figure 5.

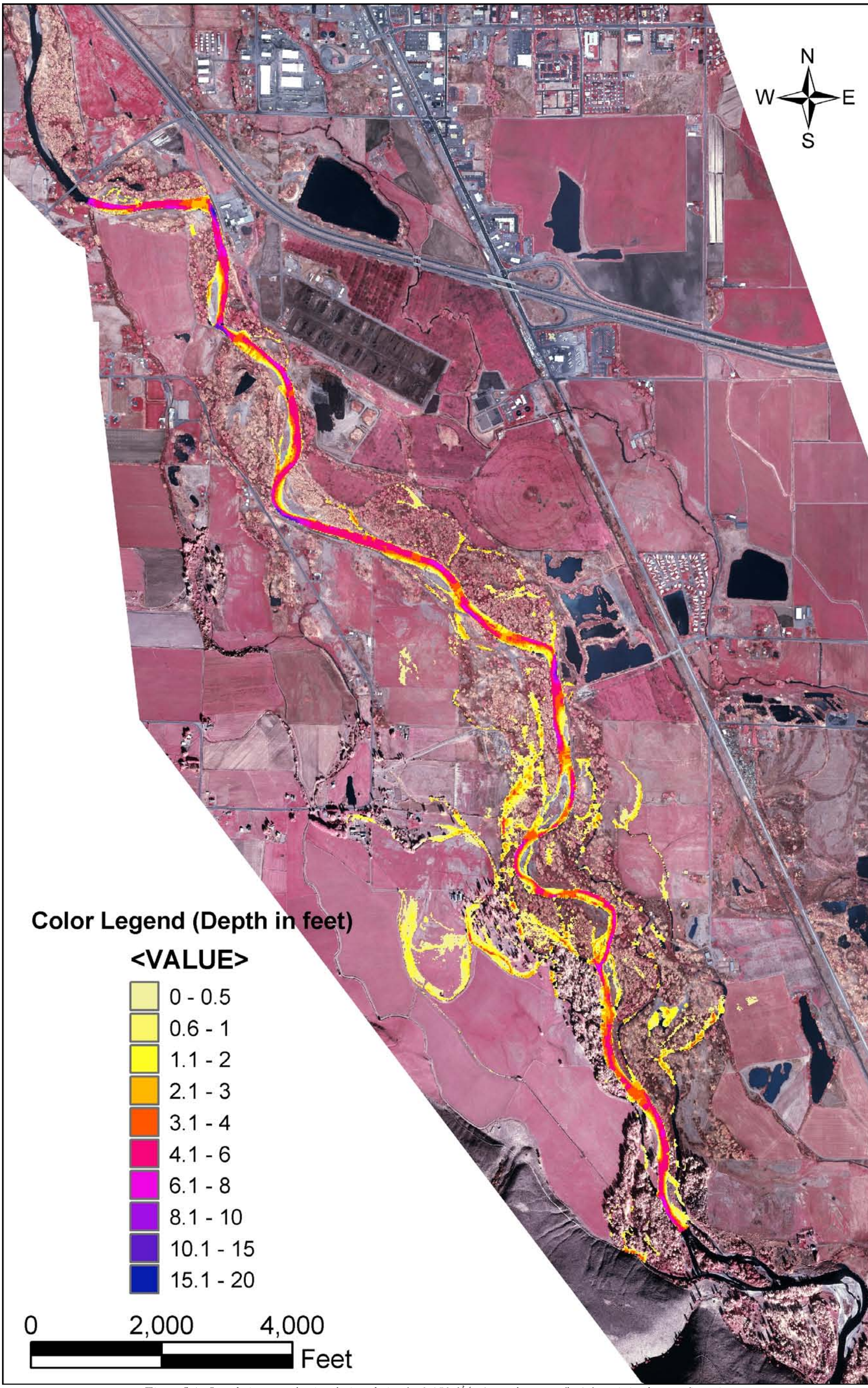

Figure C-1: Inundation map showing the inundation for 3,150 ft^3/s (normal summer flow) for existing levee configuration.

