REVIEW OF MORPHOLOGICAL EFFECTS FROM NACHES RIVER LEVEE SETBACKS

FINAL REPORT

Prepared for:

COMMITMENT • SERVICE • EXCELLENCE
YAKIMA COUNTY

Yakima County Water
Resources Management Division
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Yakima, WA
98901

19 May 2016

NHC Ref. No. 21792

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water resource specialists

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Prepared for:

Yakima County Water Resources Management Division
Yakima, WA

Prepared by:

Northwest Hydraulic Consultants Inc.
Seattle, Washington

May 19, 2016

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The following NHC staff participated in the study:

Andrew Nelson: Fluvial geomorphology

Peter Brooks: Hydraulic and morphodynamic modeling

Dave McLean: Principal river engineer

EXECUTIVE SUMMARY

Yakima County Water Resources Division (the County) is planning a series of levee setback or removal projects on the lower Naches River. The primary goal of this program is to reduce flood risks and recover floodplain ecosystems “while maintaining or improving agricultural production, water quality, and open space/recreation.” Three projects are rapidly proceeding to implementation:

1) N-9 Naches Levee Segment Removal (FC3543)

2) N-2 Trout Meadows Floodplain Restoration (FC3526)

3) N-1 Naches Levee Setback – Ramblers Phase II (FC3542)

A Planning Assistance Study (PAS) was conducted by the Seattle District of the Corps to evaluate the hydraulic, geomorphic, and sediment transport characteristics of the lower Naches River. The Corps work included developing a one-dimensional HEC-RAS hydraulic and sediment transport model to characterize sedimentation processes and geomorphic change along the river through time. The County requested that Northwest Hydraulic Consultants Inc. (NHC) continue the line of investigation carried out by the Corps as a part of the County’s contribution to execution of the PAS. The overall goals of this study include:

1) Understand the processes and rates of sediment accumulation upstream of existing levees.

2) Model sediment transport for an extended period of time at the three project sites described previously under existing and levee setback scenarios to increase understanding of impacts and benefits of the setback projects.

3) Identify change that the levee setbacks may have on sediment transfer through the study reach and into the Gap to Gap reach on the Yakima River.

The work carried out by NHC included field inspections and bed sediment sampling, interpretative geomorphic studies to assess the main factors that govern morphological changes on the river, and further development and refinement of the one-dimensional (1D) morphodynamic sediment transport model (HEC-RAS) developed by the Corps. The interpretative results of NHC’s geomorphic reach assessments are summarized in the Lower Naches River Geomorphic Atlas (NHC, 2015), which is referenced in this report.

The initial hydraulic state of each levee setback project was assessed with the 1D HEC-RAS model by simulating the existing conditions and the proposed setback conditions. The model was first run with a fixed bed (without sediment) to assess hydraulic effects using a range of discharges up to the 100-year flood. The model was then run with sediment transport in morphodynamic mode using a 25 year time series (Water Years 1984 to 2009) of daily discharge records that included a 50-year flood. Geomorphic assessments, presented in the Geomorphic Atlas (NHC, 2015), were carried out to interpret the model

results. The report results are limited by simplifying assumptions inherent to a 1D morphodynamic model, the available data resolution, and the absence of verification data to confirm 25 year simulation results. Sensitivity runs were made where any risks may have been present. The simulations included the 2014 setback of Eschbach Park levee.

The effect of the three projects on hydraulics and river morphology is summarized below.

Project	Initial Hydraulic Response	25 year Morphological Response
N-9 Levee Segment Removal	(1) Under existing conditions the right floodplain conveys less than 10% of the flow at a 100-year flood. After opening the segment, the floodplain flow will increase to 20-30% at the 100-year flood. (2) Flood levels reduced 0.5 feet at 2-year flood and 2.2 feet at 100-year flood. Region of water level lowering extends 1,200 feet. (3) Reduced shear stress in meander bend near upstream end of N-7 levee.	(1) Potential reactivated side channel on right floodplain. (2) Reduced scour and bank erosion near upstream end of N-7 levee. (3) Local deposition in main channel due to reduced transport capacity.
Trout Meadows Floodplain Restoration	(1) Flood levels reduced by 0.5 (100-year) to 1.5 feet (2 to 10-year) at Trout Meadows. (2) Flood levels reduced by 0.2 to 0.75 feet upstream of Trout Meadows. Water level reduction extends 2000 feet at 100-year flood. (3) Average bed shear stress reduced by 10% during 100-year flood in main channel near Trout Meadows.	(1) Active side channel established on right floodplain (assuming a pilot channel is constructed). (2) Reduced degradation in main channel (0.3 to 0.5 feet) over 1,500 foot reach. (3) Reduced water levels in main channel will promote closure of left bank avulsion channel. Could lead to reduction of flood hazards downstream near Rambler's Park.
N-1 Levee Set-back, Ramblers Phase I & II	(1) Phase I & II reduce 100-year flood level by up to 1.5 feet over a distance of 4,000 feet. Phase II alone reduces level by 0.5 feet.	(1) the effect of the project on sediment deposition and transfer is expected to be small due to other controls.

The report provides recommendations for further studies and for conducting pre- and post-project monitoring.

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1 INTRODUCTION

1.1 Background

Yakima County Water Resources Division (the County) is planning a series of levee setback or levee removal projects on the lower Naches River, here defined as the 18 mile reach between the confluence with the Tieton River and the mouth at the Yakima River. The projects fall under the auspices of Floodplains by Design, a partnership between the Washington State Department of Ecology, Puget Sound Partnership, and the Nature Conservancy. The primary goal of this program is to reduce flood risks and recover floodplain ecosystems "while maintaining or improving agricultural production, water quality, and open space/recreation". Northwest Hydraulic Consultants Inc. (NHC) met with the County in January 2015, where it was stated that three projects are rapidly proceeding to implementation:

1) N-9 Naches Levee Segment Removal (FC3543)

2) Trout Meadows Floodplain Restoration (FC3526)

3) N-1 Naches Levee Setback – Ramblers Phase II (FC3543)

Figure 1 shows the location of these sites. The levees being considered at these sites are enrolled in the U.S. Army Corps of Engineers (Corps) PL84-99 program. In order to facilitate this project, the County and the Seattle District Corps have coordinated efforts to execute a Planning Assistance Study (PAS).

1.2 Planning Assistance Study

The PAS conducted by the Corps was intended to evaluate the hydraulic, geomorphic, and sediment transport characteristics of the lower Naches River. The Corps work on this project included developing a one-dimensional (1D) HEC-RAS hydraulic and sediment transport model[1] of the lower 18 miles of the Naches River. In addition, the Corps conducted an investigation to characterize sedimentation processes and geomorphic change along the river through time. The Naches Public Assistance Study report (Corps, 2015) includes a description of development of the HEC-RAS model and provides an overview of the geomorphic, hydraulic, and hydrologic context for the present study reach.

[1] Herein, a hydraulic model with sediment transport capabilities is referred to as a *morphodynamic model*.

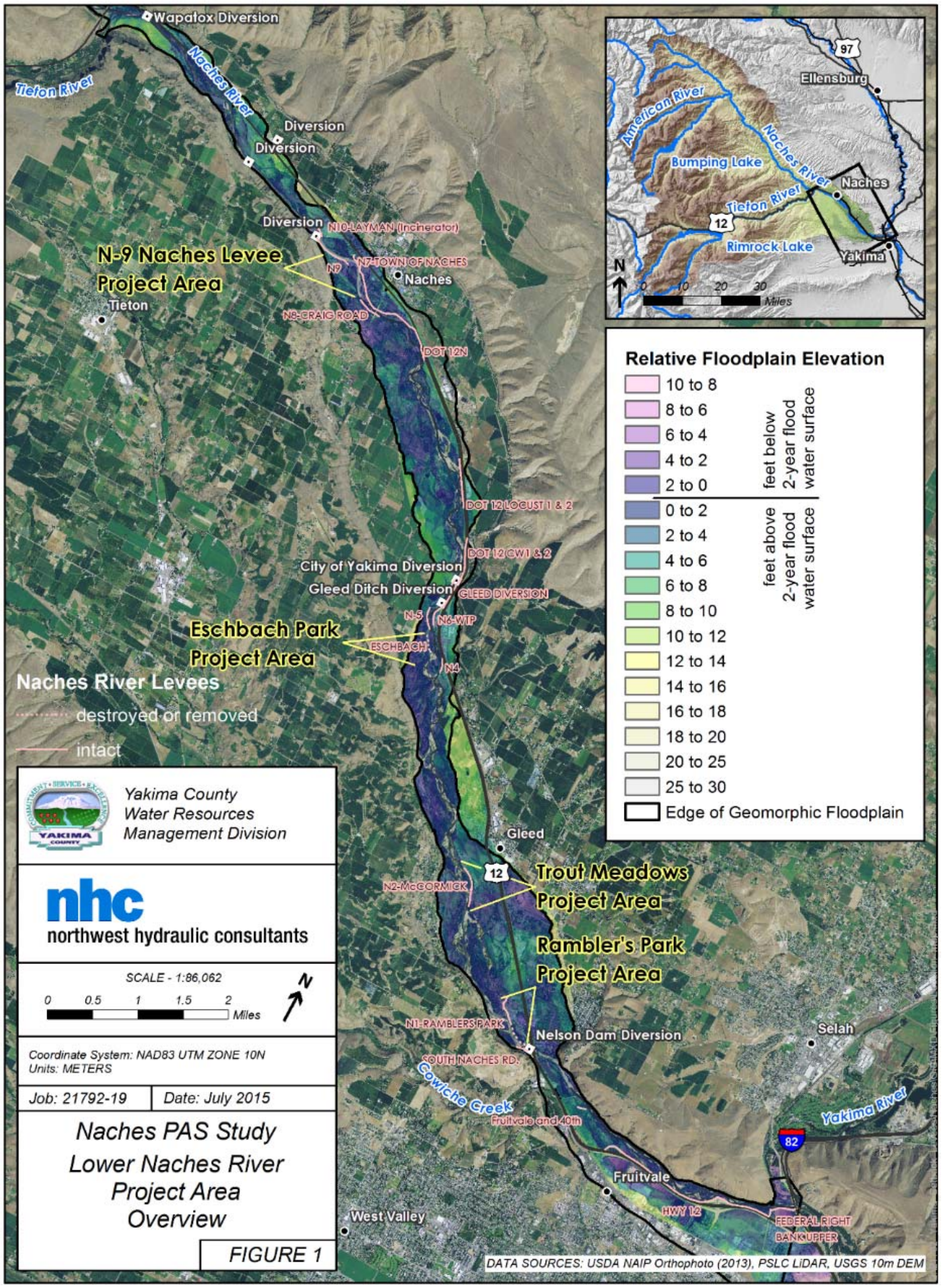

Figure 1: Study location.

1.3 Scope of Work

The County has requested that NHC continue the line of investigation carried out by the Corps as a part of the County's contribution to execution of the PAS. The overall goals of this study include:

1) Understand the processes causing and rates of sediment accumulation upstream of existing levees.

2) Model sediment transport for an extended period of time at the three project sites described previously under existing and levee setback scenarios to increase understanding of impacts and benefits to the setback projects.

3) Identify change that the levee setbacks may have on sediment transfer through the study reach and into the Gap to Gap reach on the Yakima River.

It was also indicated that other long-term plans are underway to modify or possibly install a by-pass channel around Nelson Dam to reduce upstream aggradation problems and to restore natural sediment movement downstream to the Yakima River. Work on this facet of the project was not explicitly considered as part of the current scope.

NHC's scope of work was developed under the assumption that the Corps HEC-RAS morphodynamic model was appropriate for assessing project effects. The lack of information for calibrating and validating the morphodynamic model is a significant limitation. However, the model, when combined with other geomorphic-based methods, is considered useful for preliminary project planning and assessment purposes.

1.4 Work Performed

1.4.1 Field Studies

An NHC staff engineer and geomorphologist spent two days investigating conditions along the lower Naches River and tributaries, floating the entire river from the Wonderland Bridge upstream of the Town of Naches to its confluence with the Yakima River. The float was conducted on April 8 and 9, 2015. Flows on the Naches River were very low during this period due to low mountain snowpack with an approximate reported discharge of 1,000 cfs (USBR Gage NACW, Naches River near Naches, WA). The survey allowed observation of numerous features normally submerged. During the float, NHC staff collected photographs, field notes, and sediment samples along the river. In addition, NHC staff visited local sites along both the Tieton and Naches Rivers upstream of their confluence to better understand sediment inputs to the reach of interest.

The primary goal of this field work was to increase understanding of the spatial patterns, size distribution, and rate of bed material transport in the river as well as processes governing transport. NHC staff collected observations of river planform, bar formation, bank erosion, and bank conditions including sediment, vegetation, and armoring. In particular, the surface grain size distribution of alluvial bars with actively transported sediment was defined with Wolman (1954) pebble counts collected from bar-head locations believed to be representative of actively transported sediment (e.g. Klingeman and Emmett, 1982; Parker et al., 1982). A total of 16 random walk pebble counts and eight scaled bed image samples were collected.

1.4.2 Geomorphic Assessment

A geomorphic assessment was conducted integrating collected field data and observations, hydraulic modeling results, GIS analysis of historical aerial photos (1927 to the present), and two LiDAR datasets spanning 12 years of recent channel evolution (2001 and 2013). The focus of this assessment was to understand controls on the river channel form and morphodynamics and (as with the fieldwork) patterns, texture, and volume of bed material transport in the river and processes governing bed material transport. A summary of the GIS analysis performed is provided in Appendix A.

1.4.3 Numerical Modeling

Numerical modeling of the Naches River was conducted using the U.S. Army Corps of Engineers one-dimensional HEC-RAS software package (v. 5.0 beta). The original model was developed by the Seattle District Corps (Corps, 2015) and was subsequently provided to NHC for further refinement and analysis. The model is capable of simulating hydraulic and mobile bed (morphodynamic) conditions along the lower 18 miles of the Naches River. NHC reviewed the Corps model, made refinements and used the revised model to evaluate the reach as a whole, as well as site-specific effects of the proposed levee setbacks and actions at the N-9 Levee, Trout Meadows, and Rambler's Park.

1.5 Lower Naches River Geomorphic Atlas

Due to the temporal and spatial complexity of the lower Naches River, as well as the overall scale of the 18 mile reach, NHC's fieldwork and geomorphic assessment are presented in an accompanying document: Lower Naches River Geomorphic Atlas (NHC, 2015). The atlas provides a graphical, map-based representation of the lower Naches River, with sub-reaches divided into segments of between 1.0 to 1.5 mile length. Data presented in the Geomorphic Atlas includes:

- Basin overview
- 2013 aerial base maps
- Identified floodplain constrictions (e.g. levees, roads, embankments, etc.)
- 2001 and 2013 LiDAR difference plots
- Height above water surface (HAWS) mapping
- Historic aerial photos
- Grain size sampling locations and results
- Channel profiles and cross-sections
- Bank stability observations

1.6 Outline of Present Report

In addition to this brief introduction, this report consists of six chapters. Chapter 2, Proposed Levee Setbacks and Removal Projects, describes the planned projects as documented in Yakima County's 2015 project status report. Chapter 3, River Characteristics, briefly summarizes the hydrological, geological, and geomorphic characteristics of the river that affect channel stability and sediment transport. For more detailed mapping data of the entire study reach, the reader should consult the accompanying Geomorphic Atlas (NHC, 2015). Chapter 4, HEC-RAS Morphodynamic Model, describes the Corps' model as supplied to NHC and summarizes the modifications that were subsequently made to improve its application to evaluating project effects. Chapter 5, Hydraulic And Geomorphic Effects of Projects, summarizes the results of the morphodynamic modeling and geomorphic interpretation of the model results. Chapter 6, Summary And Conclusions, summarizes the key findings of the study and identifies future work that needs to be carried out to finalize the assessments.

2 PROPOSED LEVEE SETBACKS AND REMOVAL PROJECTS

2.1 Project Rationale

The goals and perceived benefits of the levee setback and removal projects were described in the County's January 2015 status report (Yakima County, 2015). The County's experience and observations indicated that the existing levees have contributed to excessive sediment aggradation in some reaches, which has led to levee outflanking and the ongoing need to extend the levees upstream. The County also concluded that levee setbacks will have the potential to increase the available conveyance area for flood flows and release aggraded sediment, which will more closely approximate natural channel transport processes and lead to reduced risk at the levees. The following sections summarize the three projects in terms of their need, goals, and benefits and are reproduced from the County's 2015 status report.

2.2 N-9 Naches Levee Segment Removal

2.2.1 Location

The project is located on the right bank of the Naches River between RM 14.1 and 14.2 as described in the accompanying Geomorphic Atlas (NHC, 2015).

2.2.2 Project Need, Goals, and Perceived Benefits

Need[2]*: The Town of Naches levee N-7 has experienced expensive and repetitive repairs, including failure and property damage in 1996 plus near failure in 2011. Damages are in part due to the upstream levee N-9, which directs flow at the upstream end of N-7. Both levees are county owned and enrolled in the USACOE's PL84-99 program.*

Goals: The County FCZD objectives are to modify the infrastructure to increase river floodplain access, reduce backwater and thereby velocities improving levee safety, reducing flood risk for the Town of Naches and improving sediment transport to stop or reverse the channel aggradation in the area of this reach of the Naches River. The project will remove 500 feet of N-9 levee, armor a portion of Craig Road, purchase floodplain properties and construct pilot channels to promote floodplain reactivation. The project is phase 2 of a three phased project under Recommendations 26, 28, 29, and 30 of the Naches River Comprehensive Flood Hazard Management Plan.

Benefits: This project will reduce levee damages and failure risk, remove areas from the 100-yr floodplain and reconnect a large area of historically active floodplain to facilitate reach scale restoration of hydraulic and sediment processes that will also restore riverine and floodplain habitats over a 4,000 foot reach.

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[2] Italicized sections of report are reproduced from Yakima County (2015).

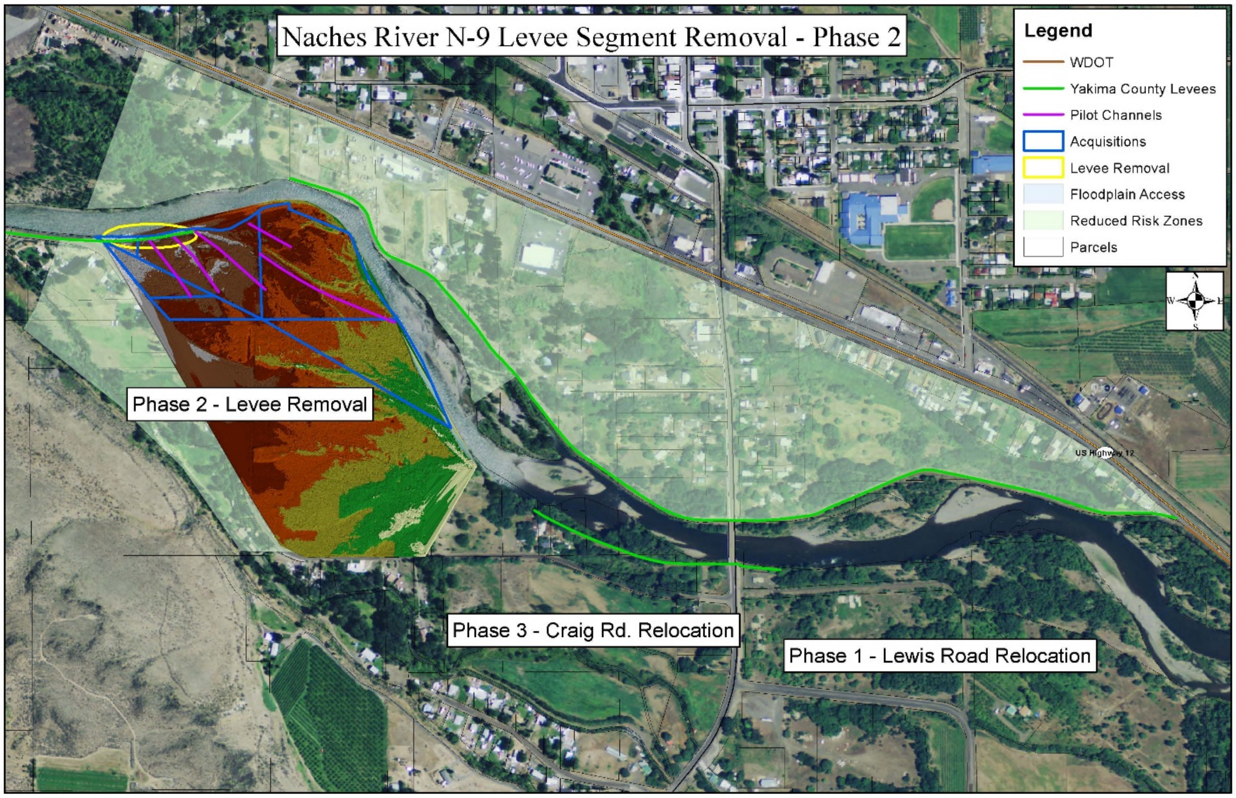

Figure 2: Conceptual site plan of N-9 Levee Segment Removal (figure from Yakima County).

