***NORTH PLATTE RIVER CHOKEPOINT***
***GEOMORPHOLOGY AND SEDIMENT TRANSPORT STUDY***

***Prepared in Support of the***
***Platte River Recovery Implementation Program***

***PREPARED FOR:***

***Platte River Recovery Implementation Program***
***Executive Directors Office***

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RIVER WORKS

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# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF APPENDICES

# EXECUTIVE SUMMARY

The Platte River Recovery Implementation Program (PRRIP or Program) continues efforts to achieve and maintain hydraulic capacity of 3,000 cfs below minor flood stage on the North Platte River near North Platte, NE. Limited hydraulic capacity through this reach, known as the Chokepoint, is a constraint on the ability to deliver water from the Lake McConaughy Environmental Account (EA) to the Program's Associated Habitat Reach (AHR) on the central Platte River downstream between Lexington and Chapman, Nebraska. Flow capacity through the Chokepoint has declined from approximately 10,000 cfs in 1938 to about 1,700 cfs today.

The ACE team conducted a detailed geomorphic and sediment transport assessment of the Chokepoint to identified and described the physical processes that have contributed to the geomorphic evolution of the North Platte River between Lake McConaughy and the Tri-County Canal Diversion structure over the last century with a specific focus on the Chokepoint segment. The assessment also analyzed the changes to the flow and sediment regimes that ultimately led to loss of hydraulic capacity at the Highway 83 Bridge in the Chokepoint segment over the last 20 years. Results of the study were used to predict trends in the future trajectory of the river and inform development of stream modification alternatives. A summary of conclusions from the study is discussed below.

The team's hydrologic analysis indicates that the changing trend in flow variables seem to have reached a general status of equilibrium over the past 20 years. Further, median flows after 1942 do not show remarkable differences to present day. This is not surprising given that median flows reflect baseflows. Average flows after 1942 range from 573 to 601 cfs except during the 1970s and 1980s when average flow was 1,007 cfs. The 1.5-year discharge (1,642 cfs) is also relatively stable between 2000-2022. Minor flood stage for the North Platte River is 6.0 feet, as currently defined by the National Weather Service (NWS), at the North Platte Gage at Highway 83. Capacity is estimated at 5,420 during the late 1980s. Capacity between 1998 and 2023 has fluctuated between 1,570 and 2,165 cfs, with current capacity estimated in 2023 at 1,764 cfs.

We also performed hydraulic modeling and inundation mapping on the North Platte River through the Chokepoint segment. The velocity and shear stress results suggest limited fluctuation in average values between reaches but reveal a decreasing trend in the downstream direction. This indicates minimal if any conveyance problems, such as blockages or constrictions. Incipient motion analysis indicates that bed material is mobilized for all flow conditions including baseflows (~400 cfs) and greater.

Sediment continuity was evaluated to estimate sediment supplied to a reach and sediment exported out of the reach. Measured mass bed changes from 2009 to 2017 and 2017 to 2023 were compared with estimated annual transport and dredging volume. Results do not indicate a strong trend in either aggradation of degradation during either period apart from the depositional zone immediately upstream of the TCCD where dredging is required. It is noted that minimal change in the channel between 2009 and 2023 indicates that the river is generally able to balance sediment supply and transport, even after the 2011 flood event. This is consistent with the stabilization in hydraulic capacity, with some natural fluctuation, as shown by results of hydraulic analyses and specific gage evaluation. This finding is consistent with a quasi-equilibrium condition.

Identifying the geomorphic characteristics and trends through the Chokepoint segment were based on pattern and planform, profile, and geometry. Interpreting the results from those analyses, the ACE team did not find substantial changes in overall geomorphic characteristics over the past twenty years. For example, active channel widths and channel area are stable based on comparison of surveyed cross-sections and hydraulic analyses, which in combination with slowly changing vegetation patterns supports relatively consistent hydraulic conveyance between 1999 and 2020. Further, since 2011, the average bed slope of the Chokepoint segment has remained within the historical range of 0.11% and 0.12%, except for the area between HWY 30 and the TCCD. Depositional impacts related to the TCCD extend much further upstream than backwater, likely due to a slowing and/or blocking of sand bed movement related to backwater conditions and the presence of the structure. This is evident through evaluation and comparison of 1940 and 2009 bed profiles that shows a “sediment wedge” extending from the TCCD upstream to HWY 83 has formed. Comparison of more contemporary bed profile information after 2009 indicates relatively consistent channel bed slopes suggesting that the river profile along the Chokepoint segment will remain within the 0.11 to 0.12% range if present-day flow characteristics and sediment supply relationships remain consistent.

**A key conclusion from the geomorphology and sediment transport study is Lake McConaughy and the TCCD have altered flow and sediment regimes in the Chokepoint segment and appear to be the primary drivers of channel aggradation and the long-term reduction in hydraulic capacity at Highway 83**. While this conclusion is based in part on a comparison of estimated 1940 and 2009 bed profiles that show the formation of the “sediment wedge” extending upstream from the TCCD to roughly HWY 83 (see Figure 1), our quantitative analyses provide multiple lines of evidence to support this conclusion. Further, the analyses demonstrate dramatic changes in processes (low and high flows, sediment transport, etc.) that directly affect form i.e., decreased slope, narrower pattern (braided evolving to single thread), reduced flow area, and increased vegetation, which together lead to reduced shear stress.

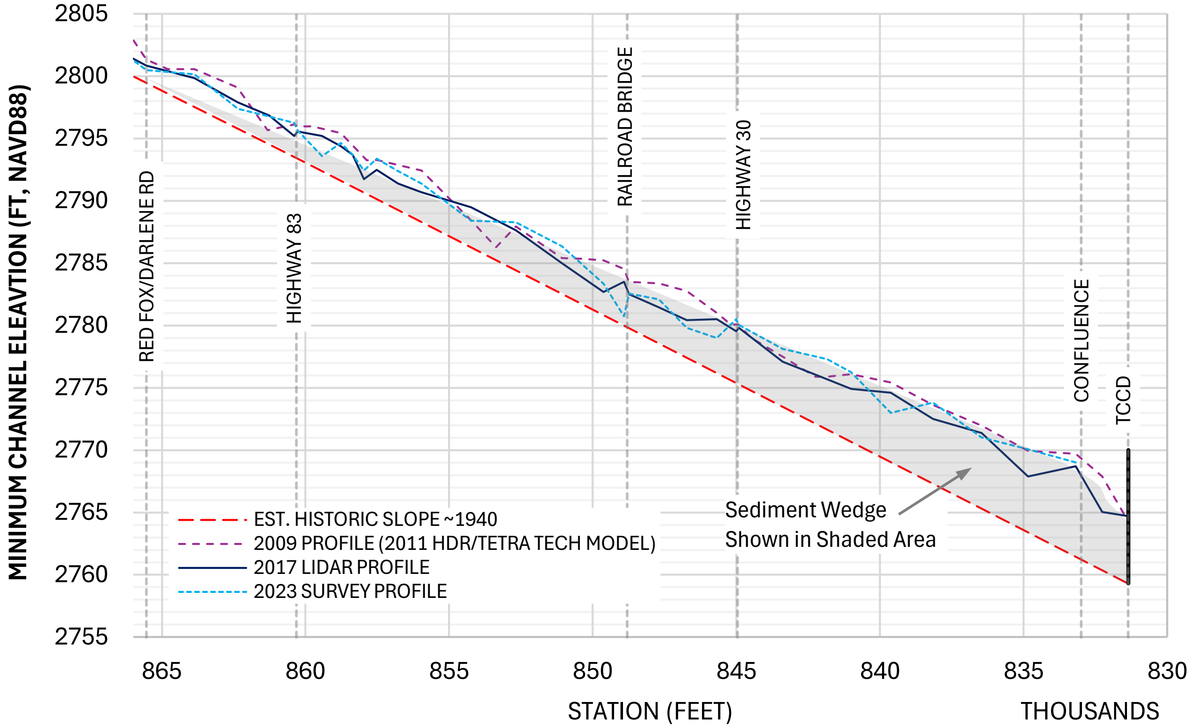



**Figure 1 North Platte River Historic and Contemporary Profile**

**The various analyses in the "North Platte River Chokepoint Geomorphology and Sediment Transport Study" suggest the evolution of the North Platte River through the Chokepoint over the past approximately 20 years has reached a state of quasi-equilibrium.** The conclusion that the Chokepoint segment has reached a general state of quasi-equilibrium is supported by the balance between active channel area and vegetated cover area, which for most reaches, has changed little since the 1980s. Further, the bankfull hydraulic capacity, which tends to correlate with the minor flood stage, appears to have settled into a range between approximately 1,200 and 1,700 cfs upstream of Highway 83 and 1,700 cfs downstream to the TCCD structure. The relatively stable average bed slopes in the Chokepoint segment are also expected to remain in a quasi-equilibrium state assuming flow characteristics and sediment supply trends are consistent with those over the previous 20 years, and dredging operations continue at the TCCD structure. Also, a large, sustained flow event, probably greater than the peak flow and duration of the most recent flood event in 2011, would likely disrupt the quasi-equilibrium state.

# 1 INTRODUCTION

The Platte River Recovery Implementation Program (PRRIP or Program) continues efforts to achieve and maintain hydraulic capacity of 3,000 cfs below minor flood stage on the North Platte River near North Platte, NE. Limited hydraulic capacity through this reach, known as the chokepoint, is a constraint on the ability to deliver water from the Lake McConaughy Environmental Account (EA) to the Program's Associated Habitat Reach (AHR) on the central Platte River downstream between Lexington and Chapman, Nebraska. Flow capacity in this reach has declined from approximately 10,000 cfs in 1938 to about 1,600 cfs today (PRRIP EDO 2021). Previous studies (Lyons and Randle, 1988, Karlinger et al. 1983) summarize those changes: "[t]he quantity of flow and sediment transported along the North Platte River has significantly changed during the 20th Century in response to water resource development, droughts, and floods. These changes in flow and sediment transport influence the river channel width, depth, and the hydraulic capacity along the Chokepoint segment near North Platte, NE."

The Program selected Anderson Consulting Engineers Inc. (ACE) to conduct the current North Platte River Chokepoint Engineering Service Project in May of 2023. The EDO has defined the project goal as identifying and screening alternative solutions to increase hydraulic capacity through the Chokepoint and/or provide delivery of flows downstream of the Chokepoint through other systems. The purpose of this report is to evaluate and summarize the fluvial geomorphology and sediment transport of the North Platte River from the confluence with the South Platte River upstream to Lake McConaughy with emphasis on the Chokepoint segment. The assessment also considers the influence of changes in flow and sediment on the hydraulic conveyance along that segment, focusing on the Chokepoint Reach

This study used a detailed, quantitative engineering and geomorphic analysis approach that included numerical hydraulic and sediment transport modeling. We consider three fluvial geomorphic characteristics – pattern, geometry, and profile – to understand and explain the North Platte River's evolution. The study also investigates the relationship between those characteristics, sediment transport continuity, vegetation, and hydraulic conveyance. The assessment included a field visit in October 2023 and desktop-based analyses leveraging historical aerial imagery, LiDAR, and ground-based survey topography.

The evaluation of temporal and spatial trends in the river corridor geomorphology was based primarily on GIS-based mapping of stream corridor features on historic and modern imagery, and analysis and summary of those datasets. LiDAR data was also used for portions of the assessment, and field observations augment the interpretations.

This study applies multiple lines of evidence to determine trends and draw conclusions. Trends and potential geomorphic changes are critical considerations in evaluating the effects of current hydrologic and sediment regimes on hydraulic capacity through the Chokepoint segment.

# 2 PROJECT LOCATION AND PHYSICAL SETTING

The North Platte River originates in the mountains of northern Colorado, flows northward into central Wyoming, then southeastward to Nebraska. In west-central Nebraska, near the City of North Platte, the river joins the South Platte River to form the Platte River (Figure 2-1). The North Platte River drains 34,900 square miles of Colorado, Wyoming, and western Nebraska. It flows approximately 665 miles from the Rocky Mountains to the confluence with the South Platte River downstream of North Platte, NE. The river once flowed across a broad floodplain in Nebraska, spanning the lowland valley with an active channel width up to 2,000 feet or more.

The North Platte Chokepoint Reach is located near the City of North Platte, Nebraska (Figure 2-2) extending approximately 11 miles upstream from the confluence with the South Platte River.

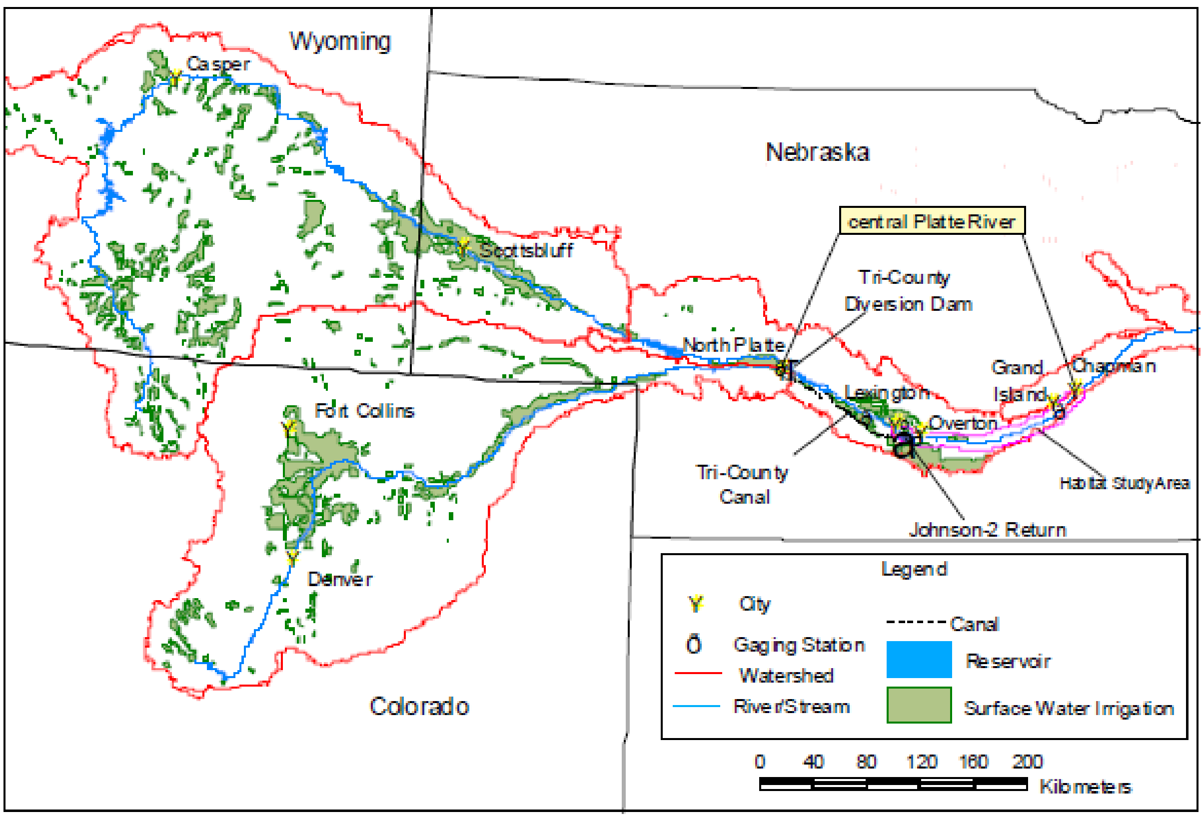



**Figure 2-1 Platte River Basin Location Map (USBR 2004)**

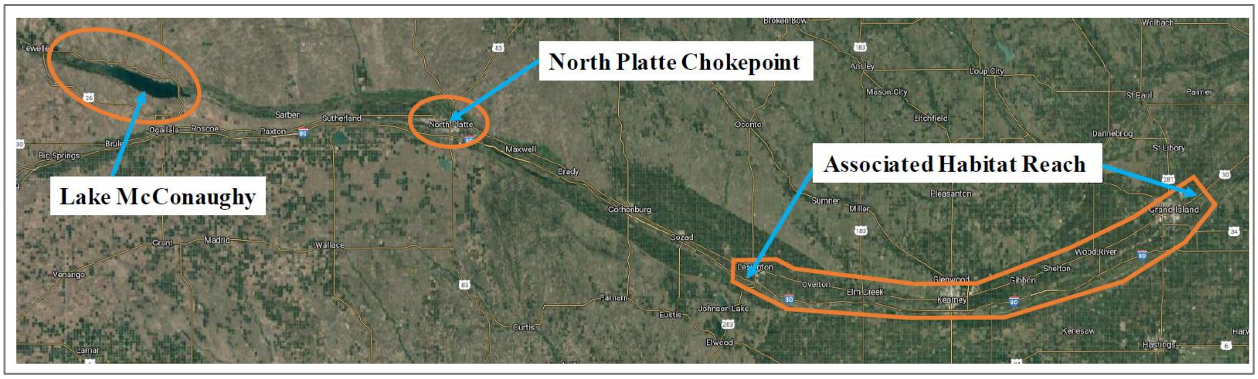



**Figure 2-2 North Platte River**

## 2.1 Physiographic Setting

Physiographic and historic information, such as geology and climate, can be used to assess the geomorphic changes to the river and the processes and trends associated with these changes. The ACE team studied physiographic and historical information with the goal of understanding trends; our study is not a comprehensive historical account but attempts to summarize the factors that may be pertinent to the geomorphology of the North Platte River upstream of the confluence with the South Platte River.

As noted in the *Platte River Channel: History and Restoration* report by the US Bureau of Reclamation (2004), fluvial processes dominate in the central Great Plains region (Hadley and Toy, 1987). In the absence of major impacts from the activities of man, the shape of river channels can be impacted by discharge, vegetation coverage and slope. In the Great Plains region, the shape of river channels is also, at least partially, a function of the sediment load that is transported from the source area (Leopold & Maddock, 1953, Schumm, 1969, Schumm and Meyer, 1979).

*For approximately 40,000 years, in a period pre-dating human development of the Platte River basin, climate has been the dominant extrinsic factor shaping the Platte River through influences on flows, sediment transport and the geologic nature of basin structure. The river has evolved, under climatic influences on flow and sediment transport, through multiple cycles of aggradation, degradation, or relative stability. Climate was the primary influence on the river in the pre-development period, but in the nineteenth century, human activities began to impact the Platte River in addition to the influences of climate* (USBR 2004).

*At the start of the nineteenth century, the aggradational trend in sediment transport (Lugn & Wenzel, 1938, Wenzel, et al., 1946) due to climate factors continues from the pre-development period. The assumption is that the river is moving a large volume of sediment through the system due to its high spring flows, relatively steep gradient, and straight alignment. It can be speculated that in the nineteenth century,* *anthropogenic factors in addition to climate have caused some increase in the sediment load of the Platte River basin* (USBR 2004 pg. 22).

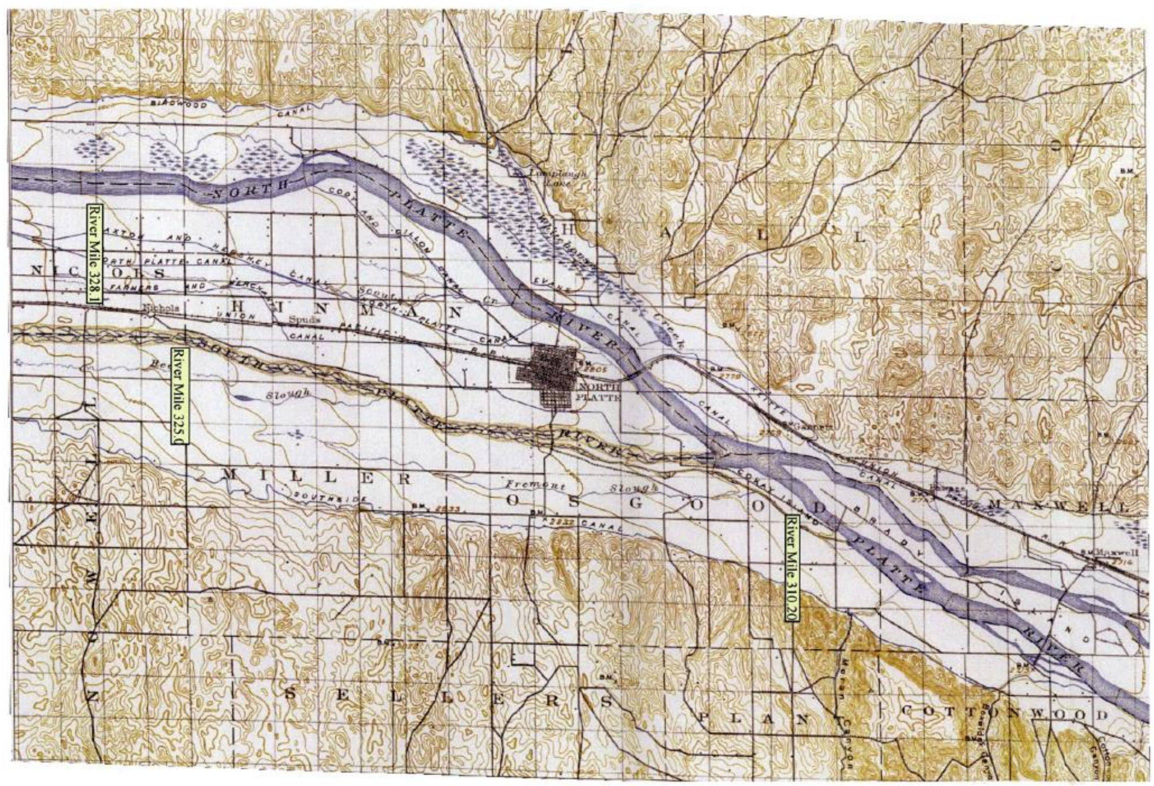



**Figure 2-3 Map of North Platte and South Platte River Near North Platte, NB (USBR 2004).**

*In the twentieth century, the impact of climate factors on the morphology of the central Platte River is largely overshadowed by the impact of anthropogenic factors. The population of the Basin continues to increase rapidly and the comparatively mild anthropogenic impacts of land use in the watershed continue into the nineteenth century but are exceeded by far more severe impacts of extensive infrastructure in the twentieth century. In the 100-year span, anthropogenic activities altered flows, and sediment loads in the central Platte River (USBR 2004 pg. 45).*

*Average and peak flows, the transport of sediment and median grain size of the channel bed, and the basin structure have all been significantly altered by human activities in the twentieth century. As a result of these changes, the central Platte River today can be described as distinctly different from the Platte River in the pre-development period (*Figure 2-3*), and the rate of this change is relatively abrupt with respect to climate induced change and geologic time.*

*The river is a peculiar one in the fact that it has a relatively steep slope and an extremely straight course, while at the same time it is building up its bed. This peculiarity is due to the fact that it is, taking the year as a whole, an overloaded stream. It is subject to great fluctuations in volume. In the springtime, when the* *mountain snows are melting, it is a river a mile in width, while at other times of the year it is almost or quite dry* (USBR 2004 pg. 43).

## 2.2 Study Reaches

The North Platte Chokepoint study area (also referred to as Chokepoint reach or segment) stretches west of the City of North Platte along the North Platte River for approximately 11 miles upstream of the confluence with the South Platte River and Tri-County Canal Diversion (TCCD). In addition to the TCCD, the study reach includes several infrastructure elements that either constrict or encroach upon the historical floodplain including three bridges, levees, residential and commercial developments, and numerous sand and gravel extraction pits.

For a more detailed evaluation of temporal and spatial trends, the study area has been broken into seven reaches; three reaches upstream of Highway 83 and four downstream of Highway 83. The location and limits of the seven reaches are summarized in Table 2-1 and Figure 2-4. For reference, the stationing of bridge crossings, diversion structures, and flow gages is provided in Table 2-2. Stationing for this study is consistent with the HEC-RAS hydraulic model of the North Platte River between Keystone Dam and the TCCD developed initially by HDR/Tetra Tech and Flatwater Group in 2011. Additional stationing in river miles upstream of the TCCD is also provided for reference. Appendix A includes a map book showing cross section locations and river stationing.

Development of reach delineations considered a wide range of variables including, but not limited to, floodplain width, bed profile, bankfull hydraulic conditions, channel geometry, hydraulic structures, adjacent and use, and sediment transport characteristics. Reaches 1, 2, and 3, located upstream of HWY 83, are not bisected by infrastructure and are relatively unimpacted by development and resource extraction. Reach 4 immediately downstream of HWY 83 flows through Cody Park and a residential area along the south bank. Reach 5 continues through the residential area and an adjacent gravel mining pit ending at the Union Pacific Railroad Bridge. Reach 6 is a short section between the Union Pacific Railroad Bridge and the Highway 30 Bridge. Reach 7 extends approximately two and half miles to the confluence with the South Platte River, ending at the TCCDD. Levees are located along the left overbank of Reaches 5, 6, and 7.

Key features characterizing the existing condition of each study reach developed from desktop analysis and field observation is provided in Figure 2-5 through Figure 2-11. The figures provide a map showing stationing, structures of interest, and bed material sample locations. A table summarizing planform slope and sinuosity, average bankfull metrics, and bed material size fractions is also included in each summary figures.

**Table 2-1 General Summary of North Platte River Project Reaches.**

| Reach No. | Reach Name | Station at Upstream Limit | Distance Upstream of TCCD (miles) | Length (mi) |
|---|---|---|---|---|
| 1 | Upstream | 889,202 | 11.0 | 1.8 |
| 2 | Campground | 879,774 | 9.2 | 2.4 |
| 3 | Upstream HWY 83 | 867,193 | 6.8 | 1.3 |
| 4 | Cody Park | 860,039 | 5.5 | 0.7 |
| 5 | Upstream UPRR | 856,779 | 4.8 | 1.5 |
| 6 | UPRR to HWY30 | 848,912 | 3.3 | 0.7 |
| 7 | HWY30 to Conf | 844,919 | 2.6 | 2.2 |

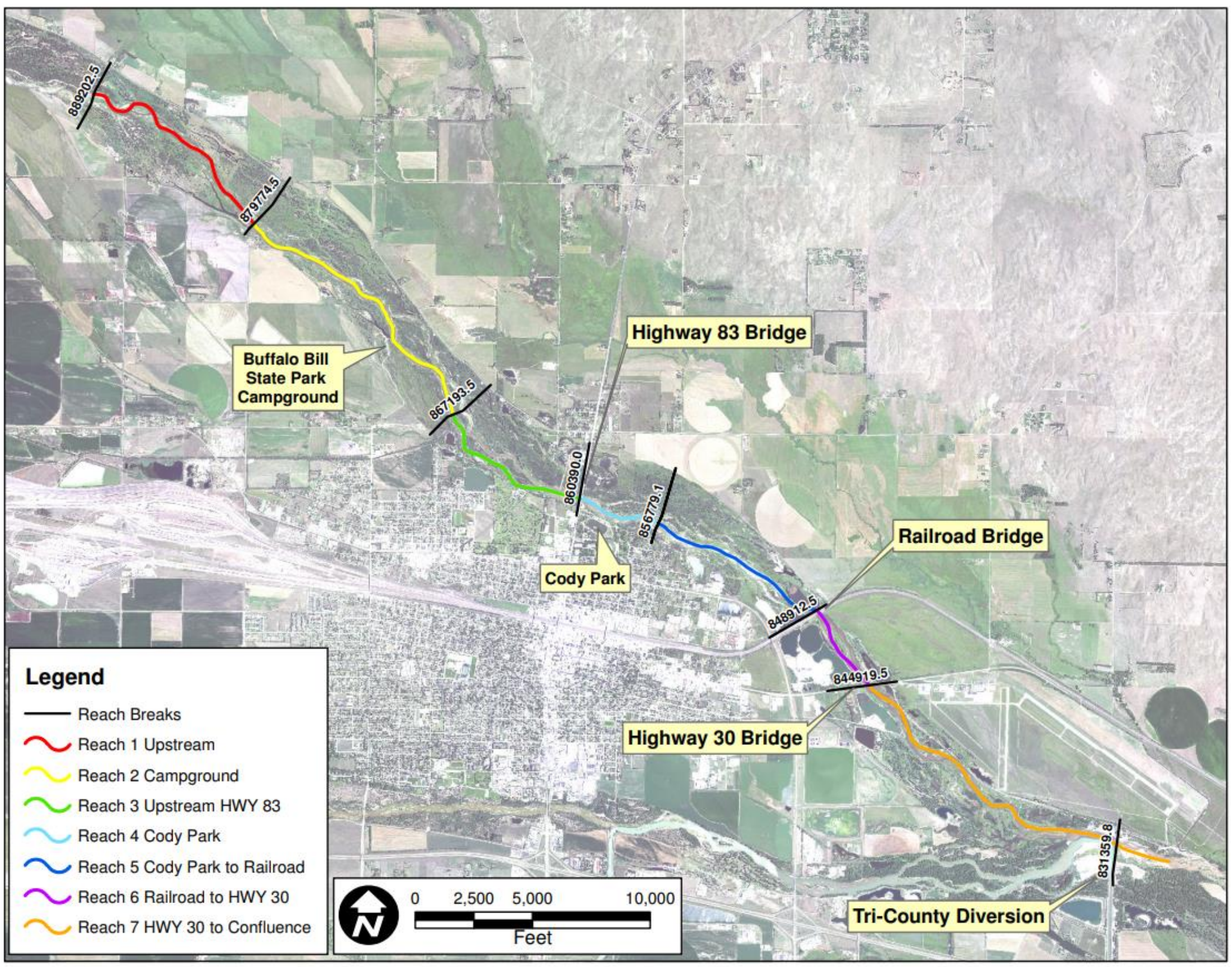
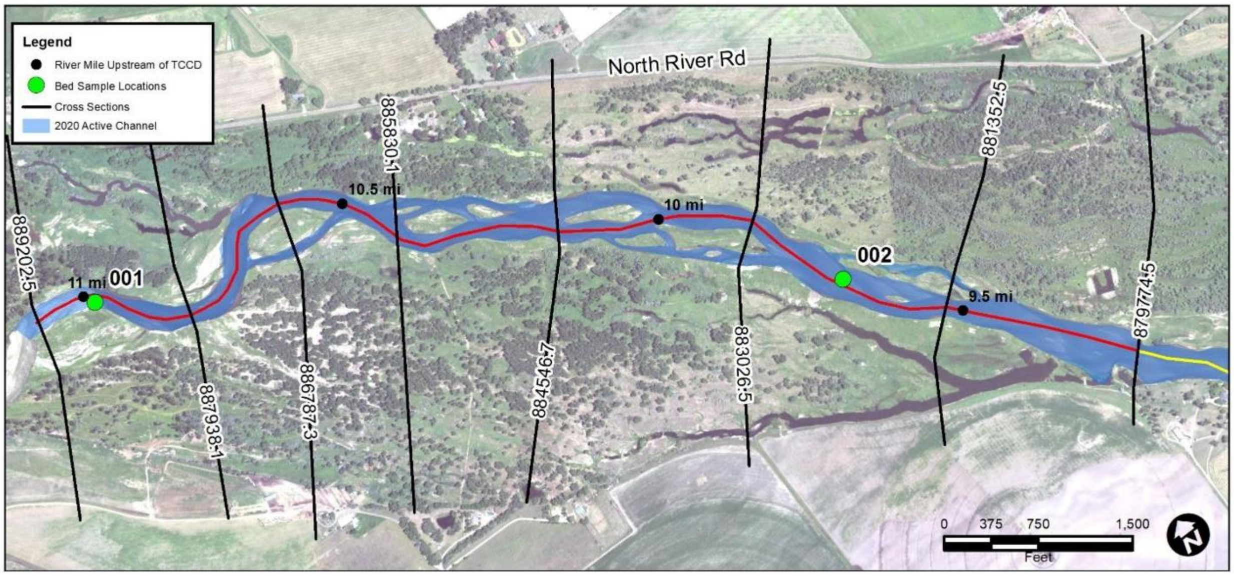



**Figure 2-4 North Platte River Chokepoint Reach Map**

Table 2-2 River Mile Locations for Road Crossings, Diversion Structures, and Gages

| River Mile [1] | Stationing [2] (feet) | Feature | |
|---|---|---|---|
| 0 | 831,359 | Tri-County Canal Diversion (TCCD) | Chokepoint Study Reach |
| 0.3 | 833,188 | South Platte Confluence | |
| 2.6 | 844,958 | Highway 30 | |
| 3.3 | 848,800 | Railroad | |
| 5.5 | 860,316 | Highway 83 / HWY 83 Gage | |
| 11.1 | 890,000 | Upstream Boundary of Study Reach | |
| 20.2 | 937,906 | Hershey Rd | |
| 23.6 | 956,200 | Birdwood Creek Confluence | |
| 26.9 | 973,426 | North Prairie Trace Rd / Sutherland Gage | |
| 29.6 | 987,504 | Suburban Canal Diversion | |
| 29.9 | 989,438 | North Platte Canal Diversion | |
| 39.2 | 1,038,255 | East V N Road | |
| 42.9 | 1,057,614 | East T N Road | |
| 45.4 | 1,071,258 | UPRR Bridge | |
| 50.3 | 1,096,818 | Keith Lincoln Canal Diversion | |
| 57.0 | 1,132,486 | Keystone-Roscoe Rd | |




| Location | |
|---|---|
| **Upstream Station (feet)** | 889202 |
| **Dist from TCCD (miles)** | 11.0 – 9.2 |
| **Reach Length (feet)** | 9,428 |
| **Reach Length (miles)** | 1.8 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.111% |
| **Sinuosity** | 1.10 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,700 |
| **Top Width (feet)** | 260 |
| **Depth (feet)** | 2.4 |
| **Bed Material** | |
| **Sample No.** | 2 |
| **d16 (mm)** | 0.39 MS |
| **d50 (mm)** | 0.79 CS |
| **d84 (mm)** | 1.74 VCS |

**Reach 1** begins approximately 11 miles upstream of the Tri-County Canal Diversion Structure. The 1.8-mile-long, slightly sinuous reach includes multiple side channels, vegetated islands, and point and middle channel bars. The reach appears to be aggrading moderately while bedforms (occasional riffles and dunes) are relatively stable. The channel is relatively narrow compared to other reaches and is generally laterally inactive; minimal active bank erosion was observed during the field visit. Abandoned side channels are visible in the floodplain, which likely reactivate during high flow events (i.e., greater than bankfull). Riparian vegetation and grasses have colonized the heads of many point bars. The bars are mainly composed of coarse sand although gravels and small cobbles were also observed during the field visit, which may limit bar migration and sediment transport along the reach. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain. The reach does not include crossing structures such as diversions or bridges.

River Mile 9.7 Bed Sample 2 Location

River Mile 10.95

**Figure 2-5 Reach 1 Summary**

**Reach 2** starts approximately 9.2 miles upstream of the Tri-County Canal Diversion Structure and includes the Buffalo Bill State Park Campground. The 2.4 mile-long mostly straight reach includes two large side channels, multiple smaller secondary channels, and vegetated islands. Point and middle channel bars are largely absent from the reach. The reach appears to be aggrading moderately while bedforms (occasional riffles and dunes) are relatively stable. The channel has the narrowest width compared to other reaches and is moderately laterally active. Eroding banks and concrete rubble to prevent erosion were observed near the Campground during the field visit. Active side channels are visible in the floodplain and appear to be active during bankfull events. Riparian vegetation and grasses have colonized the heads of many point bars. The narrow width and steeper slope tends to limit bar formation and likely maintains sediment transport along the reach. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain. The reach does not include crossing structures such as diversions or bridges.

| Location | |
|---|---|
| **Upstream Station (feet)** | 879774 |
| **Dist from TCCD (miles)** | 9.2 – 6.8 |
| **Reach Length (feet)** | 12,581 |
| **Reach Length (miles)** | 2.4 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.115% |
| **Sinuosity** | 1.07 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,500 |
| **Top Width (feet)** | 215 |
| **Depth (feet)** | 2.2 |
| **Bed Material** | |
| **Sample No.** | 3 |
| **d16 (mm)** | 0.21 FS |
| **d50 (mm)** | 0.63 CS |
| **d84 (mm)** | 2.36 VFG |

River Mile 8.1

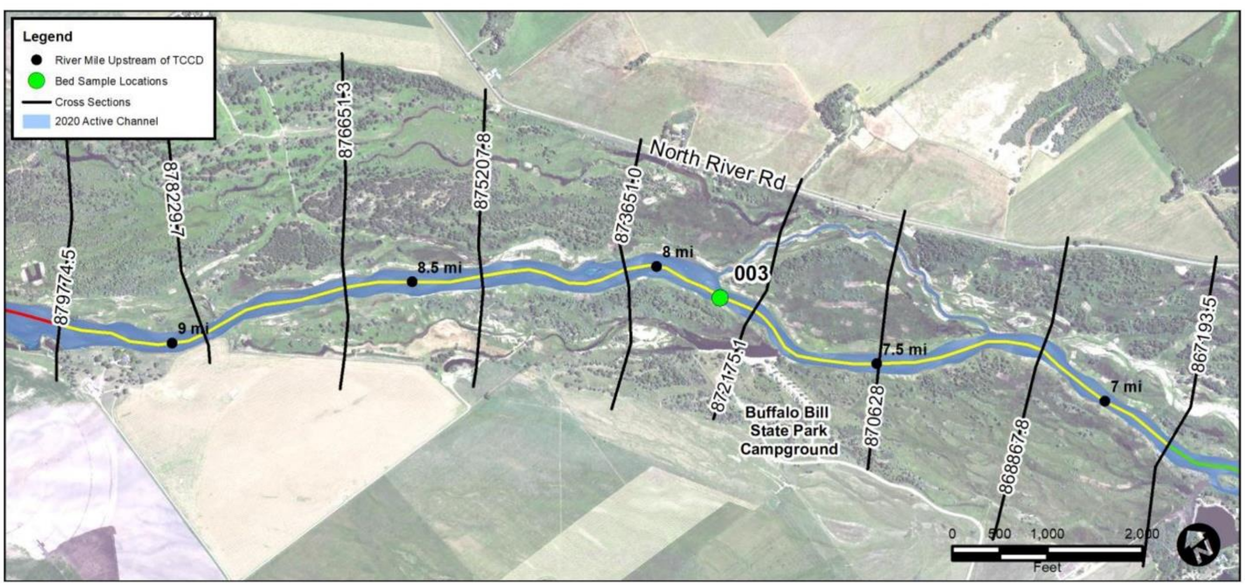
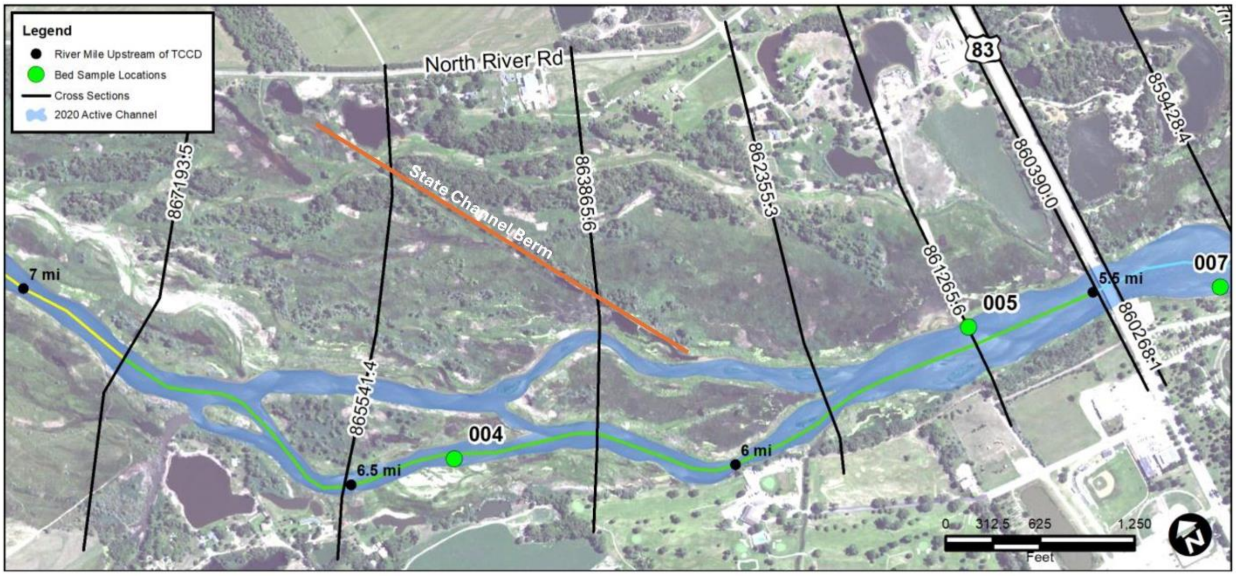



**Figure 2-6 Reach 2 Campground Summary**

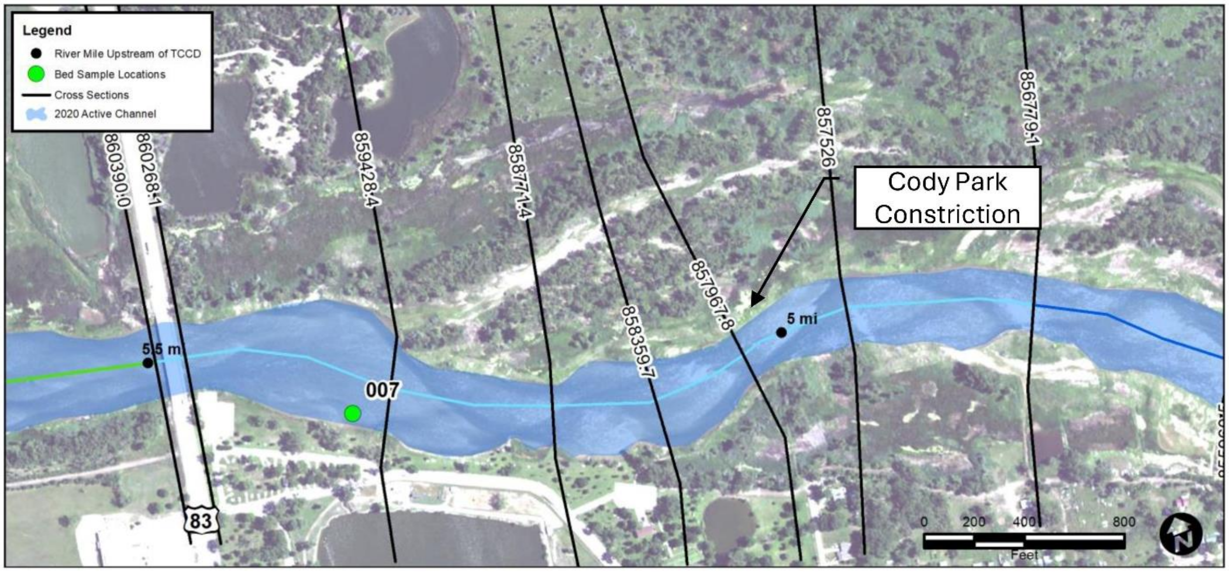



| Location | |
|---|---|
| **Upstream Station (feet)** | 867193 |
| **Dist from TCCD (miles)** | 6.8 – 5.5 |
| **Reach Length (feet)** | 6,925 |
| **Reach Length (miles)** | 1.3 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.103% |
| **Sinuosity** | 1.10 |
| **Active Channel Area (sq ft)** | 1,935,438 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,200 |
| **Top Width (feet)** | 280 |
| **Depth (feet)** | 1.9 |
| **Bed Material** | |
| **Sample No.** | 5 |
| **d16 (mm)** | 0.64 CS |
| **d50 (mm)** | 0.94 CS |
| **d84 (mm)** | 1.5 VCS |

River Mile 6.55 Right split flow around island.

**Reach 3** is upstream of the Highway 83 Bridge, beginning approximately 6.8 miles upstream of the Tri-County Canal Diversion Structure. The 1.3-mile-long reach is slightly sinuous and includes two large vegetated islands, multiple side channels, and point (transverse) bars. The reach appears to be aggrading while bedforms (occasional riffles and dunes) are relatively stable. The channel is wider compared to other reaches and is generally laterally inactive; minimal active bank erosion was observed during the field visit. Abandoned side channels are visible in the floodplain, which likely reactivate during high flow events (i.e., greater than bankfull). The bars, primarily composed of coarse sand, are actively forming, which allows for bar migration and a mobile bed along the reach. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain and islands. Hydraulic structures of influence include the recently rehabilitated State Channel Berm, the old HWY 83 embankment and the existing Highway 83 Bridge.

**Figure 2-7 Reach 3 Upstream of HWY 83 Summary**



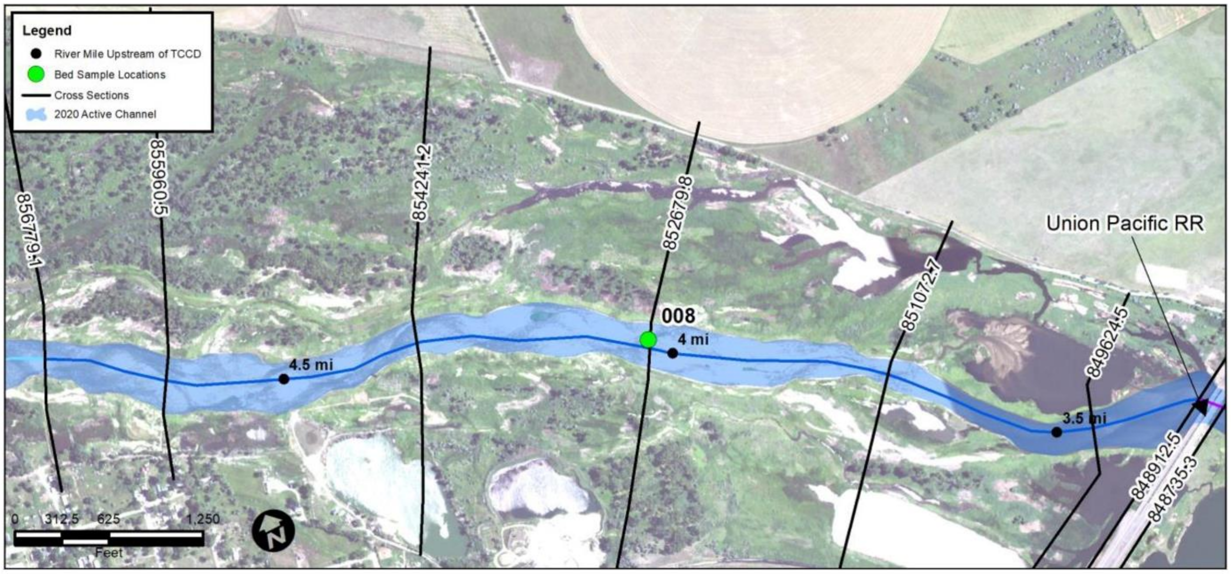

**Reach 4** begins downstream of the Highway 83 Bridge, starting approximately 5.5 miles upstream of the Tri-County Canal Diversion Structure. The short reach (0.7 miles-long) is mostly straight and includes Cody Park. The reach has a similar width as Reach 3, although it does not include islands, side channels, or point bars. This reach includes a constriction in the active channel. The reach appears to be aggrading while bedforms (mostly dunes) are relatively stable. The channel is generally laterally inactive; minimal active bank erosion was observed during the field visit. Abandoned side channels are visible in the floodplain, which likely reactivate during high flow events (i.e., greater than bankfull). Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain. Crossing structures are not present other than the Highway 83 Bridge.

| Location | |
|---|---|
| **Upstream Station (feet)** | 860268 |
| **Dist from TCCD (miles)** | 5.5 – 4.8 |
| **Reach Length (feet)** | 3,489 |
| **Reach Length (miles)** | 0.7 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.082% |
| **Sinuosity** | 1.08 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,700 |
| **Top Width (feet)** | 265 |
| **Depth (feet)** | 1.96 |
| **Bed Material** | |
| **Sample No.** | 7 |
| **d16 (mm)** | 0.31 MS |
| **d50 (mm)** | 0.63 CS |
| **d84 (mm)** | 3.01 VFG |

River Mile 5.3 Cody Park at Right

River Mile 5.3 Looking Upstream at HWY 83

**Figure 2-8 Reach 4 Cody Park Summary**



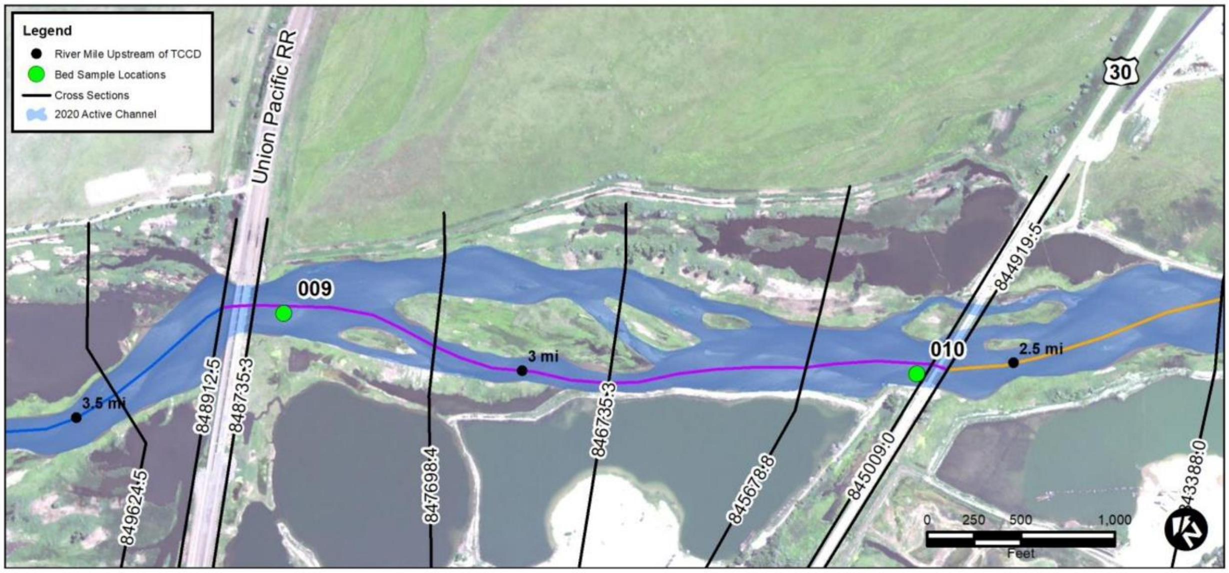

| Location | |
|---|---|
| **Upstream Station (feet)** | 856779 |
| **Dist from TCCD (miles)** | 4.8 – 3.3 |
| **Reach Length (feet)** | 8,044 |
| **Reach Length (miles)** | 1.5 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.114% |
| **Sinuosity** | 1.07 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,700 |
| **Top Width (feet)** | 300 |
| **Depth (feet)** | 2.2 |
| **Bed Material** | |
| **Sample No.** | 8 |
| **d16 (mm)** | 0.32 MS |
| **d50 (mm)** | 0.6 CS |
| **d84 (mm)** | 2.63 VFG |

**Reach 5** begins downstream of Cody Park and ends at the UPRR Bridge, starting approximately 4.8 miles upstream of the Tri-County Canal Diversion Structure. The reach is 1.5 miles-long, mostly straight, and wider than upstream reaches. Like Reach 4, it does not include islands, side channels, or point bars, although abandoned secondary channels are visible in the floodplain, which likely reactivate during high flow events (i.e., greater than bankfull). The right bank floodplain includes an active sand and gravel mining operation and several ponds and shallow wetlands. The left overbank is bounded by a levee on the north. The reach appears to be actively aggrading due to the UPRR Bridge, although bedforms (mostly dunes) are stable. The channel is generally laterally inactive; stable banks were observed during the field visit. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain.

River Mile 4.1 Bed Sample Location 8

River Mile 3.45 Looking Downstream at RR Bridge

**Figure 2-9 Reach 5 Cody Park to Railroad**



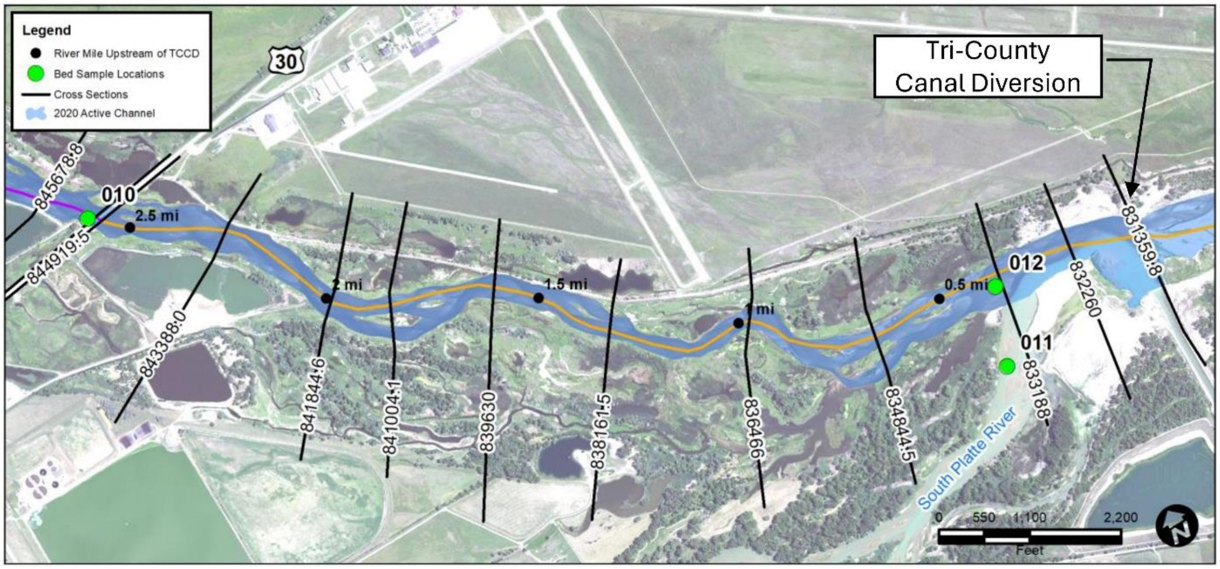

**Reach 6**, between the UPRR Bridge and Highway 30 Bridge, is a short, straight reach that begins approximately 3.3 upstream of the Tri-County Canal Diversion Structure. The reach is the widest of all other reaches and generally the shallowest. Several vegetated islands are present as well as multiple side channels, although the reach lacks any point or midchannel bars. Former sand and gravel mines are present in the left ad right bank floodplains, creating large ponds and shallow wetlands. Abandoned secondary channels are not visible in the floodplain due to the ponds. The reach appears to be actively aggrading, likely due to the TCCD's influence; bedforms (mostly dunes) are stable. The channel is generally laterally inactive; stable banks were observed during the field visit. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the floodplain. The floodplain in this reach is also bounded on the north by a levee.

River Mile 3.27 Looking Upstream at UPRR

River Mile 2.7 Looking Downstream at HWY30

| Location | |
|---|---|
| **Upstream Station (feet)** | 848735 |
| **Dist from TCCD (miles)** | 3.3 – 2.6 |
| **Reach Length (feet)** | 3,816 |
| **Reach Length (miles)** | 0.7 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.080% |
| **Sinuosity** | 1.04 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,700 |
| **Top Width (feet)** | 384 |
| **Depth (feet)** | 2.1 |
| **Bed Material** | |
| **Sample No.** | 9 |
| **d16 (mm)** | 0.31 MS |
| **d50 (mm)** | 0.81 CS |
| **d84 (mm)** | 2.12 VFG |

**Figure 2-10 Reach 6 Railroad to HWY 30**




**Reach 7**, downstream of the Highway 30 Bridge, begins approximately 2.6 miles upstream of the Tri-County Canal Diversion Structure and ends at the confluence of the North Platte and South Platte Rivers at the TCCD Structure. A levee system is located on the north side of the floodplain. The reach is slightly sinuous and includes a few vegetated islands, multiple floodplain secondary channels, and point bars. The reach appears to be aggrading due to the TCCD Structure. The channel is wide near the confluence and is generally laterally active, although the left and right banks are armored with riprap. Abandoned floodplain secondary channels likely reactivate during high flow events (i.e., greater than bankfull). The bars, primarily composed of medium to coarse sand, are actively forming, which allows for bar migration and a mobile bed along the reach. Riparian vegetation, including woody species such as cottonwoods, and invasive phragmites are present in the river right floodplain. In-channel dredging removes sediment near the TCCD intake.

| Location | |
|---|---|
| **Upstream Station (feet)** | 844919 |
| **Dist from TCCD (miles)** | 2.6 – 0.3 |
| **Reach Length (feet)** | 11,731 |
| **Reach Length (miles)** | 2.6 |
| **Planform Characteristics** | |
| **Channel Slope (percent)** | 0.101% |
| **Sinuosity** | 1.14 |
| **Average Bankfull Characteristics** | |
| **Discharge (cfs)** | 1,700 |
| **Top Width (feet)** | 300 |
| **Depth (feet)** | 2.1 |
| **Bed Material** | |
| **Sample No.** | 12 |
| **d16 (mm)** | 0.34 MS |
| **d50 (mm)** | 0.76 CS |
| **d84 (mm)** | 2.36 VFG |

River Mile 0.35 Looking Upstream from Confluence

**Figure 2-11 Reach 7 HWY 30 to Confluence**

# 3 METHODS

The geomorphology of a river system plays a significant role in many key physical and biological relationships that affect vegetation, hydraulics, fisheries habitat, wildlife habitat, and sediment transport (Simons and Associates 2000). The methods used for the geomorphic analysis are GIS-based evaluations of mapping data, hydrologic analysis, and hydraulic and sediment transport modeling, supported by previous studies, historical aerial photographs, LiDAR topographic data, and field observations.

## 3.1 Summary of Data Analyses and Methods

An inventory of hydrologic analyses, data sets, and methods is provided in Table 3-1. Hydraulic modeling models and use of results are described in Table 3-2. Table 3-3 lists sediment transport evaluations and methods. An inventory of data and a summary of the general approaches taken to generating and evaluate GIS datasets is shown in Table 3-4.

**Table 3-1 Summary of Hydrologic Analyses, Datasets, and Methods**

| Hydrologic Analysis | Dataset | Method |
|---|---|---|
| Specific Gage | Measured flow and stage data 1940 - 2022.<br>- North Platte River at North Platte (HWY 83) Gage No. 06693000<br>- North Platte River at Sutherland Gage No. 06691000 | Plot stage measurements through time for a specific discharge value (+/-10%). Evaluation informs trends in aggradation/degradation locally. |
| Median and Average Daily Flow | Daily flow series 1940 – 2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Compute median and average daily flow statistics. Values computed for various time periods. |
| Flow Duration | Daily flow series 1940 – 2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Determine percent of time flow values are equal or exceeded and plot versus daily flow to create flow duration curve. Duration curves developed for various time periods. |
| Annual Flow Histograms | Daily flow series 1940 – 2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Annual flow histograms developed using 20 logarithmically sized flow bins. |
| Ave Annual Flow Volume | Daily flow series 1940 – 2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Annual flow volumes computed per year. Average annual volumes evaluated for desired time periods. |
| Spells Analysis | Daily flow series 1940 – 2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Spells analysis utilizes daily flow series to determine the number of days a specific flow is exceeded in a given year. Daily flows are plotted by color to visualize and compare flow durations over time. |
| Flood Frequency | Annual Peak Discharge 1940-2022<br>North Platte River at North Platte (HWY 83) Gage No. 06693000 1940 – 2022 | Flood frequency analysis using annual peak flows and the USGS PeakFQ software/Bull 17B analysis to determine flood frequency. |

**Table 3-2 Summary of Hydraulic Models**

| Hydraulic Model | Model Description | Source Terrain | Model Purpose |
|---|---|---|---|
| 2011 1D HEC-RAS | 1D hydraulic model of study reach. This model was originally developed by HDR/Tetra Tech in 2011. Modifications for calibration conducted by ACE. | HDR/Tetra Tech Model, 2009 LiDAR | Computes hydraulics for a range of flows up to 9,000 cfs representative of 2009 conditions. Model geometry used to compute change in channel geometry relative to 2017 and 2023. |
| 2017 1D HEC-RAS | This model contains cross sections cut using 2017 LiDAR. This model incorporates the state channel berm. | 2017 LiDAR | Computes hydraulics for a range of flows up to 9,000 cfs representative of 2017 conditions. Model geometry used to compute change in channel geometry relative to 2017 and 2023. Model used to compute reach average transport rating curves. |
| 2023 1D HEC-RAS | This model contains cross sections cut using 2023 survey data within the channel and 2020 LiDAR in overbanks. | 2020 LiDAR<br>2023 Cross Section Survey | Computes hydraulics for a range of flows up to bankfull representative of 2023 conditions. Model geometry used to compute change in channel geometry relative to 2009 and 2023 |
| 2017 2D HEC-RAS | 2D hydraulic model of study reach. Model includes all hydraulic structures and a small portion of the South Platte River near the confluence. | 2017 LiDAR | Computes hydraulic conditions for a range of flows up to 6,000 cfs. Model results are used to develop inundation mapping for specific flows. Provides spatially distributed results of water surface, velocity, and shear stress. |

**Table 3-3 Summary of Sediment Analyses and Methods**

| Analysis | Model/Data Set | Method |
|---|---|---|
| Sediment Transport Rating | 2017 1D HEC-RAS Hydraulics<br>Range of flow up to 9,000 cfs.<br>2023 Bed Material Gradations | Rating curves developed using reach average hydraulics computed in HEC-RAS combined with bed material gradations. Transport rating curves computed using Yang. |
| Effective Discharge | Transport Rating Curves<br>Annual Flow Histograms | Transport rating curves are combined with annual flow histograms to develop a plot showing annual transport vs discharge. The peak of the curve indicates effective discharge. |
| Average Annual Transport Potential | Effective Discharge Curves | Area under effective discharge curve gives average annual sediment transport potential. |
| Mass Bed Change | 2009 HEC-RAS Model Geometry<br>2017 HEC-RAS Model Geometry<br>2023 HEC-RAS Model Geometry | Mass bed change between datasets computed by comparing channel area. Channel area below a constant elevation computed using HEC-RAS for each dataset. Area and channel length used to compute mass bed change by reach. |

Table 3-4 Summary of GIS analysis approaches taken for geomorphic assessment.

| Analysis | GIS dataset | Method |
|---|---|---|
| Braiding Index | Historic Aerial Photography: 1938, 1958, 1974, 1981, 1993, 1999, 2017 | Ratio of total channel length to primary channel length. Summarize by reach. |
| Channel Length and Sinuosity | Historic Aerial Photography: 1938, 1958, 1974, 1981, 1993, 1999, 2017, 2020 | Digitized primary channel centerline to measure channel length. Sinuosity calculated as ratio of primary flowline length to valley distance. |
| Side Channel Length | Historic Aerial Photography: 1938, 1958, 1974, 1981, 1993, 1999, 2017 | Flowlines include primary, anabranching, and secondary channels. Summarize by reach. |
| Bed Slope | 2011 HDR/Tetra Tech HEC-RAS Model<br>2017 LiDAR<br>2023 Cross Section Survey | Determine channel thalweg elevation at cross sections established in the 2011 HDR/Tetra Tech HEC-RAS modeling, which represents 2009 conditions. Use best-fit line for average gradient. |
| Active Stream Corridor Width | Historic Aerial Photography: 1938, 1958, 1974, 1981, 1993, 1999, 2017, 2020 | Digitized active stream corridor area (based on banklines and vegetation patterns) divided by the active stream corridor length. |
| Historic River Corridor Vegetation Cover | Historic Aerial Photography: 1938, 1958, 1974, 1981, 1993, 1999, 2017, 2020 | Digitized open bars, submature (sedges and shrubs) vegetation, and woody vegetation cover. |
| Relative elevation model (REM) | 2017 topographic and bathymetric LiDAR (Quantum Spatial 2018) | LiDAR data was used to develop the REM that informed geomorphic analyses to compare channel and floodplain elevations (see Section 8). |

## 3.2 Relevant Previous Studies

The studies described below focus primarily on geomorphology. There have been numerous studies conducted between 2004 and 2023 investigating mitigation alternatives to increase hydraulic capacity through the Chokepoint. Studies related to mitigation alternatives are not discussed below.

**Williams, G. 1978**. “The case of shrinking channels – the North Platte and Platte Rivers in Nebraska,” Geologic Survey Circular 781.

This reconnaissance investigation was undertaken to determine whether the channels of the North Platte and Platte Rivers in western and central Nebraska have been changing in character since the latter part of the 19th century and, if so, the general nature and extent of such changes. The 480-kilometer study extended from Minatare on the North Platte River to Grand Island on the Platte River. The study found the “channels of the North Platte and Platte Rivers in western and central Nebraska have changed considerably since about 1865. In the absence of any climatic shifts, the various channel changes described in this report most likely are due to the rather systematic decrease in water discharge (and possibly sediment discharge) that has occurred.” The study also found that at North Platte the riverbed elevation seems stable over the past 45 years (1933–1978). Geomorphic study methods included evaluating width, braiding indices, sinuosity, and bed aggradation and degradation. The study also investigated changes to hydrology and vegetation.

**USGS, 1983**. "Hydrologic and Geomorphic Studies of the Platte River Basin," Professional Paper 1277.

The chapter titled "*HYDROLOGIC AND MORPHOLOGIC CHANGES IN CHANNELS OF THE PLATTE RIVER BASIN IN COLORADO, WYOMING, AND NEBRASKA: A HISTORICAL PERSPECTIVE*" provides a summary of the major changes to the hydrologic regime and morphology since 1860. The information supports the general conclusions that changes to the hydrologic regime have altered vegetation patterns and sediment transport. "Morphologic changes of the North Platte, South Platte, and Platte Rivers have been similar despite significant differences in the hydrology of these three rivers. Construction of reservoirs and diversion of streamflow on the North Platte River have caused reductions of annual peak flows and mean annual flows of both the North Platte and Platte Rivers." The authors note the changes in streamflow patterns are manifested by changes in appearance of channels of the Platte River. Prior to water development in the 19th century, the Platte was a wide (~2- kilometer), shallow (1.8- to 2.4-meter) river characterized by bankfull spring flows and low summer flows.

**FLO Engineering, 1992**. "North Platte River Channel Stability Investigation Downstream of Keystone Dam," Prepared for Twin Platte Natural Resources District, North Platte, NE.

FLO Engineering, Inc. investigated channel stability issues on the North Platte River from Keystone Dam to the South Platte River confluence. The study describes adverse impacts identified from operation of the Kingsley Dam and the Keystone Diversion Dam. The reduction in peak flows, the curtailment of the sediment supply, and the failure to maintain the channel integrity caused the river channel to undergo "dramatic changes," including:

- Channel degradation, lowered groundwater levels, and loss of subirrigation and wet meadows,
- Channel narrowing and vegetative encroachment,
- Coarsening of the bed material, and
- Loss of channel conveyance capacity.

FLO Engineering investigated each of those channel morphological issues. The study describes the North Platte River as a wide, shallow river with high flows in May and June filling an active channel 2,000 ft or more in width until the 1920s. "During the low flow period from July to September, the river channel had numerous exposed transient sand bars, some sand bars with seedling growth, and several more permanent islands with established vegetation. Evan at low flow conditions, much of the channel between the vegetated banks was active with numerous transient bars comprised of fine sediment." Small rivulets continually migrated across the channel bottom, creating the braided pattern prominent in Nebraska.

The study also highlighted the factors that contributed to a braided river: "a large upstream sediment supply and high sediment transport rates, relatively steep valley slopes, a high and variable seasonal water discharge, and unstable banks of river alluvium." FLO Engineering describes the North Platte River as the dominant stream compared to the South Platte River based on the historical bed material size of the Platte River. It was dictated by the finer size material contributed by the North Platte River. As mainstem dams were constructed on the North Platte, the associated reservoirs captured sediment reducing the supply of coarse-grained bed material to the North Platte . They go on to state that the loss of the finer sediment in the beds of both North Platte and the Platte has decreased the mobility of the bed forms in the river.

FLO Engineering describes the channel morphology parameters that characterized channel transformation including a change in mean bed elevation, coarsening bed material sizes, a change in channel geometry and conveyance capacity, and a reduction in groundwater levels. “Channel narrowing, vegetative encroachment, and channel abandonment resulted in decreased capacity.” In addition, “while the bed material load in the North Platte has been drastically reduced, it is primarily the bedload reduction rather than the reduced suspended load that has impacted the channel narrowing. The bed material supply from the North Platte provided the sediment to keep the Platte braided. The channel narrowing process is active due to a reduction in the bed material load.”

The study concluded that “the North Platte from Keystone Dam to the confluence of the South Platte is predominantly a single channel river for 21 miles (38%) and an anabranching stream for approximately 34 miles (62%). None of this river reach can be accurately described as a braided river in the context of its pre-project form (prior to 1900). Most of the singular channel reach is located in the section from Keystone Dam to Paxton Bridge. Some of the river is influenced by bridges and bank stabilization. Most of the historic river bottom is a woodlands environment where vegetation plays an important role in stabilizing the river form.”

**Simons & Associates, 2000**. “Physical History of the Platte River in Nebraska: Focusing upon Flow, Sediment Transport, Geomorphology, and Vegetation,” prepared for the Platte River EIS Office, U.S. Department of the Interior.

This report provides a description of the Platte River that is technically based and uses a general description of the affected environment for the Environmental Impact Statement (EIS) being prepared under the three-state agreement. The purpose of the description was to compile available technical information pertinent to the affected environment, present in condensed form the technical issues, present an evaluation of the technical issues, and discuss potential approaches to resolve these issues through the EIS process. This work was guided by the concepts using the “best available” information and application of scientific methods. The study produced “an unbiased discussion by utilizing such information and by reaching scientifically justifiable conclusions or recommendations.”

The report considers the current status of the river in terms of geomorphology, sediment transport, and woody vegetation of the Platte River and its major tributaries. “Regarding sediment transport, the data suggest that the sediment supplied to the Platte River and the sediment transported through the river are roughly in balance. This is supported by bed elevation trends at the USGS stream gages and comparisons of changes in cross-sections. No significant changes in overall geomorphic channel classification have been documented. Studies of vegetation have generally shown that the previous trend of significant woodland expansion has slowed significantly, stopped, and has reversed where erosion has occurred during high flow events. The various analyses suggest that the Platte River has reached a state of dynamic equilibrium."

The report describes a hydraulic analysis using historic streamflow data and channel cross-section data from the 1920's - 1930's. The results of the hydraulic analysis suggest "the amount of channel narrowing and the timing of such changes on the North Platte, South Platte, and Platte Rivers was found to be explained to a large degree by the percentage of channel not inundated by water during the vegetation germination period." Additionally, the report notes "on the North Platte River, there are a number of large mainstem reservoirs that trap sediment and reduce sediment transport to a substantial degree. In contrast, on the South Platte, there is not nearly as much trapping of sediment, yet virtually the same amount of woodland expansions has occurred on both rivers...Thus, while it is recognized that changes in sediment transport have played a role in the changes to the channel and associated riparian vegetation, indications are that the reduction in sediment transport played a secondary role in the expansion of woody vegetation compared to the more direct effects of the significant reduction in flow, particularly during the germination season."

**Parsons Corp, 2003**. "Evaluation of Channel Capacity in the North Platte River at North Platte, NE," Report prepared for Central Nebraska Public Power and Irrigation District.

The Central Nebraska Public Power and Irrigation District (CNPPID) requested that Parsons perform a field inspection and initial assessment of changes that are "alleged to have occurred in the river channel and in the stage-discharge and discharge-flooding relationships in the North Platte River for a reach of the river immediately north of the City of North Platte, Nebraska." Parsons focused their evaluation on a developed property along the north bank upstream of the Highway 83 bridge. Parsons' study focused on an evaluation of "channel capacity," the bankfull conditions, when water is just about to escape over the top of banks of the main unvegetated conveyances in the river.

Parsons' preliminary observations and findings regarding flooding issues as they relate to the Chokepoint segment include the following:

1. The Corps of Engineers determined that the main channel bankfull capacity (not the same as flood stage or carrying capacity) in this reach during the period 1940-1986 was only 1,700 to 2,000 cfs.

2. The Corps' estimates of main channel capacity of 1,700 to 2,000 cfs match the effective or dominant discharge of 1,700 cfs, which means that the main channel capacity is as expected.

3. Channel capacity should be, and is, less than flood stage. The NWS action in 2002 of setting the flood stage carrying capacity at 1,980 cfs is commensurate in a reach with an effective discharge of 1,700 cfs.

4. Even though the capacity of the main channel to carry flow has not changed, once water leaves the main channel, the part flowing over the north floodplain in the study reach now flows deeper than the last time the NWS established the flood stage (1994). This change began to occur around 1991 and was not a gradually changing phenomenon. Evidences reveal dramatic changes in the overbank area and its hydraulic characteristics in recent years.

5. The hypothesis that flow rates which reach flood stage are less now than in the past is confirmed, but this change occurred in the 1990's and does not appear to have been gradually decreasing over time.

6. The reasons and evidences that floodplain flows are now deeper are detailed in the report. The primary causes are (1) the recent, rapid, and extensive growth of Phragmites australis and Purple loosestrife which increase the overbank resistance to flow; (2) overbank flow chutes on the north floodplain have been blocked by this vegetation, and by numerous beaver dams and rock crossings, forcing the overflow water to rise higher and flow across open ground, (3) drainage chutes and paths immediately downstream of the subject properties have been intentionally and imprudently blocked, inhibiting drainage away from, and raising water levels on, the subject properties; (4) the artificial drain created by the State around 1970 was effective but has ceased to function, and (5) large transient sand bars in the main channel (macroforms) have become larger and have entered or moved to new locations in the reach, contributing to the elevated water levels.

The report also notes "hydraulic properties at the [Highway 83] gage changed abruptly around 1991. These reductions in average flow depth and velocity and increases in flow area and top width did not occur gradually over a long period of time. By examining factors that could have caused these abrupt changes, it was discovered that Phragmites australis was reported to have begun its rapid expansion in the area around 1991, the State diversion channel became indistinguishable from floodplain ground around 1994, blockage of natural drains downstream of the subject properties appears to be total around 1995, and the macroforms began to get larger around 1992. Thus, it is hypothesized that these factors produced the adverse changes in the hydraulic properties."

**USBR, 2003**. "Platte River Flow and Sediment Transport Between North Platte and Grand Island, Nebraska (1895 - 1999)," prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center. Denver, Colorado

This report presents water and sediment budgets for the various reaches along the Platte River that are bounded by gauging stations between the cities of North Platte and Grand Island, Nebraska. The inputs of water and sediment from the North and the South Platte Rivers are included in this analysis. The indicators of channel forming discharge evaluated for this study include the 1.5-year peak flood, effective discharge (computed by two different methods), and the median sediment transporting discharge. All of these indicators of channel forming discharge have declined over the 20th century. The effective discharge and the median sediment transporting discharge values generally follow the same trend as for the 1.5-year peak flood.

Mean flows, median flows, and the 1.5-year flood peaks of the North Platte and Platte Rivers in Nebraska have significantly decreased over the 20th century in response to reservoir storage, river flow diversions, and periods of drought. The trend in the mean river discharge and the 1.5-year flood peaks are both very similar with flows being the highest during the first time period (1895 to 1909), a wetter climatic period, declining somewhat during the second period (1910 to 1935) when reservoirs began to come online, and declining to their lowest values of the 20th century during the third time period (1936 to 1969). During the third period, several reservoirs and irrigation diversions came online as part of the Tri-County canal, and two periods of drought in the 1930s and the 1950s occurred. Mean flows and the 1.5-year flood peaks increased somewhat over the fourth time period (1970 to 1999) but were still significantly less than either of the first two time periods (1895 to 1935).

These reductions in river flow have caused a substantial reduction in the sediment transport rates over the 20th century. In addition, large storage reservoirs on the North and South Platte Rivers have also trapped sediment. Reductions in river flow and sediment load would be expected to result in a narrower Platte River channel.

As an indicator of the channel forming discharge, the trends in effective discharge have implications for the width and depth of the river channel. Regardless of the method used, effective discharge has declined over the 20th century along the North Platte and Platte Rivers. In general, the effective discharge values are greatest during the period 1895 to 1909 and lowest during the period 1936 to 1969. This trend is consistent with the trends for 1.5-year flood peaks, mean-annual discharge, and the mean-annual sediment load.

For the North Platte River and all Platte River stations, the computed effective discharge was typically less than the 1.5-year flood peak for the first three time periods (1895 to 1969). For the last time period (1970 to 1999), the computed effective discharge values were both higher and lower than the 1.5-year flood peak. For the South Platte River, the effective discharge computed using the equal discharge increments was always lower than the 1.5-year flood peak. However, the effective discharge computed using either the probability increments or the median sediment transporting discharge was always higher than the 1.5-year flood peak for the South Platte River station.

**USBR, 2004**. "The Platte River Channel: History and Restoration," prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center. Denver, Colorado

This "paper" presents past channel habitat trends, their probable causes, and the likely future trends for the river channel, based on a historic review of channel evolution and field data. A strategy for a river restoration program that focuses on enhancement, or managing causes and mitigating impacts is also considered. It also summarizes geomorphic, hydraulic, and sediment transport concerns for the central Platte River between North Platte, Nebraska and Chapman, Nebraska addressing findings of qualitative geomorphic analysis and more detailed, quantitative engineering and geomorphic analysis. Numerical modeling is introduced in Murphy et al. (Draft 2001) and applied in the Platte River Recovery Implementation Program Draft Environmental Impact Statement (U.S. Department of the Interior, 2003).

The emphasis of this study is a historic review and analysis of the geomorphology of the central Platte River, to provide a better understanding of the dominant processes of this system. Understanding the dominant processes can help identify trends in river form, which aid in the selection of management alternatives for restoration that successfully maximize habitat for the target species.

The analysis presented in the "paper" is based primarily on existing historic field data, historic mapping, aerial photos, written narrative, historic photos, recorded information on Platte River Basin development, and some recent field data collection associated with this study. Historic and recent field data include measurements of river discharge, climate indicators, bed-material size gradations, average unvegetated channel widths or active channel widths, and stage-discharge relationships.

The report notes that anthropogenic impacts in the twentieth century are substantive, abrupt with respect to geologic time, and have altered three primary elements of channel morphology in the central Platte River: the in-channel flow; the transport of sediment; and the basin structure including location of flow and sediment inputs in the basin and geologic or man-made structures. For example, flows in the twentieth century show a distinct decrease from 1895 to 1969 then increase slightly in the latest period from 1970 to 1999 although never returning to pre-water infrastructure development levels.

The study also highlights that "reaches of the present channel have an unvegetated or active channel width that is 50 to 90 percent narrower than the channel that existed in the 1860s and in the period 1898 to 1902. The central Platte River has generally experienced what has been called channel narrowing throughout its length with greater reductions in unvegetated or active channel width in the upper reaches, and smaller percentage reductions with distance downstream."

This study found "narrowing of the unvegetated or active channel width and changes to channel section and form depend directly on the previous multi-year period of flow rates, the grain size and availability of sediment for transport, and the growth and decline of riparian vegetation. These changes in channel width and form also depend indirectly on: structures acting as vertical and horizontal controls" such as diversion dams and bridges.

Of most interest in this report is this paragraph, "[n]arrowing of the unvegetated or active channel widths along the [central] Platte River occurred rapidly during the early to mid-twentieth century, and these changes generally appear to have concluded at most locations today. Based on this study, the principal processes associated with this period of rapid narrowing are substantial reductions in river flow, reductions in flow peaks, and the rapid expansion of vegetation. Flows are limited to the lower-elevation areas of the channel by the reduction in flows. Following reductions in flows and flow peaks, and corresponding to reductions in the active channel width, more areas of formerly sandy banks and islands could be colonized by vegetation. The encroachment by vegetation into former channel areas reduces the mobilization of sand at higher flows, including the 1973 and 1984 flow events, and prevents the maintenance of formerly wide channels."

**River Design Group, 2023.** "North Platte Chokepoint Investigation Final Report," prepared for Crane Trust and Audubon Nebraska.

River Design Group, Inc. (RDG) was retained by the Crane Trust and Audubon Nebraska, in partnership with Ducks Unlimited, The Nature Conservancy and Nebraska Game and Parks Commission to investigate causes and potential solutions for the North Platte Chokepoint Reach located in North Platte, Nebraska. The study analyzed factors contributing to the loss of hydraulic capacity in the Chokepoint Reach and provided recommendations that address the project objectives. The study scope was developed by VESPR in the form of several key questions for which technical responses were requested.

RDG evaluated bridges in three hydraulic modeling scenarios aimed at testing the sensitivity of water surface elevations and channel capacity to the width of bridge openings. Effects on water surface elevations were evaluated at model cross sections located upstream of each bridge. The flood stage monitoring location at the Highway 83 Bridge was only affected by the constriction at the Highway 83 Bridge. Their modeling also showed the constrictions at the Union Pacific Railroad Bridge and Highway 30 Bridge had no effect on channel capacity at the flood stage monitoring location. Increasing the width of bridge openings had marginal effects on water elevations at Highway 83 (less than 0.5 foot for a discharge of 2,000 cfs). Increasing the width of the Highway 83 Bridge opening would increase localized capacity by less than 551 cfs (20%) for a discharge of 2,773 cfs.

RDG's modeling indicated that the Railroad Bridge causes the greatest constriction and localized increases in capacity of 18% to 41% could be gained by increasing the width. Further, their modeling showed that the Highway 30 Bridge is not a significant constriction likely due to effects of adjacent levees. They concluded that "based on model results, it appears that bridges may contribute to localized aggradation within one-half mile upstream of each bridge."

Their modeling results suggested that vegetation likely contributes to reach-scale deposition but has only minor effects on capacity at the bridges of less than 10%. Removal of vegetation in the model had marginal effect on water elevations at all flows.

RDG analyzed the 2017 topo-bathymetric LiDAR to "illuminate the extent of sediment deposition in the Chokepoint Reach." The average reach gradient above and below the Chokepoint Reach is 0.12% with a noticeable wedge of sediment present in the study reach. A linear interpolation of the upstream and downstream gradients through the Chokepoint Reach was completed to define an equilibrium channel profile and illustrate the reach-scale aggradation that has occurred upstream of the TCCD structure.

Based on the LiDAR analysis, RDG concluded that the TCCD structure appears to be the primary cause of reach-scale aggradation in the Chokepoint Reach. "Sedimentation extends over six miles upstream of the dam with a maximum depth of approximately six feet as measured from the bottom of the equilibrium channel profile." RDG suggested that the volume of the sediment wedge upstream of the dam is estimated to be approximately 5 million cubic yards.

RDG investigated the projected change in capacity under various management scenarios (e.g., regular sediment removal, installation of a sediment bypass system at the Tri-County Canal Diversion structure, regular in-channel vegetation control, etc.). They simulated three dredging scenarios using the hydraulic model. Scenarios included dredging a channel seven miles through the Chokepoint Reach at the estimated equilibrium channel slope for widths of 200 feet, 500 feet and 1,000 feet. The model results indicated dredging a channel 200 feet wide could increase flood stage capacity from approximately 1,500 cfs to 4,000 cfs.

## 3.3 Field Observation and Data Collection

ACE project team members conducted a site visit on October 19th and 20th, 2023, which included reconnaissance of the Chokepoint segment by kayak. General field observations were made to identify geomorphic features, areas of aggradation/degradation, bank erosion, riparian vegetation, and notation of existing river condition. Field observations are summarized in the reach descriptions provided in Section 2.2. Appendix A provides a map book of the study reach that includes river stationing, cross section locations, parcel data, and the location of photographs and bed samples. Appendix B includes the photographic documentation from the Oct 2023 site visit.

During the site visit, team members collected samples of bed material that were submitted to a geotechnical lab for gradation analysis. The sieve analyses' results were used to characterize the sediments gradation comprising the riverbed material, inform the geomorphic assessment, and as input to sediment transport calculations and modeling. Bed material gradations are provided in Appendix C.

TC Engineering surveyed 50 cross sections of the active channel between October 2nd and 15th, 2023. Cross section locations of the survey coincide with 1D hydraulic model cross sections developed by HDR/Tetra Tech as documented in a report dated November of 2011. The ACE project team used the 2023 survey data to compare against 2011 model cross sections and 2017 LiDAR to assess changes in channel slope, geometry, and sediment flux. We also used this data for calibration of sediment transport modeling. Graphical cross sections comparing 2009, 2017 and 2023 data are provided in Appendix D.

During the October site visit ACE also met with CNPPID staff to tour the Tri-County Canal Diversion facility and learn about dredging operations. CNPPID staff indicated that dredging is conducted annually for an average of 150 days with an estimated removal volume of 150,000 cy per year. This is generally observed to keep up with annual sediment delivery. Sediment captured at the TCDD is both from the North and South Platte, with South Platte contributions typically being larger than the North per observations from CNPPID. Under original FERC licensing and USACE permitting CNPPID was authorized to dredge and return sediment back to the river downstream of the diversion when a minimum flow threshold is exceeded. For the past three years changes to permitting requirements do not allow for return of sediment back to the river, creating significant challenges for CNPPID related to sediment disposal.

# 4 HYDROLOGIC CONTEXT AND ANALYSES

At the start of the 20th century, the North Platte River flowed across a nearly treeless floodplain, swelling each spring to a wide, shallow braided river spanning most of the valley with an active channel width of a half mile or more (FLO Engineering 1992). Water resource development in the Platte River basin has substantially impacted flows. A range of hydrologic analyses have been conducted to quantify change in flow patterns that are the primary driver of geomorphic change observed over the last century.

## 4.1 Water Resources Development

Prior to 1900, the flow in the North Platte River during the later summer and early fall was very low. In the Second Hydrographic Report for Nebraska by the Bureau of Irrigation, Water, Power, and Drainage (1933), it was stated that (Eschner et al. 1983):

> *"(a)lthough the flow of the Platte Rivers became very low in the summer months, historians did not mention the river as ever being dry prior to the "nineties." Statistics do not show the river as being entirely dry at North Platte until after the middle "nineties" when the irrigation ditches in the upper portion of the North Platte River, and many of the tributaries, diverted water for irrigation."*

Large depletions of late summer flows for irrigation began in the 1880s. Bentall (1982) indicated that irrigation diversion was "an important factor in the cessation of flow." He stated that "…the early recorded use of the North Platte River water was in the middle of the nineteenth century, but not until the 1880's did such use begin causing a large depletion of the middle- and late-summer flows (FLO Engineering 1992 pg. 6)

The twentieth century, when unvegetated channel widths and active channel widths exhibit a pronounced period of narrowing, is also concurrent with a change in the basin structure resulting from the construction of reservoirs and diversion structures (USBR 2004). Large infrastructure including reservoirs and extensive canal systems were constructed to meet increasing water demands, affecting both flow ( through timing shift and peak flow reduction) and sediment transport.

Beginning in 1909, large storage reservoirs were first constructed on the North Platte River to capture spring floods and provide water for irrigation during the summer. During the period 1909 to 1958, six major dams were constructed across the North Platte River in Wyoming and Nebraska, see Figure 4-1. Pathfinder (1909), Guernsey (1928), Alcova (1938), Seminoe (1939), Kingsley (1941), and Glendo (1958) reservoirs have a combined storage capacity of nearly 5 million acre-feet (Collier and others, 2000). The reservoirs store water during periods of high flow and later release the water during periods of low flow. This pattern of reservoir storage significantly reduced the annual peak flows on the North Platte River. In addition to the storage reservoirs, two structures, the Keystone Diversion Dam and the Tri-County Diversion Dam, were constructed to support large flow diversions for irrigation and hydropower in the central Platte River basin. The Keystone Diversion Dam was completed in 1936 and diverts approximately 69 percent of the average annual North Platte River water from the North Platte River channel (USBR 2004).

A6 HYDROLOGIC AND GEOMORPHIC STUDIES OF THE PLATTE RIVER BASIN

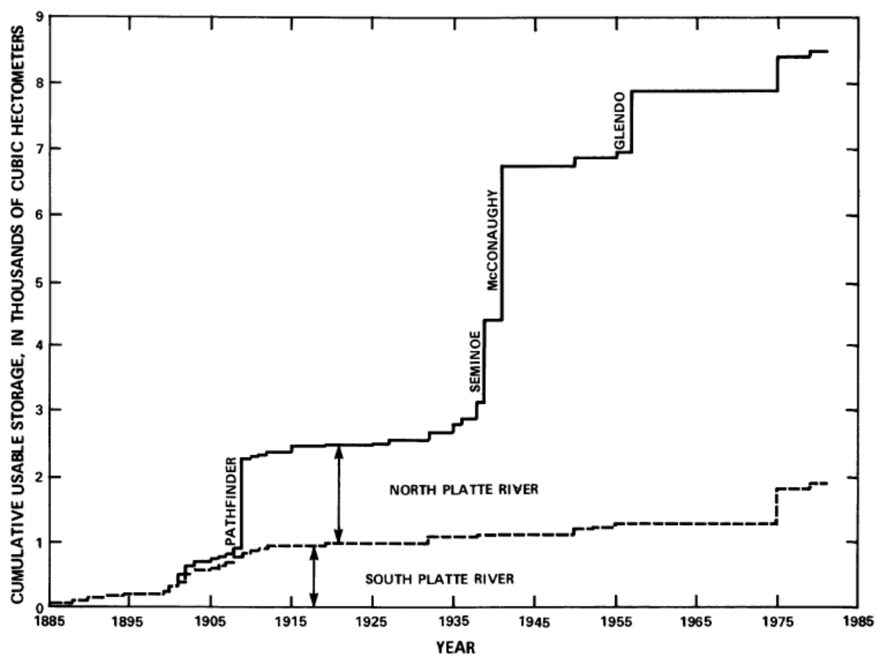



FIGURE 2.—Cumulative usable storage in reservoirs in the Platte River basin (modified from Bentall, 1975a).

**Figure 4-1 Cumulative Usable Storage in Reservoirs in the Platte River Basin (Modified from Bentall, 1975)**

Before water storage and irrigation diversions began on the North Platte River, the seasonal flow variation was characterized by high spring discharge in May and June and a low base flow from August to March (see Figure 4-2). Flow in the North Platte has been significantly reduced after construction of Lake McConaughy, as shown in Figure 4-3. Seasonal flows have been redistributed with a low base flow generally occurring between September and mid-June, with the high flow season from mid-June through August coinciding with the timing of reservoir releases to meet downstream irrigation demands.

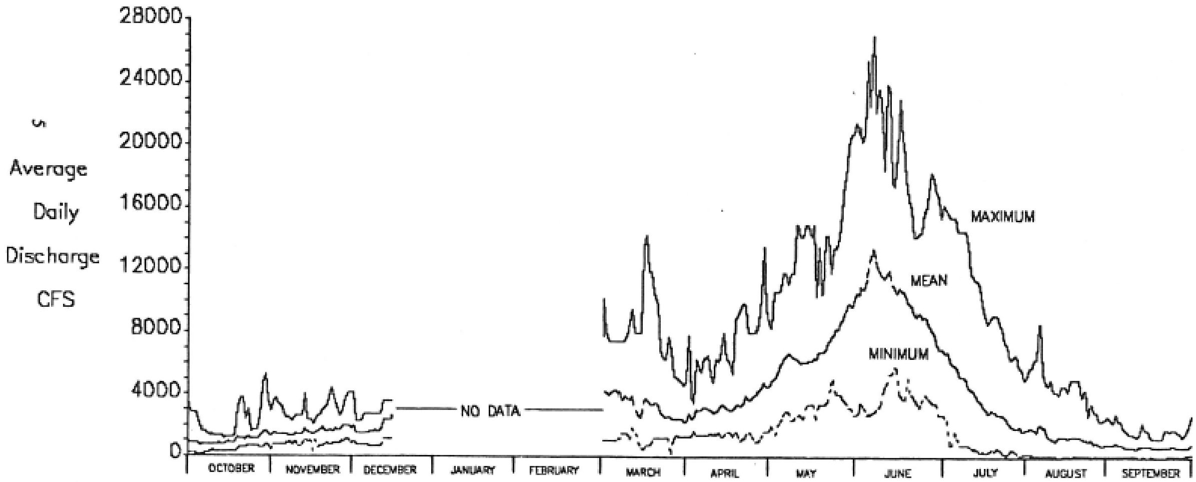



**Figure 4-2 Mean Annual Hydrograph North Platte River at HWY 83 1894 – 1909 (FLO Engineering 1992)**

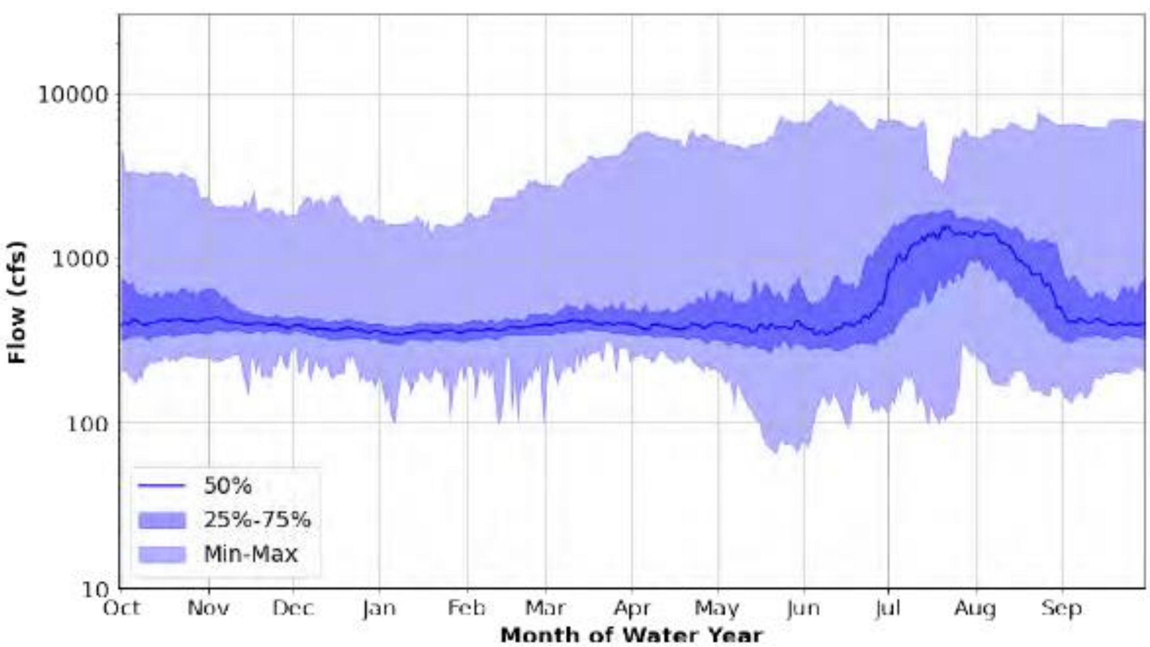



**Figure 4-3 Mean Annual Hydrograph North Platte River at HWY 83 1941 - 2022 (RDG 2023)**

## 4.2 Hydrologic Change

Impacts of water resource development have been well documented by several studies. The 2004 USBR report concluded that anthropogenic impacts associated with water resource development in the twentieth century have abruptly and substantially altered hydrologic and morphologic conditions of the Platte River basin. This section provides evaluation hydrologic change dating back to 1900 to inform impacts of not only water resources development but also fluctuations in hydrologic condition post development.