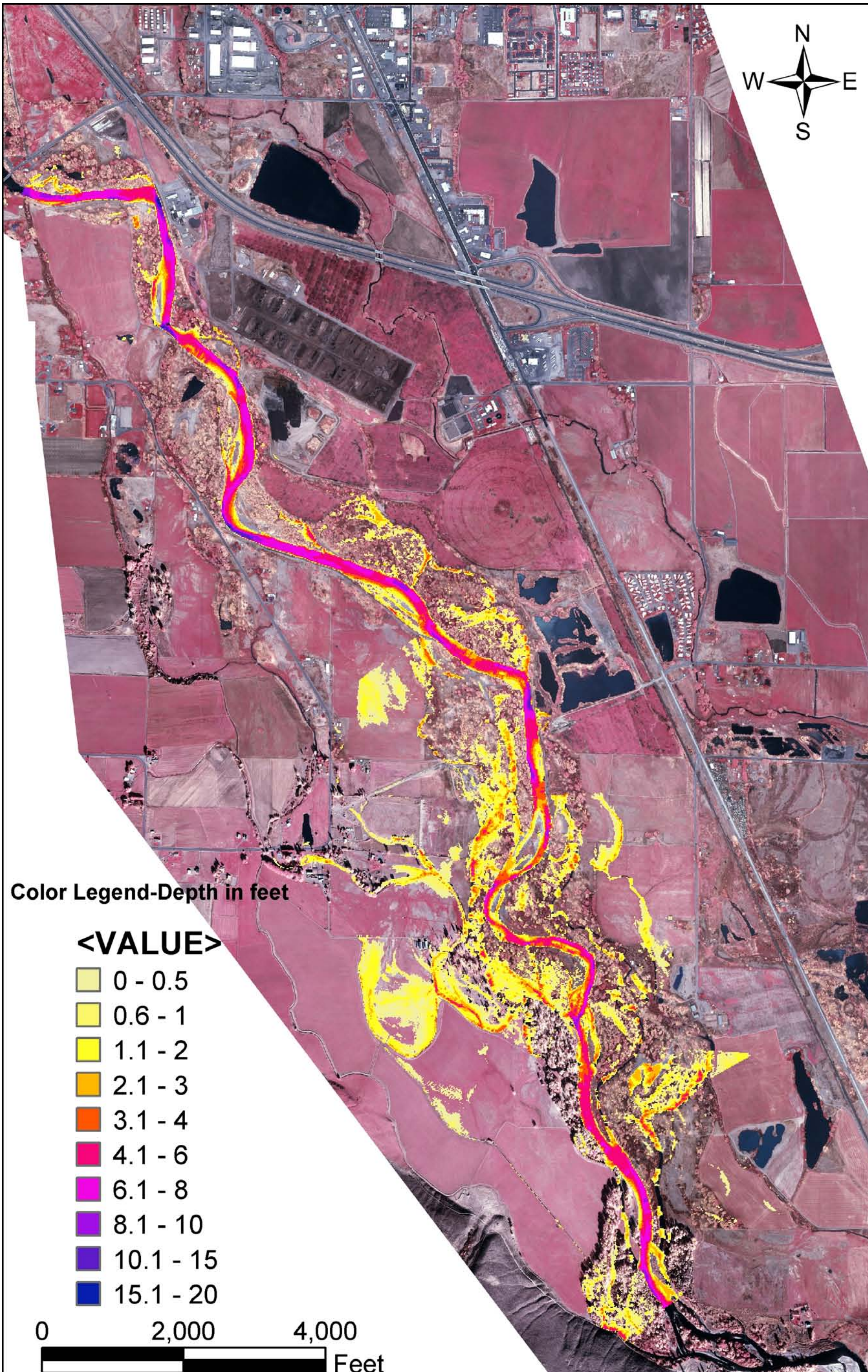

Figure C-2: Inundation map showing the 2-year return flow with existing levee configuration.