2.2.3 Project Features

The N-9 levee extends for a distance of 2,150 feet between RM 14.1 and 14.5 along the immediate right bank of the Naches River, just upstream of the Town of Naches (NHC, 2015 pp. 11 and Figure 3). The South Naches diversion structure and offtake ties into the levee at its upstream end. The levee is approximately 3 to 4 feet higher than the surrounding floodplain and currently protects the South Naches Diversion Canal and several private residences. Opposite the N-9 levee and downstream of the South Naches Diversion, there is a remnant meander bend that deactivated sometime between 1927 and 1947 on the left bank. The upstream half (RM 14.3 to 14.5) of the floodplain in this former meander bend appears to have been re-graded, and possibly filled, sometime after 1971, to construct a log sorting yard for the neighboring sawmill. The effect of this feature is to further confine the channel southward against the N-9 levee and help direct flow toward the Town of Naches and the N-7 levee. The downstream end of the N-9 levee coincides with the upstream end of the N-7 levee on the opposite left bank (Figure 3). It should be noted that an unarmored 300 foot long segment of the N-9 levee extends downstream of the 500 foot segment to be removed. This remnant segment appears to be in disrepair but currently functions as a flow constriction up to moderate flows. With removal of the upstream segment, its function as a flow constriction would become minimal.

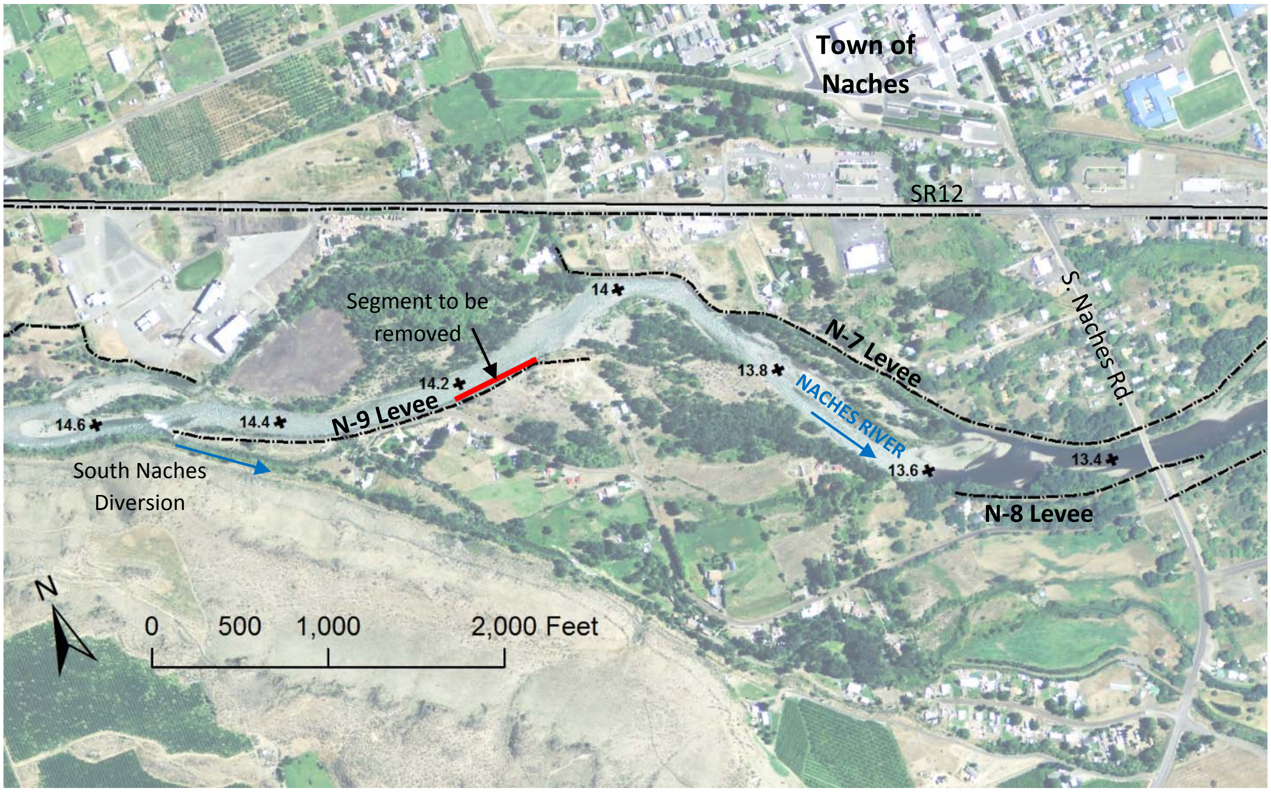

Figure 3: N-9 Levee Segment Removal site map.

The County is proposing to remove the lower 500 foot segment of the N-9 levee, which would effectively widen the flow corridor from 500 feet to over 1,000 feet. The removal would reactivate the former floodplain; however, pilot channels are being proposed to enhance flood conveyance, morphologic activity, and off-channel habitat creation.

2.3 N-2 Trout Meadows Floodplain Restoration

2.3.1 Location

The project is situated between RM 5.5 to 6.5 in the Geomorphic Atlas (NHC, 2015).

2.3.2 Project Need, Goals and Perceived Benefits

Need: The McCormick Levee on the north bank of the Naches River, and the levees and armor on the Trout Meadows property on the south bank of the river, form a constriction which is causing aggradation upstream. This aggradation has increased the risk of flanking the McCormick Levee and also has raised the 100-year base flood elevation and increased floodway width.

Goals: Reduce flood heights and floodway width and increase flood habitat in a 3 mile reach of the Lower Naches River through acquisition of 2 parcels – Ibrahim (18130612403) and Yolo (18130614003), and re-grading of the existing ponds to for side channels.

Benefits: This project will return over 65 acres to the Naches River Floodplain through levee removal and creation of side channels in the historic active floodplain. Benefits include reduced water levels in the reach through expanded flood storage and flood conveyance, plus improved off-channel and mainstream habitat. The project will reduce the potential of flanking of McCormick levee at high flows as well as reduced maintenance.

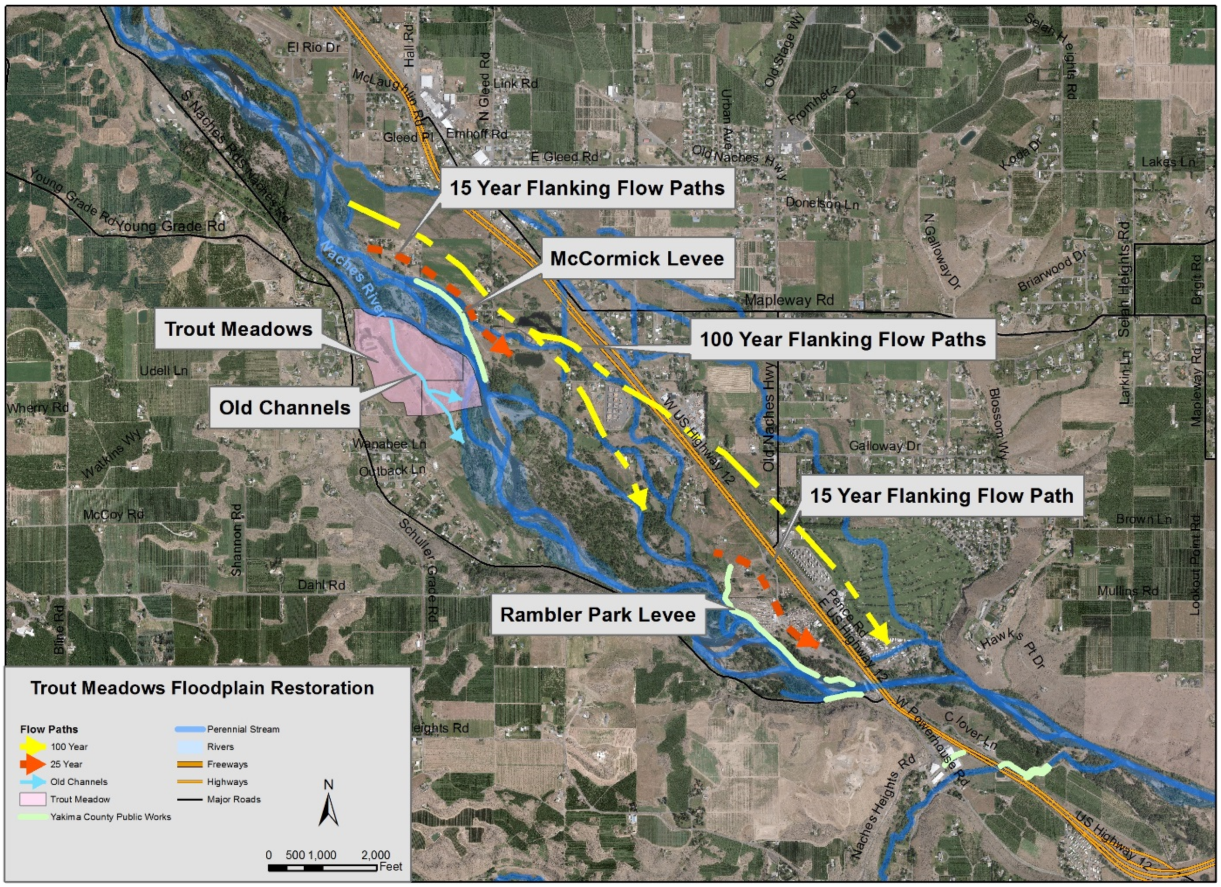

Figure 4: Conceptual plan of Trout Meadows Floodplain Restoration (figure from Yakima County).

2.3.3 Project Features

Trout Meadows is a former gravel bar complex located on the right flood corridor between RM 5.6 and 6.3, just downstream and in the lee of an outcrop of the right valley wall (NHC, 2015 pp. 23 and Figure 5). The gravel bar is 3,000 feet long and 500 to 1,300 feet wide and appears to have been stabilized between 1927 and 1947 by construction of an elevated embankment at the head of the bar and bank armoring along the active channel fringe. The elevated embankment is 4 to 6 feet higher than the surrounding floodplain and extends 400 feet laterally over the head of the bar. It appears the head of the structure was either damaged or destroyed in 1996, and presumably rebuilt afterwards. Downstream, a series of ponds were excavated in the 1970's for recreational purposes through the center of the bar. The depth of these ponds is currently unknown.

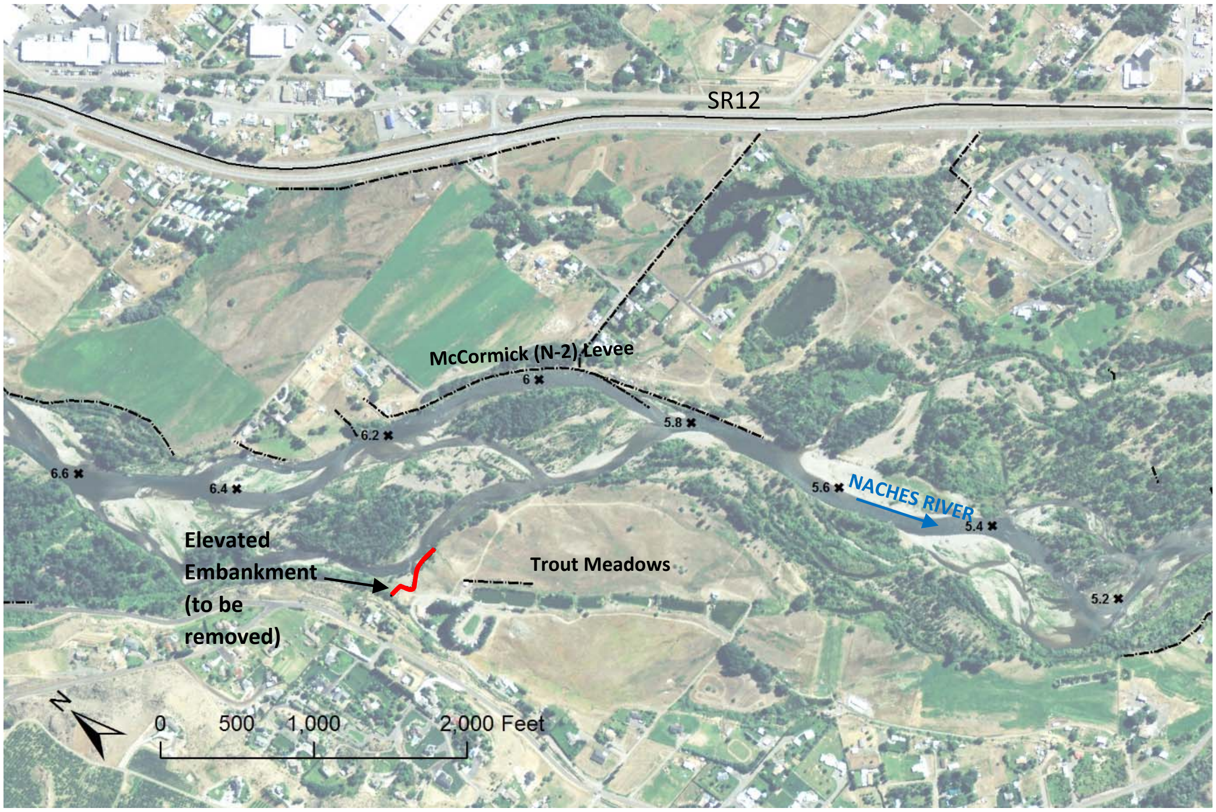

Figure 5: Trout Meadows site map.

The County is proposing to remove the elevated embankment at the head of the Trout Meadows gravel bar complex and excavate side channels through the site to reactivate channel morphology, restore side channel habitat, and improve flood conveyance.

Immediately opposite Trout Meadows, on the left bank, the N-2 (McCormick) levee extends for approximately 2,600 feet (Figure 5). The current levee appears to have been constructed in two phases: the upper 1,800 feet built between 1947 and 1968, and the lower 1,200 feet in the 1970's (NHC, 2015 pp. 23). The lower 400 feet of the first levee segment appears to have been destroyed in the 1970's, presumably from large floods, thus necessitating the subsequent downstream extension. Currently, the McCormick levee constricts the active channel down to a minimum width of 500 feet in a reach that was historically on the order of 2,000 feet wide. The height of the levee is 2 to 5 feet above the surrounding floodplain.

2.4 N-1 Naches Levee Setback-Ramblers Phase II

2.4.1 Location

The project is located on the right bank of the Naches River between RM 3.8 and 4.5 as described in the accompanying Geomorphic Atlas (NHC, 2015).

2.4.2 Project Need, Goals and Perceived Benefits

Need: The Rambler's Park Levee (N-1) is a County-owned levee, enrolled in the USCOE's PL84-99 program that protects SR12, Powerhouse Road, several businesses and residences. The Levee has experienced repeated failures during floods (1996, 2006) and at relatively low freshets (3200 cfs flood failure in 2012) and now provides limited protection at higher flows due to historic upstream flanking. This change results from sediment deposits produced by downstream backwater from the constrictions of existing levee alignment, Nelson Dam, and Highway 12.

Goals: The County objectives in this reach are to reduce backwater and improve sediment transport to either stop or reverse the channel aggradation in the infrastructure, including replacement of Nelson Dam, that reduce constriction/sedimentation. This phase of the County's four phase actions (one completed) will act to reduce flood hazard and improve riverine and floodplain habitats over a large reach of the main stem river, while improving fish passage and holding areas. The project will purchase floodway properties, reconfigure and relocate the existing wrecking yard, setback the existing 2,100 foot levee, segment 300 feet to a reduced 1,800 foot segment that allow floodplain access to a further 2 acres at the Nelson Dam approach, and create pilot channels in the long-term floodplain deposits. The project is phase two of a four phased project identified under Recommendations 14, 15, 16, and 17 of the Naches River Comprehensive Flood Hazard Management Plan.

Benefits: This project will reduce levee damages and failure risk, remove areas from the 100-yr floodplain and reconnect a large area to historically active floodplain to facilitate reach scale restoration of hydraulic and sediment processes that will also restore riverine and floodplain habitats.

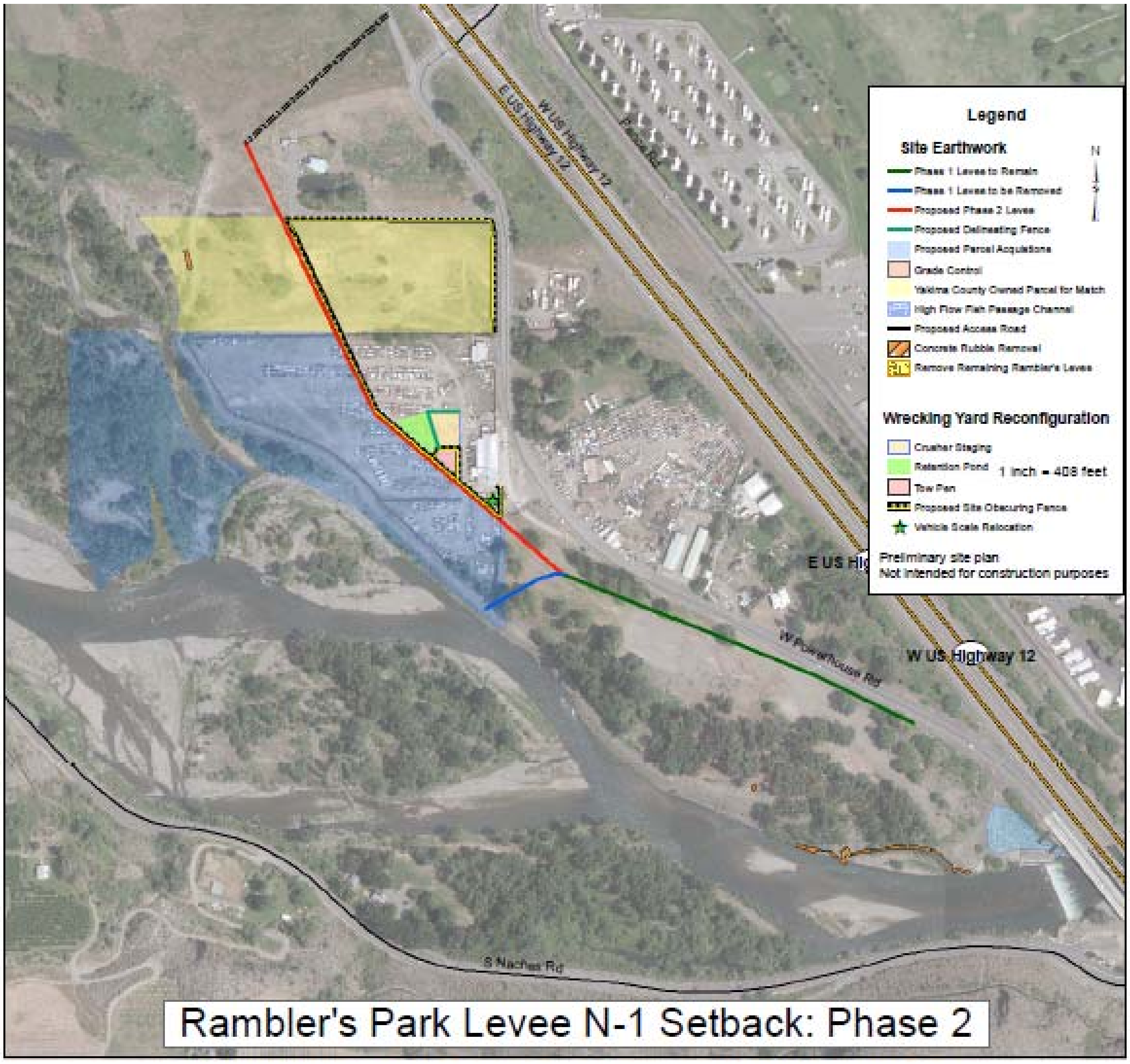

Figure 6: Conceptual site plan of N-1 Naches Levee Setback (Phases I and II) at Rambler's Park (figure from Yakima County).

2.4.3 Project Features

The Rambler's Park (N-1) levee is a County owned structure, enrolled in the Corps PL84-99 program (NHC, 2015 pp. 25, and Figure 7). The levee is part of a complex of flood protection and river training features built over the past 90 years to protect infrastructure, bridge crossings, and development located just upstream of a natural, and abrupt, constriction of the Naches River flood corridor (referred to by Corps (2015) as a 'water gap'). Here, the valley width rapidly decreases from approximately 7,200 feet to 1,400 feet in less than a mile.