### 4.2.1 *Method of Analysis*

Table 4-1 provides a summary of available gage data on the North Platte River. Hydrologic analyses pertinent to the geomorphic and sediment transport evaluation were conducted using daily flows at the HWY83 gage (see Figure 4-4 and Figure 4-5). Hydrologic evaluation of data at the Sutherland gage was not conducted given that contributing drainage area and flow patterns are very similar to HWY 83.

**Table 4-1 Summary of North Platte River Gages**

| Gage No./Name | Location | River Mile Upstream of TCCD | Contributing Drainage Area (sq mi) | Period of Record | Gage Datum |
|---|---|---|---|---|---|
| 06693000<br>At North Platte<br>(HWY 83 Gage) | Downstream side of HWY 83 | 5.5 | 26,300 | 1895 – Present | 2793.28 ft, NAVD88 |
| 06691000<br>Near Sutherland<br>(Sutherland Gage) | At North Prairie Trace Road | 26.9 | 26,120 | 1931 – Present<br>(partial daily data 1995-1999) | 2922.77 ft, NAVD88 |

Analyses important to geomorphic and sediment transport processes that were evaluated include calculation of mean and average daily flow, 1.5-year flood discharge, daily flow duration, annual peak discharge, and annual flow volumes.

Analyses were divided into five time periods occurring between 1900 and 2022. The first period (1900-1941) occurs prior to construction of Kingsley Dam and the TCCD. The following four time periods of 1942-1969, 1970-1989, 1990-1999, and 2000-2022 were divided based upon sustained trends in hydrologic periods determined by patterns in peak flows and annual flow volumes. Division of these time periods also coincide with trends in sediment aggradation or degradation estimated from specific gage analyses conducted at HWY 83 and Sutherland. Specific gage analyses are presented in a separate section of this report (see Section 5.4).

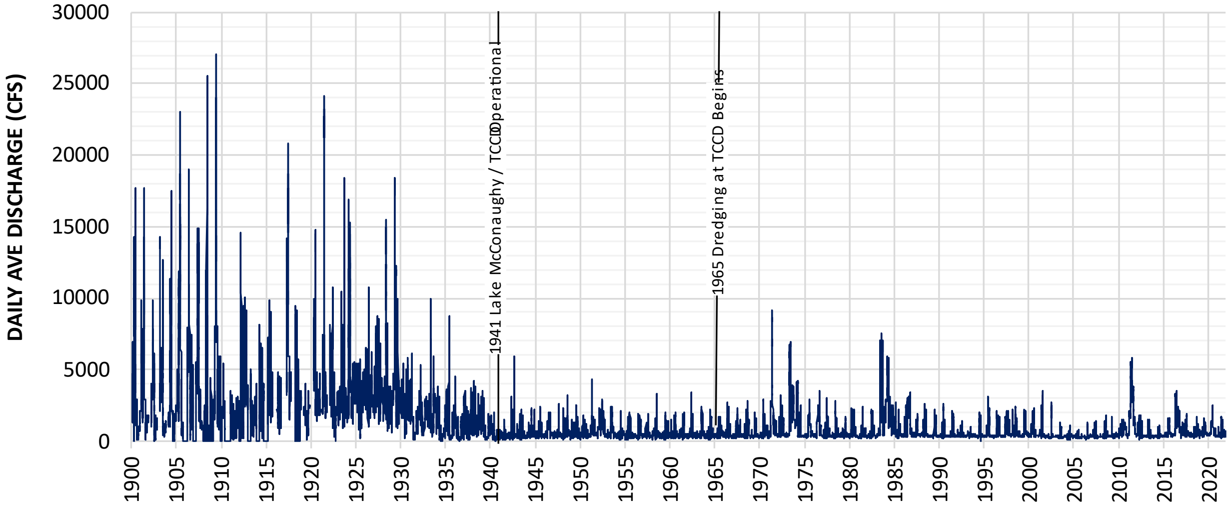



**Figure 4-4 Daily Average Discharge 1900-2022 North Platte River at HWY83**

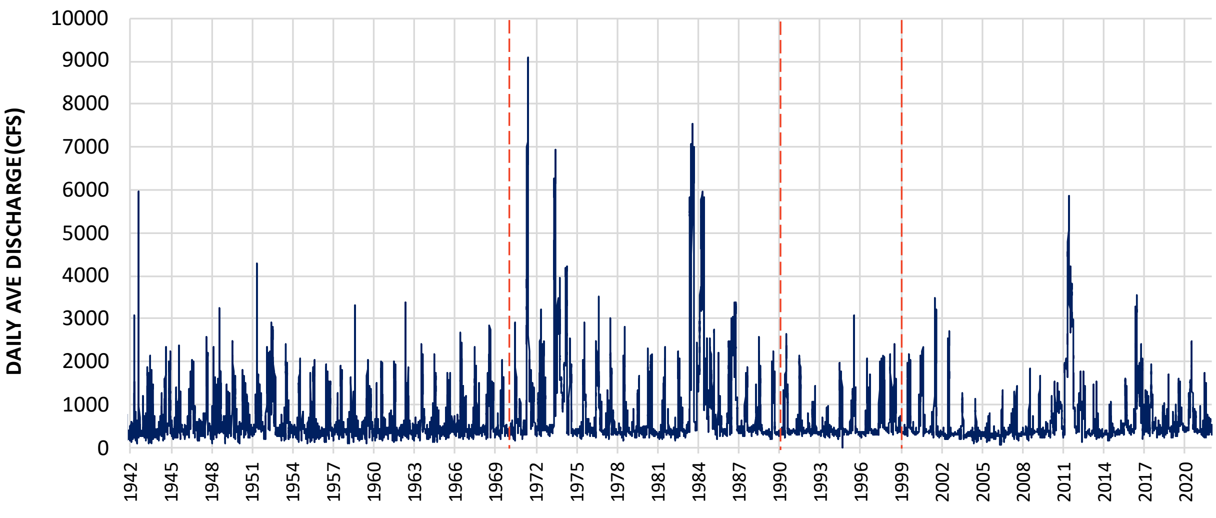



**Figure 4-5 Daily Average Discharge 1942-2022 North Platte River at HWY 83**

### 4.2.3 Results

#### *Median, Average, and 1.5-year Flows*

Mean, average, and 1.5-year flows for each time period is summarized in Table 4-2. Median, average, and 1.5-year flows significantly decreased (between 69 and 80%) after 1942 relative to the 1900-1941 baseline period. Median flows after 1942 do not show remarkable differences between time periods. This is not surprising given that median flows reflect baseflows. Average flows after 1942 range from 573 to 601 cfs except for 1970-1989 when average flow is 1,007 cfs. ACE calculated the 1.5-year discharges for the four time periods: 2,236 cfs between 1942-1969, 2,805 cfs during 1970-1989, which is followed by a steady decrease during the next two time periods to a value of 1,642 cfs in 2000-2022. Decreases in 1.5-year flows are related to smaller annual peak flows.

**Table 4-2 Median and Average Daily Flow North Platte River at HWY 83**

| Time Period | Median Flow (cfs) | % Change in Median Flow [1] | Average Flow (cfs) | % Change in Average Flow [1] | 1.5-Year Flow (cfs) | % Change in 1.5-Year Flow [1] |
|---|---|---|---|---|---|---|
| 1900-1941 | 2,000 | -- | 2,633 | -- | 7,183 | -- |
| 1942-1969 | 410 | -80 % | 597 | -77% | 2,236 | -69% |
| 1970-1989 | 440 | 7 % | 1,007 | 69% | 2,805 | 25% |
| 1990-1999 | 381 | -13 % | 573 | -43% | 2,119 | -24% |
| 2000-2022 | 378 | -1 % | 601 | 5% | 1,642 | -23% |
| 1942 - 2022 | | | | | 2,052 | -- |

[1] Percent change relative to preceding time period.

#### *Flow Duration and Spells*

Daily flow duration curves developed for each time period are shown graphically in Figure 4-6. The flow duration curves further illustrate differences in flows before and after 1942. Compared to other periods after 1942, the curve for 1970-1989 is a clear outlier because of high flow events in the early 1970s and mid-1980s. The flow exceeded 10% of the time between 1970-1989 is roughly 2,200 cfs as compared to 1,300 cfs for the other three time periods after 1942. An even larger deviation is noted at the 2% exceedance flow where during 1970-1989 it is approximately 5,800 cfs as compared to 2,000 cfs for 1942-1969, 1,980 for 1990-1999 and 2,680 for 2000-2022.

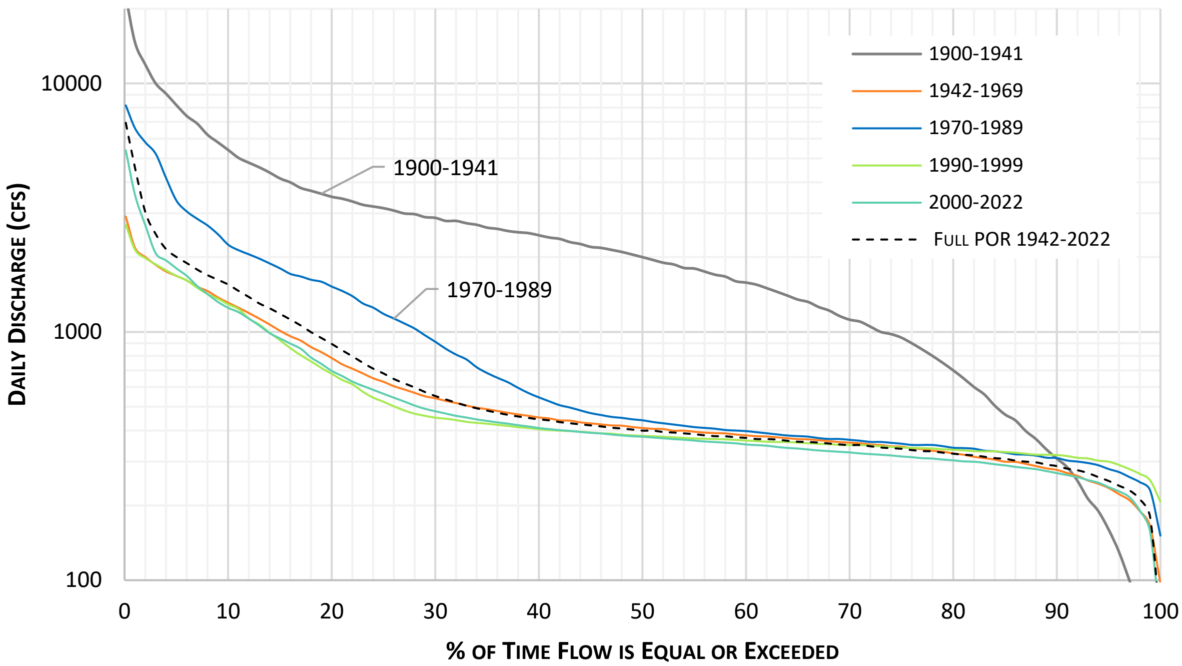



**Figure 4-6 Daily Flow Duration Curves North Platte River at HWY 83**

Spells analyses and resulting figures were developed to provide an alternative way to evaluate the occurrence and duration of flows. The spells analysis, shown in Figure 4-7, Figure 4-8, and Figure 4-9, provide a table showing the number of days in each year a given flow is equal or exceeded. The occurrence and duration of flows can be visualized in the figures by the color coding provided. Table 4-3 summarizes the average number of days per year each flow is equal or exceeded for the four time periods. The spells analysis results highlight the very wet period during the 70s and 80s that included not only large annual peak flows but significantly different duration of flows greater than 1,000 cfs. The event occurring in 2011 is similar in peak and duration to large hydrologic years that occurred in 1983, and 1984.

**Table 4-3 Spells of 1,000 to 6,000 cfs**

| Discharge (cfs) | 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 |
|---|---|---|---|---|---|---|---|
| Time Period | Average # of Days/Year Discharge is Equal or Exceeded | | | | | | |
| 1942-1969 | 53.5 | 26.2 | 7.1 | 0.3 | 0.1 | 0 | 0 |
| 1970-1989 | 104.2 | 74.8 | 46.5 | 23.0 | 16.0 | 11.6 | 11.6 |
| 1990-1999 | 50.8 | 25.9 | 7.1 | 0.1 | 0 | 0 | 0 |
| 2000-2022 | 48.4 | 25.4 | 12.3 | 5.7 | 1.9 | 1.1 | 1.1 |

| # of Days Q is Equal or Exceeded | | | | | | |
|---|---|---|---|---|---|---|
| 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 |
| 2 | | | | | | |
| 27 | 12 | 7 | 3 | 1 | 1 | 1 |
| 64 | 29 | 1 | | | | |
| 79 | 45 | 11 | | | | |
| 51 | 18 | 9 | | | | |
| 66 | 38 | 4 | | | | |
| 48 | 38 | 16 | | | | |
| 73 | 22 | 9 | 3 | | | |
| 65 | 26 | 13 | | | | |
| 49 | 6 | | | | | |
| 47 | 8 | 3 | 1 | 1 | | |
| 190 | 136 | 79 | | | | |
| 46 | 33 | 6 | | | | |
| 45 | 30 | 2 | | | | |
| 44 | 30 | 1 | | | | |
| 81 | 24 | | | | | |
| 34 | 27 | | | | | |
| 21 | 13 | 4 | 2 | | | |
| 62 | 17 | 1 | | | | |
| 31 | 19 | 2 | | | | |
| 38 | 23 | 1 | | | | |
| 24 | 10 | 4 | 1 | | | |
| 51 | 45 | 9 | | | | |
| 46 | 22 | 3 | | | | |
| 18 | 5 | | | | | |
| 58 | 30 | 14 | | | | |
| 47 | 10 | 2 | | | | |
| 101 | 28 | 4 | | | | |
| 44 | 15 | 2 | | | | |

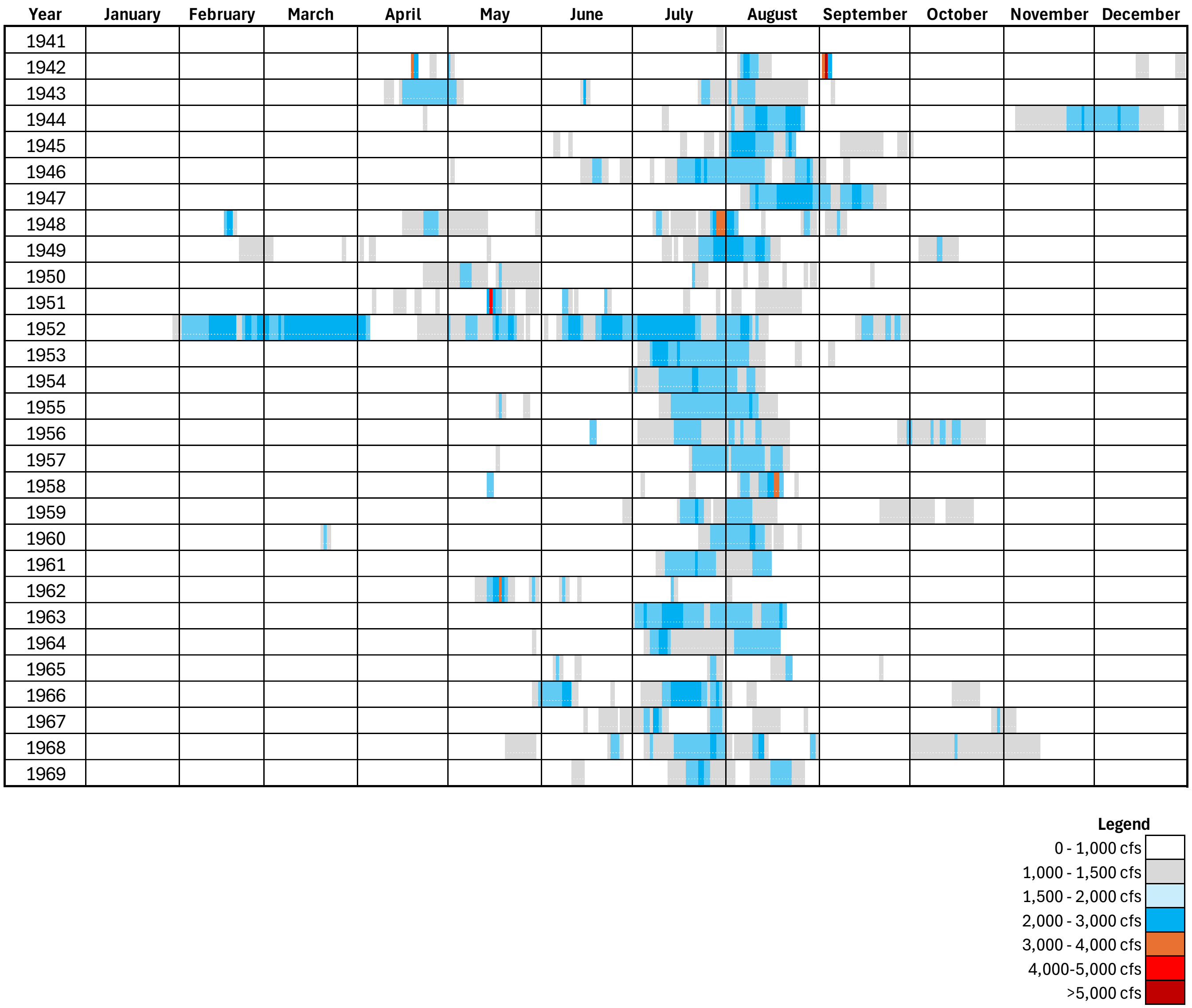



**Figure 4-7 Spells Analysis of Daily Flows 1942 – 1969 North Platte River at HWY 83**

**# of Days Q is Equal or Exceeded**

| Year | 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 |
|---|---|---|---|---|---|---|---|
| 1970 | 48 | 30 | 10 | | | | |
| 1971 | 166 | 98 | 67 | 52 | 41 | 37 | 37 |
| 1972 | 107 | 65 | 23 | 4 | | | |
| 1973 | 243 | 202 | 156 | 90 | 51 | 32 | 32 |
| 1974 | 168 | 116 | 72 | 42 | 33 | | |
| 1975 | 69 | 38 | 4 | | | | |
| 1976 | 127 | 79 | 48 | 8 | | | |
| 1977 | 48 | 38 | 17 | 1 | | | |
| 1978 | 44 | 27 | 11 | | | | |
| 1979 | 22 | 6 | | | | | |
| 1980 | 82 | 68 | 36 | | | | |
| 1981 | 33 | 16 | 4 | | | | |
| 1982 | 46 | 37 | 14 | | | | |
| 1983 | 162 | 154 | 128 | 116 | 112 | 109 | 109 |
| 1984 | 312 | 261 | 174 | 112 | 83 | 54 | 54 |
| 1985 | 87 | 43 | 21 | | | | |
| 1986 | 174 | 155 | 134 | 34 | | | |
| 1987 | 41 | 18 | | | | | |
| 1988 | 49 | 25 | 8 | | | | |
| 1989 | 55 | 20 | 3 | | | | |
| 1990 | 64 | 24 | 18 | | | | |
| 1991 | 56 | 41 | 6 | | | | |
| 1992 | 7 | | | | | | |
| 1993 | | | | | | | |
| 1994 | 34 | 18 | | | | | |
| 1995 | 75 | 25 | 17 | 1 | | | |
| 1996 | 48 | 17 | 2 | | | | |
| 1997 | 93 | 49 | 10 | | | | |
| 1998 | 83 | 51 | 14 | | | | |
| 1999 | 48 | 34 | 4 | | | | |

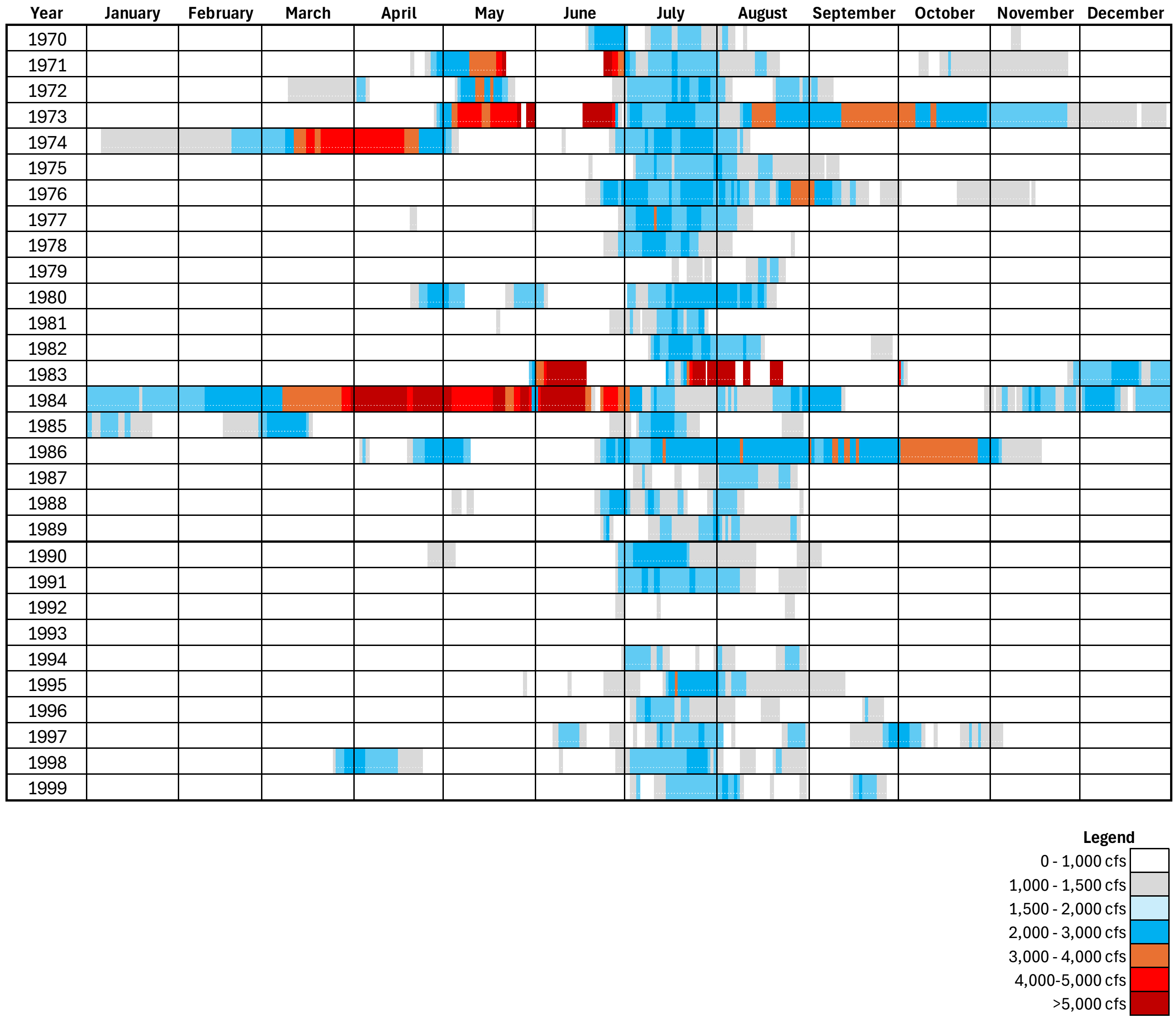



**Figure 4-8 Spells Analysis of Daily Flows 1970 - 1989 North Platte River at HWY 83**

# of Days Q is Equal or Exceeded

| 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 |
|---|---|---|---|---|---|---|
| 75 | 54 | 17 | | | | |
| 50 | 38 | 27 | 4 | | | |
| 44 | 39 | 26 | | | | |
| 15 | | | | | | |
| 2 | | | | | | |
| | | | | | | |
| 13 | | | | | | |
| 8 | | | | | | |
| 15 | 5 | | | | | |
| 6 | 3 | | | | | |
| 87 | 2 | | | | | |
| 241 | 218 | 158 | 109 | 45 | 26 | 26 |
| 68 | 9 | | | | | |
| 13 | 1 | | | | | |
| 3 | | | | | | |
| 37 | 10 | | | | | |
| 195 | 155 | 59 | 23 | | | |
| 53 | 7 | | | | | |
| 21 | 8 | | | | | |
| 31 | 3 | | | | | |
| 79 | 41 | 7 | | | | |
| 38 | 12 | | | | | |
| 63 | 4 | | | | | |
| 4 | | | | | | |

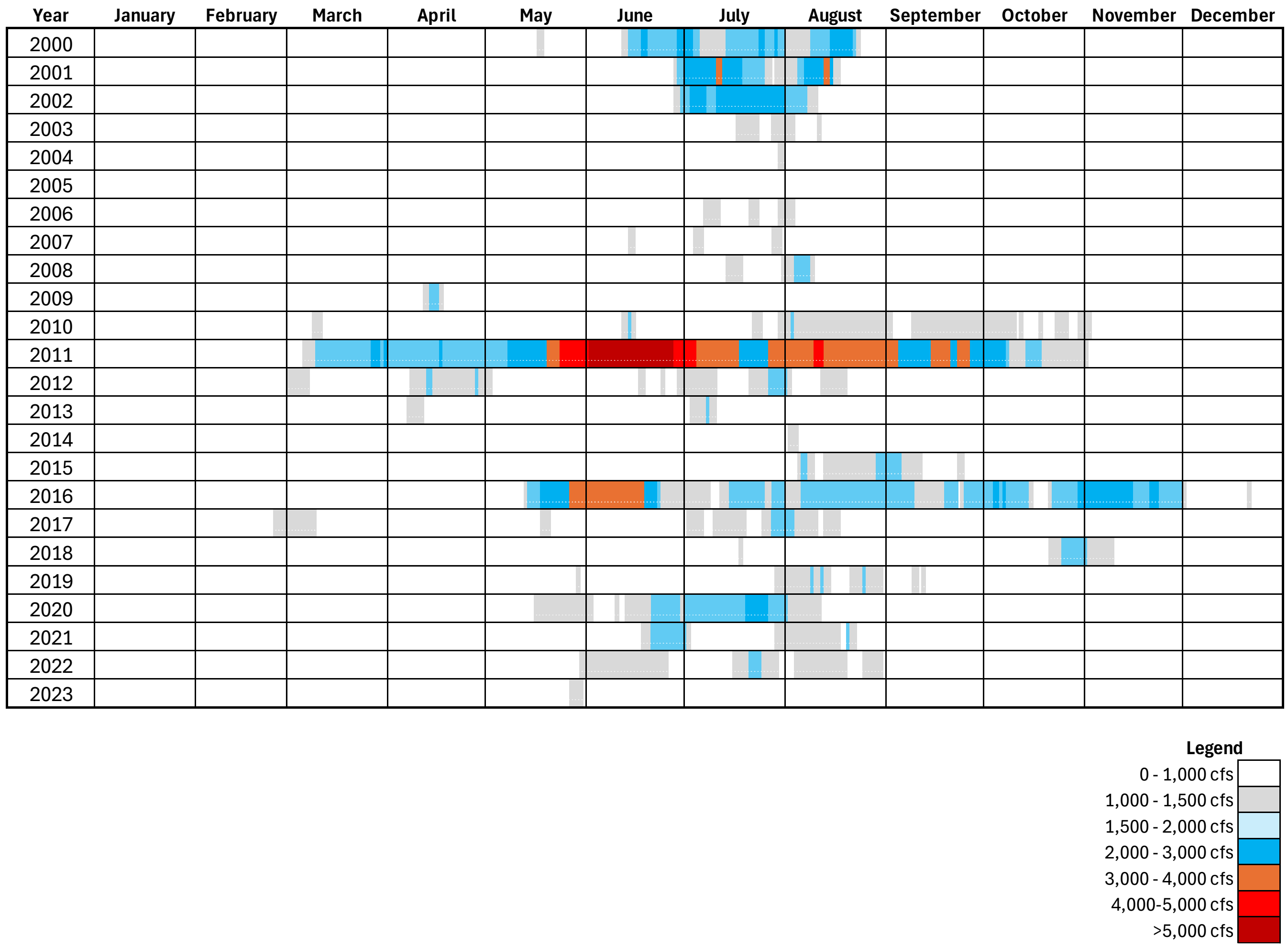



**Figure 4-9 Spells Analysis of Daily Flows 1990 - 2022 North Platte River at HWY 83**

### *Annual Peak Flow and Volume*

Annual peak flow and volume is shown graphically between 1942 and 2022 in Figure 4-10. Table 4-4 provides a summary of the average annual flow volume for each time period. Results show similar trends noted in previous analyses. There is a large reduction in flow volume (71%) post 1942. After 1942 annual flow volumes are similar except for 1970-1989, which is 44% higher. For reference, the top ten peak flow events and annual flow volumes that occurred between 1942 and 2022 are listed in Table 4-5. Note that between 1970-1989 five of ten and seven of ten peak flow and annual volumes, respectively, occurred during this time period. Annual hydrographs for the largest peak flow event in each time period is shown in Figure 4-11.

**Table 4-4 Average Annual Flow Volume North Platte River at HWY 83**

| Time Period | Average Annual Flow Volume (cfs/year) | % Change [1] |
|---|---|---|
| 1900-1941 | 756,216 | |
| 1942-1969 | 218,093 | -71% |
| 1970-1989 | 314,903 | 44% |
| 1990-1999 | 209,066 | -34% |
| 2000-2022 | 219,495 | 5% |

[1] Percent change relative to preceding time period.

**Table 4-5 Ranking of Peak Discharge and Annual Volume 1942 - 2022**

| Rank (1942-2022) | Year | Peak Q (cfs) | Year | Annual Volume (acre-ft) |
|---|---|---|---|---|
| 1 | 1971 | 9,580 | 1984 | 1,831,698 |
| 2 | 1983 | 7,800 | 1983 | 1,733,381 |
| 3 | 1973 | 6,930 | 2011 | 1,540,005 |
| 4 | 1942 | 6,610 | 1973 | 1,500,186 |
| 5 | 1984 | 6,220 | 1971 | 1,187,754 |
| 6 | 2011 | 6,040 | 1986 | 1,046,632 |
| 7 | 1951 | 5,390 | 1974 | 913,872 |
| 8 | 1974 | 4,390 | 2016 | 902,329 |
| 9 | 2016 | 3,970 | 1952 | 868,550 |
| 10 | 1958 | 3,710 | 1976 | 660,109 |
| | | | | |
| **Time Period** | **# of Peak Q Events in Top 10** | | **# of Volume Events in Top 10** | |
| **1942-1969** | 3 | | 1 | |
| **1970-1989** | 5 | | 7 | |
| **1990-1999** | 0 | | 0 | |
| **2000-2022** | 2 | | 2 | |

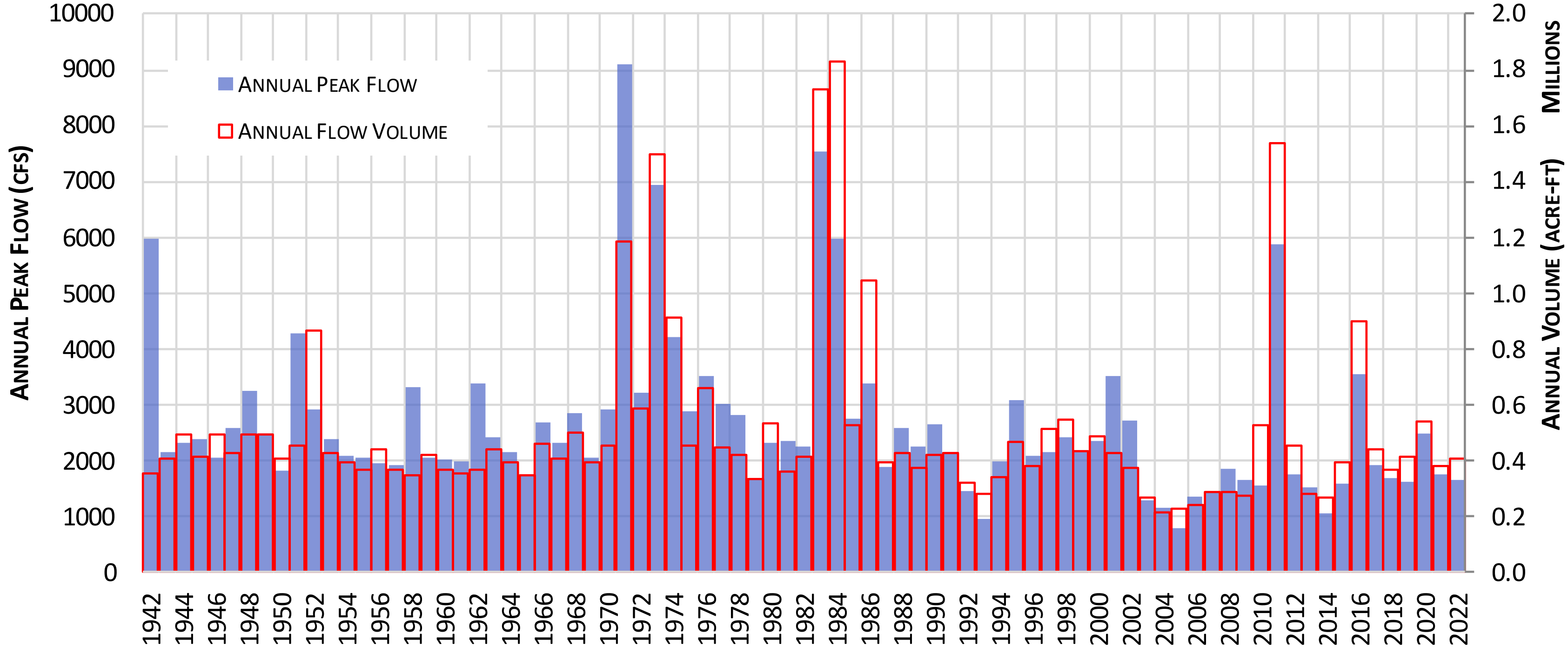



**Figure 4-10 Peak Discharge and Annual Volume 1942 – 2022 North Platte River at HWY 83**

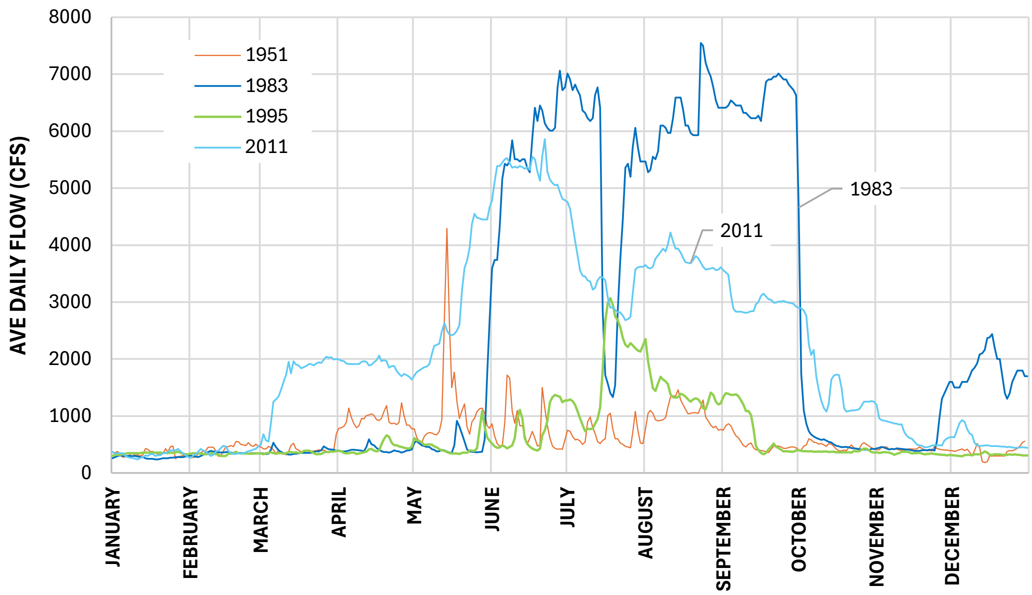



**Figure 4-11 Annual Hydrographs 1951, 1983, 1995, 2011**

### *Flood Frequency*

Peak flood discharge values from FEMA (2009) and the USACE (2013) are provided for reference in Table 4-6. Based upon the USACE 2013 flood frequency the 1983 and 1984 peak flows are roughly a 25-year flood event. The 2011 event has a roughly 10-year return period.

**Table 4-6 Flood Frequency FEMA 2009 and USACE 2013**

| Annual Exceedance Probability (%) | Annual Return Period (years) | Peak Flow (cfs) FEMA 2009 | Peak Flow (cfs) USACE 2013 |
|---|---|---|---|
| 0.5 | 2 | | 2,590 |
| 0.2 | 5 | | 4,740 |
| 0.1 | 10 | 4,900 | 6,690 |
| 0.04 | 25 | | 9,130 |
| 0.02 | 50 | 7,980 | 11,650 |
| 0.01 | 100 | 9,690 | 14,700 |
| 0.005 | 200 | | 17,600 |
| 0.002 | 500 | 14,900 | 19,400 |

# 5 HYDRAULIC CHARACTERISTICS AND CAPACITY

## 5.1 Hydraulic Modeling

### *5.1.1 Previous Hydraulic Modeling*

HDR and Tetra Tech developed 1D hydraulic modeling of the North Platte River from the Keystone Diversion downstream to the Tri-County Canal Diversion intended to be used to estimate attenuation of North Platte River flows during short duration high flow releases. Development of the model is documented in a 2011 report entitled "Platte River Recovery Implementation Program 1-D Hydraulic Modeling Technical Report. Keystone Diversion to North Platte (River Mile 370 – River Mile 310)."

The HDR/Tetra Tech 1D hydraulic model has been utilized throughout the years and is the most comprehensive model of the North Platte River downstream of the Keystone Diversion. The model was developed from 2009 LiDAR data collected on March 19, 2009. A limited amount of bathymetric survey data collected between 1998 and 2009 was incorporated within the "Chokepoint" reach of the model. In locations where no bathymetric survey was available the channel bottom was approximated by account for flow in the channel at the time of the LiDAR flight. Model calibration included iteratively adjusting the channel bed elevation so that model water surface matched LiDAR water surface to within 0.3 feet. This model is referred to in the text at the 2011 HDR/Tetra Tech model.

### *5.1.2 Updated Hydraulic Modeling in Chokepoint Reach*

Both 1D and 2D hydraulic models of the Chokepoint study reach were updated and/or developed to evaluate hydraulic conditions for a range of flows. Three variations of a 1D HEC-RAS model were developed, each referencing a different geometry (2009, 2017, and 2023). The 2011 HDR/Tetra Tech model includes 50 cross sections developed from 2009 LiDAR data and in-channel survey information as previously described. The 2017 1D model maintains the same cross sections cut using the 2017 LiDAR, which includes bathymetric survey. A 2023 1D hydraulic model was also developed, with cross section geometry derived from 2020 LiDAR in the overbanks supplemented with 2023 in channel survey collected in October of 2023. All models include the HWY 83, UPRR, and HWY 30 bridges as well as the TCCD structure. Gates at the northern end of the TCCD were opened so that incoming flow passes through the gates with a headwater elevation between 2769 and 2770 to facilitate diversion without overtopping the ogee spillway. The state channel berm is reflected in the 2017 and 2023 modeling. Models were calibrated using available measured data at the HWY 83 gage. The 1D hydraulic models were primarily used to determine capacity at the HWY 83 gage, compare channel geometry, and compute sediment transport rating curves.

A 2D hydraulic model of the entire study reach was developed in HEC-RAS 6.3.0 using the 2017 LiDAR terrain. Hydraulic structures (HWY 83, UPRR, and HWY 30 bridged, state channel berm, and TCCD) are included as well as a short portion of the South Platte River at the confluence. North Platte flow inputs range from 400 cfs up to 6,000 cfs. Flow input from the South Platte was assumed to be half of the North Platte (e.g., North Platte Q = 6,000 cfs and South Platte Q = 3,000 cfs). There is no clear relationship between North and South Platte daily discharge. The model includes two downstream boundary conditions to allow for flow to exit the model through the Tri-County Canal and downstream of the diversion structure in the Central Platte. The TCCD includes the northern outlet which is open enough for each flow event to maintain a headwater elevation between 2769 and 2770 to facilitate flow diversion without overtopping the ogee spillway. The 2017 LiDAR just upstream of the TCCD was modified to account for dredging needed to pass flow through the outlet gates. Model calibration was conducted using HWY 83 gage data. 2D model results were used in this study to provide inundation mapping and determine hydraulic characteristics for a range of flows up to 6,000 cfs. An additional SRH-2D model was also developed for 2D sediment transport modeling that will be included in a different report related to the current study.

## 5.2 Hydraulic Structures

The presence of hydraulic structures within a river system can influence flow and sediment conditions. Hydraulic structures located within the study reach are described below. Information about the potential influence of each structure on hydraulics and geomorphology are summarized below.

***HWY 83 Bridge***

The HWY 83 bridge, reconstructed in 1970, has a 350-foot-wide opening, roughly 6.5 feet of vertical opening from the bottom of the channel, and five bridge piers. Currently, this bridge can pass roughly 10,000 cfs before it becomes pressurized.

***UPRR Bridge***

The UPRR Bridge includes a 900-foot-wide opening, with 18 cell openings separated by large piers, and roughly 6 feet between the main channel bottom and low chord. Roughly 60% of the bridge width is heavily vegetated and filled with sediment, with roughly 300 feet of the total opening width left to efficiently convey flow. This bridge has the lowest capacity in the reach at just under 7,000 cfs before it becomes pressurized.

***HWY 30 Bridge***

The HWY 30 Bridge has a 550-foot-wide opening, 4 bridge piers, and a maximum of 8 feet between the channel bed and low chord. The HWY 30 bridge can pass approximately 20,000 cfs without pressurizing.

***Tri-County Canal Diversion***

The TCCD was constructed between 1936 and 1940 as part of the Tri-County Project, becoming operational in early 1941. The structure is 870 feet wide and spans the Platte River just downstream of the North and South Platte confluence. The diversion includes outlet gates located on the north and south ends of the structure to pass river flows, with a 375-foot-wide ogee spillway in between. The diversion is

10.7 feet tall from the invert of the lowest river gate (Elev 2759.3 ft, NAVD88) and the top of the ogee spillway crest (Elev 2770 ft, NAVD88). The canal has a diversion capacity of 2,250 cfs. The diversion is typically operated by adjusting gates so that headwater elevations are consistently held between 2769 and 2770 without overtopping the ogee spillway. The water surface at the TCCD is held to a consistent elevation to facilitate diversions and dredging operation. The diversion structure at the northern outlet gates failed in the mid-1980s after sustained high flows and was repaired in 1985.

Between 1941 and 1964 sediment accumulation upstream of the diversion became problematic for CNPPID operations. Observation of river response to the TCCD between 1941 and 1964 was documented in a letter written by Mr. Geo E Johnson to CNPPID in August of 1964. An excerpt from the letter is as follows:

> *"The water level at the confluence of the North and South Platte Rivers was raised nine feet at the time the Diversion Dam of the Supply Canal was constructed. At the present time there is a considerable amount of sand moving down both rivers. A part of this sand has passed through the gates of the Diversion Dam. The greater portion of the sand has been deposited in the basin above the dam.*
>
> *Before the Diversion Dam was constructed, the North Platte and South Platte Rivers were each divided into small streams. The bed of the North Platte River at the USGS Gauging Station at the bridge north of the City of North Platte shows very little change. However, for the first three-quarters of a mile above the Diversion Dam, the North Platte River is filled with an average of seven feet of sand."*

After Mr. Johnson's letter CNPPID began dredging operation at the TCCD in 1965. Since then, dredging operations have been conducted annually. Dredging occurs on average for a continuous 150 days each year with an estimated average volume of 150,000 cy of sediment removed per year, which generally keeps up with sediment delivery. Sediment captured at the TCDD is both from the North and South Platte, with South Platte contributions typically being larger than the North per observations from CNPPID.

Previous hydraulic evaluations have indicated that backwater created by the TCCD impact existing water levels in the river approximately 1 to 1.3 miles upstream (RDG 2023) of the diversion. Comparison of the historic and contemporary bed profile information between 1940 and 2009 indicates that approximately 5 to 8 feet of sand has been deposited in the bed from the TCCD upstream to HWY 30 (2.6 miles). Depositional impacts related to the TCCD extend much further upstream (as far as HWY 83) than backwater, due to a slowing and/or blocking of sand bed movement related to backwater conditions and the presence of the diversion structure. The extent of deposition related to backwater conditions is demonstrated and discussed in Section 6.4.

## 5.3 Hydraulic Capacity at HWY83

Minor flood stage for the North Platte River at North Platte gage (06693000) is 6.0 feet, as currently defined by the National Weather Service (NWS). Previous studies (HDR & Tetra Tech 2011, Parsons 2003, FLO 1992) show that discharges corresponding to flood stages fluctuate over time. Available historic gage rating curves were obtained to evaluate changes in hydraulic capacity over time. Additional data points were developed using measured gage data in the late 90s and 1D hydraulic modeling representative of 2009, 2017, and 2023 conditions. Figure 5-1 shows graphical stage discharge curves from gage rating and 1D hydraulic modeling results. Discharge capacity at minor flood stage summarized in Table 5-1. Capacity is estimated at 5,420 cfs during the late 80s. Little data is available between 1990 and 1998 due to the low range of flow conditions and unavailable gage rating curves. Capacity between 1998 and 2023 has fluctuated between 1,570 and 2,165 cfs, with current capacity estimated in 2023 at 1,764 cfs.

Parsons (2003) study that found that rating curve shifts are definitely evident, and that changes fluctuate every eight to ten years. We agree with that conclusion and that “something” happened or began to happen around 1987 that appears to cause the significant changes between 1987 and 1998. (It is noted that shifts in rating curves were not found to be related to any change in datum and/or gage location.) Further investigation related to capacity was conducted by combining specific gage analysis and results of the hydrologic evaluations.

**Table 5-1 Hydraulic Capacity at NWS 6ft Minor Flood Stage**

| Time Period | Source | Capacity at 6ft Minor Flood Stage (cfs) |
|---|---|---|
| 1986-1990 | Gage Rating | 5,420 |
| 1998 | Measured Gage Data | 1,570 |
| 1999 | Measured Gage Data | 1,910 |
| 2003-2007 | Gage Rating | 2,101 |
| 2007-2018 | Gage Rating | 1,557 |
| 2009 | 2011 HDR/Tetra Tech 1D HEC-RAS Model | 1,546 |
| 2017 | 2017 1D Hydraulic Model | 2,165 |
| 2018-2022 | Gage Rating | 1,927 |
| 2023 | 2023 1D Hydraulic Model | 1,764 |

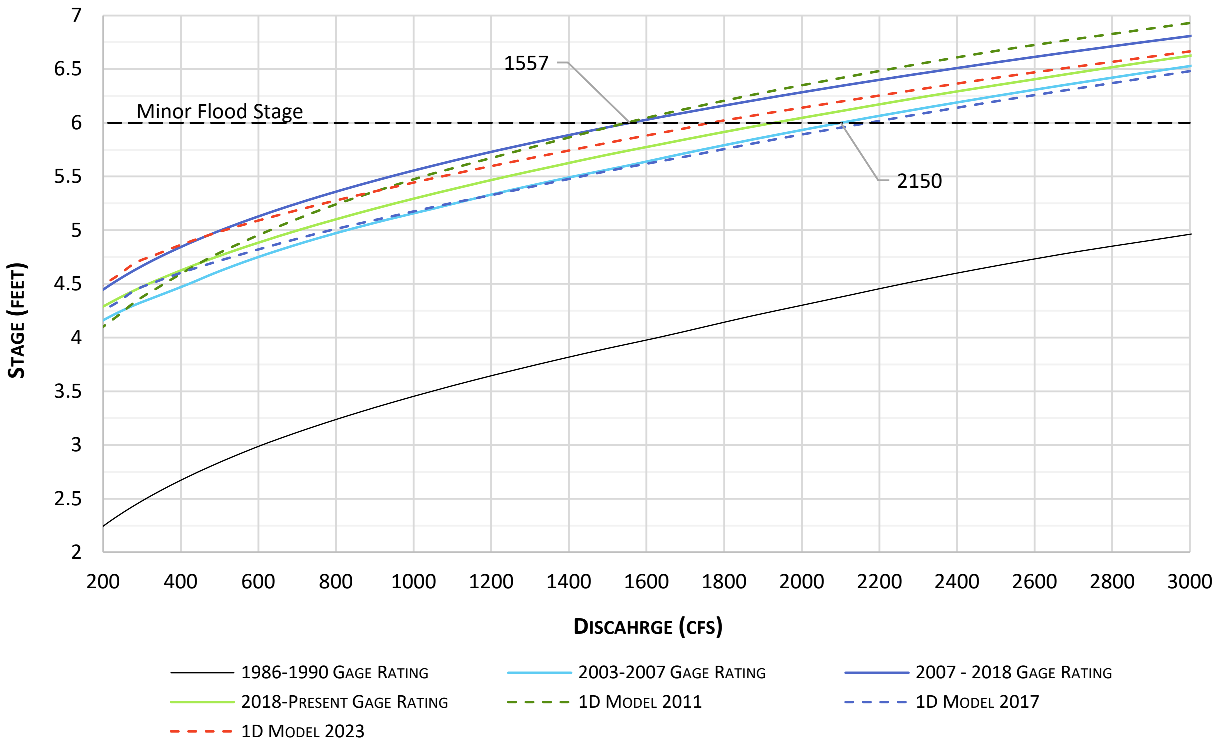



**Figure 5-1 North Platte at HWY 83 gage rating curves and results of calibrated 1D hydraulic modeling.**

## 5.4 Specific Gage Analysis

Specific gage analyses were developed at the HWY 83 and Sutherland gages to evaluate change in stage and capacity.

### *5.4.1 Methods of Analysis*

Specific gage analysis is a useful tool to indicate changes in the stage-discharge relationship. Results can be utilized to identify and inform geomorphic trends. Gage flow and stage measurements were used to construct specific gage curves for selected discharges. Stage data for flow within +/- 5% of a selected discharge value was extracted and plotted through time.

Interpretation of specific gage analyses should carefully consider potential limitations (Biedenharn et al 2017). Results can reliably depict conditions and river change near the gage but may not be representative of conditions in other reaches of the river. While changes in water surface through time can be correlated to vertical bed change (indicating trends of aggradation or degradation) changes in other channel properties should also be considered. Evaluation of active channel widths near the HWY 83 gage through historic aerial photography indicates that there was a distinct change in 1958, but no significant change since. Reconstruction of the HWY 83 Bridge in 1970 did constrict the wider floodplain but active channel widths were not shown to be greatly impacted (see Section Figure 7-12). Stability in width at the gage after 1958 indicates that changes in water surface are likely a reliable indicator of vertical bed change. Further, changes in stage on the North Platte at the HWY 83 gage have been found to be consistent with change in bed elevations from channel survey data and LiDAR.

### *5.4.2 Results*

***North Platte at HWY 83 Gage***

Specific gage plots were developed for a baseflow of 400 cfs, 2,000 cfs, and 3,000 cfs (Figure 5-2). The figure also includes corresponding daily flow records for reference. All three curves follow the same general trends, with an overall increase in stage from 1942-2022 of 2.7 feet. From 1942 to 1969, there is a gradual and consistent increase of roughly 1.2 feet. Between 1971 to 1973 there is a decrease in stage that coincides with two large floods events. This is followed by another period of gradual and consistent increase of nearly a foot until 1983. The baseflow shows a large decrease of 1.2 feet in 1983. A more rapid increase in stage is noted between 1988 and 1998. It is theorized that significant flooding, both in magnitude and duration, in the 70s and 80s scoured the upper end of the river below Lake McConaughy.

Lake McConaughy should trap most sediment coming from the upstream watershed and thus actually limit the amount of sediment within the North Platte upstream of the HWY 83 gage. Large amounts of sediments mobilized due to clear water scour downstream of Lake McConaughy took years to migrate 60 miles downstream to the Chokepoint segment given drier hydrologic conditions in the 1990s. The clear water discharge from Lake McConaughy likely initiated that slug that was then scoured by flows during the wet 1970s and 1980s, which would alter the sediment equilibrium within the majority of the channel. It is believed that the movement of the large “slug” of sediment appears in the data in the 1990s. Between 1998 and 2022 stage has remained relatively stabilized with +/- 0.5 feet fluctuations.

It is noted that for flow events over 4,000 cfs an immediate dip in stage occurs during the 70s and 80s, however after the 2011 event with a peak flow of roughly 6,000 cfs a similar response was not strongly reflected in the data.

***North Platte at Sutherland Gage***

Figure 5-3 shows specific gage results at the Sutherland Gage for a baseflow of 150 cfs, 750 cfs and 1,500 cfs. There is a gradual decrease in stage of 0.5 to 1.0 foot between 1942 and 1970 which could be attributed to reduced sediment supply and potential clear water associated with construction of Lake McConaughy. An abrupt reduction in stage is noted in 1971 and 1973, which corresponds to large flood events during those years. Stage slightly decreases until 1983/1984 and levels off between 1985 and 1991. What is remarkable is the change that occurs after 1991 where the trend reverses and stage increases rapidly until 1999. This same rate of increase is shown at the HWY 83 gage. As discussed above it is believed that the movement of the large slug of sediment mobilized in the 70s and 80s appears in the Sutherland Gage data when the trend of aggradation begins. Also similar to HWY 83, results show a stabilization in stage between 1999 to 2022 except for a temporary decrease noted in 2012 which could be response to the 2011 flood.

### *Comparison of Results at Sutherland and HWY 83*

Trends noted in the specific gage analysis at Sutherland and HWY 83 were compared by plotting the baseflow curves for each gage together, see Figure 5-4. Evaluation of changes in stage at baseflows give a good indication of bed elevation change in the North Platte based upon a comparison to bed profile changes noted using survey data. The magnitude and trends noted at HWY 83 in bed survey data correlate well with specific gage analysis of baseflow.

There are four distinct time periods where trends in specific gage results are observed including 1942-1969, 1970-1989, 1990-1999, and 2000-2022. During the 40s, 50s, and 60s there are opposing trends observed with a steady reduction in stage noted at Sutherland and a steady increase at HWY 83. The decrease at Sutherland is likely a result of river response to clear water releases from Lake McConaughy. The opposite response at HWY 83 is in part due to backwater and depositional impacts associated with the TCCD.

The opposing trends generally continue through the 70s and 80s. This period is distinctly different hydrologically in that there were several large peak flood events with significant duration, as shown in the hydrologic evaluation. Hydrologic and sediment transport evaluations suggest that hydrology occurring from 1970-1989 could mobilize much larger quantities of sediment (roughly 2.5 times higher) than in the decades before and after. At the end of this wet period, roughly 1988, there is a remarkable shift in trend to aggradation at Sutherland which aligns with HWY 83. After 1988 both gages indicate the same trends. During the 1990s stage at both locations show a rapid increase in stage occurring at a similar rate. This rapid increase, suggesting aggradation, is likely due to movement of a large "slug" of sediment mobilized during the previous decades that cannot be efficiently transported by the lower flow conditions in the 1990s. This conclusion is supported by a comparison of bed profiles between 1940 and 2009, presented and described in Section 7.2. The profile analysis shows severe degradation in the river extending roughly 9 miles downstream of Lake McConaughy, which supports clear water scour conditions. Conversely, a similarly strong signal of aggradation is shown in the profile comparison along the lower 11 to 18 miles of the North Platte upstream of the TCCD. It is also worth noting that temporal evaluation of active channel width and vegetation cover do not indicate a strong signal of change during the 1990s as shown in Figure 7-23 and Figure 8-7, respectively. Similarly, there isn't a remarkable change in side-channel lengths or braiding index during the 1990s (see Figure 7-8 and Figure 7-9), as adjustments in these metrics were largely realized prior to 1960. See Figure 10-1 in Section 10.7 for a visual comparison of specific gage results, active channel area, width, slope, and vegetation trends over time.

After 1999 both locations show a general stabilization of stage with some fluctuation. The stabilization of stage, especially after 2010, might suggest that the sediment "slug" has largely moved through the system. It may also indicate that the river is approaching quasi-equilibrium if hydrologic conditions remain relatively constant. This conclusion should be taken with caution, as projecting specific gage records into the future is not recommended (Biedenharn et. al. 2017).

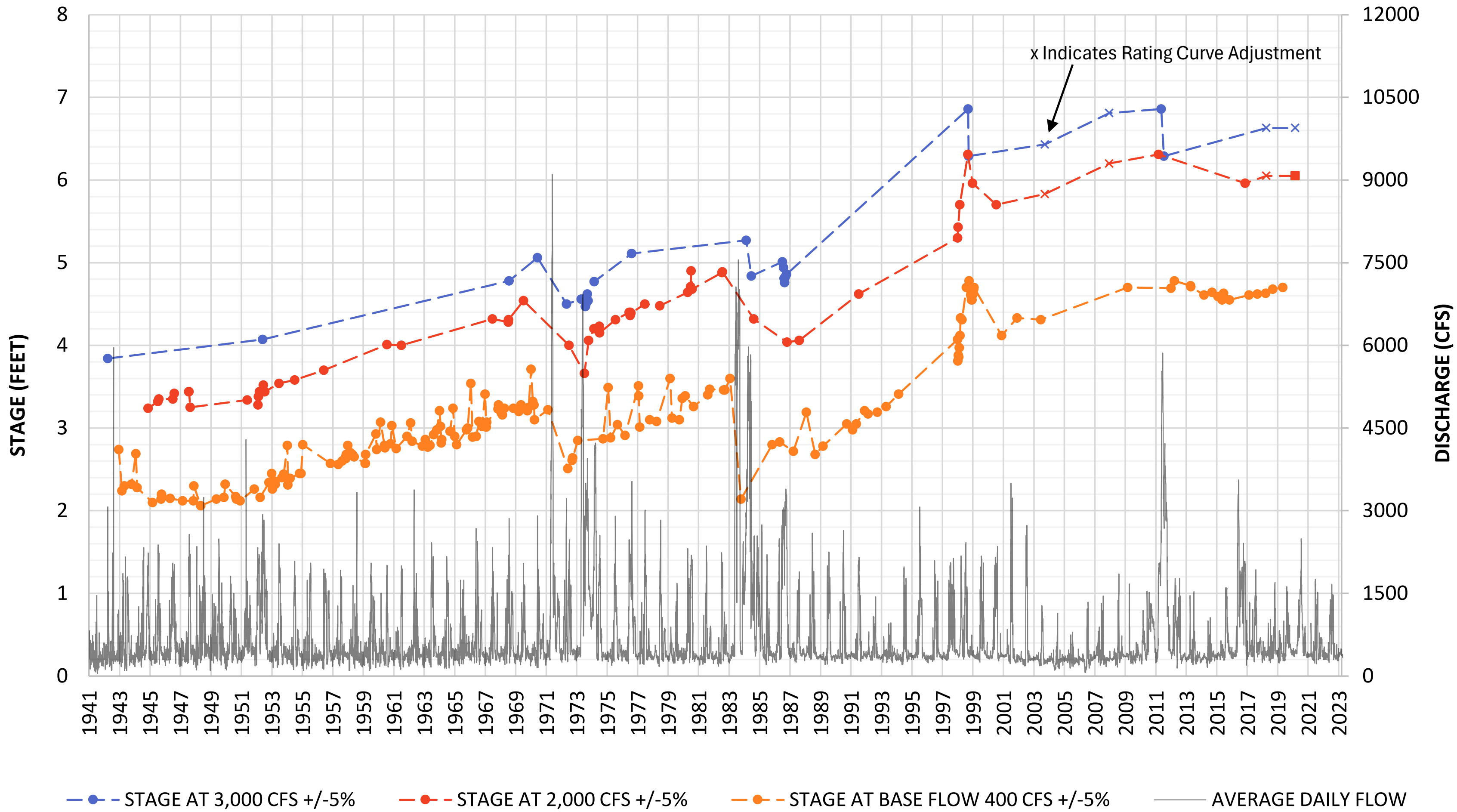



**Figure 5-2 Specific Gage Analysis North Platte River at HWY 83 1942-2022**

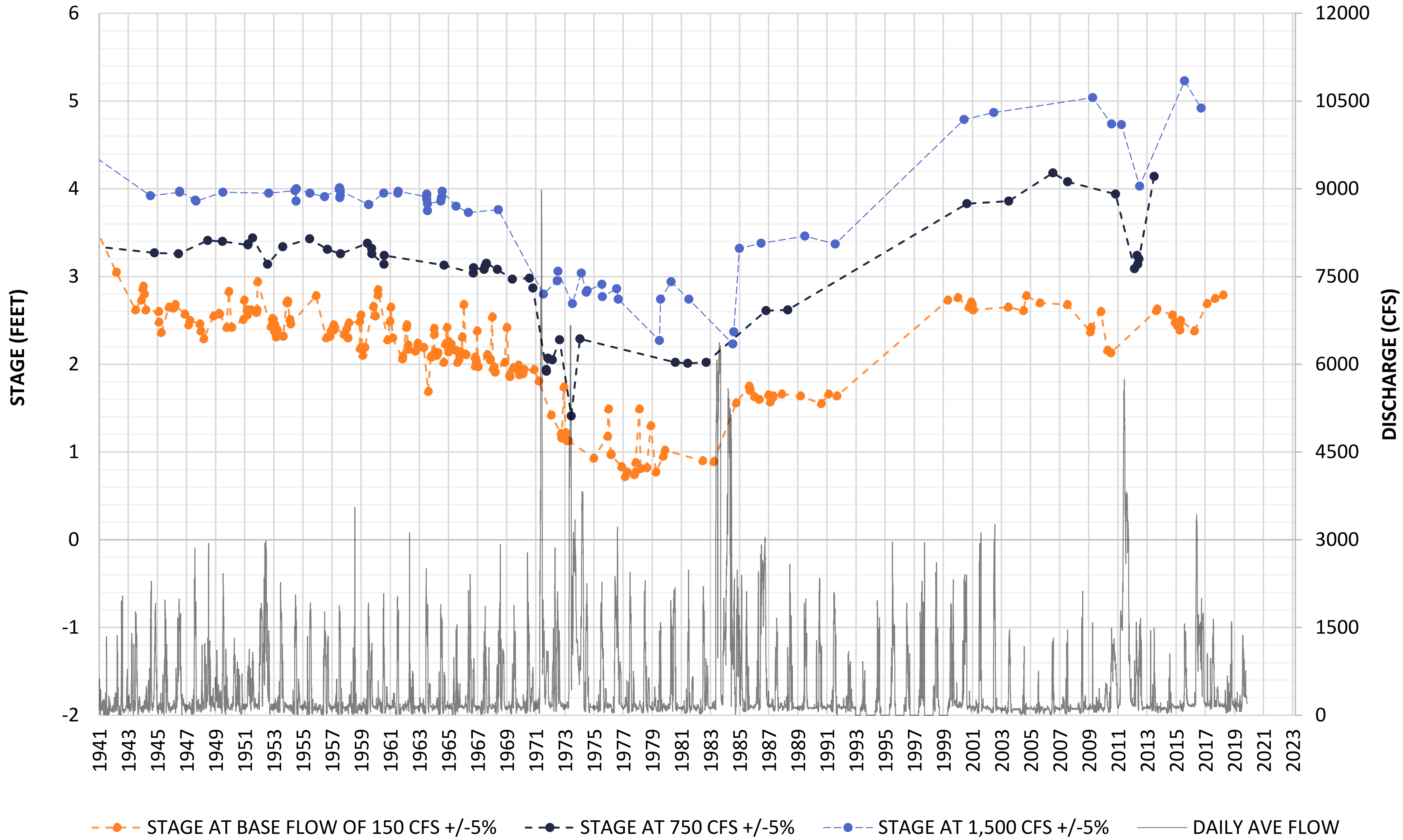



**Figure 5-3 Specific Gage Analysis North Platte River at Sutherland 1942-2022**

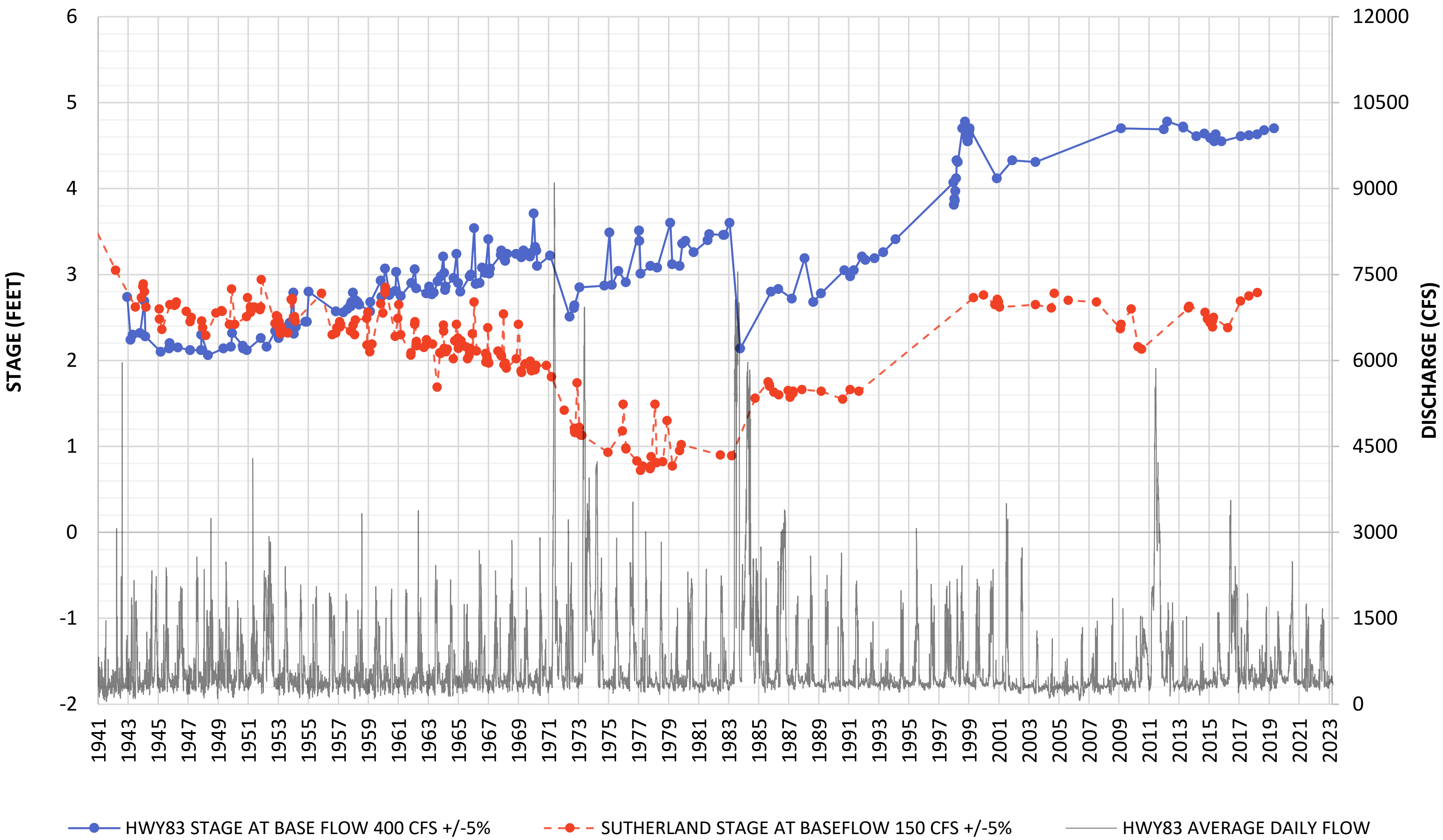



**Figure 5-4 Comparison of HWY 83 and Sutherland Specific Gage Analysis at Baseflow**

## 5.5 Hydraulic Characteristics

Spatial evaluation of hydraulic characteristics (depth, velocity, shear, etc.) are useful to inform and explain sediment transport and geomorphic trends and processes.

### *5.5.1 Method of Analysis*

Results from the 2017 2D hydraulic model were used to develop inundation mapping, water surface profiles, and evaluation of velocity and shear stress for selected flows including 400 cfs (baseflow), 1,500 cfs (just under bankfull and lower limit of capacity at minor flood stage), 2,000 cfs (just over bankfull flow and upper limit of capacity at minor flood stage), 3,000 cfs (project target flow), and 6,000 cfs (similar to peak of 2011 flood). Water surface, depth, velocity, and shear stress were extracted from the 2D hydraulic model along a profile baseline. Detailed profile plots of depth, velocity, and shear stress are shown along with a reach averaged value to provide context related to natural variability along the length of the river as well as influence of bridge structures. Average values in Reach 7 do not include data between the confluence and TCCD. Planview mapping of velocity and shear stress is provided for selected flows to illustrate variability throughout the channel and floodplain.

The force required to initiate motion of sediment particles is referred to as critical shear stress ($\tau'_c$ ). Shear stress values from the 2D hydraulic model were compared with estimated critical shear stress required at incipient motion of the bed material. Critical shear stress at initiation of motion ($\tau'_c$ ) is given by:

$$\boldsymbol{\tau'_c = \Phi\rho g(s-1)D}$$

in which:

$\Phi$ = critical dimensionless shear stress (0.02 to 0.047)
$\rho$ = mass density of fluid
g = acceleration of gravity
D = representative particle diameter of boundary material
s = mass density of sediment relative to mass density of fluid

Values of critical dimensionless shear stress **(**$\Phi$) applied to incipient motion calculations are subject to ongoing debate in the literature. A standard value of 0.047, based on the Shields diagram, is often used in practice. Recommendations in the American Society of Civil Engineers (ASCE) Manual of Practice (ASCE 2007) suggest a critical shear stress for initiation of motion in fully turbulent flow at half of the value indicated by the Shields diagram. For purposes of this study, we applied a range of critical dimensionless shear values (0.02 to 0.047). Planview mapping of velocity and shear stress is provided for selected flows to illustrate variability throughout the channel and floodplain.

### 5.5.2 Results

#### *Water Surface Profiles, and Inundation Mapping*

Water surface profiles for the selected flows are shown graphically in Figure 5-5. Figure 5-7 through Figure 5-10 show limits of inundation for 1,500, 2,000, and 3,000 cfs. Separate inundation maps of each flow are provided in Appendix E.

Backwater effects related to bridge structures can be visually seen in the profiles. HWY 83 creates some backwater at around 1,500 cfs with impacts to water surface profiles extending approximately 1,200 feet upstream. The Railroad bridge creates the largest backwater effect in the reach that extends roughly 1,500 feet upstream. The HWY 30 has limited backwater impact. Also noted in the profile is backwater associated with floodplain constriction related to the State Channel Berm (downstream limit located at station 863,000), which confines flows up to 3,000 cfs.

Historically, backwater from the TCCD extended approximately 2 miles upstream of the diversion, which has resulted in formation of a "sediment wedge" (see Section 7.2). The 2017 bed profiles show significant channel aggradation of 5 to 8 feet between HWY 30 and the TCCD (see Section 7.2). The 2017 bed elevation at the confluence with the South Platte River is approximately 2768.5, which is within 1.5 feet of the ogee spillway crest elevation, as shown in the water surface profile. Backwater specifically related to the TCCD no longer extends much more upstream than the confluence, due to bed aggradation. Currently, there are some backwater effects related to the constriction of flow just below the confluence. Figure 5-6 shows hydraulic model results between the confluence and TCCD. The figure includes inundation mapping, velocity vectors, and water surface elevations and indication of the constriction of flow described above.

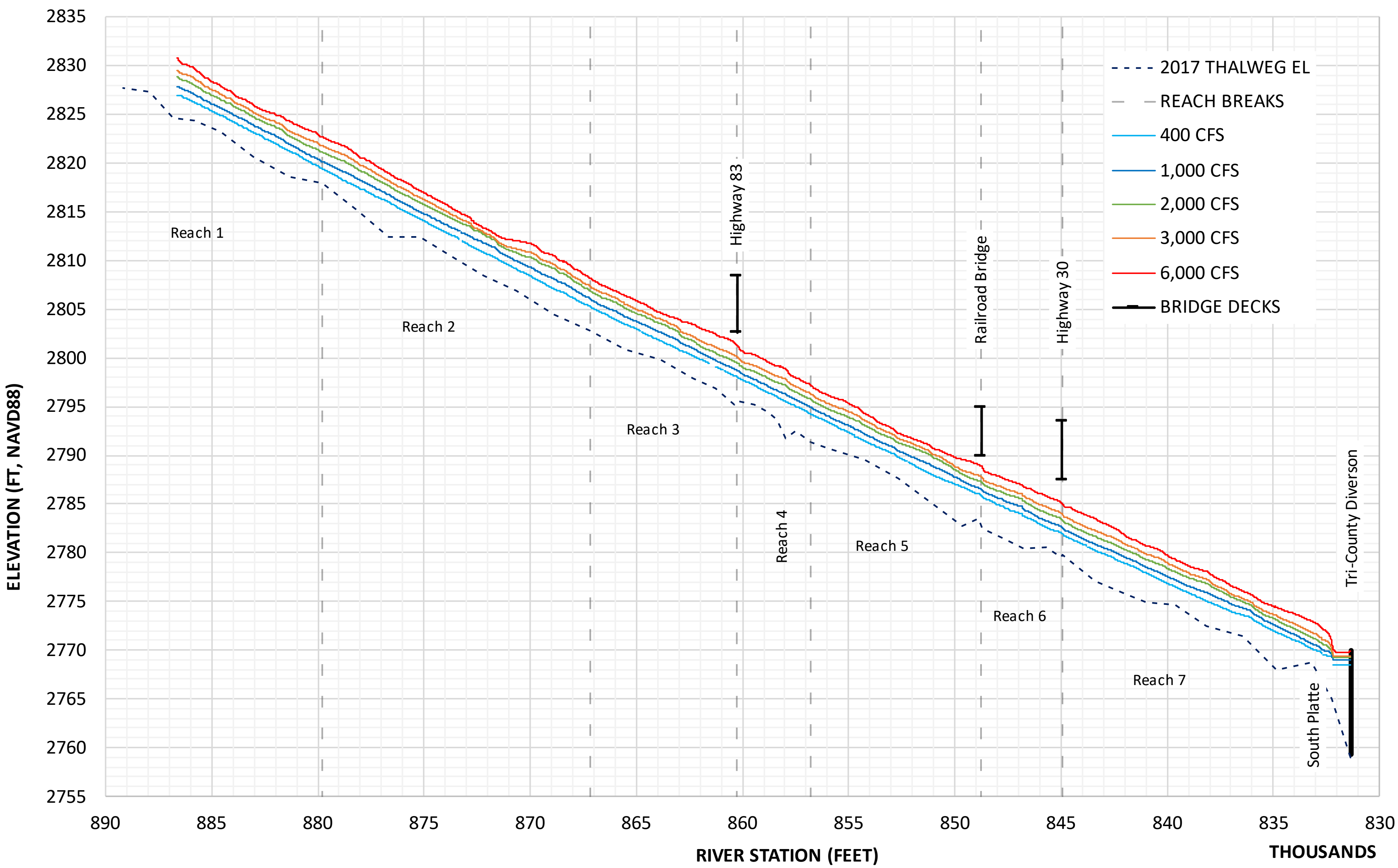



**Figure 5-5 North Platte Chokepoint 2D Hydraulic Model Water Surface Profiles 400 – 6,000 cfs.**

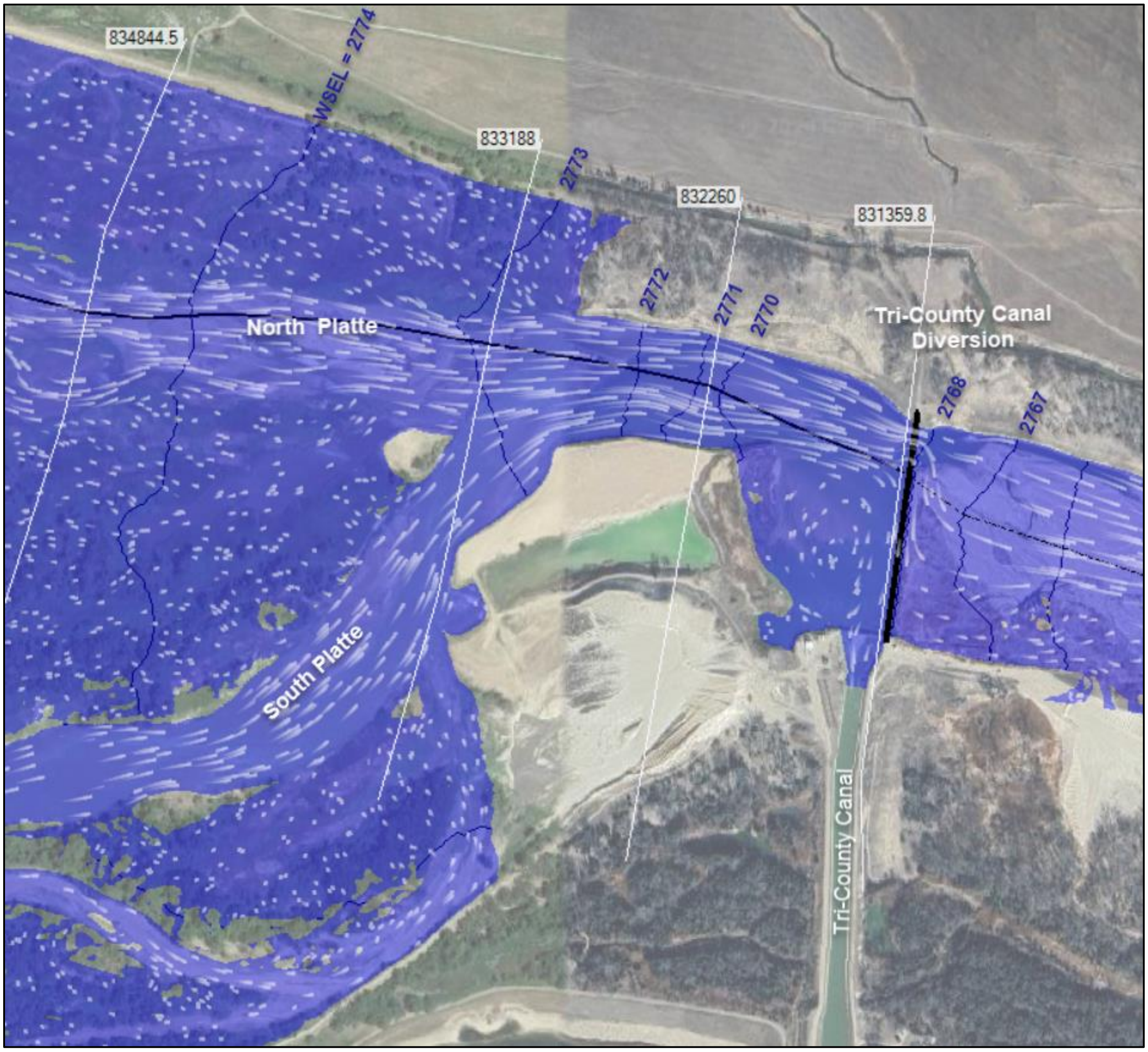



**Figure 5-6 Hydraulics at Tri-County Canal Diversion – 6,000 cfs (6,000 cfs North Platte and 3,000 cfs in South Platte).**

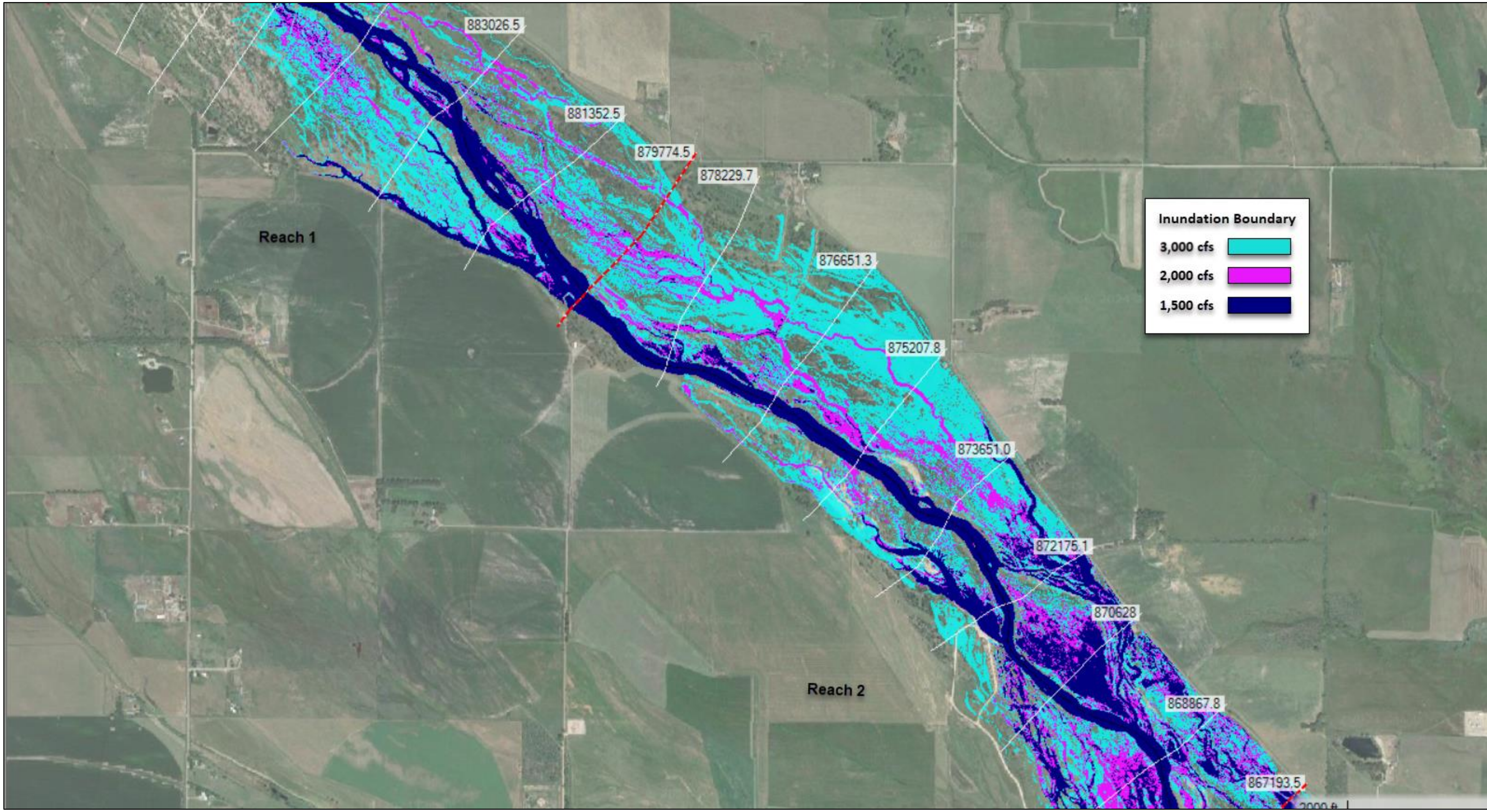



**Figure 5-7 Inundation Mapping 1,500, 2,000, and 3,000 cfs – Upstream Reach to Campground**

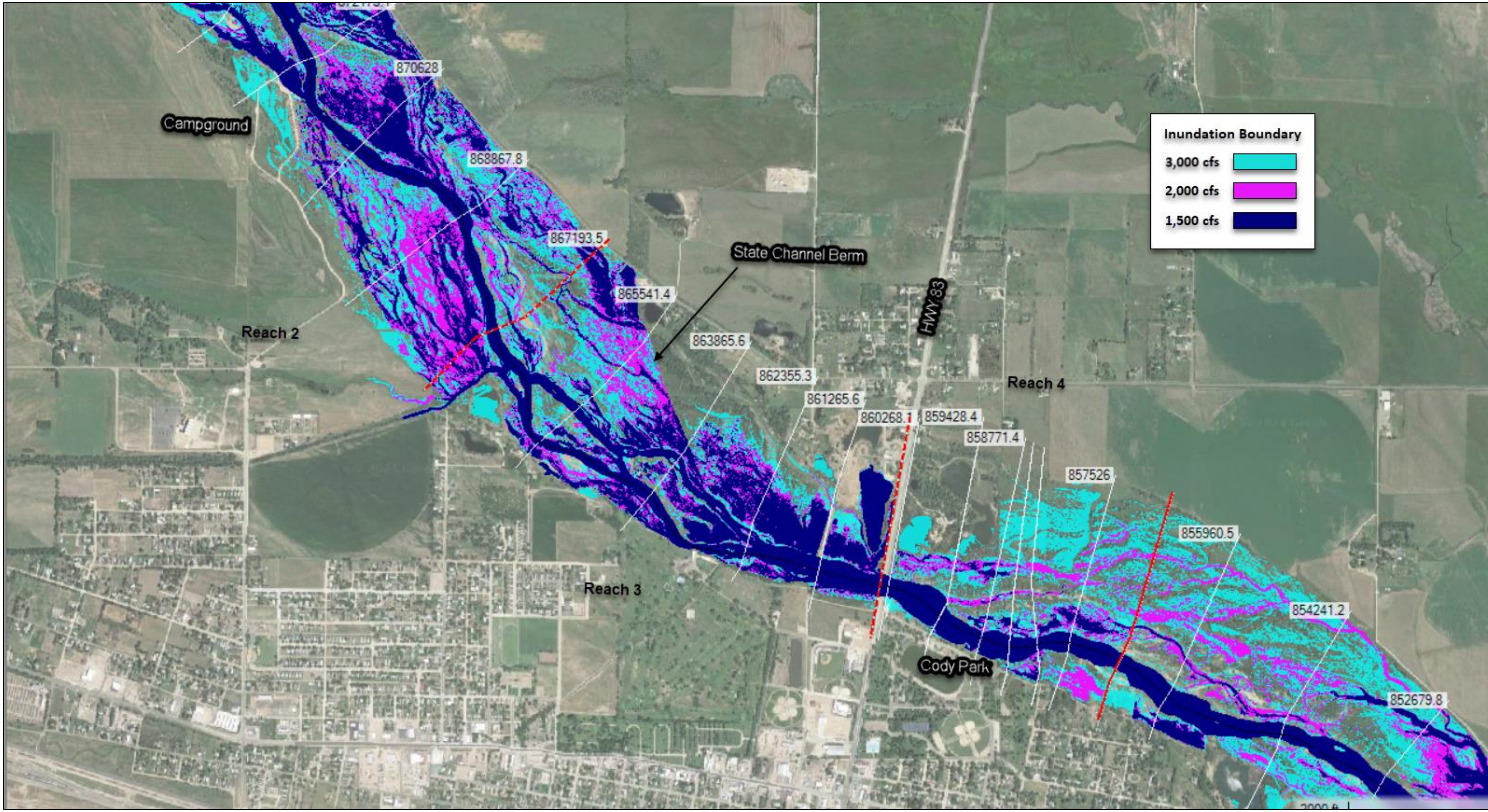



**Figure 5-8 Inundation Mapping Inundation Mapping 1,500, 2,000, and 3,000 cfs – Campground to Cody Park**

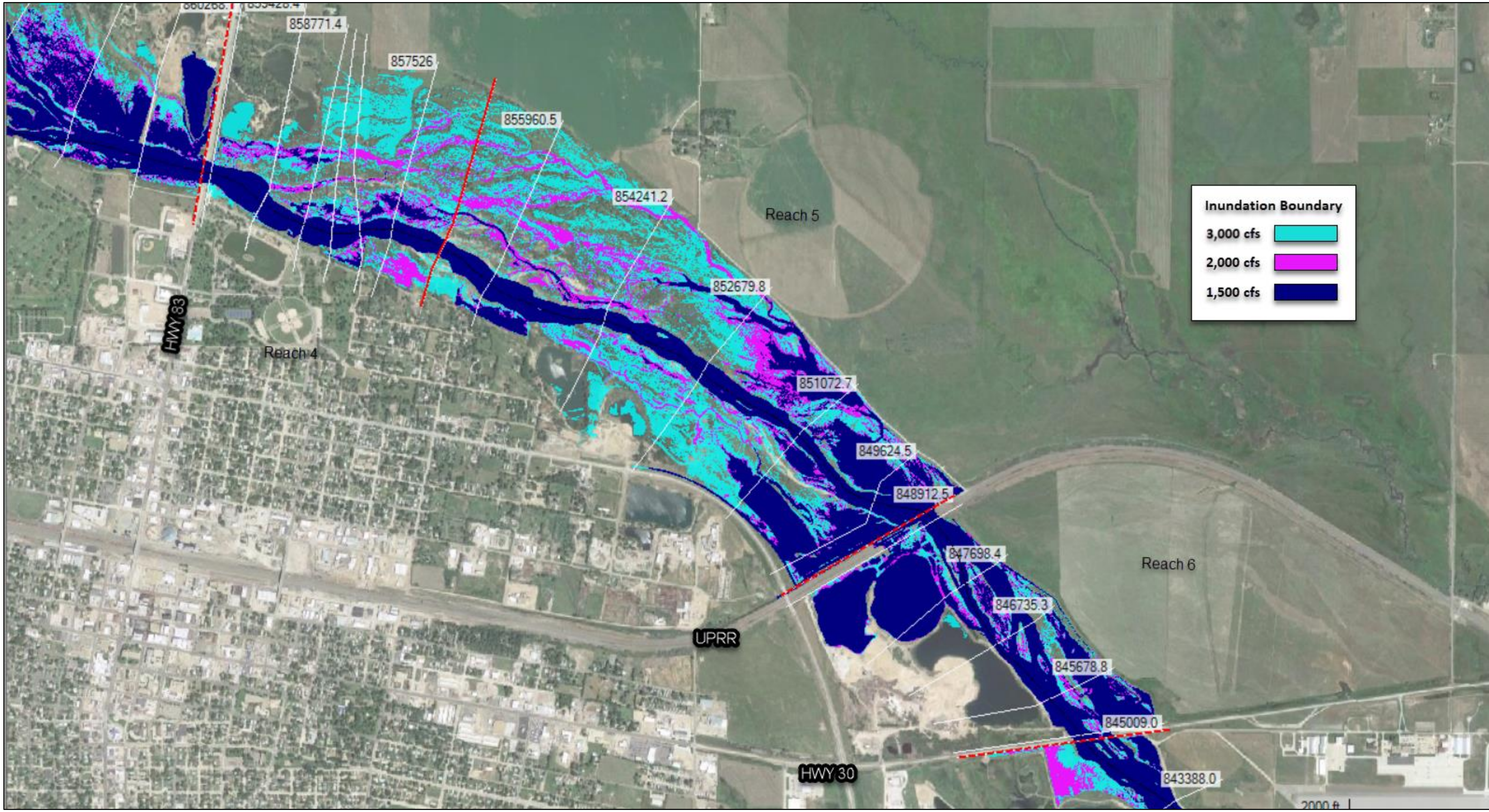



**Figure 5-9 Inundation Mapping Inundation Mapping 1,500, 2,000, and 3,000 cfs – HWY 83 to HWY 30**

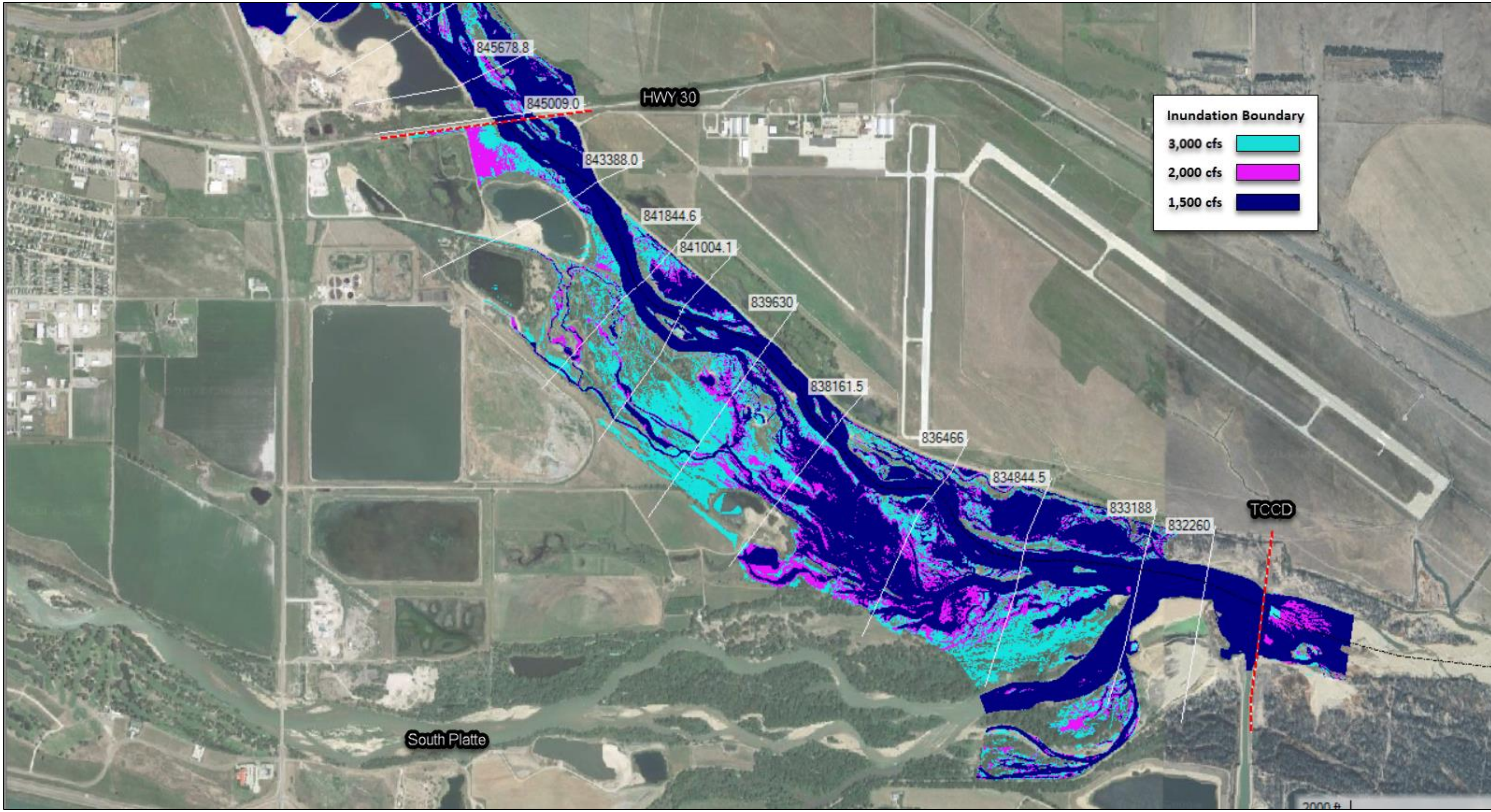



Figure 5-10 Inundation Mapping Inundation Mapping 1,500, 2,000, and 3,000 cfs – HWY 30 to Tri-County Canal Diversion

### *Velocity and Shear Stress*

Detailed velocity and shear stress for 2,000 cfs is shown graphically in Figure 5-11. Velocities for 2,000 cfs range between 2.2 and 4.5 ft/sec, with reach average values ranging from 2.8 to 3.3 ft/sec. Shear stress at 2,000 cfs ranges from 0.1 lbs/sq ft up to 0.25 lbs/sq ft, with reach average values in the range of 0.13 to 0.18 lbs/sq ft. Reach average velocity and shear stress for all other flows is shown in Figure 5-12. For flows 3,000 cfs and less there is a slight decreasing trend in velocity and shear stress in the downstream direction. Velocity and shear stress mapping is shown in Figure 5-13 through Figure 5-18. The mapping illustrates spatial variability throughout the channel and overbanks. Velocities in the floodplain do not exceed 1 ft/sec and are generally consistent in the channel. Shear stress mapping shows low values of shear stress throughout except for some areas along banks that indicate shear stress of more than 2 lbs/sq ft. These areas are consistent with bank erosion noted in the field. Additional results including profile plots and mapping for each flow evaluated are provided in Appendix E.