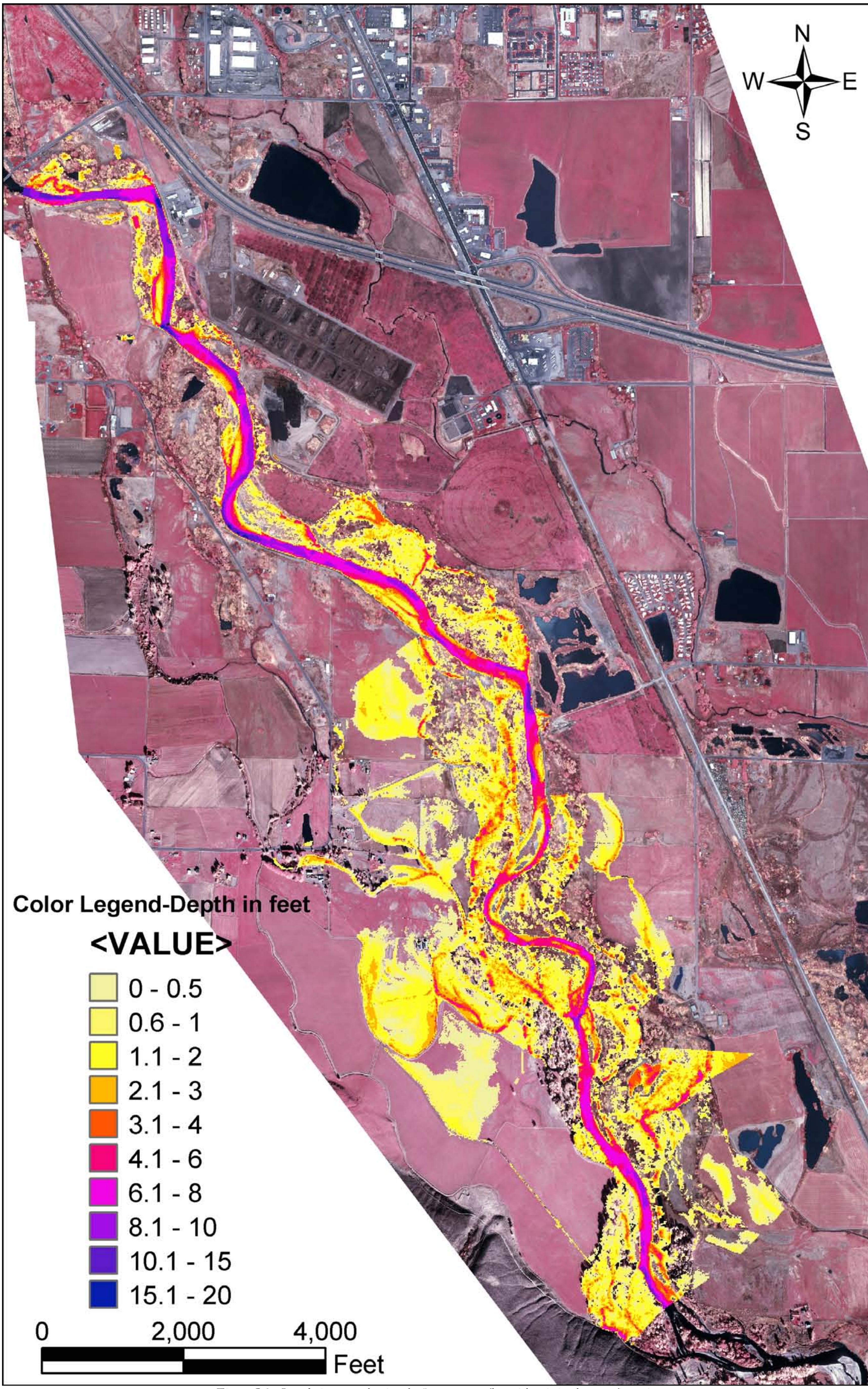

Figure C-3: Inundation map showing the 5-year return flow with existing levee configuration.