Construction of the Rambler's Park levee along the left bank occurred between 1947 and 1968, with the final 500 foot extension to block flanking in 1996 bringing the total length to 2,800 feet.

Phase I of County's site plan was implemented in 2013, with removal and setback of the downstream-most 1,600 foot levee segment (Figure 7). For Phase II of the project, the County is proposing to remove the existing 2,100 foot upstream segment and replace it with a 1,800 foot long structure setback 300 feet from the channel. In addition, a 200 foot long segment of the Powerhouse Road embankment would be removed.

The downstream limit of the Rambler's Park levee ends before the temporary access road built in 2006 to the former Power House Road bridge abutment located on the left bank (Figure 7). The access road prevents the river bypassing Nelson Dam, in its current configuration. This access road, abutment, and the hillside to the immediate south confines the channel to a 200 foot width in what was historically a 2,000 foot wide flood corridor. Immediately downstream of this constriction and the Rambler's Park levee complex is Nelson Dam, a 200 foot wide, approximately 8 foot tall diversion structure operated by the City of Yakima in cooperation with the USBR.

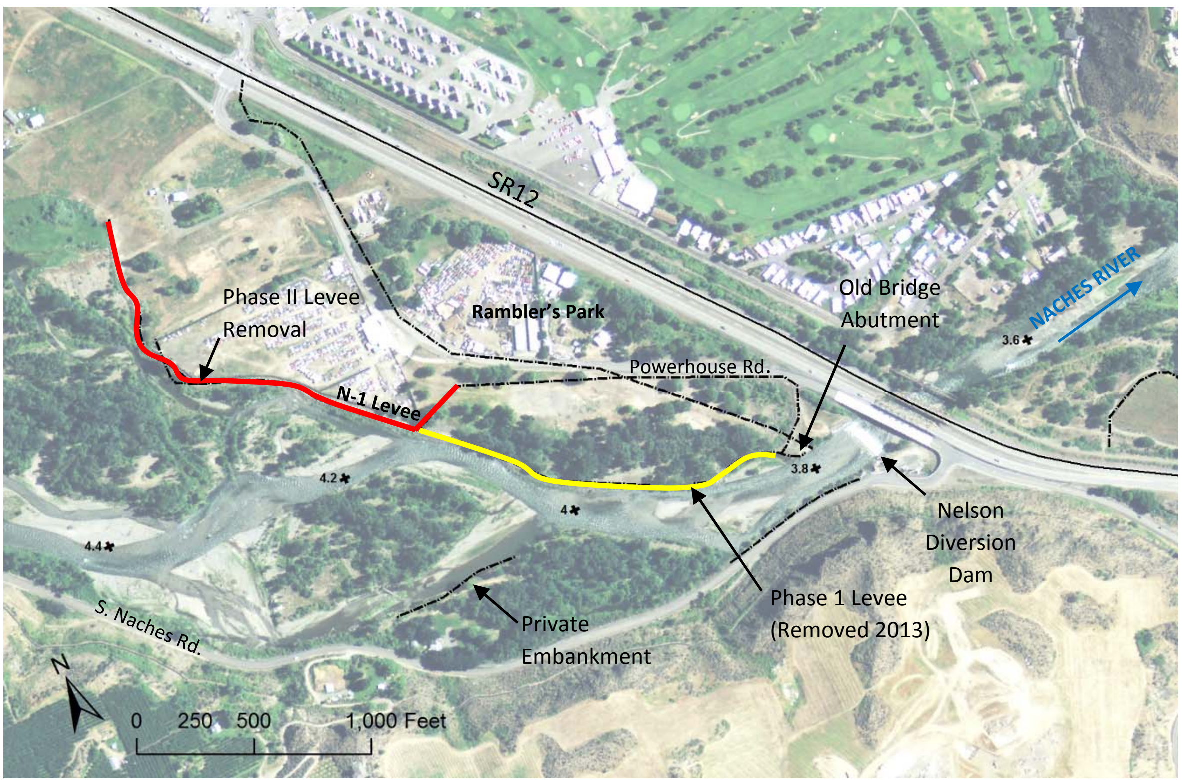

Figure 7: Rambler's Park (N-1) Levee site map with levee before setbacks.

3 RIVER CHARACTERISTICS

3.1 Previous Investigations

Several previous studies have been conducted investigating the hydrology, hydraulics, geomorphology, sediment transport, or all of the above of the Naches River. NHC reviewed relevant sections to guide the present study. Three floodplain mapping studies have been conducted including areas of the study reach. These include Corps (1970), which mapped the part of the river below the downstream Highway 12 Bridge; Corps (1972), which mapped the part of the river between the confluence of the Naches and Tieton Rivers downstream to the Highway 12 Bridge, and an updated study incorporating MIKE-11 modeling of the Naches River conducted by DHI and described in Tjerry (2007)[3]. These reports provide information on the hydrology and hydraulics of the system and historic thalweg elevations.

The USBR's Yakima River Geomorphology and Sediment Transport Study: Gap to Gap Reach (Hilldale and Godaire, 2010) includes a study of sediment flow from the Naches to the Yakima River. This was based on results of a bed load transport sampling program conducted by the USGS and development of a bed load transport rating curve for the flux of material from the Naches to the Yakima River.

Washington State Department of Transportation's Critical Environmental Deficiency Study for the lower Naches River (GeoEngineers, 2003) includes a detailed discussion of basin-scale conditions, hydrology, sediment transport, and riparian forest conditions in Appendices B through E. In addition, the main report evaluates geomorphic processes in the lowest segment of the river (RM 3.75 to 0) in detail.

The Naches River Channel Migration Zone Study (Tetra Tech, 2004) included detailed channel position mapping and description of historic channel migration trends and processes along the present study reach of the Naches River.

3.2 Setting

The Naches River basin is located on the east slope of the Cascade Mountains, between the City of Yakima and Mount Rainier. It has high relief, with elevations ranging from just over 1,000 feet to 8,100 feet and a mean basin slope of approximately 30%. It is largely underlain by a combination of volcanic rocks and moderately consolidated conglomerates including the Ellensburg formation and Thorp Gravel. Annual average precipitation generally increases from less than 15" in the eastern part of the basin to over 60" toward the crest of the Cascade Mountains (NHC, 2015 pp. 2-3).

The combination of geologic, climate, and biological conditions in the upstream basin area supports relatively high clastic sediment supply to the Naches River. Further, because of the dominance of both alpine and arid conditions in the basin area, much sediment supply to the Naches River and its tributaries likely occurs through high-magnitude, low-frequency events such as debris flows and

[3] Floodplain mapping from the MIKE-11 modeling was adopted by FEMA in the most current county-wide Flood Insurance Study (FEMA, 2012).

landslides. Sediment supply from the alpine headwaters of the Tieton River, where sediment yield is likely relatively high due to ongoing paraglacial adjustment (Ballantyne, 2002), has been cut off by impoundment of Rimrock Lake by construction of the Tieton Dam.

The lower Naches River valley bottom ranges in width from 0.32 to 1.1 miles. It is irrigated and intensively used for fruit production agriculture. Lower hills are covered in shrub-steppe vegetation and the slopes of the cascades are dominated by coniferous trees. The lowest parts of the river's floodplain (particularly abandoned channels) support dense growth of Cottonwood, while higher areas of the floodplain near the bankfull elevation tend to support sparser shrub-scrub vegetation. Terraces are nearly continuous along the valley bottom, with several terrace levels ranging from 15 to 80 feet above the presently active channel.

3.3 Hydrology

Hydrologic data for this study originates from a stream gage located on the Naches River just downstream of the confluence with the Tieton River (RM 17.25). From 1909 to 1979, the gage was operated by the USGS (Gage No: 12494000), but subsequent operation was transferred to the USBR (Gage ID: NACW). Table 1 presents flood frequency discharge estimates based on available lower Naches River gage data as reported in Corps (2015).

Table 1: Flood Frequency Discharges on the lower Naches River (from Corps (2015)).

Return Period	Annual Exceedance Probability	FEMA (2010) (cfs)	GeoEngineers (2003) (cfs)
1.01-year	99.99%	-	1,109
2-year	50%	-	6,696
5-year	20%	-	10,771
10-year	10%	12,500	13,955
20-year	5%	-	18,543
50-year	2%	20,000	22,380
100-year	1%	27,000	26,586
500-year	0.2%	47,500	-

Figure 8 shows the history of annual flood peaks at this gage site. Both instantaneous peak and mean daily discharge values are given for the period from 1909 to 1979, while only mean daily values are shown for 1980 to 2014. Instantaneous flood frequency from Table 1 are also shown for comparison, as well as construction dates of the Bumping Lake and Tieton Dams, both located upstream of the Naches-Tieton confluence (NHC, 2015). A formal analysis of regulatory effects on river flow and morphology was not conducted as part of this study; however, it has been suggested the dams have decreased flood peaks moderately and increased the duration of geomorphically active flows (Yakima County, pers. comm. 2015). Figure 8 also illustrates alternating decadal periods of relative hydrologic activity, with numerous moderate to high flow events occurring during the 1950s, 70s, and since the 1996 flood event, the second largest flood of record since regulation.

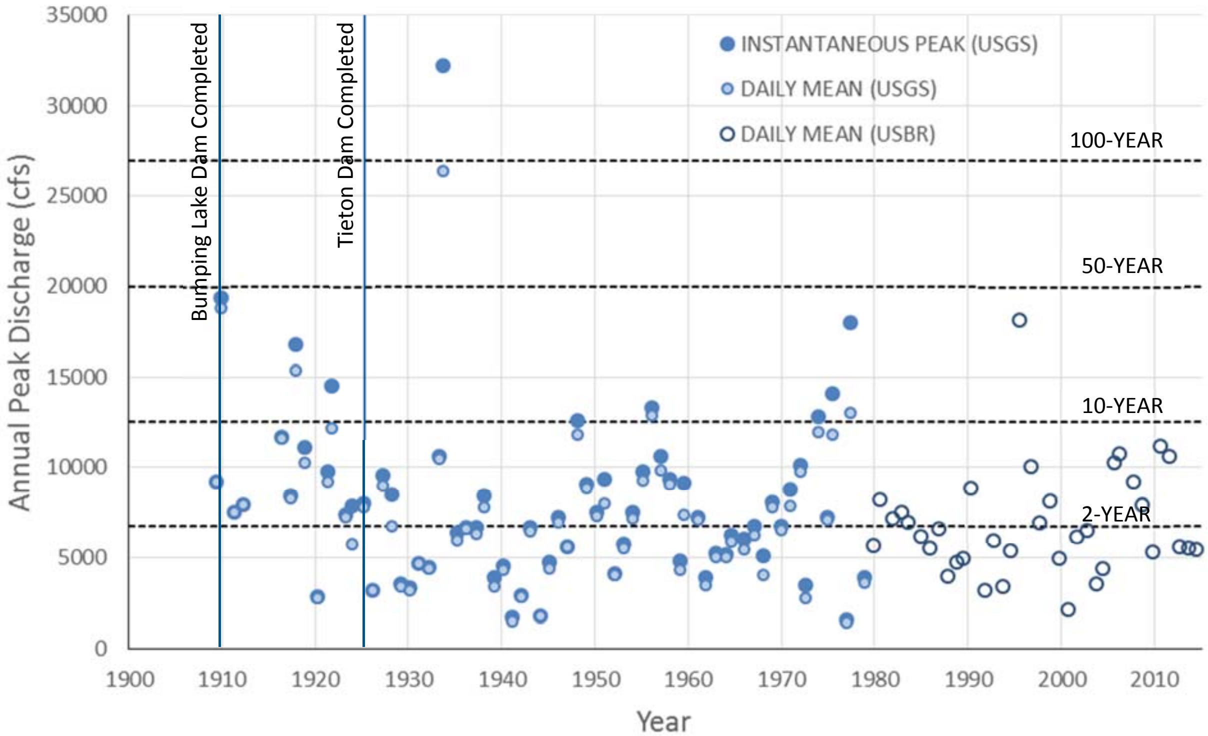

Figure 8: Historical flood peaks for the lower Naches River.

3.4 Channel Characteristics

3.4.1 Slope and Planform

The lower Naches River is a steep (0.5 to 0.62%) gravel and cobble-bedded river (NHC, 2015 p. 1). It is characterized by a laterally active wandering planform with two or three channels anabranching around forested islands, but locally, revetments and other constructions have created long single thread reaches and some other areas are braided, with four to eight channels conveying water around unstable bars during low-flow conditions (NHC, 2015 p. 33). Wandering gravel bed rivers (Type 5 of Nanson and Knighton, 1996) are a transitional form between meandering and braided systems that commonly occur in mountainous regions. In these systems, meander amplification and sedimentation within the main active channel occasionally reduce flow conveyance in that channel to the point that flow spills onto the floodplain, forming avulsion channels.

In 2013 aerial photos, the wetted channel (including all branches in multi-thread segments) ranges from about 100 to 500 feet wide, and the active channel ranges from about 150 to 900 feet wide. This variability in channel width reflects variability in bank strength, floodplain conveyance, and vertical channel stability along the reach.

Regime models accounting for these factors can elucidate the magnitude of influence these various factors play in governing channel planform and width (Eaton et al., 2004; Eaton, 2006; Eaton et al., 2010; Millar et al., 2014), as shown in Figure 9. Increasing bank strength either through vegetative establishment or placement of revetments is expected to reduce the number of channels and total active width. All other things held constant; increasing the proportion of flow in the main channel by blocking floodplain conveyance is expected to increase the total active width and number of channels in the area of concentrated flow. Deviation from predicted regime dimensions can provide an indication of vertical stability:

- Over-wide reaches suggest channel aggradation may be occurring.
- Narrow reaches indicate, high bank strength, channel downcutting, or both factors.

Often, a combination of both factors can influence channel planform (Germanoski and Schumm, 1993; Church, 2006), as is likely the case along the Gleed Diversion reach from RM 7.1 to 10.1 (NHC, 2015 pp. 17) or downstream of Nelson Dam from RM 1.5 to 3.7 (NHC, 2015 pp. 27-29). On the Lower Naches, reaches where floodplain conveyance is reduced by levees tend to be relatively narrow, suggesting that the influence of increased bank strength from revetments and channel downcutting overpower the influence of increased discharge in the channel.

Figure 9 quantitatively shows these patterns. It is divided into four subplots, each one showing how channel dimensions and the number of channels is expected to change given various controlling factors. The top pair of plots show the predicted number of channels, and the bottom pair show total active channel width. The left two subplots show the influence of bank strength (μ), which is quantitatively defined as the ratio of the shear stress required to mobilize the bank material to the shear stress required to mobilize the bed material, typical bank conditions responsible for various values of μ are shown below the axis. Diamonds represent results for a D_{50} of 91mm, crosses represent results for a D_{50} of 64 mm, and filled diamonds occur where crosses overprint the diamonds (i.e. grainsize has no influence). A value of μ=1.1 and D_{50} of 91 mm reproduces typical conditions for the most unconstrained reaches of the Naches, these are used then in the right column to explore the influence of various channel-forming discharges, which can change either as a result of levees locally blocking floodplain conveyance (e.g. NHC 2015 p. 32), or as a result of flow regulation. These results suggest that the total active width for the river may have been reduced by approximately 30% in response to flow regulation, and that number of channels may have been reduced from 3-4 to 1-2.

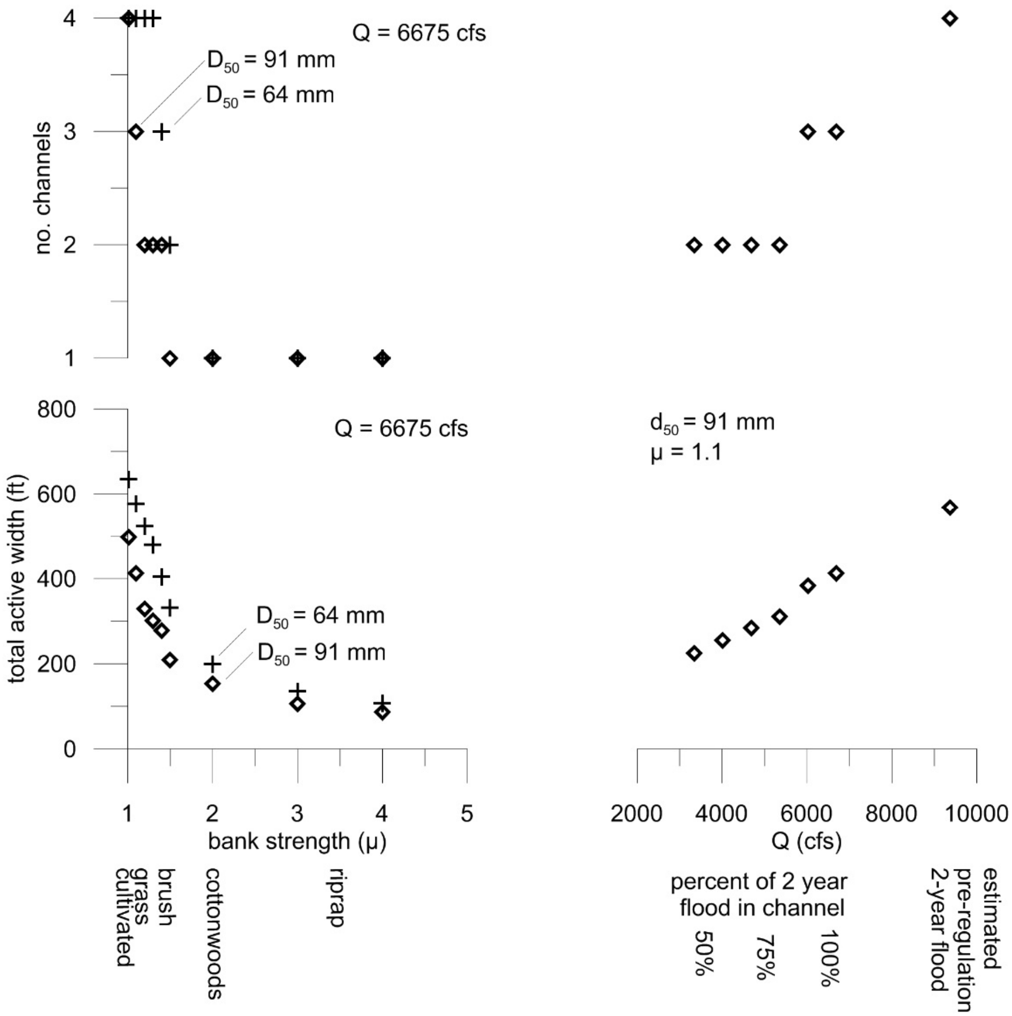

Figure 9: Regime Calculations (Millar et al., 2014) of width and number of channels for the Naches River assuming various combinations of bank strength (μ), channel-forming discharge (Q) and grain size.

3.4.2 Channel Migration and Sediment Transport

Migration of the lower Naches River occurs through two dominant processes – gradual meander bend shifting and abrupt avulsion (NHC, 2015 pp. 4-31). Observed lateral migration rates along the lower Naches vary dramatically between reaches (NHC, 2015 p. 33), from near zero in channelized reaches with armored banks to 20-60 feet/year in unstable areas.

In cases of meander bend migration, point bar growth on the inside of the bend (and occasionally mid-channel bar formation) and erosion of the bank along the outside of the bend typically exchange approximately equal volumes of material on the lower Naches River, because point bars are typically built to near-floodplain elevation (NHC 2015 p. 33). Most of the material eroded from these banks consists of coarse cobble-gravel alluvium comparable to typical bed material in the river (Photo 1). Observations of eroding banks along the continuous transect suggest that about 90% of the total volume of bank erosion comes from such coarse alluvium, based on a weighted average of observed material in eroding banks. The remaining 10% consists of sand and silt overbank deposits that would be carried as wash load in the river.

Photo 1: Characteristic bank erosion showing dominance of coarse alluvium.

On the lower Naches, avulsions typically occur after meander amplification has lengthened the course of the main channel and reduced its slope to the point where a large volume of flow escapes the channel during floods, crosses the floodplain, and excavates a shorter, more hydraulically efficient path. Numerous historic, active, and incipient avulsions are apparent from both field observations and GIS analysis (NHC, 2015 pp. 13-25; 29). As with meander migration, the floodplain material excavated by avulsions is likely coarse alluvium similar to the river's present bed material. Material filling abandoned river channels, however, is often the finest observable in the system and can range from cobble-gravel alluvium to sand and silt in backwatered abandoned channels (e.g. NHC, 2015 p. 19 and p. 24). Two parameters generally specify conditions in which avulsions are likely to occur: superelevation and slope ratio. Superelevation is a measure of how high the channel is perched above the surrounding floodplain, and slope ratio is defined as the ratio of the slope of a possible avulsion path to the down channel slope. Histograms of observed slope ratios at stable bifurcations (n=8) and unstable avulsions (n=15) on the lower Naches indicate that avulsions may occur at very low slope ratios of one to two (Figure 10).