The velocity results, and companion shear stress results, suggest limited fluctuation within reaches and along the entire segment, indicating minimal if any conveyance problems, such as blockages or constrictions.

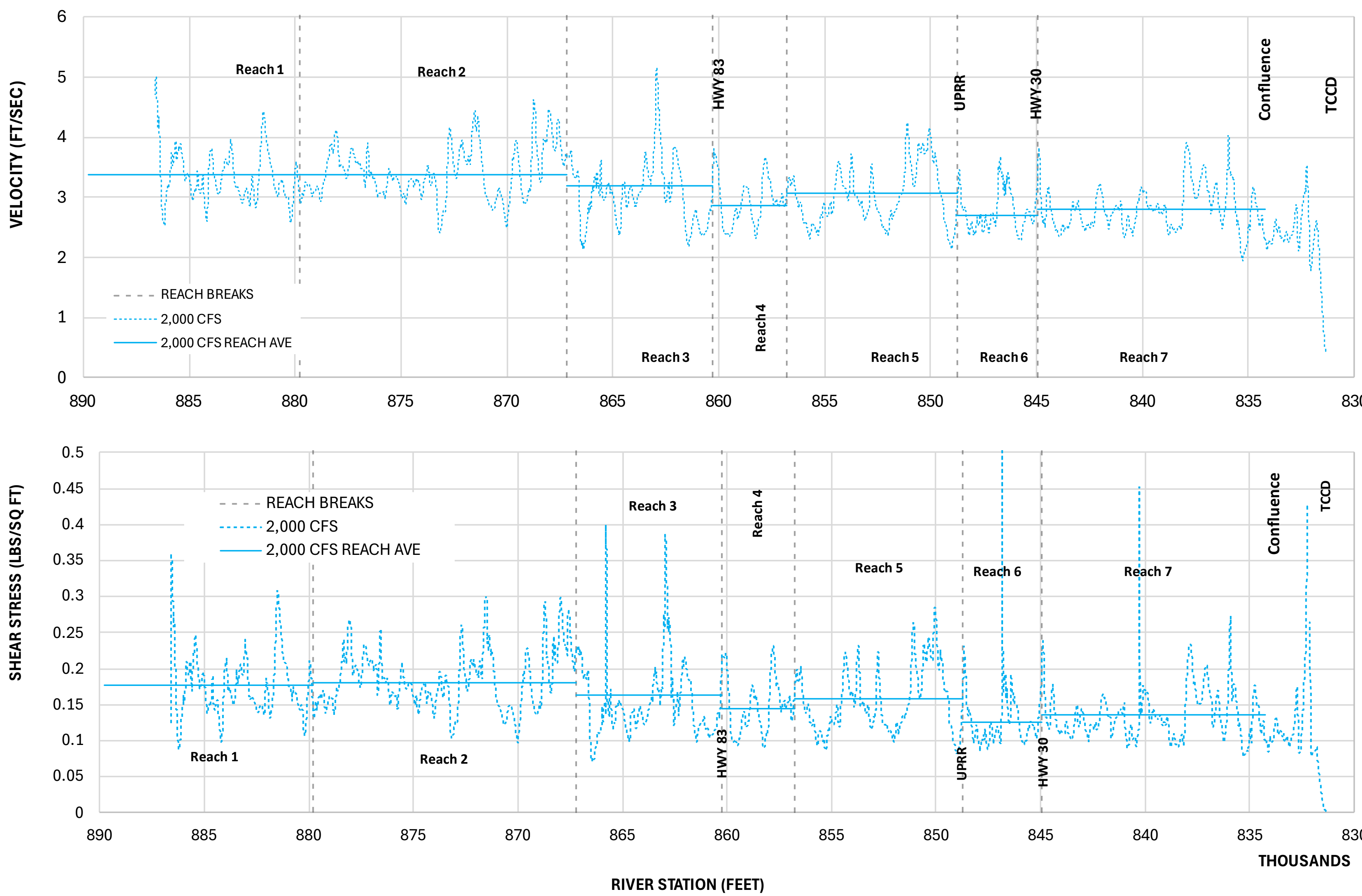



**Figure 5-11 2D Hydraulic Model Velocity and Shear Stress Profile – 2,000 cfs**

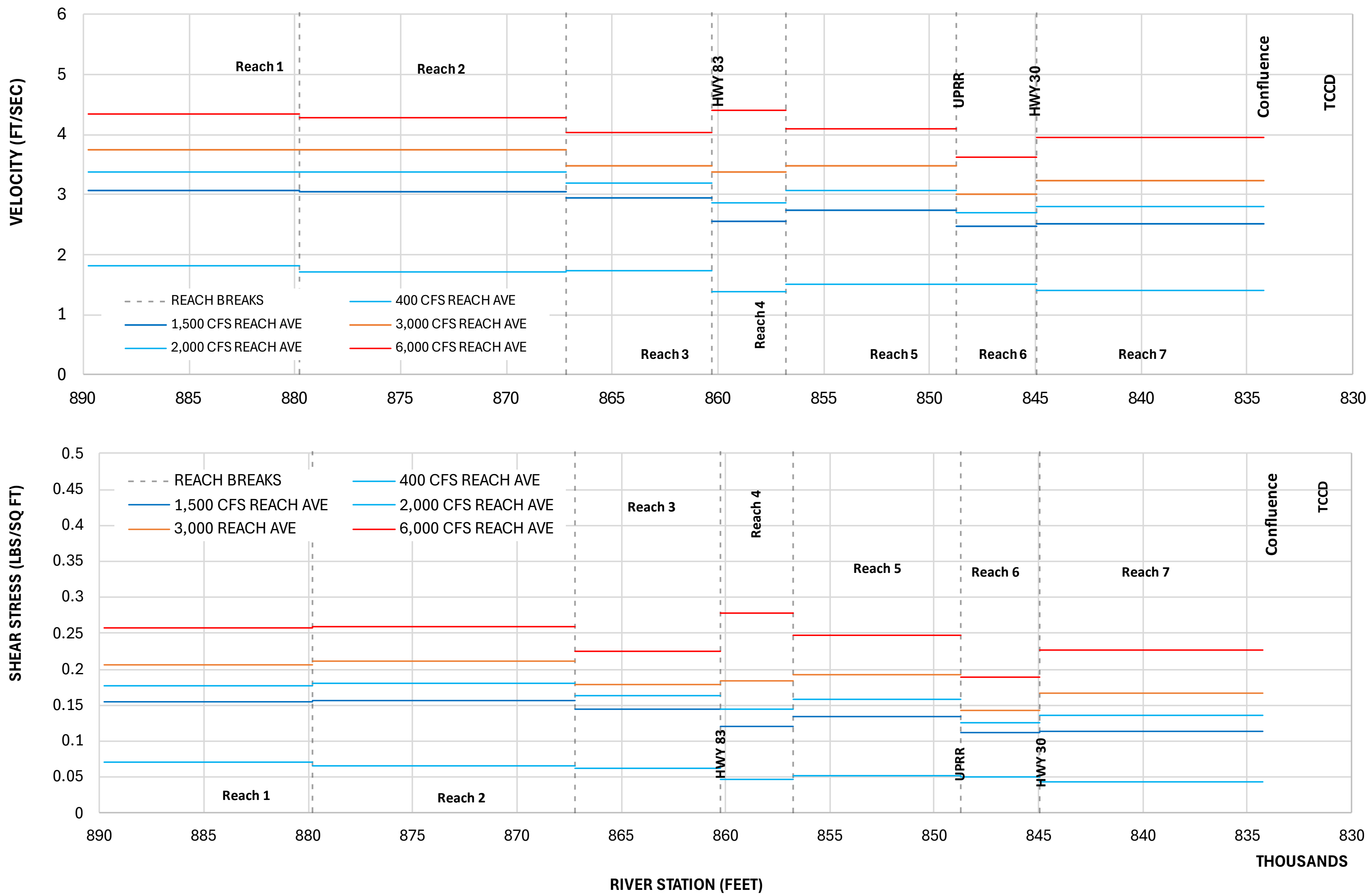



**Figure 5-12 2D Hydraulic Model Reach Average Velocity and Shear – 400, 1,500, 2,000, 3,000, and 6,000 cfs.**

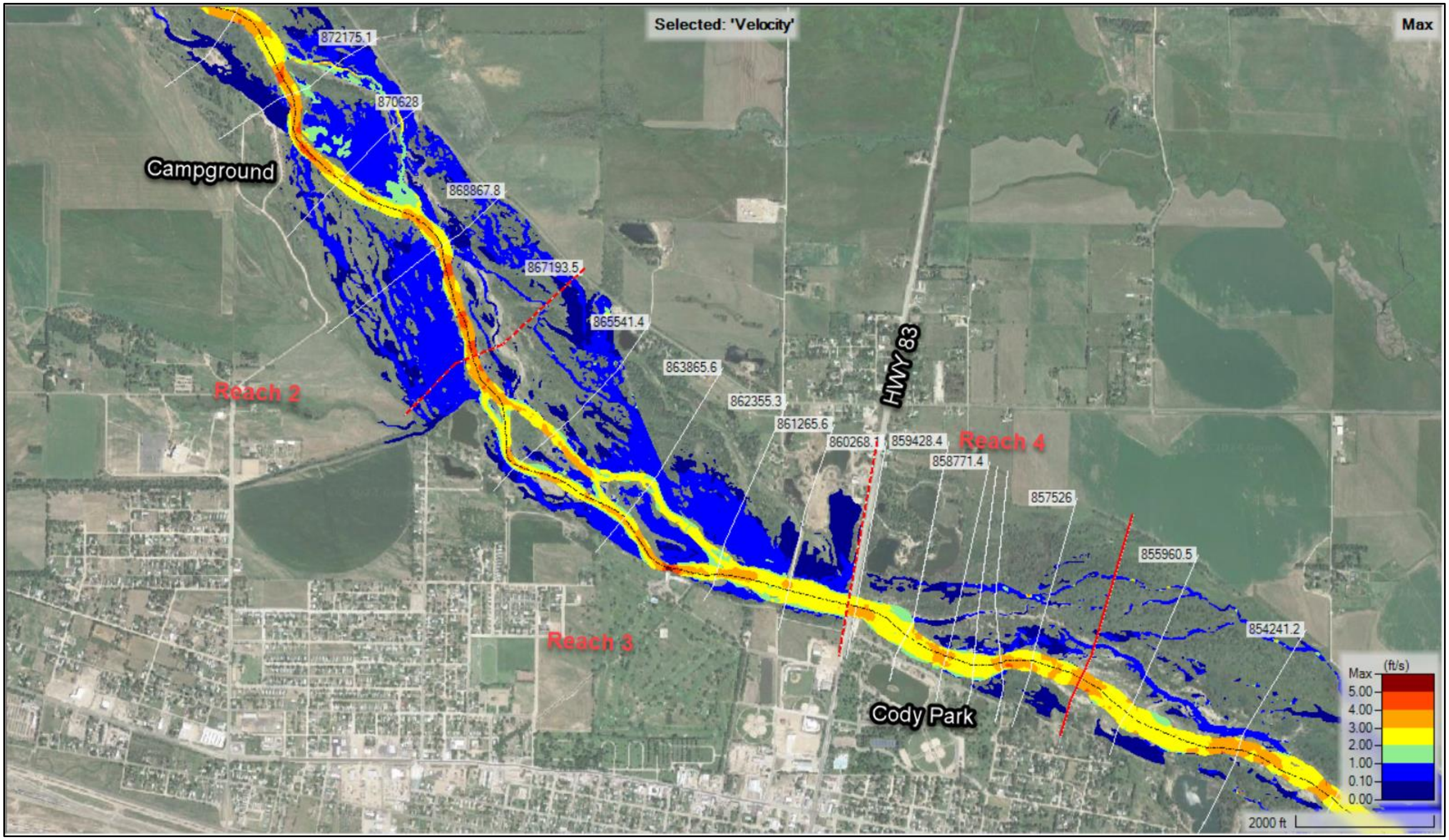



**Figure 5-13 Mapping of Velocity at 2,000 cfs – Campground to Cody Park**

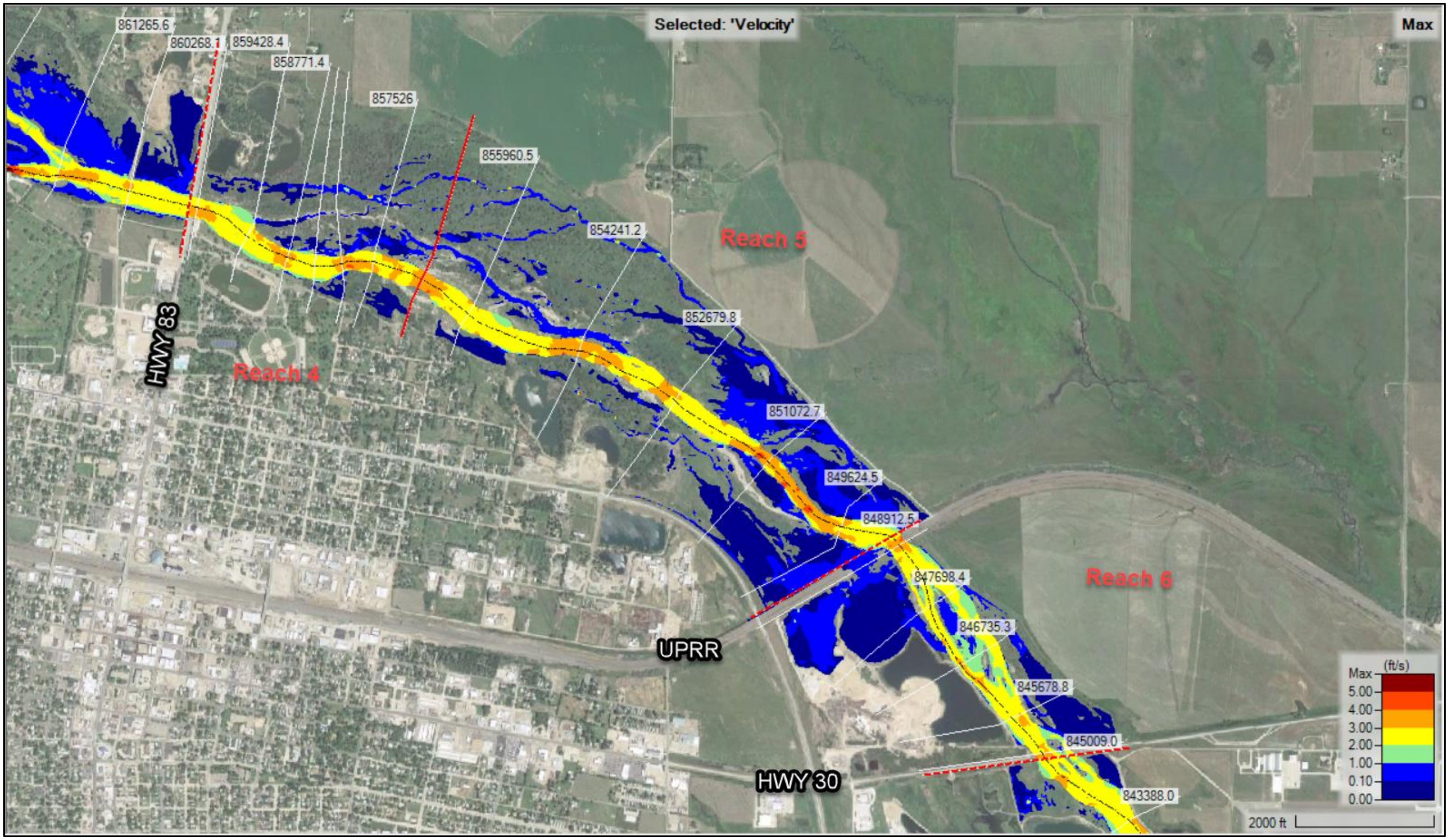



**Figure 5-14 Mapping of Velocity at 2,000 cfs – HWY 83 to HWY 30**

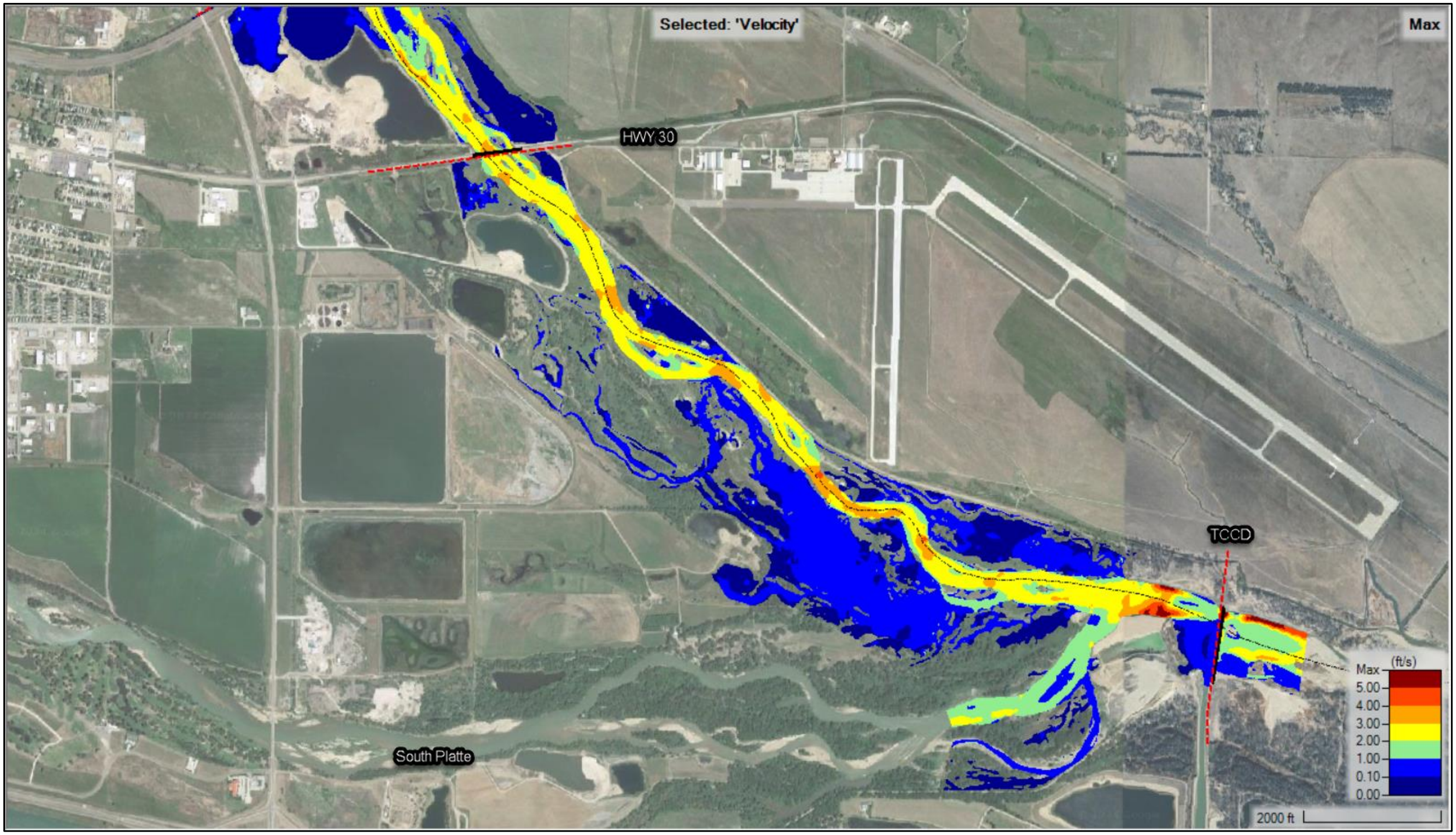



**Figure 5-15 Mapping of Velocity at 2,000 cfs – HWY 30 to Tri-County Canal Diversion**

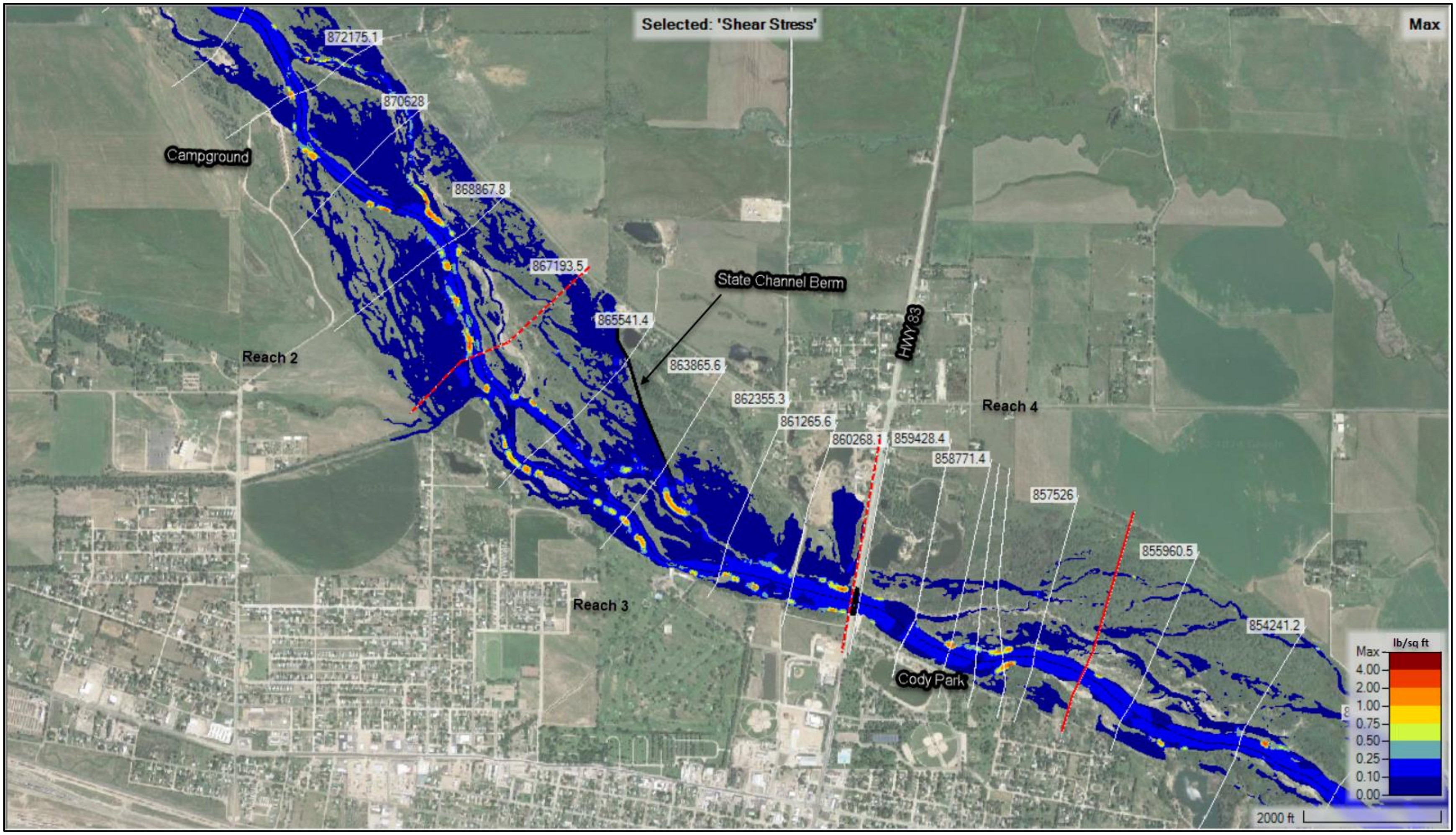



**Figure 5-16 Mapping of Shear Stress at 2,000 cfs – Campground to Cody Park**

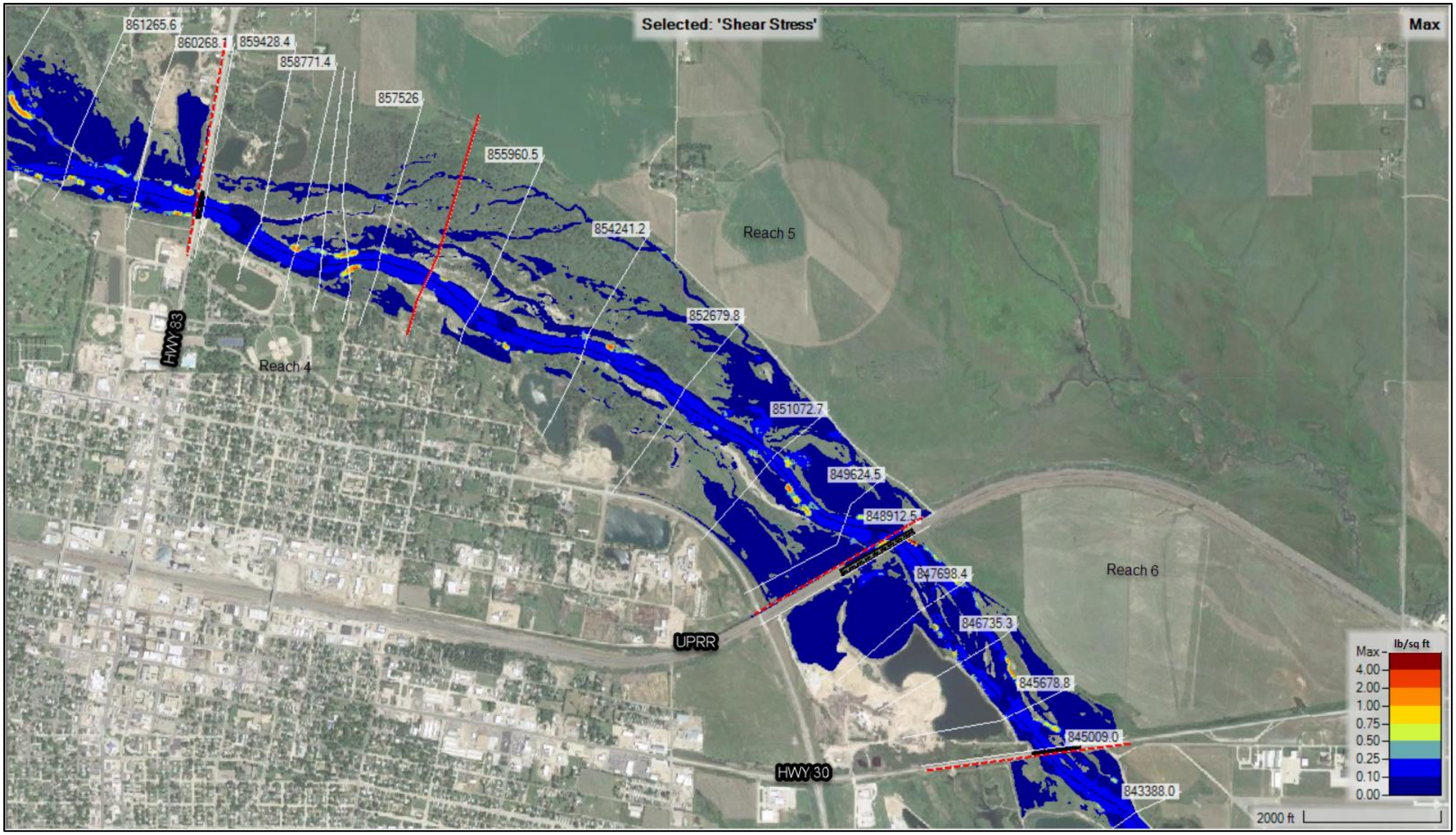



**Figure 5-17 Mapping of Shear Stress at 2,000 cfs – HWY 83 to HWY 30**

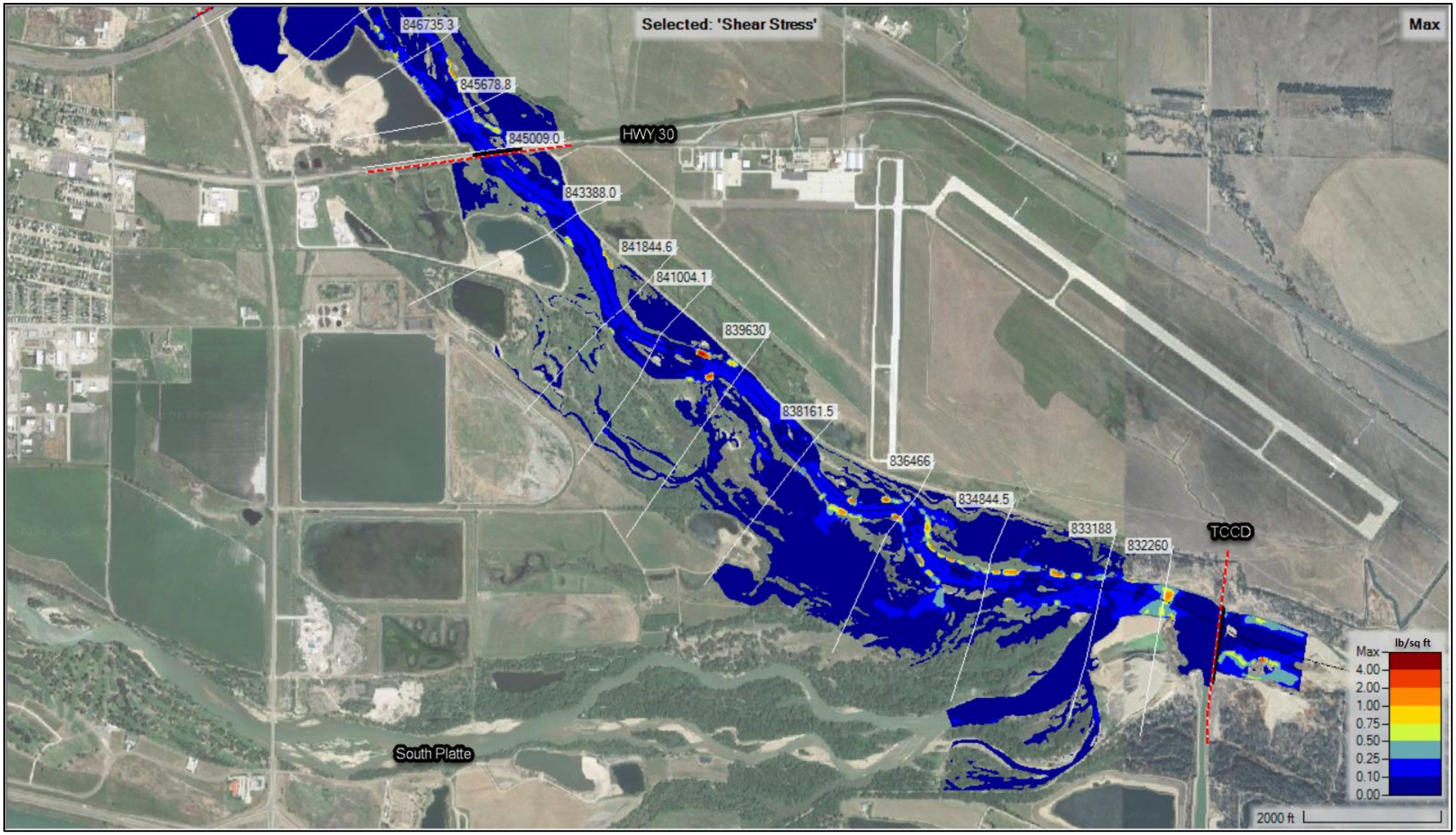



**Figure 5-18 Mapping of Shear Stress at 2,000 cfs – HWY 30 to Tri-County Canal Diversion**

***Incipient Motion***

Table 5-2 shows the estimated critical shear for a range of bed material and dimensionless critical shear values. Critical shear stress required to mobilize the median bed material size ($d_{50}$ = 0.7mm) is estimated between 0.005 to 0.011 lbs/sq ft. Critical shear required to initiate motion of very coarse sands (2 mm), representative of the coarser bed material, ranges from 0.014 to 0.032 lbs/sq ft. Critical shear stress was compared with reach average shear stress values to estimate the discharge required for mobilization of bed material. Shear values computed in the 2D hydraulic model at 400 cfs (see Figure 5-12) exceed estimated critical shear stress values indicating that the bed is easily mobilized and in motion for baseflows of 400 cfs and greater, with the exception of the area directly upstream of the TCCD.

**Table 5-2 Critical Shear Stress Required for Incipient Motion.**

| | D (mm) | Φ = 0.02 | Φ = 0.03 | Φ = 0.047 |
|---|---|---|---|---|
| | | Critical Shear Stress (lbs/sq ft) | | |
| **Bed Material $d_{16}$** | **0.30** | **0.002** | **0.003** | **0.005** |
| Medium Sands | 0.50 | 0.003 | 0.005 | 0.008 |
| **Bed Material $d_{50}$** | **0.70** | **0.005** | **0.007** | **0.011** |
| Coarse Sands | 1.00 | 0.007 | 0.010 | 0.016 |
| **Bed Material $d_{84}$** | **1.90** | **0.013** | **0.019** | **0.030** |
| Very Coarse Sand | 2.00 | 0.014 | 0.020 | 0.032 |

## 5.6 Bankfull Hydraulics

Bankfull discharge is a useful geomorphic indicator in sand bed rivers, as it is generally related to the dominant flow that forms and/or maintains channel geometry and transport conditions. Bankfull hydraulic parameters were evaluated for comparison to hydrologic and sediment transport evaluations.

### *5.6.1 Method of Analysis*

Results from the 2D hydraulic model were used to determine bankfull hydraulic parameters. Bankfull flow was identified at the point where water leaves the banks of the active channel. This was conducted individually for each reach. The corresponding average top width and depth for each reach associated with bankfull flows was extracted from the 2D model.

### *5.6.2 Results*

Average bankfull hydraulic parameters are summarized by reach in Table 5-3. For the overall study reach the bankfull discharge is 1,700 cfs. Reach 2 and 3 show a bankfull flow of 1,500 and 1,200 cfs, respectively. In Reach 2 this is due to a narrower channel width. Reach 3 shows a flatter channel slope, which could explain a lower bankfull capacity.

**Table 5-3 Average Bankfull Hydraulic Parameters**

| Reach | | Average Bankfull Parameters | | | Channel Slope (2017) |
|---|---|---|---|---|---|
| No. | Name | Q (cfs) | Top Width (ft) | Depth (ft) | |
| 1 | Upstream | 1,700 | 260 | 2.4 | 0.112% |
| 2 | Campground | 1,500 | 215 | 2.2 | 0.115% |
| 3 | Upstream HWY 83 | 1,200 | 280 | 1.9 | 0.107% |
| 4 | Cody Park | 1,700 | 265 | 2.0 | 0.133% |
| 5 | Upstream UPRR | 1,700 | 300 | 2.2 | 0.118% |
| 6 | UPRR to HWY30 | 1,700 | 384 | 2.1 | 0.069% |
| 7 | HWY30 to Conf | 1,700 | 300 | 2.1 | 0.104% |

Bankfull discharge of 1,700 cfs for the study reach is approximately equivalent with the 1.5-year flood flow 1,642 cfs while 1,200 cfs is approximately equivalent with the 1-year (annual) flood flow 1,202 cfs computed over the last 22 years (2020-2022).

# 6 SEDIMENT SUPPLY AND TRANSPORT TRENDS

The sediment sources to the North Platte River near North Platte, NE are channel, bank, and land erosion from upstream reaches and tributaries, which are also receiving sediment from adjacent hillslopes. Sediment delivery from eroding hillslopes and adjacent upland sources as well as bank erosion is a natural occurring process that is often accelerated by human-induced changes to those natural processes. However, the large storage reservoirs of the North Platte River trap the sediment load and reduce the supply to the North Platte River immediately downstream from each reservoir. For example, the construction and operation of Lake McConaughy has cut off sediment sources from the North Platte River watershed which has a contributing drainage area of 30,900 sq miles. The watershed downstream of Lake McConaughy is much smaller (1,444 sq mi) and includes Birdwood Creek and several other minor tributaries (see Figure 6-1).

While some portion of sediment enters directly from adjacent lands, most of the sediment appears to enter the North Platte River as bedload and suspended load from the bed, eroding banks and Birdwood Creek and is transported by the river down to the Chokepoint segment and TCCD. The most significant tributary between Lake McConaughy and the TCCD is Birdwood Creek, which appears to enter the North Platte at the upstream limit of measurable aggradation since 1940 (see Figure 7-19). Considerable sediment could be introduced from Birdwood Creek and later deposited along the Chokepoint segment, but hydrologic and morphologic analysis does not support this possibility.

Birdwood Creek was gaged by the USGS between 1934 and 1994. The data set indicates two peaks flows over 1,000 cfs with median annual peak flows around 300 cfs. Since 1994, the Nebraska DNR has continued to maintain and operate this gage, and only two annual peaks have exceeded 300 cfs. A cursory analysis of bed aggradation since 1940 in the North Platte shows that aggradation increases with distance downstream of Birdwood Creek. The small (and decreasing) peak floods along Birdwood Creek and a lack of a noticeable depositional signature where the creek enters the North Platte suggests that Birdwood Creek has not introduced large amounts of sediment that were unable to be mobilized during typical flows. If this was the case, the profile should show an immediate, large amount of aggradation just downstream of the confluence as well as an abrupt change in grain size which has not been observed.

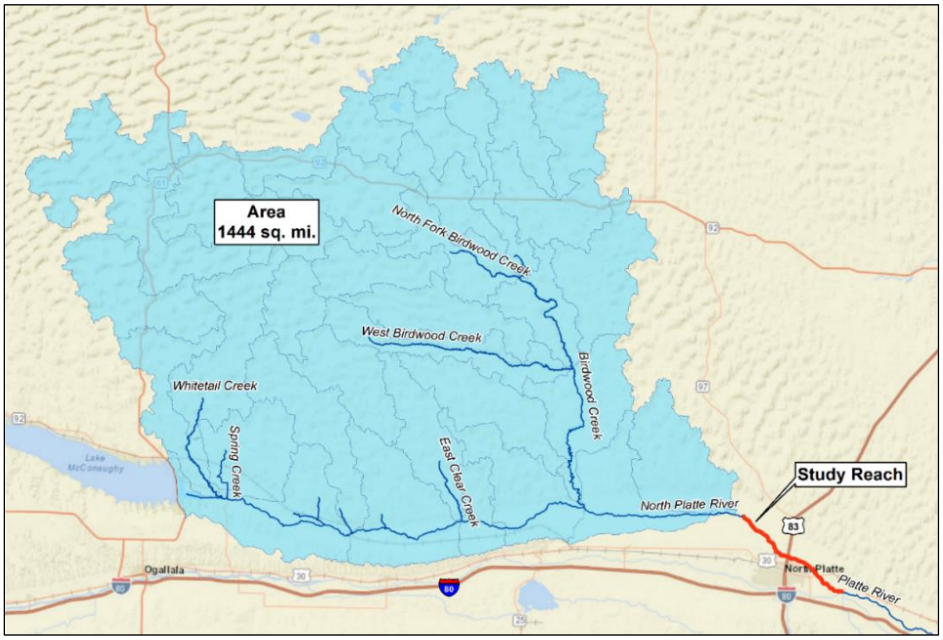



**Figure 6-1 North Platte River Watershed Downstream of Lake McConaughy**

## 6.1 Bed Material

Bed material samples were collected at several locations within the study reach. The $d_{16}$, $d_{50}$, and $d_{84}$ of samples are summarized in Table 6-1. The median bed material size ranges from medium to very coarse sand (0.6 mm up to 0.94 mm), with an average of 0.7 mm (classified as coarse sand). Bed material samples collected in 1931 by the USACE indicated a $d_{50}$ of 0.4 mm on the North Platte at HWY 83. Samples collected by Flatwater Group in 2010 show a median bed material size at HWY 83 of 0.6 mm. Bed material sample data is provided in Appendix C.

**Table 6-1 North Platte River, Bed Material Samples Collected October of 2023**

| Reach | | Bed Material [1] | | |
|---|---|---|---|---|
| **No.** | **Name** | **d16 (mm)** | **d50 (mm)** | **d84 (mm)** |
| 1 | Upstream | 0.39 MS | 0.79 CS | 1.74 VCS |
| 2 | Campground | 0.21 FS | 0.63 CS | 2.36 VFG |
| 3 | Upstream HWY 83 | 0.64 CS | 0.94 CS | 1.5 VCS |
| 4 | Cody Park | 0.31 MS | 0.63 CS | 3.01 VFG |
| 5 | Cody Park to UPRR | 0.32 MS | 0.6 CS | 2.63 VFG |
| 6 | UPRR to HWY30 | 0.31 MS | 0.81 CS | 2.12 VFG |
| 7 | HWY30 to Conf | 0.34 MS | 0.76 CS | 2.36 VFG |
| Composite Gradation | | 0.3 MS | 0.7 CS | 1.9 VCS |

[1] FS = fine sand, MS = medium sand, CS = coarse sand, VCS = very coarse sand, VFG = very fine gravel.

## 6.2 Sediment Transport

Sediment transport was evaluated up and downstream of HWY 83 within the study reach.

### *6.2.1 Method of Analysis*

A sediment transport rating curve was computed using the Yang equation upstream and downstream of HWY 83. Yang is a total load equation (bed and suspended load) which computes transport based on stream power, which is a function of shear stress and velocity. The Yang equation is applicable for streams with sediment sizes between 0.062 and 7.0 mm, channel widths up to 1,750 ft, flow depths ranging up to 49 feet, average channel velocity from 0.75 to 6.45 ft/sec, and channel slopes ranging from 0.000043 to 0.029 ft/ft. Other equations including Ackers-White, Laursen Copeland, and Engelund-Hansen were evaluated. Relative to measured bed change and estimated dredging at the TCCD the Laursen Copeland equation was found to overestimate transport capacity and was not used further. Engelund-Hansen, Ackers-White, and Yang produce similarly shaped curves and annual transport volumes. Use of other equations will be further explored during calibration of detailed sediment transport modeling developed for this project. For the purpose of estimating an annual capacity for use in the geomorphic assessment Yang was utilized.

Reach average hydraulics from the 2017 1D hydraulic model and bed material gradations were used in computations. Sediment transport rating curves represent the capacity (or potential) of the river to transport material if it is available for transport.

Rating curves were combined with flow duration to develop effective discharge curves and estimate total average annual sediment transport capacity. For effective discharge computations the flow duration was discretized into 20 logarithmically spaced bins. Effective discharge and total average annual capacity values were computed using flow duration of different time periods dating back to 1942. It should be noted that estimates of annual sediment transport capacity using historic flow duration curves utilize 2017 hydraulic conditions.

### *6.2.2 Results*

***Sediment Transport Rating Curves***

Transport rating curves computed upstream and downstream of HWY 83 are shown in Figure 6-2. Rating curves for the study reach were compared with curves developed in previous studies by Kircher (1983) and Simons (2000). Both Kircher and Simons transport relationships were based on regression equations developed from measured data. The Kircher curve was developed on the North Platte at HWY 83 and the Simons curve on the North Platte near Sutherland. In comparison to Kircher the Yang curves have a higher capacity with increasing discharge.

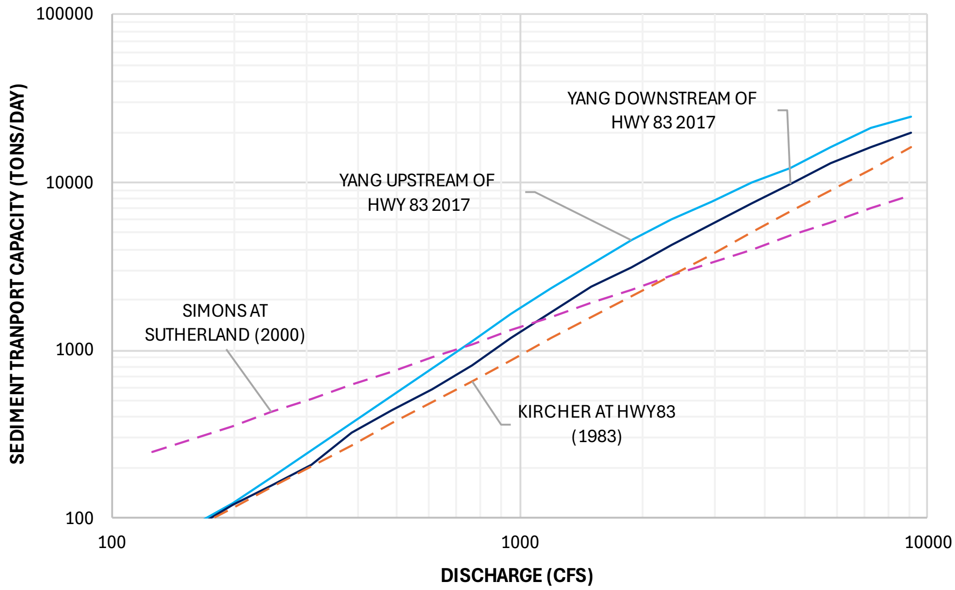



**Figure 6-2 Sediment Transport Rating Curves**

### *Effective Discharge*

Effective discharge is the flow that most efficiently transports the largest amount of sediment over time. Evaluation of effective discharge is key to estimating geomorphic response to change in the river system (natural or man-made). Effective discharge curves upstream and downstream of HWY 83 computed for different time periods are shown in Figure 6-3 and Figure 6-4, respectively. Considering the full period of hydrology from 1942 – 2022 the effective discharge upstream and downstream of HWY 83 is approximately 2,000 cfs. Comparison of effective discharge curves for varying time periods indicates a fluctuation between 1,900 cfs and 2,200 cfs, see Table 6-2. Effective discharge of 2,000 cfs computed between 1942-2022 is higher than the bankfull flow of 1,700 cfs but compares well to the 1.5-year discharge of 2,052 cfs computed for the same time period. The limited variation in effective discharges suggests that the relationship between sediment transport dynamics and channel bed change has remained consistent over the full period of record (see Section 8.2 for discussion on the channel bed profile).

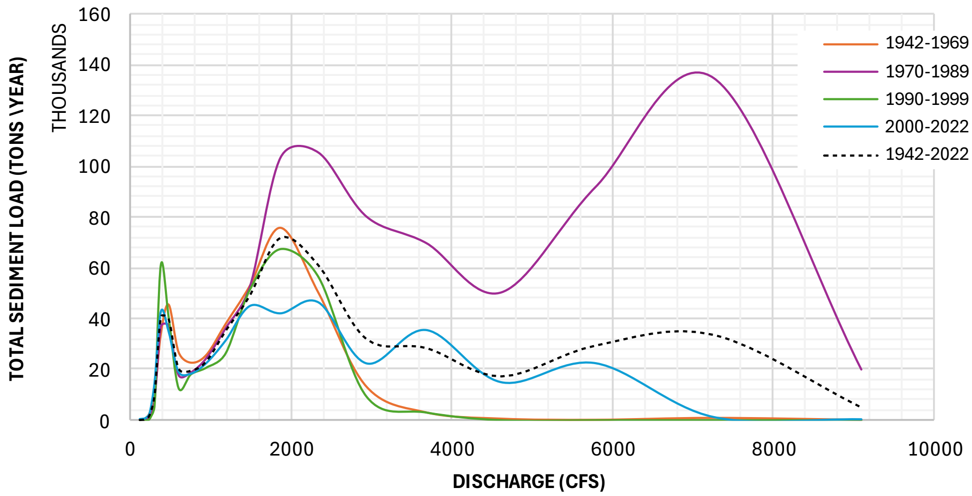



**Figure 6-3 Effective Discharge Curves Upstream of HWY 83 for Different Hydrologic Periods**

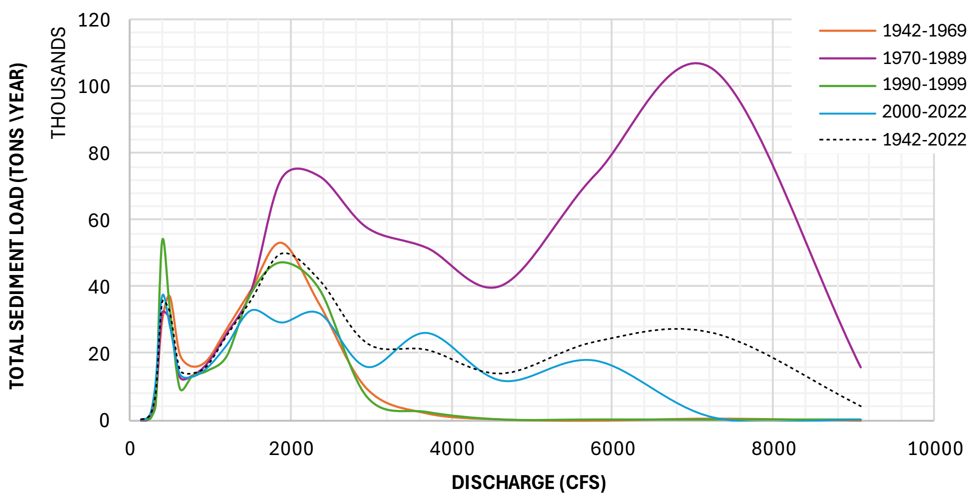



**Figure 6-4 Effective Discharge Curves Downstream of HWY 83 for Different Hydrologic Periods**

**Table 6-2 Effective Discharge**

| Time Period | Effective Q (cfs) |
|---|---|
| **1942-2022** | 2,000 |
| 1942-1969 | 1,900 |
| 1970-1989 | 2,200 / 7,100 [1] |
| 1990-1999 | 1,950 |
| 2000-2022 | 2,200 |

[1] Two peaks reported

### *Average Annual Sediment Transport Capacity*

Total average annual transport capacity is summarized for each period in Table 6-3 and shown graphically in Figure 6-5. The average annual capacity downstream of HWY 83 is approximately 75% of the upstream capacity due to hydraulic conditions and specifically a reduction in velocity and shear stress in the downstream direction influenced by backwater and flattened bed slope created at the TCCD. The difference in capacity from upstream to downstream is shown in the table. In comparison, CNPPID estimates that it dredges approximately 188,000 tons (or 150,000 cy) of sand annually, which includes deposition from both the North and South Platte. The difference in estimated annual transport above and below HWY 83 is of the same order of magnitude as dredging quantities.

Comparison of transport loads computed using hydrology associated with different historic time periods gives insight into the large amounts of sediment that were mobilized during the 70s and 80s and subsequently moved through the system in the 90s. The average annual capacity in the 70s and 80s was roughly 2.1 to 2.4 times higher than all other time periods.

**Table 6-3 Average Annual Sediment Transport Capacity**

| Time Period | Ave Annual Transport Capacity (tons/year) | | Difference (tons/year) | Ave Annual Transport Capacity (cy/year) [1] | | Difference (cy/year) |
|---|---|---|---|---|---|---|
| | Upstream of HWY 83 | Downstream of HWY 83 | | Upstream of HWY 83 | Downstream of HWY 83 | |
| 1942-1969 | 399,899 | 297,646 | 102,253 | 318,518 | 237,074 | 81,444 |
| 1970-1989 | 888,445 | 669,406 | 219,039 | 707,642 | 533,179 | 174,464 |
| 1990-1999 | 374,248 | 281,637 | 92,611 | 298,087 | 224,323 | 73,764 |
| 2000-2022 | 413,061 | 312,243 | 100,818 | 329,001 | 248,700 | 80,301 |

[1] Converted from tons using sand density of 93 lbs/$ft^3$

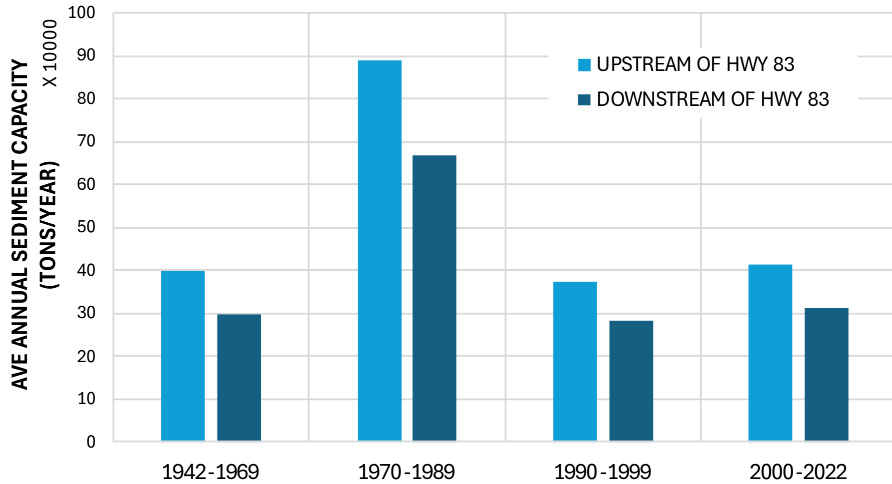



**Figure 6-5 Average Annual Sediment Transport Capacity by Time Period**

## 6.3 Sediment Continuity

Sediment continuity (sediment in = sediment out) provides the basis for estimating sediment transfer from changes in river channel morphology. For this study, sediment continuity considers the net balance and impact of imbalances of sediment supplied to a reach and sediment exported out of the reach. Continuity is achieved when the stream has the power or competence to move the size and quantity of incoming sediment. Competence is a stream's ability to transport enough sediment to achieve continuity and is typically evaluated by applying hydraulic analyses that provide velocity, shear stress, and stream power outputs and sediment transport models. Hydraulic and sediment transport evaluations in the previous section were developed and compared to measured fluctuations in channel cross sections to describe sediment continuity of the study reach.

### *6.3.1 Method of Analysis*

Measured change in bed volume over time was evaluated using available data for comparison to other analyses. Cross sectional comparisons within the active channel width were conducted using the 2009, 2017, and 2023 1D hydraulic model geometries. Changes in cross sectional area of the channel were computed at each cross section. Cross sectional plots are shown graphically in Appendix D. Volumes were computed using the distance between cross sections to develop estimates of mass bed change. Measured mass bed change was compared with estimated annual transport volumes.

### 6.3.2 Results

The measured mass bed change along the profile of the study reach for 2009-2017 and 2017-2023 is shown graphically in Figure 6-6. The total mass bed change for each reach is shown in Figure 6-7.

Changes from 2009 to 2017 show an increase in bed mass in Reach 1, no change in Reach 2 and 3. A reduction is measured in the reaches downstream of HWY 83. Changes in bed elevation for the same time period (see Section 7.2) show a lowering of the thalweg between 1 to 2 feet. Evaluation of hydrologic conditions during this time includes the 2011 flood event with a peak of ~6,000 cfs and a total of 158 days of flow above 2,000 cfs (this flow is effective at moving sediments). In 2016 flow also exceeded 2,000 cfs for 59 days. Note that the total change in Reach 7 showing a decrease does not account for annual dredging quantities. The net mass bed change for the study reach is approximately -13,000 cy/year, which is roughly 4 to 5% of the estimated average annual sediment transport capacity (~249,000 to 329,000 cy/year noted in Table 6-3). This comparison provides a perspective of the scale of measured bed change relative to the estimated amount of sediment that is transported through the reach in an average year.

Between 2017 and 2023 results show minimal change in Reaches 1 through 4, and slight deposition in Reaches 5, 6, and 7, located between Cody Park and the TCCD, increasing in the downstream direction. This corresponds with minimal fluctuation of +/-0.5 feet in bed elevation upstream of HWY 83 and an increase of 1 to 1.5 feet with some areas of bed decrease (see Section 7.2). Flows during this time only exceeded 2,000 cfs for a total of 7 days in 2020. Again, note that annual dredging at the TCCD in Reach 7 is not reflected in the total mass bed change computations shown below. The net mass bed change for the study reach is approximately +26,000 cy/year, which is roughly 8% to 10% of the estimated average annual sediment transport capacity (~249,000 to 329,000 cy/year noted in Table 6-3).

Comparison of bed change for both time periods show opposing trends but of similar magnitude (approx. +/- 20,000 cy/yr). When considering the magnitude of change relative to transport rates and dredging quantities a strong trend towards aggradation or degradation is not apparent. The exception to this is the depositional zone within the backwater area above the TCCD where dredging is required. It is noted that minimal change in the channel between 2009 and 2023 indicates that the river is generally able to balance sediment supply and transport, even after the 2011 flood event. This is consistent with the stabilization in hydraulic capacity, with natural fluctuation, as shown by results of the hydraulic analyses and specific gage evaluation. This conclusion is also consistent with findings in the geomorphic analyses (next section) and supports the recent trend that flows and sediment are roughly in quasi-equilibrium (see Section 10.7 Summary of Current Trends), meaning the amount of sediment brought into the Chokepoint reach is similar to what would have occurred naturally without the existence of Lake McConaughy.

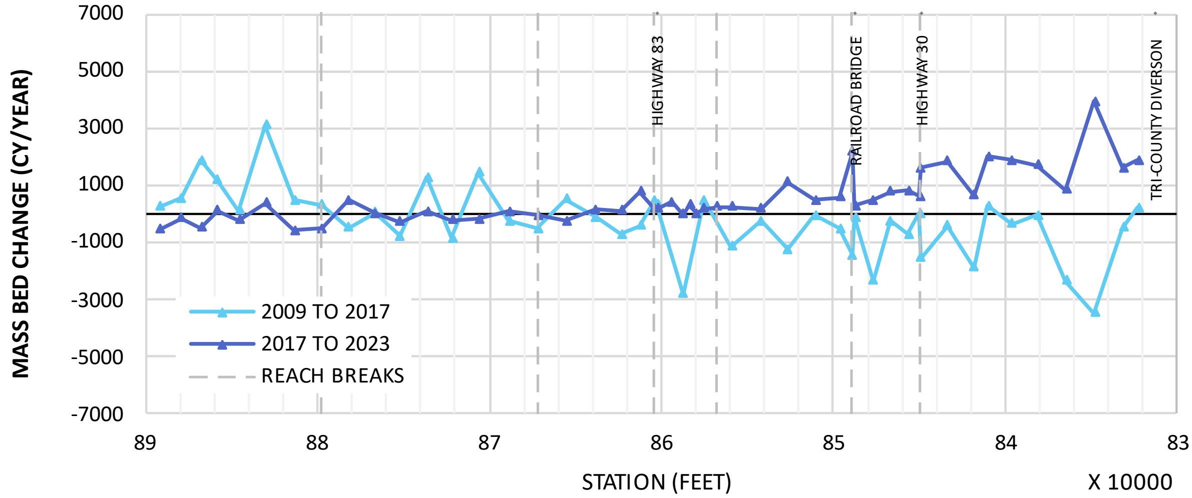



**Figure 6-6 Profile of Mass Bed Change 2009 – 2023**

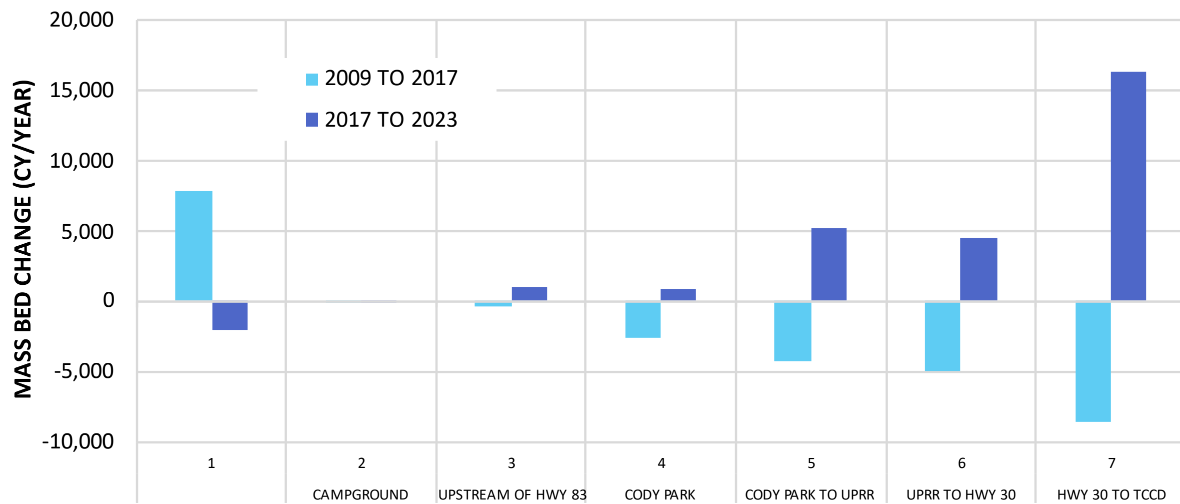



**Figure 6-7 Total Mass Bed Change by Reach 2009 – 2023**

CNPPID dredges approximately 150,000 cy/year just upstream of the TCDD. Figure 6-8 shows the mass bed change by reach with estimated dredging quantities included in Reach 7. The figure assumes that 40% of the annual dredging is attributed to the North Platte. This assumption is based on preliminary sediment transport modeling that indicates the North Platte contributes roughly 40% of sediment inflow at the confluence between 2009 and 2023. The figure provides a visual showing that the mass bed change is minor compared with dredging volumes. Table 6-4 summarizes the mass bed change upstream and downstream of HWY 83 and incorporates estimated dredging quantities. Inclusion of dredging quantities results in an estimated 40,000 cy/year of sediment deposition occurring downstream of HWY 83, mostly at the TCCD, between 2009 and 2017 and 87,000 cy/year between 2017 and 2023. These results compare well to the difference in sediment transport capacity computed upstream and downstream of HWY 83 and shown in Table 6-3. Results indicate an imbalance in the ability of the river to transport sediment loads downstream of HWY 83 and past the TCCD, largely due to the presence of the TCCD.

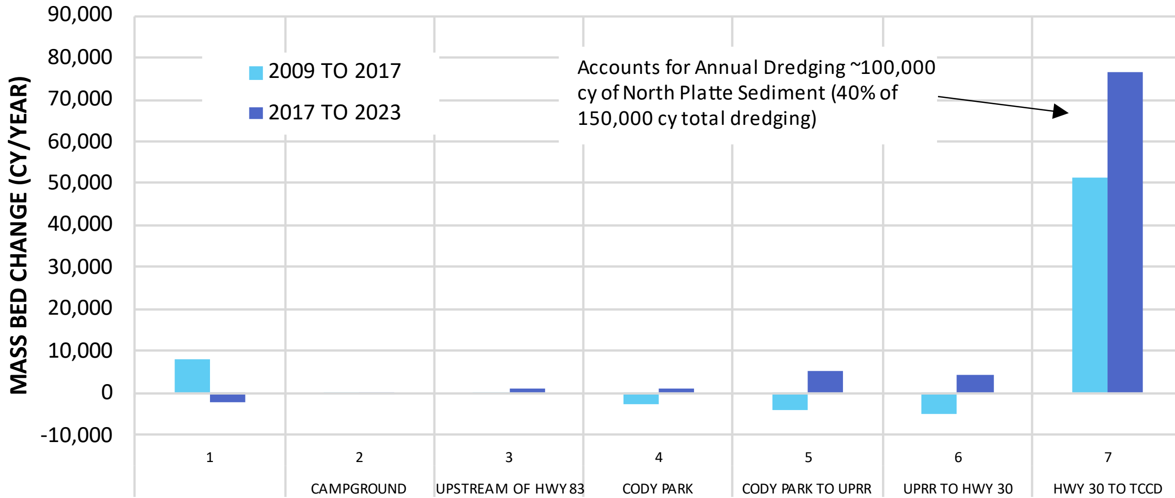



**Figure 6-8 Total Mass Bed Change by Reach 2009 – 2023, Dredging Accounted for in Reach 7**

**Table 6-4 Mass Bed Change and Dredging**

| | **Mass Bed Change (cy/yr)** | |
|---|---|---|
| | **2009-2017** | **2017-2023** |
| Upstream HWY 83 | 7,465 | -1,093 |
| Downstream HWY 83 | -20,267 | 26,952 |
| Annual Dredging at TCCD ~150,000 cy/yr (Assumes 40% from North Platte) | 60,000 | 60,000 |
| Mass Bed Change Downstream of HWY 83 Plus Dredging | 39,733 | 86,952 |

## 6.4 Impacts from the Tri-County Canal Diversion

As noted in Section 5.5, depositional impacts related to the TCCD are attributed to backwater and a slowing and/or blocking of sand bed movement related to backwater conditions created by the TCCD structure.

As the North Platte flow nears the region of decreased water surface slope associated with the TCCD, larger sediment sizes will stop moving before more easily transported sediment such as silt and clay (Figure 6-9). Our evaluation of the channel profile (see Section 7.2) shows that between 1940 and 2011 up to eight feet of sediment has been deposited as a wedge from the TCCD upstream to HWY 30 (2.6 miles, about 14,000 feet) (see Figure 7-19). It is reasonable to assume that fine sediments transported as wash load do not settle out due to water PPNID continuously pushing water through the TCCD, but the deposition of sand and larger sized sediment fits the conceptual diagram.

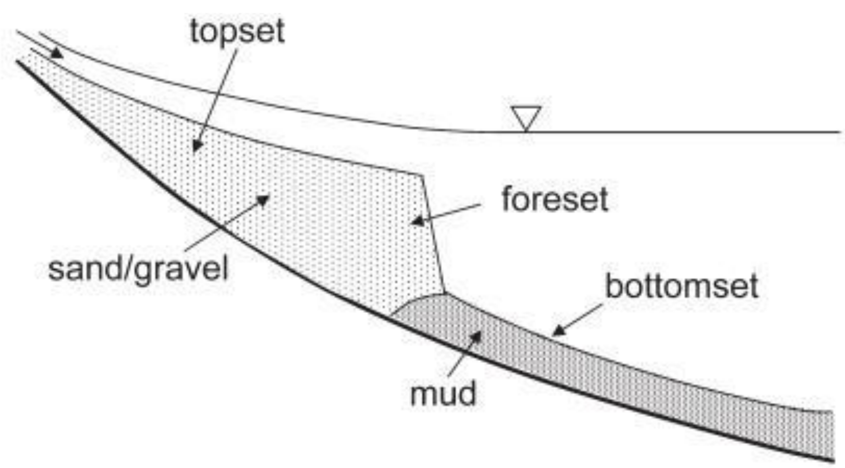



**Figure 6-9 Sediment Dynamics of a River Entering a Backwater Zone.**
Note how deposition of sand and gravel extends upstream of the backwater trigger point, resulting in a wedge-shaped pattern that increases water surface elevation upstream of the structure that creates the backwater profile (assuming a model of river flow into a reservoir). Adapted from Garcia, 2008.

### *6.4.1 Method of Analysis*

Computational modeling to demonstrate the spatial impact of backwater conditions at the TCCD on the North Platte was developed. The ACE team developed a spreadsheet model to calculate historic 1D riverbed elevation variation due to backwater. The model uses an approximated initial slope, a constant width, and uniform grain size based on data provided herein and 2,200 cfs (~effective discharge) for the flow. The downstream water surface elevation was fixed at 3.35 m (11 ft) to approximate the height of the TCCD structure. The model used an intermittency of 0.1, meaning the flow was assumed to happen 10% of the year, with no morphodynamic change during the rest of the year. Upstream sediment supply was estimated as the model-computed transport capacity.

The 1D model calculates the bed variation in streamwise dimension. This simplification assumes bedload sediment transport that moves along a uniform, rectangular channel. Thus, all depositional or erosional triggers such as changes in base level can only move sediment longitudinally and ignore the ability of a river to adjust its width by eroding or depositing sediment laterally. In addition, capacity-limited channels like the Chokepoint segment are better conceptualized as a tank or bathtub at the end of a flume (Figure 6-10).

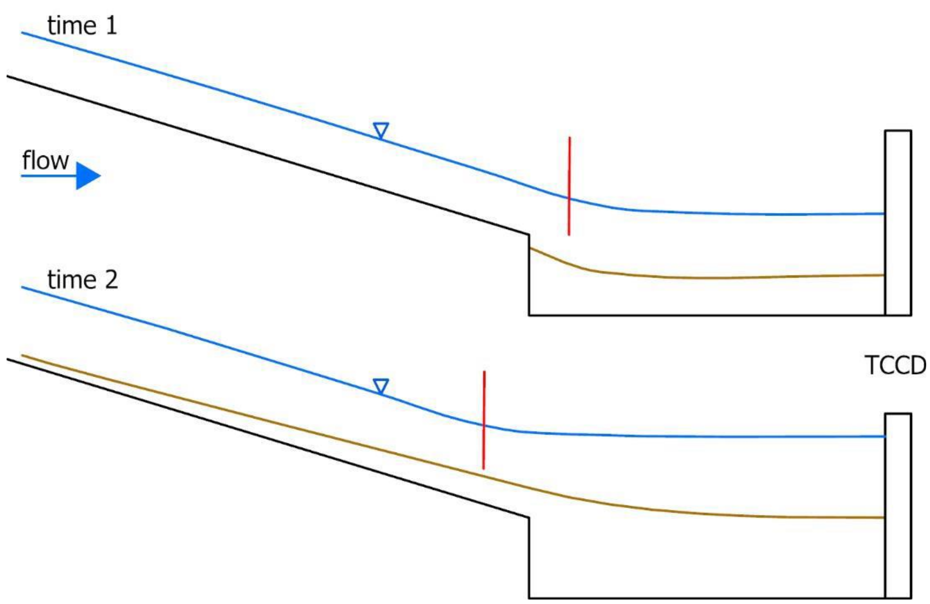



**Figure 6-10 Conceptual Diagram of the Side-View of a Flume Entering a Tank that Fills with Sediment.** The downstream end of the tank is analogous to the TCCD. The black lines are the tank and flume bed, the brown line is the sediment that has filled the tank and flume, the blue line is the water surface, and the red vertical line is the trigger point of the backwater effect where flow begins to lose sufficient energy to transport sediment.

### *6.4.2 Results*

Our analysis demonstrates the sediment prograding creates the “sediment wedge,” leading to deposition further upstream, above the height of the downstream water level created by the TCCD (see Figure 6-11). The analysis indicates that upstream impacts could extend up to ~10m (~30 ft) above the dam height, and longitudinal approximately 13,000 meters (~8 miles) upstream, which is consistent with observed channel impacts shown in profile comparisons (See Section 7.2). This supports the conclusion that backwater from the TCCD has contributed to deposition in the channel as far upstream as HWY83.

The results also indicate that the “trigger point” will only move once the accommodation space is filled in. This is an important consideration for the longevity of sediment removal/dredging and its effects on backwater at Hwy 83. Note the accommodation space in the “tank” does not need to be filled in completely to have upstream impacts.

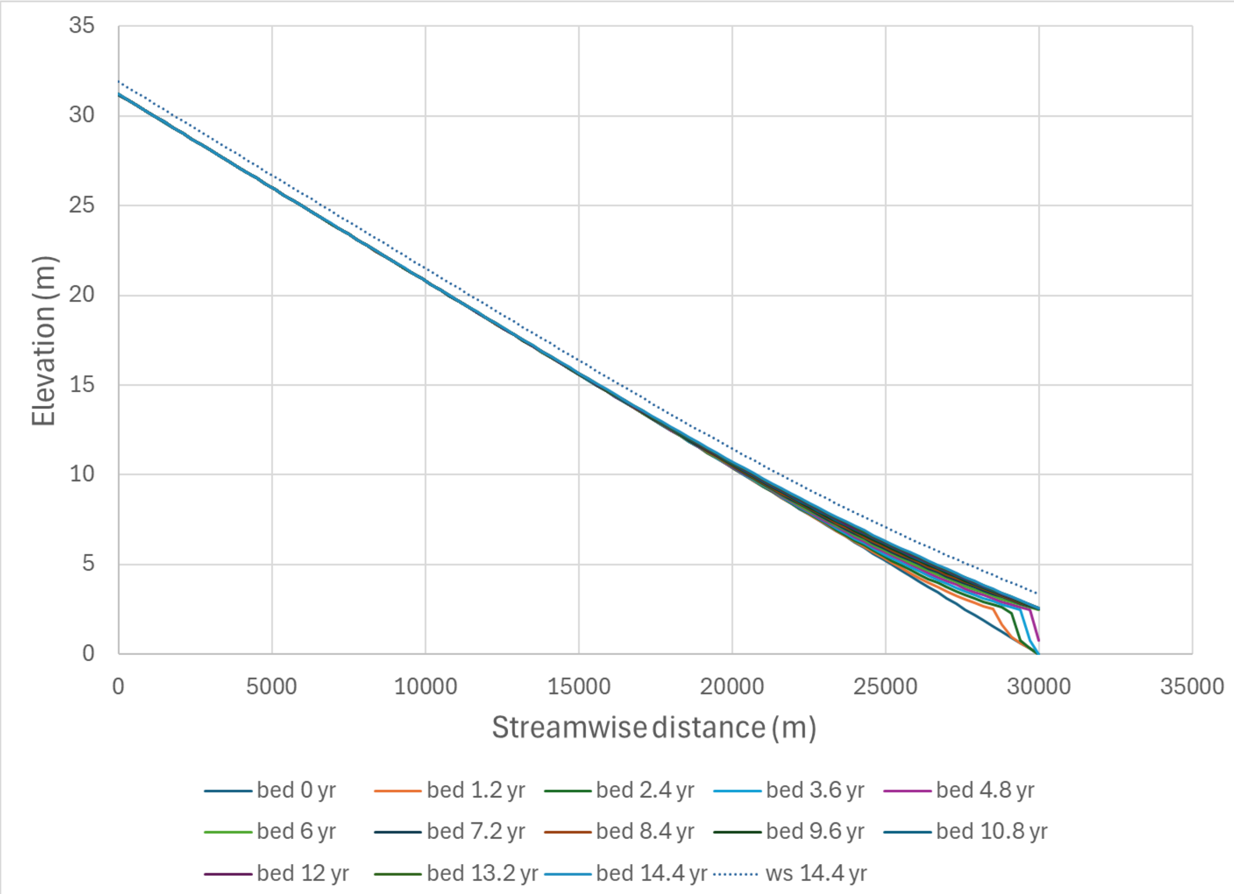



**Figure 6-11 Results from 1D morphodynamic modeling of TCCD backwater.**

# 7 GEOMORPHIC ANALYSES AND TRENDS

ACE performed a series of qualitative and quantitative analyses to describe the North Platte River's geomorphic trends through the Chokepoint segment. The analyses focus on three fluvial geomorphic characteristics: pattern and planform, profile, and geometry. This section summarizes the methods and results of each analysis and provides geomorphic and conveyance implications.

## 7.1 Channel Pattern and Planform

Channel planform, defined as the configuration of a river in planview, provides a reach-scale summary of the channel and floodplain characteristics. Flow patterns and the distribution of geomorphic forms for different planform types are major determinants of channel shape (Brierley and Fryirs 2005).

### *7.1.1 Method of Analysis*

Geomorphologists typically identify four main types of alluvial channel patterns based on the number of channels: straight, meandering, braided, and anabranching. Straight is as described – the valley length and channel length are approximately equal. Meandering rivers are typically single channeled systems with a low sinuosity (< 1.3) and low width to depth ratios. They tend to have a relatively low bedload transport capacity (i.e., generally mixed or suspended load). Further, fine-grained alluvial rivers commonly exhibit a passive meandering channel alignment. In these cases, there is little evidence of active erosion, and the lack of bedload material limits the development of point bars. The lack of bedload material also limits the range of instream geomorphic units (Brierley and Fryirs 2005).

Braiding is the formation of two or more alluvial channels, separated by one or more bars, within a main channel, while anabranching refers to channels separated by islands. The braiding process tends to produce a network of small, interlaced channels. Braided rivers such as the historic North Platte have identifiable geomorphic indicators and traits. At high flows, they are wide and relatively shallow flowing bank to bank typically without any visible bars or islands. At lower flows, transient sand bars create braids that move across the channel bed in ever changing patterns. At very low flows, some of the active sand bars stop moving, creating islands that support vegetation growth (FLO Engineering 1992).

Braided rivers are often made up of secondary and side channels caused by anastomosing, the creation of split channels separated by stables bars or vegetated islands. Secondary channels are those flow paths that are separated from the main channel by unvegetated gravel bars. Secondary channels can be more difficult to map because they may be discontinuous or poorly formed. Anabranching rivers have side channels that are separated from the main channel by vegetated islands. These channels are continuous and active under bankfull flow conditions.

Rivers with sufficiently high energy to transport sediment moving as bedload, and with weak bank materials or limited floodplain vegetation, like the pre-water development North Platte River, tend to have very wide channels that feature multi-thread, braided patterns with high width-depth ratios. The braided pattern typical of the river prior to the 1900s required sufficient sediment and seasonal pulse flows from spring runoff. Previous studies (see Section 3) have documented the evolution of the North Platte River from a braided pattern to a single thread channel due to the changes in sediment supply and flow regime.

Braiding indices and sinuosity are common methods to classify river planform and evaluate temporal changes. Main channel, side channel, and valley lengths and the associated reach braiding indices and sinuosities through the Chokepoint section were computed. All lengths and channel types were determined from aerial photographs. The existing main channel on aerial photographs was readily identifiable as a broad, sandy, generally unvegetated area.

### *7.1.2 Channel Length and Braiding Index*

The length of a stream is the distance measured along the stream channel from the source to a given point, a distance that is often estimated from aerial photographs. Comparing temporal changes in channel lengths (main and side), combined with braiding indices and sinuosity, provides information on the changes to a river's planform and flow pattern. Patterns of braided, multi-thread channels are quantified as the measure of the degree of braiding, referred to as a braiding index (Church 1995).

$$BI = \frac{sum\ of\ lenghth\ of\ side\ channels\ in\ reach + sum\ of\ length\ of\ main\ channel\ in\ reach}{length\ of\ main\ channel\ in\ reach}$$

This braiding index evaluation considers only side channels created by islands and omits bars, so it is primarily an indication of flow consolidation. For this purpose, an island is defined as a land mass which is located within the main channel, is surrounded by water channels, and is stabilized by perennial vegetation. The higher the index value, the more braiding; an index value greater than five indicates an intensely braided channel, between two and four means the river channel is moderately braided while a value of 1.0 means no braiding (i.e., single thread channel and no islands).

The limitation of this braiding index is that a reach with many small islands could produce a braiding index that is equal to or greater than the same reach distance with one large island. As noted in Williams (1978), a complete braiding index probably should include not only the lengths of the islands but also their number and density. The latter two features are reflected only indirectly in the braiding index used here. In many situations, however, the present braiding index should be generally indicative of anastomosing tendencies within a channel.

### 7.1.3 Sinuosity

Channel planform is typically measured using sinuosity. Sinuosity is defined by the ratio of stream length to straight-line valley length between two points. The degree and type of sinuosity are dictated by the slope of the river, the sediment caliber (i.e., texture) of the river, and the type or combination of meander growth and shift forms (Brierley and Fryirs 2005). For example, rivers in cohesive material tend to be more sinuous than rivers with sand and gravel substrates. Rivers with a sinuosity of 1 to 1.05 are considered straight while rivers with a sinuosity between 1.06 and 1.30 are classified as low sinuosity. Rivers with a sinuosity greater than 1.3 are described as sinuous or meandering (Brierley and Fryirs 2005).

Channel planform was investigated by digitizing the apparent thalweg using geo-rectified aerial photography and other remote sensing imagery. Measurement of planform changes over time provides useful information on system dynamics and magnitude and rates of channel change. Assessment of recent and historic planform change also provides an important context for river management (Brierley and Fryirs, 2005).

### 7.1.4 Results

#### Channel Length and Braiding Index

Main channel lengths were digitized using the time series of geo-rectified aerial photography (see Figure 7-1 through Figure 7-6). Active main channel and side channel lengths for all reaches are shown in Figure 7-7 and Figure 7-8. An evaluation of changes in main and side channel lengths through time shows that since 1938, all main channel reach lengths have remained relatively consistent while side channel lengths have all decreased. Those changes have resulted in relatively limited changes in main channel length while the time series shows that since 1938, there have been consistent trends of side channel shortening along all the Chokepoint segment (Figure 7-8), most of which occurred between 1938 and 1958. Both main and active channel length results show similar trends in terms of overall length. A time series of pattern changes are shown in Figure 7-10 through Figure 7-15.