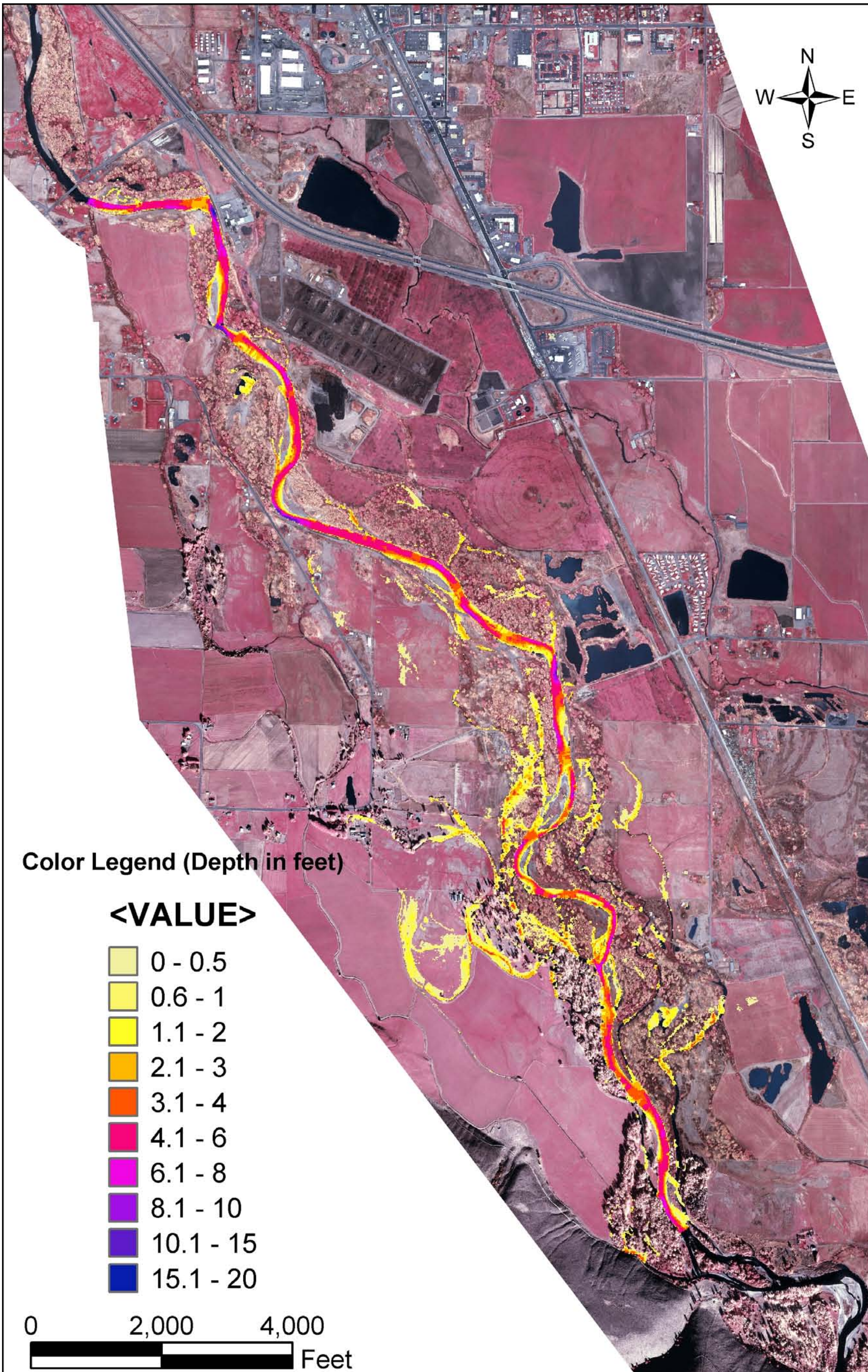

Figure C-4: Inundation map of 3,150 ft^3/s with the right levees removed and Riverbottom Road acting as the levee.