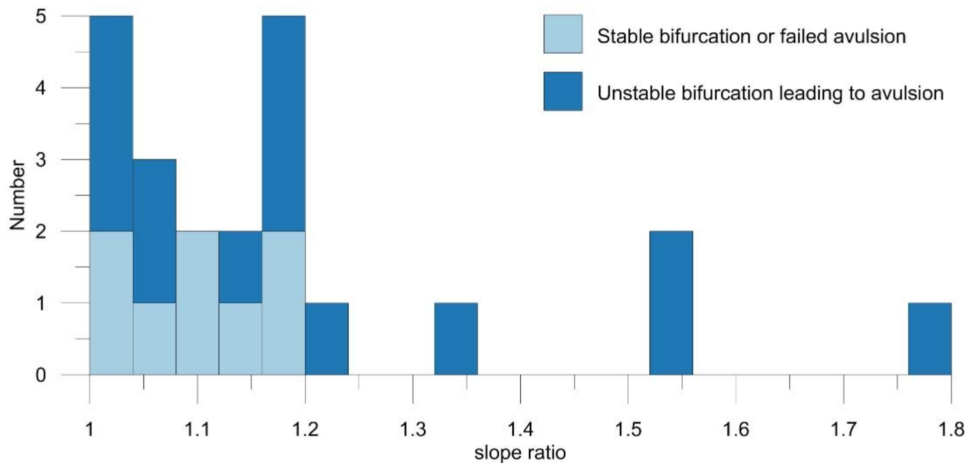

Figure 10: Histograms of lower Naches River bifurcation slope ratios.

It is critical to hold the channel migration dynamics of a river in mind while considering sediment transport, as the two processes are intimately connected (Wickert et al., 2013; Constantine et al., 2014; Nelson and Dubé, 2016). In sedimentation reaches[4] of the lower Naches, field observations and grainsize distributions suggest that bed load is typically mobilized from eroding banks, transported a short distance downstream (1-2 meander wavelengths or 1-2 times the distance between major bars), and deposited locally in bars. These bars then often stabilize with vegetation and become a floodplain until the channel again — perhaps after decades or centuries — migrates into that position, erodes the material, and passes it to bars downstream. This pattern of bed material transport, where sediment transfer occurs primarily through channel migration is characteristic of wandering gravel bed rivers like the lower Naches (Neill, 1983, Church, 2010; Reid & Church, 2015). The exception to this pattern occurs in reaches laterally constricted by infrastructure such as in the vicinity of the Gleed Diversion (NHC 2015 p. 17), where revetments make the banks immobile. High shear stress in these areas flushes bed load downstream and may move it directly from active bar to active bar without long immobile periods in the floodplain. A combination of reduced local sediment supply from bank erosion, channel planform response to bank strengthening, and increased shear stress can cause these reaches to downcut (Galay, 1983; Reid & Church, 2015).

Because most bed load transport in sedimentation reaches occurs through the process of bank migration and bar growth, cut-and-fill volumes between the 2001 and 2013 LiDAR datasets can be used to estimate the river's bed load transport rate. Over this period, local erosion and deposition volumes in sedimentation zones were typically between 10,000 and 40,000 yd^3 per 0.2 mile segment of the river (NHC 2015 p. 33), which gives a range from 0.8 to 3 yd^3/ft/yr. Before this value can be converted to a sediment transport rate, the distance material moves after it is eroded from a bank must be determined to define the appropriate scale of aggregation. The minimum plausible distance is the typical length of eroding banks (930 ± 430 ft). The estimated virtual velocity for the sediment based on the regression of

[4] A stream reach that flows through a relatively unconfined valley where bar formation forces active channel migration (sensu. Church, 1983). This does not necessarily imply channel bed aggradation or a net increase in sediment storage.

Beechie (2001), which scales as approximately 20 times the river's bankfull width, probably provides the best estimate. Applying this range of input parameters and correcting for the estimate of 10% washload for areas of floodplain erosion gives a morphologic estimate of the river's bed material load transport rate, shown in Table 2. Though a broad range of plausible values are presented, the 20X bfw (narrow) condition is most representative of conditions found in most reaches along the river, indicating the average annual bed load transport rate ranges between 2,880 to 10,880 cubic yards/year.

Table 2: Morphologic estimate of lower Naches River bed material load transport rate, given in yd^3/yr.

Typical volumetric change (yd^3/ft/yr)	**Mean eroding bank length** 930 ft	**Mean eroding bank length +1 σ** 1360 ft	**20 X bfw (narrow)** 4000 ft	**20 X bfw (medium)** 6000 ft
0.8	670	979	2,880	4,320
3	2,511	3,672	10,800	16,200

The USGS measured bed load transport on three dates on the lower Naches River at the I-82 Bridge in May 2008. The discharges during the period of sampling ranged between 8,250 and 9,300 cfs. The bedload transport rates ranged from 772 to 1,430 t/day. Hilldale and Godaire (2010) used these measurements along with other suspended sediment sampling and sediment transport analysis to develop a total sand and gravel rating curve (which they termed "bed material load") as a boundary condition for a 1D sediment model of the Yakima River. By excluding the suspended sand load (which constituted most of the transport rate), a bed load rating curve was produced for the Naches River. This bed load relation represents only the gravel and sand moving directly on the bed of the river, and excludes the suspended sand load in the water column. Daily discharges from the USGS gaging station "Naches River Below Tieton River" (12494000) were used to develop annual load for the period 1926 to 1979.

The average annual bed load transport was estimated to be 2,900 t/year, with loads reaching less than 900 t/year in low flood years. The annual load was found to be strongly affected by both the peak flood flow and the frequency and duration of high flows. As a result, the computed annual bed load transport for years with similar peak floods (10-year return period) but very different hydrographs ranged between 2,600 t/year and 11,000 t/year. Assuming a dry bulk density of 1.4 t/cubic yard, the corresponding average annual transport rate is 2,100 cubic yards/year. The corresponding volumetric transport rates during years experiencing a 10-year flood ranged between 1,900 and 8,000 cubic yards/year.

The morphologic-based estimates from Table 2 and results from the direct measurements are comparable to bed load estimates from typical regional sediment yield and bed load fractions shown below in Table 3.

Table 3: Empirical estimates of lower Naches River bed load

Sediment Yield Estimate Source	Sediment yield (tons/mi²/yr)	Total load* yd³/yr	Bed load assuming various bed load fractions** (yd³/yr) 0.4	0.2	0.1
Church and Slaymaker (1989) BC trend	100	60,000	24,000	12,000	6000
Average of Czuba et al (2011) & upper bound of Church & Slaymaker main trend	480	290,000	110,000	57,000	28,500

* assuming 660 mi^2 bed load contributing basin and bulk density of 1.1 tons/yd^3. A total load approaching or greater than 87,000 yd^3/yr is unlikely given that figure is Hilldale and Godaire's (2010) estimate of the average annual total load for the Gap to Gap reach of the Yakima River.

** These values represent the likely range of bed load fraction for the Naches, based on regional experience (Dunne et al., 1980) and empirical estimates by basin area (Turowski et al., 2010). Values as low as zero are possible, and values between 10 and 20% are most likely.

The direct measurements and morphologic-based estimates are more representative of local conditions than the regional sediment yields. The average annual load transport on the Naches River is likely to be in the range of 2,000 to 3,000 cubic yards/year, with the transport increasing up to 8,000 cubic yards/year during a 10-year flood event.

4 HEC-RAS MORPHODYNAMIC MODEL

4.1 Model Description

The 1D HEC-RAS model developed by the Corps evaluates both hydraulic and mobile bed (morphodynamic) conditions along the lower 18.2 miles of the Naches River, from the mouth at the Yakima River to the confluence with the Tieton River (Corps, 2015). The model reach is divided into three sub-reaches: upper and lower main stem reaches divided at RM 3.6 and an overbank (H12) reach intended to model overtopping of Highway 12 upstream of Rambler's Park near RM 6. Model geometry consists of 213 cross-sections constructed using a combination of 2003 channel survey and 2013 LiDAR topographic data. Channel geometry was exported from a MIKE-11 hydraulic model originally developed by DHI, Inc. for floodplain mapping purposes (FEMA, 2010). Cross-sections surveyed by NHC in 2014 were not included by the Corps in their model, nor in the model revised by NHC. NHC determined addition of these few sections would not substantially benefit hydraulic or morphodynamic modeling of the reach considering the varying dates of previously collected survey and LiDAR data.

Manning's roughness coefficients in the Corps model were defined using aerial photos to characterize land cover classification. Channel and overbank values vary from 0.035 to 0.07 (Corps, 2015). For comparison, roughness coefficients in the MIKE-11 model (used to map the effective FEMA flood hazard area) were set to generally more conservative values of 0.035 in the channel and 0.105 on adjacent floodplains (Weinstein, 2006). Both models were reported as calibrated, but only to the limited data that was available (Corps, 2015, Section 7.3). As such, the overall accuracy of the model remains uncertain.

Several structures are included in the Corps model. The model contains a total of 11 bridge crossings; the most relevant to this analysis being South Naches Road, Powerhouse Road, and SR12. Of the six major diversion structures located along the reach, only the Wapatox Intake RM 17.8 and the Nelson Dam are included as inline weir structures. The crest height of these structures were estimated based on 2013 LiDAR data and County data (Corps, 2015). It should be noted that the South Naches Diversion structure, located at RM 14.6 was not included in the model. As such, project impacts to this structure cannot be explicitly evaluated.

The model geometry contains several levees including the N-7, N-8, and N-9 structures near the Town of Naches, the N-6 levee adjacent to the wastewater treatment plant, the McCormick levee (N-2) near Trout Meadows, and the N-1 levee at Rambler's Park. Recent levee setbacks at Eschbach and Rambler's Park were accounted for in the model received from the Corps.

For bed material grain size distributions, the Corps model used surface and subsurface samples collected by the County in 2014.

4.2 Model Refinement

Model revisions made by NHC fall into two categories: general revisions made to the entire 18.2 mile reach and revisions for setting up sediment transport (morphodynamic) modeling. Documentation of these refinements are provided in the following sections.

4.2.1 General Revisions

The Corps' three reach model was converted to a single computational reach by eliminating the H12 overflow upstream of Rambler's Park and merging the upper and lower Naches reaches just downstream of Nelson Dam. The H12 overflow reach, located to the northeast of SR12 and Rambler's Park, is intended for mapping floodplain extent, but has little relevance to geomorphic processes along the reach. As such, it was removed to simplify the model.

Further refinements included adjusting ineffective flow boundaries to represent the estimated active flow conveyance area at each cross section. The Corps model made use of ineffective flow areas but generally assumed unconfined flow laterally across cross sections. This methodology is most valid for high magnitude (e.g. 100-year) events when the entire floodplain is activated, but for lower magnitude events it may over-estimate overbank conveyance and lateral continuity in complex reaches. To address this, NHC manually adjusted the ineffective flow boundaries to the estimated active channel edge, as indicated by LiDAR and aerial photos. These adjustments resulted in some computed increases in localized water surface elevation, but they also made the flood profiles generally more uniform and improved continuity in channel conveyance.

In two locations additional measures were required to estimate the distribution of overbank flow. Near the Town of Naches lateral weir structures were added to the crests of the N-7, N-8, and N-9 levees to help estimate flow distribution in the highly complex reach, particularly around the South Naches Road bridge crossing at RM 13.4. Here, flow overtopping lateral structures was routed to estimated downstream locations where it would rejoin the main channel, thus flood attenuation was not considered. Similarly, a lateral structure was added to the left bank just downstream of the McCormick levee and a former gravel pit (RM 5.6), to estimate overflow into the remnant avulsion channel located on the far left edge of the active channel. The crest height for this lateral weir was based on 2013 LiDAR topography of the bar surface.

Construction of pilot channels, described in Section 2, was not considered at the N-9 and Rambler's Park sites, but was at Trout Meadows. Here, a channel following the existing pond alignment was estimated based on water surface elevations from the 2013 LiDAR data.

4.2.2 1D Morphodynamic Model Setup

NHC truncated the 18.2 mile HEC-RAS model reach into two sub-reaches to evaluate project effects on sediment transport and morphodynamics. Truncating the model to shorter reaches allowed for a more focused refinement and analysis of the sediment model at project sites, while also eliminating uncertainties associated with conditions elsewhere along the reach. Furthermore, it significantly reduced computation time. Simulations were conducted at each site for a 25 year period (Water Year 1985 to 2009) using the continuous daily mean hydrograph for the Naches River developed by Hilldale and Godaire (2010). Downstream boundary conditions for each site consisted of stage-discharge rating curves computed by the HEC-RAS model of the entire reach. Grain size distribution data recently collected by NHC, reported in NHC (2015), were input to the model and replaced data provided by the County. The County grain size samples tended to be quite coarse and likely represented material rarely transported by the river, perhaps a sub-armor layer related to pre-regulation flow conditions. NHC samples, the locations of which are shown in NHC (2015), were generally taken in areas where recent transport was apparent (e.g. bar heads) thus assumed to better reflect bed load moving through the system. Further information on NHC's samples are contained in NHC (2015). Both models utilized the Meyer-Peter & Mueller bed material transport function as modified by Wong & Parker (2006).

The Rambler's Park and Trout Meadows project sites were modeled as a single 3.8 mile long segment extending from Nelson Dam to approximately 1.2 miles upstream of the McCormick levee (RS 19857 to RS 39626). The upstream sediment boundary condition for this segment was set to equilibrium bed load.

The N-9 levee removal site was modeled using a 2.3 mile segment extending from downstream of the South Naches Road bridge crossing (RS 13.4) to approximately 0.6 miles upstream of the South Naches diversion structure (RS 79798). The South Naches Road bridge geometry was removed from the model, but more critical features such as the levees, abutment constriction, and lateral structures were retained. The upstream sediment boundary condition was also set to equilibrium bed load, but a coarser bed material composition was input beginning at the N-7 levee (RS 74156) and extending to the upstream model limit. The choice to use a coarser bed material composition in this sub-reach was based on observations of supply-limited conditions (Montgomery & Buffington, 1997) made during the site visit, as indicated by the presence of large boulder sized material in the channel, the confinement of the reach, and lack of substantial gravel bar deposits. Accordingly, the surface bed material sample collected by the County at RM 13.5 was used to define bed material composition with a median particle diameter (D_{50}) of approximately 300 mm. A coarse bed material composition used here, in conjunction with equilibrium bed load transport assumption, results in low sediment input to the study reach. This assumption may underestimate periodic sediment pulses from events, e.g. the 2009 Nile Landslide. As such, the current model setup likely represents a lower bound for sediment load to the reach, and therefore, is more likely to be conservative in terms of predicting degradation rates.

4.3 Model Limitations

1D morphodynamic modeling of anabranching gravel-bed rivers with erodible bed and banks is limited both by the ability to represent the key processes that govern channel and bar morphology, as well as the inherent limitations of one-dimensional modeling of complex multi-thread systems. As discussed in Section 3.4.2, bed load is typically mobilized from eroding banks, transported a short distance (on the order of a typical meander bend) downstream, and deposited locally in bars which may eventually stabilize in the form of islands or be incorporated into the floodplain. As a result, there is a linkage between lateral channel instability, bank erosion, and sediment transport; a morphodynamic model cannot explicitly represent these processes. Instead, a morphodynamic model routes bed load from cross section to cross section, based on the computed transport capacity at each section ignoring channel form, lateral sediment inputs from bank erosion and local variations in shear stresses caused by meanders or riffle-pool dynamics. Furthermore, it has been shown that neglect of lateral hydraulic variation in one-dimensional modeling, by use of cross-sectional average values, can result in underestimation of computed sediment transport volumes, particularly at low to moderate flows (Ferguson, 2003; Bertoldi et al, 2009).

In addition to these general modeling limitations, there are others that are specific to the existing HEC-RAS model of the Naches River including:

- Model geometry was constructed from survey and floodplain data that spanned a relatively long time frame and do not always represent present conditions.

- Structures such as Nelson Dam and various diversion structures were represented only approximately in the Corps model using available topo data.

- Data with which to define the inflow sediment transport boundary conditions are unavailable.

Regarding the last item above, the accuracy of morphodynamic model predictions depends on having adequate information to calibrate and validate the model predictions, since there is considerable uncertainty associated with estimating bed load transport rates in coarse gravel-bed rivers. The HEC-RAS model provided by the Corps had limited hydraulic calibration but was essentially un-calibrated in terms of sediment transport modeling.

With appropriate judgement and interpretation, morphodynamic models can still provide insight when evaluating vertical channel changes and the relative magnitude of responses following project implementation. However, it is important to conduct other geomorphic-based analysis to guide and interpret the modeling.

5 HYDRAULIC AND GEOMORPHIC EFFECTS OF PROJECTS

5.1 N-9 Naches Levee Segment Removal

5.1.1 N-9 Existing Hydraulic Conditions

Limited sedimentation is currently occurring in the reach at the N-9 levee. Comparison of the 2001 and 2013 LiDAR showed approximately 1 to 2 feet of aggradation occurred (NHC, 2015 p. 11) on the right bank point bar immediately downstream of the N-9 levee and opposite the N-7 levee. However, the morphology of this bar is likely in a general state of equilibrium, with the transport capacity controlled by confinement between the opposing levee sections. Extreme floods could still produce sediment deposition on the bar, deflecting more of the flow towards the N-7 levee.

Sediment loading to the reach appears to be supply-limited (Montgomery & Buffington, 1997). The 1.2 mile reach upstream of the N-9 levee has been straightened, either through natural processes or anthropogenic actions, and is confined by various river training structures on the left bank and a steep hillside on the right. The resulting channel has likely incised as evidenced by a relative disconnection between the channel and adjacent floodplains with estimated 2-year flood elevations up to 6 feet below the adjacent floodplain (NHC, 2015 pp. 8-9). Observations made during the site visit suggest the channel bed in this reach is, at least, partially armored by boulder sized material, perhaps originating from colluvium on the right bank (NHC, 2015 p. 7). The nearest substantial area of sedimentation is located approximately 2 miles upstream at a large bar complex; although, localized sedimentation is also occurring immediately upstream of the South Naches Diversion structure at RM 14.5-14.7 (NHC, 2015 p. 9). Overall loading to the lower Naches River is influenced by a number of factors including basin geology, flow regulation, forestry practices, and other anthropogenic modifications (e.g. bank stabilization and highway construction). The effect of these factors on sediment loading to the lower Naches River is still unclear (GeoEngineers, 2003; Corps, 2015), but current channel confinement and coarse bed material composition conditions along, and upstream of, the N-9 levee reach suggest loading here is more episodic rather than continuous. As previously noted in Section 4.2.2, supply-limited loading was accounted for in the morphodynamic model setup.

Further downstream (RM 13.5 to 13.7), a major sediment zone has developed by backwater from the South Naches Road Bridge (RM 13.4). The focus of deposition is presently a bar complex located 500 to 1,000 feet above the bridge.

5.1.2 N-9 Project – Initial Effect on River Hydraulics

Removing the N-9 levee segment will reactivate a portion of the right floodplain located across from the Town of Naches and the N-7 levee (Figure 11).

Figure 12 compares the estimated flow on the right overbank, relative to total river discharge, for existing and proposed conditions at RS 74156. For existing conditions, the right overbank flow was computed as that overtopping the lateral weir placed along the crest of the N-9 levee segment. For proposed conditions, with the levee segment removed, flow in the right overbank was computed based on added conveyance to the cross section. Overtopping of the existing N-9 levee begins near the 2-year event along the lowermost portions of the segment, with significant overtopping of the entire segment only occurring at discharge greater than the 50-year event. Under these conditions, with the lower N-9 segment in place, the right floodplain will receive a relatively small proportion of the total flow; less than 10%, for discharges up to the 100-year event. Under the proposed conditions, the proportion of flow in the right floodplain will increase markedly. At river discharges between 5,000 and 6,700 cfs (2-year event), approximately 10-20% of the total flow will be conveyed in the right overbank. At higher discharges the proportion of flow increases to 20-30%. These estimates are computed without inclusion of proposed pilot channels, which would further increase the expected discharges into the right floodplain and potentially activate the bar at discharges less than the 2-year event.

With increased conveyance on the right overbank, the computed flood levels are reduced where the N-9 levee removal occurs and at the head of the N-7 levee. Figure 13 compares the computed 2-, 10-, and 100-year profiles for existing and proposed conditions. Maximum reduction in water level occurs at RS 74156, i.e. the existing constriction between the opposite levee segments. At the 2-year discharge, the maximum reduction is approximately 0.5 feet, but at the 100-year discharge it increases to 2.2 feet. Flood level reductions extend upstream to the limit of the proposed levee removal (RS 74992), but do not propagate further upstream due to the steepness of the river through this reach. It should be noted that the constriction created by the existing N-9 and N-7 levees does create a backwater, but it is relatively localized and extends only 1,000 feet upstream from RS 74156 at flows up to the 100-year discharge. Downstream, more modest reductions occur in the 1,800 foot reach downstream of the N-7 levee head.