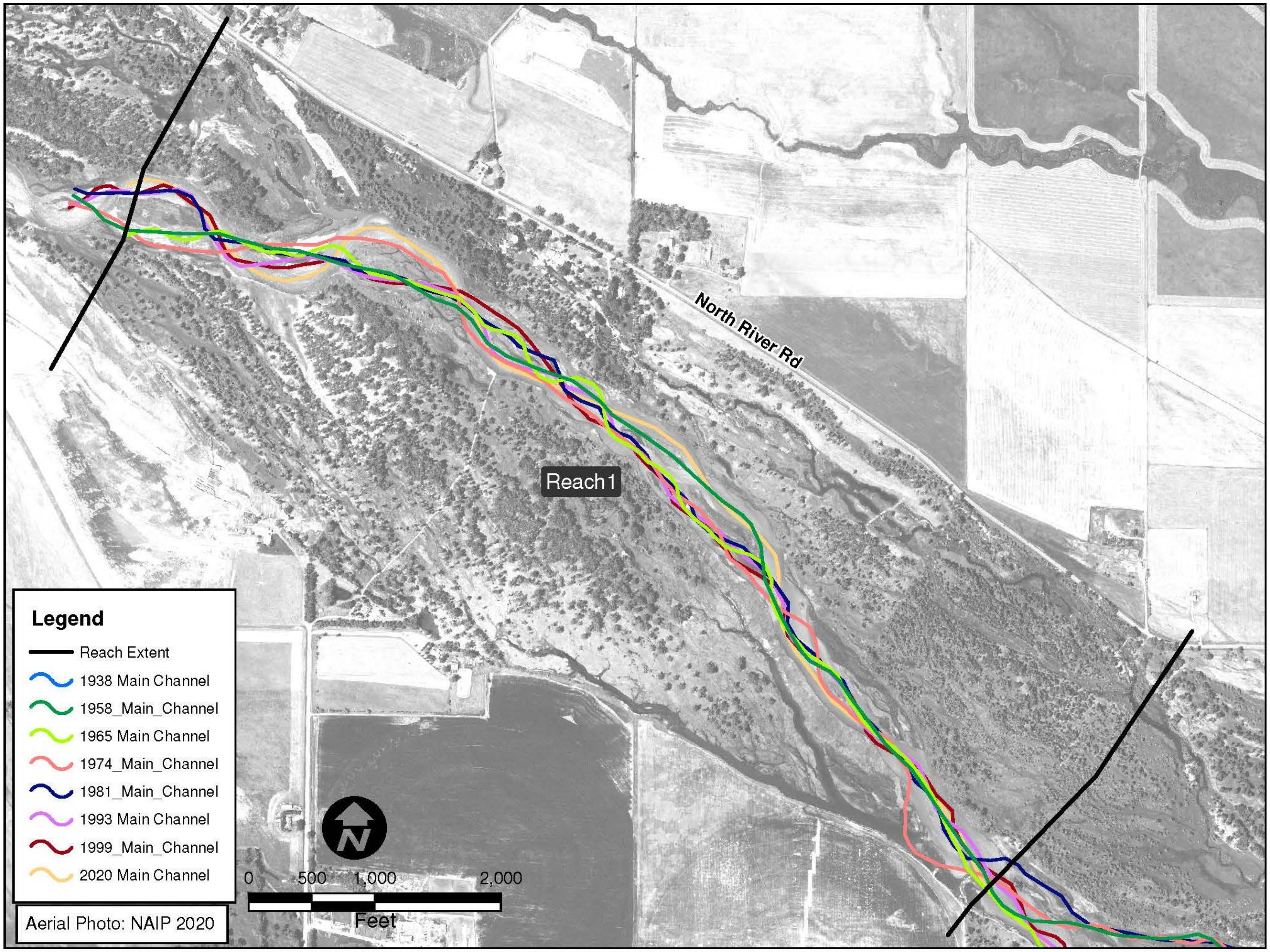



**Figure 7-1 Reach 1 main channel centerline through time (1938 – 2020)**

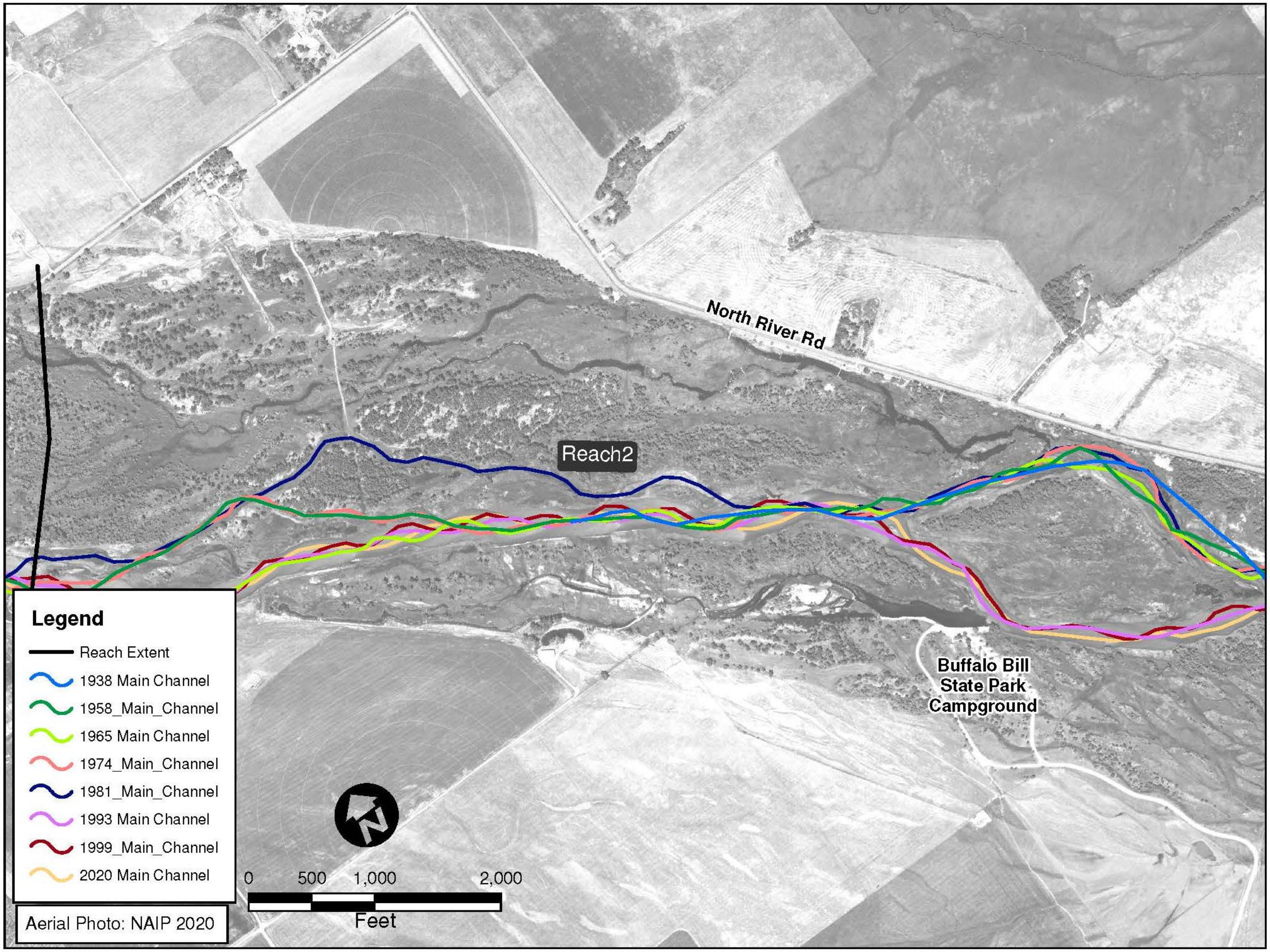



**Figure 7-2 Reach 2 main channel centerline through time (1938 – 2020)**

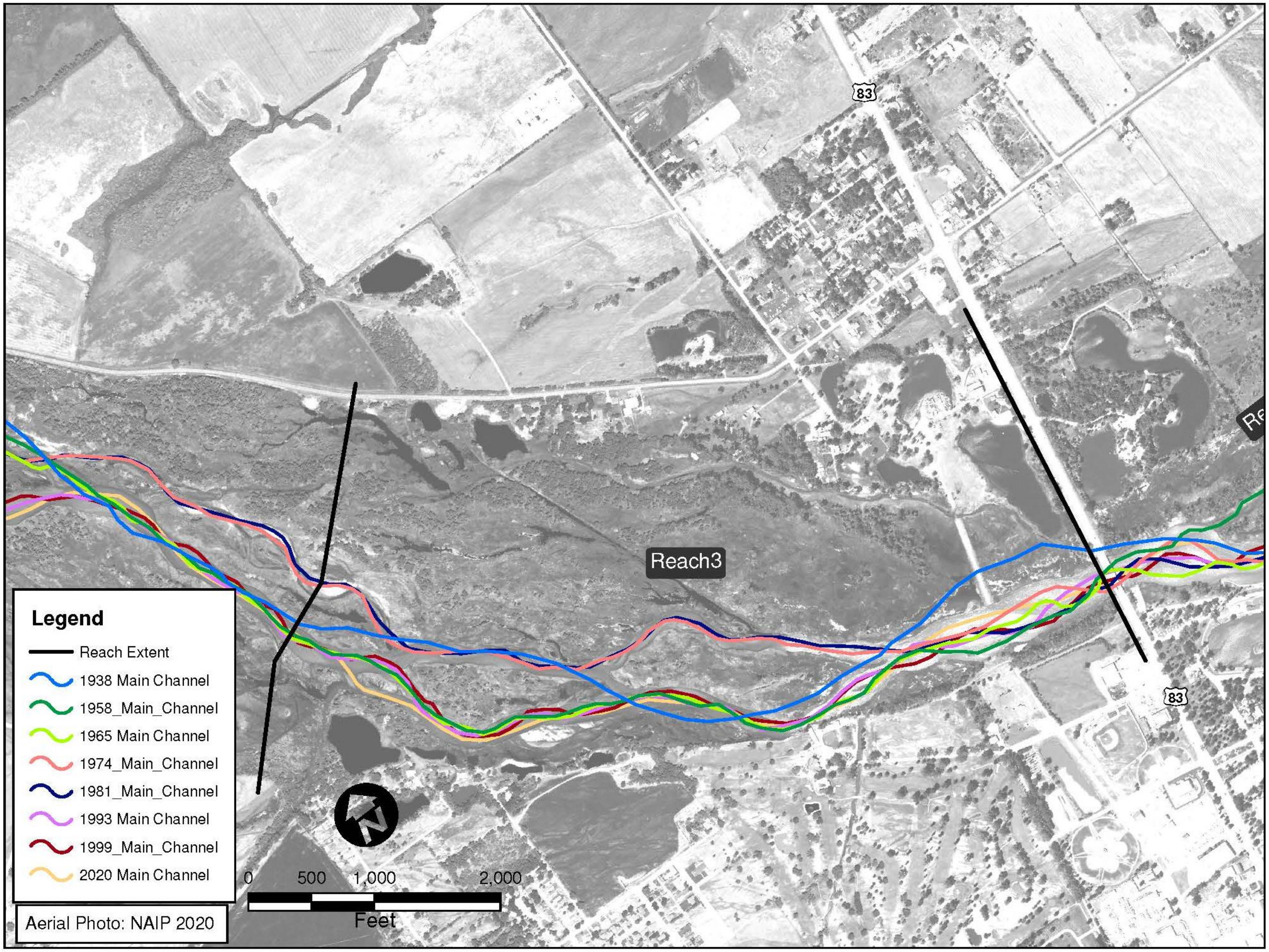



**Figure 7-3 Reach 3 main channel centerline through time (1938 – 2020)**

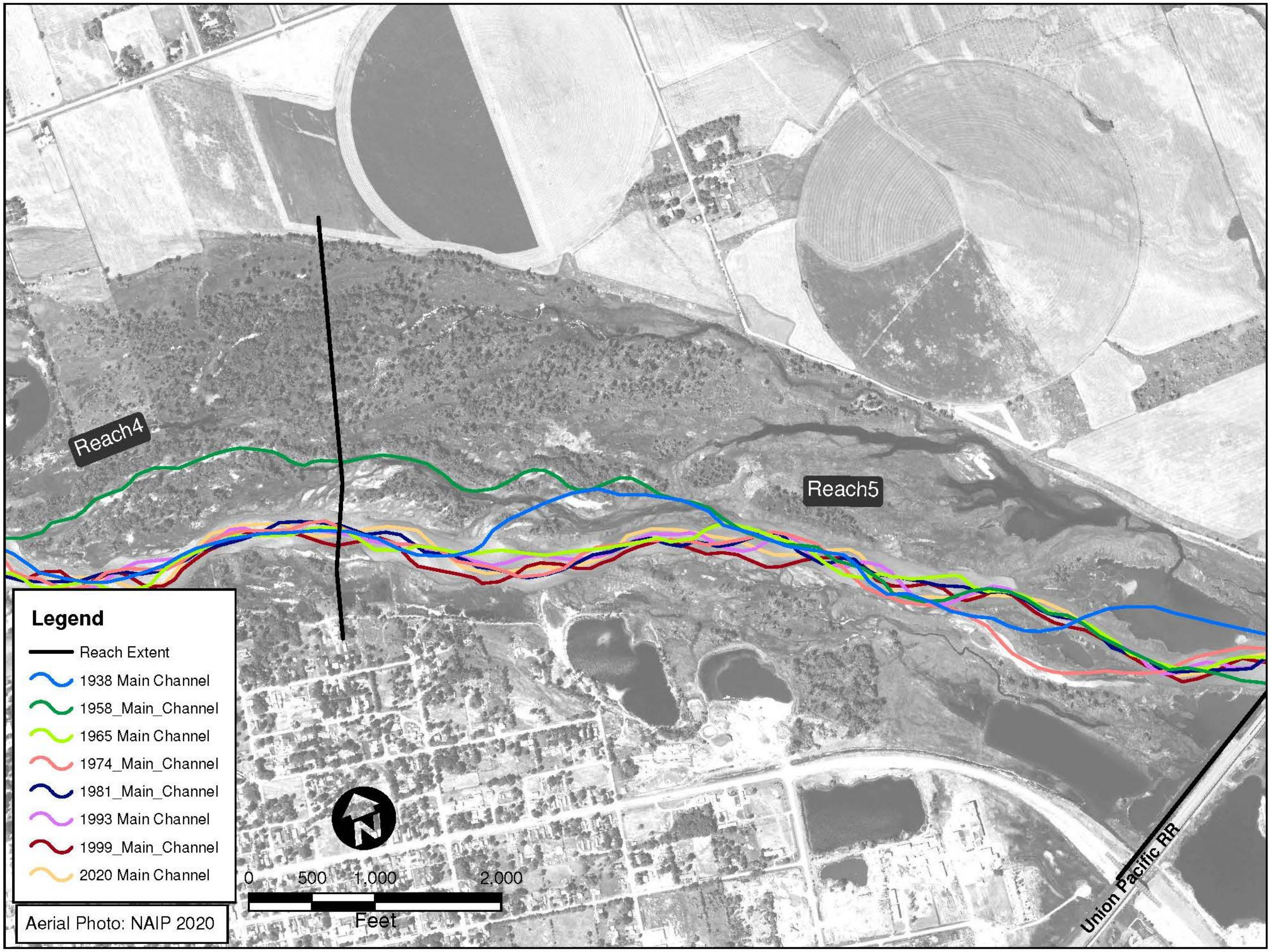



Figure 7-4 Reach 4 and Reach 5 main channel centerline through time (1938 – 2020)

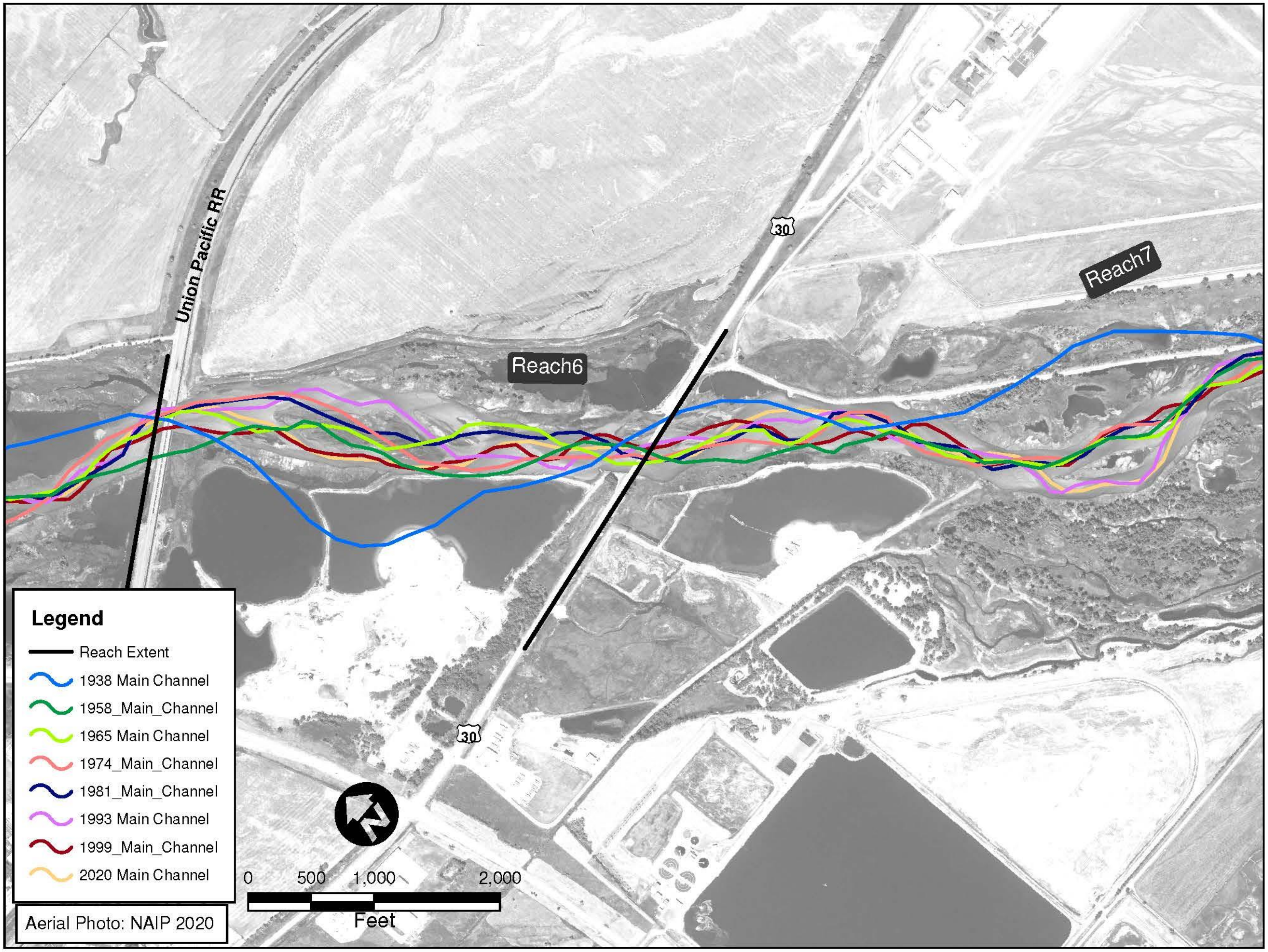



**Figure 7-5 Reach 6 main channel centerline through time (1938 – 2020)**

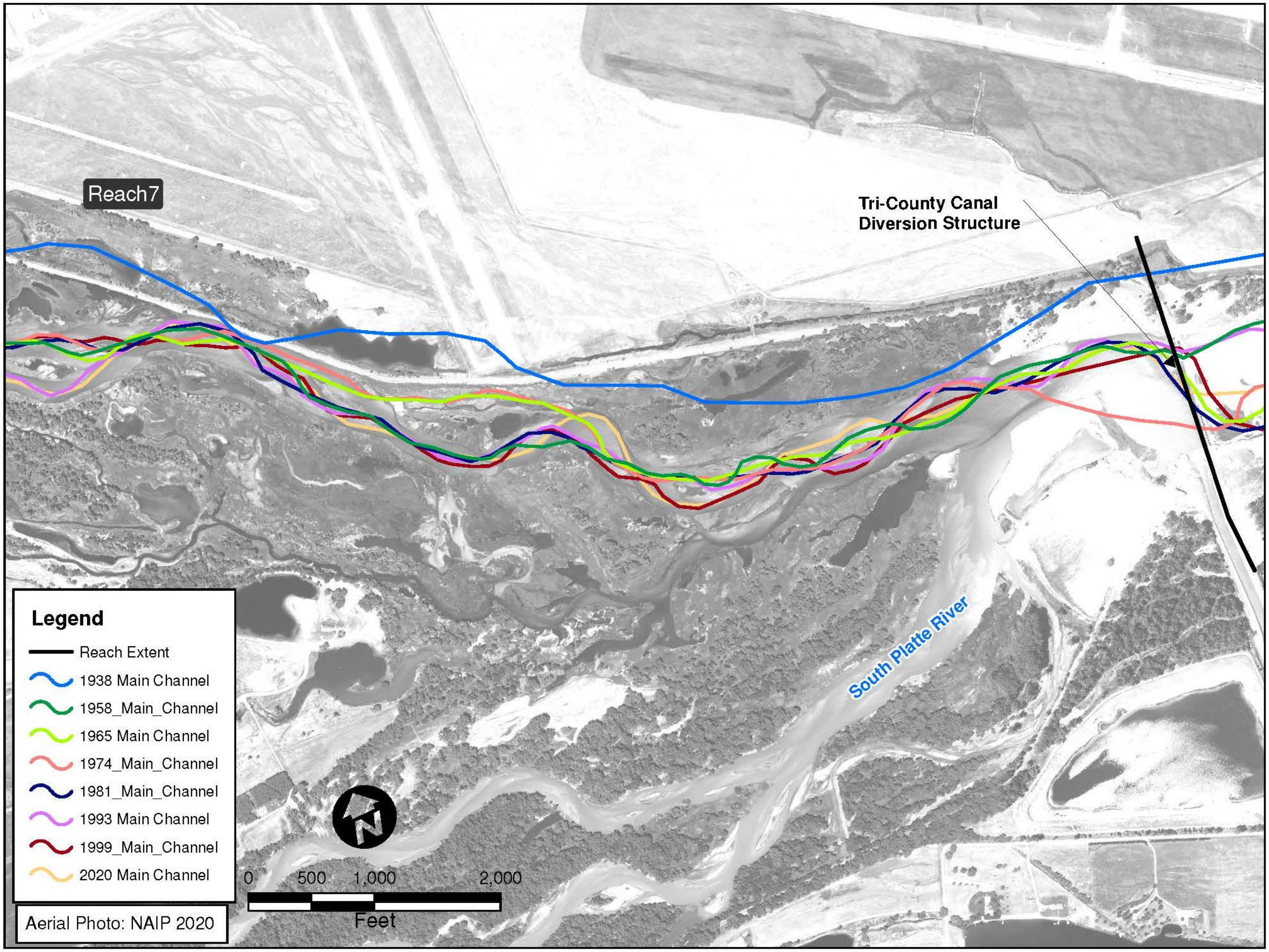



**Figure 7-6 Reach 7 main channel centerline through time (1938 – 2020)**

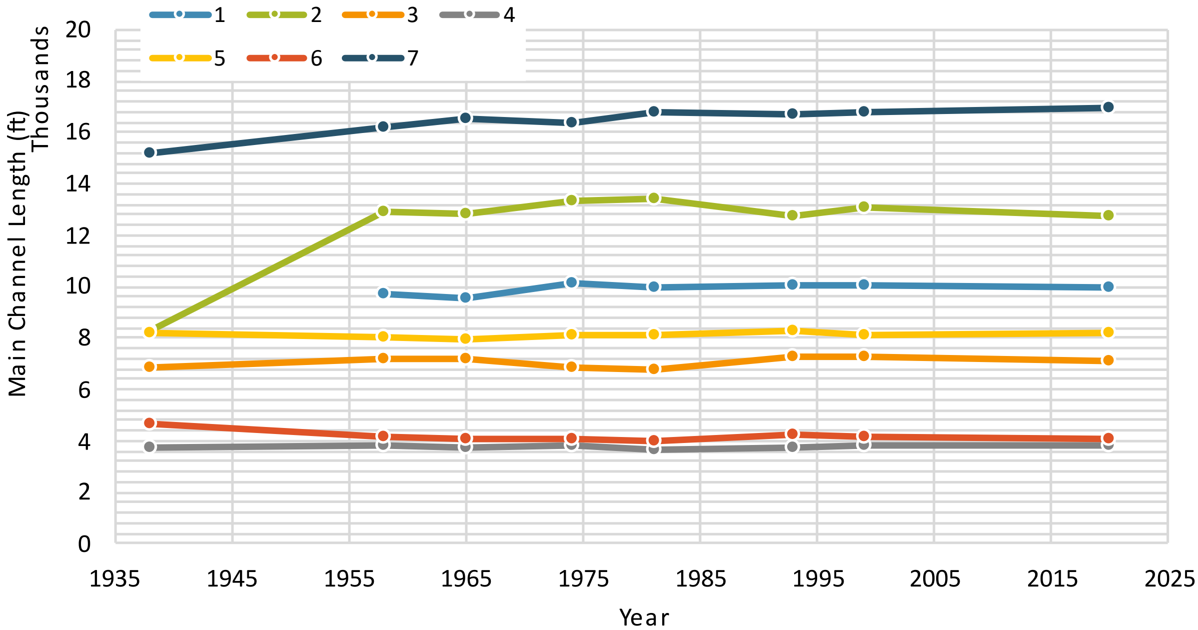



**Figure 7-7 Main channel length through time for project reaches. Note the 1938 Reach 1 length is not included due to lack of aerial photograph extent.**

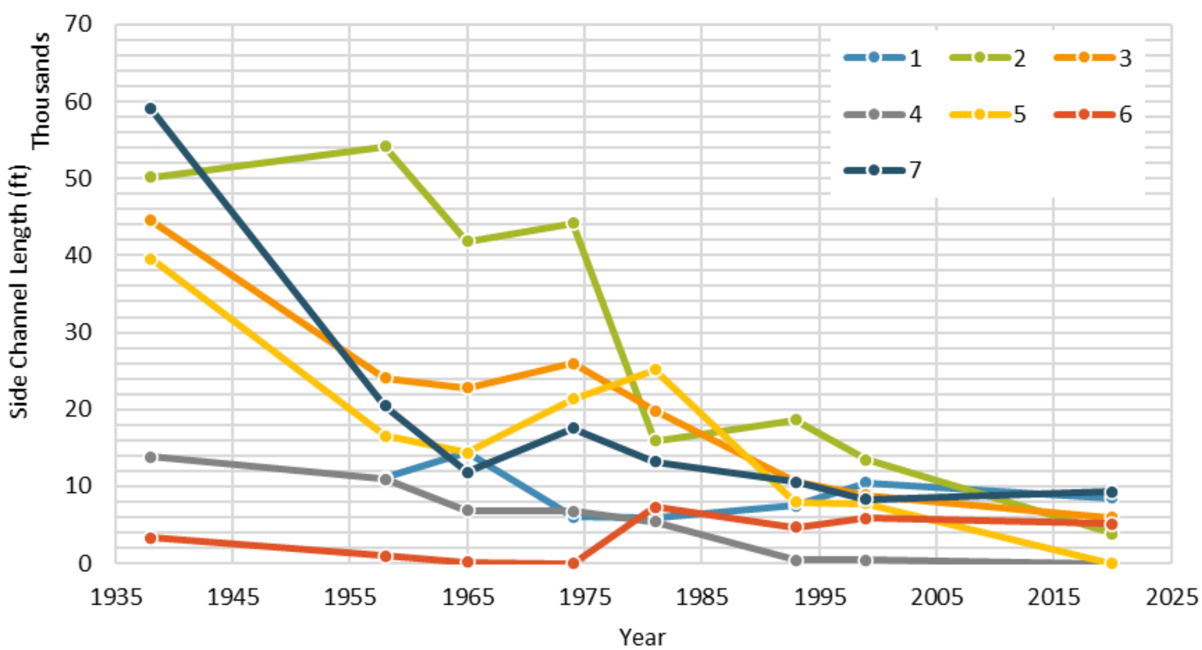



**Figure 7-8 Side channel length through time for project reaches. Note the 1938 Reach 1 length is not included due to lack of aerial photograph extent.**

Figure 7-8 shows that, for the entire Chokepoint segment, there has been a consistent trend of side channel loss for both anabranching and secondary channels since 1938. In contrast, the total length of the main channel length has remained relatively consistent since the late 1930s.

Figure 7-9 shows the braiding index for the North Platte River upstream and downstream of Highway 83 over the course of eight years. The index varies between 7.5 and 1.7 in 1938 and 2.3 and 1.0 in 2020. Figure 7-9 shows how these indices vary with distance downstream. All reaches sampled in present-day show signs of braiding to varying extents apart from Reach 4 and Reach 5. Throughout the Chokepoint reach, the river is less braided, mainly due to decreasing side channel lengths. This conclusion is similar to the results from Williams (1978).

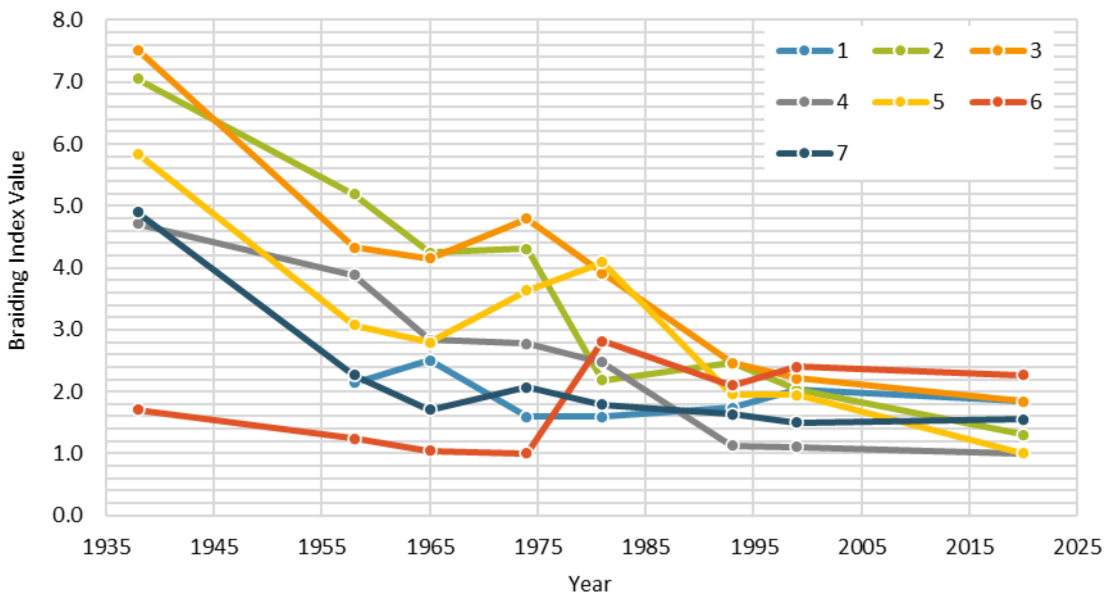



**Figure 7-9 Braiding index for North Platte River near North Platte, NE between 1938 and 2020.**

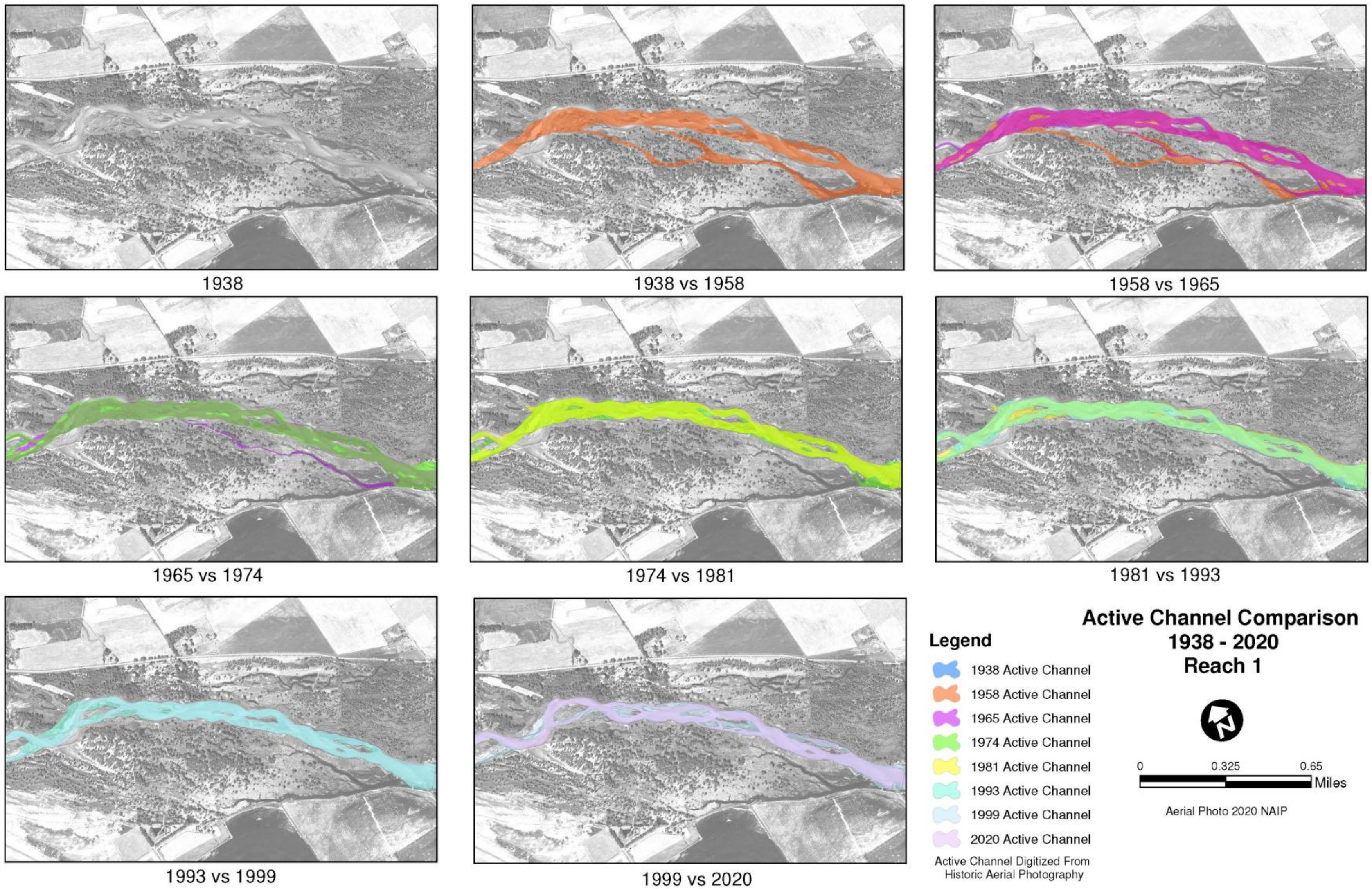



**Figure 7-10 North Platte River near North Platte, NE Chokepoint: Reach 1 Main Channel and Side Channel Comparisons between 1938 – 2020**

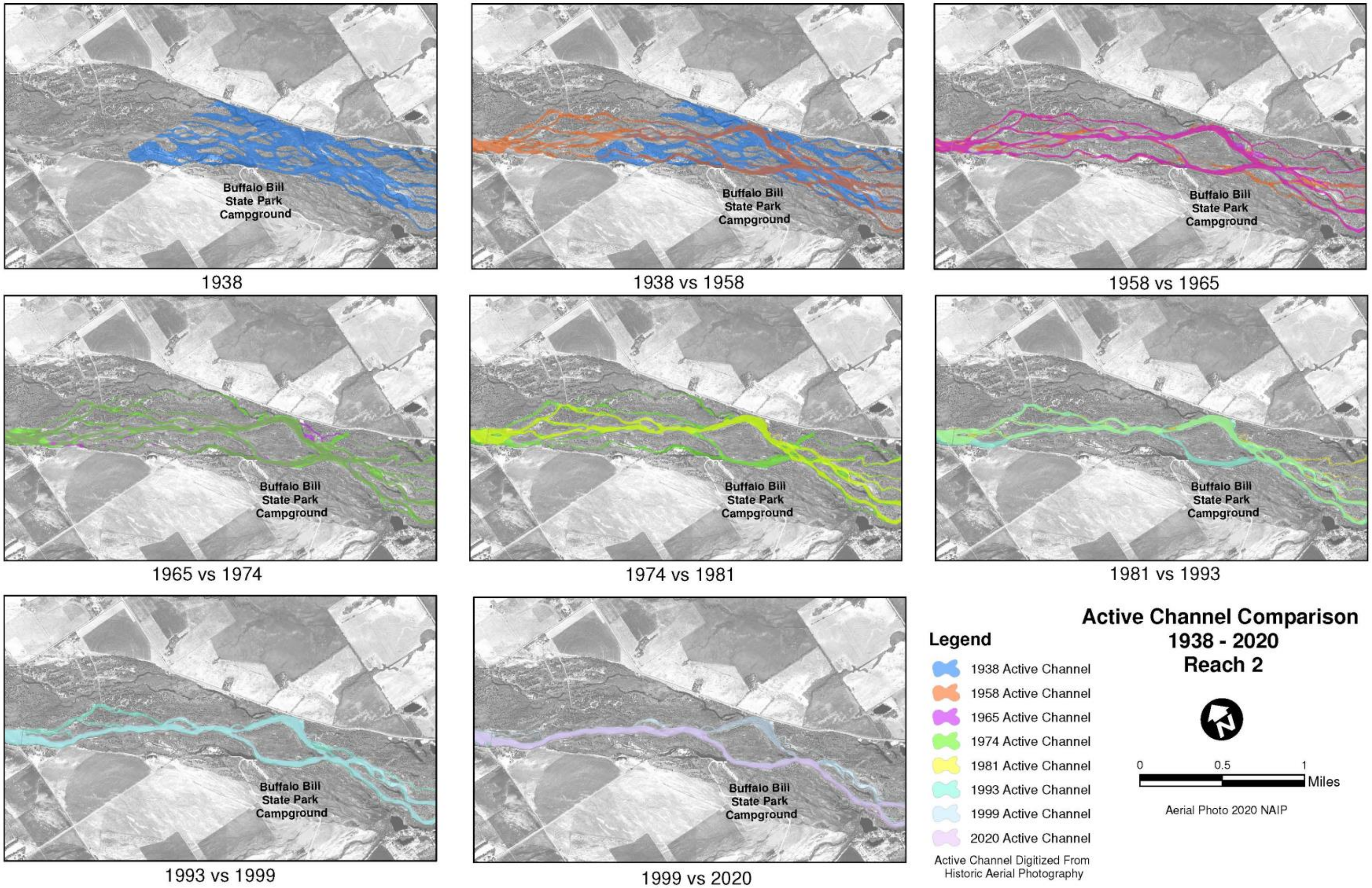



**Figure 7-11 North Platte River near North Platte, NE Chokepoint: Reach 2 Main Channel and Side Channel Comparisons between 1938 – 2020**

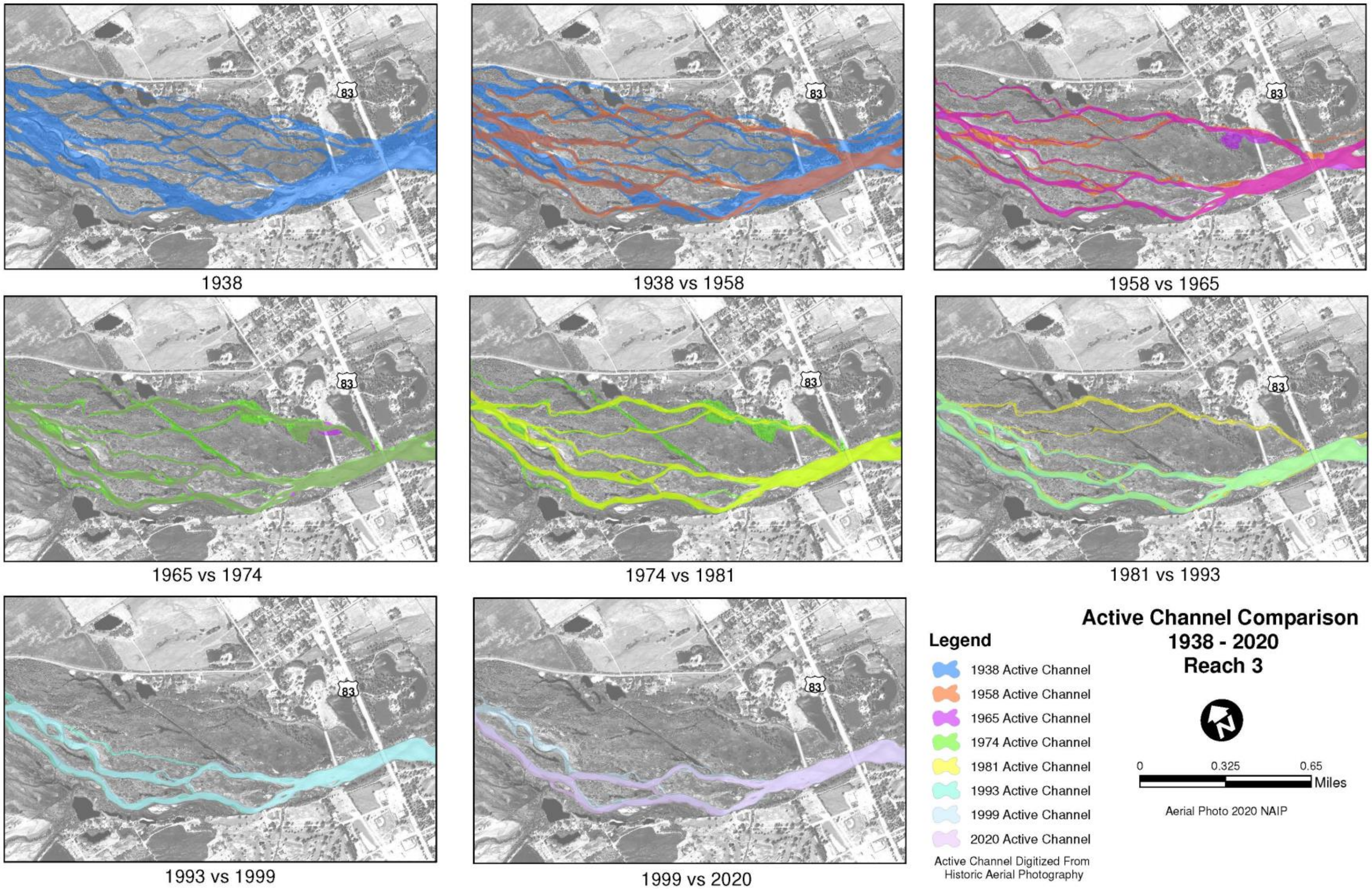



**Figure 7-12 North Platte River near North Platte, NE Chokepoint: Reach 3 Main Channel and Side Channel Comparisons between 1938 – 2020**

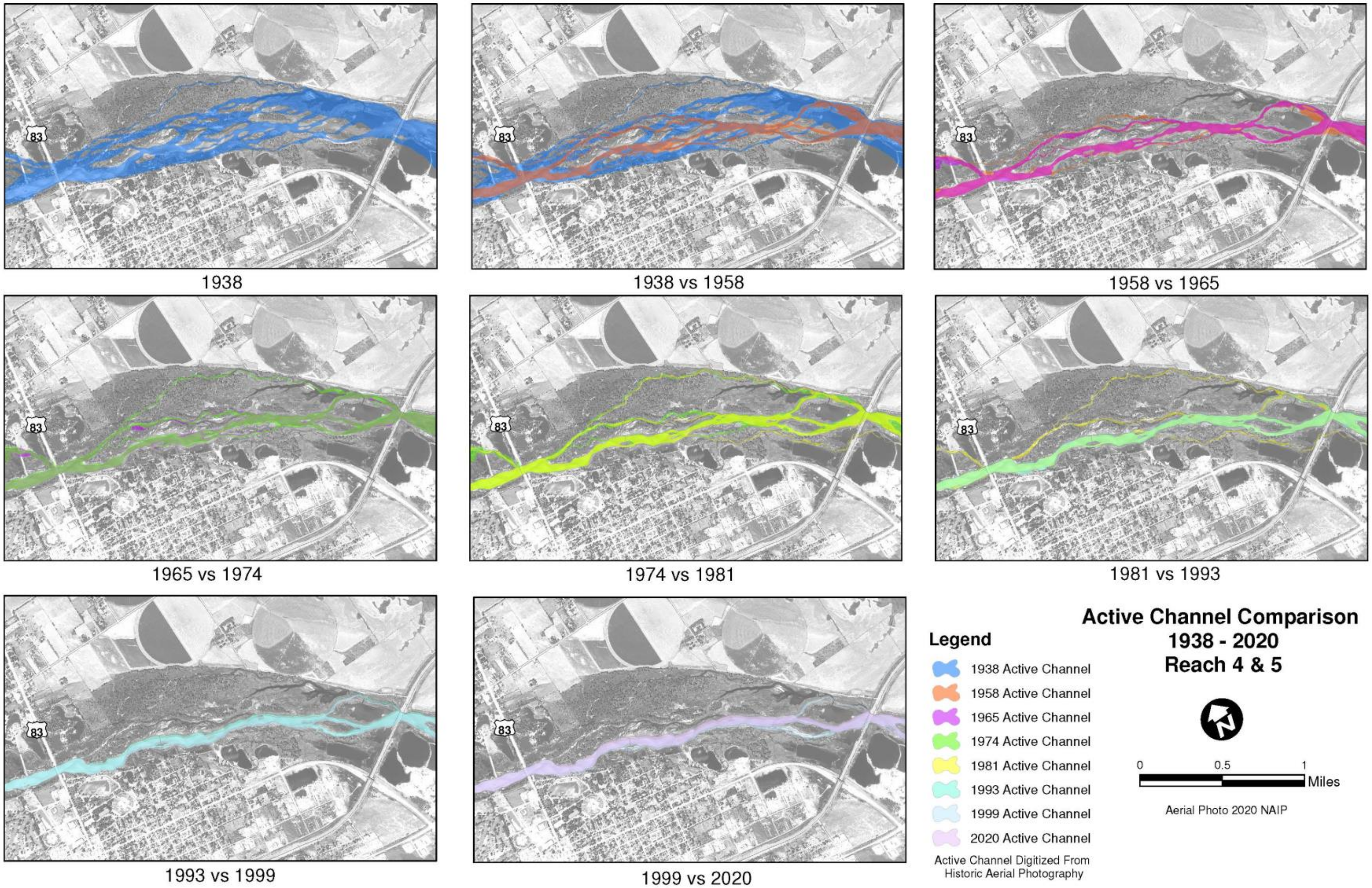



**Figure 7-13 North Platte River near North Platte, NE Chokepoint: Reach 4 and Reach 5 Main Channel and Side Channel Comparisons between 1938 – 2020**

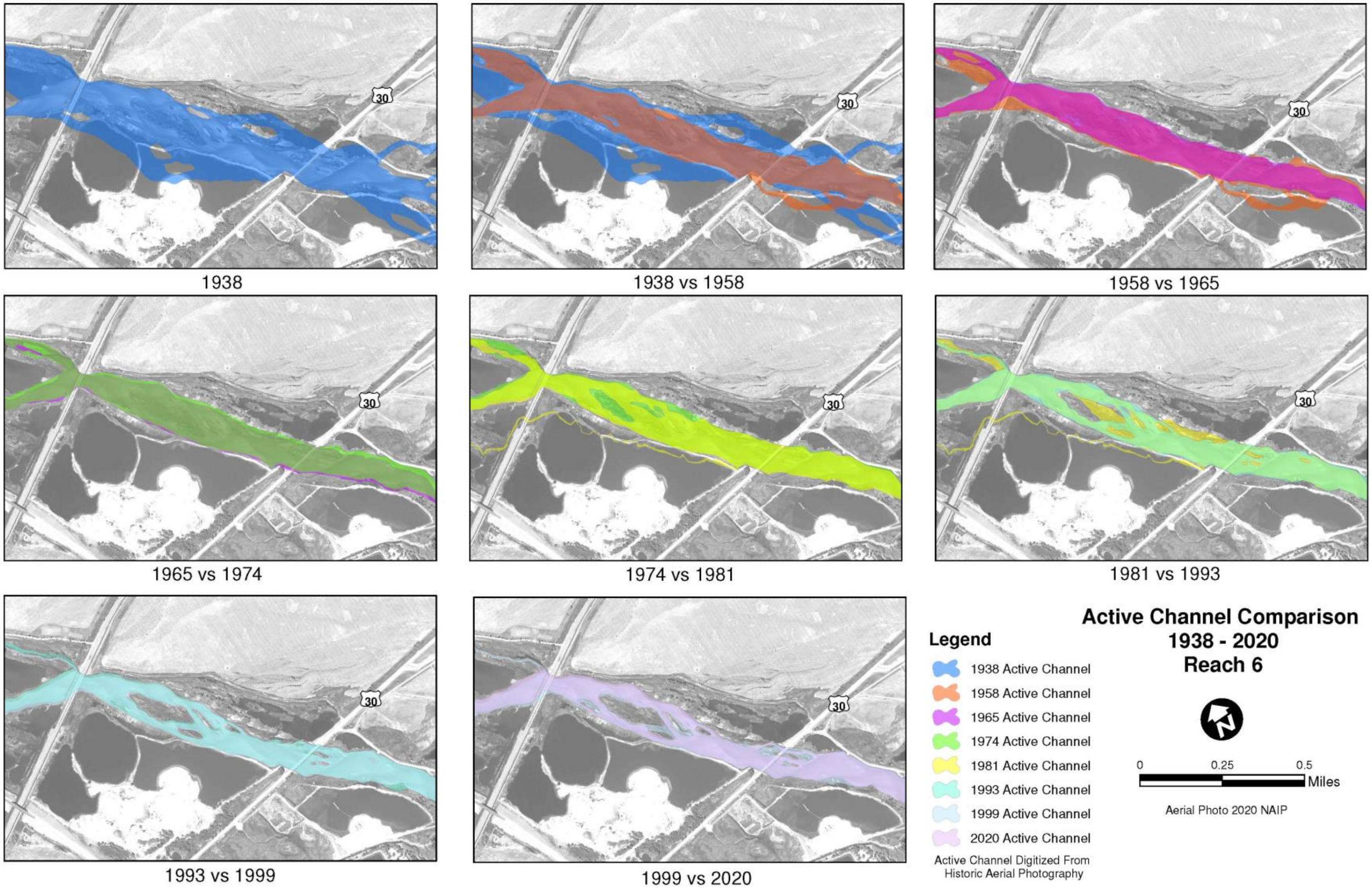



**Figure 7-14 North Platte River near North Platte, NE Chokepoint: Reach 6 Main Channel and Side Channel Comparisons between 1938 – 2020**

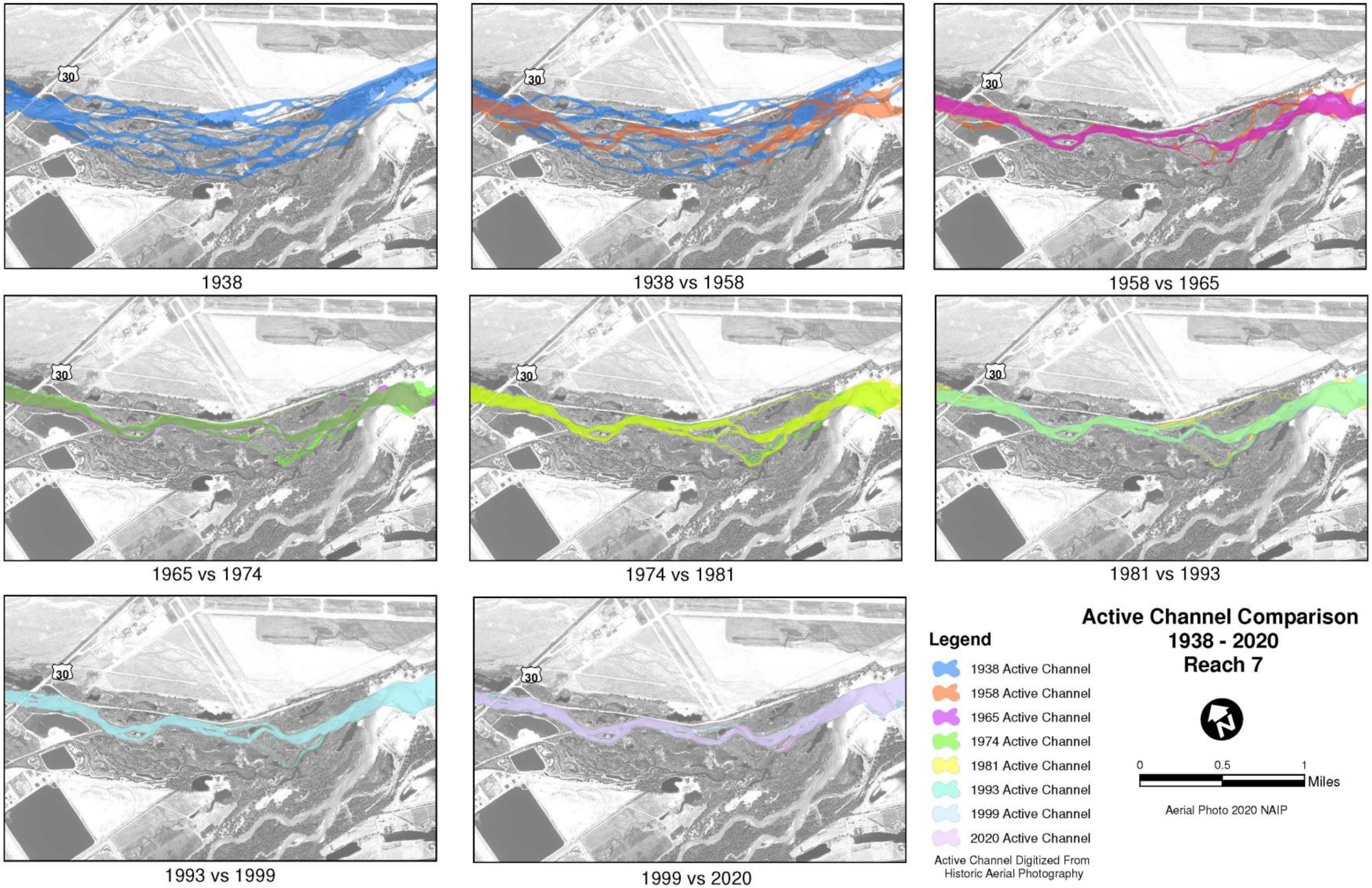



**Figure 7-15 North Platte River near North Platte, NE Chokepoint: Reach 7 Main Channel and Side Channel Comparisons between 1938 – 2020**

***Sinuosity***

Figure 7-16 below lists the main channel sinuosity values between 1938 and 2020. The average sinuosity along the full study North Platte-Chokepoint segment has remained relatively constant in the 1.05 to 1.15 index range. Note Schumm (1969) indicated that while the transformation of the North Platte River from a braided to a meandering river is not complete, it has become more sinuous. While that is likely true generally along the North Platte River, changes to sinuosity along the 11-mile Chokepoint segment remain relatively consistent with mostly straight reaches.

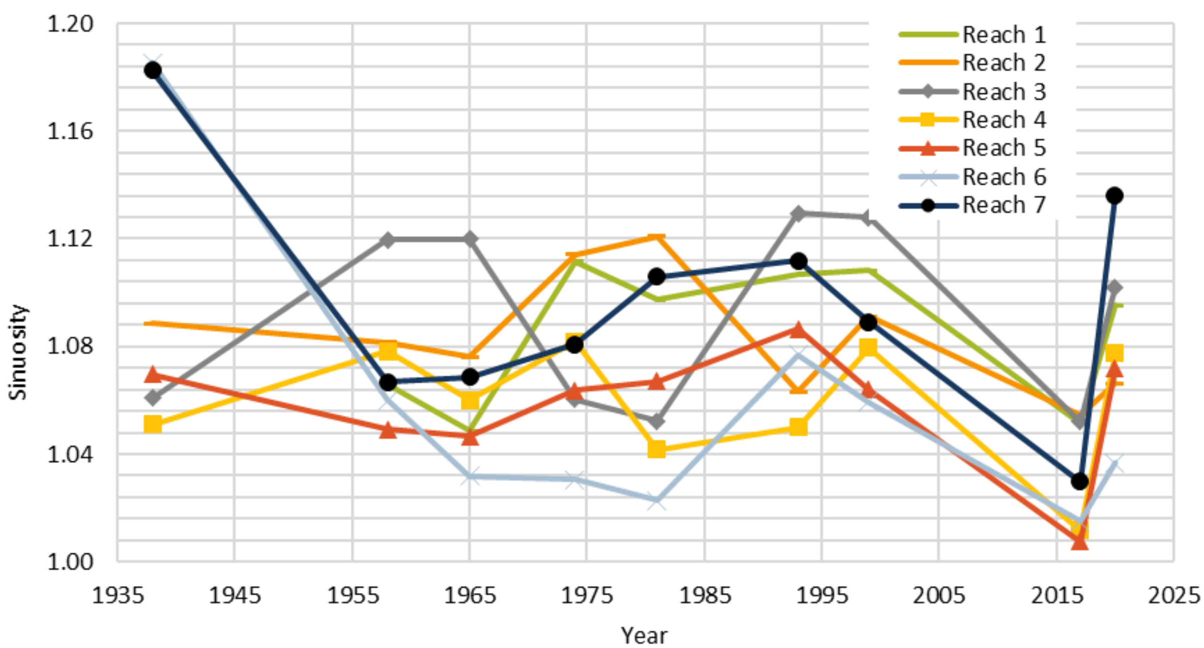



**Figure 7-16 Sinuosity values for the North Platte River Chokepoint segment.**

### *7.1.5 Geomorphic and Conveyance Implications*

The evolution of a braided stream pattern to an anastomosing, single thread channel is due to changes in hydrologic and sediment regimes combined with encroaching vegetation. As noted in Simons & Assoc. (2000), the North Platte River tends to be on the inflection point between braided and anabranching and is now more representative of a single-thread river. Further, sediment deposition and vegetation growth driven by flow changes have caused the river to anastomose and abandon secondary channels, forming vegetated islands that reduce side channels. This planform change, in combination with a decrease slope (see Section 7.2.2 and reduced channel area (see Section 7.3.2Figure 7-24) contributes to decrease in hydraulic conveyance. Williams (1978) and other previous studies (FLO Engineering, USBR 2003) have documented this transition from a braided channel to a single thread channel, contributing to a long-term reduction in active channel widths and hydraulic conveyance.

The main channel length, side channel length, braiding index, and sinuosity have all remained relatively consistent since the mid-1990s, indicating the contemporary North Platte River in the Chokepoint segment has evolved into a single-thread, mostly straight channel with occasional vegetated islands caused by anastomosing. That trend is reinforced by limited changes in stage and discharge shown in the North Platte River at Highway 83 specific gage analysis (see Section 6). The lines of evidence described above also suggest the current river pattern will remain stable in response to contemporary flow and sediment discharges. This stability could be interrupted due to a large flood as suggested by the geomorphic responses to the high flow events between 1970 and 1985.

## 7.2 Channel Profile

The channel bed profile is an indicator of the range of river conditions. The longitudinal channel bed profile is based on minimum bed elevations, and the distance along the river channel. It is used to determine the slope of the river channel and changes to bed elevation when a time series of geometric data is available. Changes in such bed elevation should reflect a general trend in aggradation or degradation (Williams 1978 pg. 26). Bed slope is therefore a useful indicator to investigate changes in geomorphic characteristics.

Bed slope at any point represents the combined history of hydrology, hydraulics, sediment characteristics, geology, and anthropogenic influences such as bridges and hydraulic structures. The study area includes three bridges: 1) U.S. Highway 83 Bridge, 2) Union Pacific Railroad Bridge, and 3) U.S. Highway 30 Bridge and the Tri-County Canal Diversion (TCCD) Structure. The three bridges span the North Platte River's active channel and generally encroach into the floodplain. The Hydraulic Characteristics Section provides further information on the bridges. The TCCD was constructed between 1936 and 1940 as part of the Tri-County Project, becoming operational in early 1941. The TCCD Structure is a 10.7-foot high, 874-foot-long channel-spanning concrete structure located immediately downstream of the confluence of the North Platte and South Platte Rivers. The channel spanning Structure acts as grade control and creates a depositional zone due to raising the channel bed elevation.

Between 1941 and 1964 sediment accumulation upstream of the diversion became problematic for CNPPID operations. Observation of river response to the TCCD between 1941 and 1964 was documented in a letter written by Mr. Geo E Johnson to CNPPID in August of 1964. Mr. Johnson noted "t*he bed of the North Platte River at the USGS Gauging Station at the bridge north of the City of North Platte shows very little change. However, for the first three-quarters of a mile above the Diversion Dam, the North Platte River is filled with an average of seven feet of sand."* Understanding the TCCD Structure's zone of influence on the profile and depositional patterns (i.e., sediment "wedge") is a key question related to hydraulic conveyance.

### 7.2.1 Method of Analysis

Measuring bed elevation change for a sand-bed channel is not a precise concept. The shifting nature of small- and large-scale bed forms causes a continuous fluctuation in the elevation of the bed at any one spot (Williams 1978). However, in a stable channel, the bed elevation should be reasonably constant if measured over a long enough time relative to the passage of bed forms. ACE evaluated several data sources to develop multiple channel bed profiles over a period of different time periods.

- Gannett (1901) interpreted from USBR 2004
- Design drawings and/or survey of diversion structures
- FEMA Flood Insurance Study (1979)
- Simons & Associates (2000)
- HDR/Tetra Tech 1D Hydraulic Model (2011)
- LiDAR (2017)
- River Design Group (2023) based on 2017 LiDAR
- Field survey (2023)

We have plotted available channel bed elevations and slopes from each of these data sources along the study area. Profile plots were also prepared for the North Platte River from the TCCD Structure to Keystone Dam.

### 7.2.2 Results

***Comparison of Channel Bed Profiles (1940, 1972, and 2009)***

The Keith Lincoln, North Platte, Suburban, and TCCD diversions have acted as grade control structures that hold the local bed elevation of the river. For example, the lack of change in bed elevation in the 35 miles of river between the erosional zone downstream of Lake McConaughy and HWY 83 can be attributed to the two diversion structures (Keith Lincoln and North Platte Canal), which has likely slowed the progression of clear water scour in the downstream direction. This transport section of the river has also maintained a steeper slope and, therefore, a higher shear stress and sediment transport capacity.

The slope between structures was used to estimate the historic bed slope in 1940. The Keith Lincoln, North Platte, and Suburban diversion structures were originally constructed in 1894/1895. Design drawings with elevation information were not available. In lieu of design and/or survey information, the invert elevation of the diversion outlet gates of each structure was estimated using profile information from the 2011 HDR/Tetra Tech HEC-RAS hydraulic model, which references NAVD88. Design drawings of the TCCD Structure repairs conducted in 1985 were obtained. Elevation of the TCCD Structure outlet gate was determined from the design drawings combined with survey data collected in 2023 that reference NAVD88. Additional points at the Sutherland and HWY 83 gage locations were estimated in 1940 using gage data measurements at the lowest discharge values.

The 1940 bed slope estimated between diversion structures is shown in Figure 7-17 and compared with the 2009 bed profile from the 2011 HDR/Tetra Tech model between Keystone Dam and the TCCD Structure. Changes in bed elevation between 1940 and 2009 were checked against observations provided by the USBR (2004) as well as data at the Sutherland and HWY 83 gages, as noted in Figure 7-17. The difference in 1940 and 2009 bed profile is shown graphically in Figure 7-18 to provide insight into general trends in aggradation and degradation. In general, clear water releases from Keystone Dam have resulted in degradation downstream to the Keith Lincoln Diversion. Conversely, aggradation increasingly occurred between Hershey and the TCCD. This figure should be evaluated with caution. A signal towards aggradation and degradation is noted when differences are +/- 1 to 1.5 feet due to uncertainty in bathymetric data approximations associated with the 2011 HDR/Tetra Tech model and estimated 1940 historic profile.

Within the current study reach additional bed profile information was obtained from the FEMA Flood Insurance Study (FIS) dated May of 1979. The 1979 FIS included bed profile information from a hydraulic study conducted in 1972. The FIS profile references NGVD29 and was converted to NAVD88 so that comparison to other data sets could be made. Flood Insurance Rate Maps (FIRMs) included in the FIS provided cross section location mapping that was utilized to correlate the FIS profile stationing with the current study. Figure 7-19 shows a comparison of the 1940, 1972, and 2009 bed profiles for the current study reach. Table 7-1 provides a summary and comparison of slope information for the years 1940, 1972, and 2009.

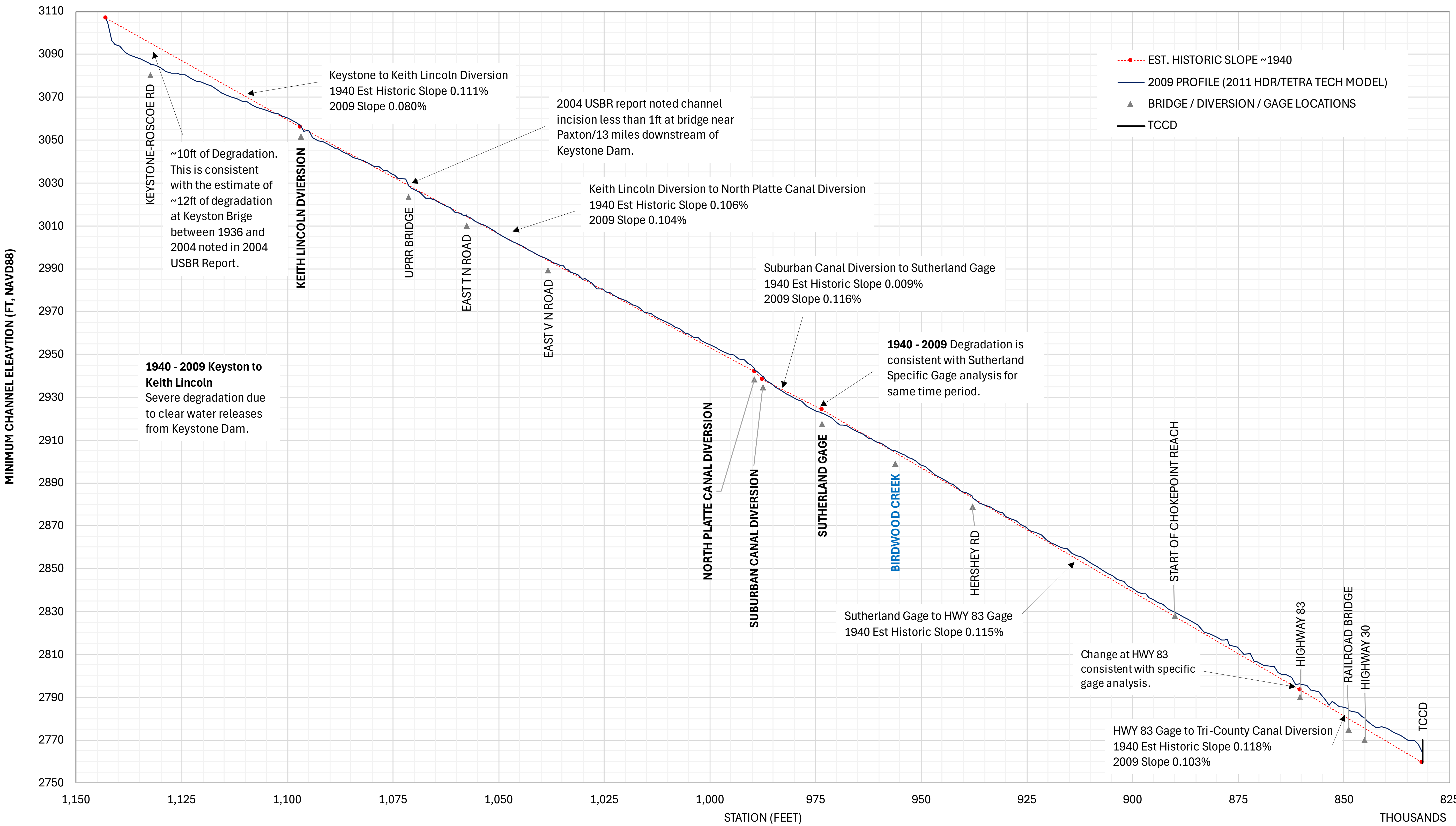



**Figure 7-17 North Platte Bed Profile Keystone to Tri-County Canal Diversion 1940 - 2011**

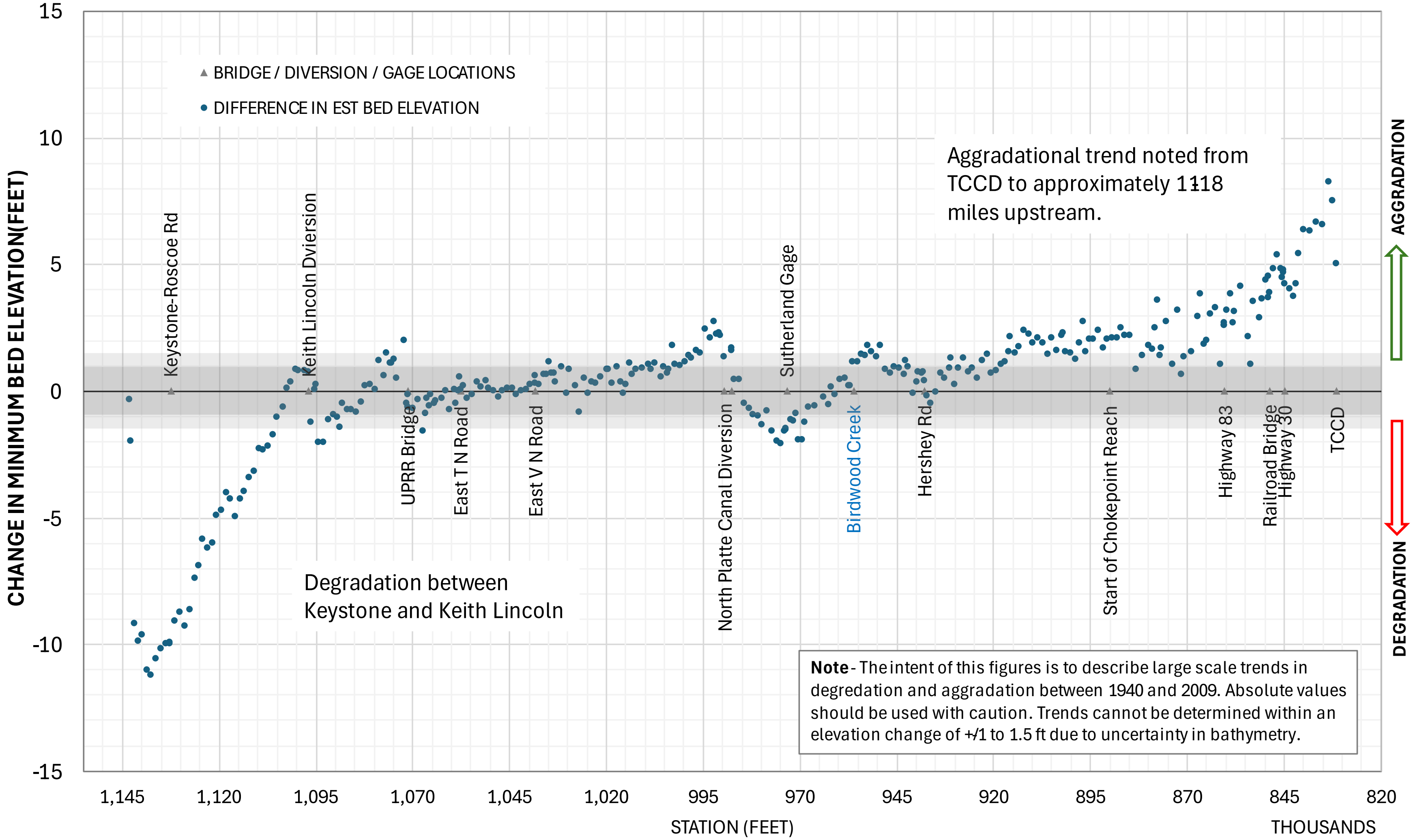



**Figure 7-18 Estimated Change in Bed Elevation 1940 to 2009.**

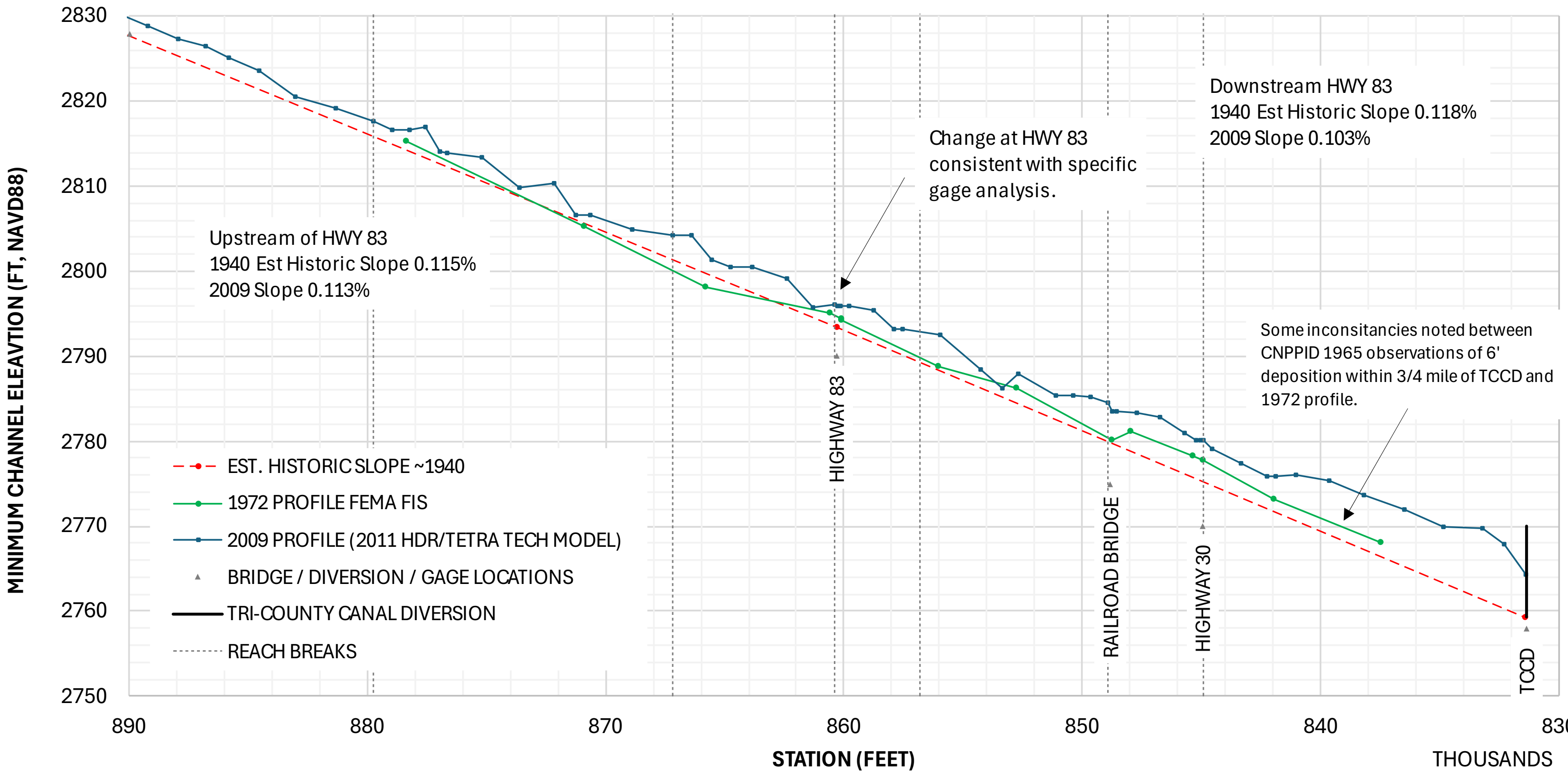



**Figure 7-19 North Platte River Channel Bed Profile Study Reach 1940, 1972, and 2009**

**Table 7-1 Channel bed slopes between Keystone Dam and the TCCD Structure for 1940, 1972, and 2009.**

<table>
<tr><th>River Section</th><th>Est 1940 Slope</th><th>1972 Slope</th><th>2009 Slope</th></tr>
<tr><td>Keystone Dam to Keith Lincoln</td><td>0.111%</td><td>--</td><td>0.080%</td></tr>
<tr><td>Keith Lincoln to North Platte Diversion</td><td>0.106%</td><td>--</td><td>0.104%</td></tr>
<tr><td>Suburban Canal Diversion to Sutherland Gage</td><td>0.099%</td><td>--</td><td>0.116%</td></tr>
<tr><td>Sutherland Gage to Upstream Limit Study Reach</td><td rowspan="2">0.115%</td><td>--</td><td>0.112%</td></tr>
<tr><td>Upstream Limit Study Reach to HWY 83 Gage</td><td rowspan="2">0.111%</td><td>0.113%</td></tr>
<tr><td>HWY 83 Gage to Tri-County Canal Diversion</td><td>0.118%</td><td>0.103%</td></tr>
</table>

Within the study reach, the estimated 1940 overall channel bed slope ranges from 0.115 to 0.118%, which is consistent with 2009 bed slopes downstream of the Suburban Canal Diversion. The 1972 estimate channel bed slope is marginally shallower than the 1940 slope in the Chokepoint segment. The 2009 channel bed slope slopes are less than the 0.116% slope upstream of the Suburban Canal Diversion likely due to the ongoing clear water flows scouring the bed downstream of the Keystone Dam.

The estimated historic slope aligns with measurements and observations from previous studies. For example, *a Letter from the Secretary of War (1934;* USBR 2004, pg. 13), notes "*from the confluence upstream, the grade is 6.1 ft per mile to 6.7 ft per mile (0.0012 to 0.0013) persisting on the North Platte tributary, upstream of the confluence of the North Platte and South Platte Rivers*." Further, as noted in USGS Water Supply and Irrigation Paper No. 44 (Gannett 1901), the slopes of the Platte River and the lower portion of the North Platte are remarkably constant and have a slope of 0.00126 between North Platte and Chapman, Nebraska, or 6.65 ft of fall per mile (USBR 2004). The USBR (2004) noted the average channel slope of the Platte River (0.00126) is considered steep for a sand-bed river of this size. The North Platte River historical slope above the confluence with the South Platte River was likely shallower than the Platte River due to differences in flow and sediment regimes. The 2009 average channel bed slope in the study area is also shallower than the historical 0.116% slope.

Comparing the 1940 to 2009 channel bed profiles suggests a strong aggradational trend from the TCCD Structure to approximately 11 to 18 miles upstream. The TCCD Structure and three bridge crossings are at least partial causes of the aggradation, which is decreasing the average bed slope along the North Platte River through the Chokepoint segment. Most notable is the decreased bed slope between HWY 83 and the TCCD.

### *Comparison of Channel Bed Profiles (2009, 2017, and 2023)*

ACE developed channel bed profiles for the seven reaches in the study area for the years 2009, 2017, and 2023 based on LiDAR and field survey data. The three channel bed profiles are shown in Figure 7-20. Change in bed elevation is shown graphically in Figure 7-21, which indicates change in bed elevation upstream of HWY 83 of -2 to +1 feet, and -3 to +2 feet downstream. Reach averaged bed slopes computed using 2023 survey data using both minimum and maximum channel elevation are shown in profile in Figure 7-22. The figure indicates that slopes computed with minimum and maximum channel elevations are consistent. Contemporary slope of the channel (both min and max) decreases in the downstream direction and ranges from 0.08% up to 0.115%.

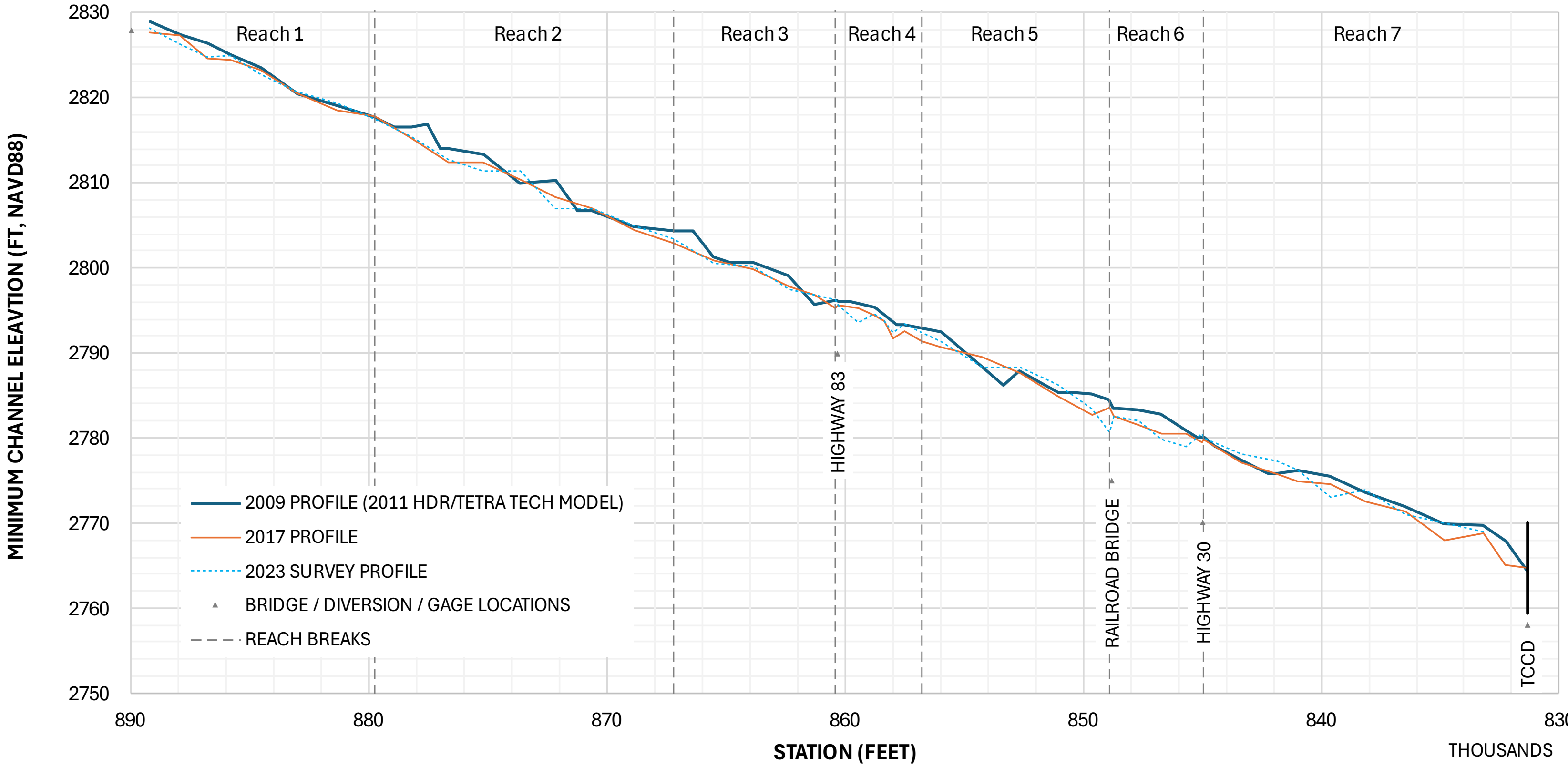



**Figure 7-20 North Platte River Channel Bed Profile 2009, 2017, and 2023**

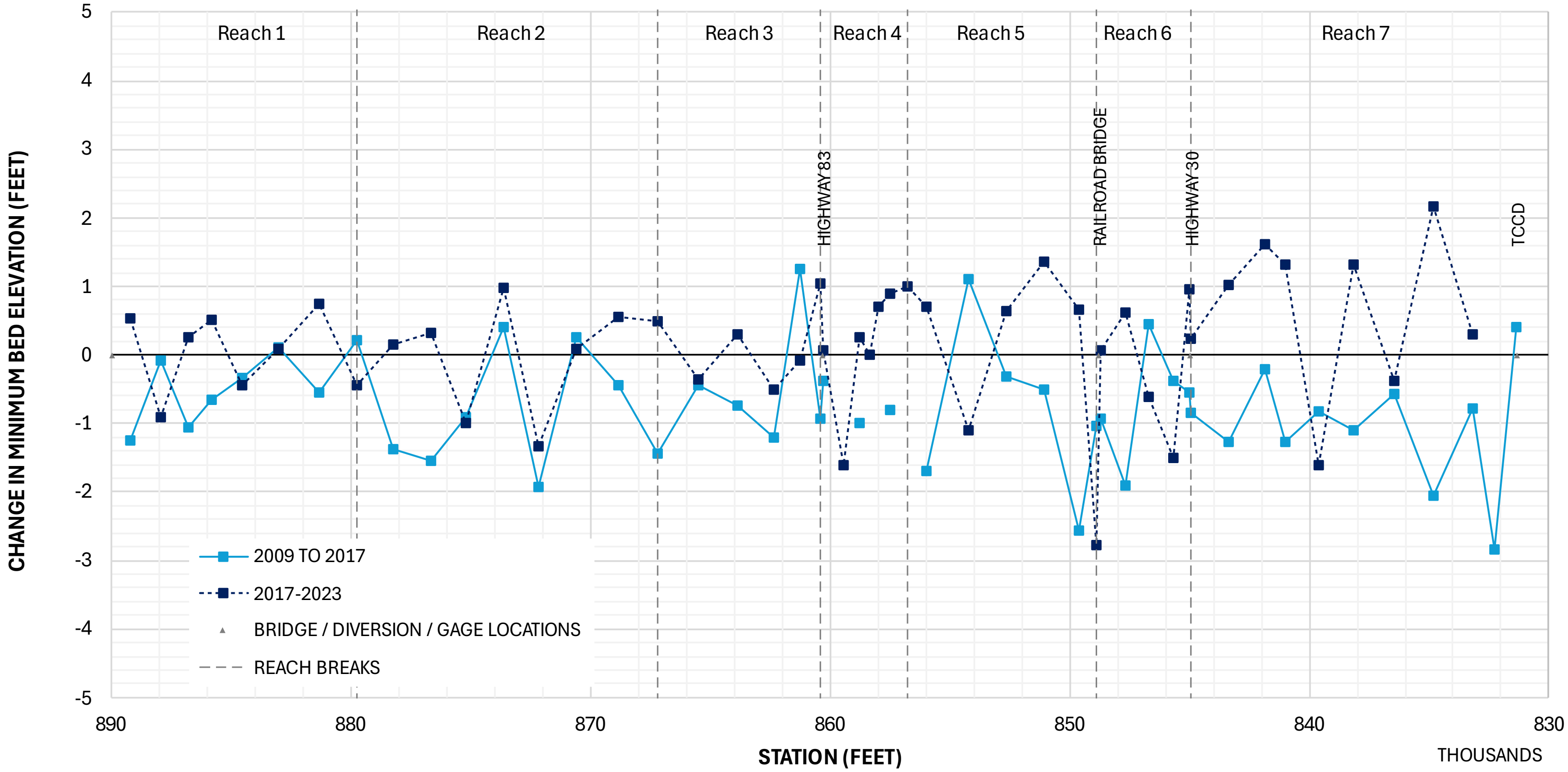



**Figure 7-21  Change in Bed Elevation between 2009 and 2023.**

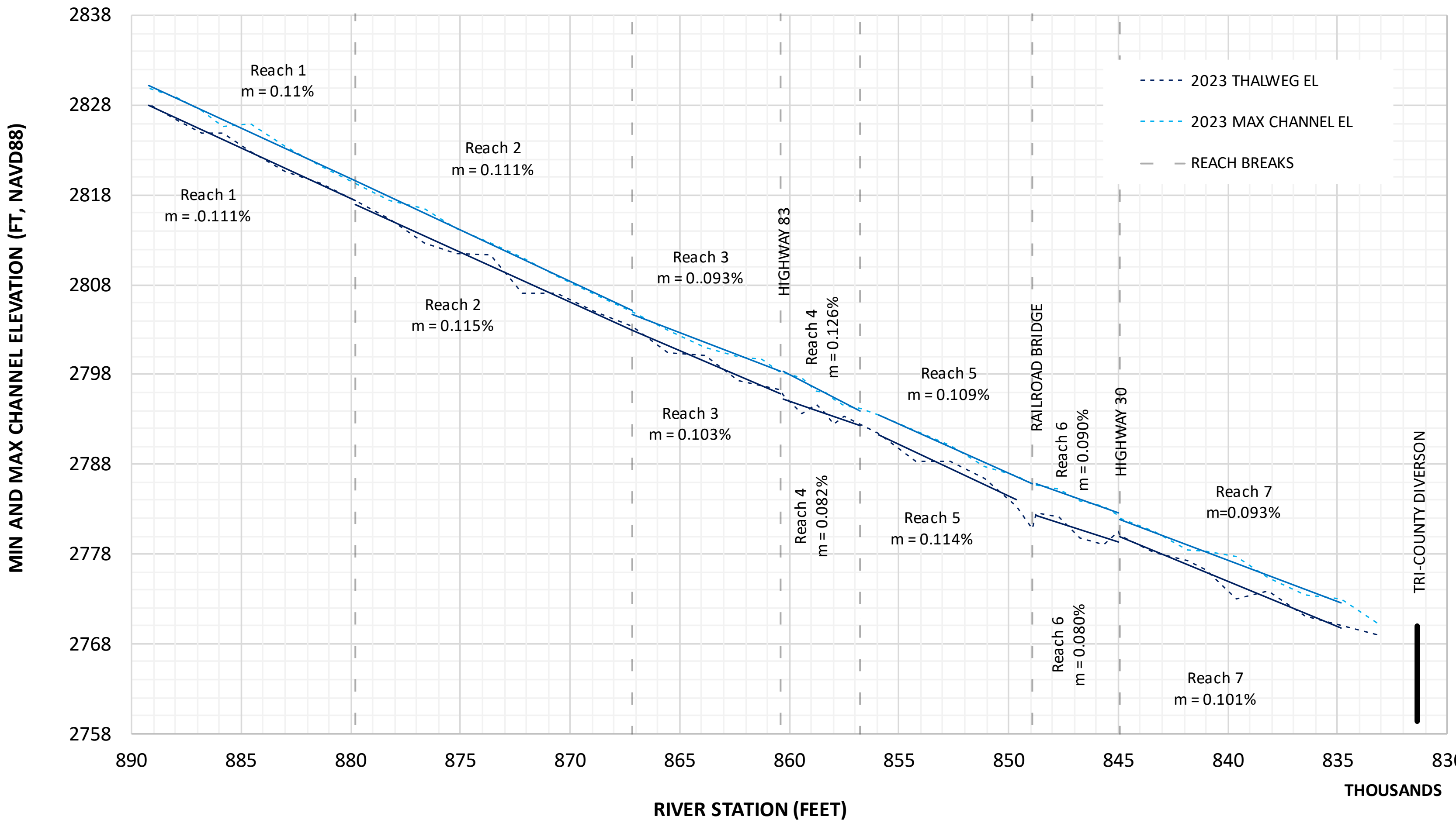



**Figure 7-22 North Platte River Min and Max Channel Bed Profile and Reach Averaged Slopes 2023**

The time series comparison in Figure 7-20 and Figure 7-21 highlights localized changes in mean bed elevations and associated slopes. Minor changes are observed in Reaches 1 and 2, which suggests a stable bed slope. However, the bed elevation data establishes a decrease in mean bed elevation and average slope for Reaches 3, 4, and 6 between 2009 and 2023, suggesting a degrading channel bed. An increasing bed slope trend is seen in the Reach 5 bed slope due to moderate aggradation. The large increase in Reach 4's and Reach 5's bed slope between 2009 and 2017 and then subsequent decrease between 2017 and 2023 may be attributed to the large flow event in 2011, but that trend is not observed in the other reaches, so we cannot draw a direct cause and effect relationship to that flow event and bed slope changes.

The bed elevation data used to develop reach averaged slopes over a 14-year period indicates some decreases and increases in the minimum bed elevation and channel bed slopes. Interpreting the longitudinal profile suggests the changes are localized and represent expected variations in an alluvial river. Note channel bed armoring in reaches 1, 2, and 3 at bar heads and dune formations along the bed in those reaches, observed during the field visit, may limit the depth of channel degradation along with the resultant decrease in local river slope.

***Geomorphic and Conveyance Implications***

Channel bed slope is directly related to flow energy and is a function of both sediment caliber and discharge. Thus, the bed profile changes because of variations in flow, bed material size and shape, geomorphic features, and riparian vegetation. While the flow and sediment discharges have changed, the slope of the North Platte River has remained relatively constant over the past 15 to 20 years (see Figure 7-17). This conclusion is supported by previous studies (Williams 1978, FLO Engineering 1992, USBR 2003). The Fish and Wildlife Service extending the analysis to 1992 showed that the riverbed at the North Platte gage has shown periodic 0.5 feet rise and fall, with no net aggradation and degradation over the long term. That statement is generally true along the Chokepoint segment, although the slopes have adjusted near the TCCD.

The current trend in stable bed slopes described above suggests the current river profile along the Chokepoint segment will remain within the 0.11 to 0.12% range. The consistent channel bed elevation and corresponding relatively stable bed slope trend over the past 20 years suggests quasi-equilibrium, which is expected to continue in response to contemporary flow and sediment discharges. Widening Reach 3 and Reach 4, however, to increase hydraulic conveyance, could potentially increase aggradation and thereby decrease the channel bed slopes.

## 7.3 Geometry

Alluvial channels like the North Platte River adjust their geometry to convey the water and sediment supplied to them. Local-scale variability in bed and bank materials, the distribution of in-channel structures (natural and anthropogenic), and the role of riparian vegetation and large wood all influence the channel geometry.

### *7.3.1 Method of Analysis*

In order to evaluate changes in the width of the active main channel through time, we digitized banklines to create a total footprint of active channel area within each reach. This footprint reflects the channel area occupied by active channels that can be mapped as continuous unvegetated features that are active at bankfull discharge. The active channel width is a measurement of channel area divided by length of main channel.

$$Cw = \frac{Channel\ area\ in\ a\ reach}{Total\ main\ channel\ reach\ length}$$

ACE also reviewed REMs based on the 2017 LiDAR to visually consider the active channel depths, widths, and shape as well as the floodplain connection and floodplain encroachment from infrastructure and development into this analysis. Relative elevation maps for the Chokepoint Reach are provided in Appendix F and G. Note vegetated floodplain areas adjacent to the channel are not included in the active main channel footprint, even though they may inundate during high water.

### *7.3.2 Results*

Figure 7-23 shows channel width changes between 1938 and 2020. These results are substantiated by previous studies. For example, Williams (1978) describes the reduction in active channel widths between 1865, 1938, and 1965. Active channel widths in 1938 were greater than 800 feet and have decreased to less than 300 feet upstream of Highway 83 and 400 feet downstream of Highway 83 in 2020. The narrowing of the river's width through time generally follows the trend of lost side channel length, although since about 1990 the loss rate of side channel length has slowed while width has continued to narrow.

Channel widths in recent topographic cross-sectional surveys (2011 and 2023) have documented local widening of the channel, typically less than 10 feet on average, downstream of Highway 83 along Reach 4, Reach 5, and Reach 7. That widening may be contributing to the increase in conveyance at the minor flood stage (see Figure 5). See Appendix D for 2011, 2017, and 2023 surveyed cross sections plots.

These results collectively document a system that has consolidated into fewer channels over the last century, which has in turn resulted in a narrowing of the active stream corridor and reduction in hydraulic conveyance. These results also demonstrate the relatively wide and shallow nature of the channel geometry of the North Platte River, indicated by bankfull width to depth ratios ranging between 100 and 180. For context, historical bankfull width to depth ratios prior to water development were likely 5 to 10 times higher, which reinforces the observed trend in reduction of the active channel width over the past sixty to eighty years.

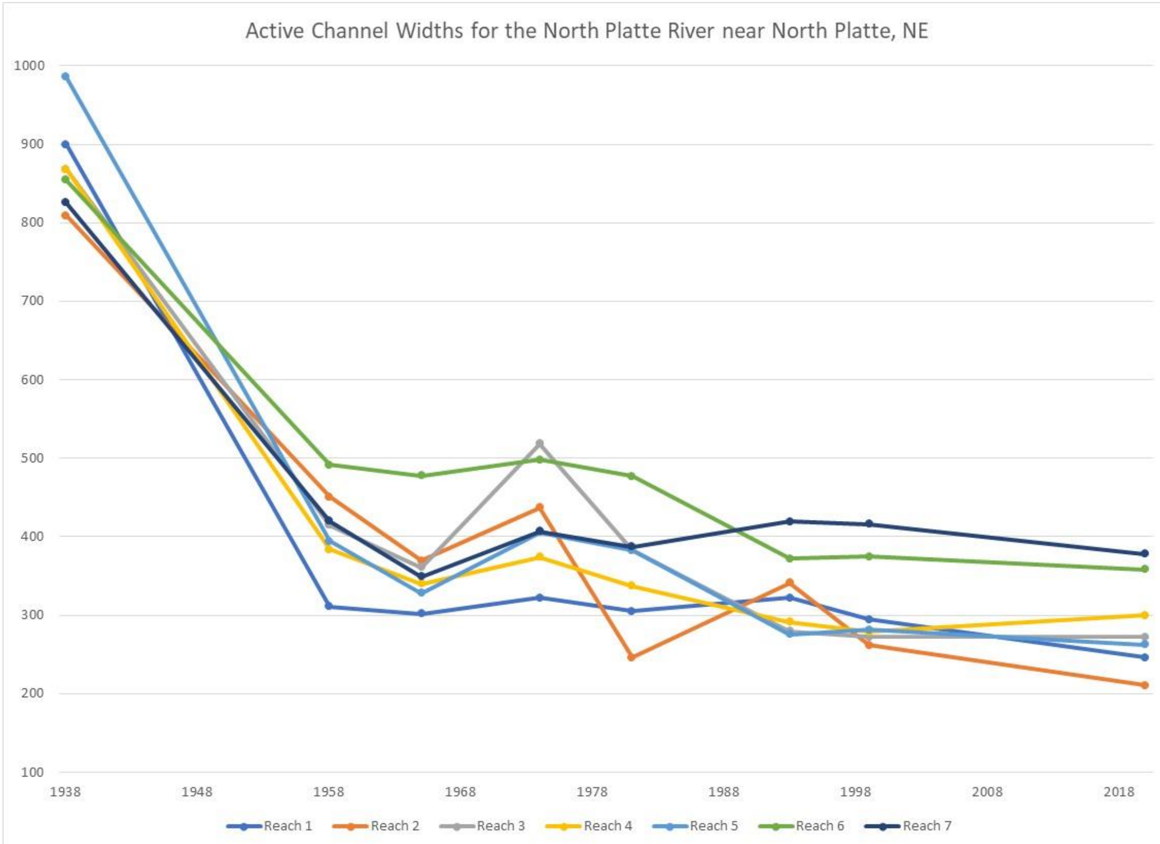



**Figure 7-23 Active channel widths between 1938 and 2020**

### *7.3.3 Geomorphic and Conveyance Implications*

Reduction of channel width has been documented extensively (Figure 7-24) and has been shown to coincide with changes to the hydrologic regime, sediment inputs, and riparian vegetation cover (See Section 8). Those changes modified the North Platte River patterns and rates of depositional and erosional processes, which also influences its geometry, particularly wetted width.

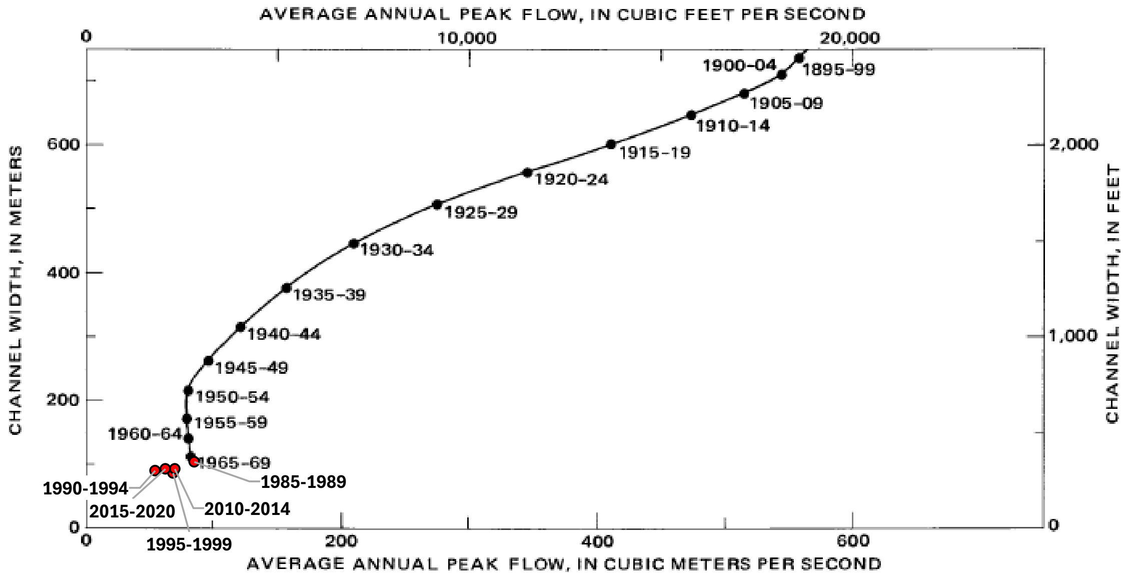



**Figure 7-24 Relation of channel width to 5-year-averaged annual peal flows, North Platte River at North Platte (Williams 1978)**

Yang (1986, 1996) developed the equation below (Dariaio et al. 2003, pg. 4) that shows the contributing factors to the determination of channel width: sediment and water discharge ($Q_s$ and Q), channel slope (S), sediment particle size diameter (d), and channel depth (D).

$$W = \frac{Q^2 SK}{Q_s d^{0.5} D}$$

Within the Chokepoint segment, there has been a reduction in channel width due to a decrease in flow discharge and sediment supply, an increase in depth, and a marginal increase in particle size. While the slope has adjusted in some reaches (see Section 7.2 Channel Profiles), it has remained relatively constant. Based on this relationship, reduction in peak discharge and sediment load are the master variables driving channel narrowing in the Chokepoint segment, although the reduction in channel width is also a result from floodplain vegetation establishment, bridge structures, diversion dams, and bank protection is a localized effect.

The trend in narrower active channel widths, and associated decrease in width to depth ratios, likely contributes to a decrease in channel area. The smaller channel area combined with shallower channel bed slopes reduces hydraulic conveyance. Sediment deposition and vegetation growth driven by flow changes have caused the river to abandon secondary channels and begin a transition from braided to a single thread channel. Williams (1978) and other previous studies (FLO Engineering, USBR 2003) have documented this transition from a braided channel to a single thread channel, contributing to a long-term reduction in active channel widths and hydraulic conveyance.

# 8 VEGETATION CHANGES

Using desktop-based GIS analysis, ACE evaluated temporal and spatial changes to vegetation to identify trends through the Chokepoint segment. The analysis focused on digitizing mature and submature vegetation along the river corridor and floodplain between 1938 and 2022. This section summarizes the methods and results of that analysis and provides geomorphic and conveyance implications.

## 8.1 Method of Analysis

The 1938 – 2020 time series of cover types can be interpreted to show changes in the channel and floodplain, which is another line of evidence in understanding channel dynamics and conveyance. Historical aerial photographs were used to digitize and map three cover types (open bar, submature, and mature) for the seven reaches in the Chokepoint segment. We defined the high flow channel area with mid-channel bars and point bars as open bars. Established woody vegetation was classified as mature vegetation (mapped as closed canopy) while herbaceous sedges and shrubs (e.g., willows), and grasses were classified as submature vegetation. Note deciphering vegetation cover types from historical aerial imagery can be challenging due to image quality, coarser resolution, and varying spatial coverage (Morgan et al., 2013), so the results are used as relative comparisons and not absolute values.