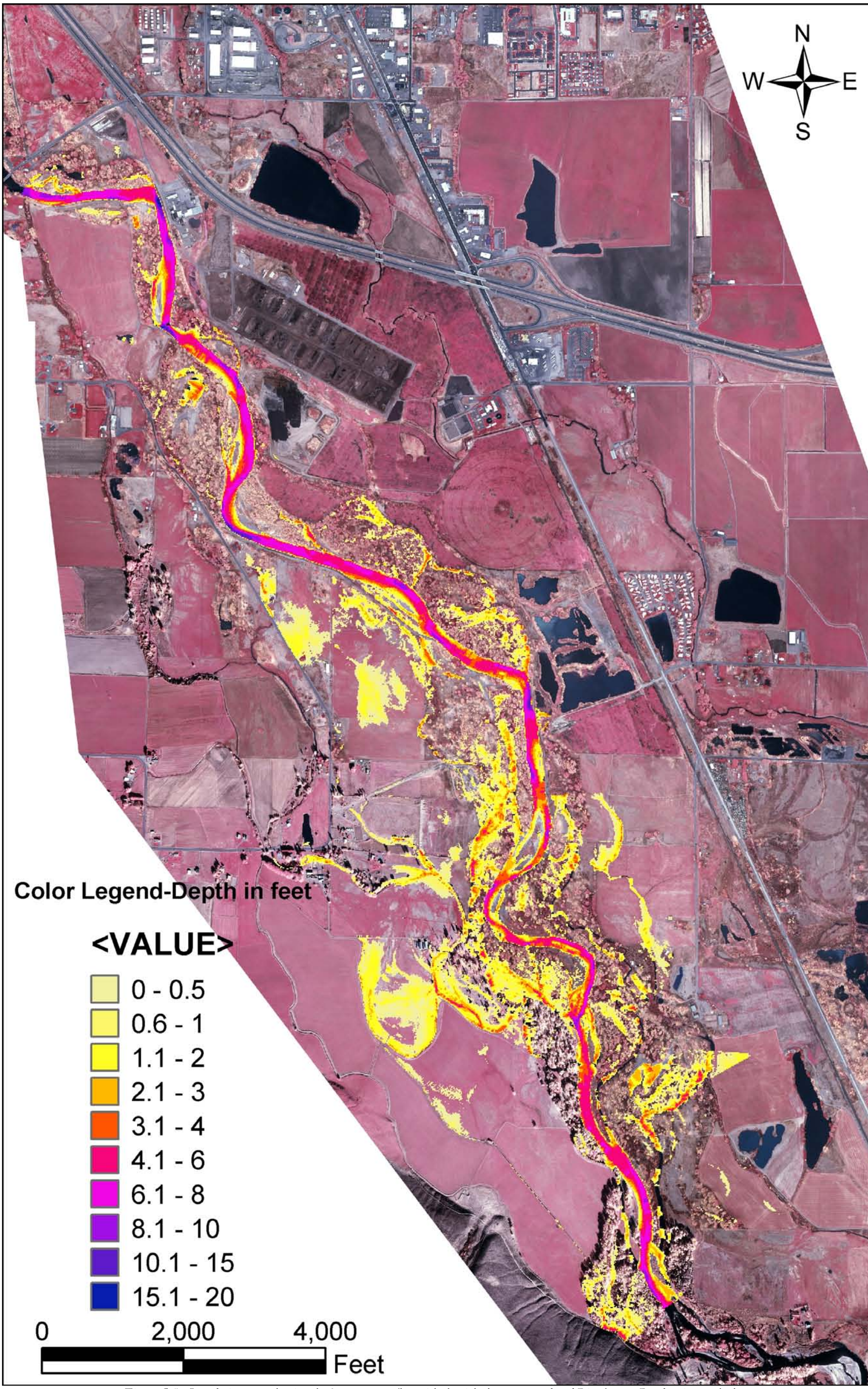

Figure C-5: Inundation map showing the 2-year return flow with the right levees removed and Riverbottom Road acting as the levee.