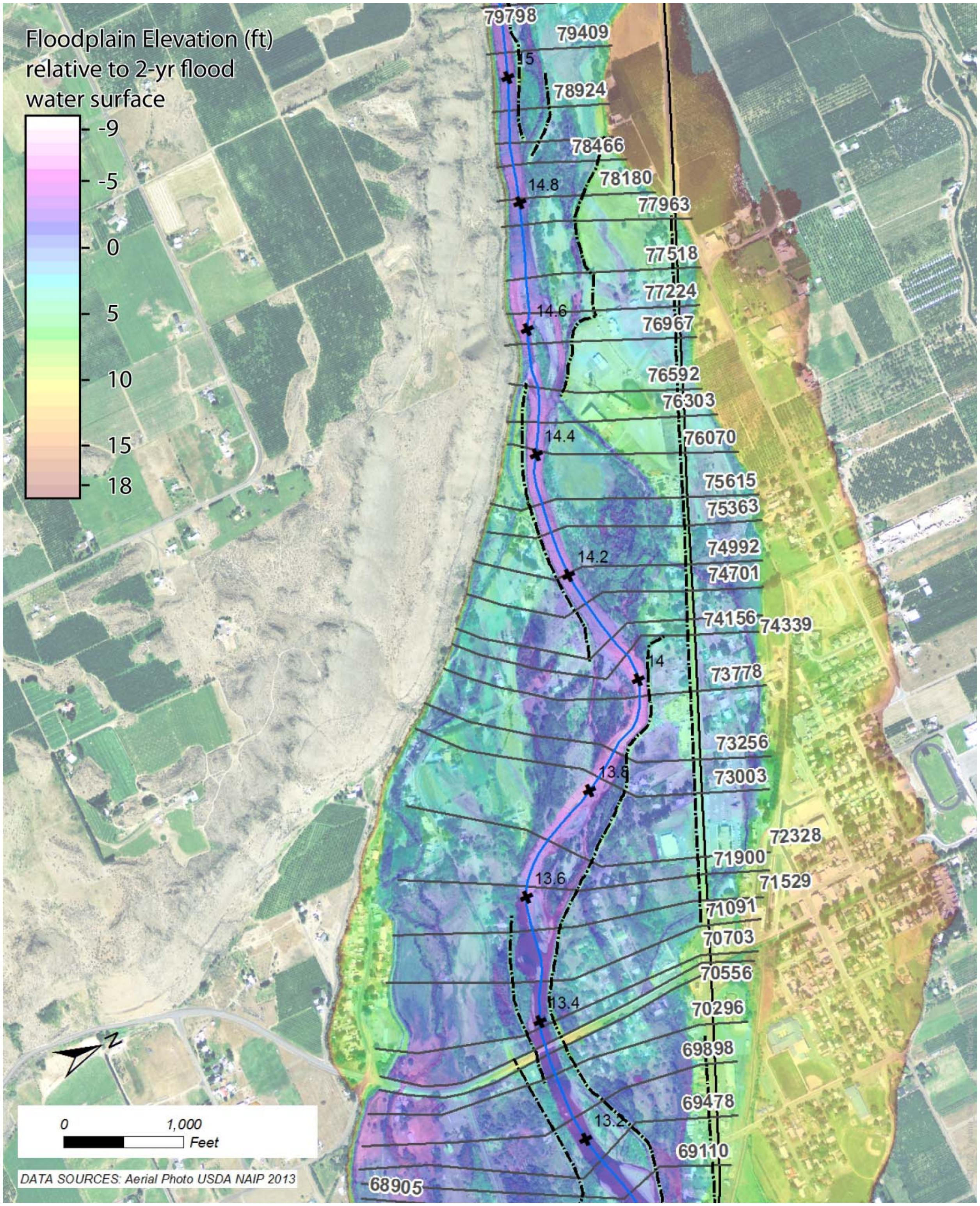

Figure 11: HEC-RAS model cross section locations and height above water surface (HAWS) topographic map along N-9 Levee study reach.

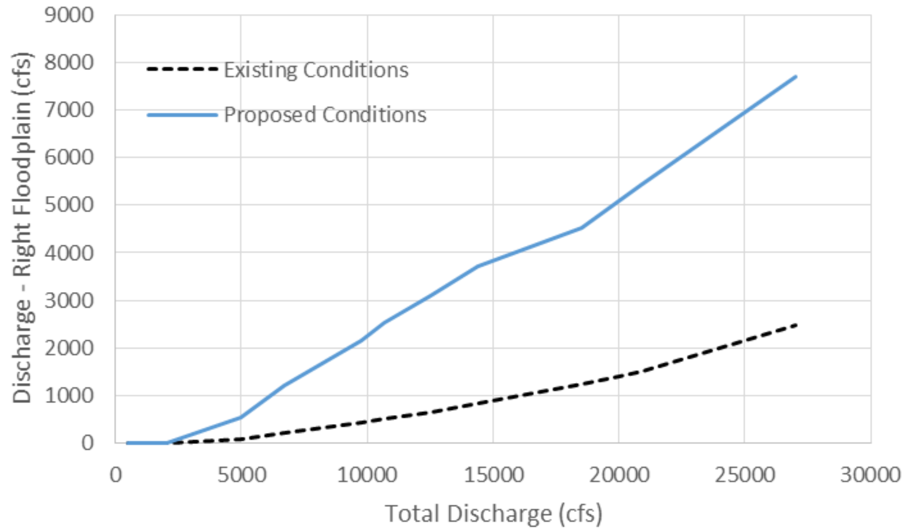

Figure 12: Comparison of estimate flow on right overbank at RS 74156 for existing and proposed conditions.

Overall, with levee removal, the water surface slope through the reach becomes more uniform; however, a slope break is still computed in the vicinity of the levee removal. Upstream average water surface slopes are on the order of 0.0058, but reduce to 0.0048 downstream. This can be explained by the rapid expansion of flow that occurs as a result of the levee removal, which has implications towards sediment transport through the reach.

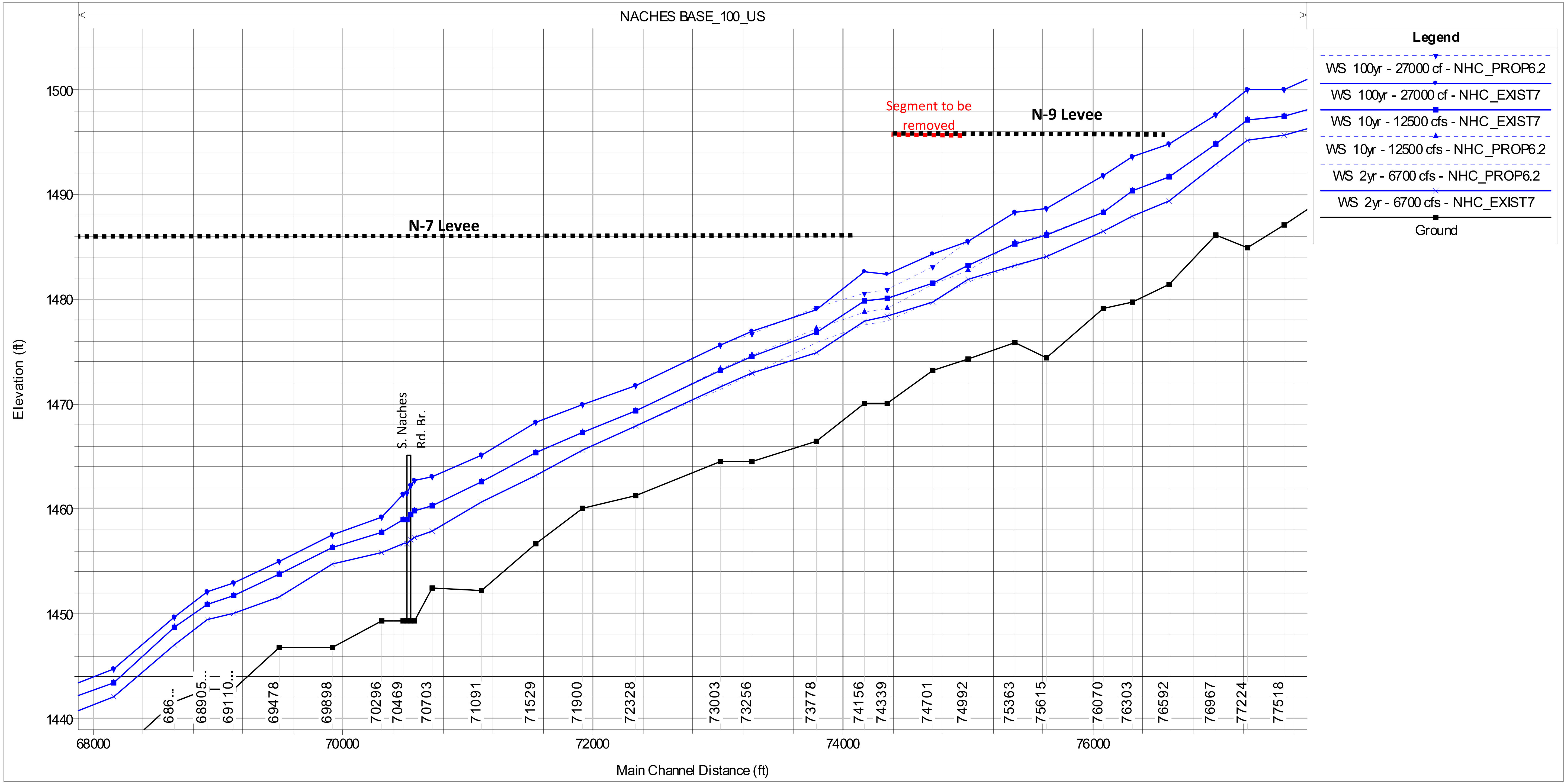

Figure 13: Computed 2-, 10-, and 100-year flood profiles at the N-9 project site for existing and proposed conditions.

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5.1.3 N-9 Project – Initial Effect on River Morphology

Modeling indicated that removal of the N-9 levee segment will lower the average channel shear stress and sediment transport capacity through the reach. Figure 14 shows 2-, 10-, and 50-year average channel shear profiles, computed as a three section running average for existing and proposed conditions. The shear stress required to mobilize 90 mm cobble (the approximate D_{50} particle diameter for the reach), is also shown[5]. Under existing conditions, incipient motion occurs at discharges between the 2- and 10-year flood peak. With the N-9 levee segment removed, a substantial drop in the average channel shear was computed. As a result, transport of cobble sized material, even at a 50-year discharge, is not expected. However, one-dimensional hydraulic computations do not consider the effect of acceleration around a bend, which occurs at this site and can result in locally higher values of shear stress. Based on methods outlined in ISPG (2003), the estimated shear stress in the bend is expected to be 1.65 times higher than that computed by the one-dimensional model. Accounting for this effect, the local shear stresses on the outside of the bend would be competent to mobilize the coarse material following removal of the segment. The reduction in shear stress is expected to reduce potential bank erosion on the left bank at the outer (concave) bank in the bend. Further upstream of the levee segment removal, there is no computed increase in average channel shear, but values remain competent to transport cobble sized particles.

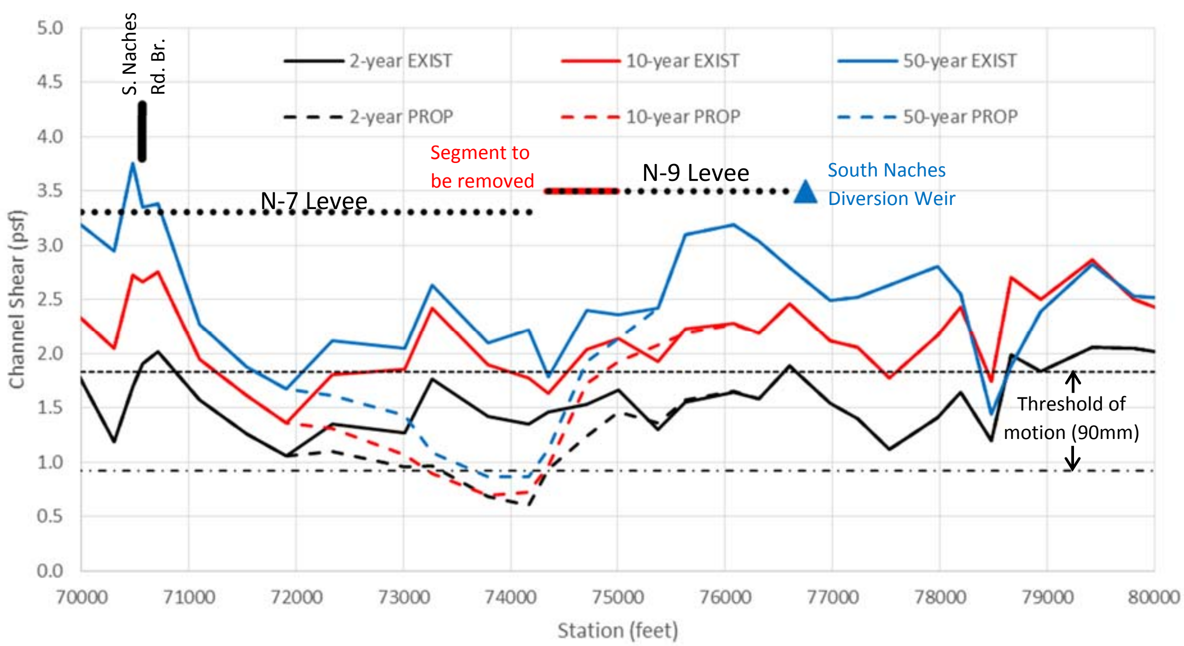

Figure 14: Computed 2-, 10-, and 50-year average channel shear stress profiles for existing and proposed conditions at the N-9 levee. Threshold of motion for a 90 mm particle also shown.

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[5] Incipient motion range calculated using Shield's stress (τ^*_c) values of 0.03 to 0.06 (Corps, 1994).

5.1.4 N-9 Project – Long Term Effect on River Morphology

Figure 15 compares the computed thalweg profiles and net invert changes after 25 year morphodynamic model simulations of existing and proposed project conditions. Under both conditions, a pattern of alternating scour and infill was computed throughout the reach. There was no indication of upstream propagating degradation (e.g. headcutting), nor downstream aggradation, such as in the vicinity of the N-9 segment removal (Figure 14).

Under existing conditions, localized degradation of 1 to 2.5 feet was predicted just upstream of the South Naches Road Bridge and the upstream end of the N-7 levee segment (Figure 15). The upper portion of the N-7 levee has been identified as a high hazards area where overtopping has occurred in the past and damage to the levee has required frequent maintenance. The model supports these observations with computed maximum scour of the thalweg after a 25 year simulation of approximately 1.8 feet. In this section, the flow is concentrated between alternating levee segments through a bend. The simulation of the proposed project condition showed that removal of the N-9 levee segment reduced the scour by almost half. This reduction in scour indicates a reduced level of attack on the upper N-7 levee segment. The 1D model cannot represent the effect of secondary current on scour along the outside of a bend. Therefore, the reduced scour at this site represents only the reduction in average bed shear due to the reduced flow in the main channel. The actual reduction in scour is expected to be greater than the value predicted in the model.

Figure 16 shows the cumulative computed sediment load entering and exiting the N-9 study reach at the upstream and downstream boundaries, respectively. The incoming sediment load is small due to the supply-limited modeling assumption at the upstream boundary. Annualized, the output sediment load from this reach is on the order of 1,000 yd^3/year, which is low, but within the same range estimated using geomorphic methods (Section 3.4.2). The majority of computed sediment transport within the reach coincides with high flow events in November 1995 and February 1996. Comparison of the total output load for existing and proposed conditions showed negligible difference at the end of the 25 year simulation.

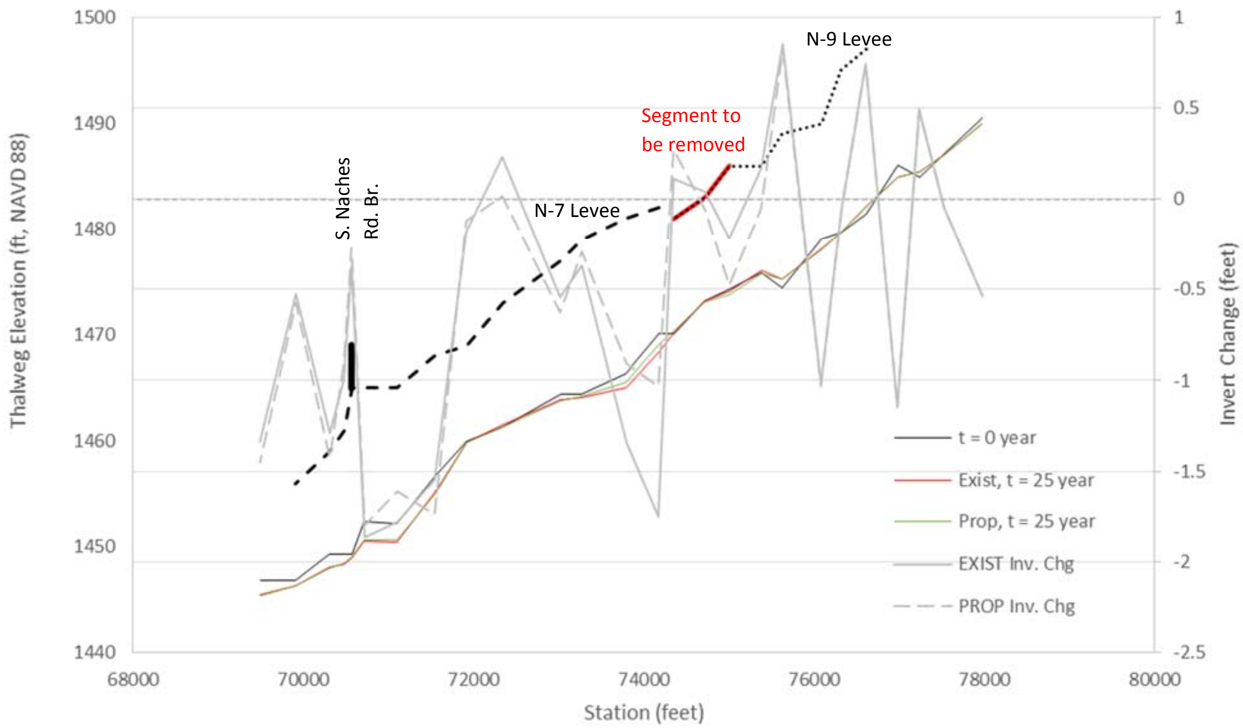

Figure 15: Comparison of computed thalweg profiles and net invert change after a 25 year simulations for existing and proposed conditions at the N-9 levee.

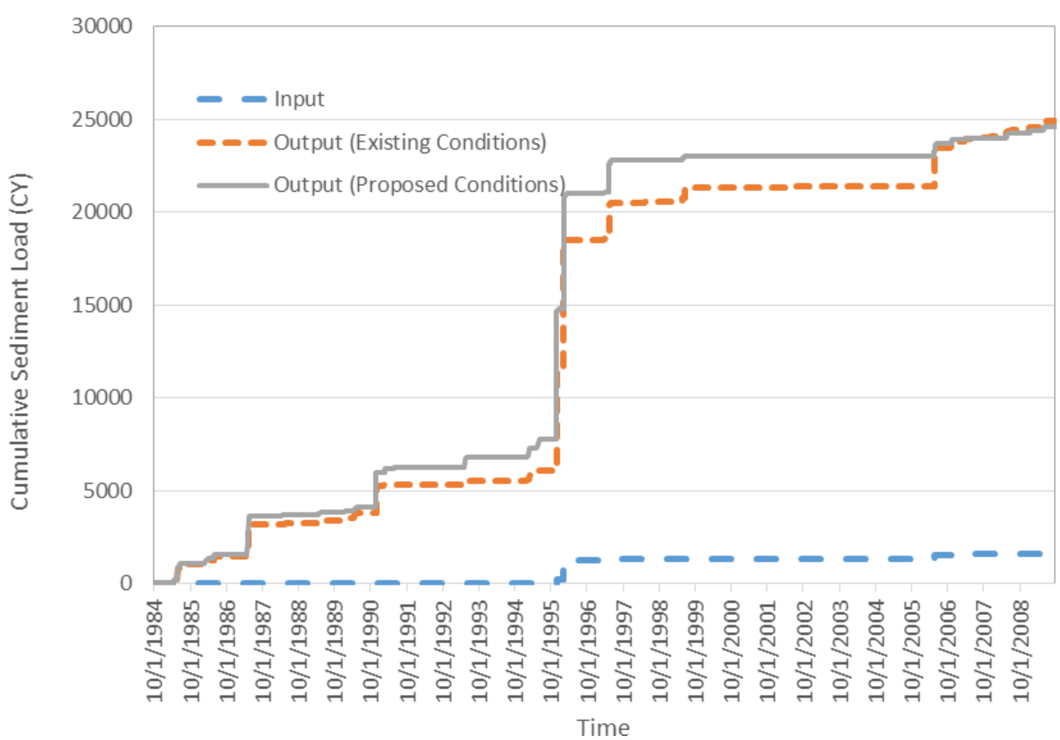

Figure 16: Computed cumulative sediment load entering and exiting the N-9 study reach.