## 8.2 Results

The 1938-2020 vegetation cover types are shown in Figure 8-1 through Figure 8-6. Figure 8-7 shows that the major shift between 1938 and 1999 has been towards less open bar area and submature vegetation due to increased mature woody vegetation. Upstream of Highway 83, the extent of mature woody vegetation has increased by roughly 400 acres between 1938 and 2020, which is approximately a 200% change (Figure 8-8). The extent of open bar area decreased in all reaches except Reach 4 between 1938 and 2020 (Figure 8-9). Overall changes from submature to mature between 1938 and 1999 are generally incremental and show a consistent trend that follows the decrease in flows and sediment supply. Between 1999 and 2020, the trend flips to more acres of submature than mature vegetation. ACE's evaluation of vegetation cover changes between 1938 – 2020 have generally shown that the previous trend of significant woodland expansion has slowed and appears to reverse starting in the early 1990s.

To verify the 1993 to 2020 vegetation cover type trends, ACE reviewed 2012 NAIP imagery and 1993 imagery to compare cover types to the 1999 and 2020 cover types (see Appendix H). 2012 imagery showed less mature cover than 1999, but more than the 2020 imagery captures. 1999 imagery is difficult to interpret vegetation cover types due to low-resolution quality imagery, but the 1993 imagery and 2012 NAIP imagery provide high-resolution sources to delineate vegetation cover and both data were captured during the growing season.

The specific cause driving the change in vegetation cover type coverage, starting in the early 1990s, is unclear. We do know from previous studies (Friedman et al., 1998, Johnson, 1998) that reductions in flow in braided streams show a loss of riparian vegetation and increases in woody vegetation establishment and forested area. As the North Platte River has evolved from a braided to a single-thread channel, an increase in woody vegetation is apparent. We also observe phragmites taking over low-lying areas along the North Platte River including riverbanks, wetlands, meadows, side channels, sloughs and sandbars. While the PRRIP has executed vegetation control (PVWMA 2019) along the North Platte over the past 20 years to control phragmites, it has established in the overbank areas and created a stable floodplain along the single thread channel.

The response of vegetation to changes of flow caused by dams and reservoirs is highly variable and is dependent on pre-existing conditions of flow regime, sediment characteristics, and channel form (Friedman et al., 1998). So, changes in vegetation cover types over the past 30 years is possibly due to multiple factors, including the large flood events in the early 1980s that resulted sediment accretion on the floodplain as well as the channel evolving from braided to single-thread, and intensive phragmites treatment, which included spraying and mechanical removal of vegetation.

## 8.3 Geomorphic and Conveyance Implications

The results of the vegetation change analysis indicate significant increases in mature vegetation occurred along the Chokepoint segment, mainly in the 1930's through 1960's. Many researchers have documented the expansion of woody vegetation into the channels of Platte River and its principal tributaries (Williams 1978, USBR 2004). Simons and Associates (2000) also noted active channel widths between areas of vegetation on islands and on the banks were considerably greater under pre-development conditions compared to current conditions. The same is true today as observed during the 2023 field visit: mature, woody vegetation still occupies approximately 35% of floodplain beyond the active channel.

Figure 7-23 shows the reduction in the percentage of active channel over time as mature vegetation progressively expanded into the active channel. The complement to the percentage reduction in active channel width is the expansion of vegetation. This analysis highlights that for the locations analyzed in the Chokepoint segment, woody vegetation has expanded onto approximately 70 to 90 percent of the total channel width (leaving only about 10 to 30 percent of the former total channel width as active, non-vegetated width). The development of vegetation on sandbars within the old channel and establishment of woody vegetation on the floodplain coincides with the decrease in hydraulic conveyance through the Chokepoint segment. As noted in USBR (2004), changes in vegetation and channel form are highly dependent and complex, so drawing direct cause-and-effect relationship is difficult. However, the trends summarized above indicate vegetation encroachment is a variable in the stabilization of channel widths as the channel evolved from braided to single-thread. The vegetation changes, particular the increase in mature woody species, have also contributed to the decrease in hydraulic conveyance, primarily through an increase in hydraulic roughness.

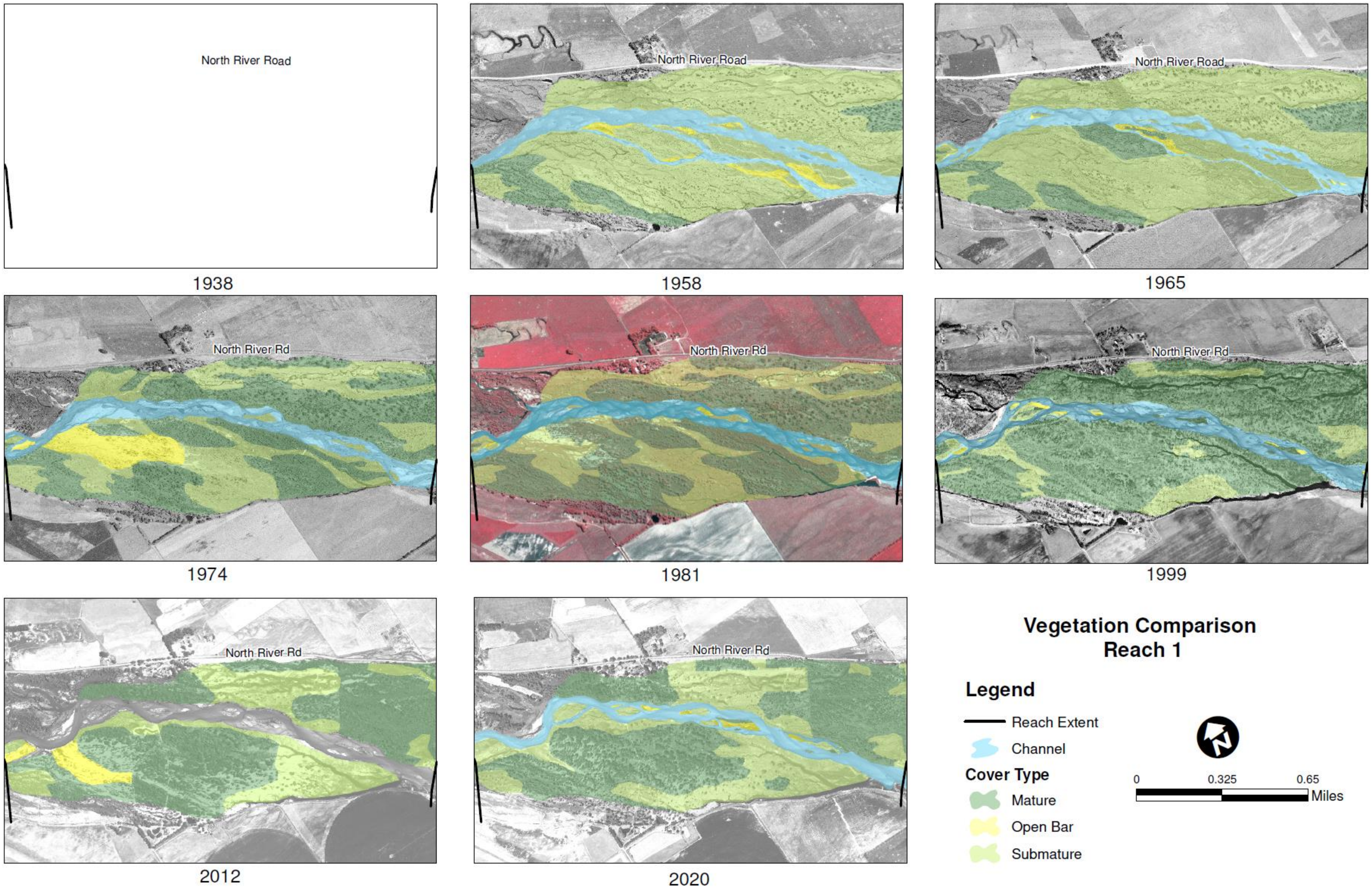



**Figure 8-1 Chokepoint Reach 1 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

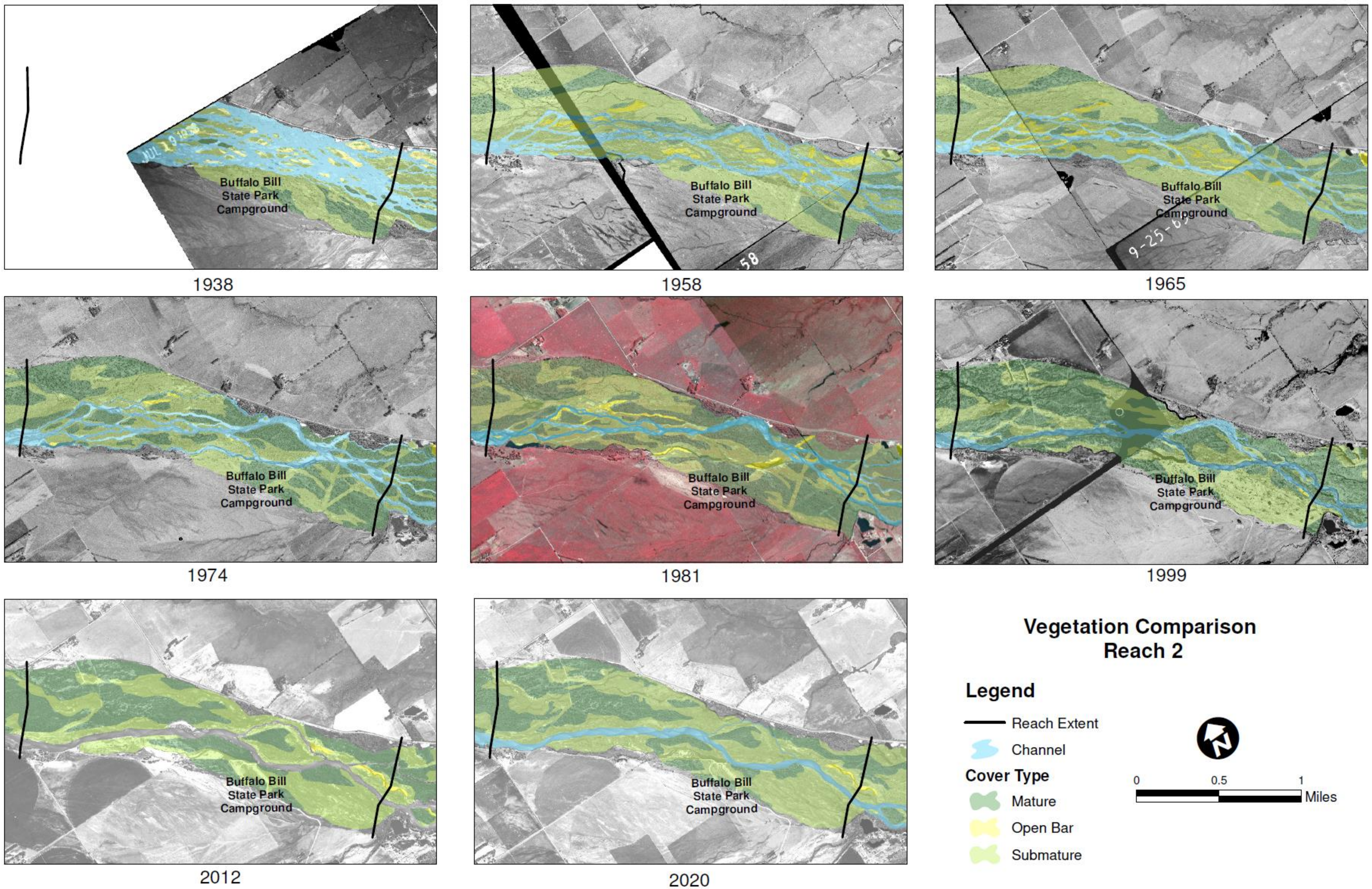



**Figure 8-2 Chokepoint Reach 2 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

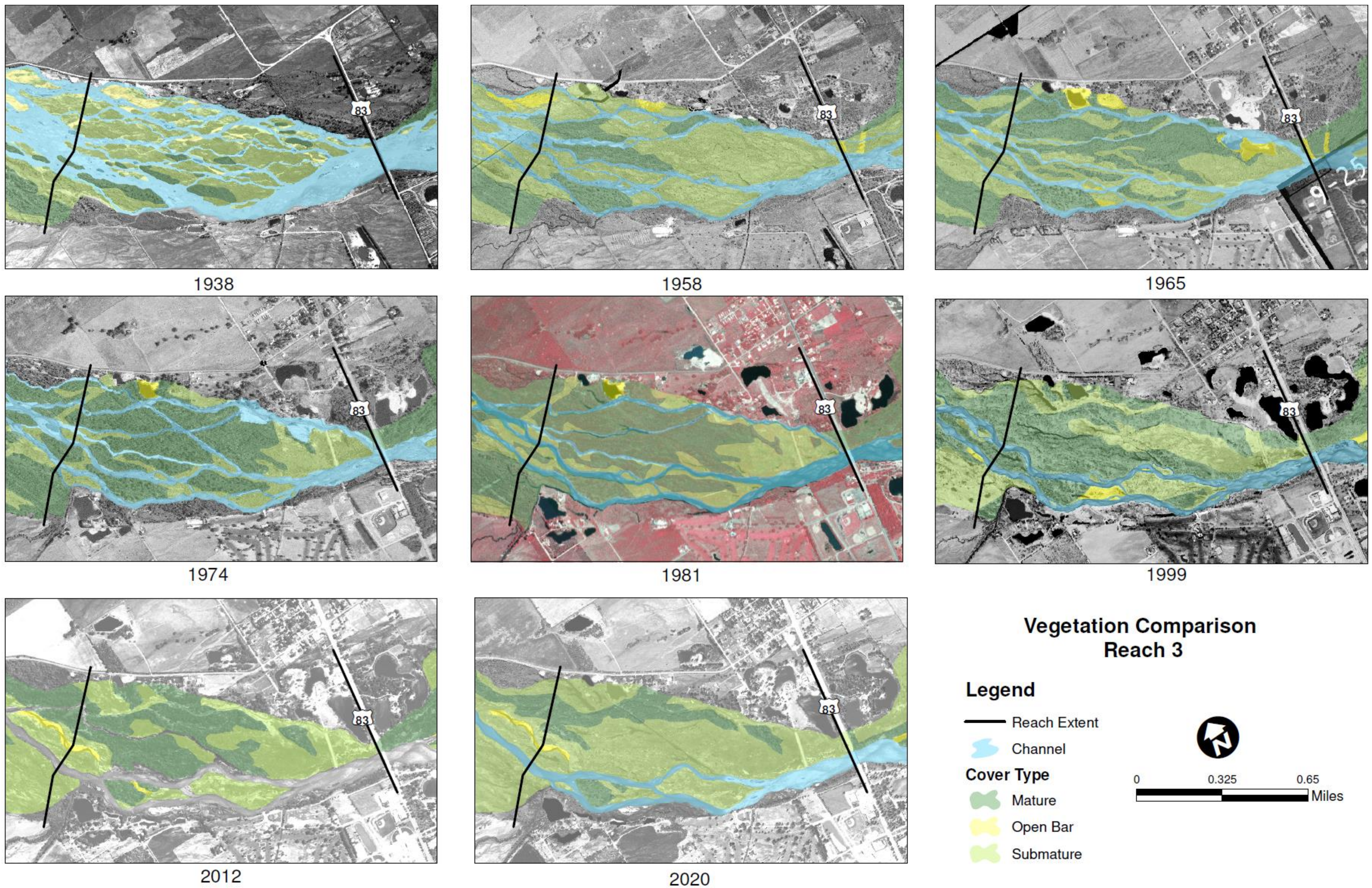



**Figure 8-3 Chokepoint Reach 3 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

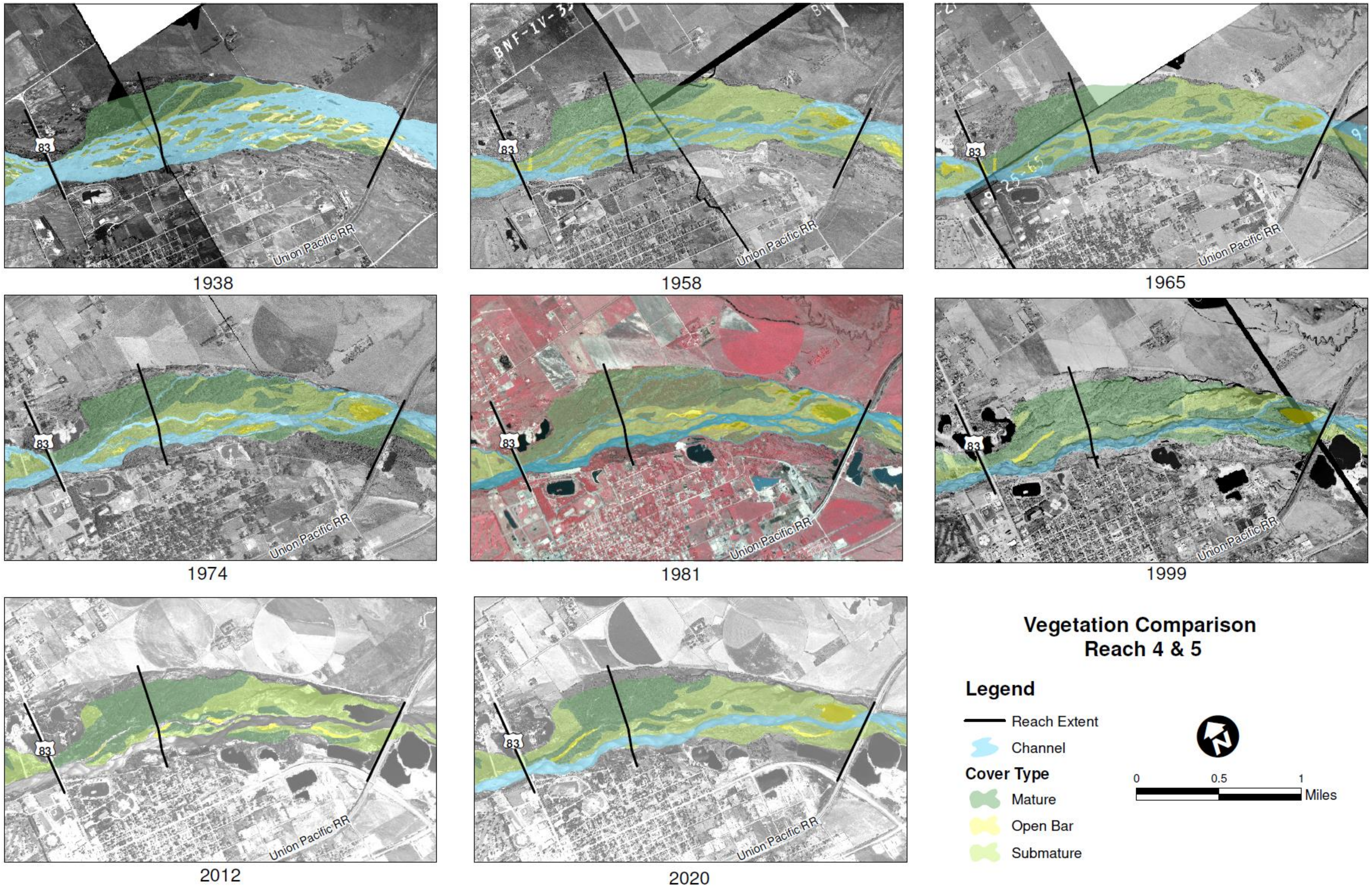



**Figure 8-4 Chokepoint Reach 4 and Reach 5 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

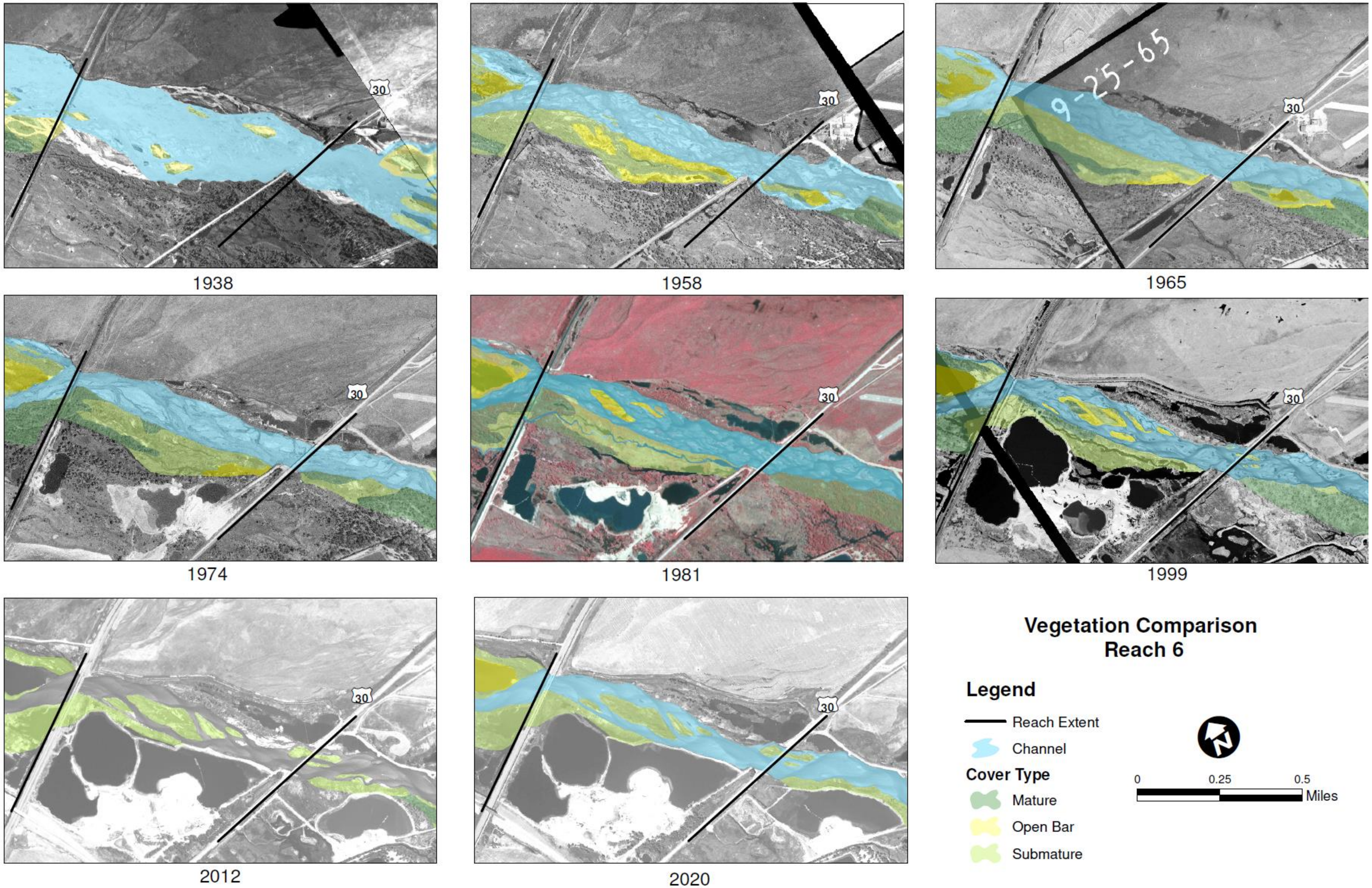



**Figure 8-5 Chokepoint Reach 6 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

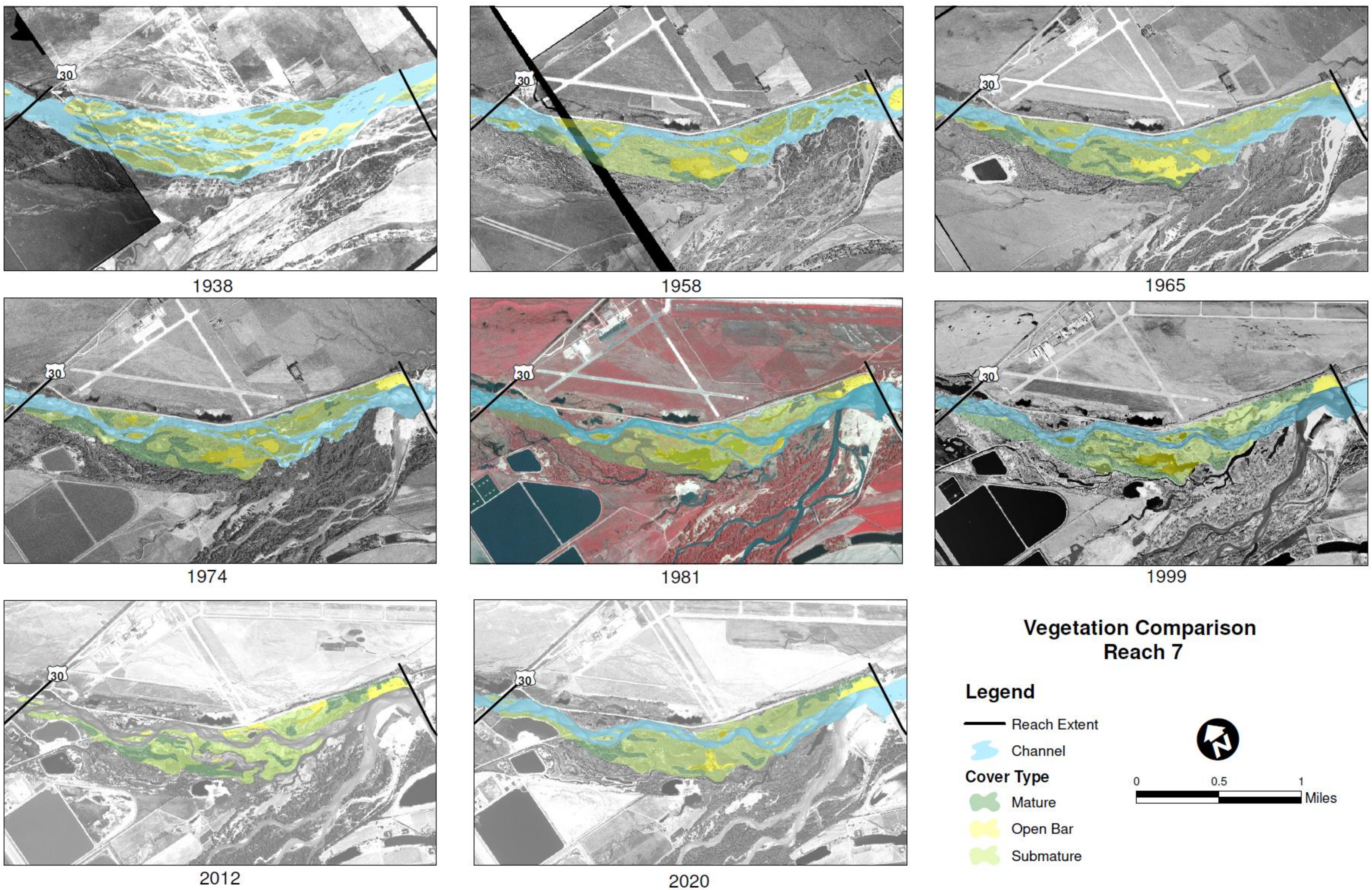



**Figure 8-6 Chokepoint Reach 7 time series comparison (1938 -2020) of vegetation types (open bar, submature, and mature)**

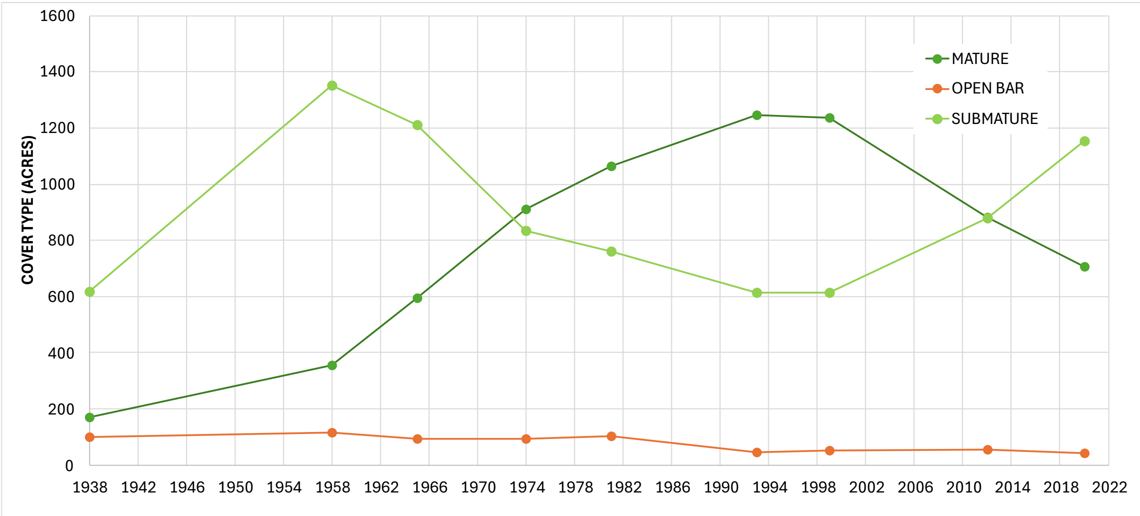



**Figure 8-7 Vegetation classifications (open bar, submature, and mature) in the Chokepoint segment between 1938 and 2020.**

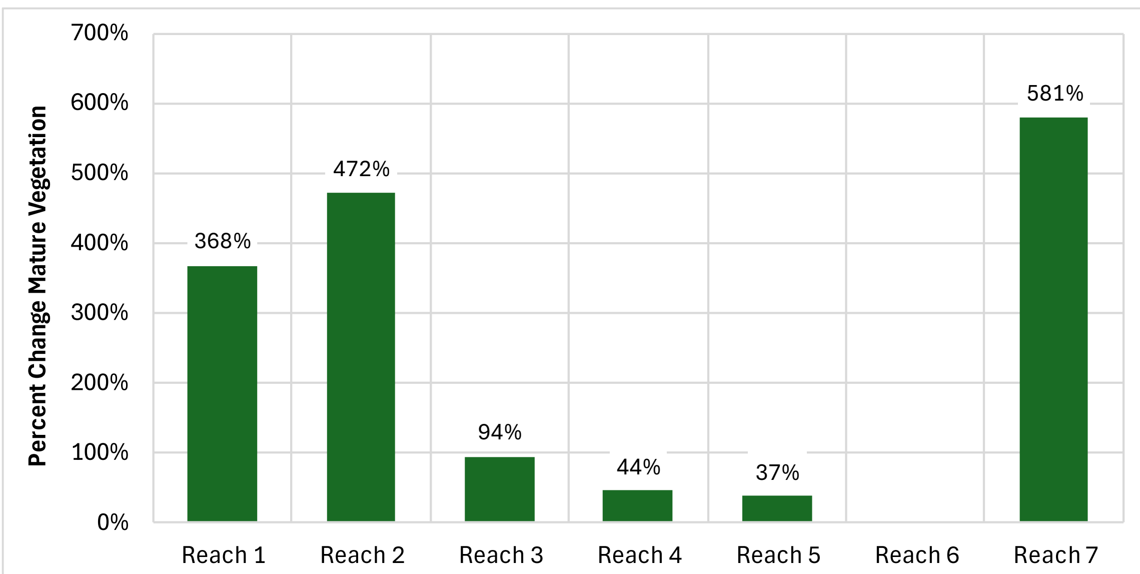



**Figure 8-8 Percent change of mature vegetation between 1938 and 2020 by reach in the Chokepoint segment.**

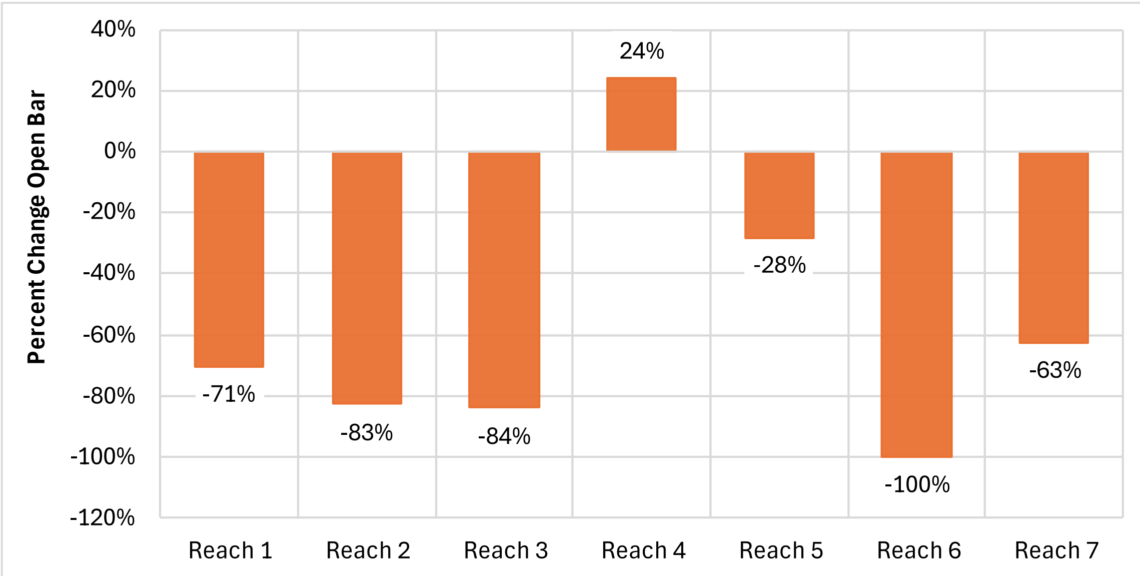



**Figure 8-9 Percent change of open bar between 1938 and 2020 by reach in the Chokepoint segment.**

# 9 GEOMORPHIC REACH SUMMARIES

The following tables summarizes the current hydraulic, sediment, and geomorphic conditions of the North Platte River through the Chokepoint segment upstream (Table 9-1) and downstream (Table 9-2) of Highway 83 based on the information presented in the sections above. Results from analyses of the seven study reaches were combined into two segments, upstream and downstream of HWY 83, for simplification and similarity in results. Interpreting the information presented in Table 9-1 and Table 9-2 highlight the physical differences between the reaches upstream and downstream of Highway 83. The bed material and slope tend to be coarser and steeper, respectively, upstream of Highway 83, which drives varied bedforms and a narrower active channel. The shallower slope and wider active channel downstream of Highway 83 reduce velocities and shear stresses, which decreases sediment transport and causes aggradation.

Regarding hydrology, as discussed above, the flow characteristics (median, average, and bankfull) through the Chokepoint segment are similar within all reaches and have not changed over the past 20 years, other than the bankfull flow, which has decreased by approximately 20% from previous time periods.

**Table 9-1 Chokepoint Upstream of HWY 83 (Reaches 1 – 3) Summary of Current Conditions**

| Study Characteristic or Parameter | Description of Condition |
|---|---|
| Bankfull Flow | 1,200 to 1,700 cfs |
| Velocity Range at Bankfull Flow (average) | 3.0 cfs |
| Shear Stress Range (average) | 0.15 lbs/ sq ft |
| Flow Depth | 1.9 to 2.4 ft |
| Bed Material | Coarse Sand |
| Geomorphic Units and Bedforms | Dune with occasional riffles and bars (point and mid-channel) |
| Ave Annual Transport Capacity | 550,000 tons/yr |
| Mass Bed Change (2017 – 2023) | -1,000 CY/year |
| Sediment Transport Cycle | Stable (in ≈ out) |
| Channel Pattern | Moderately anastomosed planform with vegetated islands and side channels |
| Channel Pattern: Braiding Index | 1.3 to 1.8 |
| Channel Pattern: Sinuosity | 1.07 to 1.10 |
| Channel Bed Slope | 0.113% |
| Active Channel Width | 215 – 280 ft |
| Vegetation Pattern | Woody species mixed with sedges, grasses, and phragmites |

**Table 9-2 Chokepoint Downstream of HWY 83 (Reaches 4 – 7) Summary of Current Conditions**

| Study Characteristic or Parameter | Description of Condition |
|---|---|
| Bankfull Flow | 1,700 cfs |
| Velocity Range at Bankfull Flow (average) | 2.7 cfs |
| Shear Stress Range (average) | 0.12 lbs/ sq ft |
| Flow Depth | 2.0 to 2.2 ft |
| Bed Material | Medium to coarse sand |
| Geomorphic Units and Bedforms | Dunes |
| Ave Annual Transport Capacity | 400,000 tons/year |
| Mass Bed Change (2017 – 2023) | 27,000 CY/year |
| Mass Bed Change + Dredging (2017-2023) | 127,000 cy/year |
| Sediment Transport Cycle | Aggradation (in > out) |
| Channel Pattern | Single thread bankfull channel with moderate braiding in Reach 7 |
| Channel Pattern: Braiding Index | 1.0 to 2.3 |
| Channel Pattern: Sinuosity | 1.04 to 1.14 |
| Channel Bed Slope (average) | 0.095% |
| Active Channel Width | 265 – 384 ft |
| Vegetation Pattern | Primarily sedges, grasses, and phragmites mixed with occasional woody species |

# 10 CONCLUSIONS

The morphology and hydraulic capacity of the North Platte River is a function of flow, the quantity and size of the sediment load, and the character and composition of the materials, including vegetation, composing the bed and banks of the channel. The numerous previous studies that have been conducted on the North Platte River Chokepoint segment and the updated analyses included in this report provide insights and lines of evidence of the river's current morphology and capacity in terms of flow and hydraulic characteristics, sediment transport, geomorphic characteristics, and vegetation patterns. This section draws conclusions from those factors to describe multiple lines of evidence. The conclusions are not intended to be deterministic; rather describe how each of those factors affect hydraulic capacity through the Chokepoint segment.

## 10.1 Flow Characteristics

Previous studies have documented the anthropogenic impacts associated with water resources development in the twentieth century that abruptly and substantially altered hydrologic conditions of the Platte River basin. Flow in the North Platte, for example, was significantly reduced after the completion of Kingsley Dam, which created Lake McConaughy (see Figure 4-1). Not surprisingly, therefore, median, average, and 1.5-year flows significantly decreased (between 69 and 80%) after 1942 relative to the 1900-1941 baseline period. Seasonal flows have been redistributed with a low base flow generally occurring between September and mid-June, with the high flow season from mid-June through August coinciding with the timing of reservoir releases to meet downstream irrigation demands.

ACE's hydrologic analysis indicates that the changing trend in flow variables have reached a general status of equilibrium over the past 20 years. Further, median flows after 1942 do not show remarkable differences to present day. This is not surprising given that median flows reflect baseflows. Average flows after 1942 range from 573 to 601 cfs except during the 70s and 80s when average flow was 1,007 cfs. The 1.5-year discharge (1,642 cfs) is also relatively stable between 2000-2022.

Flow duration curves illustrate the current trend in flow exceedances. Over the last 22 years flows exceeded 10% and 2% of the time were calculated as 1,300 cfs and 2,000 cfs, respectively. The flow duration curve and spells analysis results highlight the very wet period during the 70s and 80s that included not only large annual peak flows but significantly different duration of flows greater than 1,000 cfs. The event occurring in 2011 is similar in peak and duration to large hydrologic years that occurred in 1983, and 1984.

Annual peak flow and volume results show similar trends – a large reduction in peak flow and volume occurred after 1942, as a result of dam construction, and have remained consistent over the past 80 years except between 1970-1989. Between 1970-1989 five out of ten peak flow events and seven of the ten highest volumetric flow years occurred during this period.

### 10.2 Hydraulic Capacity and Characteristics

Minor flood stage for the North Platte River is 6.0 feet, as currently defined by the National Weather Service (NWS), at the North Platte Gage at Highway 83. Previous studies (HDR & Tetra Tech 2011, Parsons 2003, FLO 1992) show that discharges corresponding to flood stages fluctuate over time. Capacity is estimated at 5,420 during the late 80s. Capacity between 1998 and 2023 has fluctuated between 1,570 and 2,165 cfs, with current capacity estimated in 2023 at 1,764 cfs.

Specific gage analyses were developed at the HWY 83 and Sutherland gages to evaluate change in stage and capacity using flow and stage measurements for selected discharges. Change in stage was used to indicate bed change and identify trends in aggradation and degradation. Results can reliably depict conditions and river changes near the gage but may not be representative of conditions in other reaches of the river. During the 40s, 50s, and 60s there are opposing trends observed with a steady reduction in stage noted at Sutherland and a steady increase at HWY 83. The decrease at Sutherland is likely a result of river response to clear water releases from Lake McConaughy. The opposite response at HWY 83 is in part due to deposition in the channel related to the TCCD. The opposing trends generally continue through the 70s and 80s. This period is distinctly different hydrologically in that there were several large peak flood events with significant duration, as shown in the hydrologic evaluation. Hydrologic and sediment transport evaluations suggest that hydrology occurring from 1970-1989 could mobilize much larger quantities of sediment (roughly 2.5 times higher) than in the decades before and after. At the end of this wet period, roughly 1988, there is a remarkable shift in trend to aggradation at Sutherland which aligns with HWY 83. After 1988 both gages indicate the same trends. During the 1990s stage at both locations show a rapid increase in stage occurring at a similar rate. This rapid increase, suggesting aggradation, is likely due to movement of a large “slug” of sediment mobilized during the previous decades that cannot be efficiently transported by the lower flow conditions in the 1990s. Stage has remained relatively stabilized with +/- 0.5 feet fluctuations between 1998 and 2022 at both gages. The stabilization of stage, especially after 2010, might suggest that the sediment “slug” has largely moved through the system. It may also indicate that the river is approaching a quasi-equilibrium if hydrologic conditions remain relatively constant.

ACE performed hydraulic modeling and inundation mapping on the North Platte River through the Chokepoint segment. Velocities for 2,000 cfs range between 2.2 and 4.5 ft/sec, with reach average values ranging from 2.8 to 3.3 ft/sec, with a slight decreasing trend in the downstream direction. The average bankfull discharge is approximately 1,700 cfs through the Chokepoint segment. Reach 2 and 3 show a bankfull flow of 1,500 and 1,200 cfs, respectively. In Reach 2 this is due to a narrower channel width. Reach 3 shows a flatter channel slope, which could explain the lower bankfull capacity.

The velocity and shear stress results suggest limited fluctuation in average values between reaches but reveal a decreasing trend in the downstream direction. This indicates minimal if any conveyance problems, such as blockages or constrictions. Incipient motion analysis indicates that bed material is mobilized for all flow conditions including baseflows and greater.

## 10.3 Sediment Supply and Transport

Most of the sediment appears to enter the North Platte River as bedload and suspended load from the bed, eroding banks, and Birdwood Creek. Sediment is transported by the river downstream to the Chokepoint reach and TCCD. The median bed material size ranges from medium to very coarse sand (0.6 mm up to 0.94 mm), with an average of 0.7 mm (classified as coarse sand). Bed material samples collected in 1931 by the USACE indicated a $d_{50}$ of 0.4 mm on the North Platte at HWY 83. Samples collected around 2011 show a median bed material size at HWY 83 of 0.6 mm.

Sediment transport rating curves were developed using the Yang equation upstream and downstream of HWY 83. Rating curves were combined with flow duration to develop effective discharge curves and estimate total average annual sediment transport capacity. Considering the full period of hydrology from 1942 – 2022 the effective discharge upstream and downstream of HWY 83 is approximately 2,000 cfs. Comparison of effective discharge curves for varying time periods indicates a fluctuation between 1,900 cfs and 2,200 cfs. Note the estimates of annual sediment transport capacity using historic flow duration curves utilize 2017 hydraulic conditions.

Sediment continuity was evaluated to estimate sediment supplied to a reach and sediment exported out of the reach. Measured mass bed changes from 2009- to 2017 and 2017 to 2023 were compared with estimated annual transport and dredging volume. Results do not indicate a strong trend in either aggradation of degradation during either period with the exception of the depositional zone immediately upstream of the TCCD where dredging is required. It is noted that minimal change in the channel between 2009 and 2023 indicates that the river is generally able to balance sediment supply and transport, even after the 2011 flood event. This is consistent with the stabilization in hydraulic capacity, with some natural fluctuation, as shown by results of the hydraulic analyses and specific gage evaluation. This finding is consistent with a quasi-equilibrium condition.

## 10.4 Geomorphic Analyses

ACE performed a series of qualitative and quantitative analyses to describe the North Platte River's geomorphic characteristic and trends through the Chokepoint segment. The analyses focused on three fluvial geomorphic characteristics: pattern and planform, profile, and geometry. Interpreting the results from those analyses, ACE did not find substantial changes in overall geomorphic characteristics over the past twenty years.

**Pattern**: Sediment deposition and vegetation growth driven by flow changes have caused the river to abandon secondary channels and prevent bar migration, reducing side channels and forcing the transition from braided to straight single thread channel with occasional anastomosing and vegetated islands. The contemporary North Platte River through the Chokepoint segment is more representative of a single thread river than its historical braided pattern. The main channel length, side channel length, braiding index, and sinuosity have all remained relatively consistent since the mid-1990s. That trend is reinforced by limited changes in stage and discharge shown in the North Platte River at Highway 83 specific gage analysis.

**Profile:** Since 2011, the average bed slope of the Chokepoint segment has remained within the historical range of 0.11% and 0.12%, except Reach 7 near the TCCD. Depositional impacts related to the TCCD extend much further upstream than backwater, likely due to a slowing and/or blocking of sand bed movement related to backwater conditions and the presence of the structure. This is evident through evaluation and comparison of 1940 and 2009 bed profiles that shows a “sediment wedge” extending from the TCCD upstream to HWY 83 has formed. Comparison of more contemporary bed profile information after 2009 indicates relatively consistent channel bed slopes suggesting that the river profile along the Chokepoint segment will remain within the 0.11 to 0.12% range if present-day flow characteristics and sediment supply relationships remain consistent.

**Geometry**: Narrower active channel widths have contributed to a decrease in channel area, which in combination with relatively shallow bankfull depths, limits hydraulic conveyance. Within the Chokepoint segment, channel widths have remained consistent between mid-1990s and 2020. The single thread channel pattern has also not changed over that period with active channel widths ranging consistently between about 265 and 380 feet.

## 10.5 Vegetation Changes

The results of the vegetation change analysis show significant increases in mature vegetation along the Chokepoint segment, occurring mainly in the 1930’s through 1960’s. The narrowing of active channel widths between areas of vegetation on islands and banks is an outcome of the current vegetation conditions. Evaluation of vegetation cover changes between 1938 – 2020 has generally shown that the previous trend of significant woodland expansion has slowed significantly, stopped, and has reversed likely due to phragmites treatment.

## 10.6 Impact of Tri-County Canal Diversion Structure

The TCCD structure has trapped inflowing sediment from both the North and South Platte River since 1942. Dredging operations beginning in 1965 have removed sediment accumulation in the immediate vicinity of the structure on an annual basis. The results from the analyses summarized in this report indicate the TCCD structure has caused bed aggradation upstream and formation of a sediment “wedge” which has reduced bed slope and corresponding sediment transport potential. The impact of the reduced transport potential extends from the structure upstream to Highway 83 and likely into the lower portion of Reach 3. Aggradation upstream of the TCCD structure is evident over the past 80 years, with a noticeable increase in deposition starting in early-1980s. Hydrology during the late 1970s and early 1980s was substantially different than previous time periods, including peak flows and volumes. Further, the clear water flows released from Lake McConaughy scoured bed and banks downstream of the reservoir, generating sediment sources that high flows transported downstream to the TCCD structure.

Depositional impacts related to the TCCD are attributed to backwater and a slowing and/or blocking of sand bed movement related to backwater conditions and the presence of the structure. Comparison of estimated 1940 and 2009 bed profiles show the formation of a “sediment wedge” extending upstream from the TCCD to roughly HWY 83. Historic morphodynamic modeling verified that backwater from the TCCD resulted in the observed extent of deposition. This sediment wedge has contributed to increased stage and decreased hydraulic capacity.

## 10.7 Summary of Current Trends

Analysis of the hydrology, geomorphology, and sediment transport behavior of the North Platte River along the Chokepoint segment shows that there are several identifiable trends, summarized below and shown in Figure 10-1.

- Lake McConaughy and the TCCD have altered flow and sediment regimes in the Chokepoint segment and appear to be the primary drivers for the long-term reduction in flow stage at Highway 83 Bridge. This conclusion is based in part on a comparison of estimated 1940 and 2009 bed profiles that show the formation of a “sediment wedge” extending upstream from the TCCD to roughly HWY 83. The quantitative hydrologic, geomorphic, and sediment transport analyses included in this report, as well as many others’ previous analyses referenced herein, provide multiple lines of evidence to support this conclusion.

- The hydrologic, geomorphic, and sediment transport analyses in this report indicate that the changing trend in flow, morphology, profile, and sediment capacity variables have reached a general status of equilibrium over the past 20 years.

- The specific gage analysis using the Highway 83 gage data indicates a relatively stable bed elevation at Highway 83 between 2000-2022. During the 1990s, the stage shows a rapid increase in stage. This rapid increase, suggesting aggradation, is likely due to movement of a large “slug” of sediment mobilized during the previous decades that could not be efficiently transported by the lower flow conditions in the 1990s. After 1999, the specific gage analysis shows a general stabilization of stage with some fluctuation.

- The sediment transport analyses suggest that the sediment supplied to the North Platte River and the sediment transported through the reaches upstream of Highway 83 are roughly in balance.

This is supported by bed elevation trends at the Highway 83 gage and comparisons of changes in channel bed slopes, profiles, and cross-sections.

- The measured mass bed changes from 2017 to 2023 suggest a stable grade trend (i.e., "sediment in equals sediment out") with no clear signal towards degradation or aggradation in Reaches 1 through 6. Aggradation is noted in Reach 7 near the TCCD where dredging is required. These trends are supported by the changes in bed elevation and slopes and measured mass bed change.

- Active channel widths and channel area are stable based on comparison of surveyed cross-sections and hydraulic analyses, which in combination with slowly changing vegetation patterns supports relatively consistent hydraulic conveyance between 1999 and 2020.

Rivers continue to evolve to achieve an equilibrium relationship between dominant discharge (i.e., channel-forming) and sediment load by adjusting its hydraulic variables (e.g., channel width and depth, velocity, roughness, and water slope). This fluvial process is referred to as quasi-equilibrium. River pattern reflects the quasi-equilibrium form of a channel in response to concentration/dissipation of energy (driven by slope), associated transfer and storage of sediment, and bank vegetation characteristics.

The various analyses, summarized in Figure 10-1, suggest the evolution of the North Platte River through the Chokepoint over the past approximately 20 years has reached a state of quasi-equilibrium, or dynamic equilibrium. Dynamic equilibrium on the Platte River was defined by Simons & Associates (1990), "This condition of relatively steady widths with minor fluctuations in narrowing and widening." The conclusion that the Chokepoint segment has reached a general state of dynamic equilibrium is supported by the balance between active channel area and vegetated cover area, which for most reaches, has changed little since the 1980s. Further, the bankfull hydraulic capacity, which tends to correlate with the minor flood stage, appears to have settled into a range between approximately 1,200 and 1,700 cfs upstream of Highway 83 and 1,700 cfs downstream to the TCCD structure. Also, a large, sustained flow event, probably greater than the peak flow and duration of the most recent flood event in 2011, would likely disrupt the quasi-equilibrium state

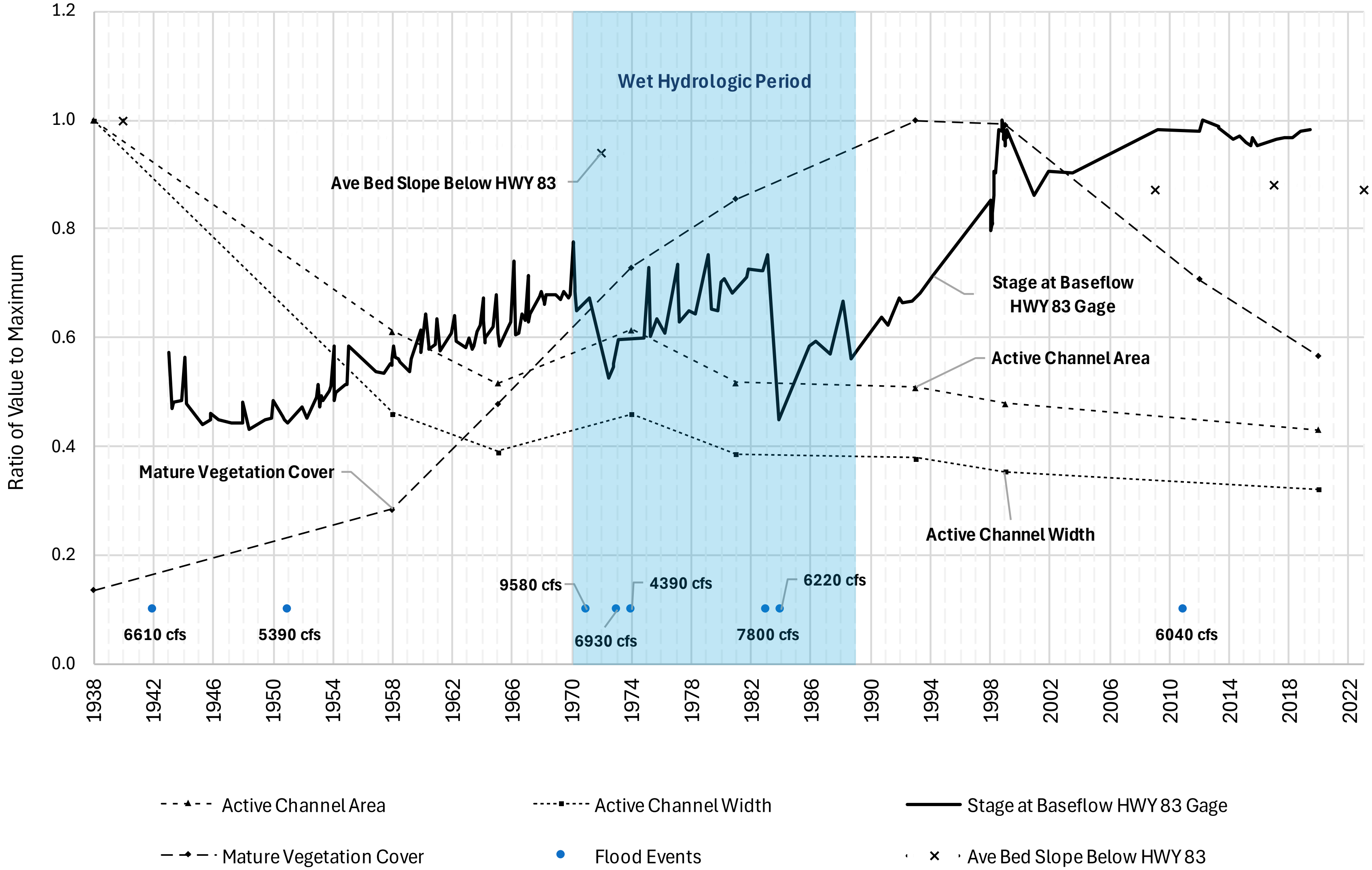



**Figure 10-1 Comparison of temporal change in geomorphic analyses.**

## 10.8 Future Trajectory

To frame the trends described above, we use a conceptual model – Lane's Balance – to conceptualize future trajectories of channel width, slope, and capacity. Lane (1955) first developed the relationship between sediment discharge, sediment caliber, flow rate, and channel slope:

$$Qsd \sim QS$$

where Qs is the sediment discharge, d is the sediment particle diameter, and S is the channel slope. Yang (1986, 1996) develop a similar equation to Lane's relationship, but Yang's equation can be used directly to predict the dynamic adjustments of a river channel due natural and man-caused events (USBR 2004), where W is the channel width, D is the channel depth, and K is a site-specific parameter.

$$\frac{Q_s d^{0.5}}{K} = \frac{Q^2 S}{WD}$$

The equation demonstrates that channel adjustments are most sensitive to changes in water discharge because water discharge is raised to the second power. This equation also predicts that if the discharge and the bed slope remain constant or changes very slowly, then the product of channel width, channel depth, sediment load, and bed-material particle diameter will also remain consistent.

Assuming no significant change in reservoir, diversion structure, dredging operations, or climate shifts, the recent 20 years of hydrologic and sediment data provide the best available representation of probable future flow and sediment transport conditions. If those remain consistent, Lane's Balance and Yang's equation suggest the current active channel widths and bankfull depths will remain stable in response to contemporary flow and sediment discharges. Further, the relatively stable average bed slopes in the Chokepoint segment are also expected to remain in a quasi-equilibrium state assuming flow characteristics and sediment supply trends are consistent with those over the previous 20 years, and dredging operations continue at the TCCD structure. The stabilization of stage at the Highway 83 gage may also indicate a quasi-equilibrium state if hydrologic and sediment conditions remain relatively constant. This conclusion should be taken with extreme caution, as projecting specific gage records into the future is not recommended (Biedenharn et. al. 2017). **Also, a large, sustained flow event would likely disrupt the quasi-equilibrium state, as observed after the 1980s.**

If the active channel widths, bankfull depths, and bed slopes remain consistent, the hydraulic capacity at the Highway 83 bridge is expected to continue to be between approximately 1,600 and 2,100 cfs. Hydraulic characteristics of velocities and shear stresses are projected to remain between 2.2 and 4.5 ft/sec and 0.1 to 0.3 lbs/sq ft, respectively, for the 2,000 cfs range.

## 10.9 Predicted River Response to Stream Modification

The Platte River Recovery Implementation Program (PRRIP or Program) continues efforts to achieve and maintain hydraulic capacity of 3,000 cfs below minor flood stage on the North Platte River through the Chokepoint segment. As described above, we project the river's future hydraulic capacity through this segment to remain between 1,600 and 2,000 cfs, which is less than the Program's goal of 3,000 cfs.

Developing and evaluating potential alternatives to improve the hydraulic capacity through the Chokepoint segment and achieve downstream flow targets have been ongoing for nearly 20 years. Alternative development as part of this study has focused on conveyance solutions that either bypass the Chokepoint or increase capacity through the Chokepoint. Potential stream modification options to increase capacity through the study area currently under consideration include dredging/sediment removal, channel widening, use of jetties, and modification to the TCCD. Stream modifications focus on Reaches 3 – 7, and do not include Reaches 1 and 2 because those reaches are considered stable. A general prediction of river response for each concept is provided below.

***Channel Widening***

Widening of the channel downstream of HWY 83 to increase hydraulic conveyance would reduce channel velocity and shear stress and potentially increase aggradation. With no change in hydrologic conditions, sediment discharge, or bed material size, the river would subsequently respond to aggradation by decreasing its slope and bankfull depth (conceptually applying Yang's equation above). This would likely diminish hydraulic capacity back to existing levels over time. If channel widths were increased, an increase in effective discharge would be required to maintain bed slopes and hydraulic capacity. Modification of effective discharge through flow releases would entail increasing peak flow magnitude, volume, and duration (i.e., channel maintenance flow). Channel maintenance flow requirements are unknown at this time and would need to be investigated with additional sediment transport modeling.

***Channel Widening with Jetties***

A previous alternative included the concept of installing low-profile jetties upstream of Highway 83. The jetties would increase stream power and sediment transport during low/moderate flow by constricting the channel up to a specified elevation, above which the jetties would be overtopped. Increased channel width is available to convey larger flows after jetties are overtopped. Placement of jetties in tandem with channel widening could lessen aggradation and/or require smaller increases in flow magnitude and duration. Application of jetties in addition to widening would need to properly balance flow constriction without increasing water surface elevations at critical flood levels. Effectiveness of jetties may be limited given the shallow depth of the channel through the Chokepoint.

### *Dredging*

Large scale removal of accumulated sediment between HWY 83 and the TCCD structure (Reaches 4 – 7) would lower the bed elevation and restore historic bed slope (0.11% to 0.12%), thereby increasing the hydraulic capacity. Assuming operations at the TCCD structure remain the same, the dredged channel would likely aggrade and re-establish the sediment "wedge". This process would start at the TCCD structure and gradually continue to move upstream over time and would ultimately diminish hydraulic capacity. The rate of aggradation is currently unknown but could be estimated with mobile bed sediment transport (or morphodynamic) modeling. River response to dredging is expected to be the same with widening or jetties, which could also be investigated through additional modeling.

### *Modification of the TCCD*

Modification of the TCCD structure to pass sediment downstream would benefit overall sediment continuity in the North and Central Platte, although the feasibility of modifying the TCCD structure requires further investigation. Degradation of the sediment "wedge" or movement of a headcut upstream by providing passage of sediment through the TCCD structure would be possible but the rate would likely be extremely slow and would take years or decades to reach HWY 83 and increase hydraulic capacity. This process would be slow given that the structure would remain in place to continue diverting water to the Tri-County canal. Incoming sediment loads and accumulated bed sediment from the "wedge" would both need to be transported. Further, the transport capacity would likely be limited with current sediment supply and tailwater associated with TCCD operations. Rates of transport could be estimated with further sediment transport modeling.

### *Dredging with Modification of the TCCD*

Dredging in the channel as described above combined with modification of the TCCD would provide increased hydraulic capacity at HWY 83 and reduce the rate of aggradation within the dredged channel by balancing sediment continuity through the reaches downstream of HWY 83. The benefits of dredging associated with modification to the TCCD structure, including the sustainability of the dredged channel, could be estimated using additional sediment transport modeling.

# 11 REFERENCES


ASCE. (2007). Sedimentation Engineering. Processes, Measurements and Practice (Vol. ASCE Manuals and Reports on Engineering Practice No 110). (M. H. Garcia, Ed.) Reston, Virginia: American Society of Civil Engineers.

Bentall, R. (1982). Nebraska's Platte River: a graphic analysis of flows.

Biedenharn, D. S., Allison, M. A., Little Jr, C. D., Thorne, C. R., & Watson, C. C. (2017). *Large-scale geomorphic change in the Mississippi River from St. Louis, MO, to Donaldsonville, LA, as revealed by specific gage records*. US Army Corps of Engineers, Mississippi Valley Division, Engineer Research and Development Center.

Brierley G.J. and Fryirs K.A. (2005). Geomorphology and River Management: Applications of the River Styles Framework. Blackwell Publishing, Oxford, UK, 398pp.

Collier, M., Webb, R.H., and J.C. Schmidt (2000). "Dams and Rivers, A Primer on the Downstream Effects of Dams," U.S. Geological Survey Circular 1126, Denver, Colorado, 94 pp.

Cluer, B. and Thorne, C. (2014), A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS. River Res. Applic., 30: 135-154. https://doi.org/10.1002/rra.2631

Daraio, J. A., T.J. Randle, C. T. Yang, Reply to Parsons' Report "Investigations of the Platte River Channel Dynamics and Comparison with Foundational assumptions and Hypothesis of EIS Team's 'White Paper'"(2003).

Eschner, R.F. Hadley, and Crowley, K.D. (1983). Hydrologic and Morphologic Changes in Channel of the Platte River Basin in Colorado, Wyoming, and Nebraska: A Historical Perspective. Geological Survey Professional paper 1277-A.

FEMA (1979) Flood Insurance Study, City of North Platte, Nebraska, Lincoln County.

FLO Engineering, Inc. (1992). North Platte River Channel Stability Investigation Downstream of Keystone Dam. (June 10).

Friedman, M. F., W.R. Osterkamp, M.L. Scott, and G.T. Auble (1998). "Downstream Effects of Dams on Channel Geometry and Bottomland Vegetation: Regional Patterns in the Great Plains," Wetlands, v. 18, n. 4, pp. 619-633.

HDR and Tetra Tech (2011). Final Technical Memorandum, Evaluation of Alternatives for Improvements in Carrying Capacity of the North Platte River at North Platte.

HDR and Tetra Tech (2011). Platte River Recovery Implementation Program 1-D Hydraulic and sediment Transport Model Modeling Technical Report, Tri-County Diversion to Chapman (River Mile 310 – River Mile 156). January 28, 2011.

HDR and Tetra Tech (2011). Platte River Recovery Implementation Program 1-D Hydraulic Modeling Technical Report, Keystone Diversion to North Platte (River Mile 370 – River Mile 310). August 31st, 2011.

Johnson, W.C. (1998). "Adjustment of riparian vegetation to river regulation in the Great Plains, USA," Wetlands, v.18, n. 4, pp. 608-618.

Johnson, W. C., & Boettcher, S. E. (1999). Restoration of the Platte River: what is the target?. *Land and Water*, *43*(3), 20-23.

Kircher, J.T. (1983). "Interpretation of sediment data for the South Platte River in Colorado and Nebraska, and the North Platte and Platte Rivers in Nebraska." U.S. Geological Survey Professional Paper 1277-D, Reston, Virginia

Leopold, L. B., & Maddock, T. (1953). *The hydraulic geometry of stream channels and some physiographic implications* (Vol. 252). US Government Printing Office.

Leopold, L. B., Wolman, M. G., Miller, J. P., & Wohl, E. E. (2020). *Fluvial processes in geomorphology*. Courier Dover Publications

Lyons, J. K., & Randle, T. J. (1988). Platte River Channel Characteristics in the Big Bend Reach. *Bureau of Reclamation, Denver Office, Denver, CO*

Parsons (2003). Preliminary Evaluation of Channel Capacity in the North Platte River at North Platte, Nebraska. Prepared for Central Nebraska Public Power and Irrigation District.

Platte Valley Weed Management Area (PVWMA) (2019). West Central and Platte Valley Weed Management Area's Invasive Species Control along the Platte River FY 2009 – 2019.

PRRIP EDO (2021). North Platte Chokepoint Alternatives (April 6, 2021).

River Design Group (2023). North Platte Chokepoint Investigation, Final Report (January).

Schumm, S.A. (1969). River metamorphosis, J. Hydraul. Div. Am. Soc.Civ. Eng., 1: 255-273.

Schumm, S. A., & Meyer, D. F. (1979). Morphology of alluvial rivers of the Great Plains. *Great Plains Agricultural Council*, *91*, 9-14.

Sidle, J. G., & Faanes, C. A. (1997). *Platte River ecosystem resources and management, with emphasis on the Big Bend reach in Nebraska*. Grand Island, Nebraska, USA: US Fish and Wildlife Service.

Simon, A., & Hupp, C.R. (1987). CHANNEL EVOLUTION IN MODIFIED ALLUVIAL STREAMS. Transportation Research Record, 16-24.

Simons & Associates, Inc. (1990). "Platte River System Geomorphic Analysis," Appendix V - Geomorphology, Joint Response concerning the Re-licensing of Kingsley Dam before the Federal Energy Regulatory Commission, Washington, DC, 158 pp.

Simons & Associates, Inc. (2000). Physical History of the Platter River in Nebraska: Focusing upon Flow, Sediment Transport, Geomorphology, and Vegetation (August 2000).

Toy, T. J., & Hadley, R. F. (1987). Geomorphology and reclamation of disturbed lands.

USBR (2003). Platte River Flow and Sediment Transport Between North Platte and Grand Island, Nebraska (1895-1999), (October 9, 2003)

USBR (2004). The Platte River Channel: History and Restoration (April 2004).

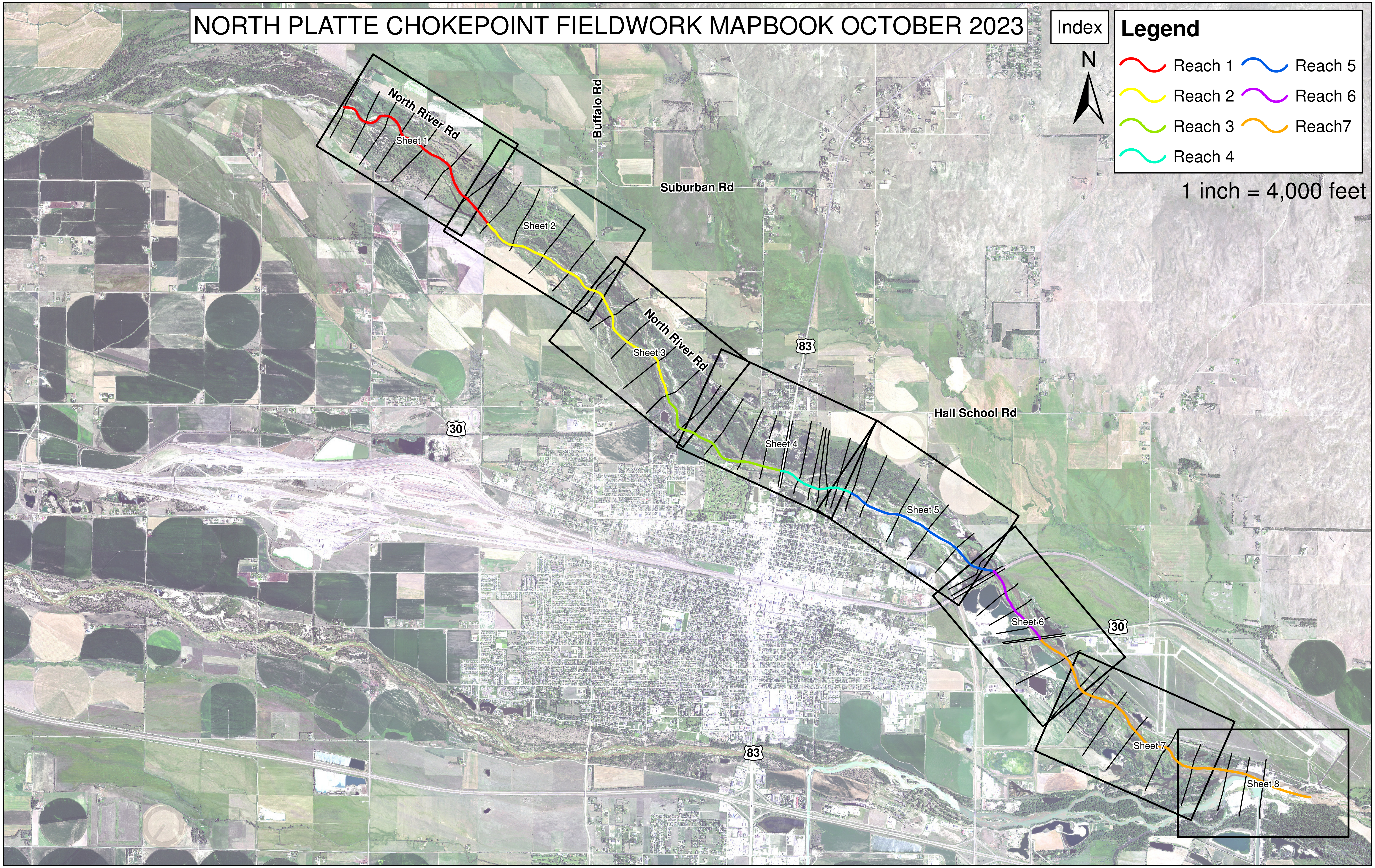
USGS (1983). Hydrologic and Geomorphic Studies of the Platte River Basin. Geological Survey Professional Paper 1277.

Williams, G. P. (1978). Bank-full discharge of rivers. *Water resources research*, *14*(6), 1141-1154.

Yang, C.T. (1986). “Minimum Unit Stream Power and Fluvial Hydraulics,” Journal of the Hydraulics Division, ASCE, v. 102, n. HY7, pp. 919-934.

Yang, C.T. (1996). Sediment Transport Theory and Practice, McGraw-Hill, New York, NY, 397 pp.

# APPENDIX A. MAP BOOK


NORTH PLATTE CHOKEPOINT FIELDWORK MAPBOOK OCTOBER 2023
Index
Legend
Reach 1
Reach 2
Reach 3
Reach 4
Reach 5
Reach 6
Reach7
N
1 inch = 4,000 feet
North River Rd
Buffalo Rd
Suburban Rd
North River Rd
Hall School Rd
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Sheet 1
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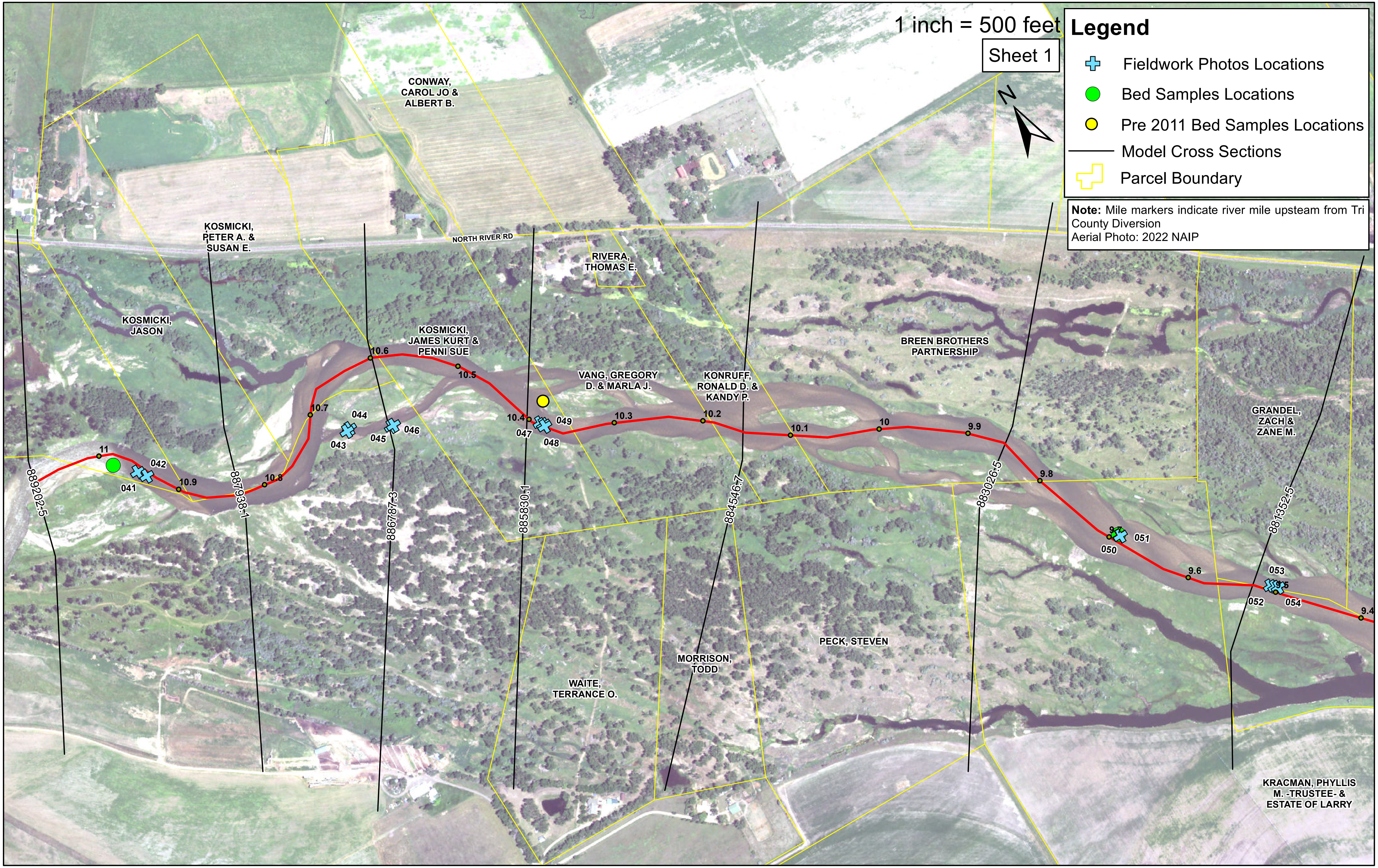
Sheet 8



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Bed Samples Locations
Pre 2011 Bed Samples Locations
Model Cross Sections
Parcel Boundary
Note: Mile markers indicate river mile upsteam from Tri County Diversion
Aerial Photo: 2022 NAIP
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NORTH RIVER RD
CONWAY, CAROL JO & ALBERT B.
KOSMICKI, PETER A. & SUSAN E.
RIVERA, THOMAS E.
KOSMICKI, JASON
KOSMICKI, JAMES KURT & PENNI SUE
VANG, GREGORY D. & MARLA J.
KONRUFF, RONALD D. & KANDY P.
BREEN BROTHERS PARTNERSHIP
GRANDEL, ZACH & ZANE M.
PECK, STEVEN
MORRISON, TODD
WAITE, TERRANCE O.
KRACMAN, PHYLLIS M. -TRUSTEE- & ESTATE OF LARRY
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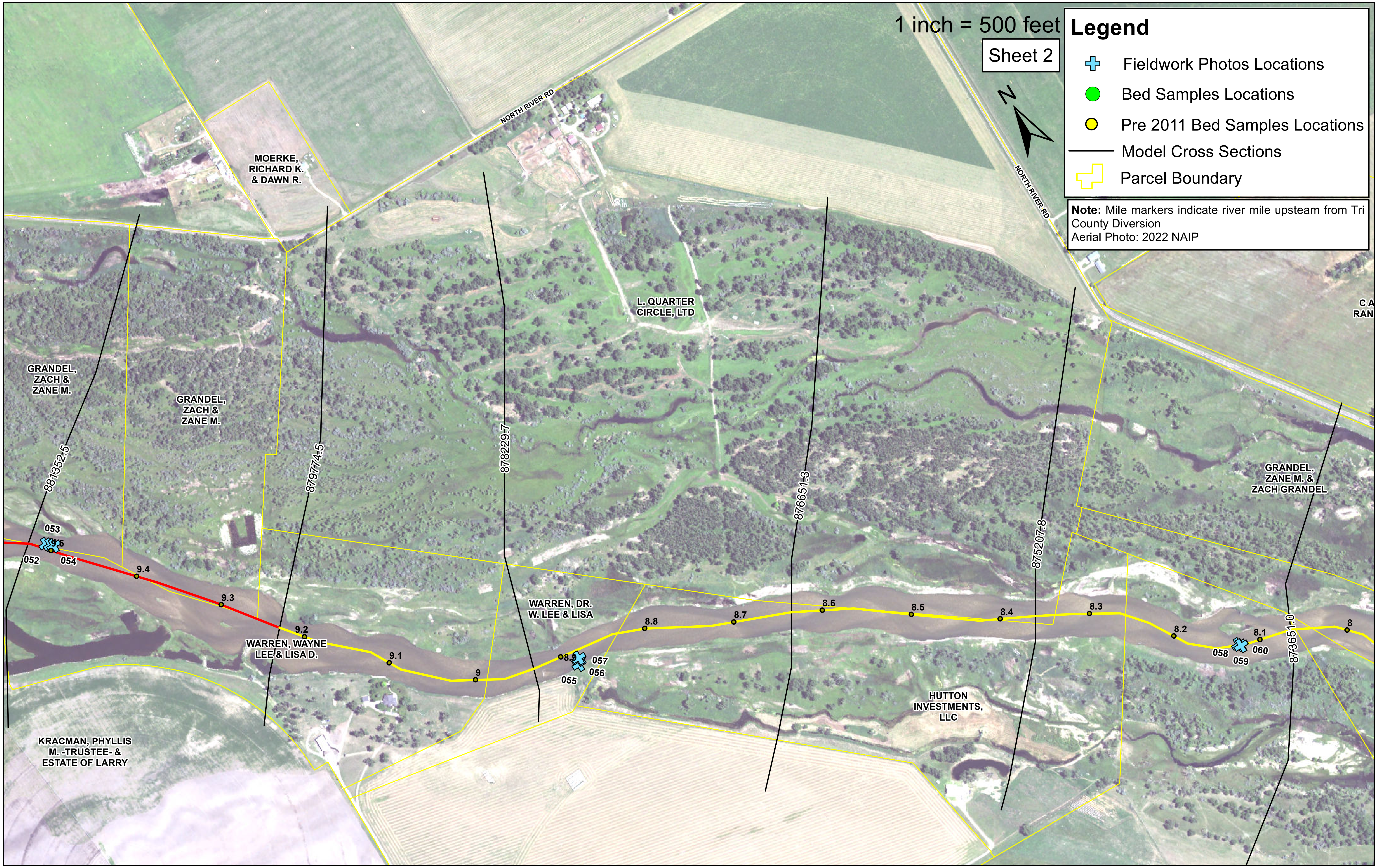

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MOERKE, RICHARD K. & DAWN R.
L. QUARTER CIRCLE, LTD
GRANDEL, ZACH & ZANE M.
GRANDEL, ZACH & ZANE M.
GRANDEL, ZANE M. & ZACH GRANDEL
WARREN, DR. W. LEE & LISA
WARREN, WAYNE LEE & LISA D.
KRACMAN, PHYLLIS M. -TRUSTEE- & ESTATE OF LARRY
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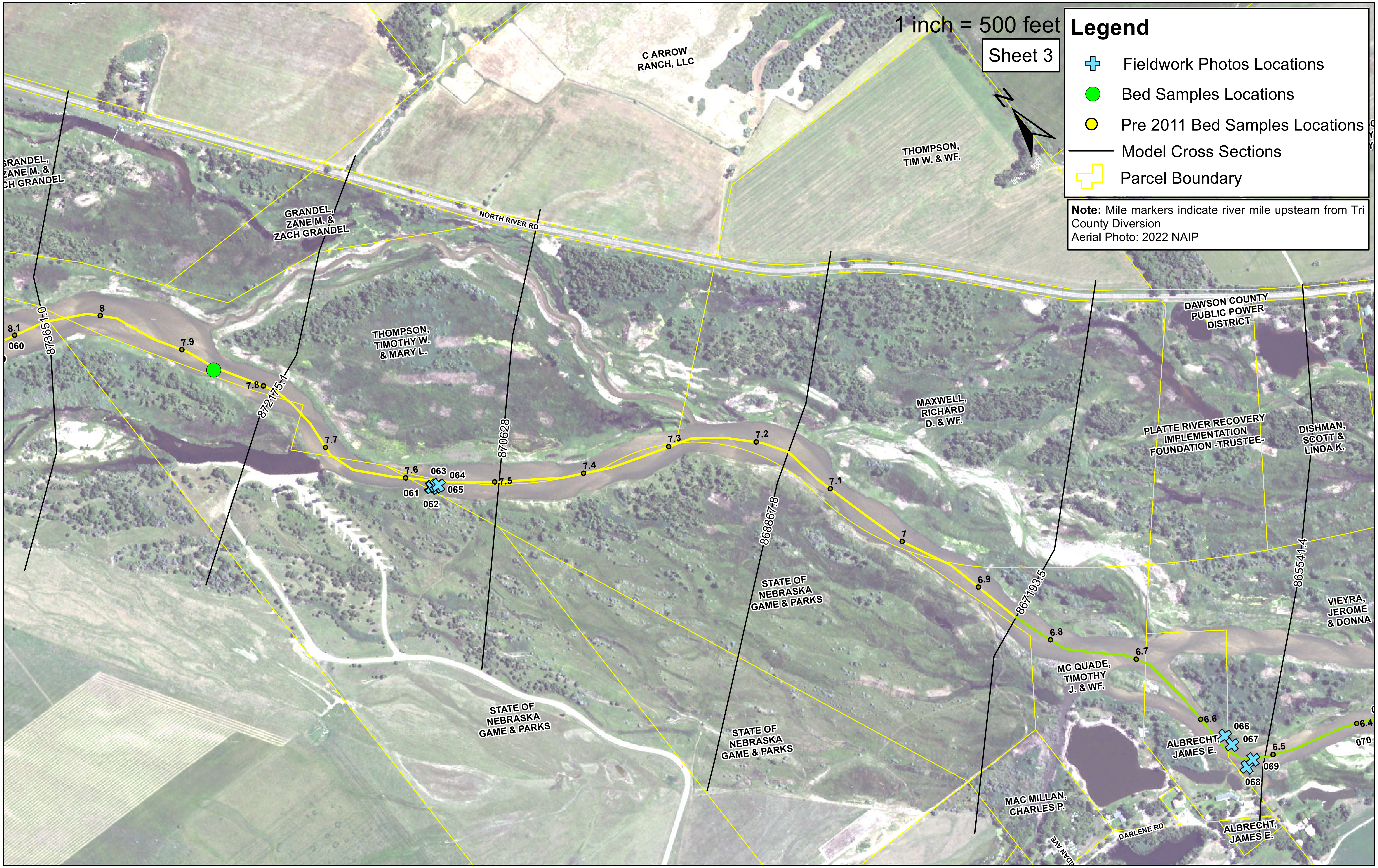

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GRANDEL, ZANE M. & ZACH GRANDEL
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THOMPSON, TIMOTHY W. & MARY L.
MAXWELL, RICHARD D. & WF.
DAWSON COUNTY PUBLIC POWER DISTRICT
PLATTE RIVER RECOVERY IMPLEMENTATION FOUNDATION -TRUSTEE-
DISHMAN, SCOTT & LINDA K.
VIEYRA, JEROME & DONNA
STATE OF NEBRASKA GAME & PARKS
MC QUADE, TIMOTHY J. & WF.
ALBRECHT, JAMES E.
MAC MILLAN, CHARLES P.
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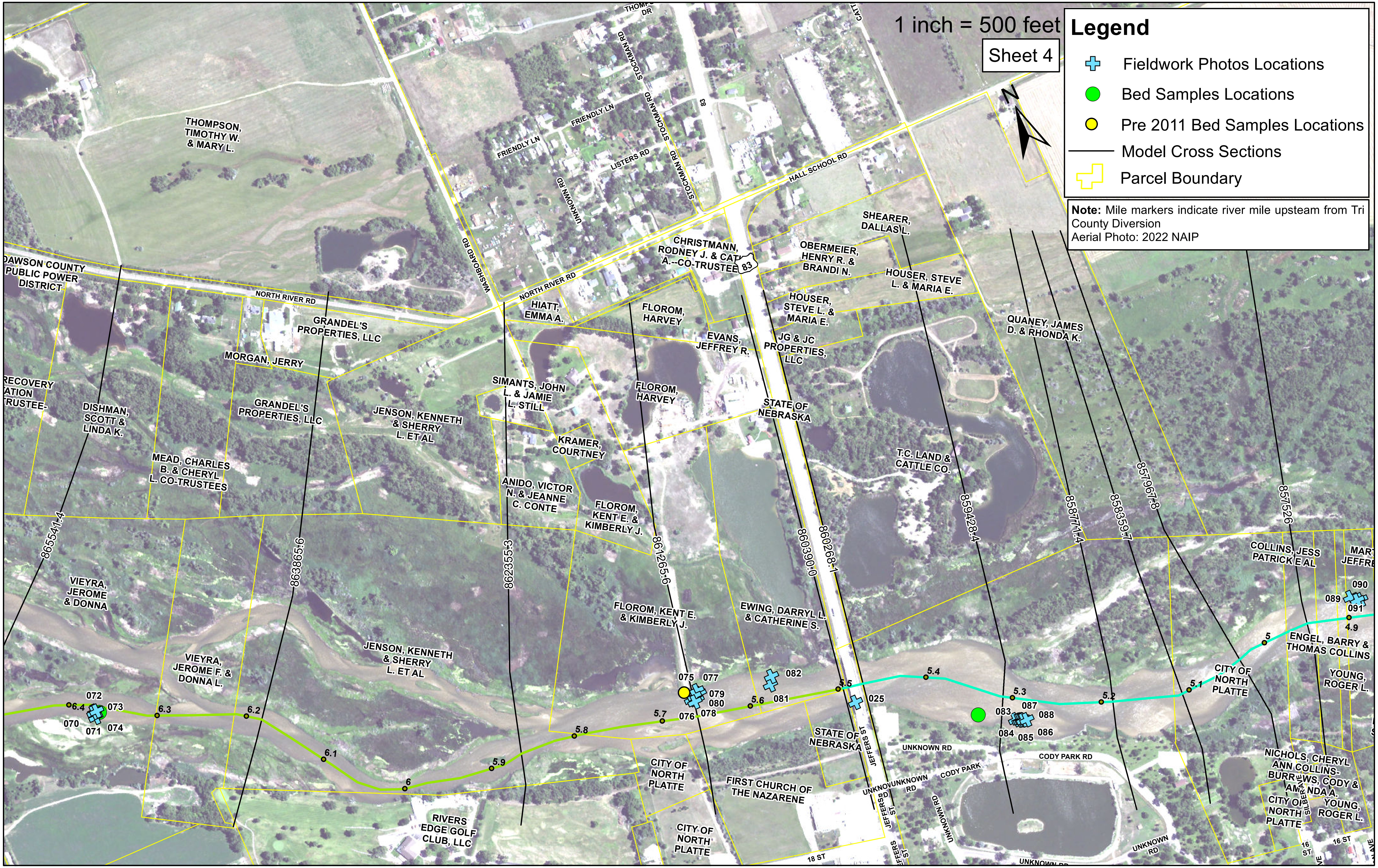
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Model Cross Sections
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DISHMAN, SCOTT & LINDA K.
MEAD, CHARLES B. & CHERYL L. CO-TRUSTEES
JENSON, KENNETH & SHERRY L. ET AL
SIMANTS, JOHN L. & JAMIE L. STILL
KRAMER, COURTNEY
ANIDO, VICTOR N. & JEANNE C. CONTE
FLOROM, KENT E. & KIMBERLY J.
FLOROM, HARVEY
HIATT, EMMA A.
CHRISTMANN, RODNEY J. & CATH A. - CO-TRUSTEE
EVANS, JEFFREY R.
OBERMEIER, HENRY R. & BRANDI N.
HOUSER, STEVE L. & MARIA E.
JG & JC PROPERTIES, LLC
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SHEARER, DALLAS L.
QUANEY, JAMES D. & RHONDA K.
T.C. LAND & CATTLE CO.
COLLINS, JESS PATRICK E AL
VIEYRA, JEROME & DONNA
VIEYRA, JEROME F. & DONNA L.
EWING, DARRYL L. & CATHERINE S.
ENGEL, BARRY & THOMAS COLLINS
YOUNG, ROGER L.
CITY OF NORTH PLATTE
FIRST CHURCH OF THE NAZARENE
RIVERS EDGE GOLF CLUB, LLC
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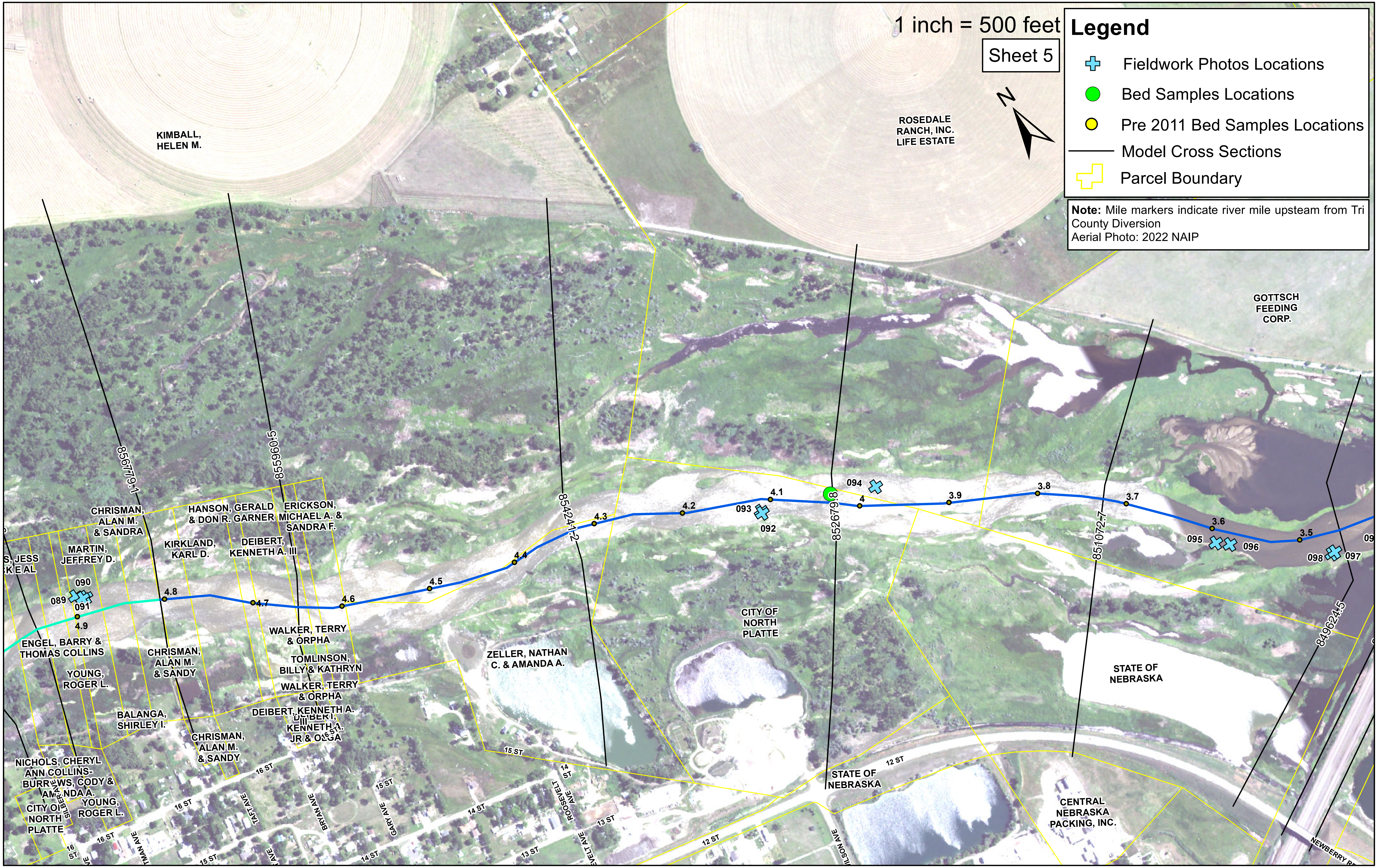