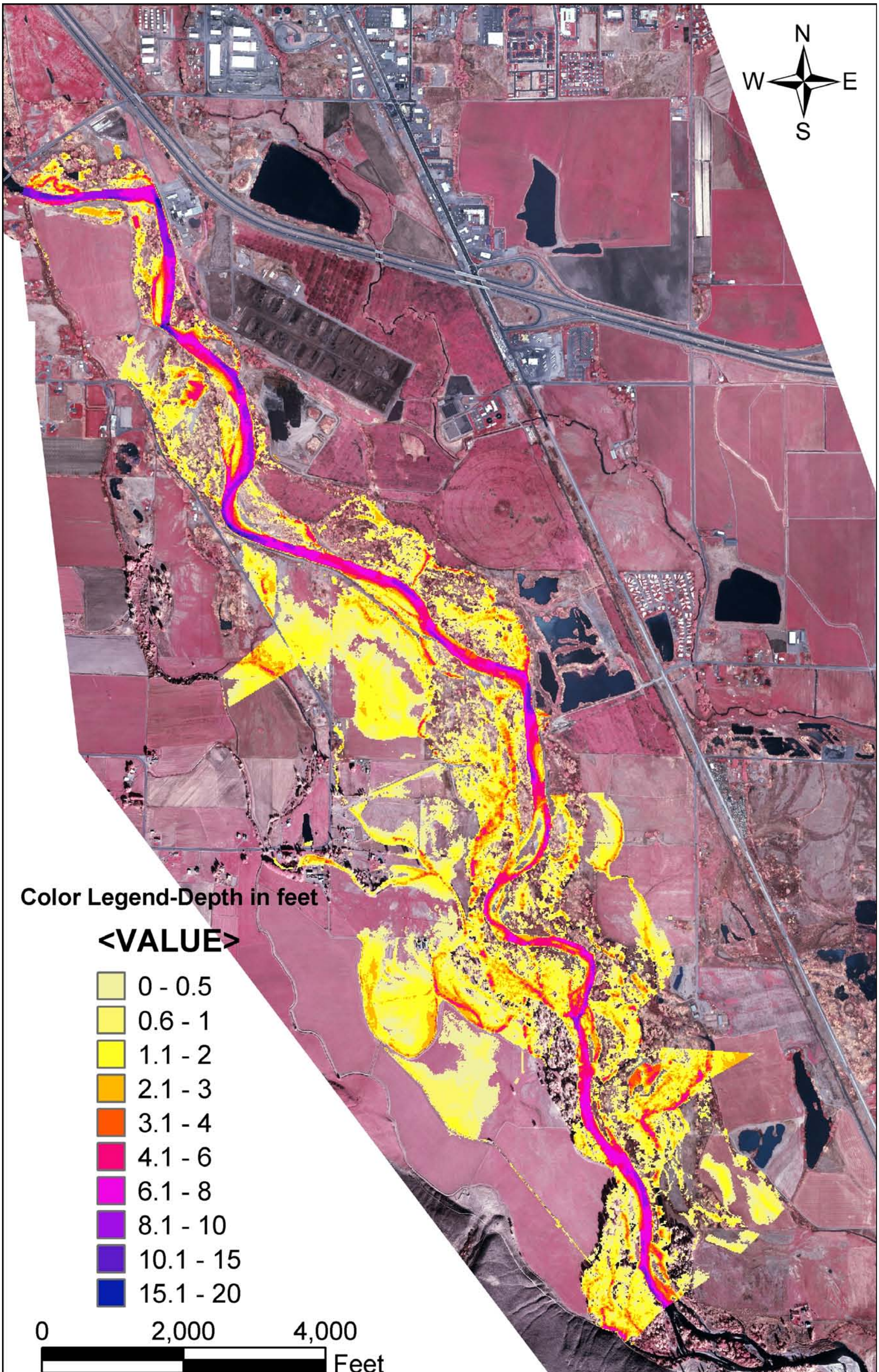

Figure C-6: Inundation map showing the 5-year return flow with the right levees removed and Riverbottom Road acting as the levee.