5.1.5 N-9 Project – Geomorphic Assessment (Short and Long Term)

Based on the geomorphic assessment of existing reach conditions, the limited upstream sediment supply and coarse nature of the channel bed material are considered the most important factors with respect to the expected geomorphic response at the N-9 project site. Removing the lower 500 foot segment of the N-9 levee will nearly double the existing channel corridor width, increase flood conveyance, and correspondingly lower water surface elevations and velocities through the reach. These conditions will reduce the shear stress in the bend, particularly along the left bank near the upstream end of the N-7 levee, which should reduce the risk of erosion at the levee.

The new conditions will shift the local shear stress minima from the current depositional zone located approximately 1,500 feet upstream from the South Naches Road Bridge to just downstream of the N-9 levee removal (Figure 14), creating a potential depositional environment for any incoming sediment. However, under present conditions the rate of sediment inflow in this reach is believed to be very low.

Removal of the N-9 levee segment will also result in localized over-steepening of the upstream water surface gradient. Mobile bed simulations utilizing coarse bed material indicate a stable bed upstream of the site. Sensitivity runs using a finer bed composition resulted in approximately 2 feet of degradation extending upstream to the South Naches Diversion structure. However, it is expected this portion of the channel has already adjusted to the presence of the diversion structure over the years, through downstream incision and bed coarsening, thus the risk of further degradation is likely minimal. Regardless, further assessment of bed material composition is recommended at this location to confirm model results and assess channel stability.

Yakima County indicated that consideration was being given to constructing a pilot on the floodplain downstream from the removed levee segment. This concept has not been formally defined at this stage. Construction of pilot channels in the right bank floodplain could mitigate excess deposition in this area. Comparing the length of the potential side channel to the existing channel length through this reach provides a measure of the relative slopes along these paths. The slope ratio for the side channel was estimated to be 1.13, which is high enough that these pilot channels are expected to be stable or enlarge over time, provided the entrance remains open. Development of a stable side channel across this section of the floodplain would further reduce the potential bank attack near the upstream end of the N-7 levee.

5.2 Trout Meadows Floodplain Restoration

5.2.1 N-2 Existing Hydraulic Conditions

This section of river transitions from having a relatively stable, wandering planform in the reach between RM 6.5 and 5.8, but becomes increasingly unstable and more braided in character downstream of RM 5.8. A large slug of sediment has deposited in this reach, driving rapid lateral channel migration and elevating the main channel well above relict channels to either side, particularly in the area of RM 5.5 and 5.2 (NHC, 2015 and Figure 17).

The existing HEC-RAS model of this reach does not predict overbank flow on the left bank upstream of the McCormick levee, even at the 100-year discharge. A comparison between base flood elevations (BFE) shown on effective FEMA mapping and existing model results indicates that the latter are approximately 2 feet lower. The model results are inconsistent with observations from the February 1996 and 2011 flood events when overbank flow flanked the McCormick levee. The estimated return periods for these two floods are 50- and 10-years, respectively. A review of aerial photos prior to and immediately after these events indicates that there is a complex interaction between gravel bar aggradation, vegetation establishment and channel avulsion that has a localized effect on flood levels. These effects may consist of local flow constrictions and redirection towards the left bank, as well as temporal changes in channel roughness. All of these factors can contribute to locally high water surface elevations upstream of the McCormick levee (Figure 18), but are difficult to simulate in a one-dimensional model.

Currently, the channel has a relatively wider corridor, free of dense vegetation, which is represented in the existing model with reduced roughness (Manning's 'n') values. Without knowing if specific changes to localized bed elevations occurred during the 1996 or 2011 events, lower roughness in the flood conveyance corridor may at least partially explain the discrepancy between modeled flood levels and those observed historically. As such, the more conservative roughness values used in the most recent FEMA mapping may better represent flood levels in this reach; however, the Corps model is still useful for evaluating relative project impacts to flood levels.

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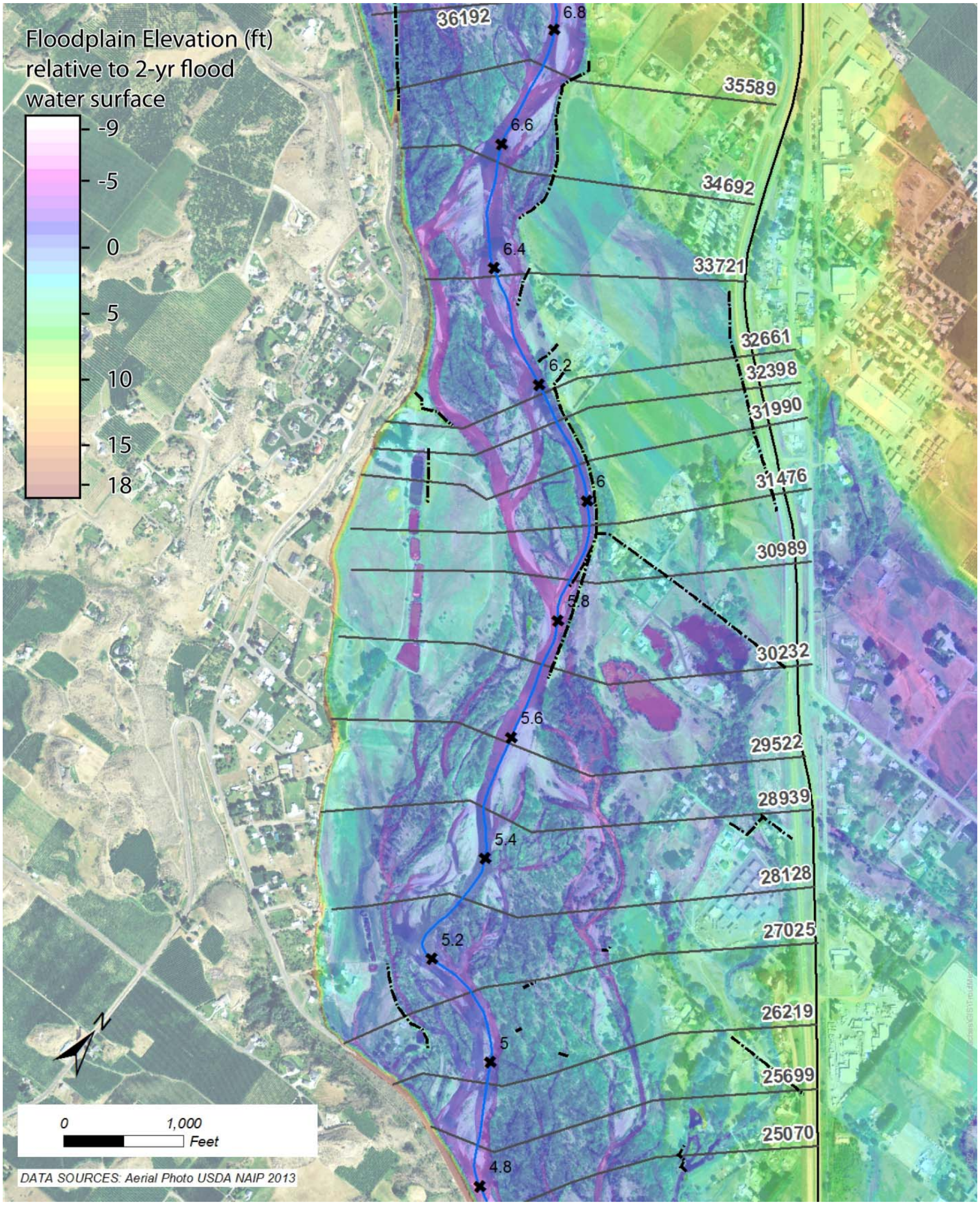

Figure 17: HEC-RAS model cross section locations and height above water surface (HAWS) topographic map along Trout Meadows study reach.

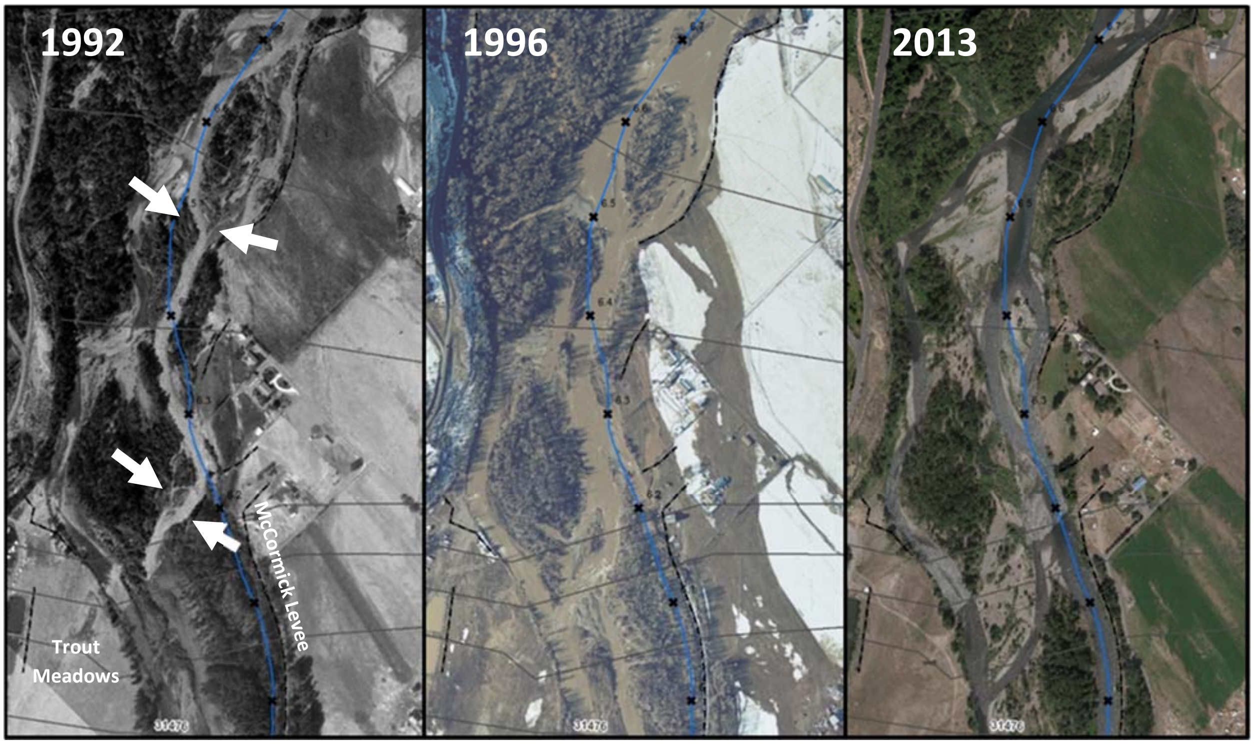

Figure 18: Channel corridor conditions at Trout Meadows in 1992, 1996, and 2013 with estimated pre-1996 pinch points (white arrows) in flood corridor.

5.2.2 N-2 Project – Initial Effect on River Hydraulics

Removal of the Trout Meadows embankment and excavation of a floodplain channel through the existing ponds increases conveyance and reduces flood levels through the reach. Figure 19 compares computed 2-, 10-, and 100-year profiles for existing and proposed conditions at Trout Meadows. Flood level reductions are generally larger in magnitude for the 2- and 10-year flows and occur in the mid- to downstream portion of the Trout Meadows reach (RS 30232 to 31476). Computed reductions here are on the order of 0.5 to 1.5 feet and can be attributed to the increased conveyance provided by the excavated floodplain channel. At 100-year flows, the flood level reduction is approximately 0.5 feet. Upstream of Trout Meadows, computed flood level reductions become more modest, ranging from 0.2 to 0.75 feet, and propagate approximately 2,000 feet upstream. It should be noted that preliminary runs, without the added conveyance of the floodplain channel, indicated limited reductions of the flood levels from 0.2 to 0.5 feet that did not persist upstream of Trout Meadows. This indicates that flood level reductions are primarily a function of added conveyance from an excavated channel, rather than removal of the Trout Meadows embankment which is not surprising given the relatively high elevation of the Trout Meadows floodplain compared to the present channel. Furthermore, it suggests that the current constriction created by the Trout Meadows embankment exerts limited backwater effect, which again is not surprising because the constriction, formed by the left bank levees and the edge of the geomorphic floodplain 1,000 feet upstream is narrower (NHC, 2015 pp. 23 and 35).

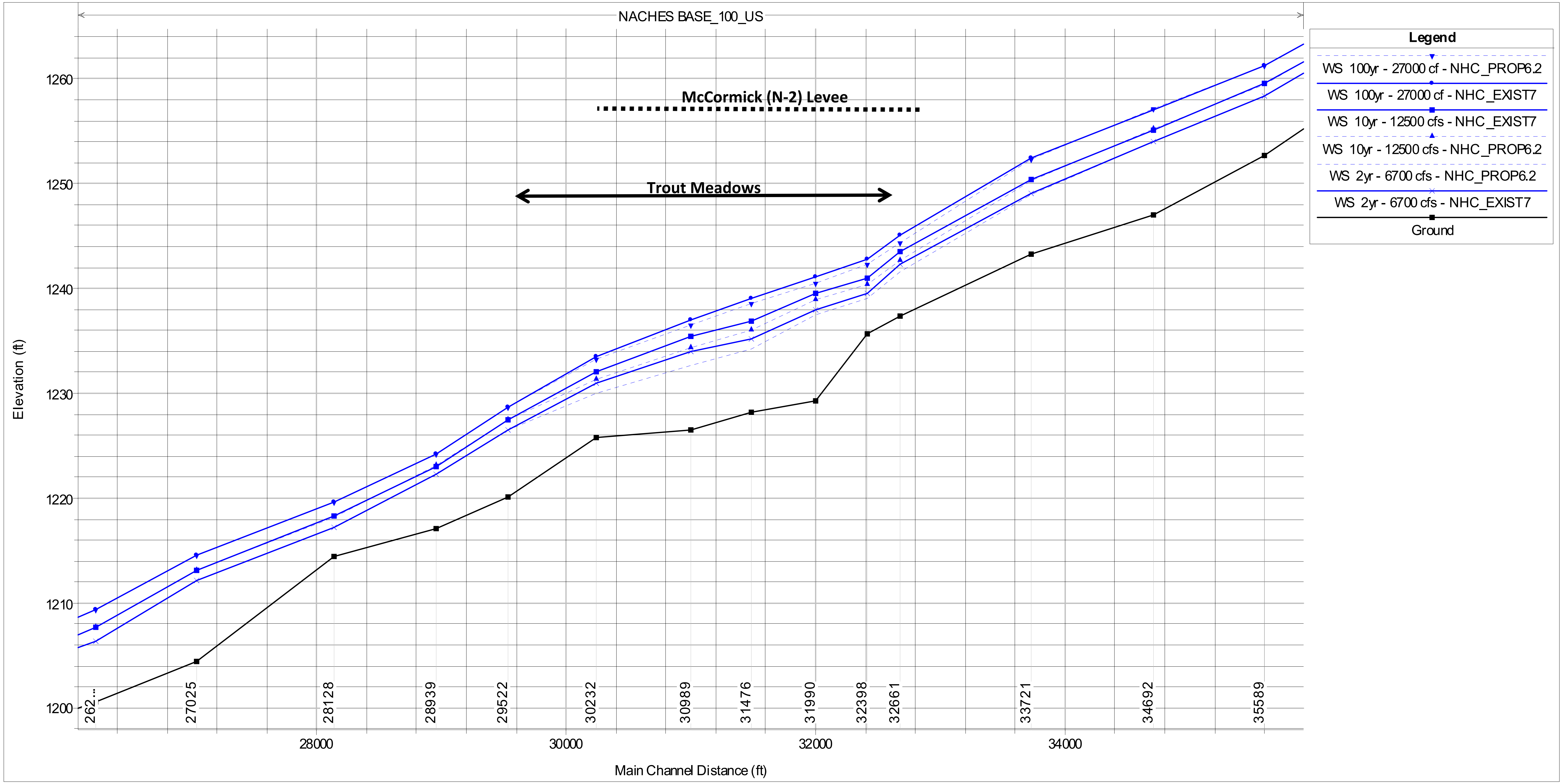

Figure 19: Computed 2-, 10-, and 100-year flood profiles at the Trout Meadows project site for existing and proposed conditions.

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5.2.3 N-2 Project – Initial Effect on River Morphology

Modeling indicated that removal of the embankment and excavation of the channel shows a slight reductions in average channel shear stress in the main channel between RS 29000 and 34000. Figure 20 shows computed 2-, 10-, and 50-year channel shear profiles for existing and proposed conditions, as well as the estimated incipient motion threshold for 64 mm diameter gravel, which corresponds to the approximate D_{50} particle diameter in the reach. Under both existing and proposed conditions, the computed average shear stress is sufficient to mobilize and transport 64 mm diameter sediment through the reach. It is notable that even at the 10-year flood, the average channel shear does not exceed the upper threshold of motion, which indicates the transport rate is low. The variation in average shear stress through the reach is consistent with observations of deposition at the head of the McCormick levee (RS 31000-32000) and downstream past Trout Meadows (RS 28000-29000) and more competent transport conditions in the central portion of the reach.

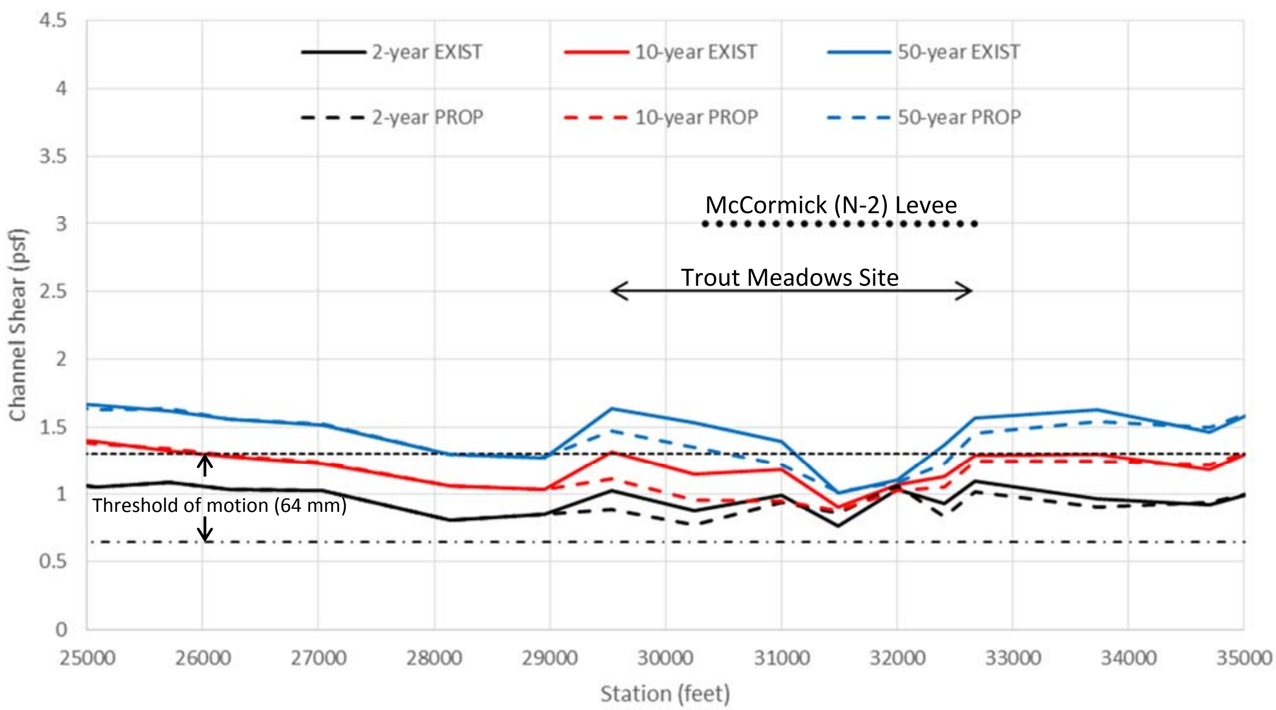

Figure 20: Computed 2-, 10-, and 50-year average channel shear stress profiles for existing and proposed conditions at Trout Meadows. Threshold of motion for a 64 mm particle also shown.