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HANSON, GERALD & DON R. GARNER
ERICKSON, MICHAEL A. & SANDRA F.
KIRKLAND, KARL D.
DEIBERT, KENNETH A. III
MARTIN, JEFFREY D.
ENGEL, BARRY & THOMAS COLLINS
YOUNG, ROGER L.
CHRISMAN, ALAN M. & SANDY
WALKER, TERRY & ORPHA
TOMLINSON, BILLY & KATHRYN
BALANGA, SHIRLEY I.
DEIBERT, KENNETH A. III
NICHOLS, CHERYL ANN COLLINS-
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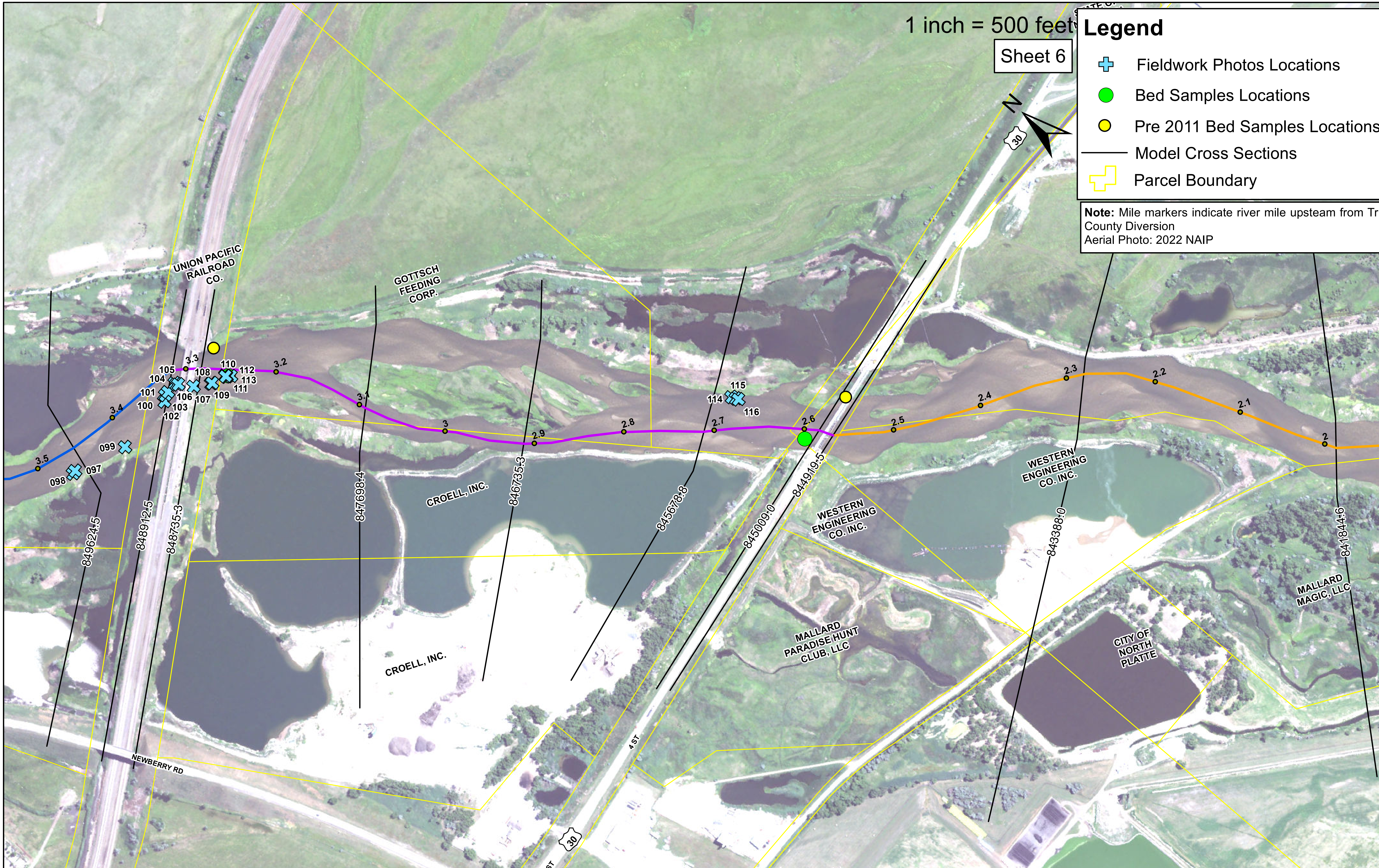
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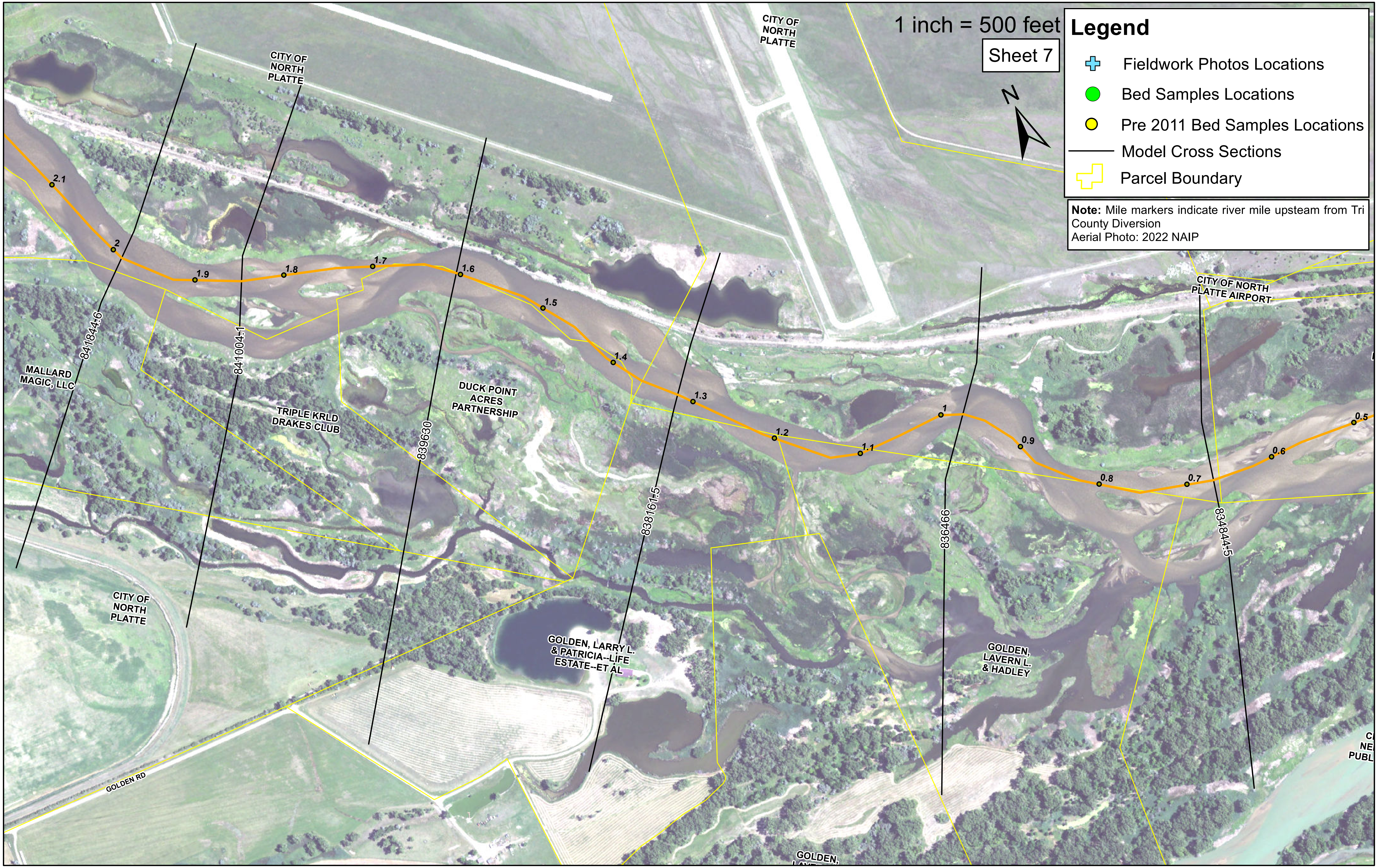
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TRIPLE KRLD DRAKES CLUB
DUCK POINT ACRES PARTNERSHIP
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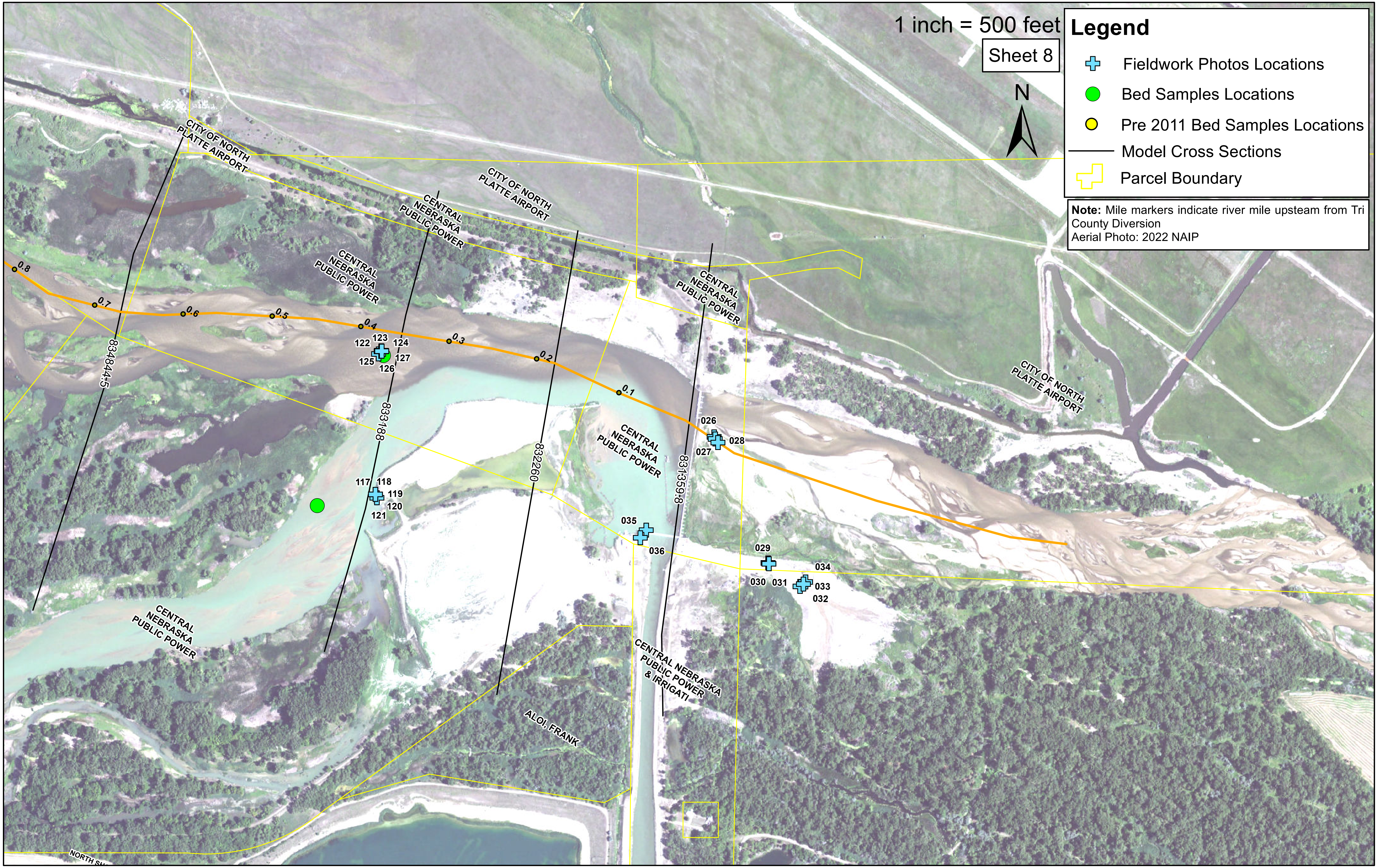

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# APPENDIX B. SITE VISIT PHOTOS OCT 2023


Log ID = 25 / File ID = 000025.jpg 2023-10-25

River Mile 5.5 - Looking downstream from HWY 83 Bridge


Log ID = 26 / File ID = 000026.jpg 2023-10-25

River Mile 0 - Looking upstream at Tri-County Diversion


Log ID = 27 / File ID = 000027.jpg 2023-10-25

River Mile 0 - Looking upstream at Tri-County Diversion


Log ID = 28 / File ID = 000028.jpg 2023-10-25

River Mile 0 - at Tri-County Diversion


Log ID = 29 / File ID = 000029.jpg 2023-10-25

River Mile 0 - Sand pile at Tri-County - 2 years' worth of dredging


Log ID = 30 / File ID = 000030.jpg 2023-10-25

River Mile 0 - Sand pile at Tri-County - 2 years' worth of dredging


Log ID = 31 / File ID = 000031.jpg 2023-10-25

River Mile 0 - Looking upstream at Tri-County Diversion


Log ID = 32 / File ID = 000032.jpg 2023-10-25

River Mile 0 - Looking upstream at Tri-County Diversion


Log ID = 33 / File ID = 000033.jpg 2023-10-25

River Mile 0 - Looking upstream at Tri-County Diversion


Log ID = 34 / File ID = 000034.jpg 2023-10-25

River Mile 0 - Sand pile at Tri-County - 2 years' worth of dredging


Log ID = 35 / File ID = 000035.jpg 2023-10-25

River Mile 0 - Dredging Operation at Tri-County Diversion


Log ID = 36 / File ID = 000036.jpg 2023-10-25

River Mile 0 - Dredging Operation at Tri-County Diversion


Log ID = 37 / File ID = 000037.jpg 2023-10-25

River Mile 11.1 - Upstream limit of study reach


Log ID = 38 / File ID = 000038.jpg 2023-10-25

River Mile 11.1 -


Log ID = 39 / File ID = 000039.jpg 2023-10-25

River Mile 11.1 -


Log ID = 40 / File ID = 000040.jpg 2023-10-25

River Mile 11.1 -


Log ID = 41 / File ID = 000041.jpg 2023-10-25

River Mile 10.95 - Near Bed Sample 1


Log ID = 42 / File ID = 000042.jpg 2023-10-25

River Mile 10.95 -


Log ID = 43 / File ID = 000043.jpg 2023-10-25

River Mile 10.75 - Right split flow path


Log ID = 44 / File ID = 000044.jpg 2023-10-25

River Mile 10.75 - Right split flow path


Log ID = 45 / File ID = 000045.jpg 2023-10-25

River Mile 10.6 - Right split flow path


Log ID = 46 / File ID = 000046.jpg 2023-10-25

River Mile 10.6 - Right split flow path


Log ID = 47 / File ID = 000047.jpg 2023-10-25

River Mile 10.4 -


Log ID = 48 / File ID = 000048.jpg 2023-10-25

River Mile 10.4 -


Log ID = 49 / File ID = 000049.jpg 2023-10-25

River Mile 10.4 -


Log ID = 50 / File ID = 000050.jpg 2023-10-25

River Mile 9.7 - Location of Bed Material Sample 2


Log ID = 51 / File ID = 000051.jpg 2023-10-25

River Mile 9.7 - Location of Bed Material Sample 2


Log ID = 52 / File ID = 000052.jpg 2023-10-25

River Mile 9.5 -


Log ID = 53 / File ID = 000053.jpg 2023-10-25

River Mile 9.5 -


Log ID = 54 / File ID = 000054.jpg 2023-10-25

River Mile 9.5 -


Log ID = 55 / File ID = 000055.jpg 2023-10-25

River Mile 8.9 -


Log ID = 56 / File ID = 000056.jpg 2023-10-25

River Mile 8.9 -


Log ID = 57 / File ID = 000057.jpg 2023-10-25

River Mile 8.9 - Note rock rubble on right bank for erosion control


Log ID = 58 / File ID = 000058.jpg 2023-10-25

River Mile 8.1 -


Log ID = 59 / File ID = 000059.jpg 2023-10-25

River Mile 8.1 -


Log ID = 60 / File ID = 000060.jpg 2023-10-25

River Mile 8.1 -


Log ID = 61 / File ID = 000061.jpg 2023-10-25

River Mile 7.55 - At Buffalo Bill Campground


Log ID = 62 / File ID = 000062.jpg 2023-10-25

River Mile 7.55 - At Buffalo Bill Campground


Log ID = 63 / File ID = 000063.jpg 2023-10-25

River Mile 7.55 - At Buffalo Bill Campground


Log ID = 64 / File ID = 000064.jpg 2023-10-25

River Mile 7.55 - At Buffalo Bill Campground


Log ID = 65 / File ID = 000065.jpg 2023-10-25

River Mile 7.55 - At Buffalo Bill Campground


Log ID = 66 / File ID = 000066.jpg 2023-10-25

River Mile 6.55 - Right split flow around island


Log ID = 67 / File ID = 000067.jpg 2023-10-25

River Mile 6.55 - Right split flow around island, erosion of island at left


Log ID = 68 / File ID = 000068.jpg 2023-10-25

River Mile 6.55 - Right split flow around island, old concrete structure


Log ID = 69 / File ID = 000069.jpg 2023-10-25

River Mile 6.55 - Right split flow around island, old concrete structure


Log ID = 70 / File ID = 000070.jpg 2023-10-25

River Mile 6.37 - Location of Bed Material Sample 4


Log ID = 71 / File ID = 000071.jpg 2023-10-25

River Mile 6.37 -


Log ID = 72 / File ID = 000072.jpg 2023-10-25

River Mile 6.37 -


Log ID = 73 / File ID = 000073.jpg 2023-10-25

River Mile 6.37 -


Log ID = 74 / File ID = 000074.jpg 2023-10-25

River Mile 6.37 -


Log ID = 75 / File ID = 000075.jpg 2023-10-25

River Mile 5.66 - Location of Bed Material Sample 5


Log ID = 76 / File ID = 000076.jpg 2023-10-25

River Mile 5.66 - Taken from old Highway bypass


Log ID = 77 / File ID = 000077.jpg 2023-10-25

River Mile 5.66 - Taken from old Highway bypass


Log ID = 78 / File ID = 000078.jpg 2023-10-25

River Mile 5.66 - Taken from old Highway bypass


Log ID = 79 / File ID = 000079.jpg 2023-10-25

River Mile 5.66 - Taken from old Highway bypass


Log ID = 80 / File ID = 000080.jpg 2023-10-25

River Mile 5.57 - Upstream of Highway 83


Log ID = 81 / File ID = 000081.jpg 2023-10-25

River Mile 5.57 - Upstream of Highway 83


Log ID = 82 / File ID = 000082.jpg 2023-10-25

River Mile 5.57 - Upstream of Highway 83


Log ID = 83 / File ID = 000083.jpg 2023-10-25

River Mile 5.3 - At Cody Park


Log ID = 84 / File ID = 000084.jpg 2023-10-25

River Mile 5.3 - Looking Upstream towards HW 83


Log ID = 85 / File ID = 000085.jpg 2023-10-25

River Mile 5.3 - At Cody Park


Log ID = 86 / File ID = 000086.jpg 2023-10-25

River Mile 5.3 - At Cody Park


Log ID = 87 / File ID = 000087.jpg 2023-10-25

River Mile 5.3 - At Cody Park


Log ID = 88 / File ID = 000088.jpg 2023-10-25

River Mile 5.3 - At Cody Park


Log ID = 89 / File ID = 000089.jpg 2023-10-25

River Mile 4.9 -


Log ID = 90 / File ID = 000090.jpg 2023-10-25

River Mile 4.9 -


Log ID = 91 / File ID = 000091.jpg 2023-10-25

River Mile 4.1 -


Log ID = 92 / File ID = 000092.jpg

2023-10-25


Log ID = 93 / File ID = 000093.jpg 2023-10-25

River Mile 4.1 -


Log ID = 94 / File ID = 000094.jpg 2023-10-25

River Mile 4.03 - at Bed Sample Location 8


Log ID = 95 / File ID = 000095.jpg 2023-10-25

River Mile 3.59 -


Log ID = 96 / File ID = 000096.jpg 2023-10-25

River Mile 3.58 -


Log ID = 97 / File ID = 000097.jpg 2023-10-25

River Mile 3.45 - Looking downstream at RR Bridge


Log ID = 98 / File ID = 000098.jpg 2023-10-25

River Mile 3.45 - Looking downstream at RR Bridge


Log ID = 99 / File ID = 000099.jpg 2023-10-25

River Mile 3.4 - Looking downstream at RR Bridge


Log ID = 100 / File ID = 000100.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 101 / File ID = 000101.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 102 / File ID = 000102.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 103 / File ID = 000103.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 104 / File ID = 000104.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 105 / File ID = 000105.jpg 2023-10-25

River Mile 3.31 - Looking downstream at RR Bridge


Log ID = 106 / File ID = 000106.jpg 2023-10-25

River Mile 3.31 - Inside RR Bridge


Log ID = 107 / File ID = 000107.jpg 2023-10-25

River Mile 3.29 - Looking upstream at downstream face of RR Bridge


Log ID = 108 / File ID = 000108.jpg 2023-10-25

River Mile 3.28 - Looking upstream at downstream face of RR Bridge


Log ID = 109 / File ID = 000109.jpg 2023-10-25

River Mile 3.28 - Looking upstream at downstream face of RR Bridge


Log ID = 110 / File ID = 000110.jpg 2023-10-25

River Mile 3.27 - Looking upstream at downstream face of RR Bridge


Log ID = 111 / File ID = 000111.jpg 2023-10-25

River Mile 3.27 - Looking upstream at downstream face of RR Bridge


Log ID = 112 / File ID = 000112.jpg 2023-10-25

River Mile 3.27 - Looking upstream at downstream face of RR Bridge


Log ID = 113 / File ID = 000113.jpg 2023-10-25

River Mile 3.27 - Looking upstream at downstream face of RR Bridge


Log ID = 114 / File ID = 000114.jpg 2023-10-25

River Mile 2.7 - Looking downstream at HWY 30


Log ID = 115 / File ID = 000115.jpg 2023-10-25

River Mile 2.7 - Looking downstream at HWY 30


Log ID = 116 / File ID = 000116.jpg 2023-10-25

River Mile 2.7 - Looking downstream at HWY 30


Log ID = 117 / File ID = 000117.jpg 2023-10-25

South Platte River upstream of confluence


Log ID = 118 / File ID = 000118.jpg 2023-10-25

South Platte River upstream of confluence, rock jetty at left


Log ID = 119 / File ID = 000119.jpg 2023-10-25

South Platte River upstream of confluence


Log ID = 120 / File ID = 000120.jpg 2023-10-25

South Platte River upstream of confluence


Log ID = 121 / File ID = 000121.jpg 2023-10-25

Looking towards confluence


Log ID = 122 / File ID = 000122.jpg 2023-10-25

River Mile 0.35 - North Platte just upstream of confluence


Log ID = 123 / File ID = 000123.jpg 2023-10-25

River Mile 0.35 - at Bed sample Location 12


Log ID = 124 / File ID = 000124.jpg 2023-10-25

River Mile 0.35 - North Platte just upstream of confluence


Log ID = 125 / File ID = 000125.jpg 2023-10-25

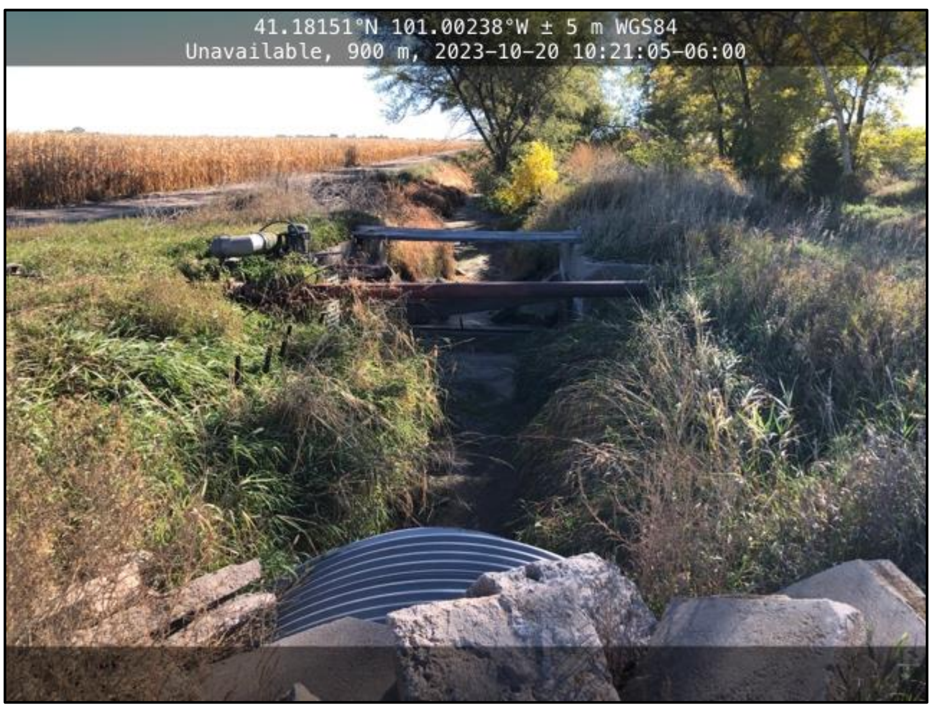
River Mile 0.35 - North Platte just upstream of confluence


Log ID = 126 / File ID = 000126.jpg 2023-10-25

River Mile 0.35 - North Platte just upstream of confluence


Log ID = 127 / File ID = 000127.jpg 2023-10-25

River Mile 0.35 - North Platte just upstream of confluence




Log ID = 128 / File ID = 000128.jpg 2023-10-25

Lateral canal adjacent to North Platte Canal at Hershey Rd


Log ID = 129 / File ID = 000129.jpg

2023-10-25


Log ID = 130 / File ID = 000130.jpg 2023-10-25

Lateral canal adjacent to North Platte Canal at Hershey Rd


Log ID = 131 / File ID = 000131.jpg

2023-10-25


Log ID = 132 / File ID = 000132.jpg 2023-10-25

Lateral canal adjacent to North Platte Canal at Hershey Rd


Log ID = 133 / File ID = 000133.jpg 2023-10-25

North Platte Canal at Hershey Rd


Log ID = 134 / File ID = 000134.jpg 2023-10-25

North Platte Canal at Hershey Rd


Log ID = 135 / File ID = 000135.jpg 2023-10-25

North Platte Canal at Hershey Rd


Log ID = 136 / File ID = 000136.jpg 2023-10-25

Suburban Canal at Hershey Rd


Log ID = 137 / File ID = 000137.jpg 2023-10-25

Suburban Canal at Hershey Rd


Log ID = 138 / File ID = 000138.jpg 2023-10-25

Sign at North Platte River Access Point


Log ID = 139 / File ID = 000139.jpg 2023-10-25

North Platte River at Hershey Rd, Looking upstream


Log ID = 140 / File ID = 000140.jpg 2023-10-25

North Platte looking upstream from Hershey Rd


Log ID = 141 / File ID = 000141.jpg 2023-10-25

North Platte looking upstream from Hershey Road


Log ID = 142 / File ID = 000142.jpg 2023-10-25

North Platte looking downstream from Hershey Road


Log ID = 143 / File ID = 000143.jpg 2023-10-25

North Platte at Prairie Trace Rd


Log ID = 144 / File ID = 000144.jpg 2023-10-25

North Platte at Prairie Trace Rd


Log ID = 145 / File ID = 000145.jpg 2023-10-25

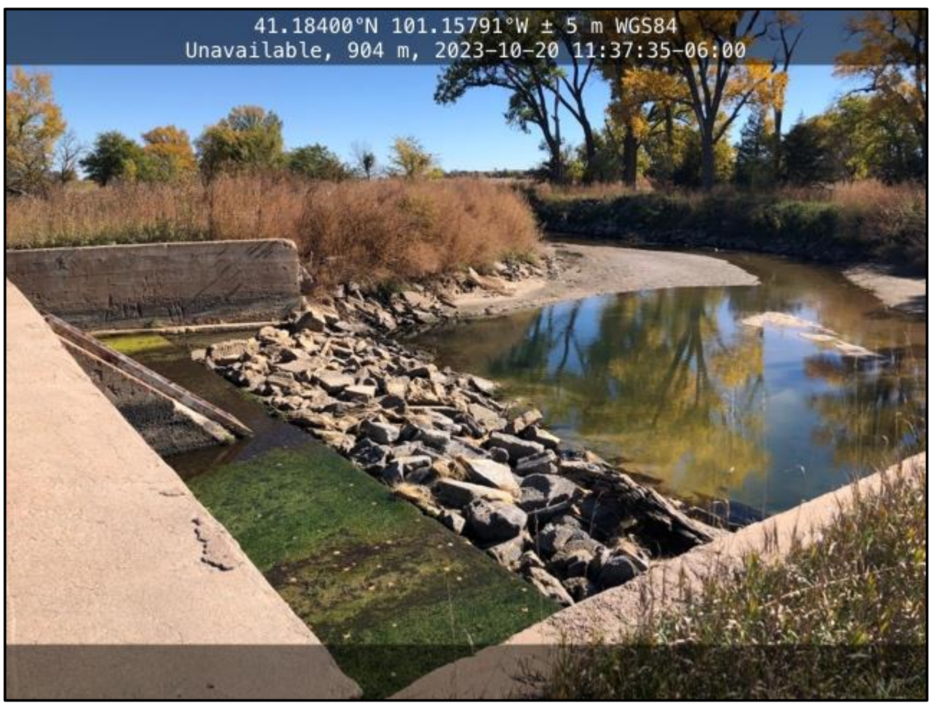
North Platte at Prairie Trace Rd


Log ID = 146 / File ID = 000146.jpg 2023-10-25

North Platte Canal Diversion


Log ID = 147 / File ID = 000147.jpg 2023-10-25

North Platte Canal Diversion




Log ID = 148 / File ID = 000148.jpg 2023-10-25

Head of North Platte Canal


Log ID = 149 / File ID = 000149.jpg 2023-10-25

Looking upstream from North Platte Canal Diversion at River


Log ID = 150 / File ID = 000150.jpg 2023-10-25

North Platte Canal Diversion


Log ID = 151 / File ID = 000151.jpg 2023-10-25

North Platte Canal Diversion


Log ID = 152 / File ID = 000152.jpg 2023-10-25

North Platte Canal Diversion


Log ID = 153 / File ID = 000153.jpg 2023-10-25

North Platte Canal Diversion


Log ID = 154 / File ID = 000154.jpg

2023-10-25


Log ID = 155 / File ID = 000155.jpg 2023-10-25

North Platte River at E County Rd V


Log ID = 156 / File ID = 000156.jpg 2023-10-25

North Platte River at E County Rd V


Log ID = 157 / File ID = 000157.jpg 2023-10-25

North Platte River at E County Rd T


Log ID = 158 / File ID = 000158.jpg 2023-10-25

North Platte River at E County Rd T


Log ID = 159 / File ID = 000159.jpg 2023-10-25

North Platte River at Keystone Roscoe Rd


Log ID = 160 / File ID = 000160.jpg 2023-10-25

North Platte River at Keystone Roscoe Rd


Log ID = 161 / File ID = 000161.jpg 2023-10-25

Grade control on North Platte just downstream of Keystone Diversion Dam

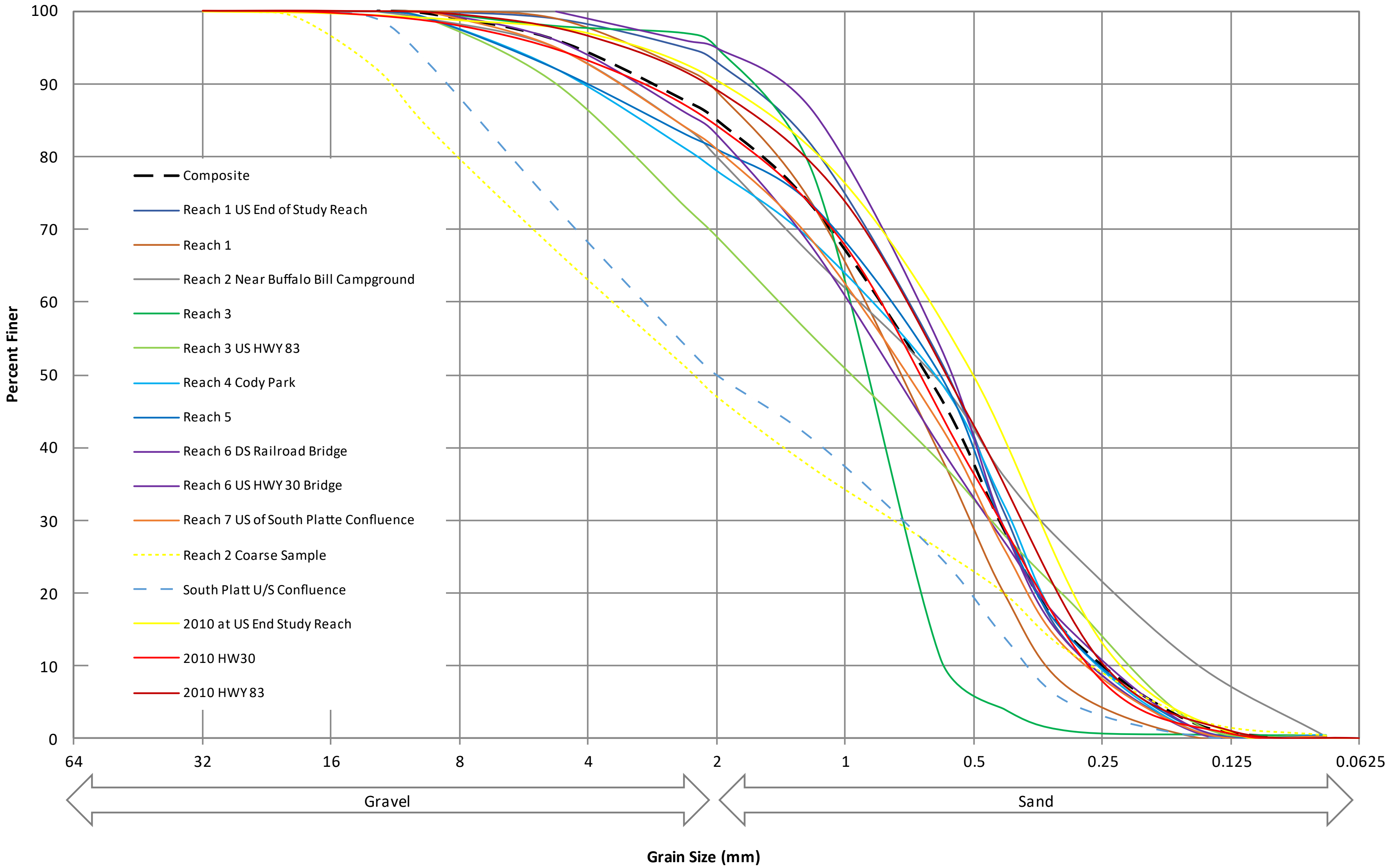

Log ID = 162 / File ID = 000162.jpg 2023-10-25

Looking upstream at Keystone Diversion Dam

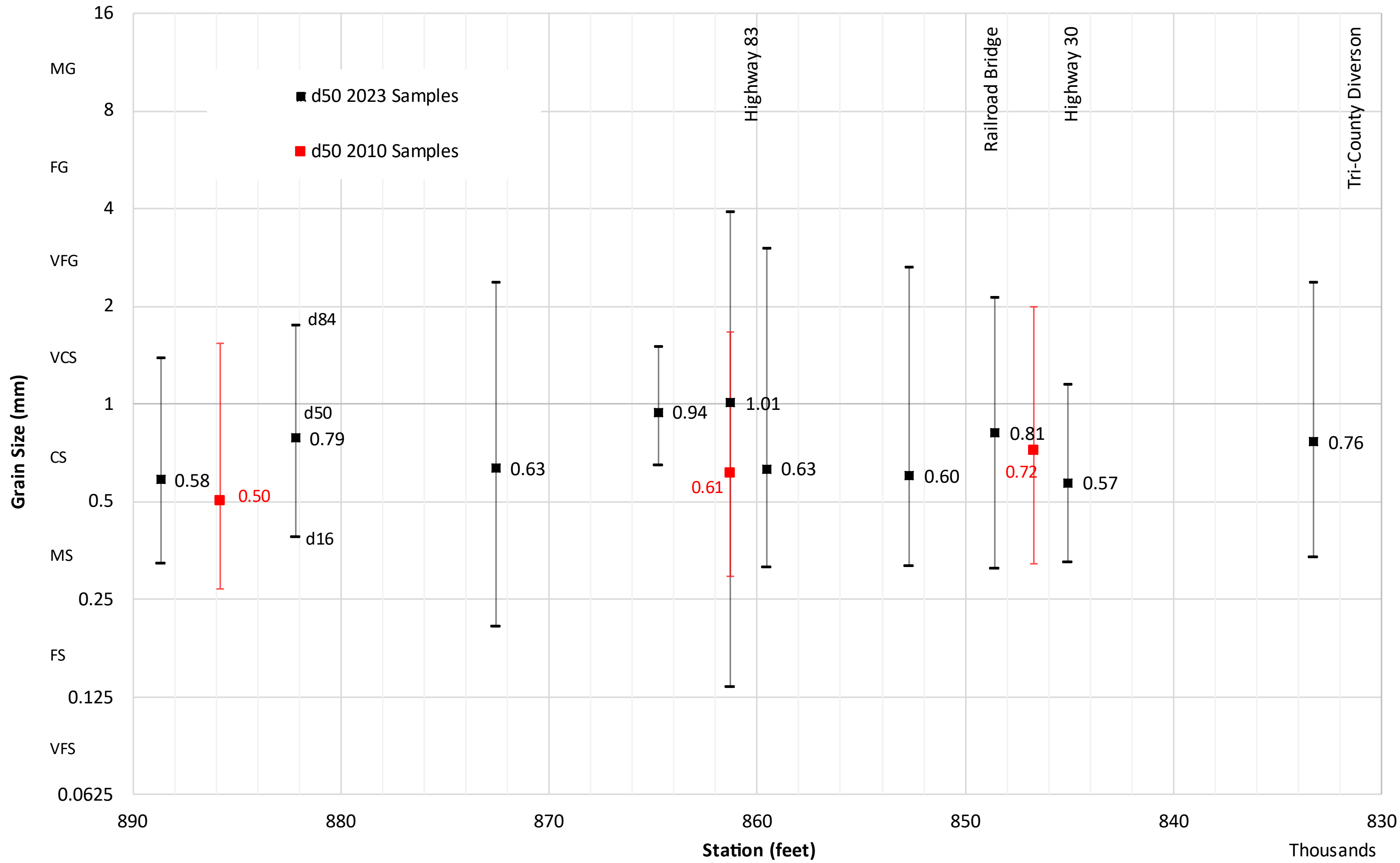

Log ID = 163 / File ID = 000163.jpg 2023-10-25

Sutherland Canal

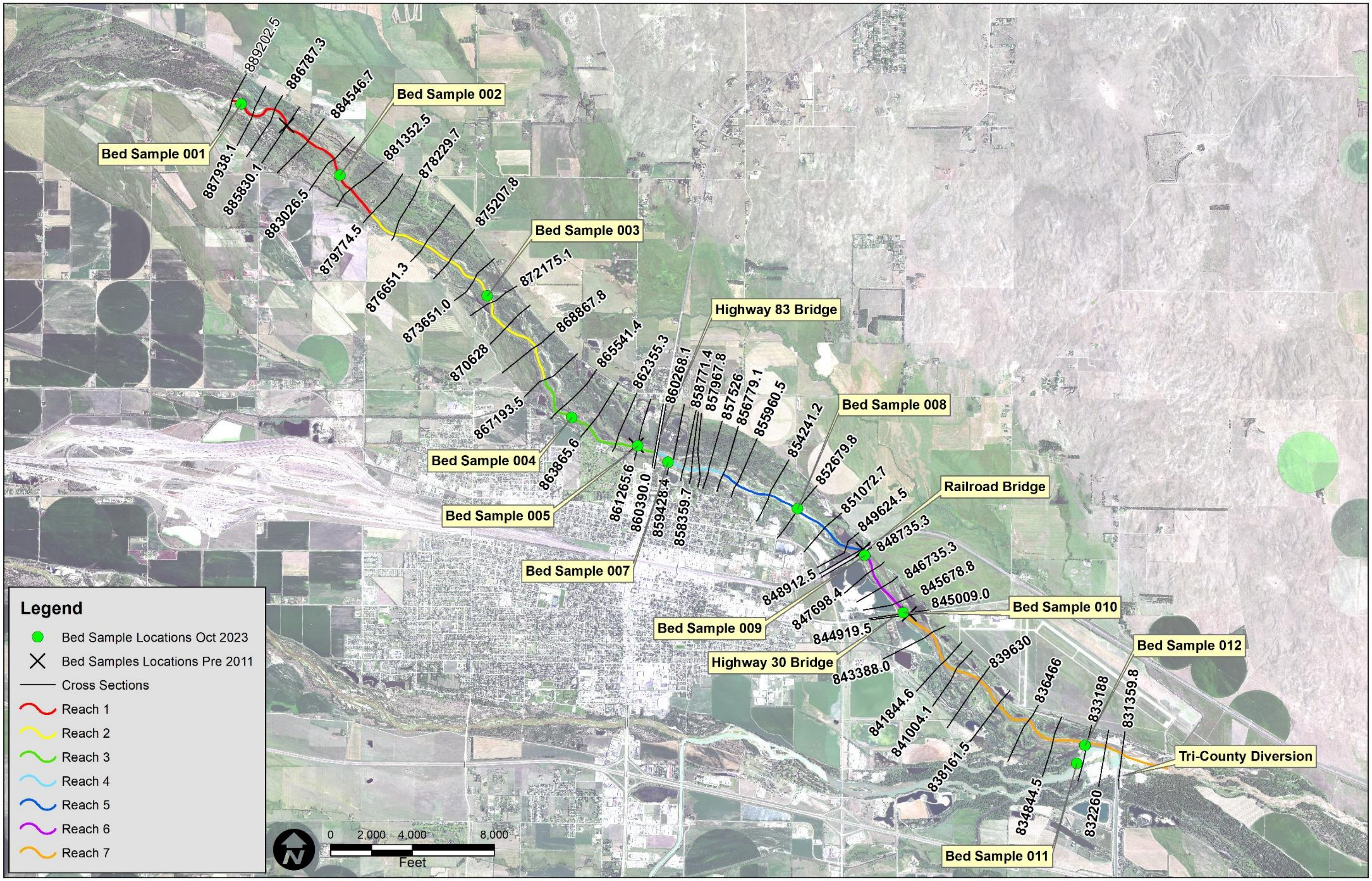
# APPENDIX C. BED MATERIAL SAMPLES OCT 2023