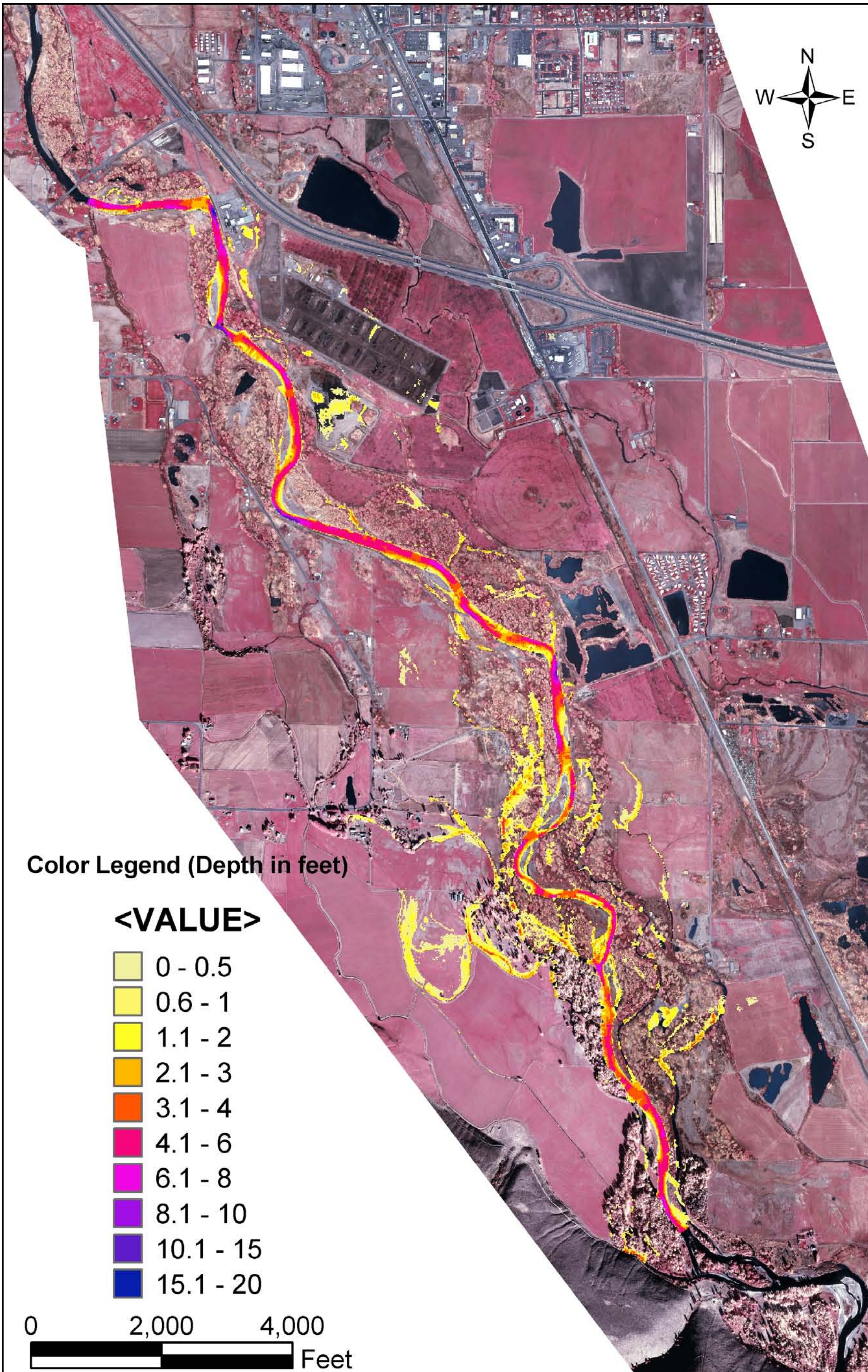

Figure C-7: Inundation map showing 3,150 ft^3/s with the right levee setback.

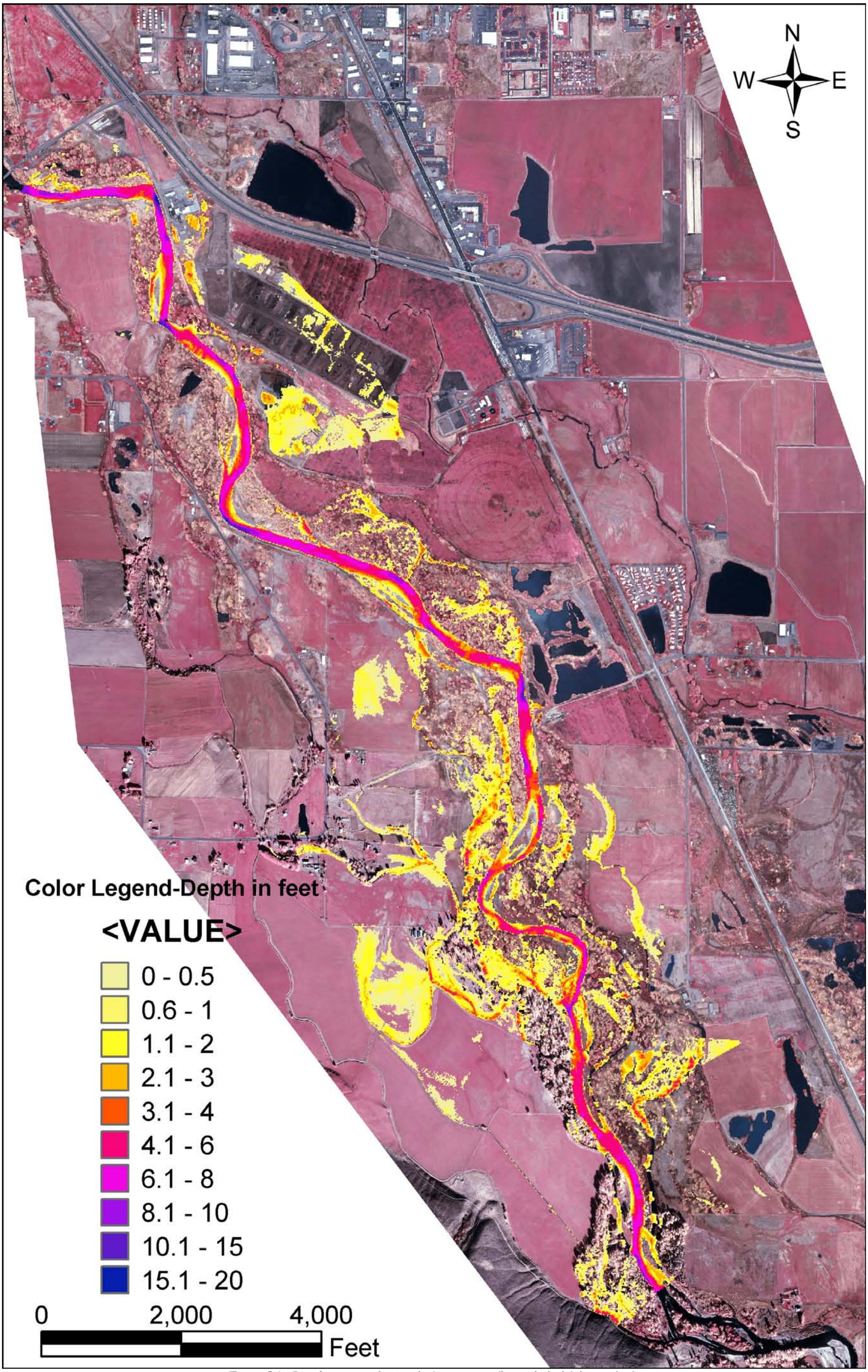

Figure C-8: Inundation map showing the 2-year return flow with the left levee setback.