5.2.4 N-2 Project – Long Term Effect on River Morphology

The morphodynamic model simulations of existing and proposed project conditions show only minor differences. Figure 21 compares the computed thalweg profiles and net invert change after a 25 year simulation. The fluctuations in bed change are generally less than 1 foot for both runs; although, under proposed conditions a focus of deposition just exceeding 1 foot shifts upstream approximately 2,000 feet to coincide with the central Trout Meadows reach (RS 31000). Further upstream, relative changes to bed levels are more modest.

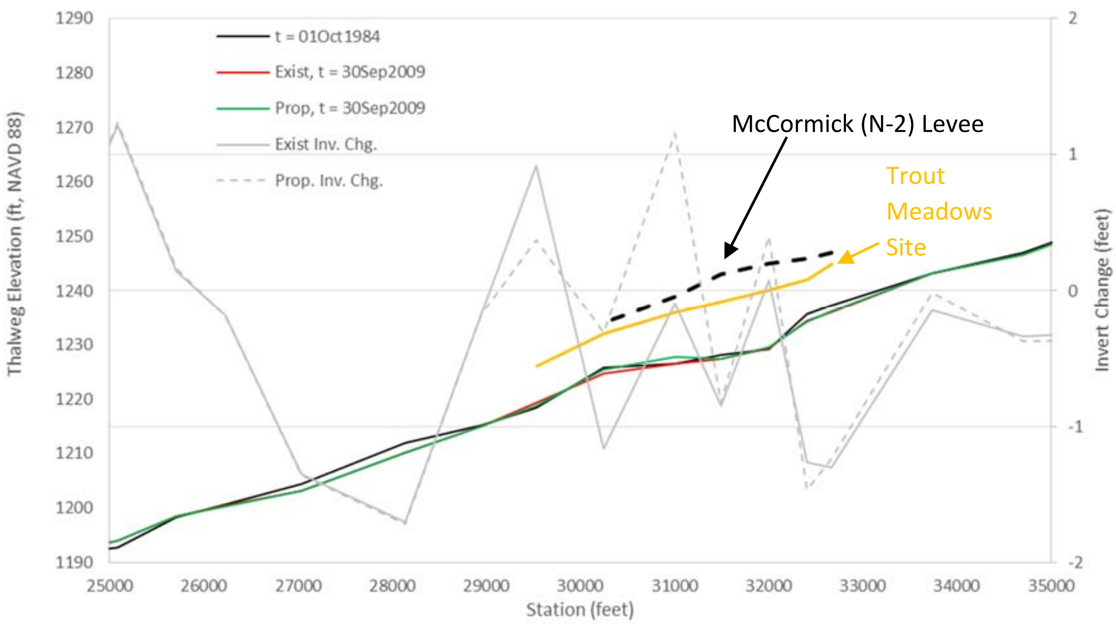

Figure 21: Comparison of computed thalweg profiles and net invert change after a 25 year simulations for existing and proposed conditions at Trout Meadows.

5.2.5 N-2 Project – Geomorphic Assessment (Short and Long Term)

Based on the geomorphic context of the Trout Meadows site and the hydraulic and morphodynamic modeling results, the effects of the project on river morphology are expected to be subtle. This is because the magnitude of the hydraulic changes in the main channel due to the project are relatively small. For example, the average bed shear stress is reduced by about 10%, which is similar to the typical variability within the reach. Local shear-stress minima in the influenced reach and the adjacent areas are relatively unaffected by the project. The section between RS 28000 and 29000 (Figure 20, RM 5.3-5.5 in NHC 2015 p. 23) is experiencing pronounced aggradation at present because the channel is over-widened. At RS 31000 to 32000, low shear can be attributed to the transition between an upstream aggradation and downstream transport reach, with the former likely influenced by adjacent levees and embankments.

The Trout Meadows reach exhibits characteristics most typical of the Naches River given the current hydraulic regime, slope, and bed material (NHC, 2015 p. 22) (Figure 9). Increasing the available active channel corridor at this site may result in a shifting of the corridor's position and a decrease in the proportion of the corridor edge interacting with left bank revetments. Conversely, long-term forcing of the main channel against the McCormick levee could limit engagement of the Trout Meadows floodplain area.

Based on the interpretative geomorphic studies, the proposed pilot channel excavation on the floodplain has the potential to develop a stable, active side channel. The cut-off slope ratio (ratio of existing channel length to side channel length) was estimated to range between 1.05 to 1.12, depending on assumptions about the pilot channel position and which branch of the existing channel network is used for the reference channel length (Figure 10). However, the projected change in discharge in the main channel is significant (30-40% reduction during the 2-year flow), which may cause a nearly proportional reduction in the active channel width, likely through closure of one of the three existing main channel branches in the vicinity of RM 6.0-6.2(Figure 9).

One potentially important effect of the project is a reduction in water levels at the entrance to the left bank avulsion channel at RM 5.6 (Figure 17). This channel formed by a gravel pit capture in the 1970s, and has progressively shrunk over the past decades. Flow through a constructed Trout Meadows side channel would slightly reduce the amount of flow conveyed through the left bank channel. Initially, impacts on conveyance through the left bank avulsion channel during large floods would be small (~5% reduction). However, impacts on the channel-forming flow in this channel would be significant (~20% reduction at the 2-year), which may accelerate channel closure and establishment of vegetation, increasing roughness and reducing channel dimensions, and conveyance capacity through time. These influences may ultimately much reduce the proportion of the flow conveyed by this channel during large floods, with potential flood reduction benefits downstream in the vicinity of Rambler's Park (see next section).

5.3 N-1 Naches Levee Setback – Rambler's Phase II

5.3.1 N-1 Existing Hydraulic Conditions

Hydraulic conditions in the Rambler's Park reach are primarily controlled by the 200 foot constriction created by Nelson Dam and the former Power House Road bridge abutment at the downstream limit of the Rambler's Park levee complex at RM 3.8. Backwater effects from this constriction propagate 500 to 1,500 feet upstream of Nelson Dam during high flood flows (approximately to cross section 21137 on Figure 22 and Figure 23).

Flanking of the uppermost portions of the Rambler's Park levee appear to be more a function of an upstream avulsion rather than sediment deposition triggered by the downstream constriction at the dam. The avulsion path, located along the left floodplain between RM 4.4 and 5.7 (Figure 23), was originally initiated by capture of a gravel mining pit at RM 5.7 in the late 1970's or early 1980's. In the 15 year period following pit capture, the Naches River main channel appears to have followed the avulsion path. During the 1996 flood event, a substantial amount of flow was routed down the left avulsion channel, but also initiated an avulsion back toward the right bank. The N-1 levee on the left bank was flanked during this flood resulting in wide-scale property damage at this location, and a 600 foot levee extension upstream. Since 1996, the main channel of the Naches has followed this right alignment through reach, but the left avulsion path has remained active during higher flow events. With relatively infrequent flows, vegetative encroachment and sediment deposition have constricted the left avulsion path, but relatively clear conditions at the head of the channel, just downstream of the McCormick levee, mean it still receives substantial flow. In 2011, during a 10-year flood the elevations at the upstream terminus of N-1 extended were 0.4 feet from overtopping. The substantial flow combined with constricted conditions likely explain the frequent outflanking that currently occurs at Rambler's Park.

5.3.2 N-1 Project – Initial Effect on River Hydraulics

Setback of the N-1 Levee at Rambler's Park reduces flood levels through the reach by widening the existing 300 to 900 foot channel corridor an additional 300 to 450 feet. The realignment at the upstream end will reduce the potential for flanking by setting back the levee away from the current active channel.

Figure 22 compares computed 2-, 10-, and 100-year profiles for existing and proposed conditions. The Phase I setback, completed in 2013 between RS 20277 and 21755, accounts for the most substantial 100-year flood level reduction of approximately 1.5 feet. Flood level reductions associated with the proposed Phase II setback, between RS 21755 and 23724 are on the order of 0.5 feet for the 100-year flood condition. However, the realignment at the upstream end will reduce the potential for flanking by setting back the levee away from the current active channel. The Phase I and Phase II project reduces the 100-year flood level over a total distance of approximately 4,500 feet. The Phase II project reduces flood levels over a distance of 2,200 feet. Due to the relatively steep slope of the river, the water level changes do not extend past the upstream end of the Project.

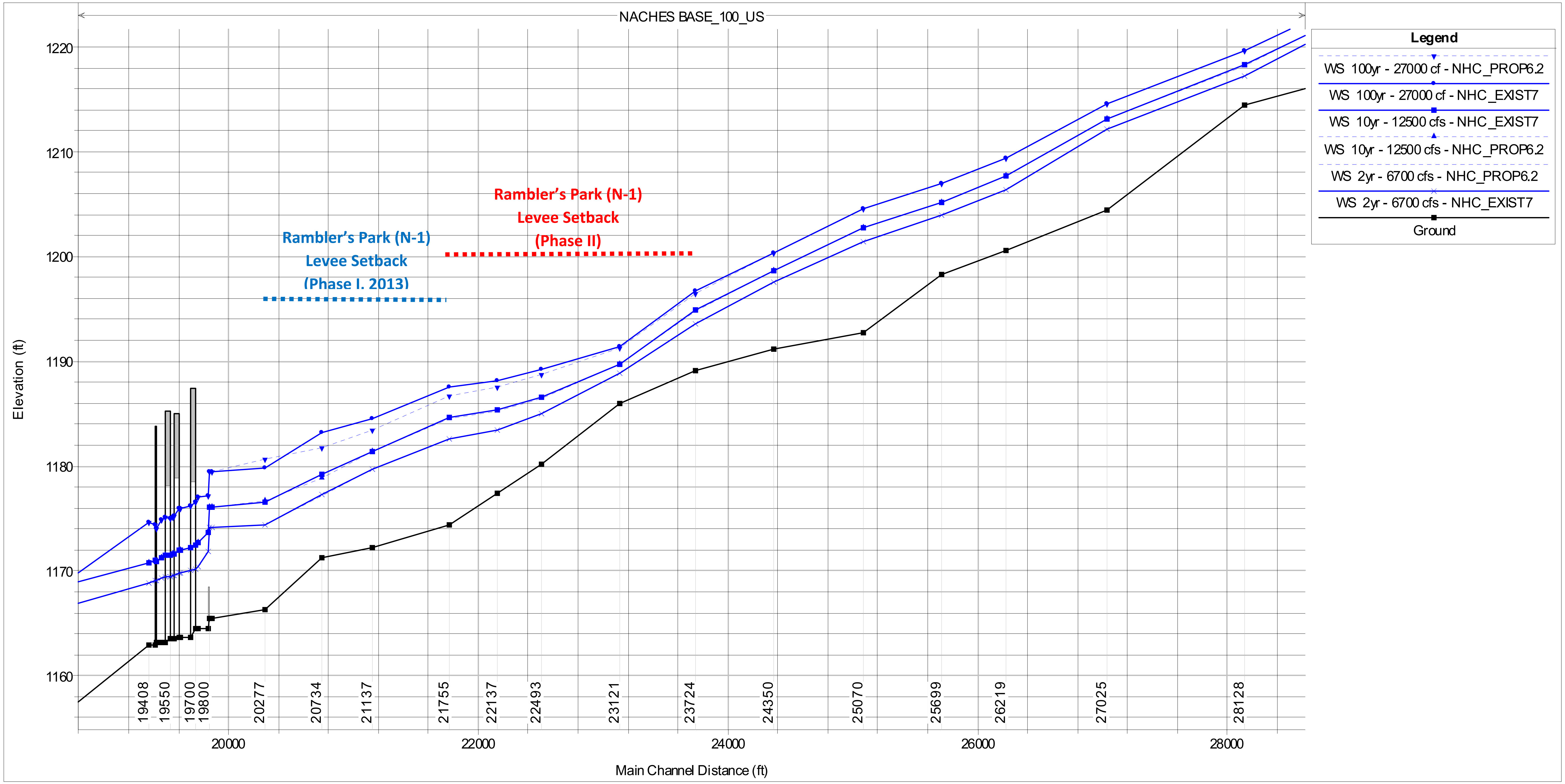

Figure 22: Computed 2-, 10-, and 100-year flood profiles at the Rambler's Park project site for existing (pre-2013) and proposed conditions.

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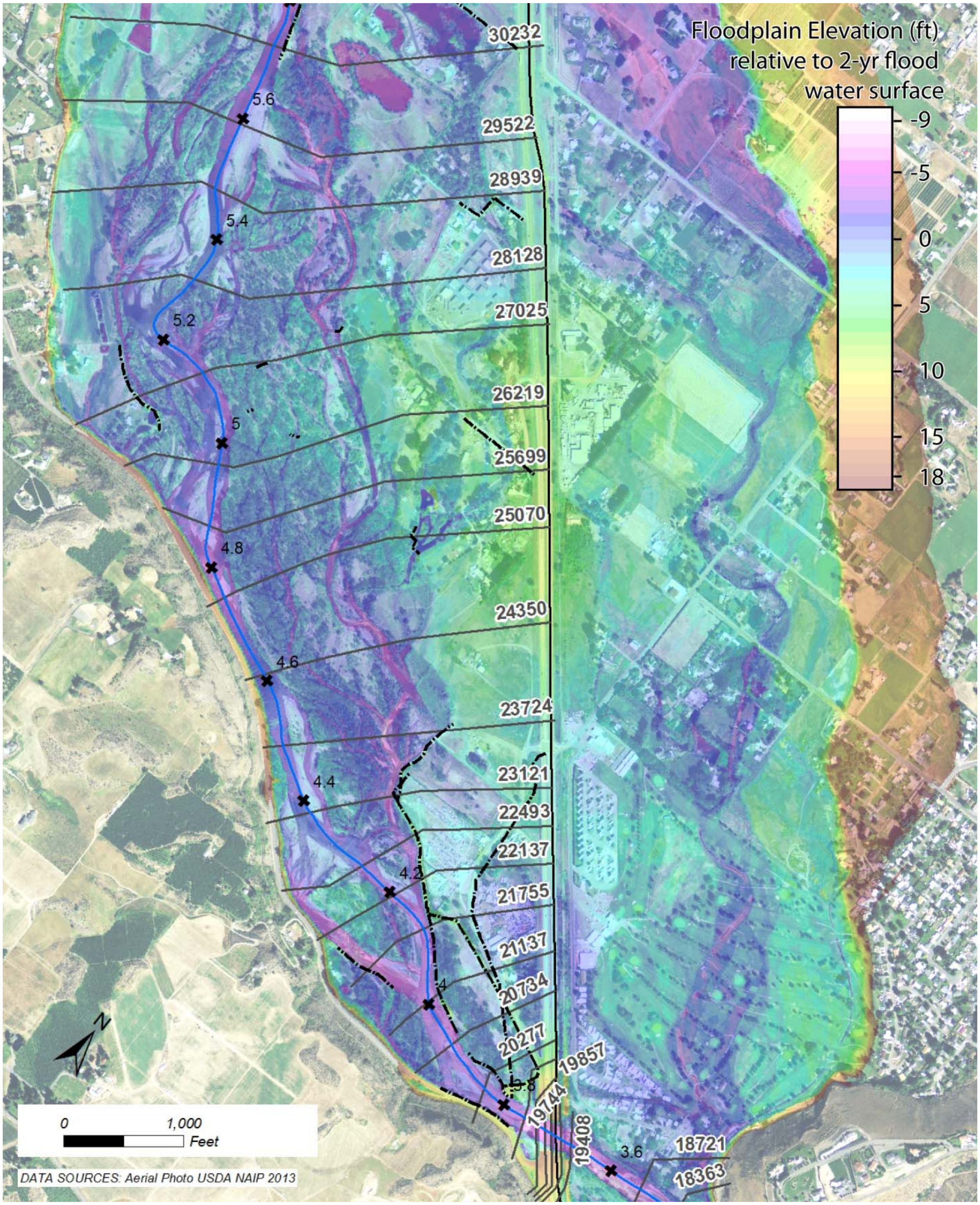

Figure 23: HEC-RAS model cross-section locations and height above water surface (HAWS) topographic map along Rambler's Park study reach.

5.3.3 N-1 Project – Initial Effect on River Morphology

Figure 24 shows the computed 2-, 10-, and 50-year bed shear stress for the existing and proposed conditions, as well as the incipient motion threshold for 64 mm diameter gravel, which corresponds to the approximate D_{50} bed material size in the reach. For both existing and proposed conditions, the average bed shear stress is capable of transporting the coarse bed material between the 2- and 50-year discharges.

A distinct shear stress minima occurs in the profiles just downstream of Nelson Dam (near RS 19700 on Figure 23). This apparent reduction is due to the low energy gradient computed in the scour pool below the dam and reflects the limitations of the one-dimensional model, which cannot represent the complex three-dimensional flow conditions in the scour pool.

A persistent peak in average channel shear stress occurs in the constricted reach immediately upstream of Nelson Dam (near RS 20734 on Figure 23). The project reduces the shear stress here, during high magnitude events (50-year and 100-year) when the hydraulic effect of the constriction is most pronounced. The magnitude of the reduction is approximately 0.3 psf at the 100-year flood, representing a 12% reduction in the peak value. Further upstream, at the top of the N-1 levee, the shear stress reductions are of a similar magnitude. The channel remains competent to transport large gravel under both existing and proposed project conditions.

The average bed shear stress drops appreciably at RS 22137 (RM 4.2), for both existing and proposed conditions. This decrease in stream competence is a result of localized backwater and corresponding low energy gradient computed between the N-1 levee and a private embankment on the right bank located just downstream (Figure 7). The embankment still constricts flows during events greater than the 2-year return period. The presence of a persistent mid channel bar just upstream that has maintained itself through the aerial photo record (NHC, 2015 pp. 24-25) is likely an effect of this constriction. Comparison of the shear stresses computed for existing and proposed conditions indicates that set-back of the N-1 levee *alone* will have limited impacts to the mid channel bar. However, this neglects the influence of two-dimensional processes, such as lateral channel migration following levee set-back. With a broader corridor available, channel migration could potentially activate the bar resulting increased sediment loading downstream. This process cannot be represented in a one-dimensional model.

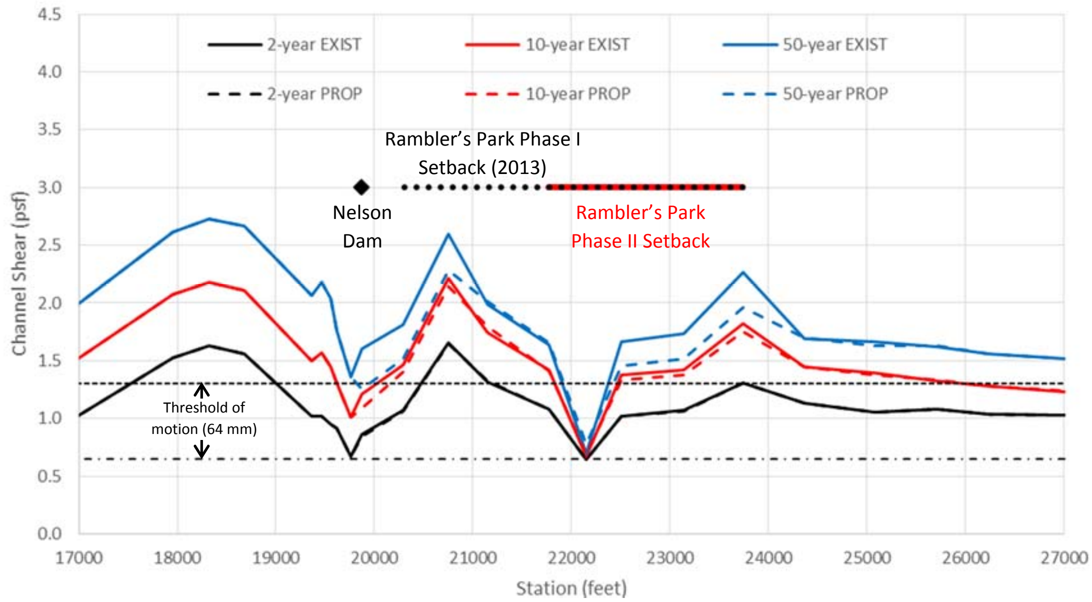

Figure 24: Computed 2-, 10-, and 50-year average channel shear stress profiles for existing and proposed conditions at Rambler's Park. Threshold of motion for a 64 mm particle also shown.