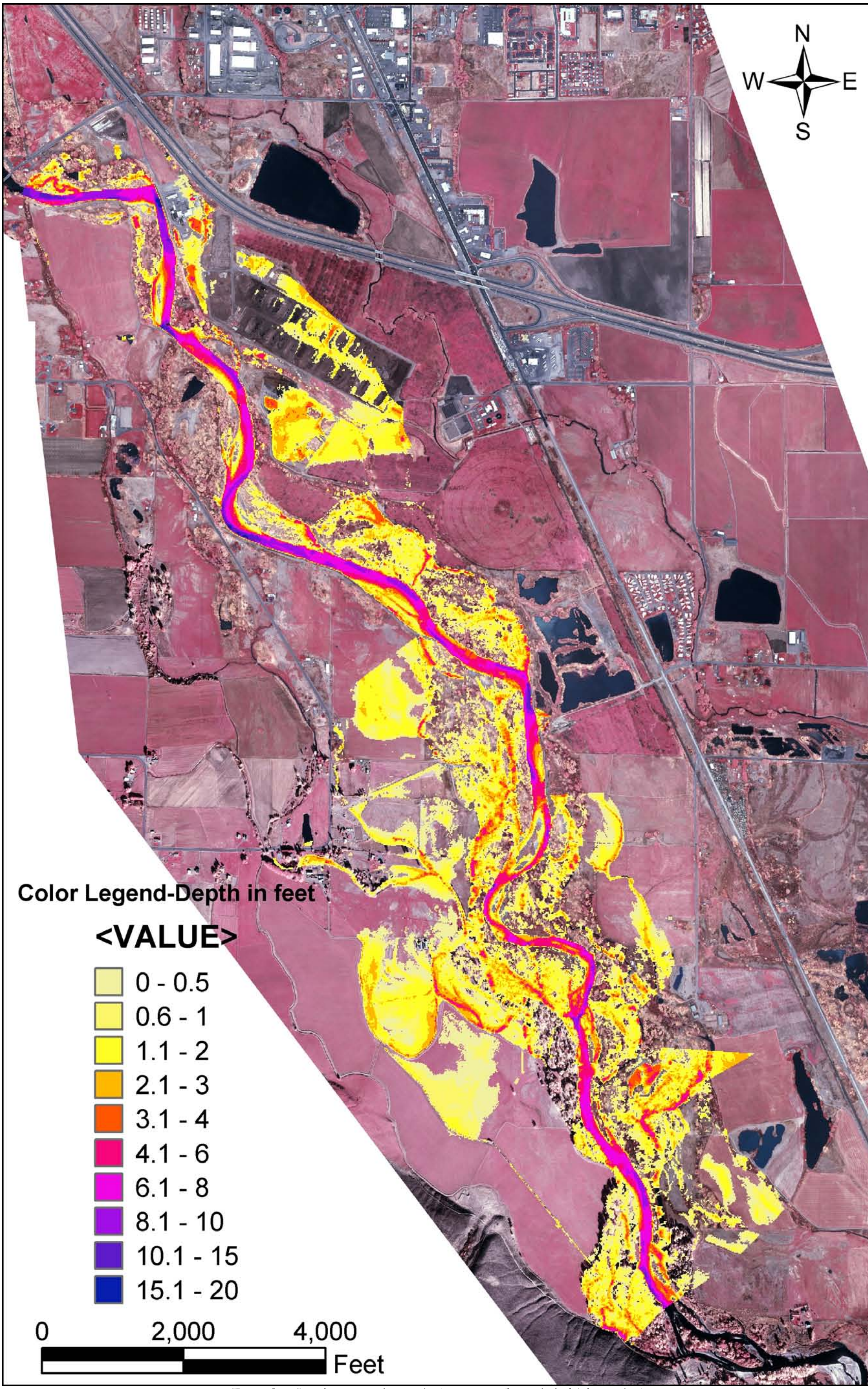

Figure C-9: Inundation map showing the 5-year return flow with the left levee setback.