5.3.4 N-1 Project – Long Term Effect on River Morphology

Figure 25 shows the predicted bed profiles from the morphodynamic modeling of the Rambler's Park reach after 25 years. Under existing conditions, the model predicted an alternating pattern of scour and fill, with aggradation of 0.5 to 1 feet immediately upstream of Nelson Dam and bed lowering of 1 to 2 feet further upstream. The simulated proposed condition patterns are similar, with relative differences in bed levels being negligible. This suggests that the levee setbacks will have limited impact on sediment transport through the reach; however, the processes in this reach are highly two-dimensional and not represented well by the current one-dimensional model.

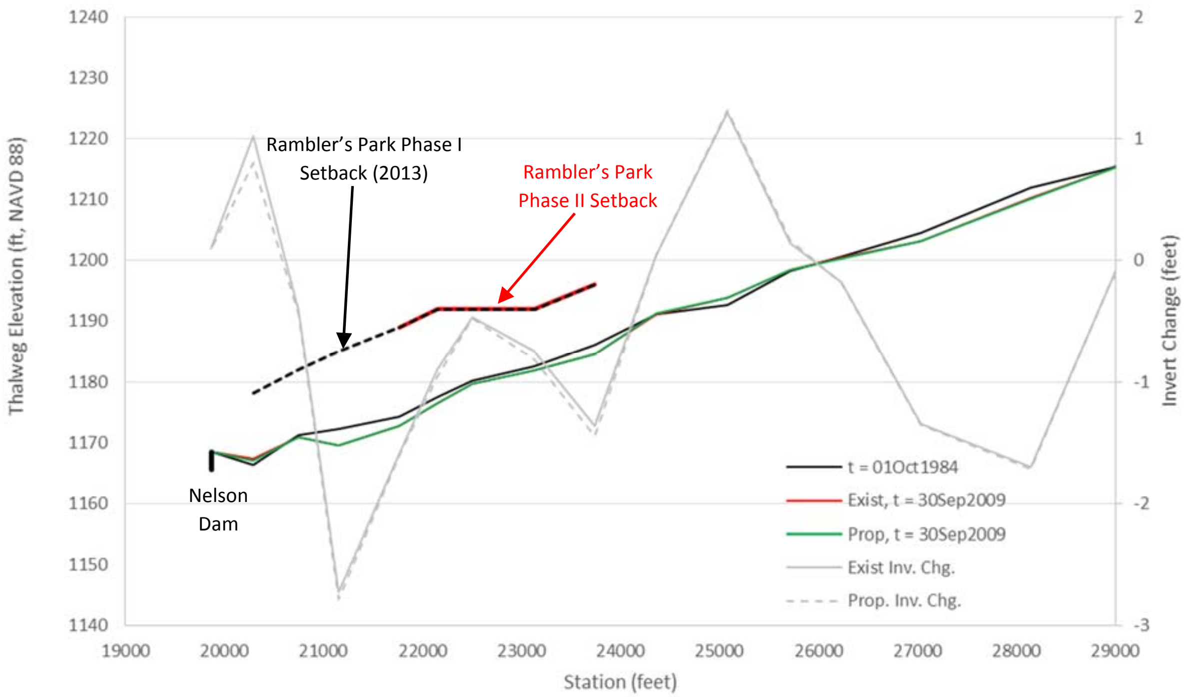

Figure 25: Comparison of computed thalweg profiles and net invert change after a 25 year simulation for existing and proposed conditions at Rambler's Park.

Figure 26 shows the cumulative computed sediment load entering and exiting the combined Trout Meadows-Rambler's Park study reach (RS 39626 to 19857). The cumulative load computed as entering the reach over a 25 year simulation is approximately 68,000 yd^3, which annualizes to 2,700 yd^3/yr. This value is consistent with average annual load estimated through direct measurement and morphologic based methods (Section 3.4.2,Table 2). The cumulative load exiting the reach is approximately half of the volume entering upstream (35,000 yd^3), suggesting net deposition is occurring. Furthermore, simulations with the combined Trout Meadows-Ramber Park projects showed the cumulative sediment volume exiting the reach was virtually unchanged. These findings indicate that the proposed projects at Trout Meadows and Rambler's Park will have limited impact to sediment loading downstream of Nelson Dam, from which it can be inferred that loading to the Yakima River further downstream will be unaffected.

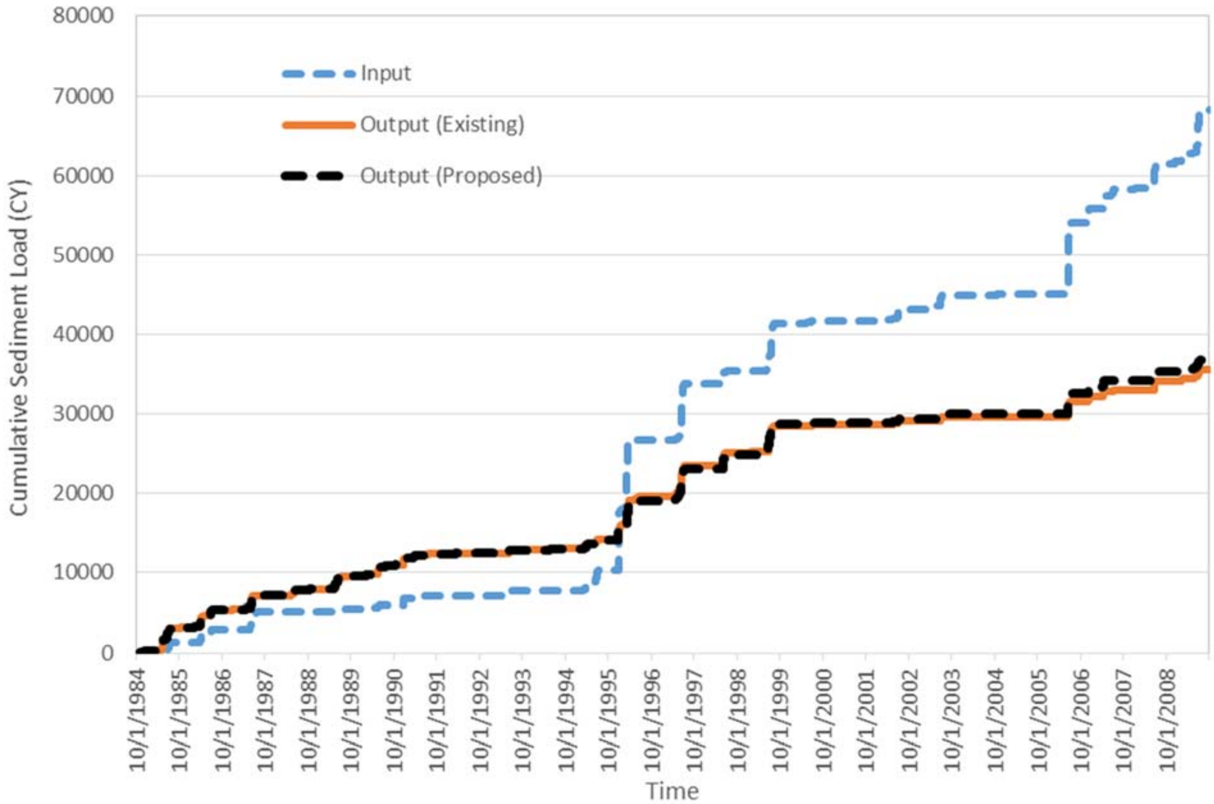

Figure 26: Computed cumulative sediment load entering and exiting Trout Meadows-Rambler's Park reach.

5.3.5 N-1 Project – Geomorphic Assessment (Short and Long Term)

Based on the geomorphic assessment of existing reach conditions the dominant geomorphic control in this reach remains to be the constriction and grade control created by Nelson Dam, downstream bridges, and associated infrastructure. Neither the magnitude nor position of shear stress minima in the reach change as a result of the modeled project geometry. As such, the influence of the project on patterns of sediment deposition and transfer is expected to be small and sediment loading to the Yakima River is not expected to be significantly altered relative to existing conditions.

Model results and theoretical calculations suggest that the backwater influence and aggradation caused by the Nelson Dam grade control and constriction extends, at the most, 1,000 to 2,000 feet upstream. The presence of a break in slope and persistent avulsion node at RM 4.35 suggests this may be the limit of that influence. It is possible that the Rambler's Park levee setbacks would have an important effect in concert with modifications to Nelson Dam and associated infrastructure, but understanding those effects would require further detailed study.

6 SUMMARY AND CONCLUSIONS

6.1 Basis of Findings

This study extends the preliminary geomorphic and numerical modeling work that was conducted by the Corps in a previous phase of the project (Corps, 2015). The Corps' geomorphic investigations included an overview of the physiography, geology, and hydrology of the basin, a discussion of upstream sediment sources from landslides, a review of available bed sediment data collected previously by Yakima County, and a preliminary reach classification of the river. The Corps developed a 1D HEC-RAS morphodynamic model of the Naches River from the mouth of the Yakima River to the confluence with the Tieton River. Although sensitivity testing was carried out, formal calibration or validation was not performed on the morphodynamic sediment transport components of the model; although, refinements based on field observations and sampling were made to increase confidence in predictive capabilities.

NHC conducted field studies including site inspections and bed material sampling along an 18 mile reach of the Naches River. Interpretative geomorphic studies were carried out, including a detailed analysis of historic changes, identification and classification of morphological features, and an interpretation of the main factors that have driven morphologic changes in each reach. The results of this assessment were submitted separately in the form of a Geomorphic Atlas (NHC, 2015) and were used in parallel with this present report.

NHC reviewed and improved the Corps' HEC-RAS model, particularly in representing the bed material and refining the hydraulic model in the vicinity of the three project sites. The model was considered suitable for planning purposes. NHC conducted 25 year morphodynamic simulations of "existing" and "proposed" conditions at each of the three project sites. Further development could be carried out to identify risk for project design where critical issues are identified through sensitivity analyses. An initial risk assessment of this type was provided, herein, at N-9 Levee Segment Removal site.

The proposed levee setback and levee removal project concepts and plans were based on information provided by Yakima County (2015).

6.2 Principal Results

6.2.1 Channel Processes

Migration of the lower Naches River occurs through two dominant processes – gradual meander bend shifting and abrupt avulsion. Observed lateral migration rates along the lower Naches vary dramatically between reaches, from near zero in channelized reaches with armored banks to 20-60 feet/year in unstable areas. On the lower Naches, avulsions typically occur after meander amplification has lengthened the course of the main channel and reduced its slope to the point where a large volume of flow escapes the channel during floods, crosses the floodplain, and excavates a shorter, more hydraulically efficient path.

Gravel bed load is typically mobilized from eroding banks, transported a short distance downstream (1-2 meander wavelengths or 1-2 times the distance between major bars), and then deposited locally in bars. These bars then often stabilize with vegetation and become floodplain until the channel again — perhaps after decades or centuries— migrates into that position, erodes the material and passes it to bars downstream. One-dimensional morphodynamic models compute the bed load transport capacity at each cross section using the average hydraulic properties and then estimate deposition or scour by comparing the difference in sediment volume entering and exiting a control volume. As such, one-dimensional morphodynamic modeling provide limited insight into the linked sediment transfer processes described above.

The annual bed load transport rate of the Naches River was estimated from morphological methods and from previous bed load measurements and sediment transport computations by Hilldale and Godaire (2010). Based on this information, the gravel bed load component was estimated to range between 2,000 to 3,000 cubic yards/year.

6.2.2 Project Effects

The project effects were assessed using a combination of methods including HEC-RAS hydraulic modeling, HEC-RAS morphodynamic modeling and the interpretive geomorphic methods. Results of this assessment are summarized below in Table 4. This table separates the effects in terms of the initial hydraulic effects and the subsequent morphological effects which are expected to occur over a period of approximately 25 years. The actual time frame for morphological effects will be strongly dependent on the pattern of flood flows that occur in the future. Large floods are expected to accelerate the changes. The effects of other major perturbations such as changes in upstream sediment supply or upstream channel instability are not considered in this assessment.

Table 4: Summary of project effects

Project	Initial Hydraulic Response	25 year Morphological Response
N-9 Levee Segment Removal	(1) Under existing conditions the right floodplain conveys less than 10% of the flow at a 100-year flood. After opening the segment, the floodplain flow will increase to 20-30% at the 100-year flood. (2) Flood levels reduced 0.5 feet at 2-year flood and 2.2 feet at 100-year flood. Region of water level lowering extends 1,200 feet. (3) Reduced shear stress in meander bend near upstream end of N-7 levee.	(1) Potential reactivated side channel on right floodplain. (2) Reduced scour and bank erosion near upstream end of N-7 levee. (3) Local deposition in main channel due to reduced transport capacity.
Trout Meadows Floodplain Restoration	(1) Flood levels reduced by 0.5 (100-year) to 1.5 feet (2 to 10-year) at Trout Meadows. (2) Flood levels reduced by 0.2 to 0.75 feet upstream of Trout Meadows. Water level reduction extends 2,000 feet at 100-year flood. (3) Average bed shear stress reduced by 10% during 100-year flood in main channel near Trout Meadows.	(1) Active side channel established on right floodplain (assuming a pilot channel is constructed). (2) Reduced degradation in main channel (0.3 to 0.5 feet) over 1,500 foot reach. (3) Reduced water levels in main channel will promote closure of left bank avulsion channel. Could lead to reduction of flood hazards downstream near Rambler's Park.
N-1 Levee Set-back, Ramblers Phase I & II	(1) Phase I & II reduce 100-year flood level by up to 1.5 feet over a distance of 4,000 feet. Phase II alone reduces level by 0.5 feet.	(1) The effect of the project on sediment deposition and transfer is expected to be small due to other controls.

6.3 Conclusions

The proposed levee setback projects will result in localized flood level reductions, as described above in Table 4.

Persistent, reactivated side channels could be developed on the right floodplain at the N-9 Levee Segment Removal Project and Trout Meadows Floodplain Restoration Project.

The computed changes to the sediment transport regime are expected to be generally minor and do not warrant further analyses for risk. The results from the one-dimensional morphodynamic model were limited by the complex, two-dimensional nature of the Naches River. Regardless, from a morphologic standpoint, reactivation of floodplains with levee setback and constructed pilot channels will expose more material available for transport and invariably improve off-channel habitat through diversification.

6.4 Recommendations

6.4.1 Other Work

A layout should be developed for a floodplain pilot channel at the N-9 Levee Segment Removal Project. Criteria for defining preferred side channel characteristics should be established. The pilot channel should be represented in the morphodynamic model to test its effect on flow hydraulics and related bed profile changes. This would require representing the side channel as a new branch in the model network, which is a significant modification to the model.

Further analysis should be conducted prior to project implementation to assess the effect of potential degradation at the South Naches Diversion structure. This would include obtaining information on the design details and current condition of the structure and a review of past maintenance and repairs.

6.4.2 Future Model Development

The Corps provided a number of recommendations for improving the HEC-RAS hydraulic model (Corps, 2015). Some of this work will require substantial upgrading of the model geometry and inclusion of new hydraulic structures. Furthermore, additional analysis to compare the current HEC-RAS model with the FEMA MIKE-11 model may be warranted to investigate differences in computed flood levels.

The Corps also made a number of recommendations for improving the 1D morphodynamic model, particularly conducting bed load measurements to improve estimates of sediment inflows. This would be useful but potentially very difficult to implement effectively. Other approaches, such as morphological-based methods, could be more cost-effective and could also be used for reach-scale validation of the model.

Two-dimensional morphodynamic modeling could improve the representation of local hydraulics and sediment transport conditions in some areas. However, without better data (topography, bed and bank material and bed load inputs) it is unlikely that a two-dimensional model would significantly improve the reliability of the morphodynamic predictions.

6.4.3 Long-term Monitoring

Long-term monitoring programs should be designed and implemented prior to carrying out the three projects. This could involve setting up relatively simple cross section monitoring sites through the project reach, including sections upstream and downstream as controls, photo grid sampling of bar material, and photo documentation from the ground and low level fixed-wing oblique photos. The length of the surveyed reaches should be at least 3,000 feet for the N-9 Levee Segment Removal Project and 6,000 feet each for the Trout Meadows and Rambler's Park Projects.

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APPENDIX A

(GIS ANALYSIS SUMMARY)

The GIS analysis conducted for the geomorphic assessment included the following key elements:

- Qualitative assessment of channel change utilizing the whole set of aerial photos (Table 5).
- Creation of a detrended valley bottom topography map (Jones, 2006) from the 2013 LiDAR (Quantum Spatial, 2014).
- Delineation of the geomorphic floodplain[6] based on historic aerial photos, LiDAR topography and published geological mapping (DNR, 2010).
- Identification of significant anthropogenic floodplain blockages from LiDAR topography. Historical aerial photos were utilized to determine the timing of floodplain blockage construction (and sometimes destruction).
- Delineation of the wetted channel, and sediment bar surfaces for the years 1992, 1996, 2002, and 2013. Corps (2015) manually delineated the channels for 1992, 1996, and 2002. For 2013, wetted channel and sediment bars were defined utilizing a supervised image classification scheme followed by automated generalization to remove small misclassified areas and manual corrections.
- Differencing of the 2001 (Horizons Inc., 2001) and 2013 (Quantum Spatial, 2014) LiDAR datasets to produce a DEM difference map. While the 2013 dataset has dense point coverage, the 2001 dataset has low point density and high uncertainty. The channel water surface and areas under dense floodplain vegetation are particularly uncertain. Change outside of the wetted channel and within the 2002-2013 channel migration zone, as determined by aerial photo mapping, is likely reliable. Change under dense vegetation is uncertain, as is change in areas that were submerged during acquisition of the 2001, 2013, or both LiDAR datasets. Detection of geomorphic change between raster surfaces is a somewhat complex process that depends on the confidence in elevation estimates for each individual raster (e.g. Wheaton et al., 2010). To help address this, the analysis used a simple and conservative method to filter out DEM uncertainty and find areas of "real change." First, all areas with absolute change in magnitude < 30 cm were filtered out based on the assumption that these changes are due to noise in the LiDAR data or due to local agricultural grading. This value was selected as a conservative value slightly higher than the typical errors for the LiDAR bare earth model relative to ground control points. Second, the uncertainty (u) for each DEM cell was defined as:

  $$u = x \tan \alpha \qquad (1)$$

  where x is the DEM cell size and α is the local slope between adjacent grid cells. This approach gives an uncertainty value based on the range of elevations expected to lie within the DEM cell area. Cells were excluded from the analysis when the estimated change was less than the uncertainty for either compared raster, or where the compared area was submerged during both LiDAR acquisitions. The resulting elevation change map, interpreted as suggested above,

[6] The geomorphic floodplain is defined here as the relatively flat area adjacent to the channel system that is low-lying (at approximately the elevation of the river's banks) and displays geomorphic features typical of channel erosion and depositional processes.

shows areas of erosion and deposition and can be used to estimate the relative amount of geomorphic activity at a given location and to indicate the total change in storage component of the sediment budget.

- Centerlines for each wetted channel were created and used to calculated total sinuosity for each segment of the river. Total sinuosity is calculated as the total channel length (including braid branches) divided by the floodplain length, and provides a metric describing braiding intensity for the Naches River.
- Evaluating the channel mapping and overlaying the channel change maps for individual years with each other and the LiDAR change map allows numerous derivative metrics describing the rivers morphodynamics to be calculated. These include: wetted and active channel width, average lateral migration rate, total sinuosity, and volume of sediment eroded and deposited. These were computed for 0.2 mile long segments along the river and plotted to show longitudinal trends.

Comparison of the mapping products and longitudinal geomorphic data with hydraulic and sediment transport model results and field data then provided the basis for interpretation of geomorphic behavior of the river.

Table 5: Aerial photos utilized in Geomorphic Assessment.

Date	Type	Grid Resolution	Rectification Quality*
1927	Black and White Mosaic	3 ft	Poor to moderate
1947	Black and White Mosaic	5 ft	Poor to moderate
1968	Black and White Mosaic	2.5 ft	Moderate
1971	Black and White Mosaic	0.66 ft	Moderate
1981	False Color Infrared	18 ft	Moderate
1992	Black and White Orthophotos	1.5 ft	Good
1996	Color Orthophotos (flown just post-flood)	1 ft	Good
2002	Color Orthophotos	1 ft	Good
2006	Color Orthophotos (NAIP)	3.3 ft	Good
2009	Color Orthophotos (NAIP)	3.3 ft	Good
2011	Color Orthophotos (NAIP)	3.3 ft	Good
2013	Color Orthophotos (NAIP)	3.3 ft	Good
2013	Color Orthophotos	0.5 ft	Good

* Good rectification quality signifies that absolute positions shown in images are correct relative to the scale of river features and geospatial analysis; moderate indicates that images are internally consistent but absolute positions may be wrong, such that extreme caution must be employed when using the image to calculate changes in channel or bar position; poor indicates that images are not necessarily internally consistent, such that caution must be employed when utilizing the image for measurement of features such as channel width.