**Gradation Plots of North Platte Bed Material Samples Collected October 2023 and 2010**

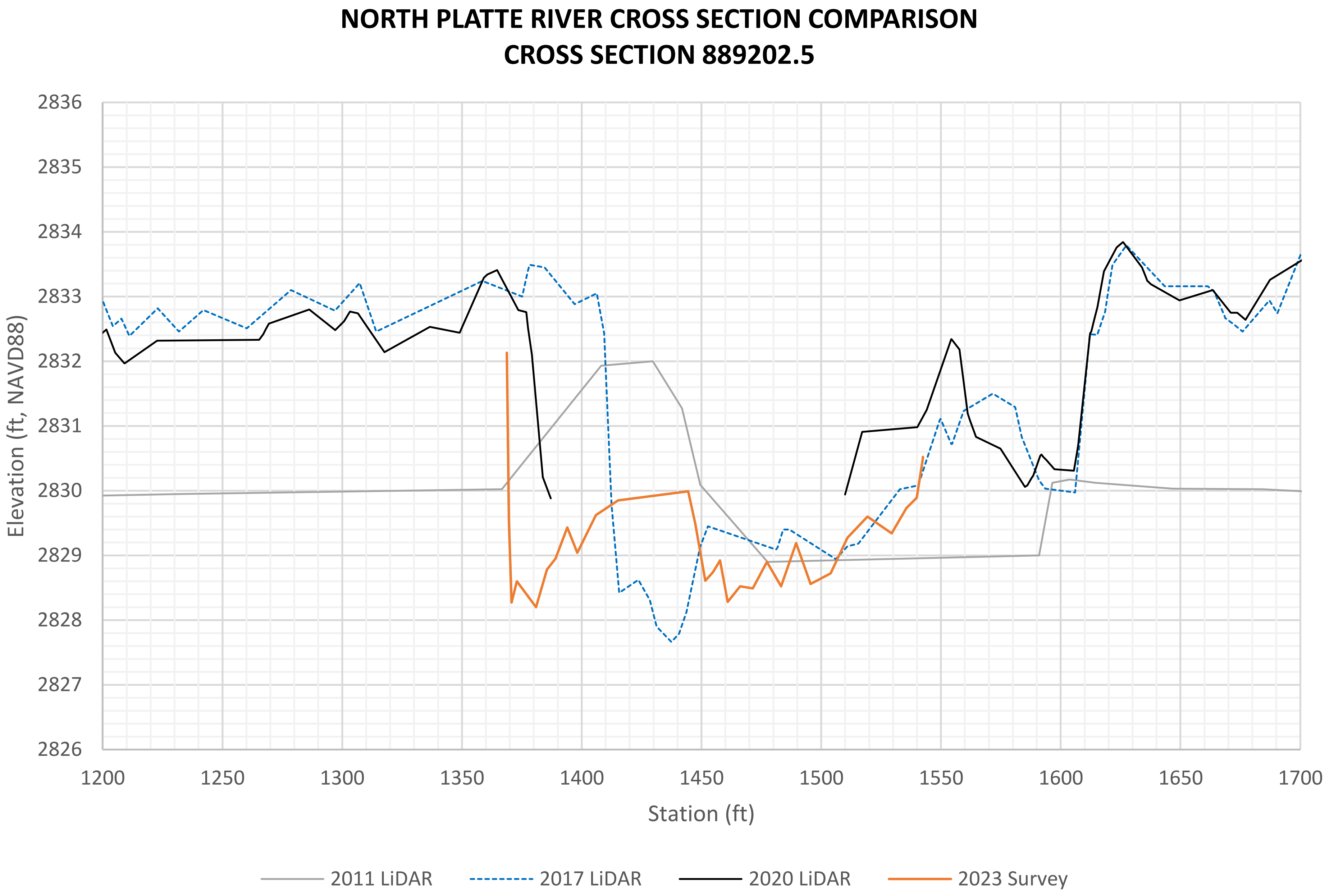



**North Platte River Bed Material Sample – d16, d50, and d84**



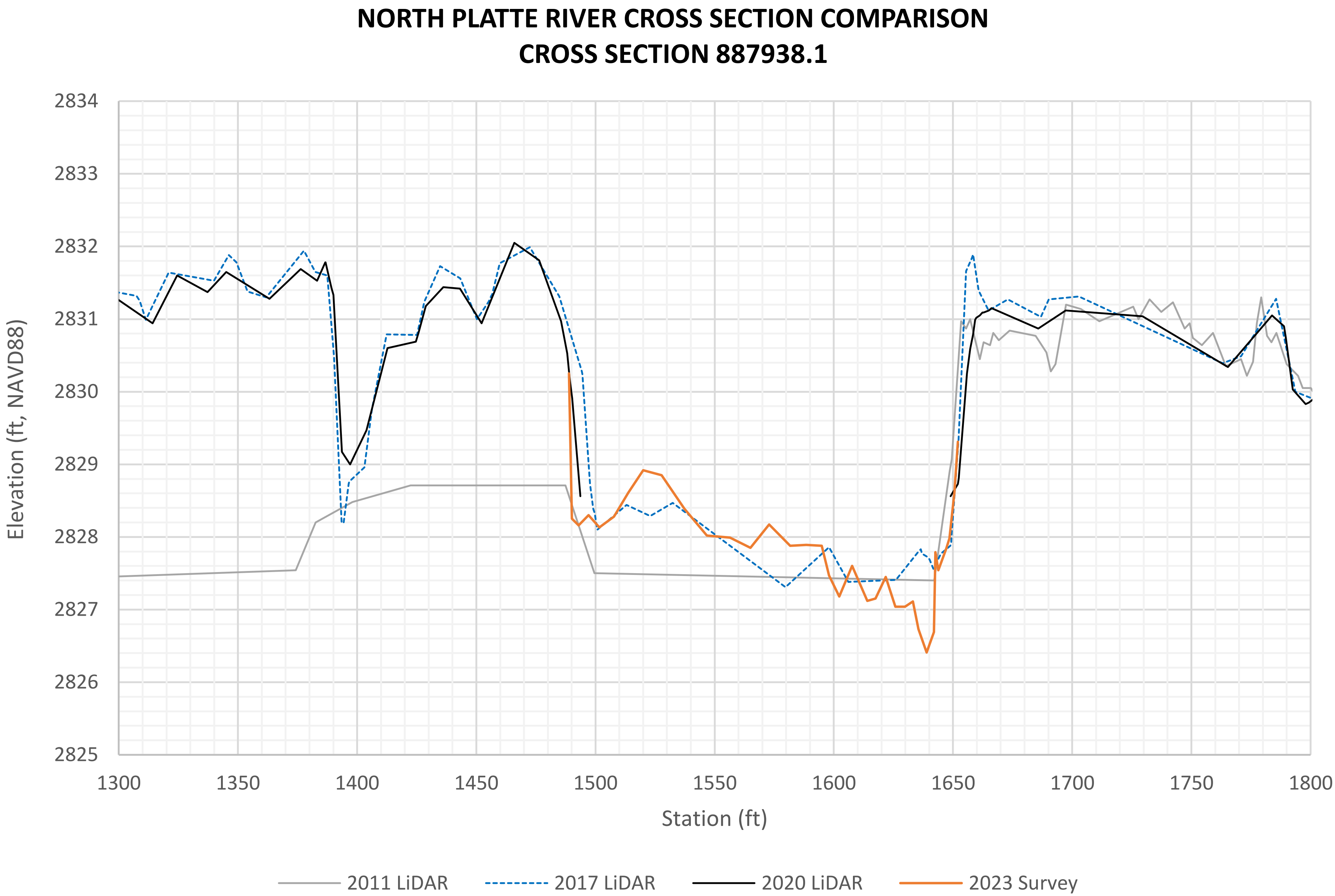

**Map of Bed Material Sample Locations**

# APPENDIX D. CROSS SECTION COMPARISONS 2011, 2017, AND 2023 ACTIVE CHANNEL ONLY



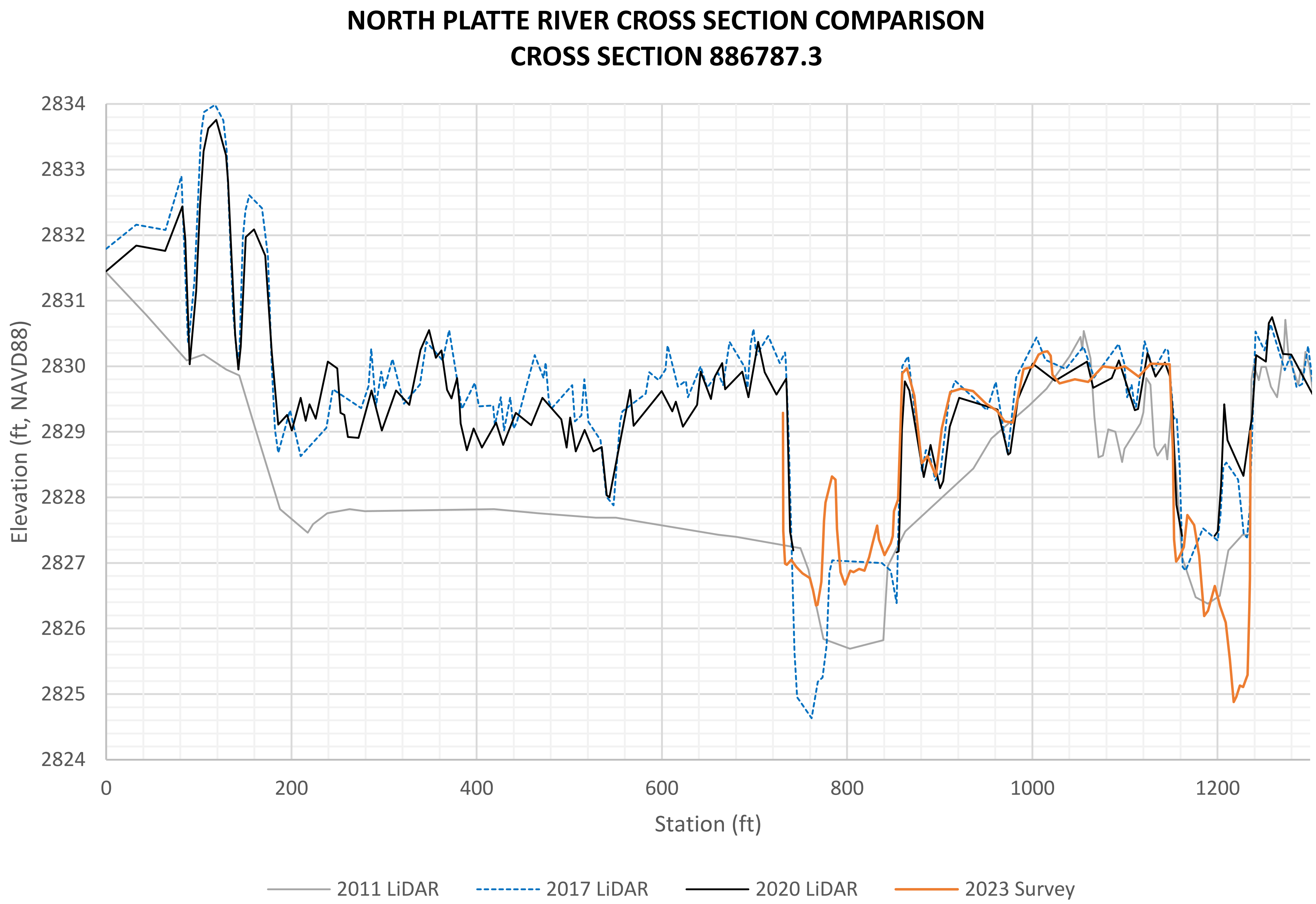



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



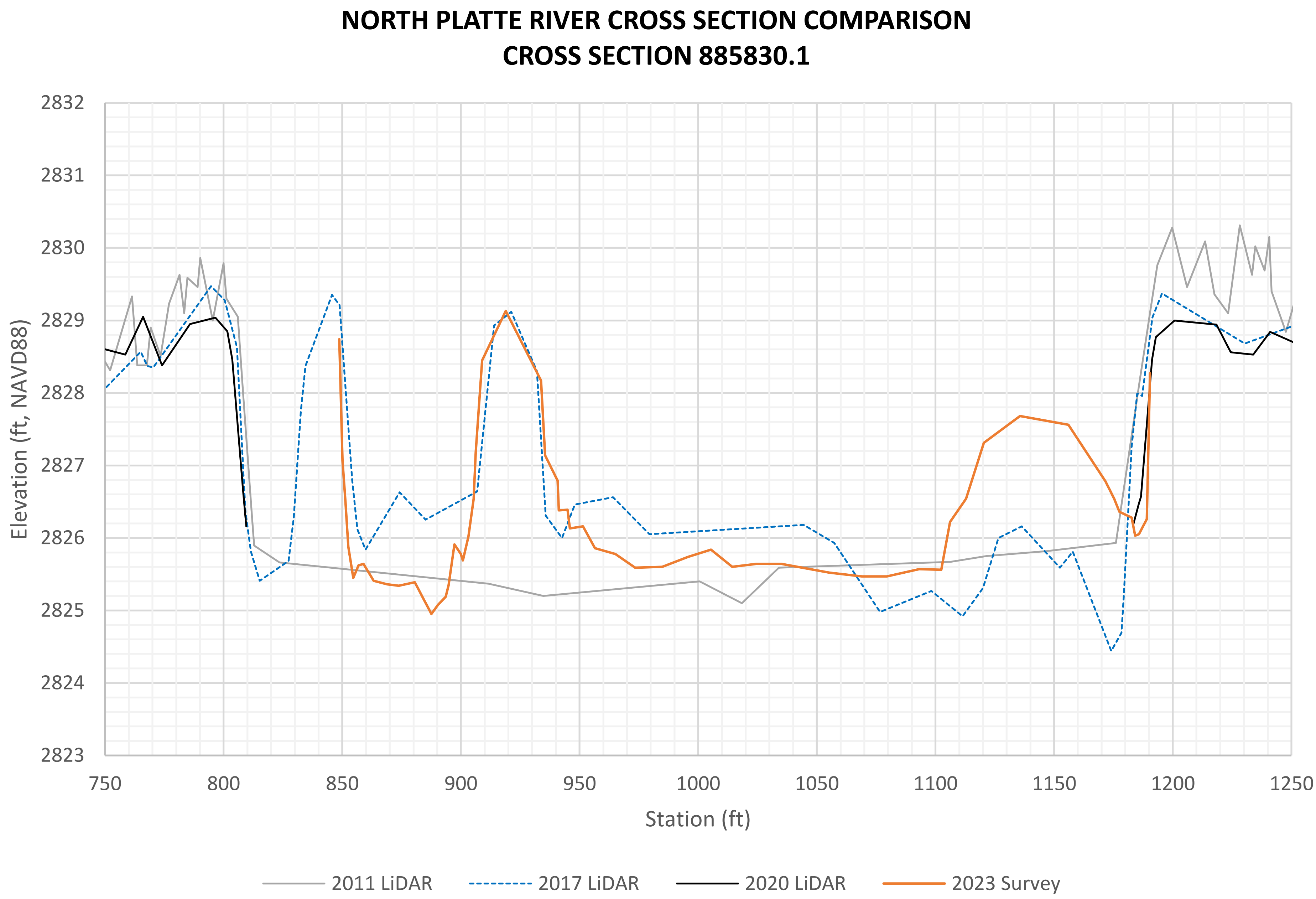



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



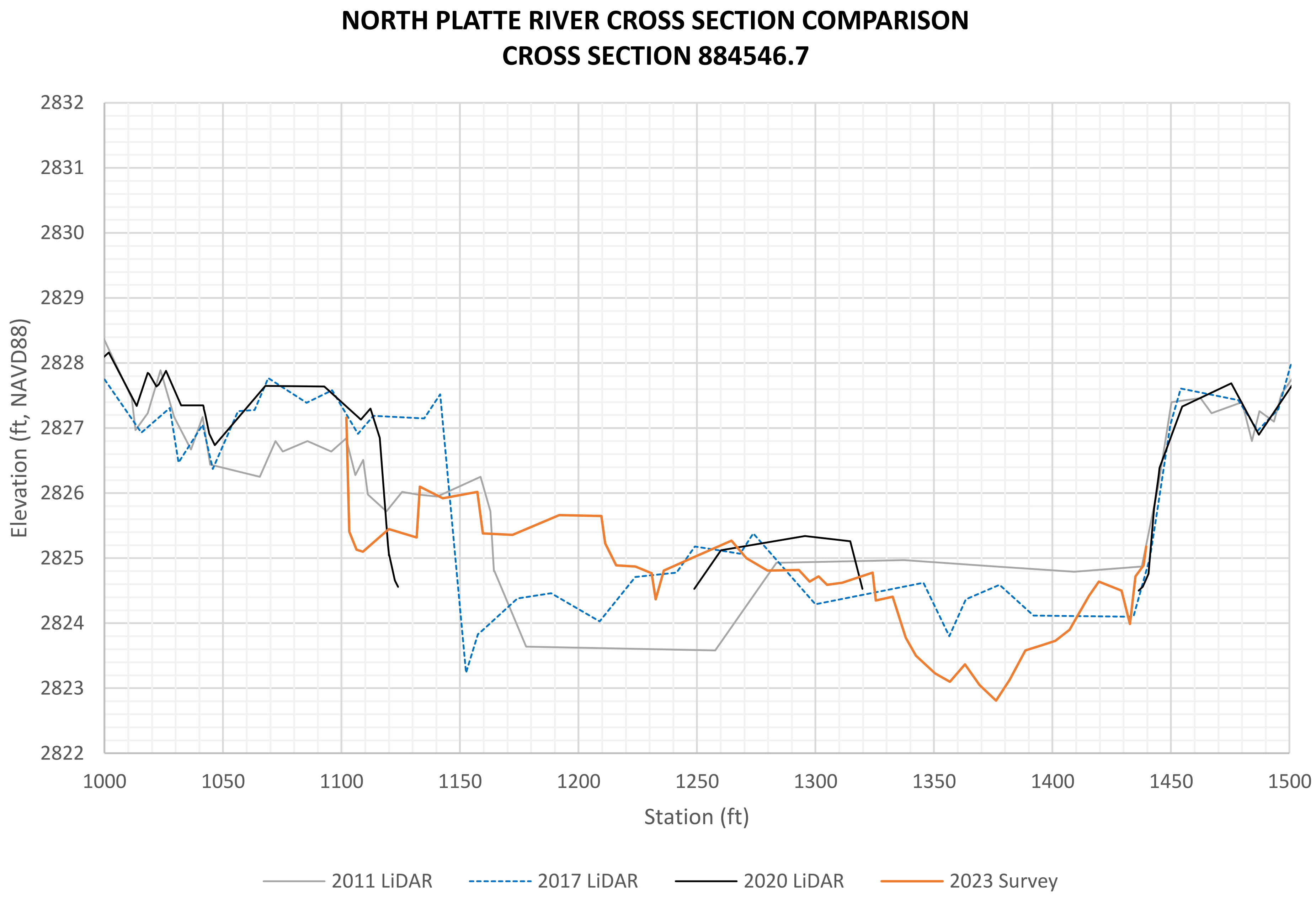



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





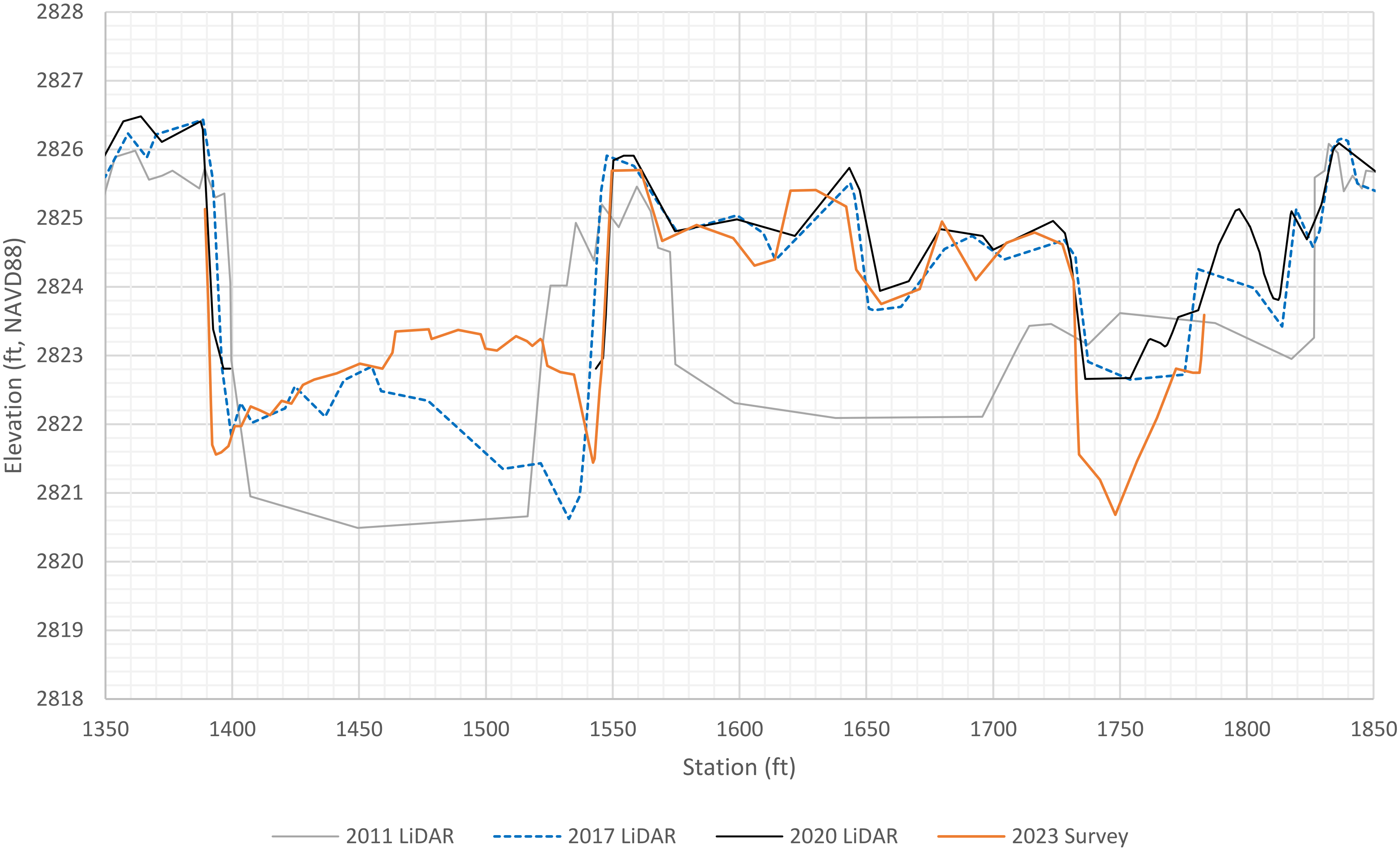

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions






Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

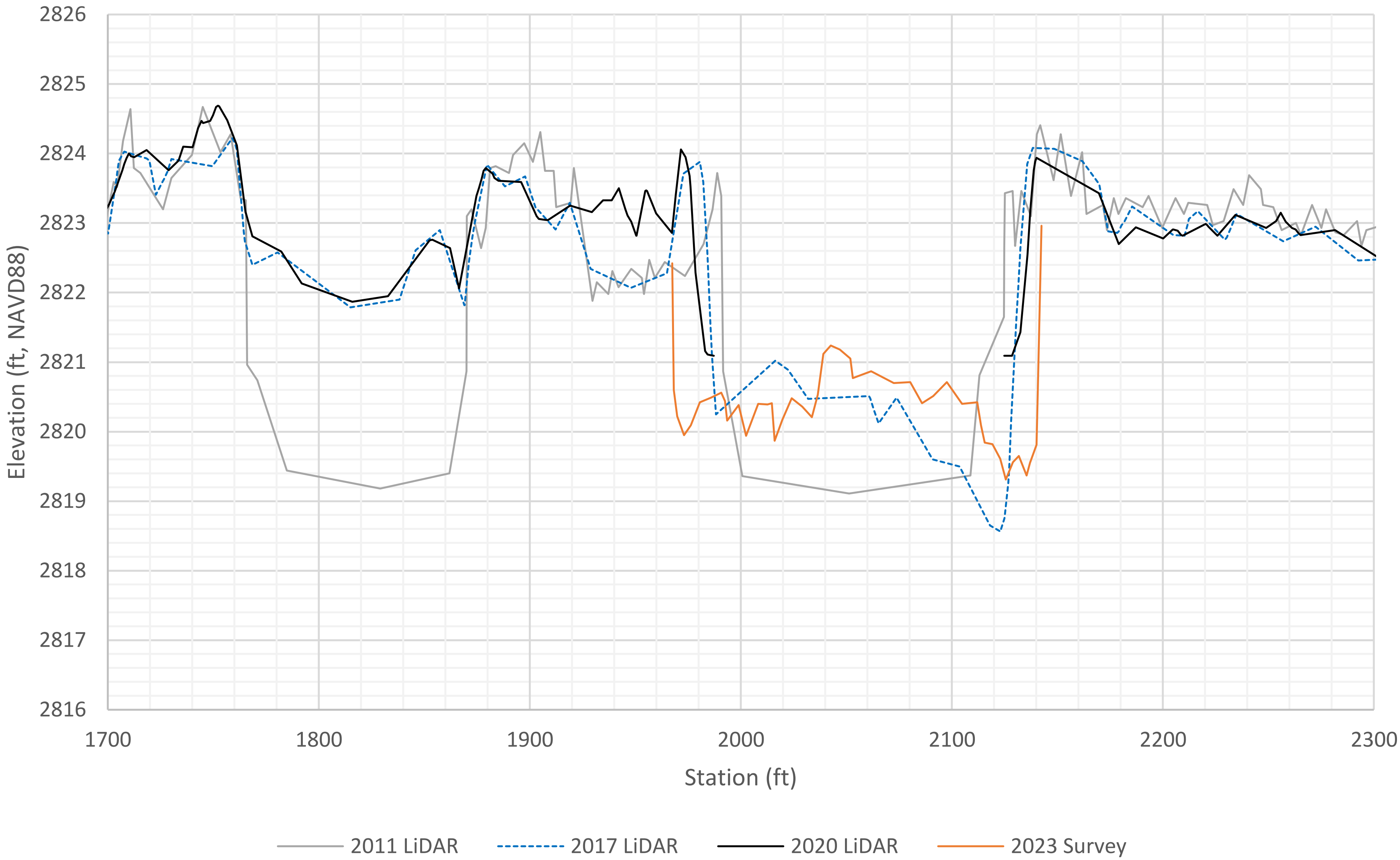
# NORTH PLATTE RIVER CROSS SECTION COMPARISON
# CROSS SECTION 883026.5





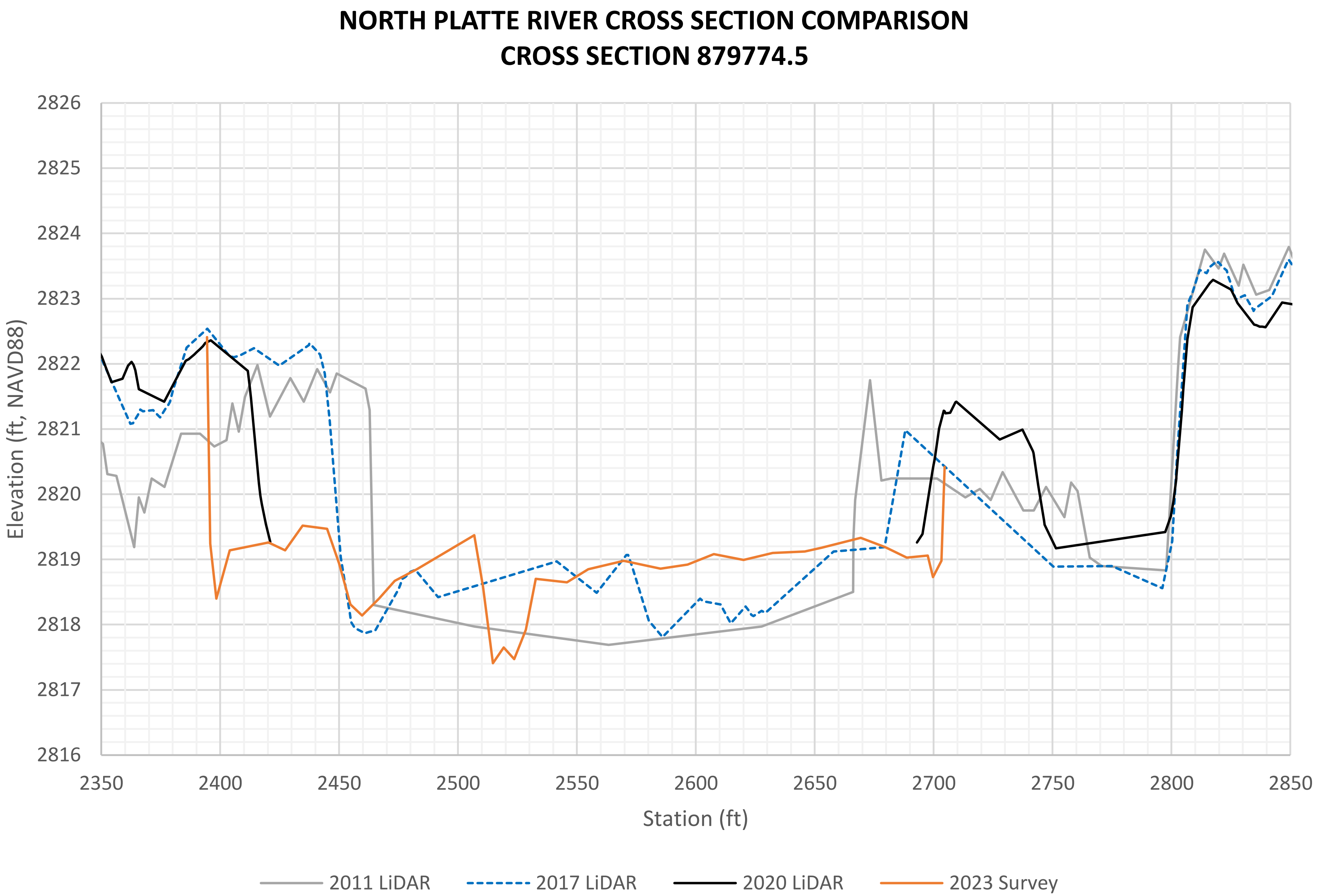

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

# NORTH PLATTE RIVER CROSS SECTION COMPARISON
# CROSS SECTION 881352.5



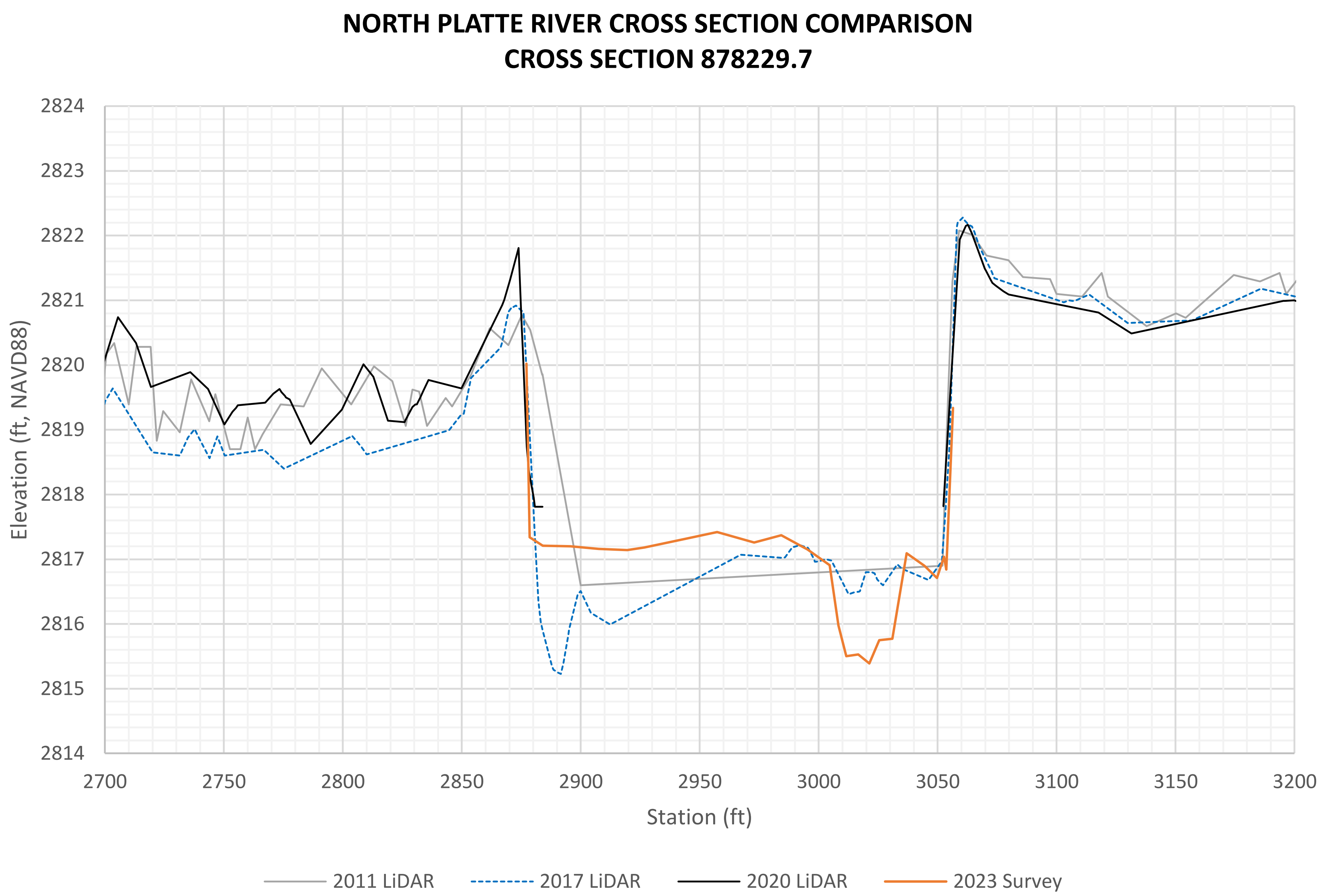



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



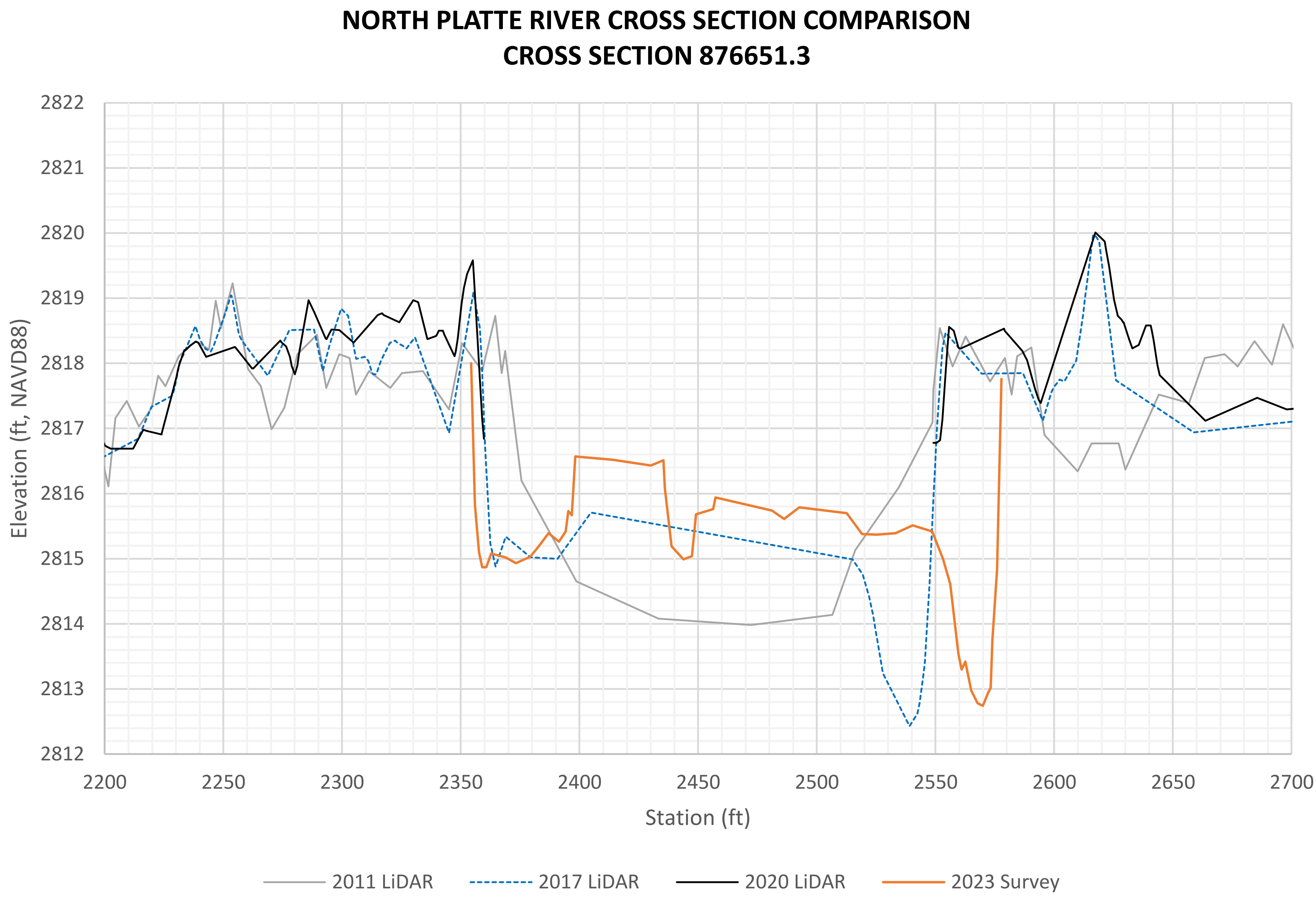



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



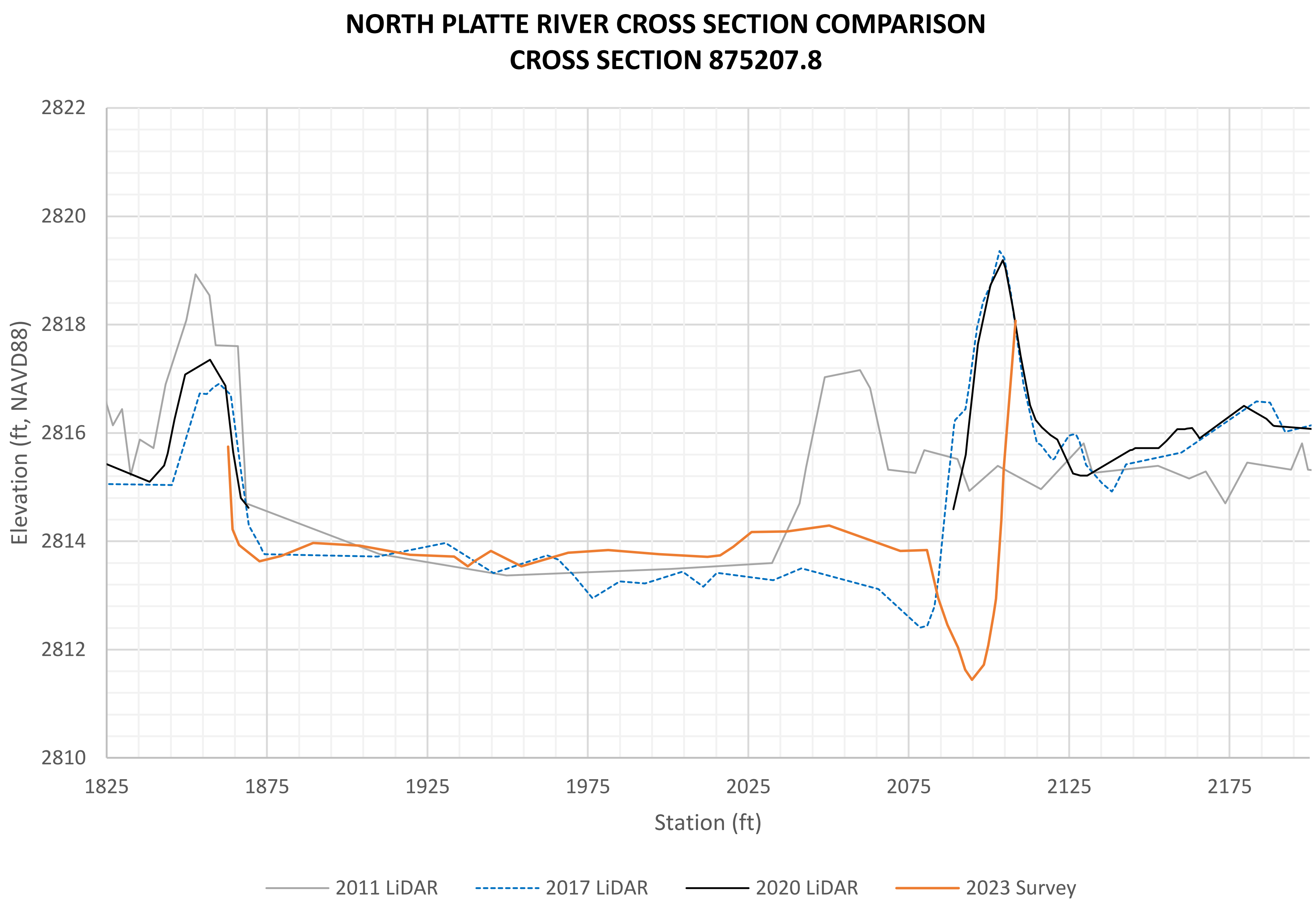



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



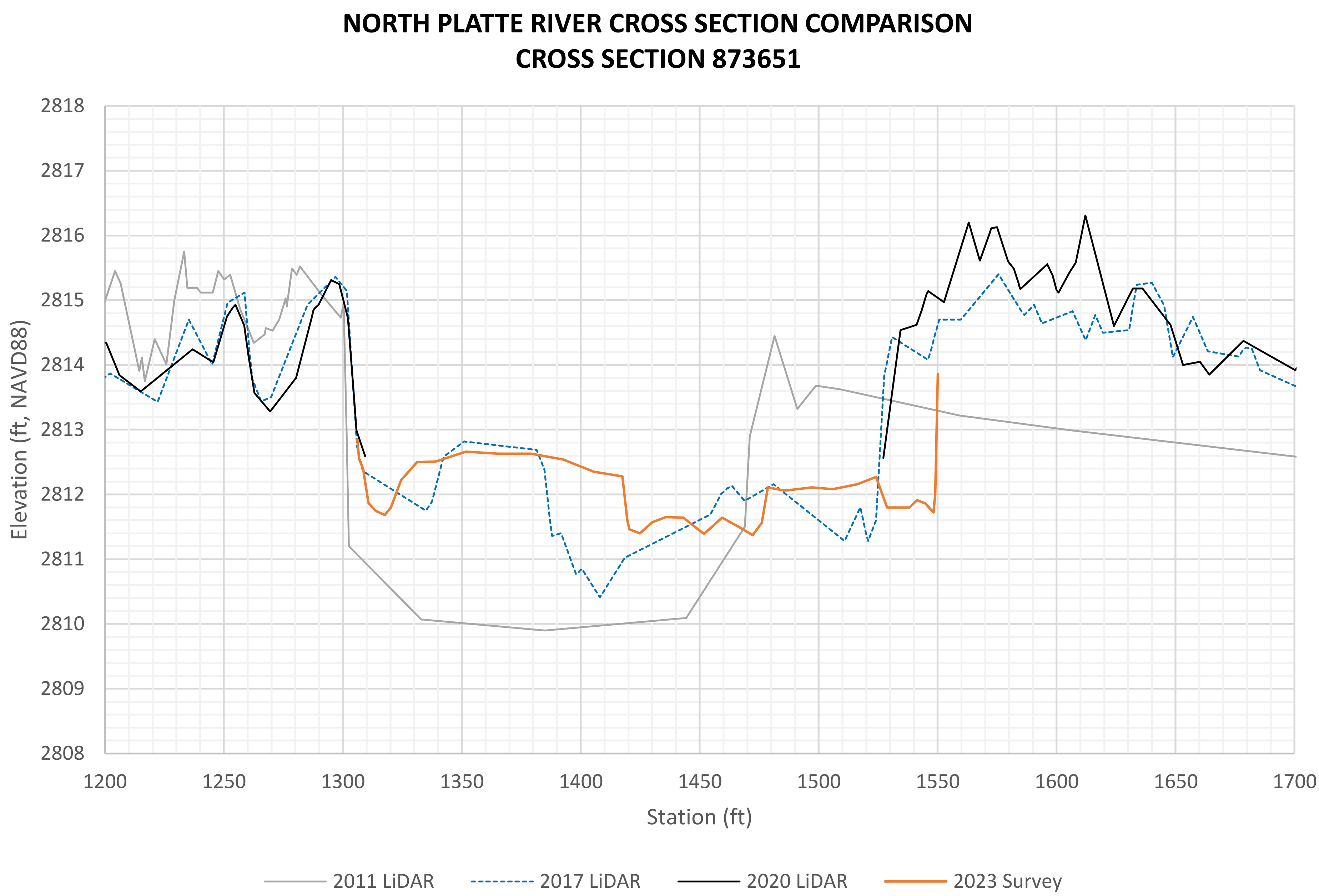



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



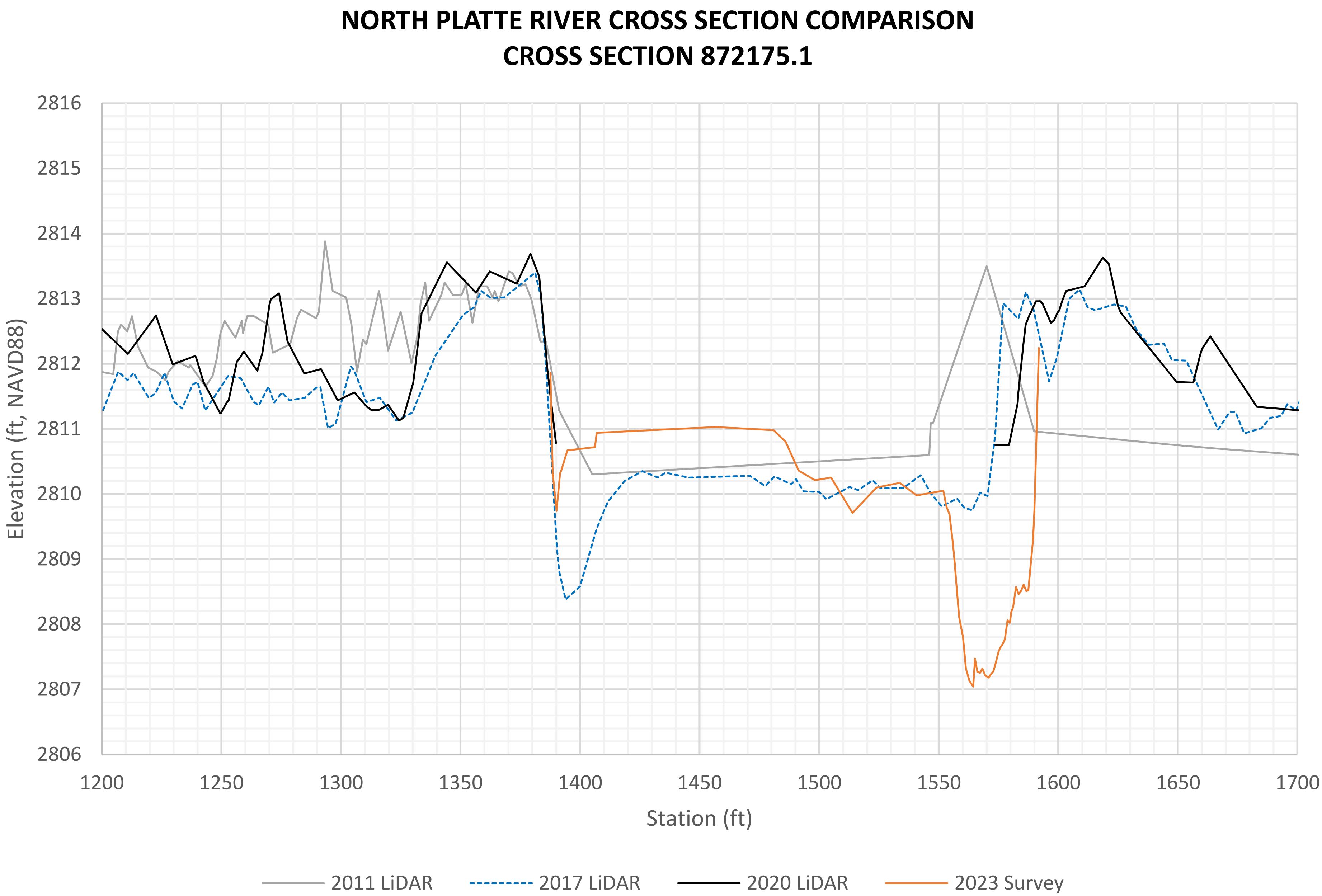


Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





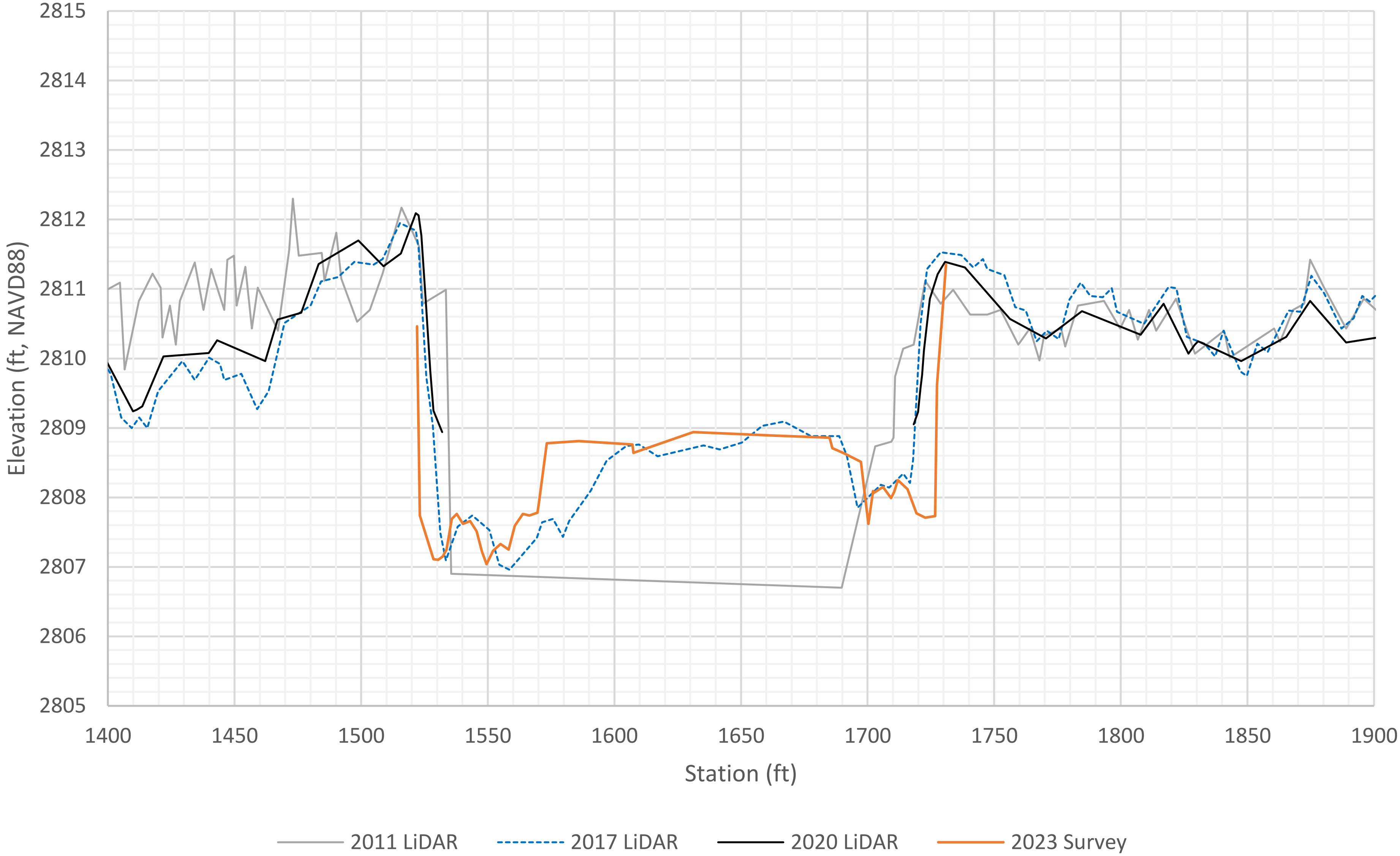

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





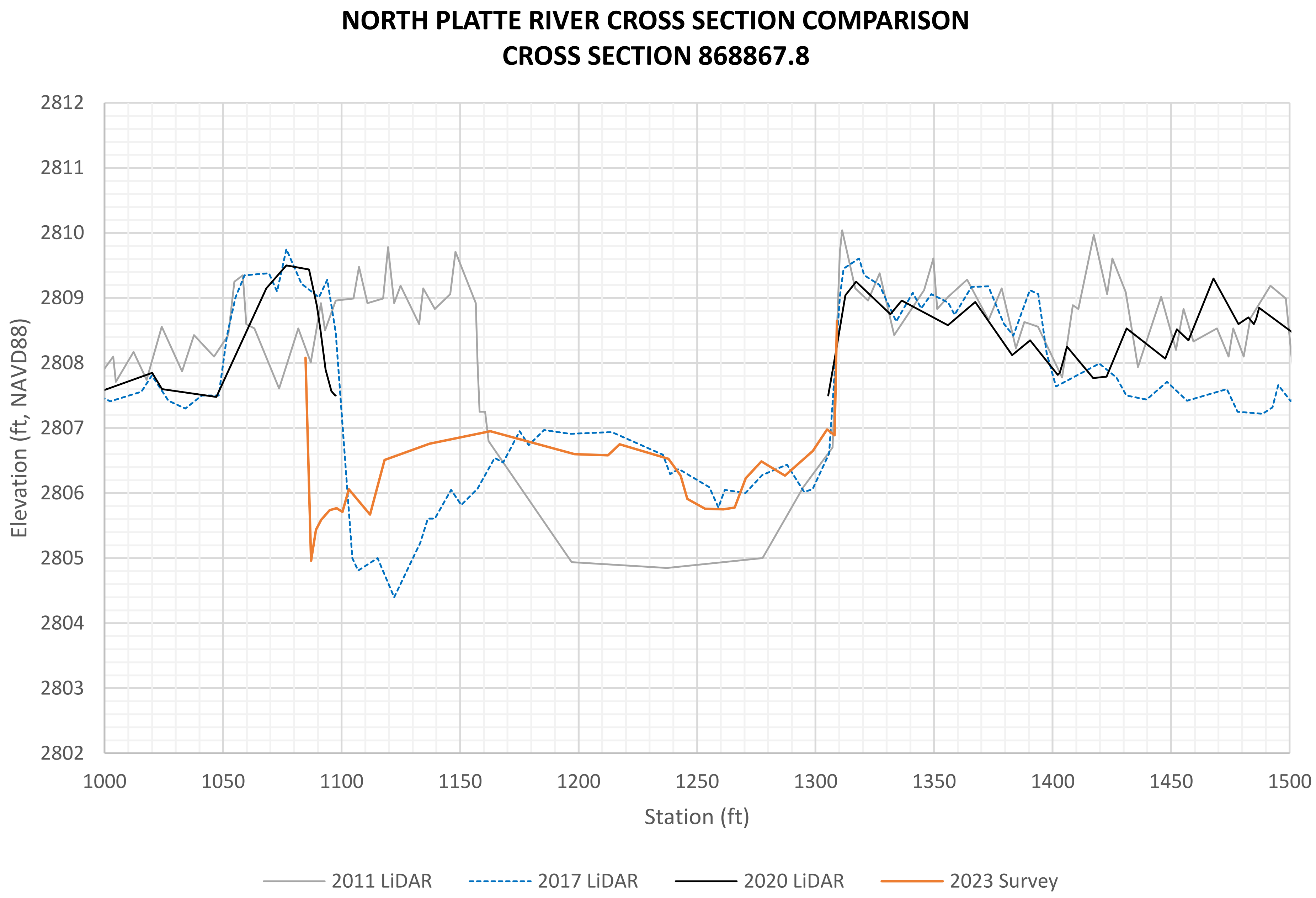

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

# NORTH PLATTE RIVER CROSS SECTION COMPARISON
# CROSS SECTION 870628





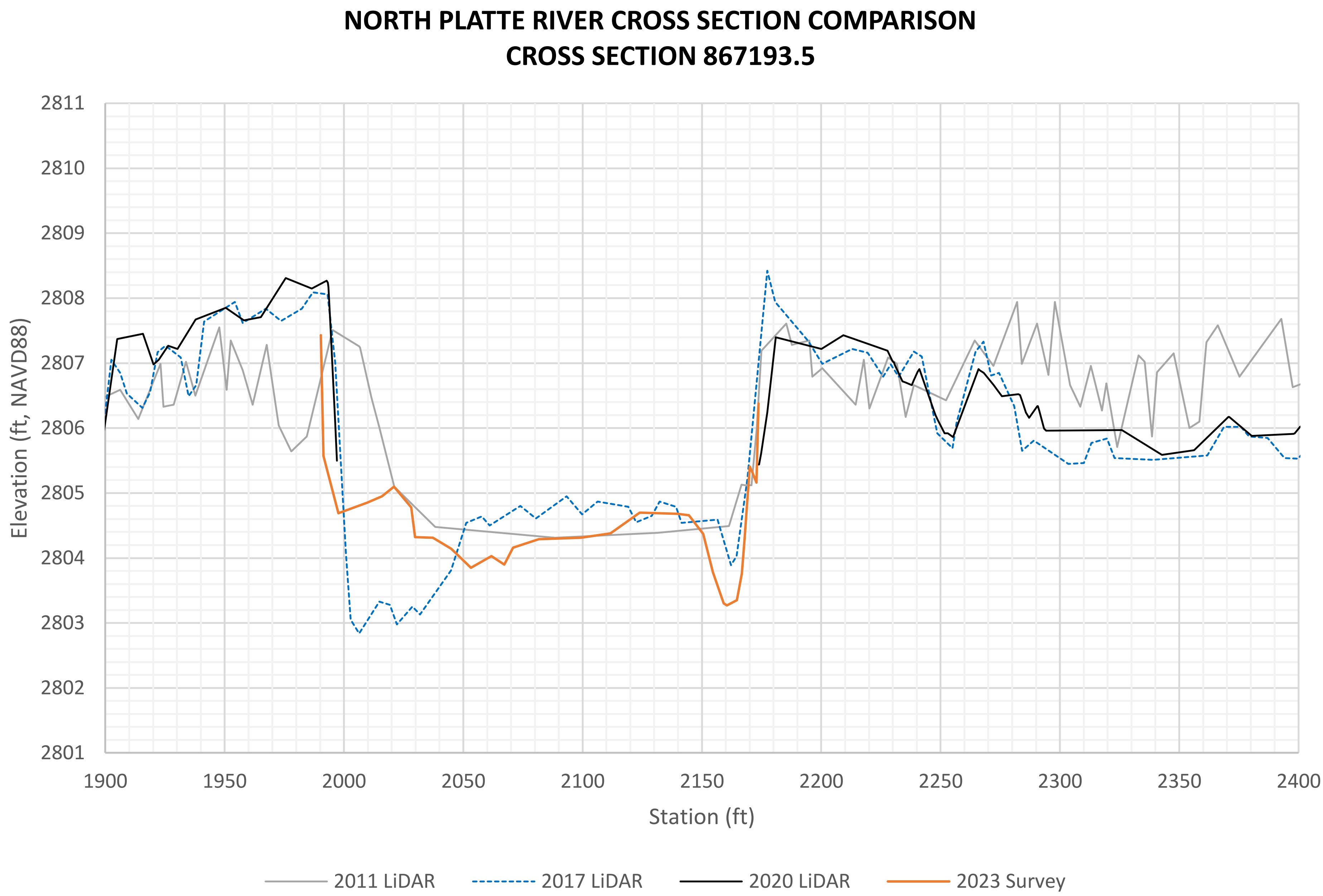

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





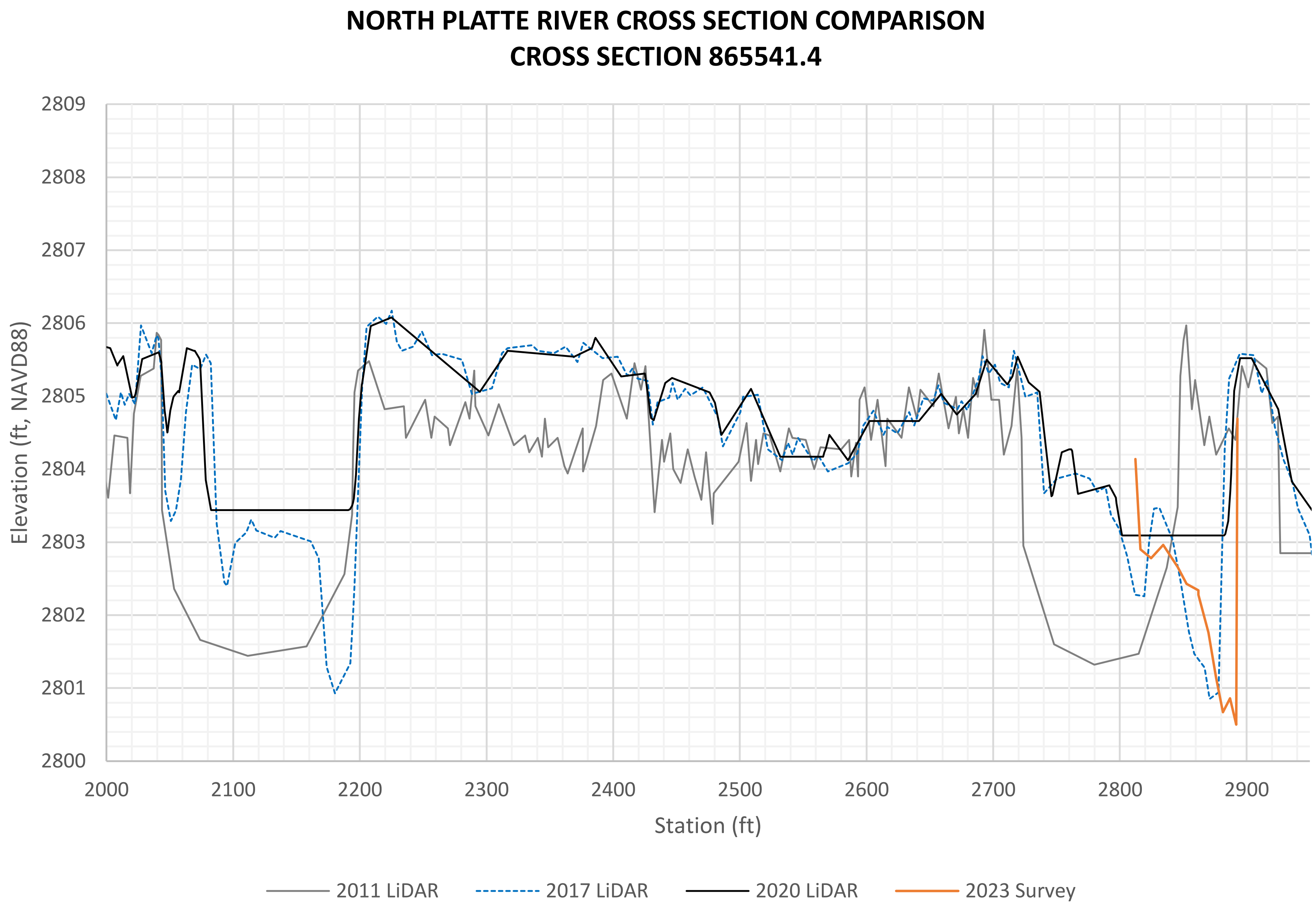



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



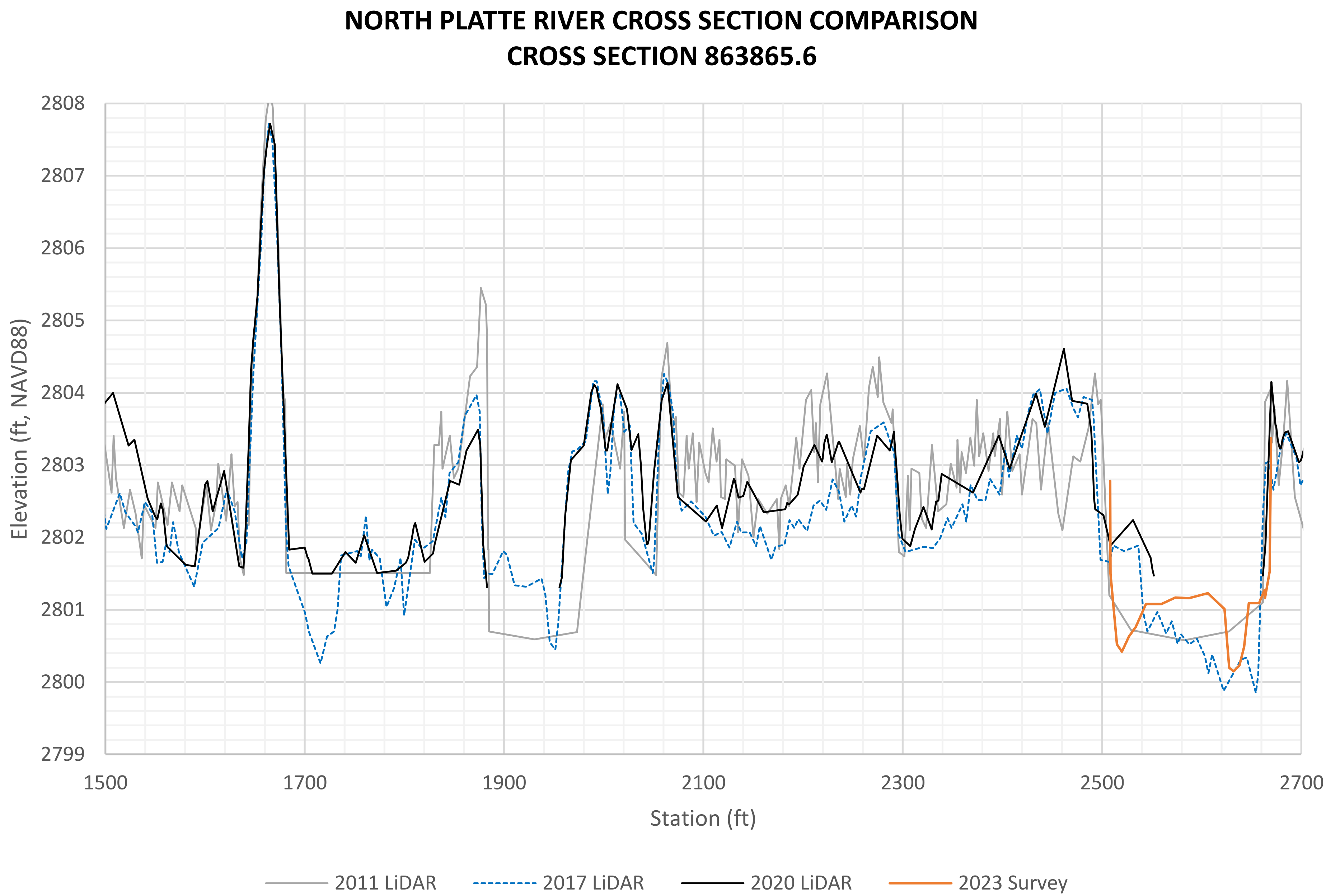



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



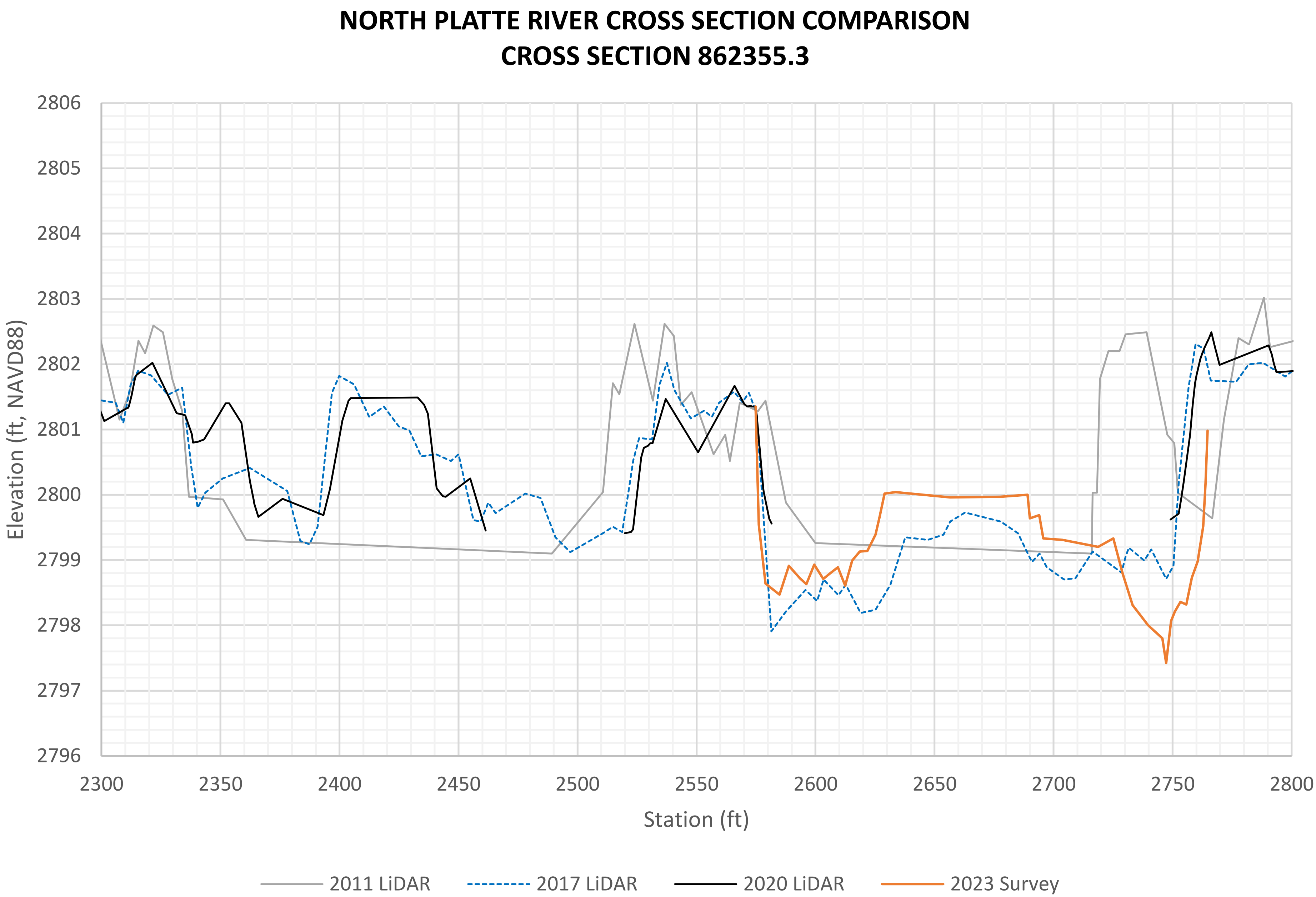



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



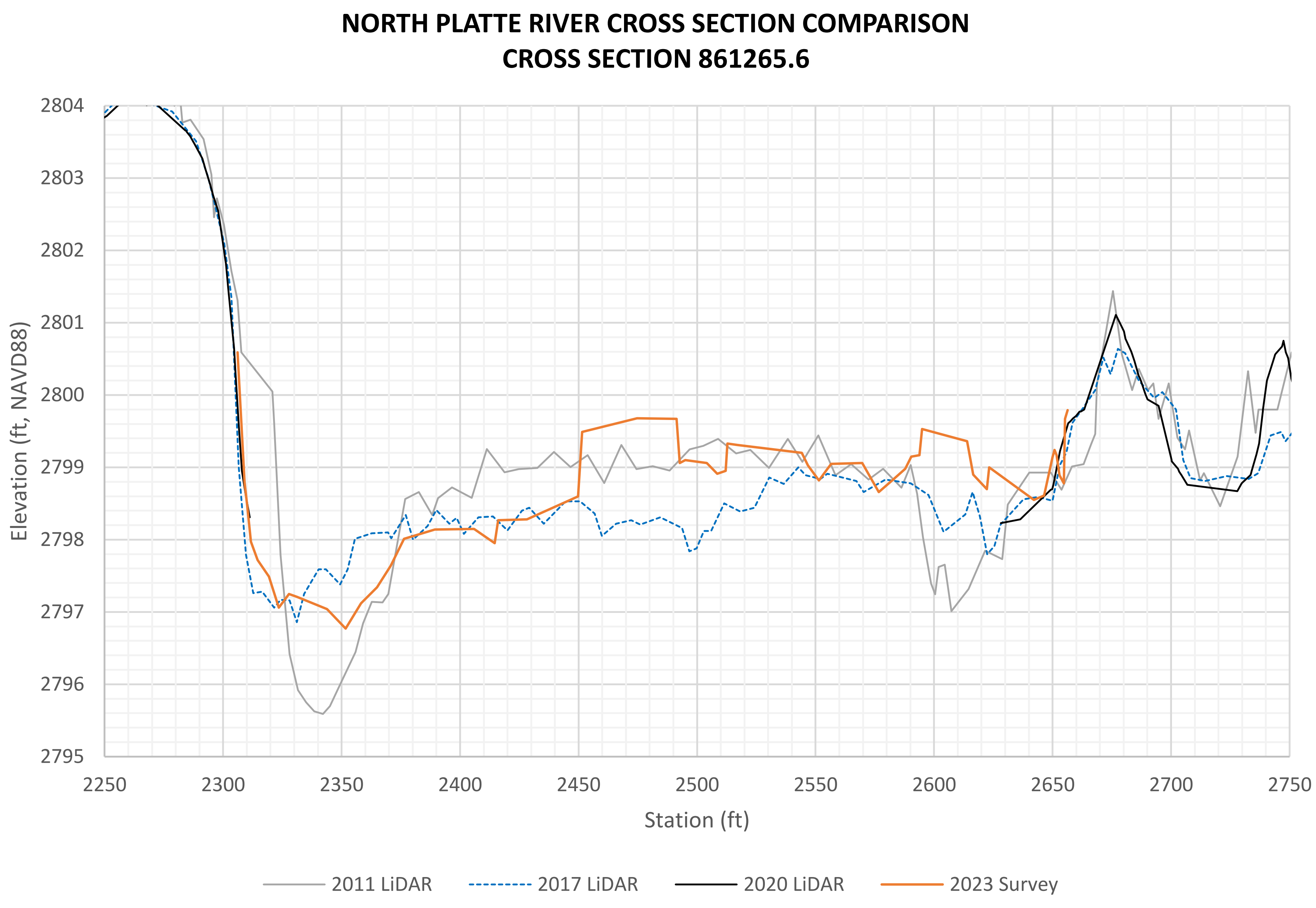



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



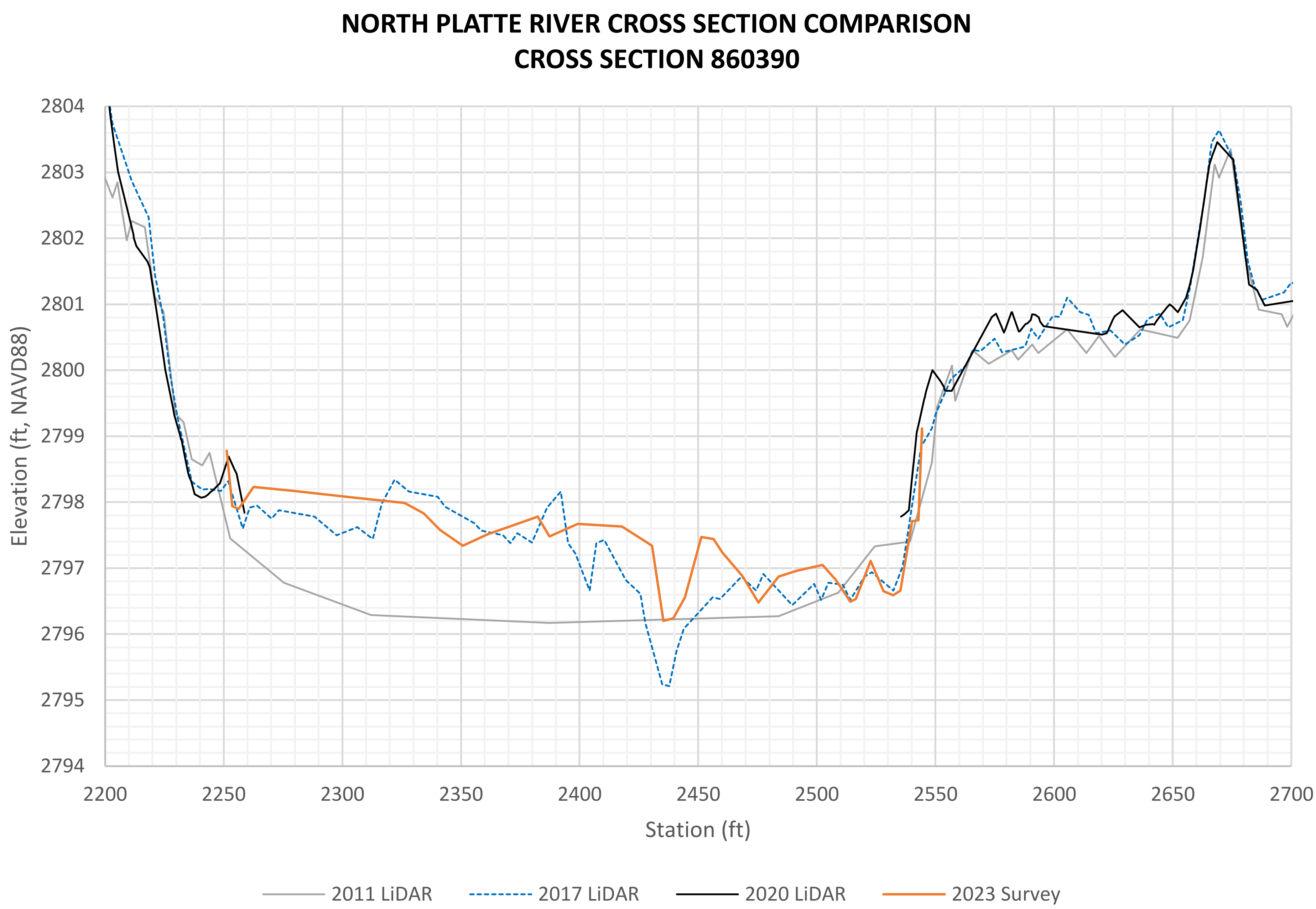



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





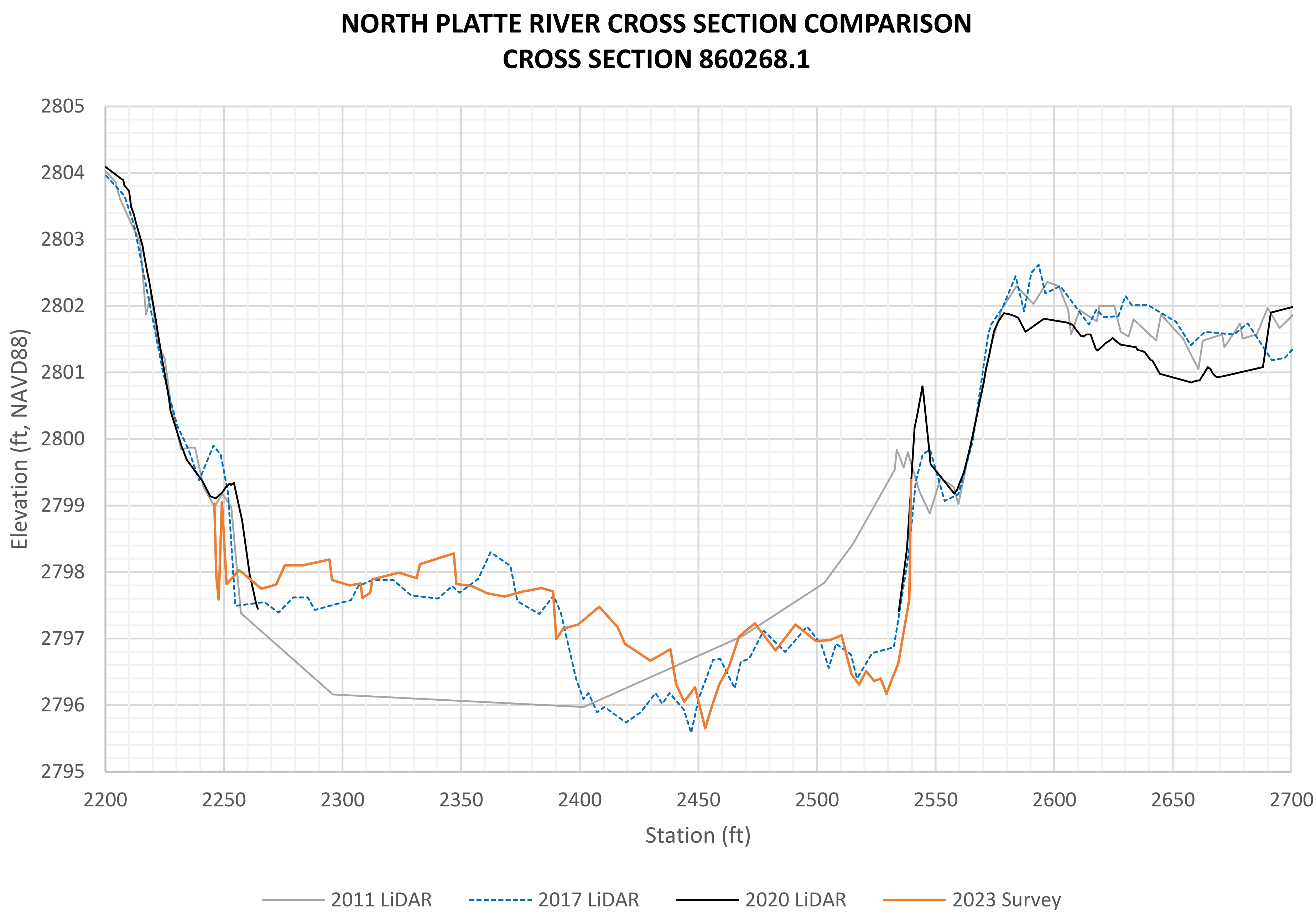

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions




Upstream Face of HWY 83 Bridge



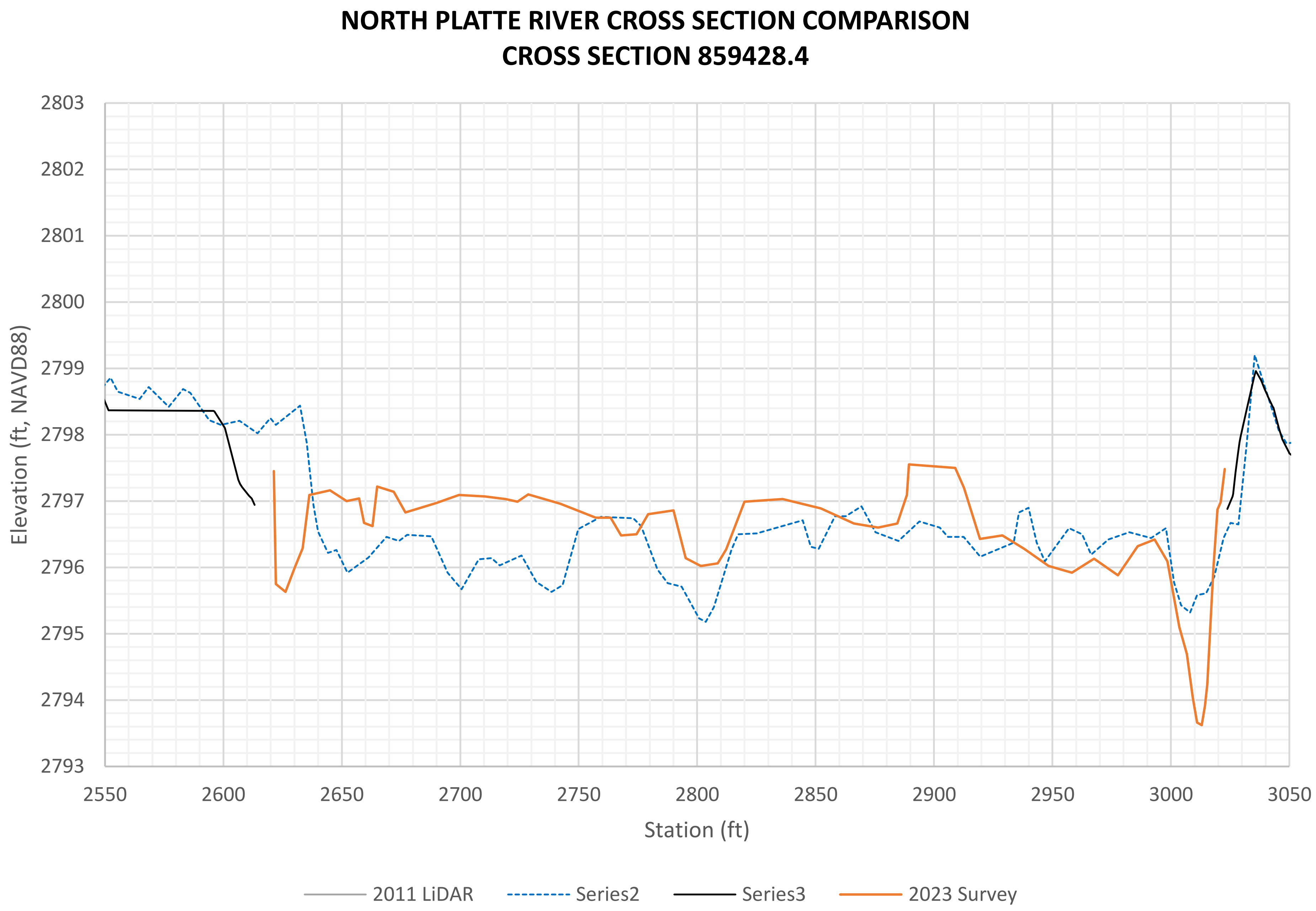
Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions




Downstream Face of HWY 83 Bridge – NWS Gage Location

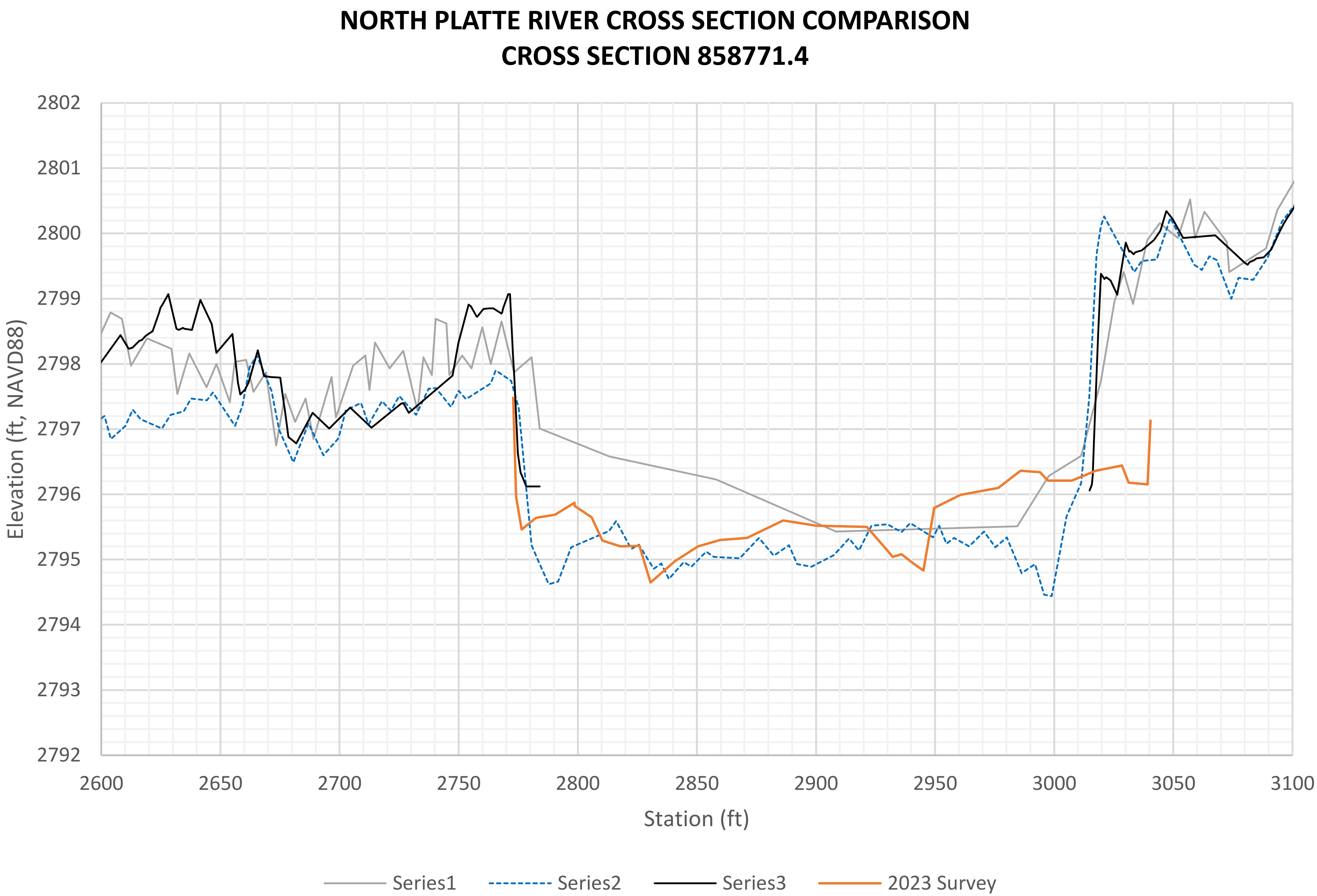


Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



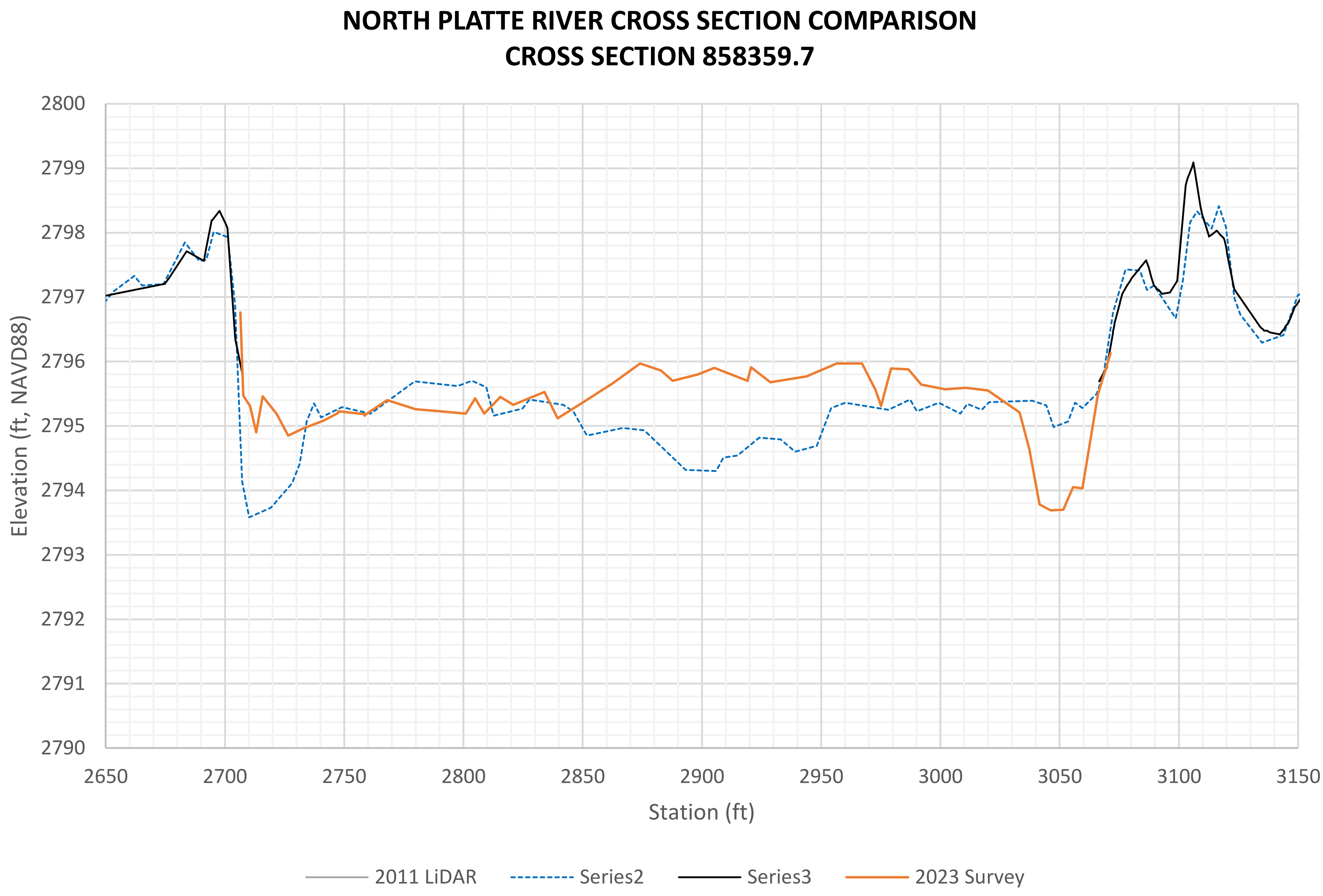



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



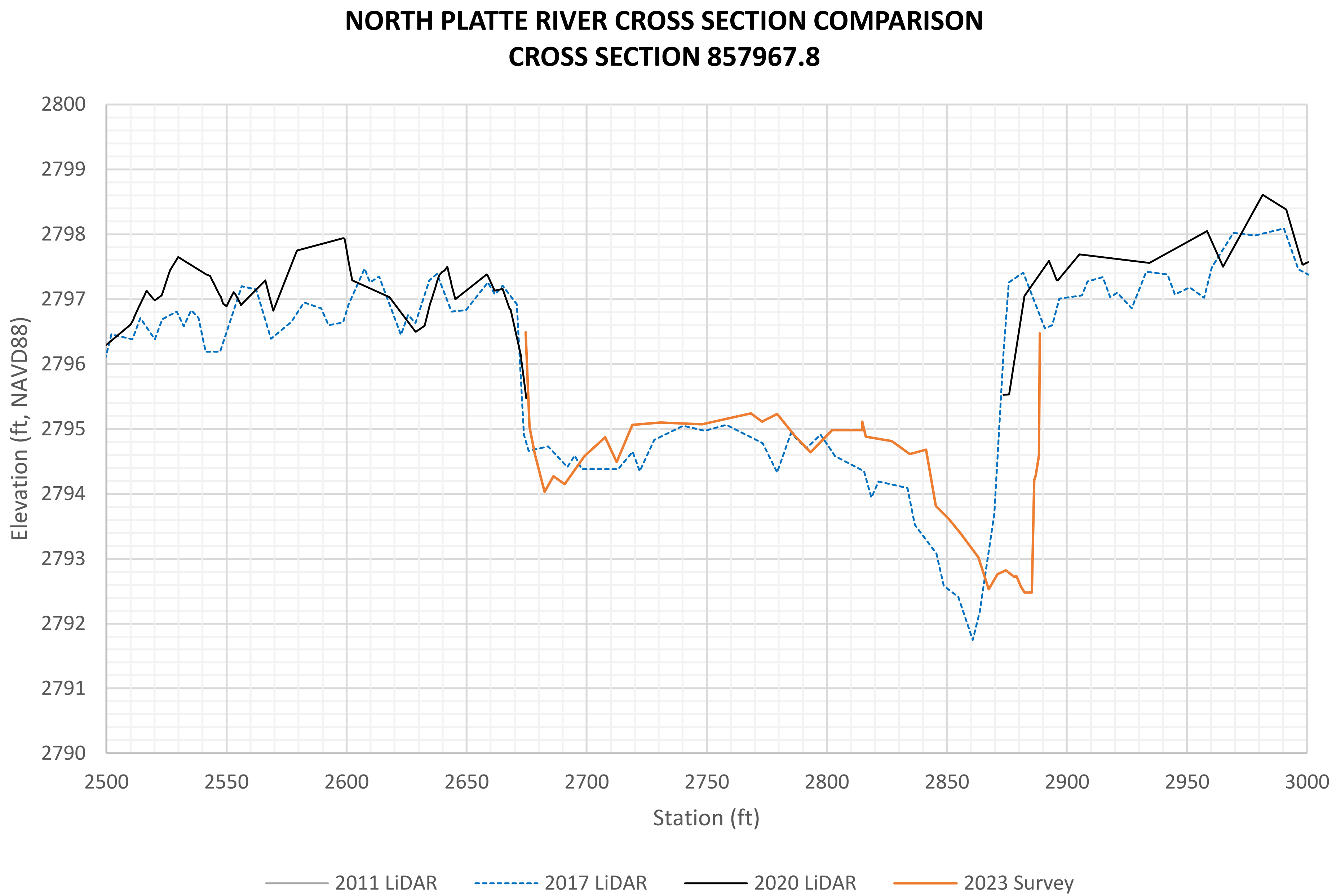



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





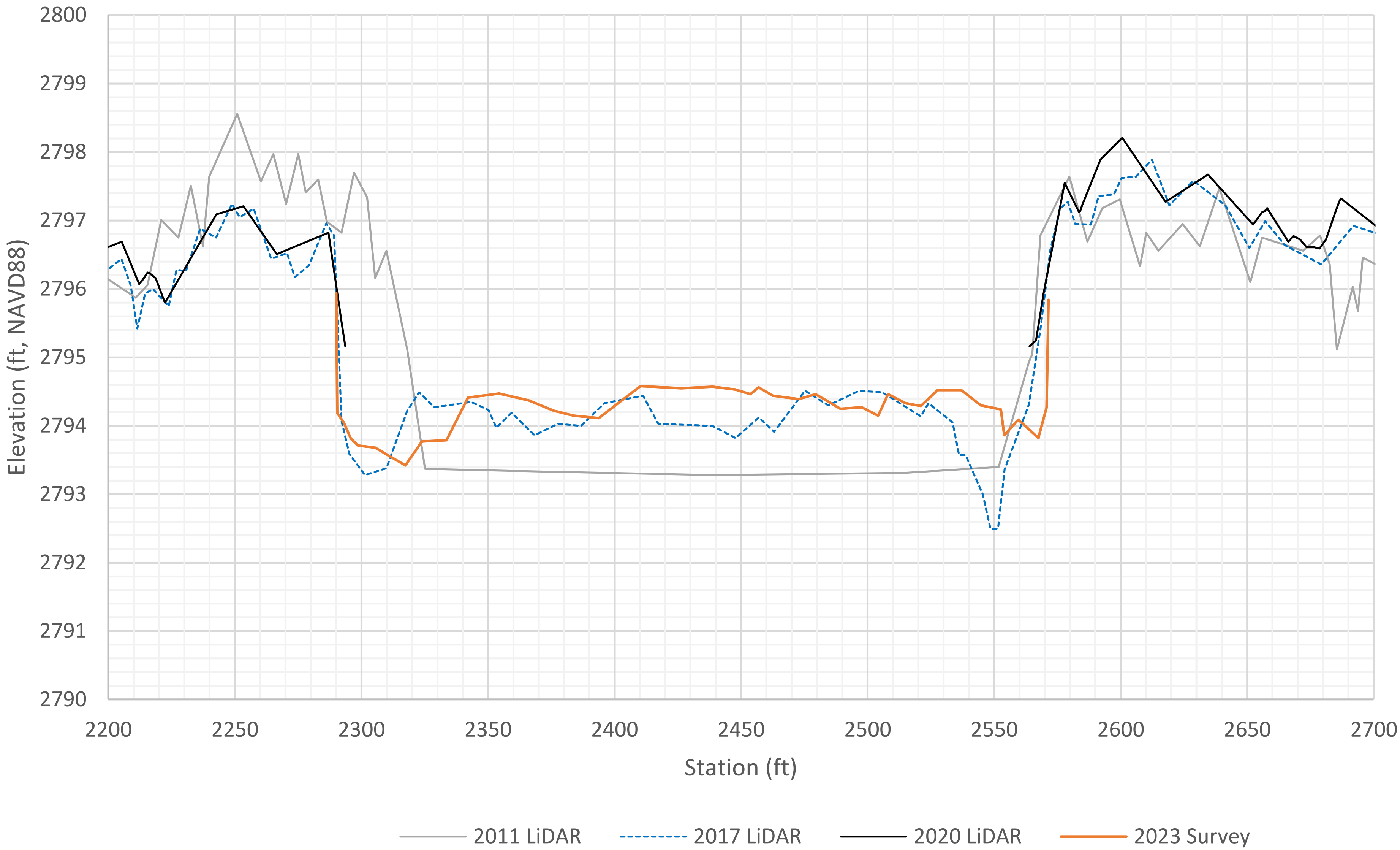

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





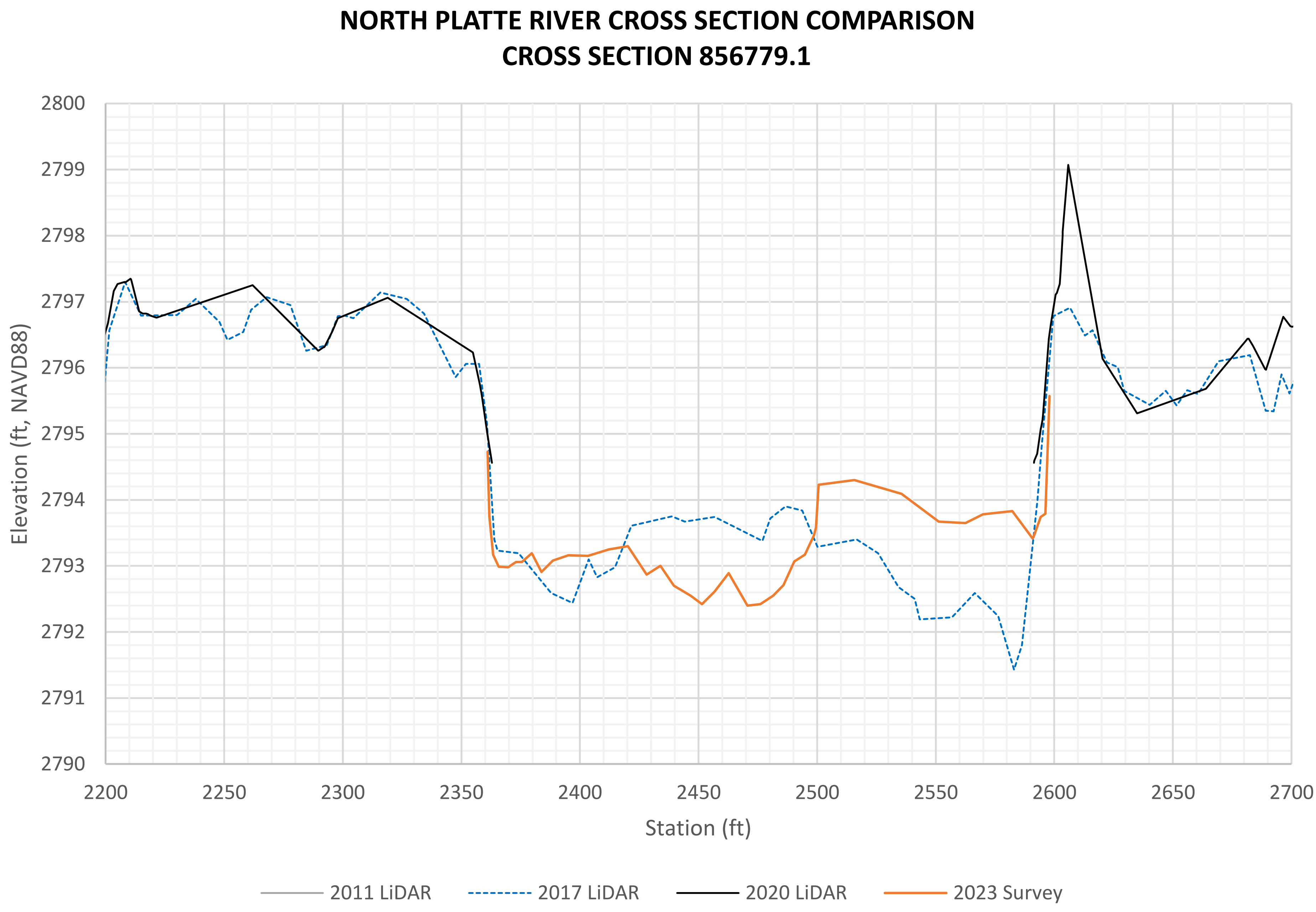

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

## NORTH PLATTE RIVER CROSS SECTION COMPARISON
## CROSS SECTION 857526



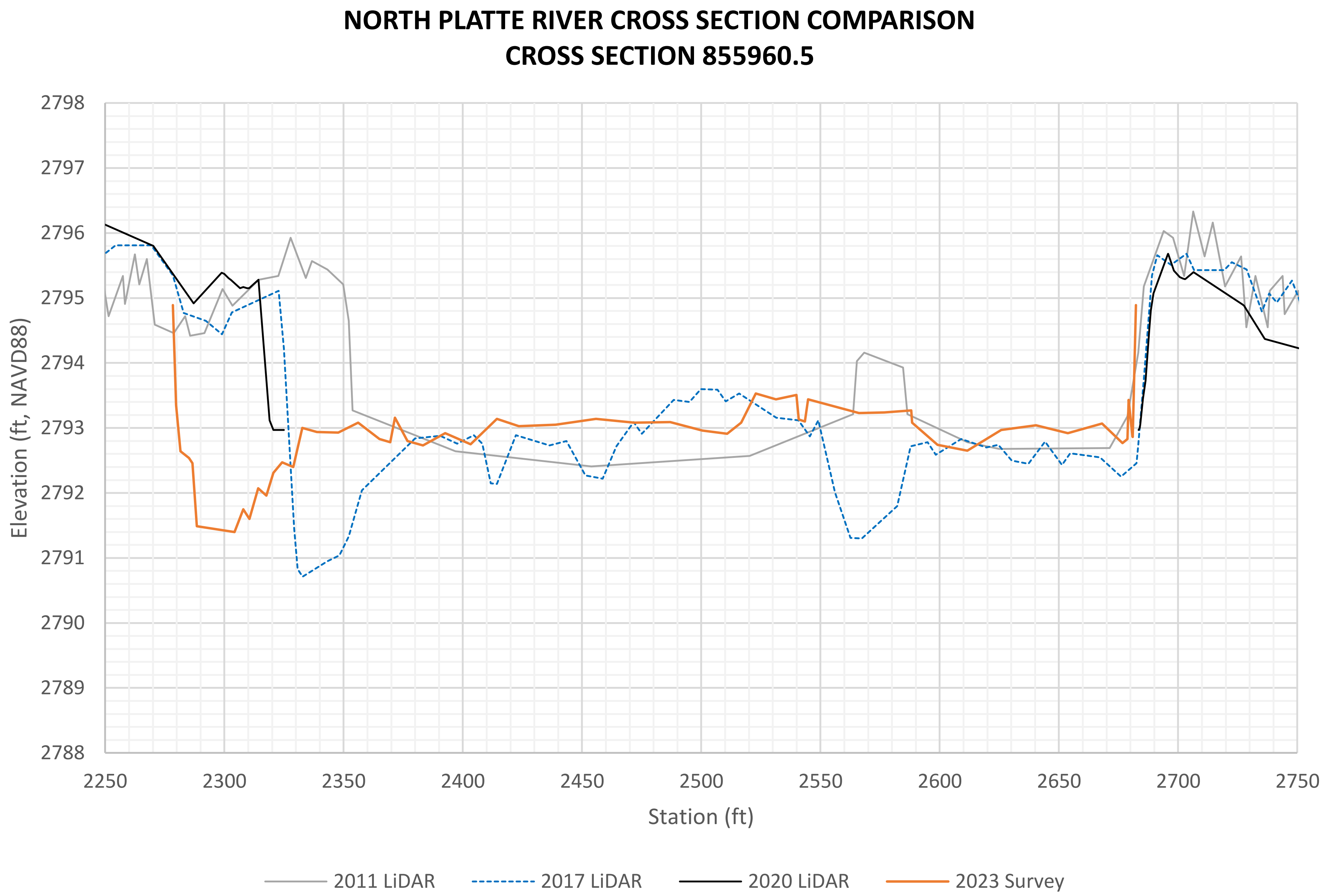



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



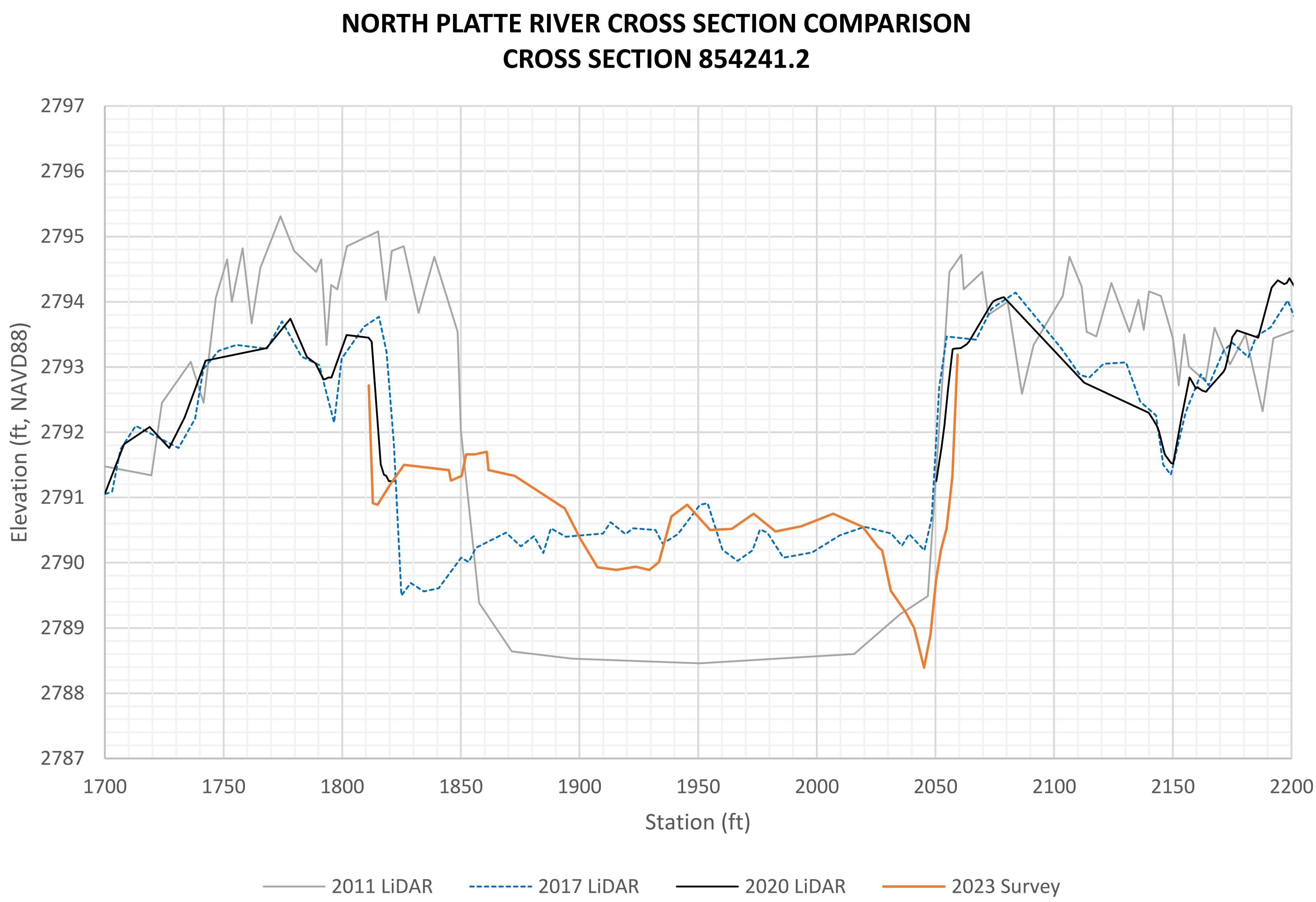


Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



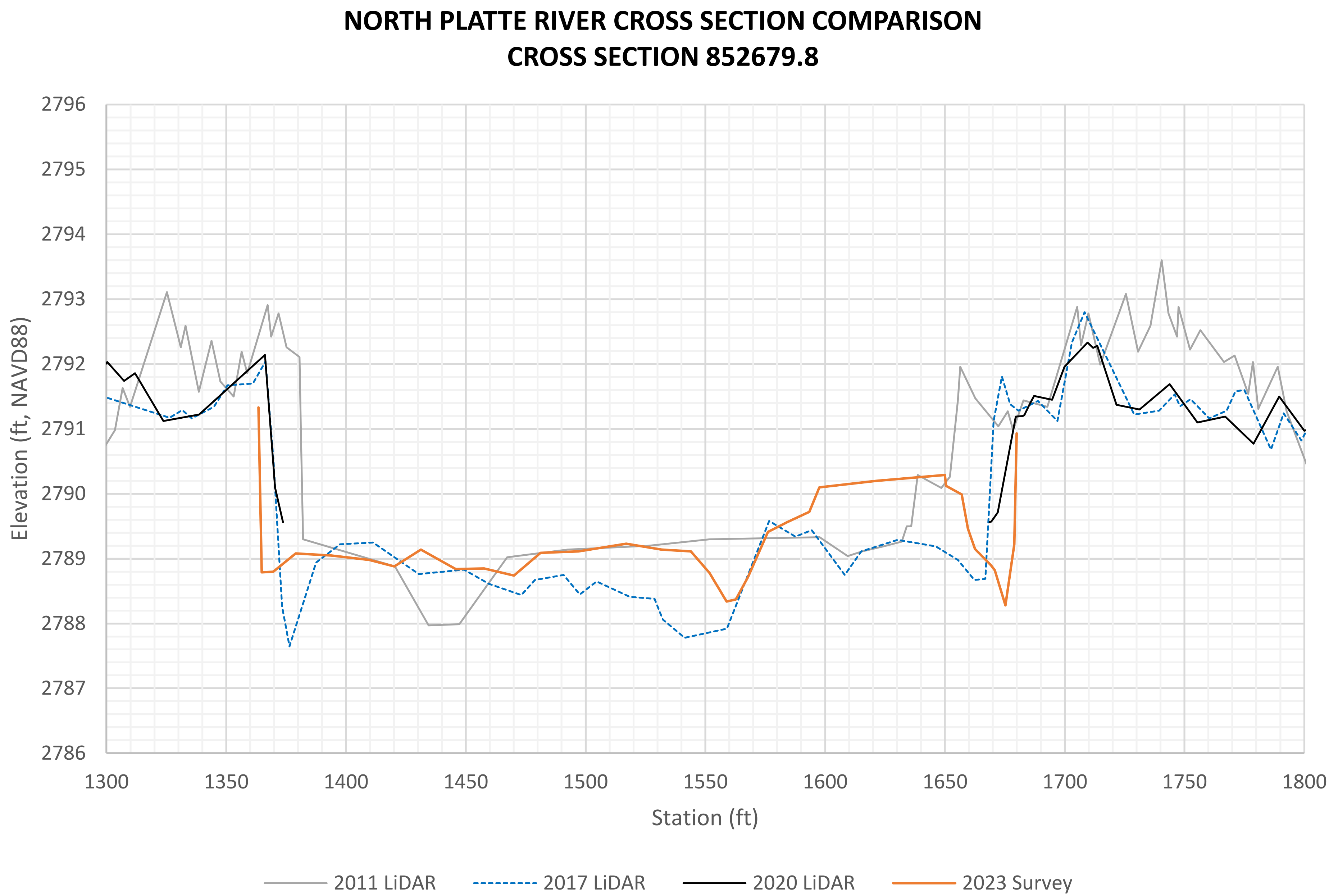



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



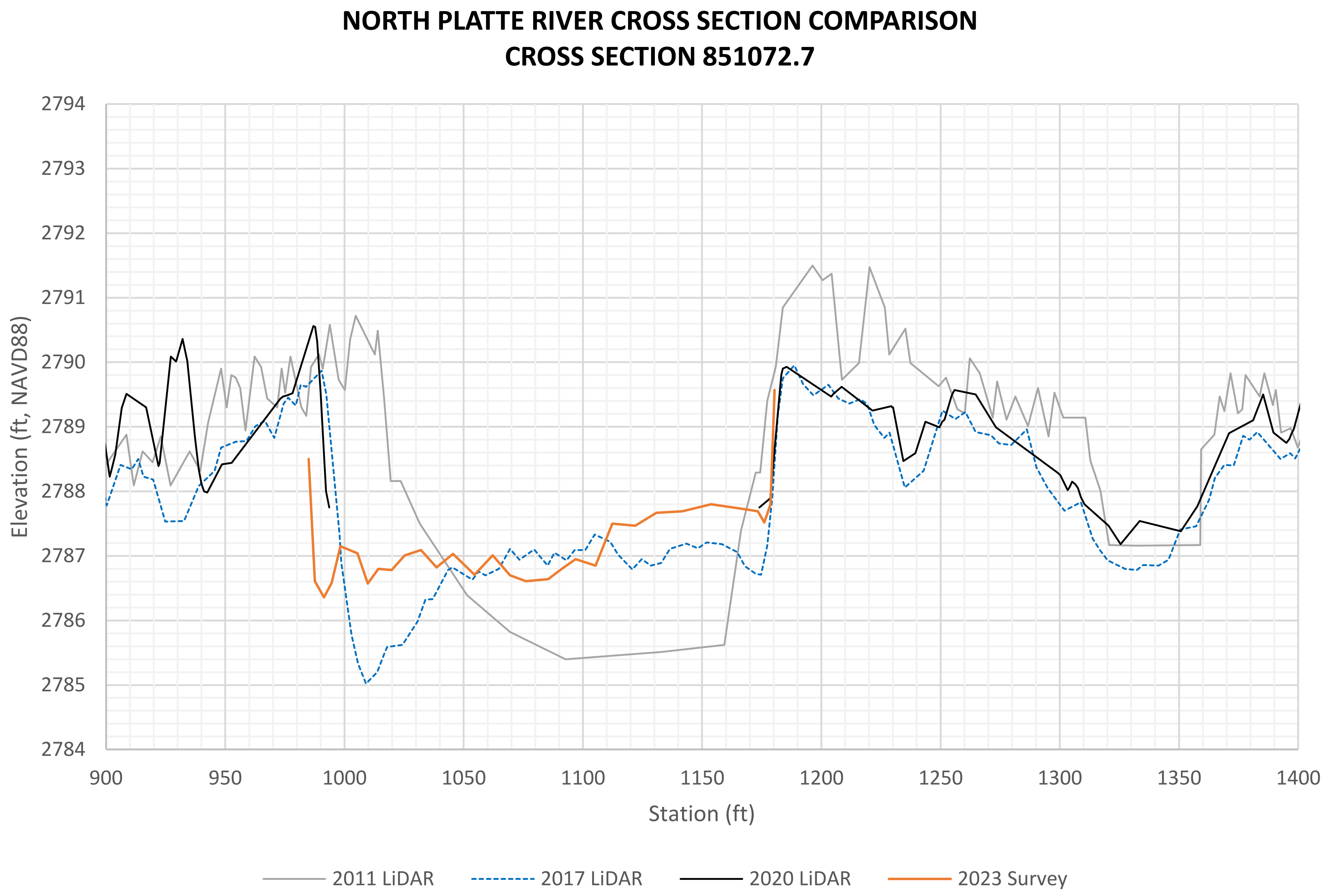



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



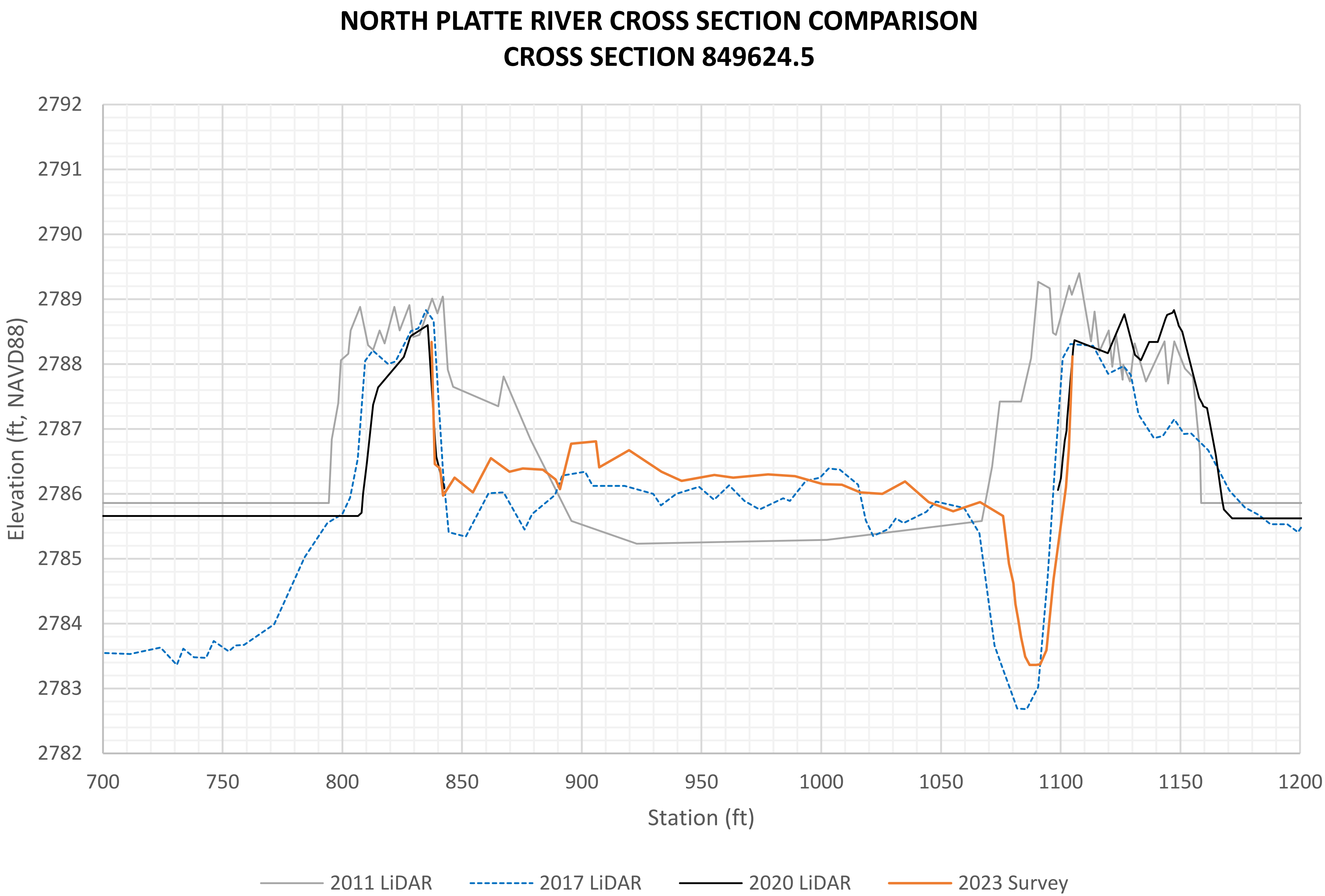



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



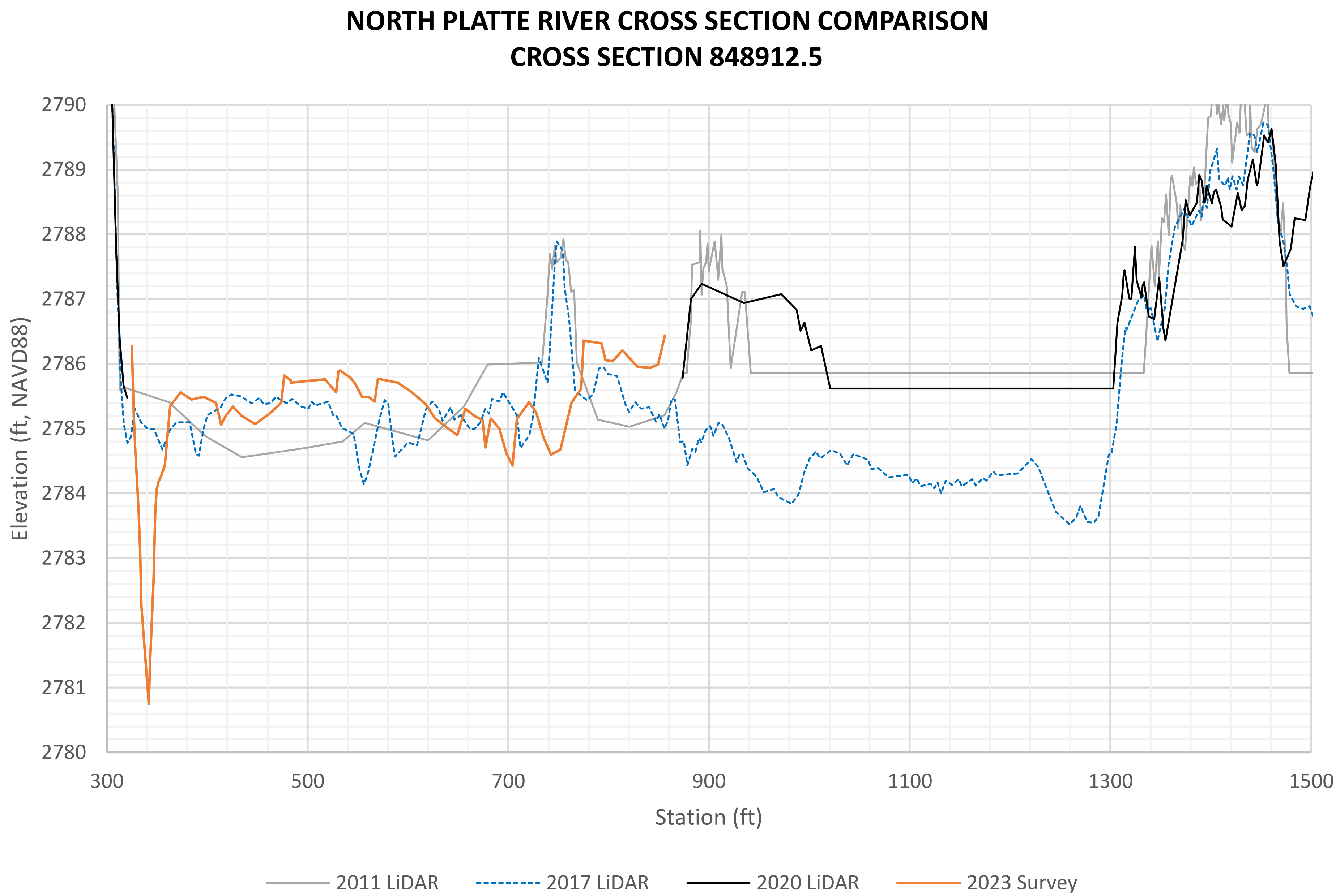



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





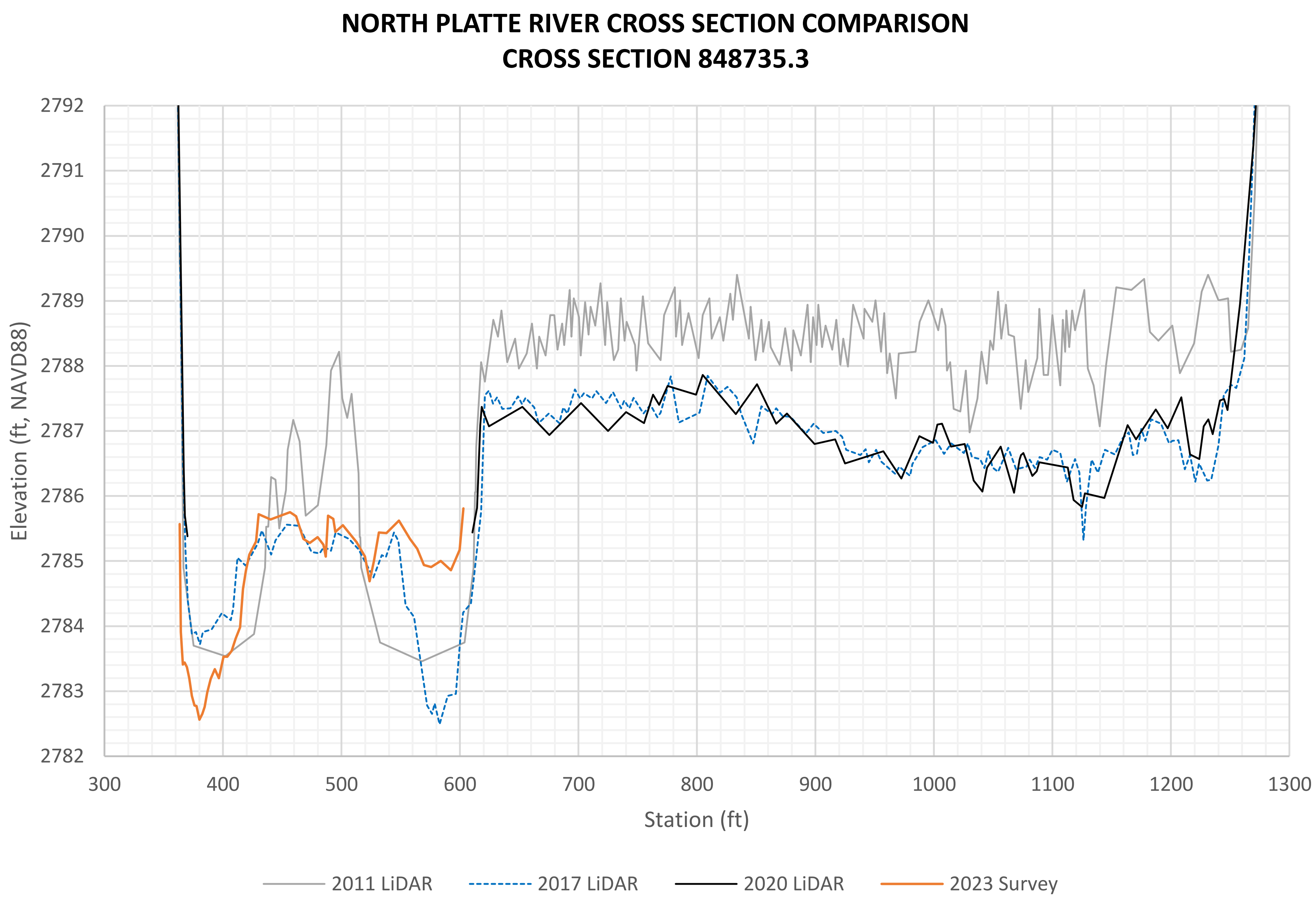

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions




Upstream Face of Railroad



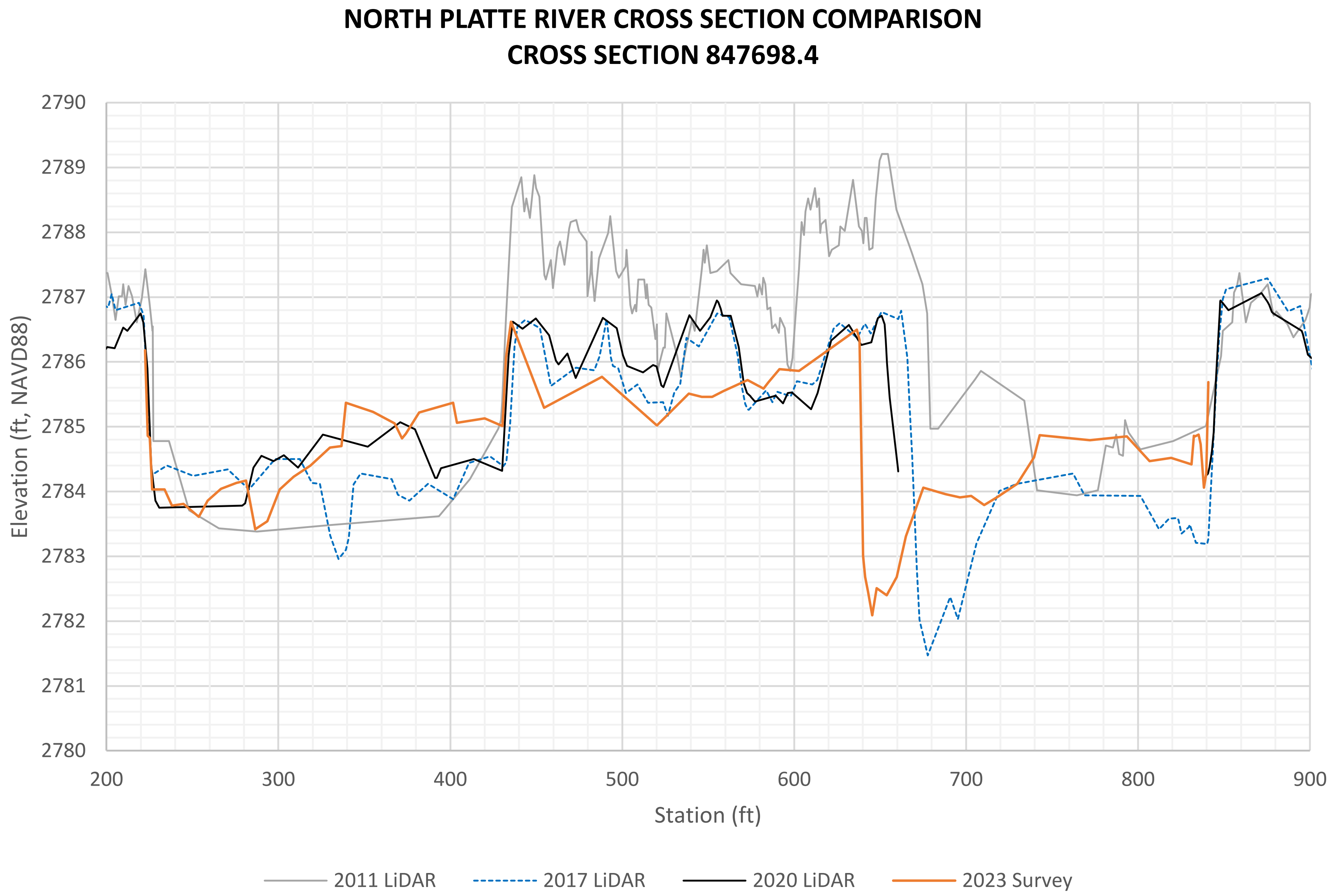
Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions




Downstream Face of Railroad



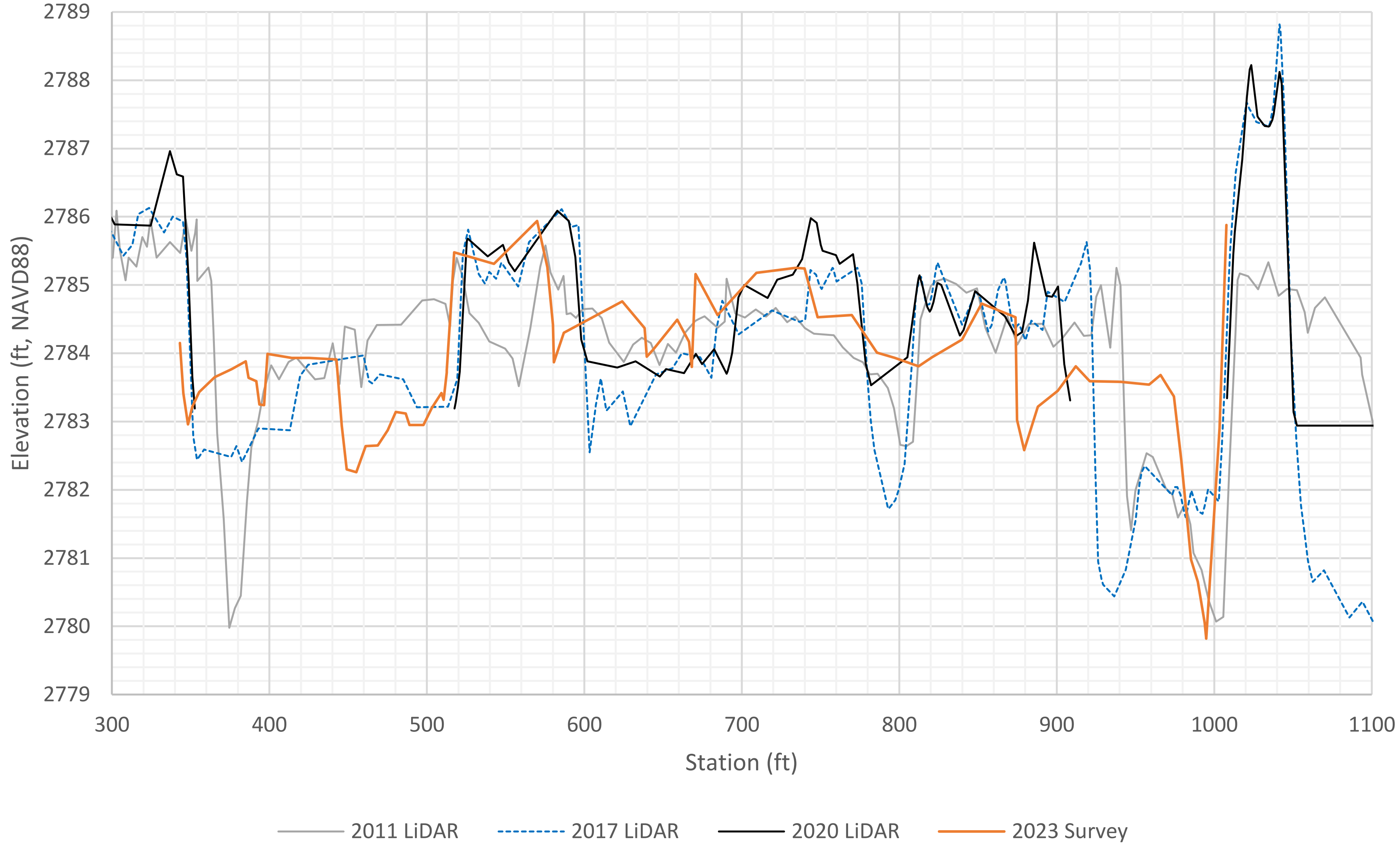
Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions





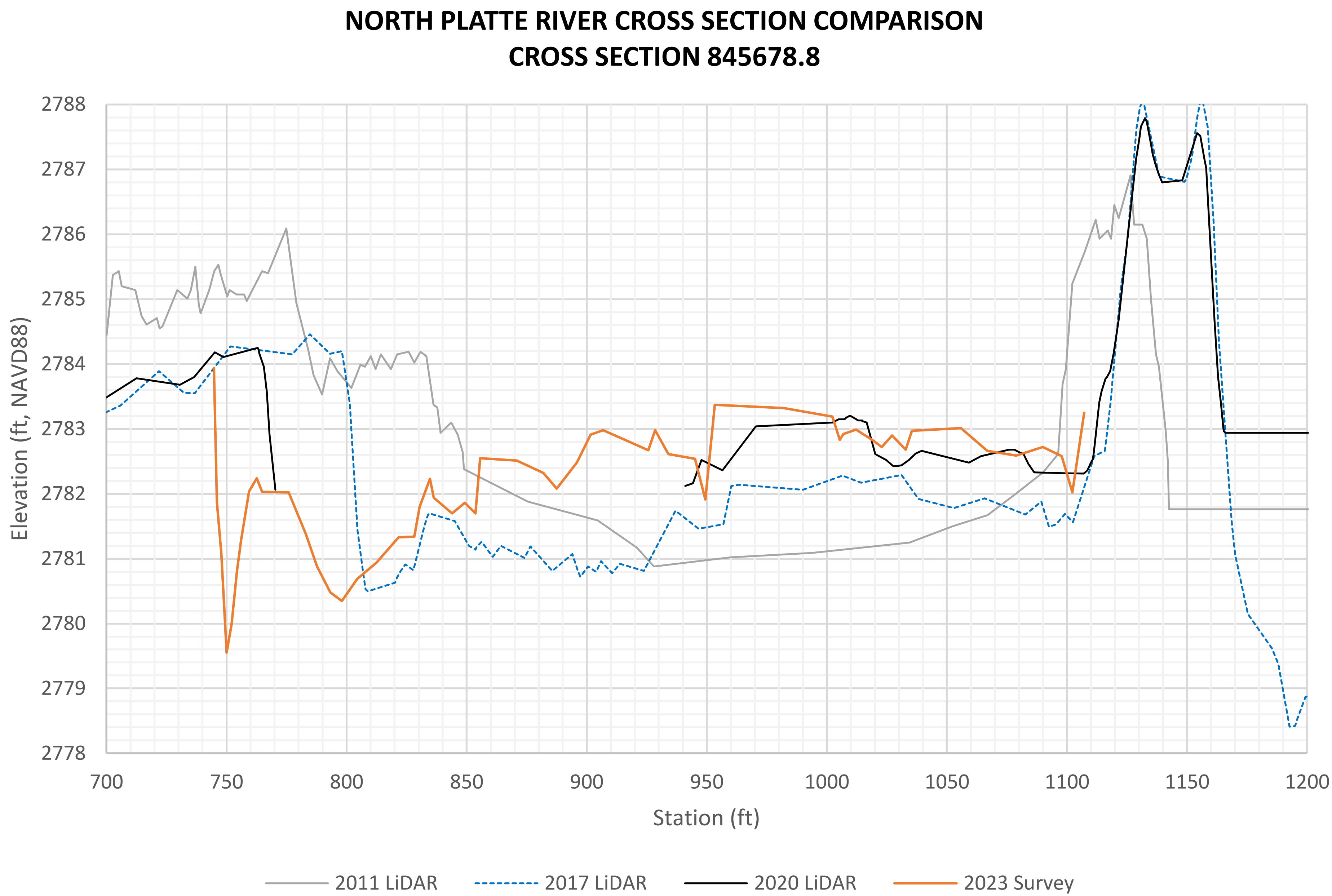

Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

NORTH PLATTE RIVER CROSS SECTION COMPARISON
CROSS SECTION 846735.3





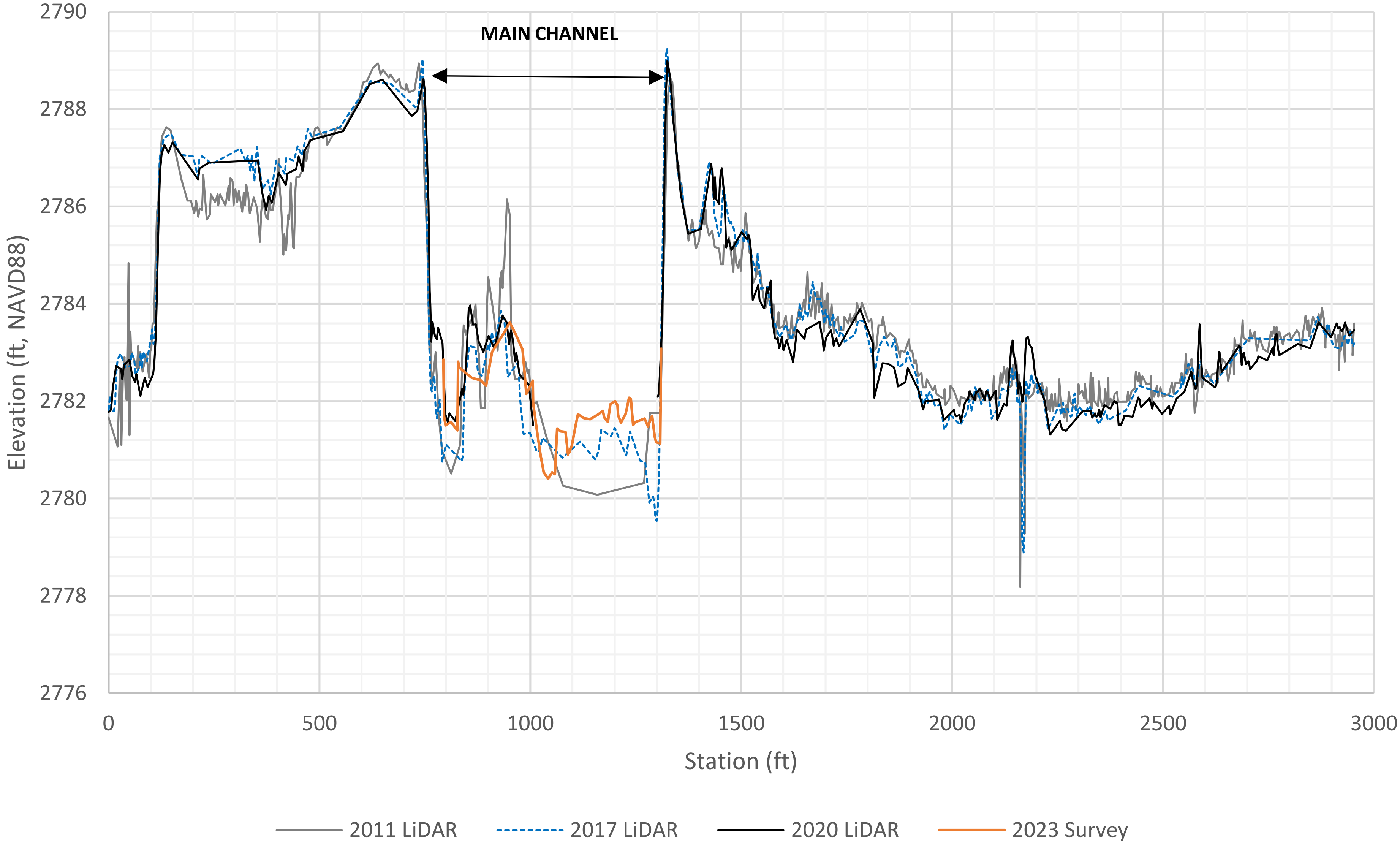
Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions






Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

# NORTH PLATTE RIVER CROSS SECTION COMPARISON
# CROSS SECTION 845009

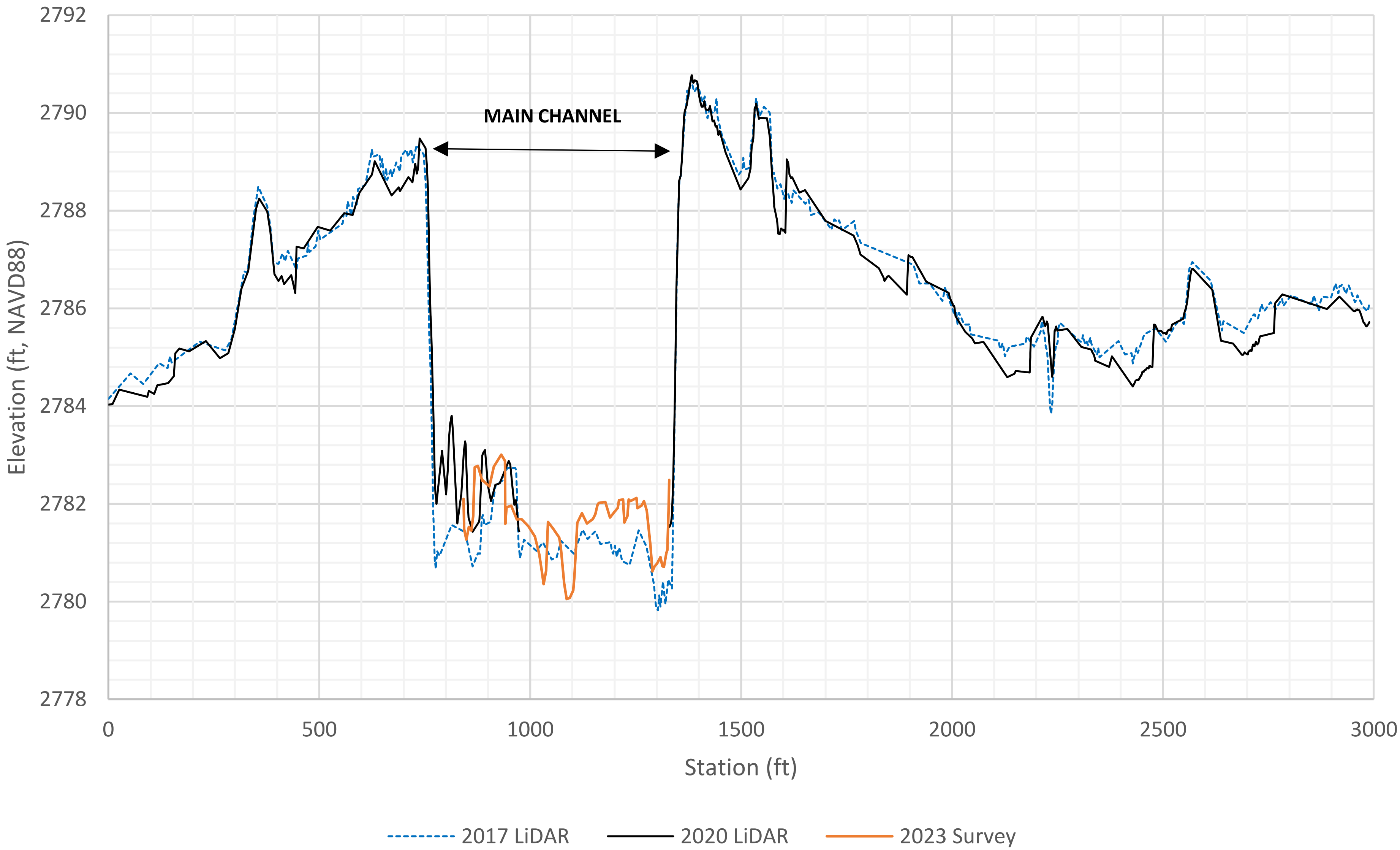



Upstream Face of HWY 30



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

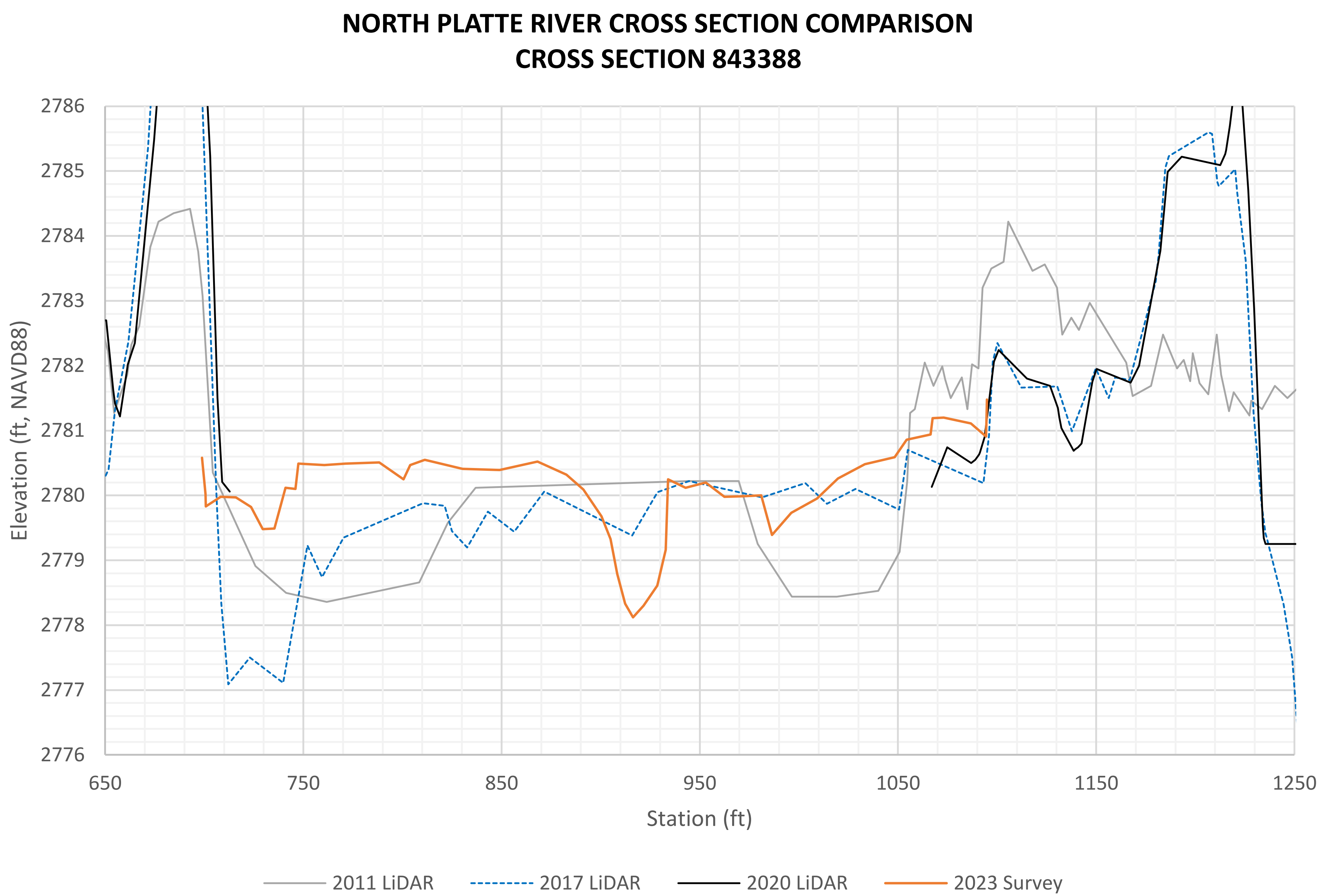
# NORTH PLATTE RIVER CROSS SECTION COMPARISON
# CROSS SECTION 844919.5




Downstream Face of HWY 30

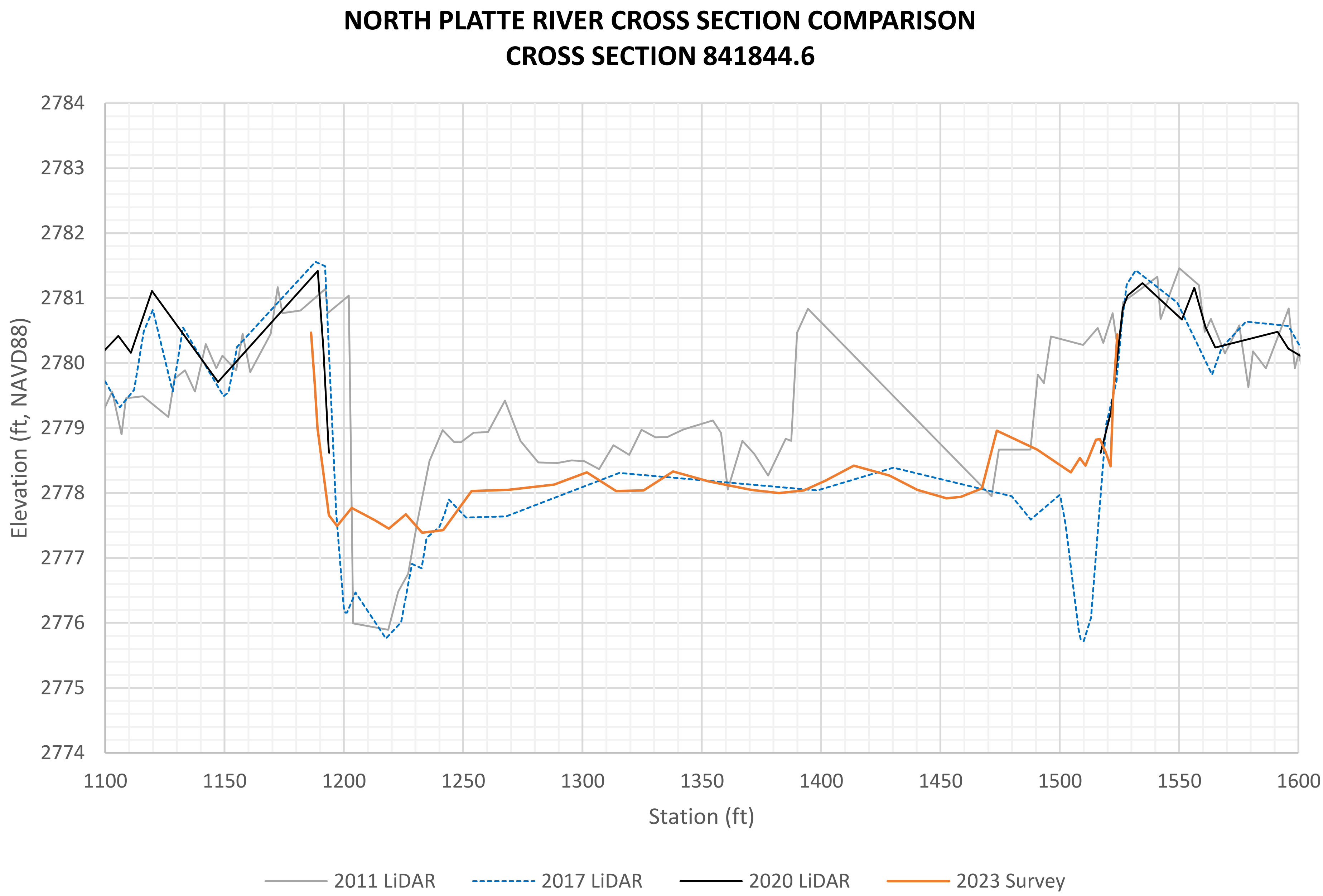


Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



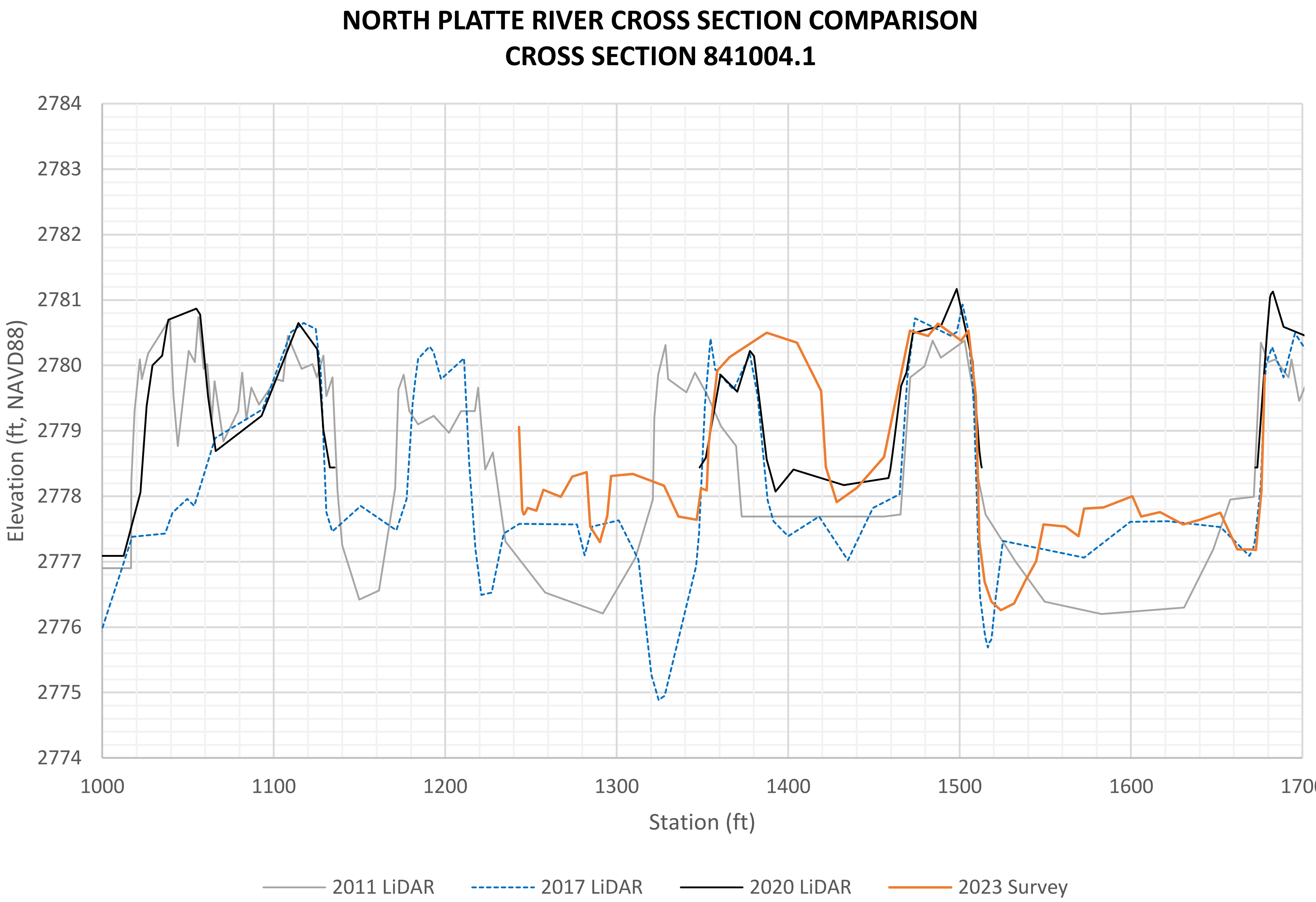



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



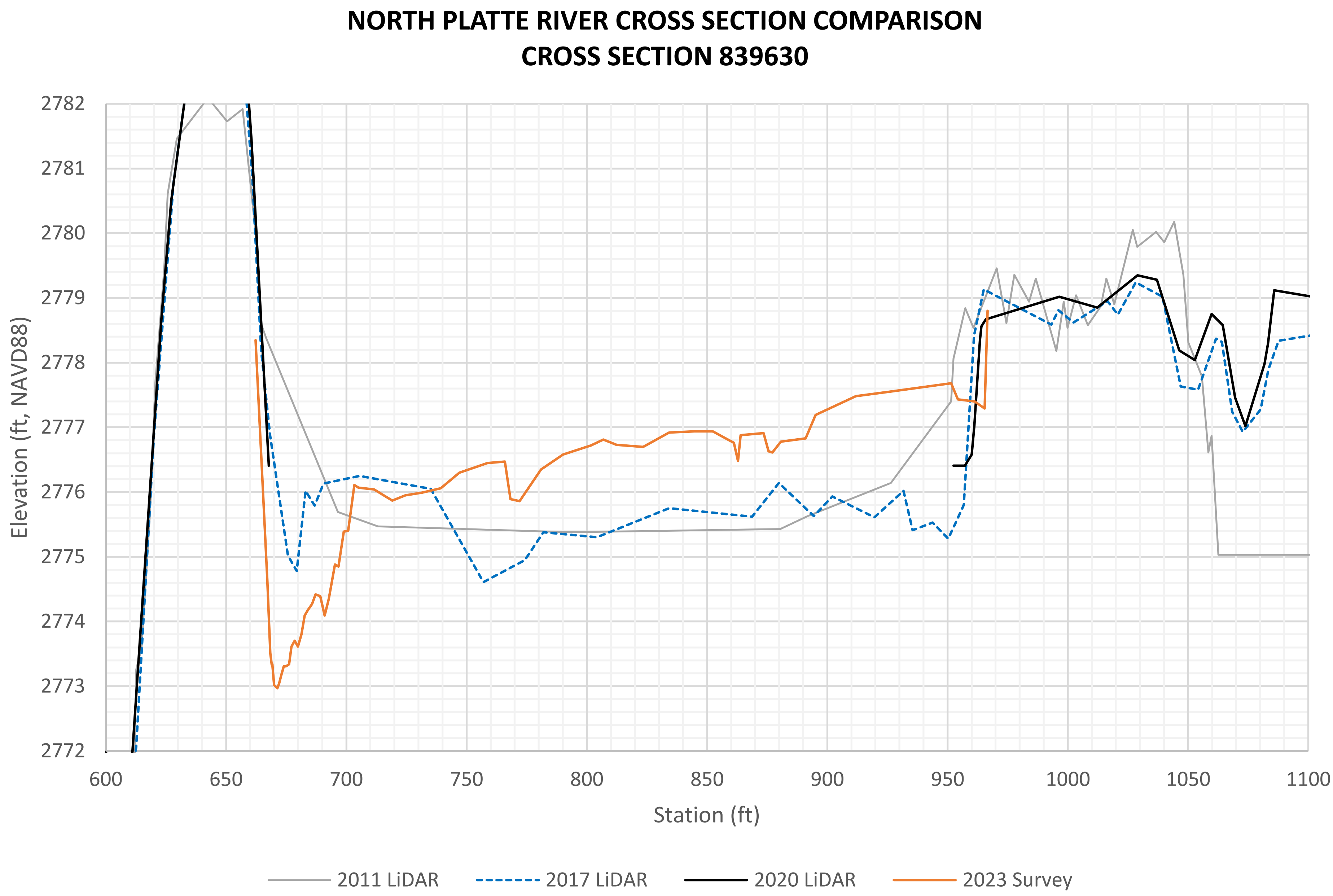


Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



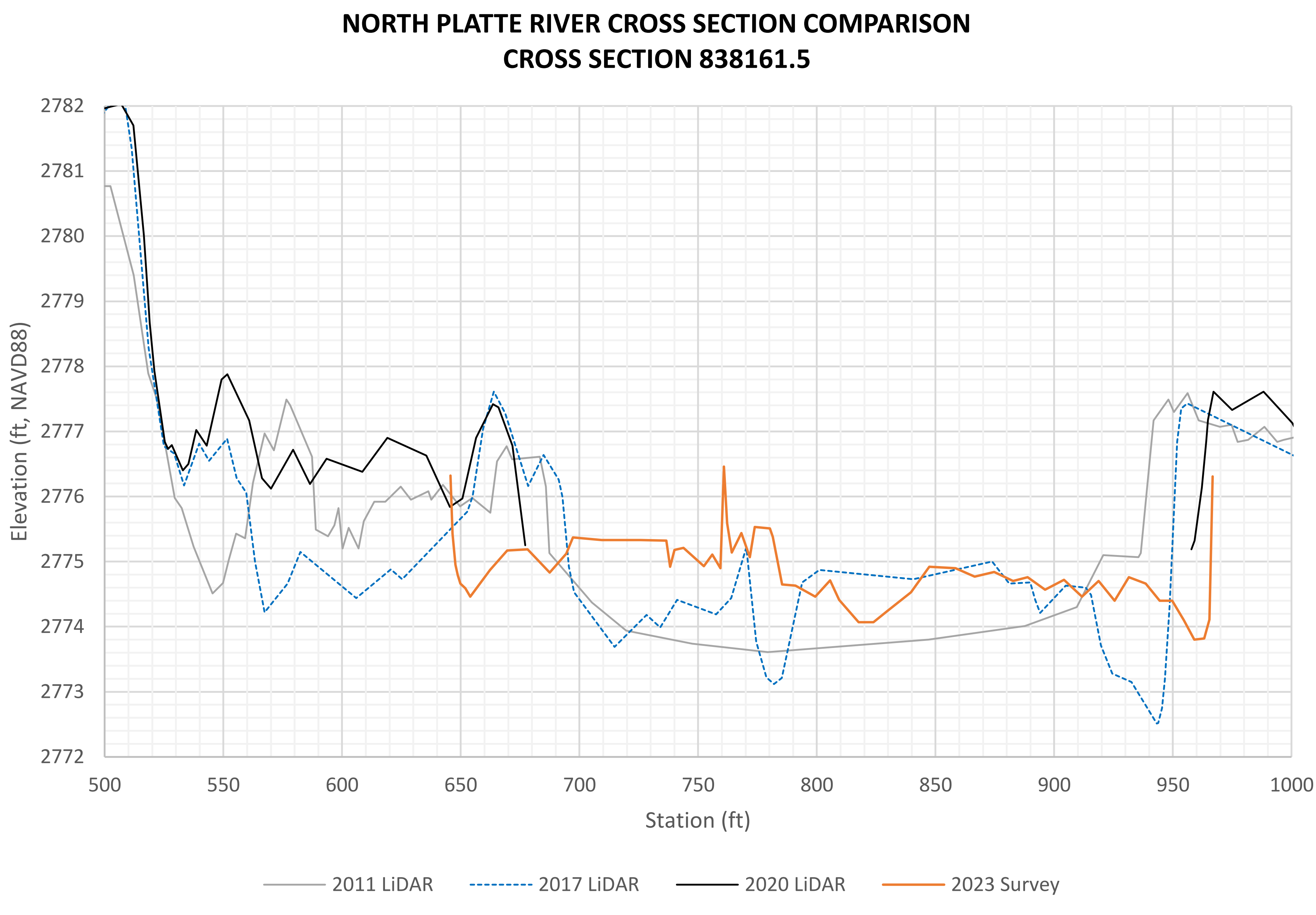



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



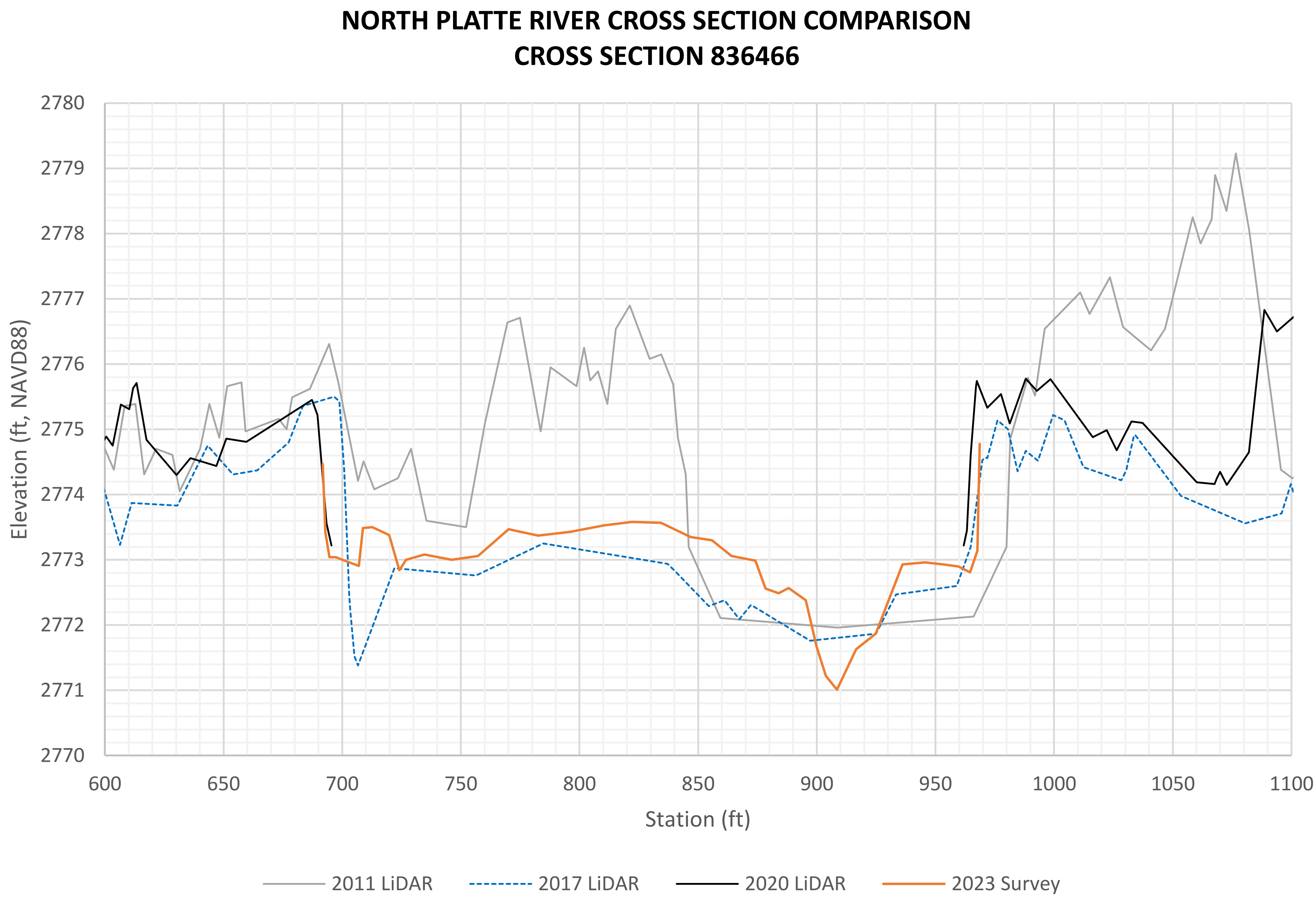



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions



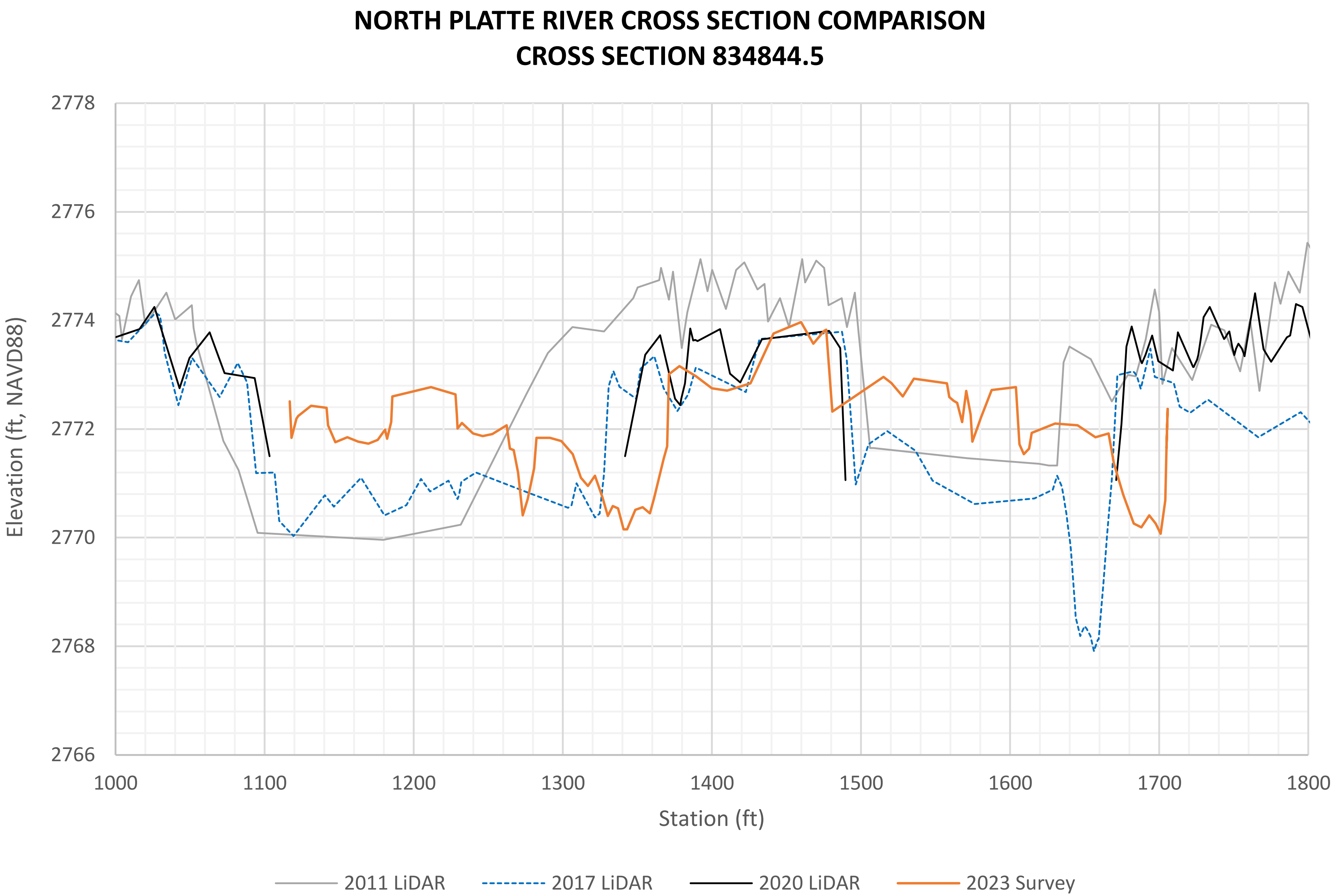



Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions






Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions






Note: 2011 refers to 2011 HDR/Tetra Tech Model representing 2009 Conditions

# APPENDIX E. HYDRAULICS


**Figure E-1 Inundation Mapping 400 cfs – Reaches 1 and 2**


**Figure E-2 Inundation Mapping 400 cfs – Campground to Cody Park**

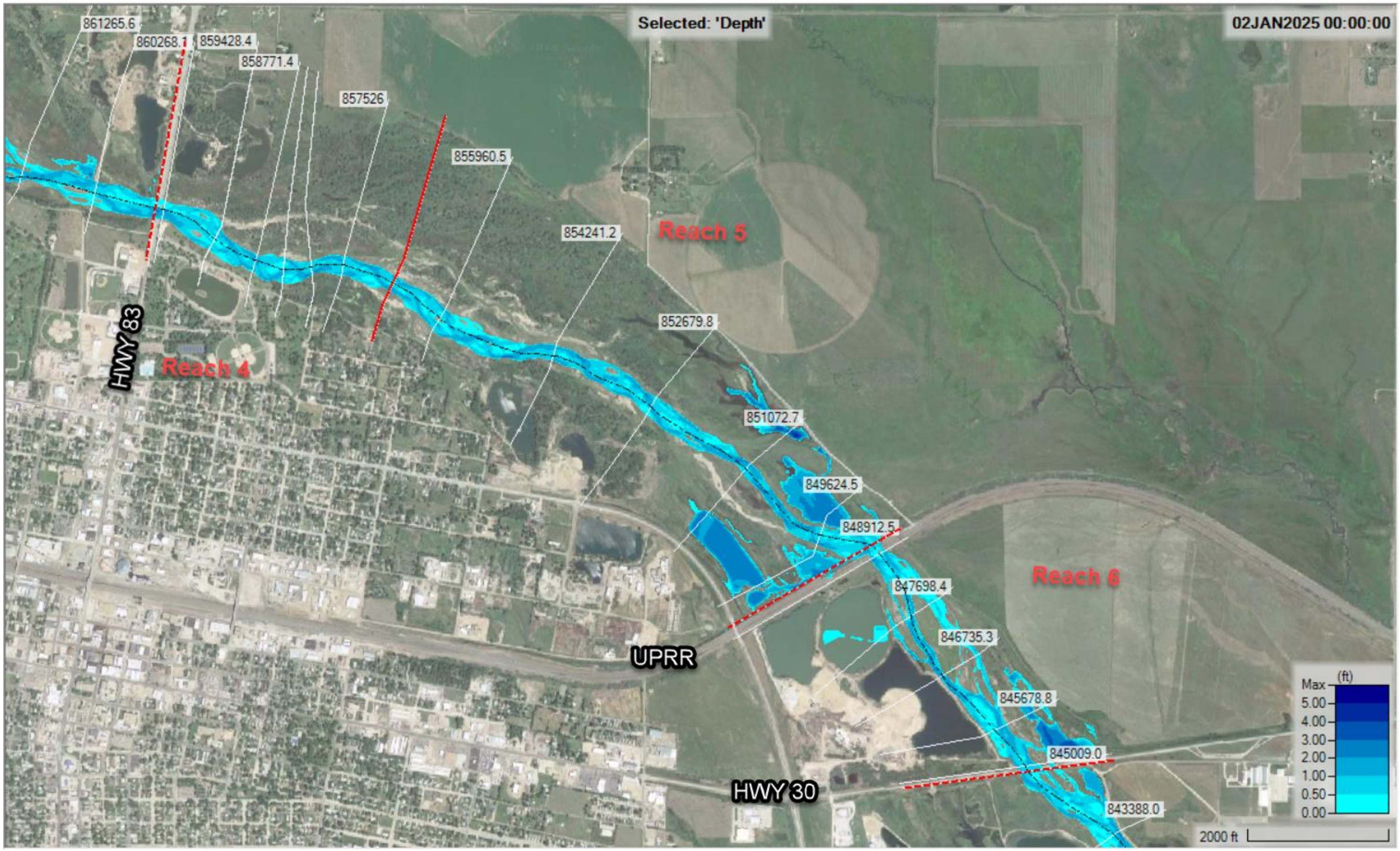



**Figure E-3 Inundation Mapping 400 cfs – HWY 83 to HWY 30**


**Figure E-4 Inundation Mapping 400 cfs – HWY 30 to Tri-County Diversion**

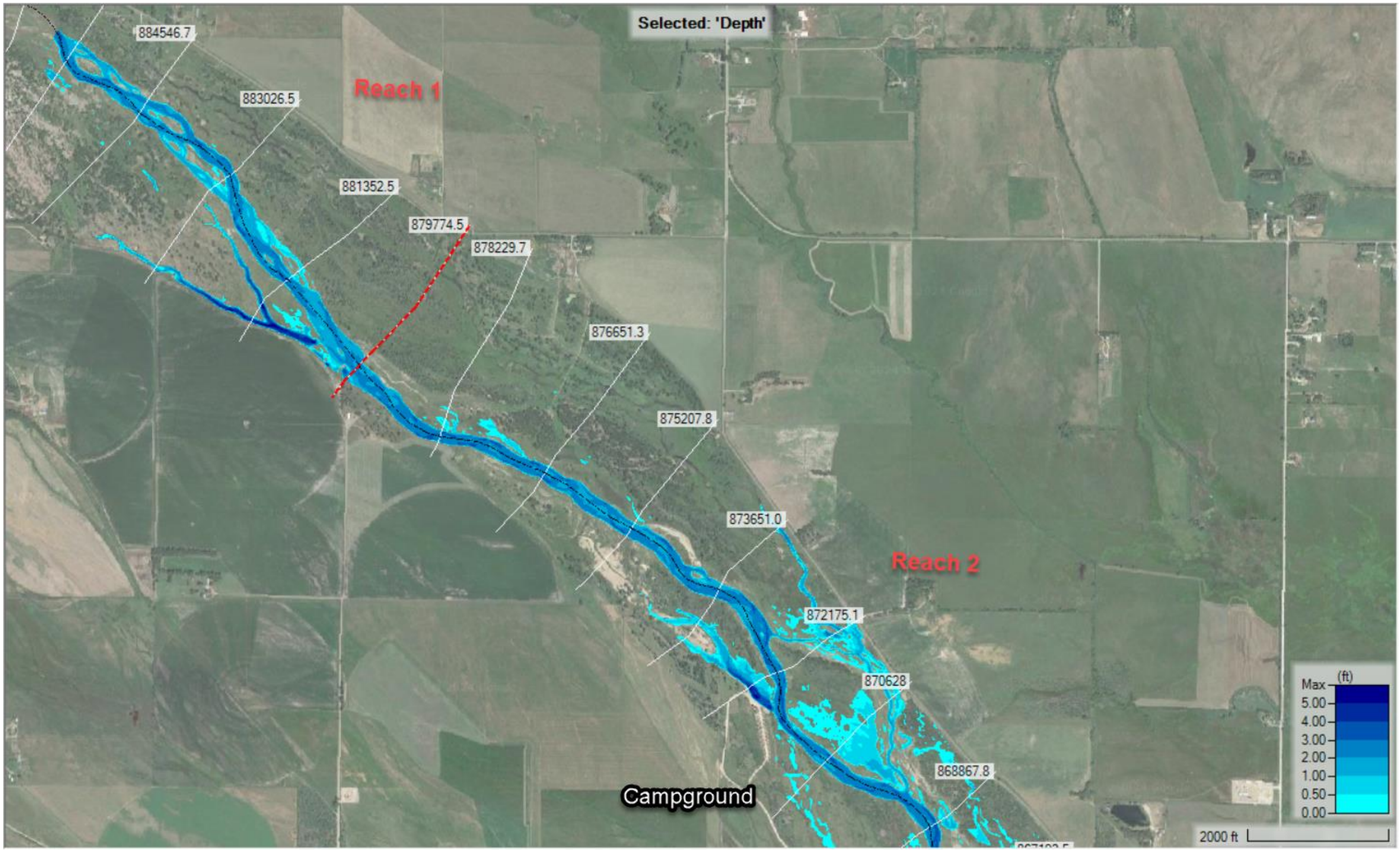



**Figure E-5 Inundation Mapping 1,500 cfs – Reaches 1 and 2**

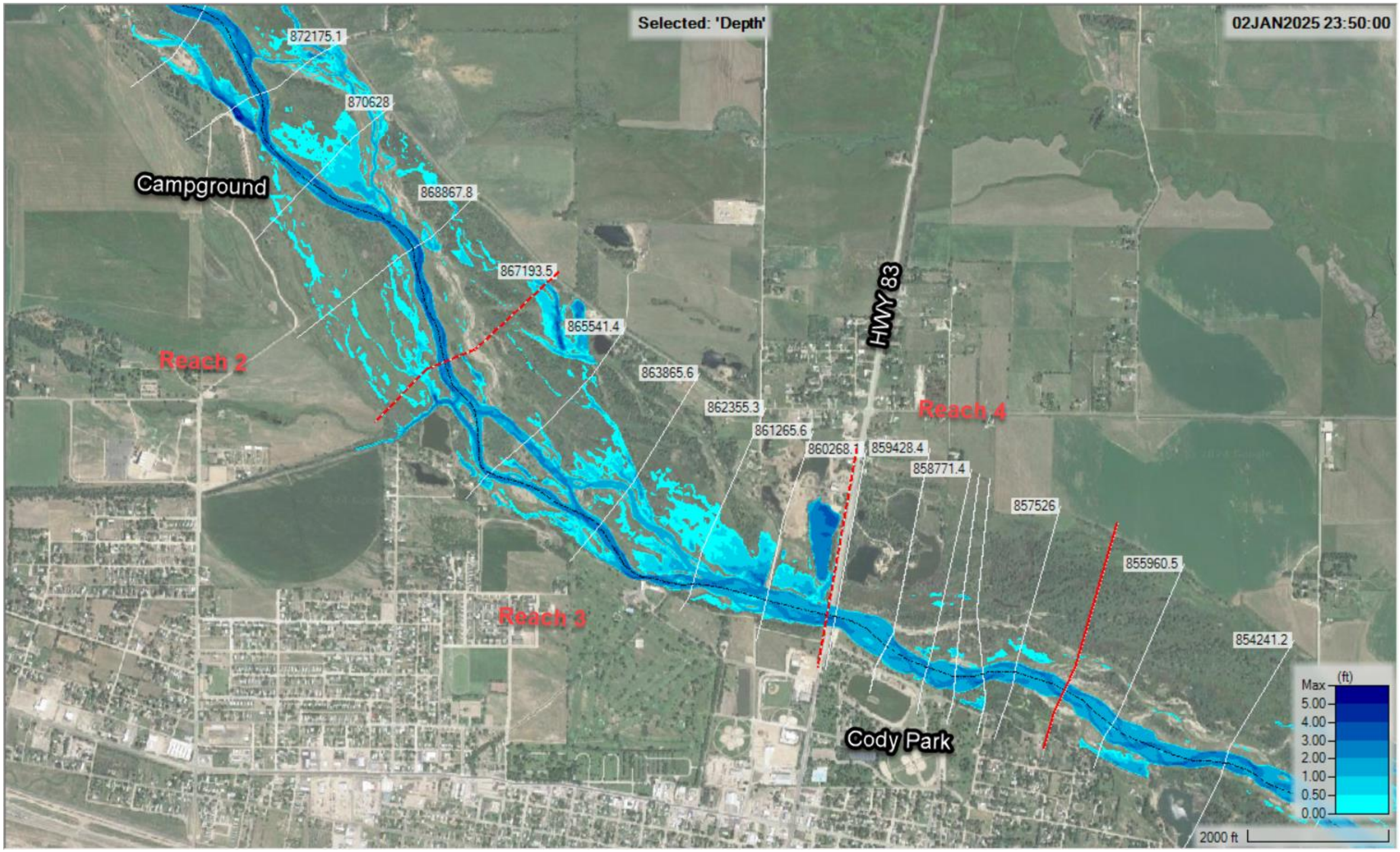



Figure E-6 Inundation Mapping 1,500 cfs – Campground to Cody Park

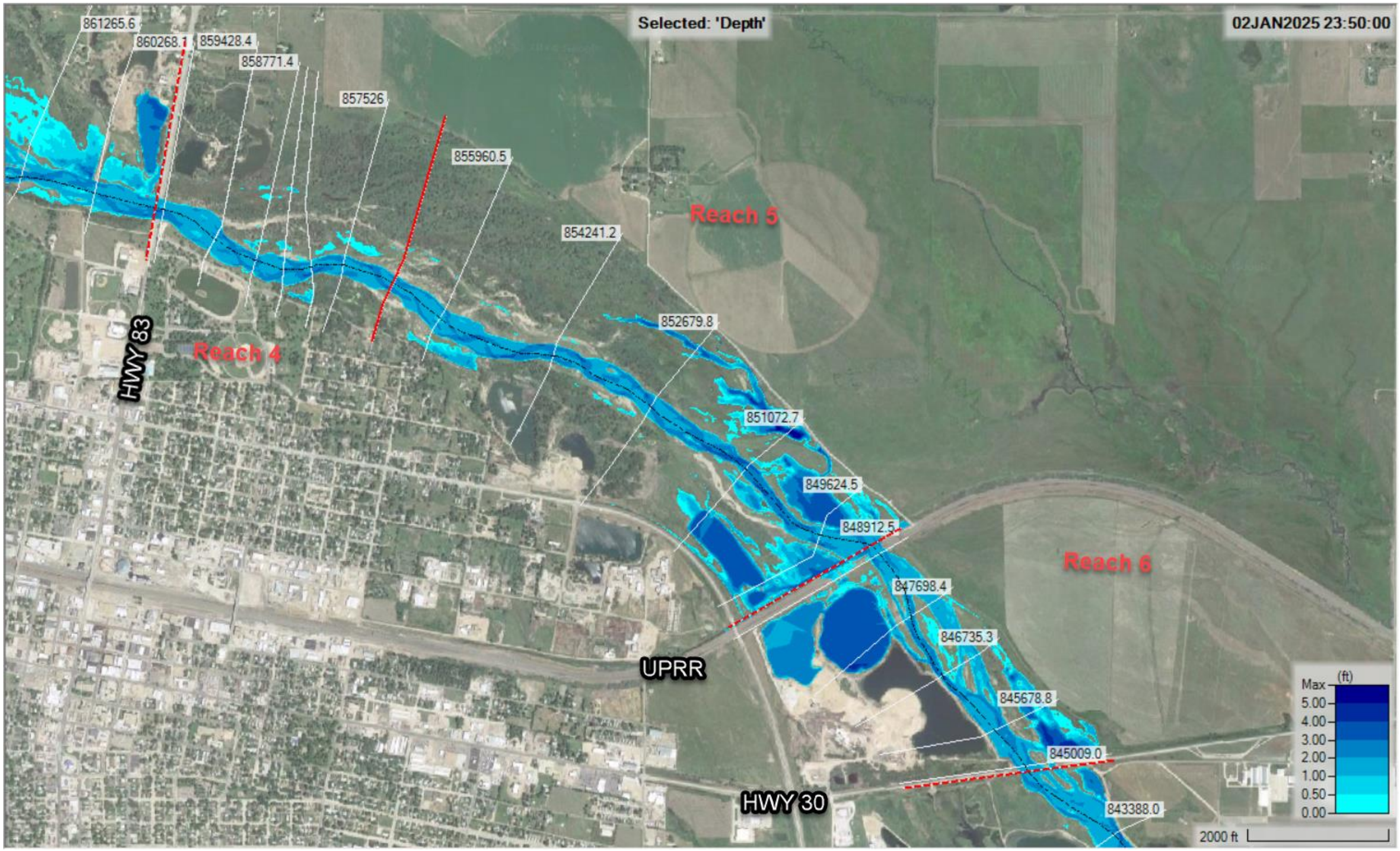



**Figure E-7 Inundation Mapping 1,500 cfs – HWY 83 to HWY 30**

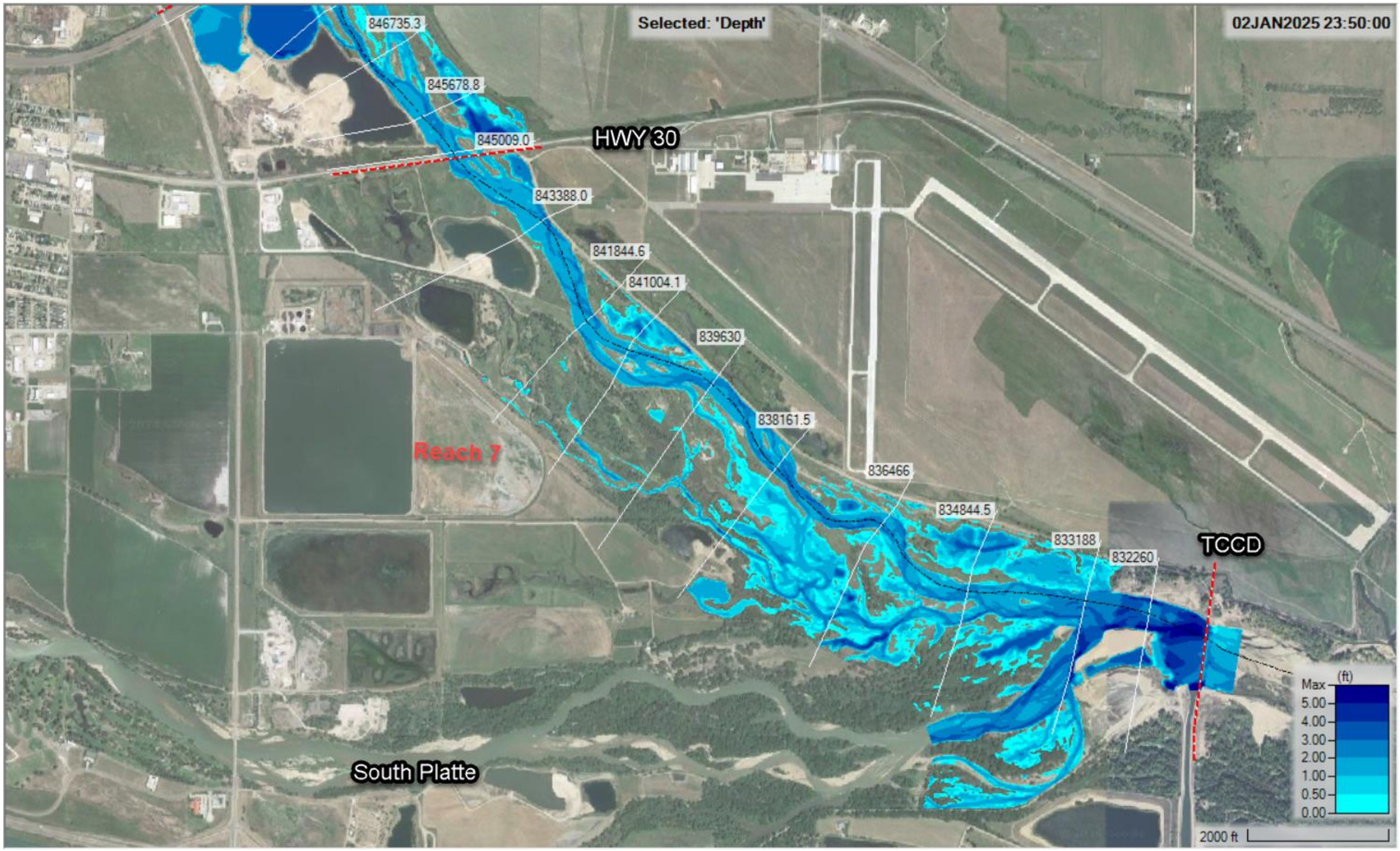



**Figure E-8 Inundation Mapping 1,500 cfs – HWY 30 to Tri-County Diversion**

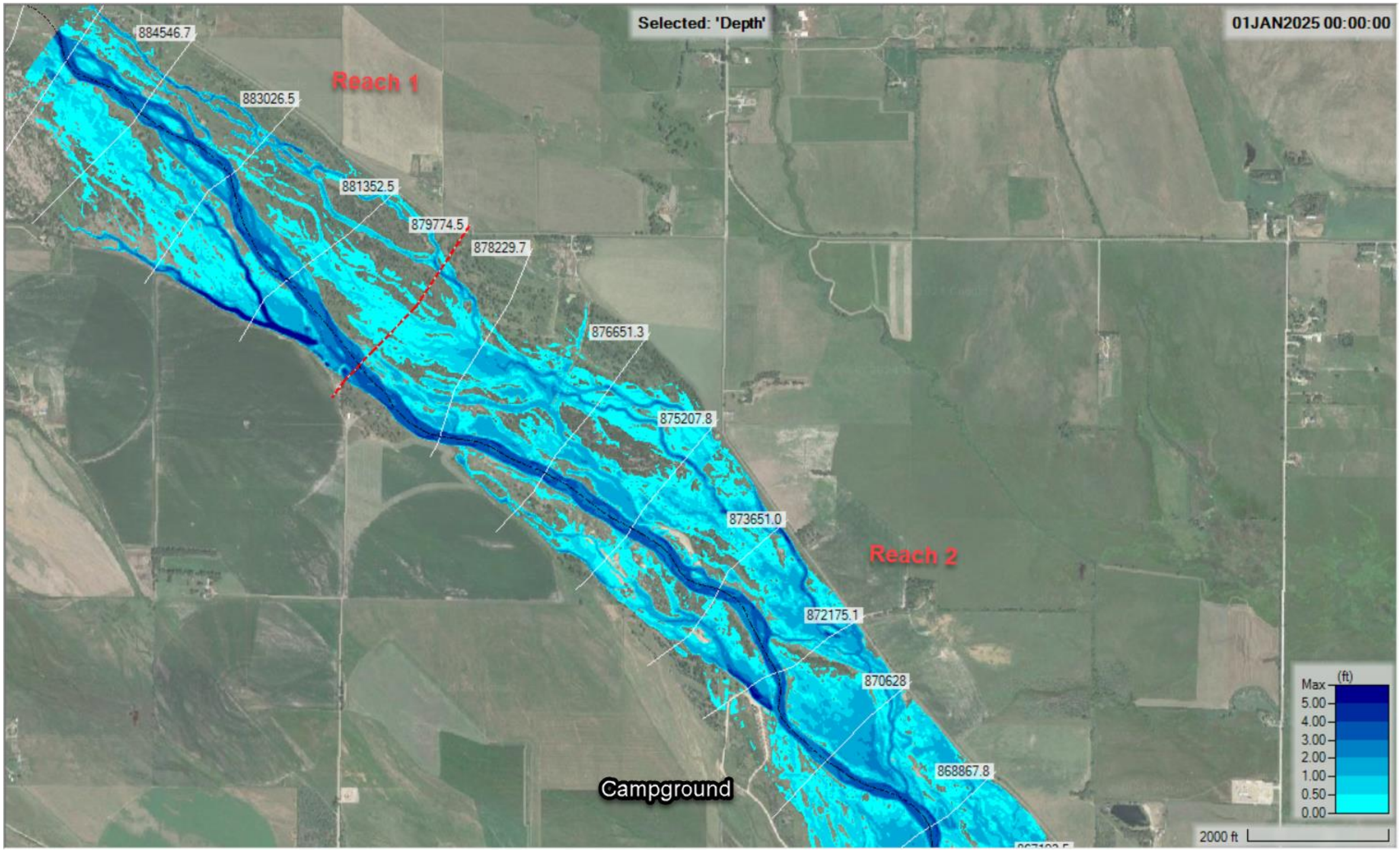



**Figure E-9 Inundation Mapping 3,000 cfs – Reaches 1 and 2**

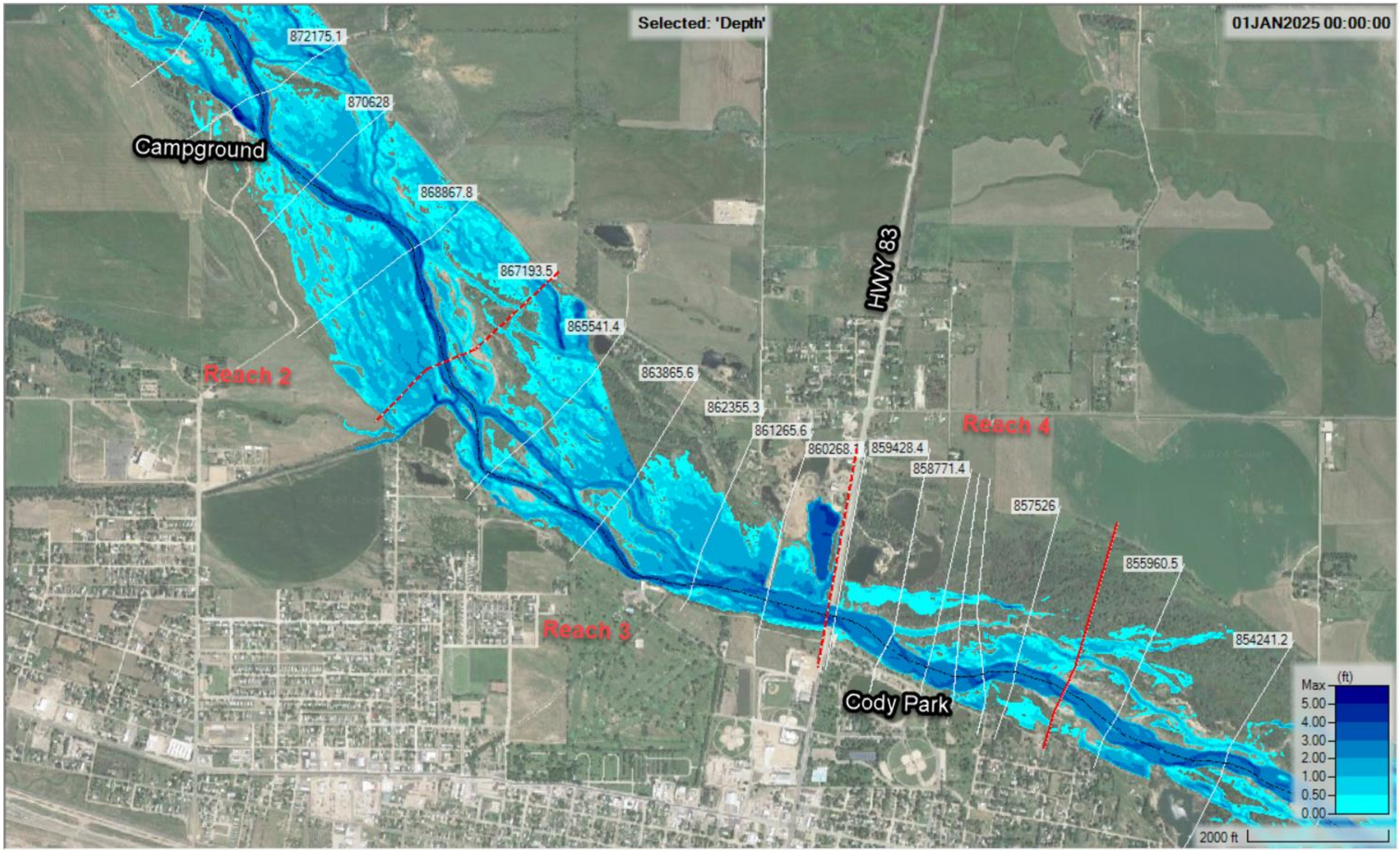



**Figure E-10 Inundation Mapping 3,000 cfs – Campground to Cody Park**

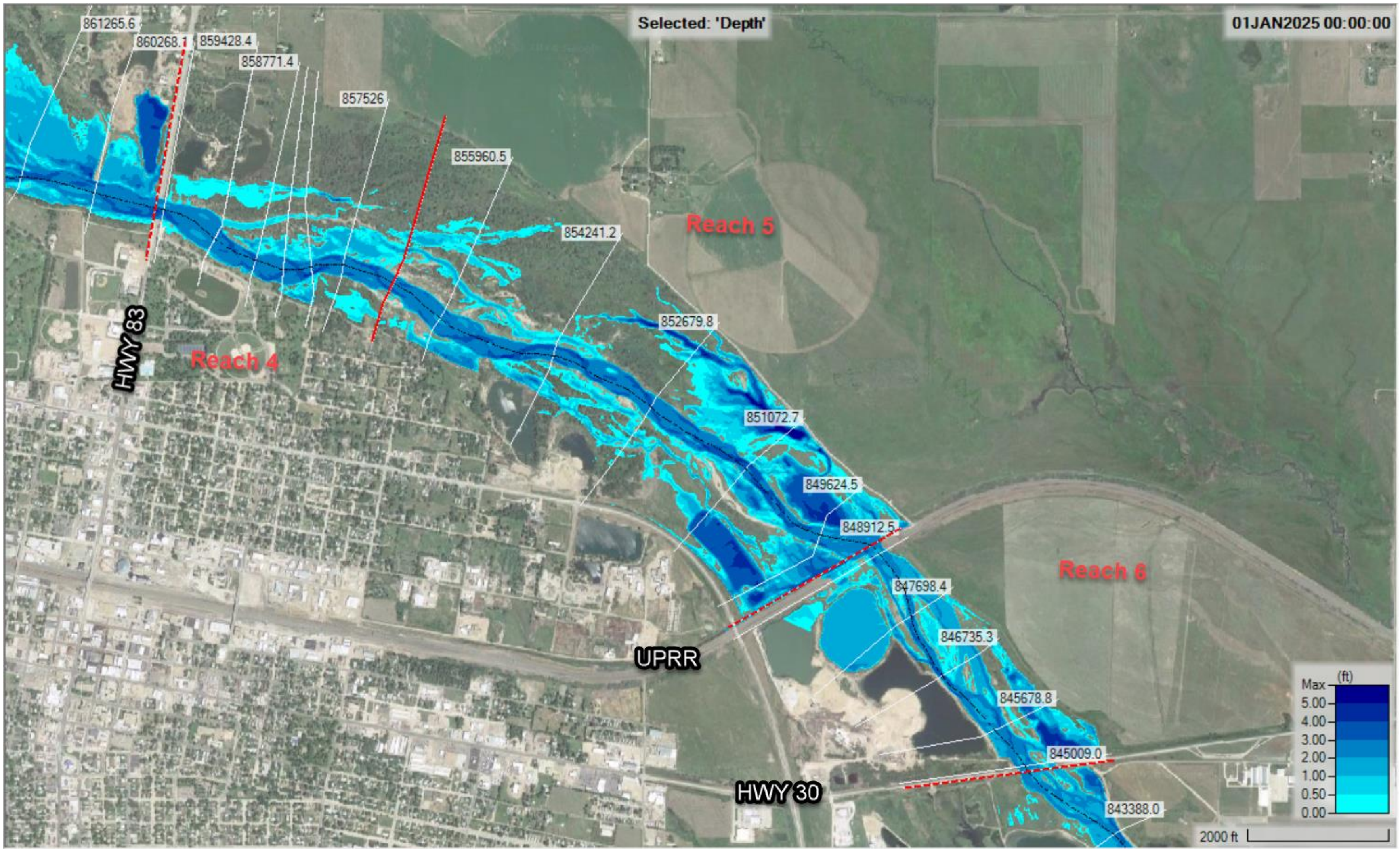



**Figure E-11 Inundation Mapping 3,000 cfs – HWY 83 to HWY 30**

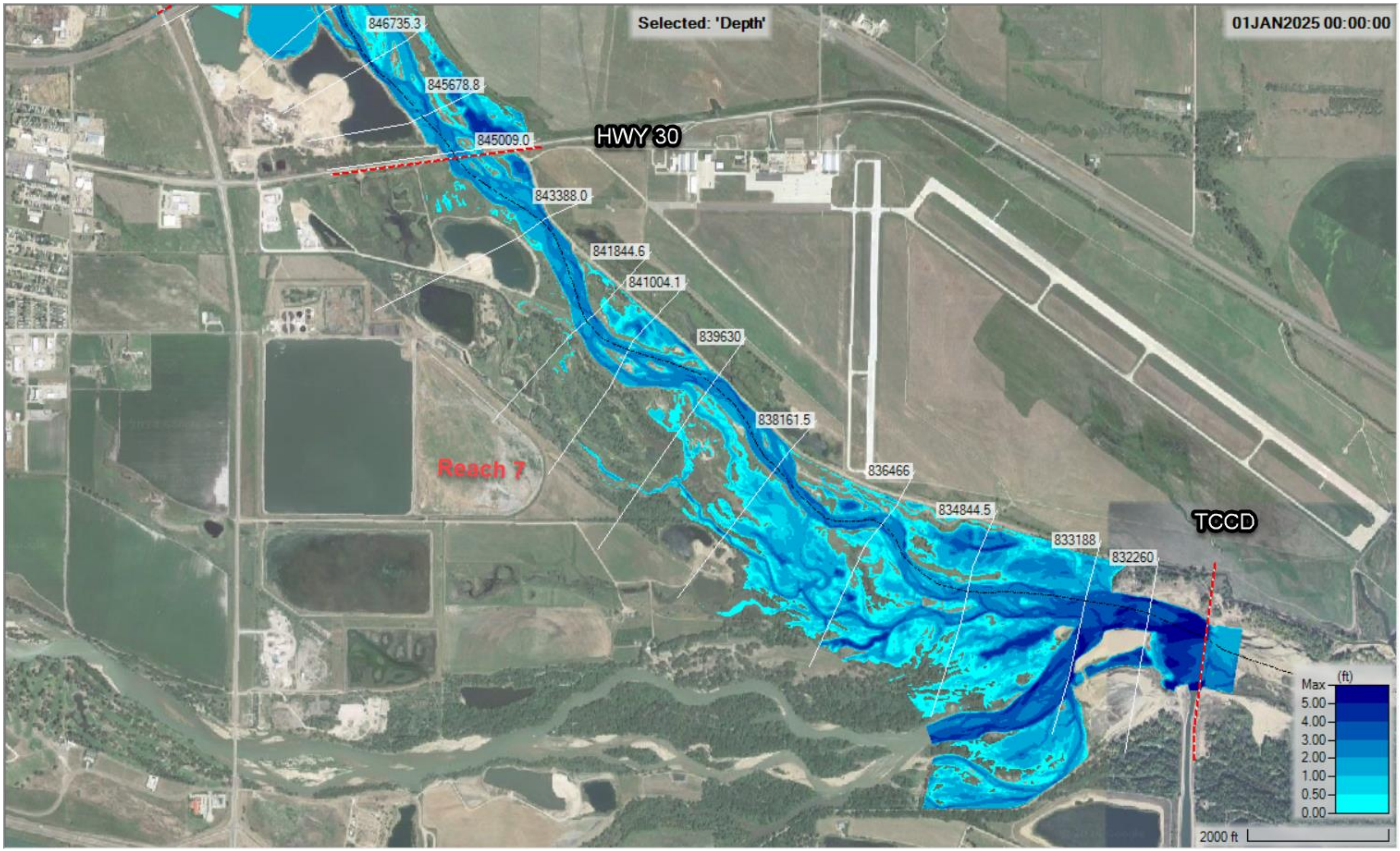



**Figure E-12 Inundation Mapping 3,000 cfs – HWY 30 to Tri-County Diversion**

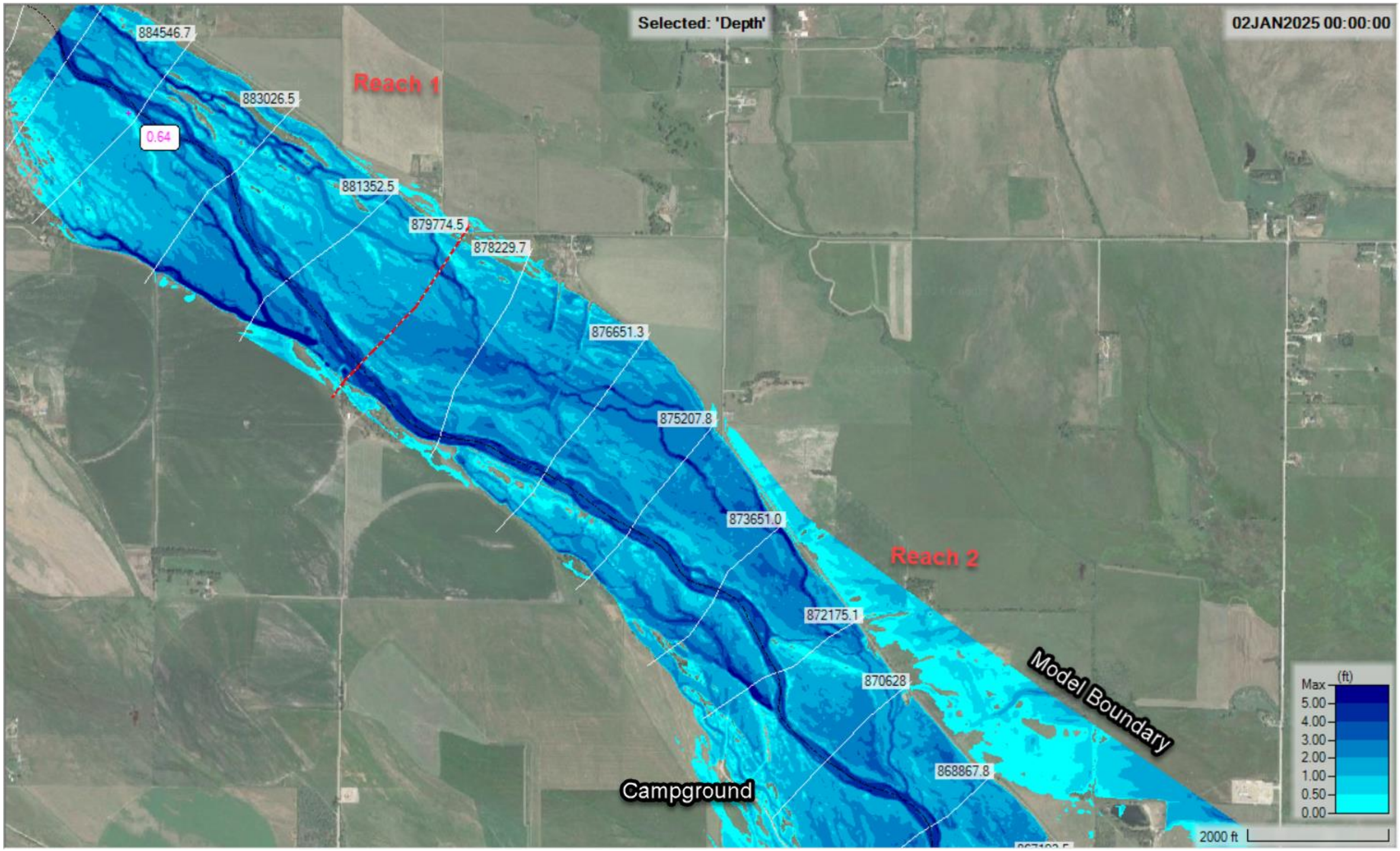



**Figure E-13 Inundation Mapping 6,000 cfs – Reaches 1 and 2**

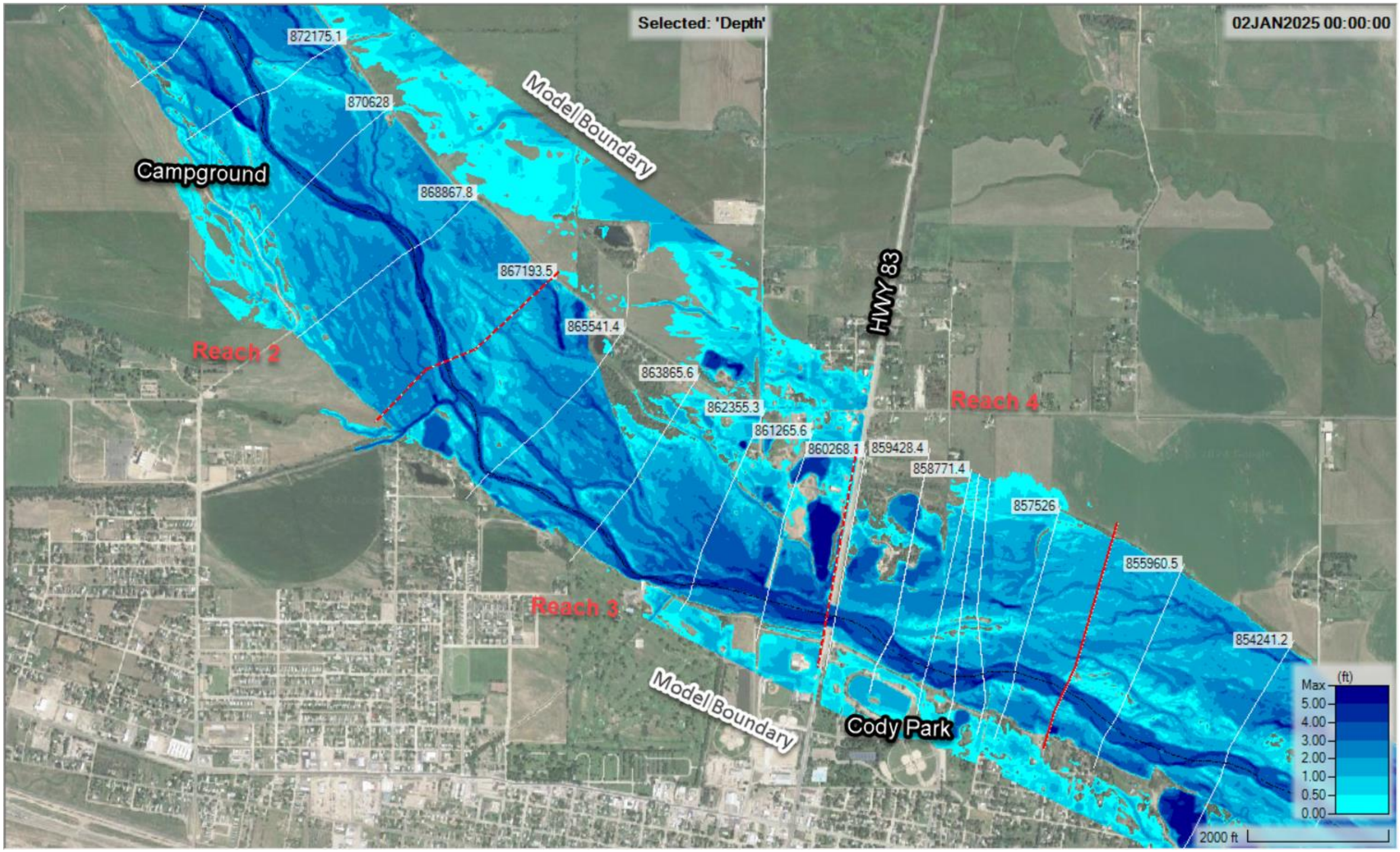



**Figure E-14 Inundation Mapping 6,000 cfs – Campground to Cody Park**

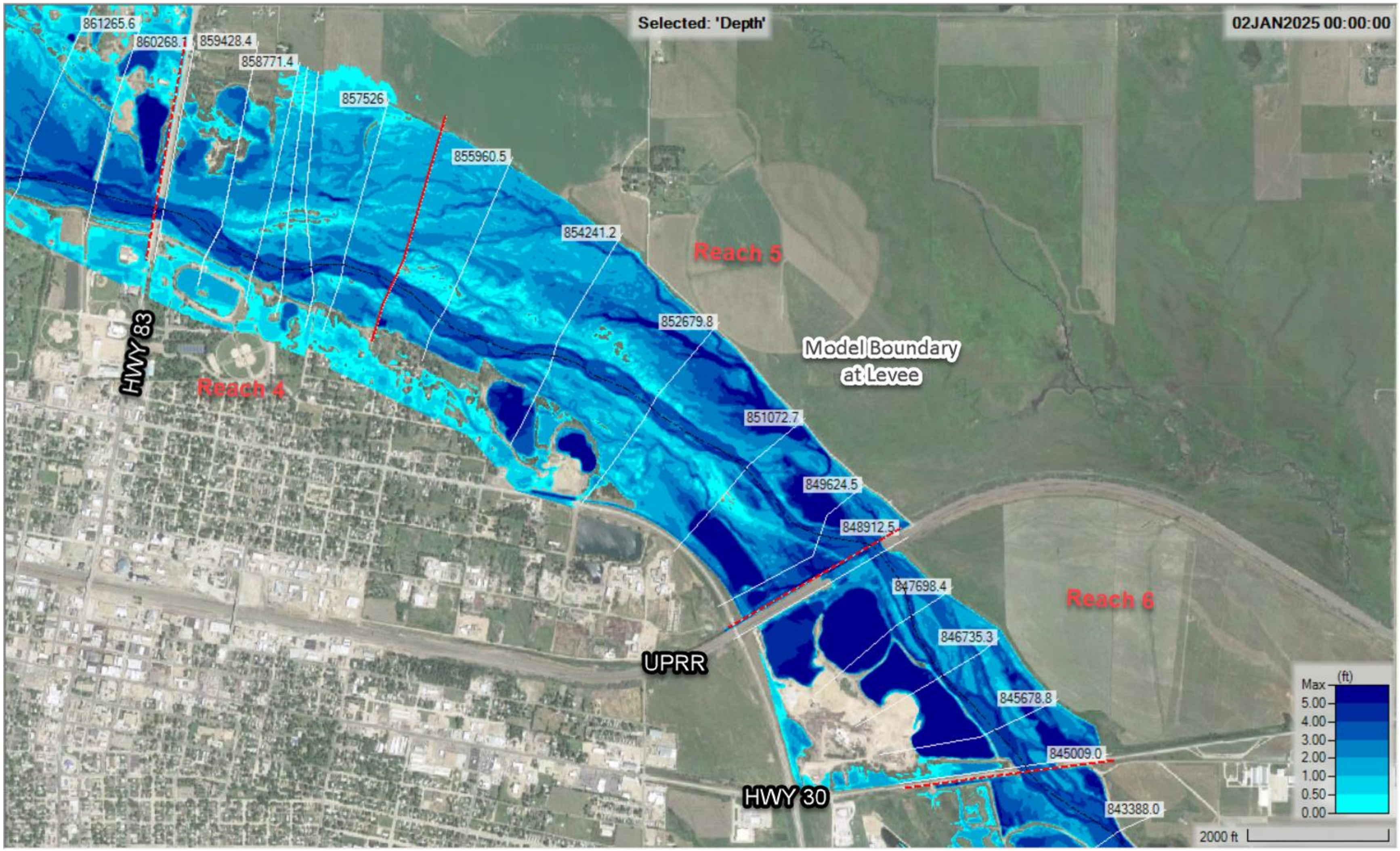



**Figure E-15 Inundation Mapping 6,000 cfs – HWY 83 to HWY 30**

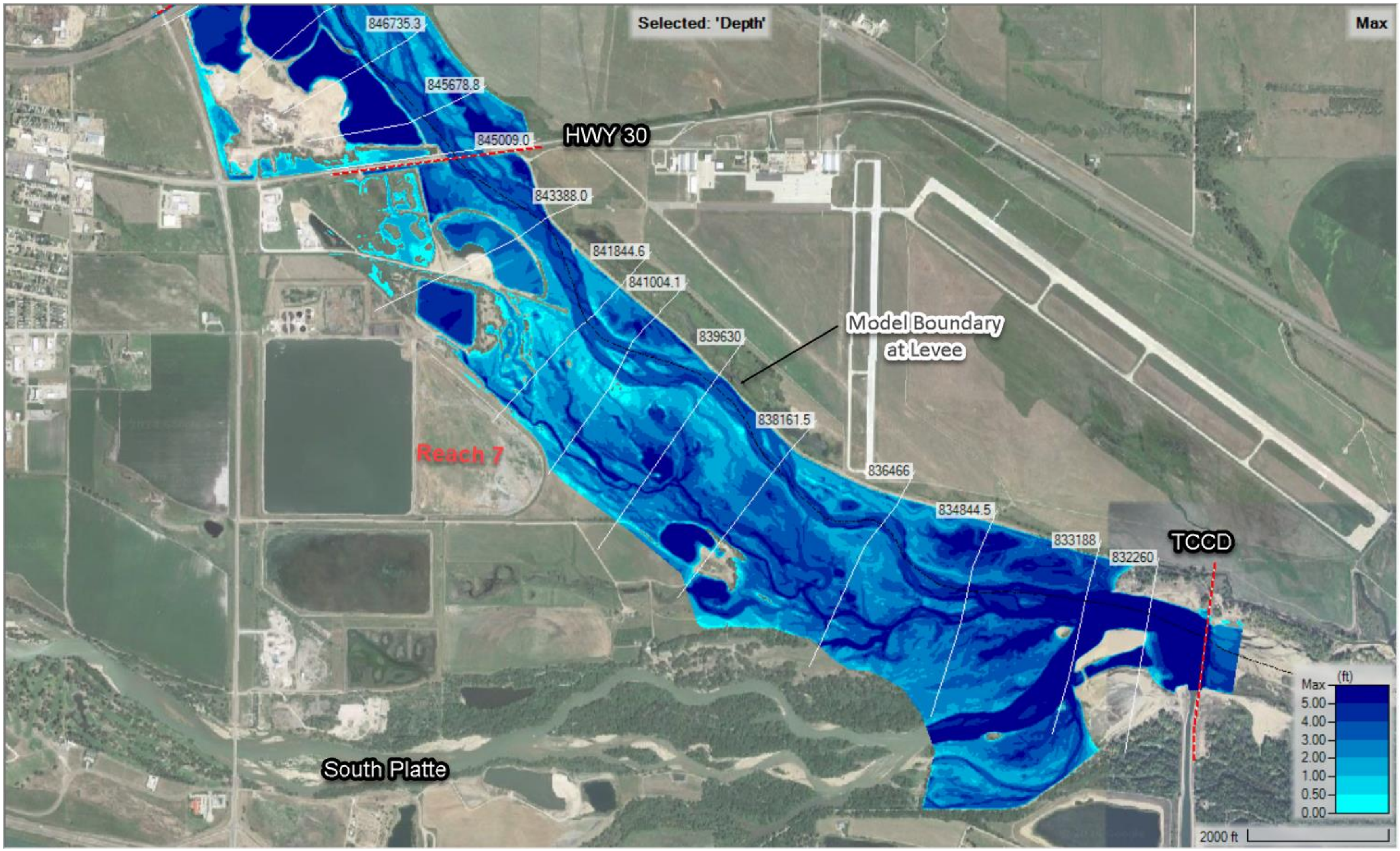



**Figure E-16 Inundation Mapping 6,000 cfs – HWY 30 to Tri-County Diversion**

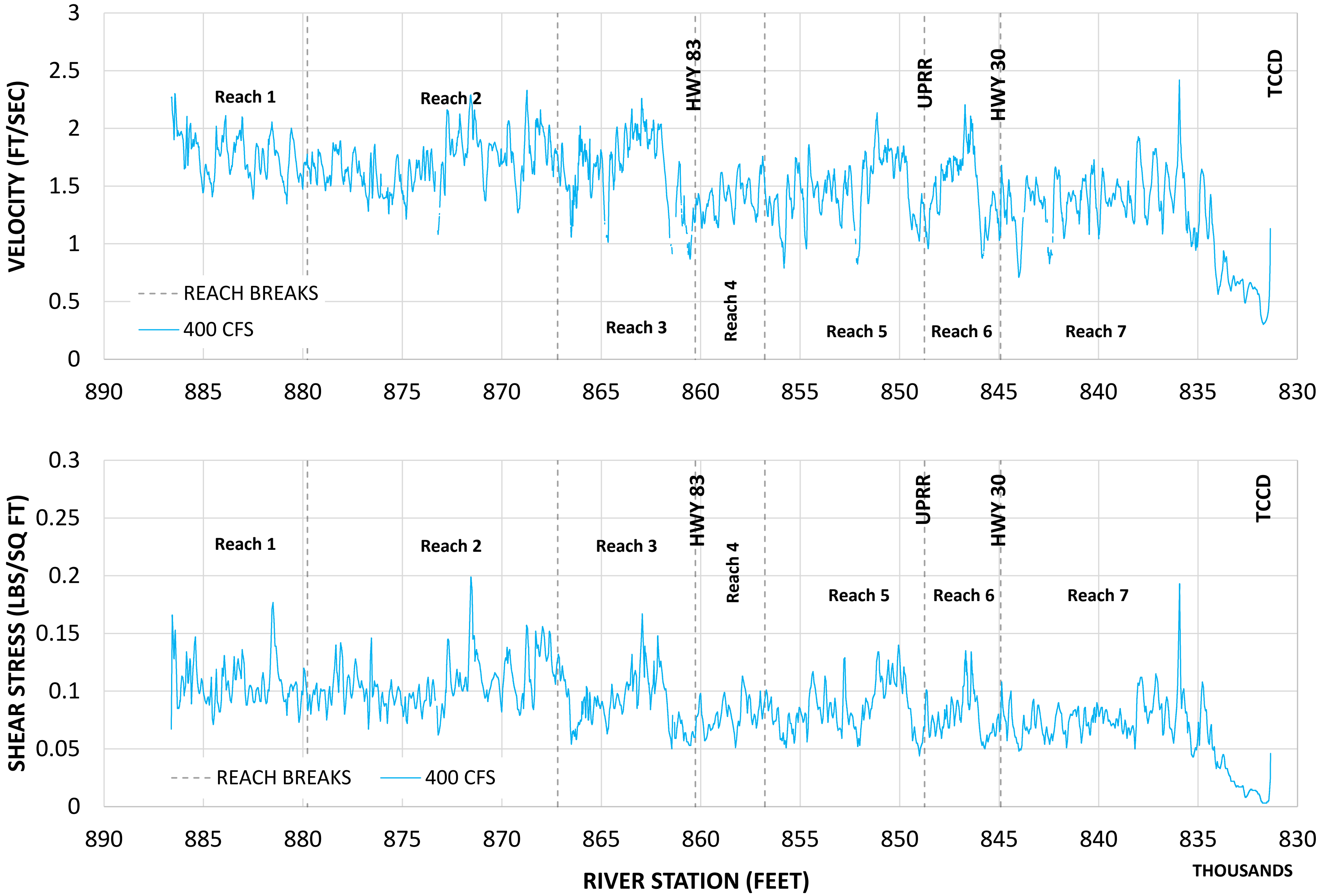



**Figure E-17 Channel Velocity and Shear Stress Profile – 400 cfs Baseflow**

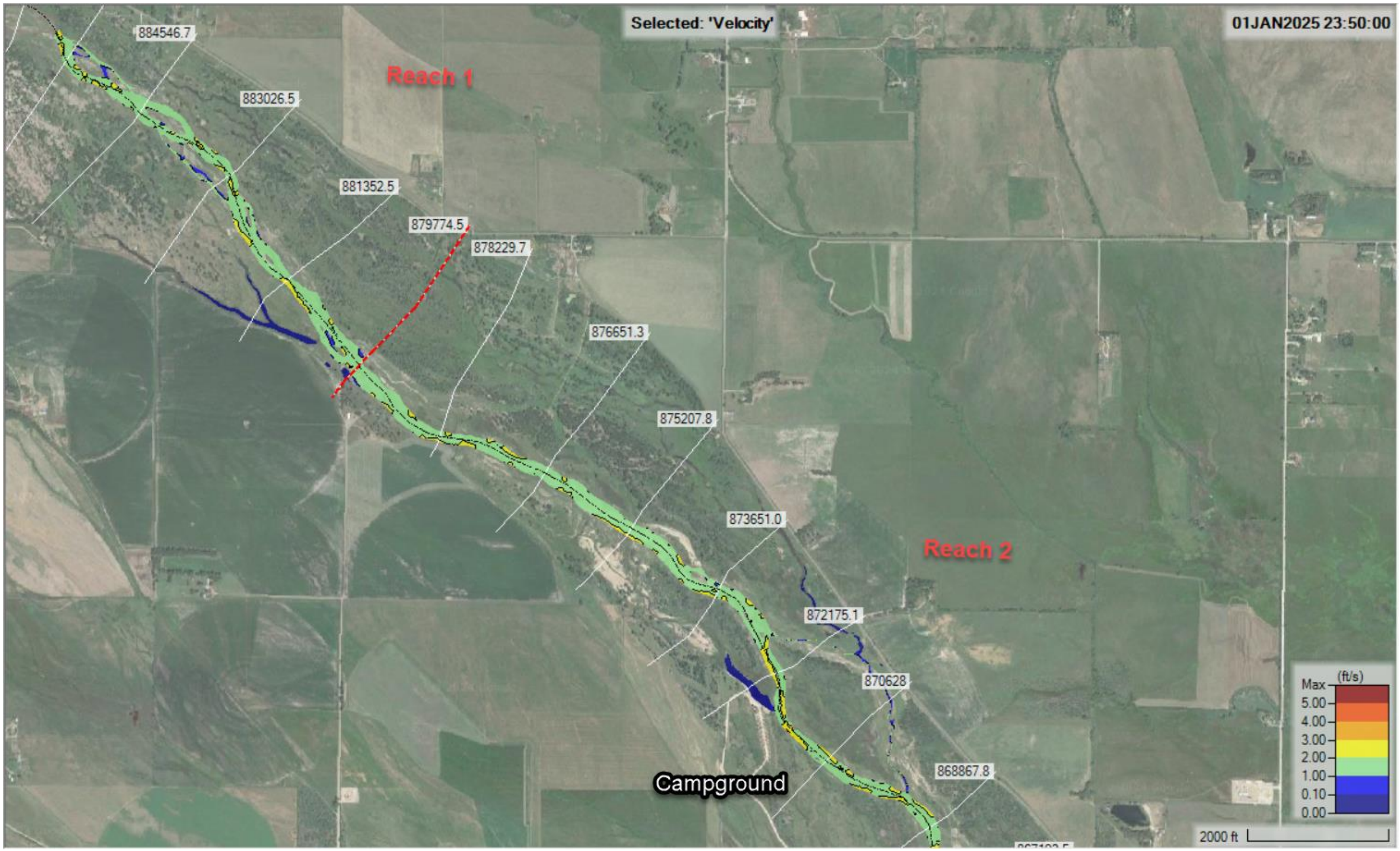



**Figure E-18 Velocity (ft/sec) Mapping 400 cfs – Reaches 1 and 2**


**Figure E-19 Velocity (ft/sec) Mapping 400 cfs – Campground to Cody Park**

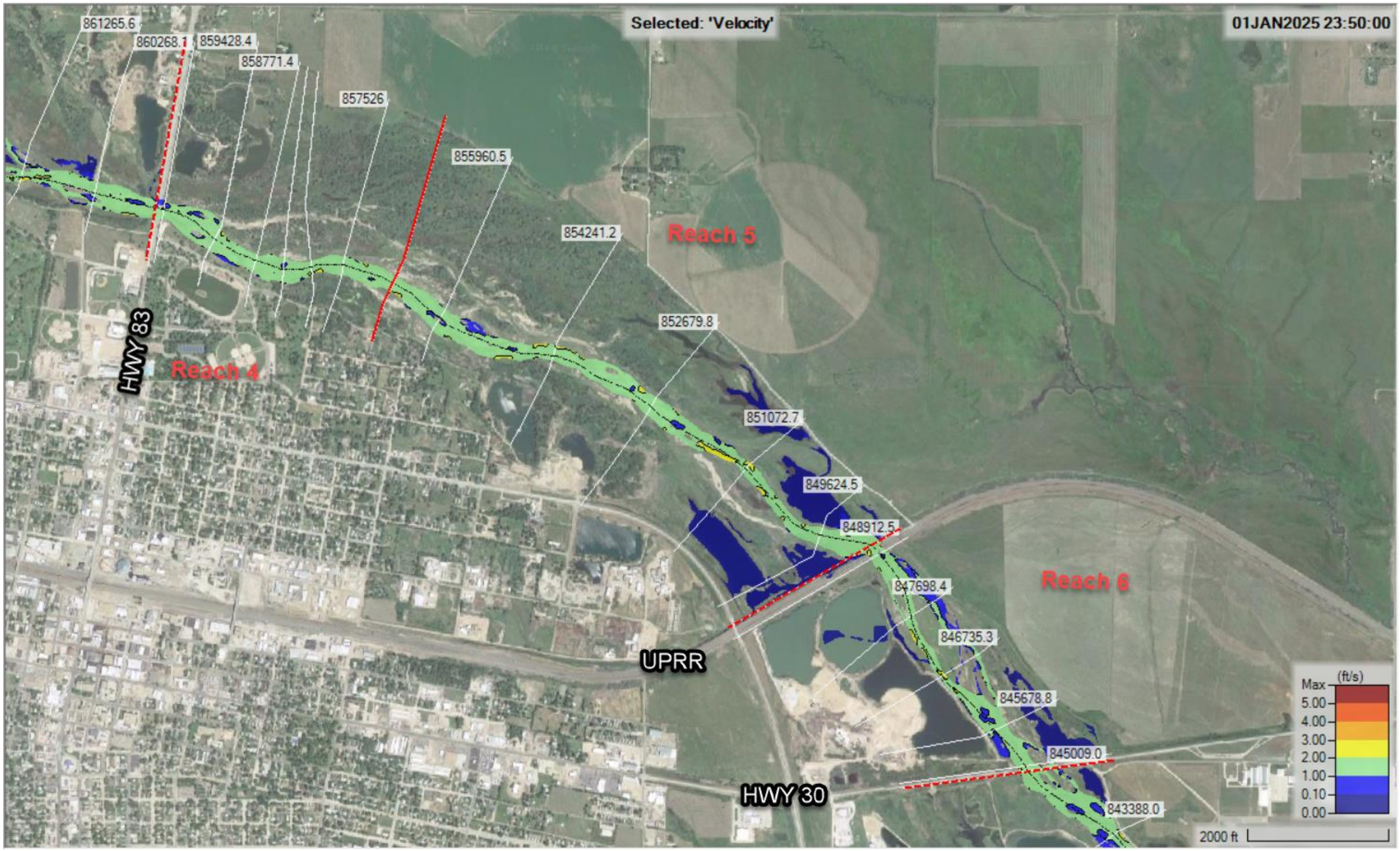



**Figure E-20 Velocity (ft/sec) Mapping 400 cfs – HWY 83 to HWY 30**


Figure E-21 Velocity (ft/sec) Mapping 400 cfs – HWY 30 to Tri-County Diversion


**Figure E-22 Shear Stress (lbs/ft2) Mapping 400 cfs – Reaches 1 and 2**


**Figure E-23 Shear Stress (lbs/ft2) Mapping 400 cfs – Campground to Cody Park**

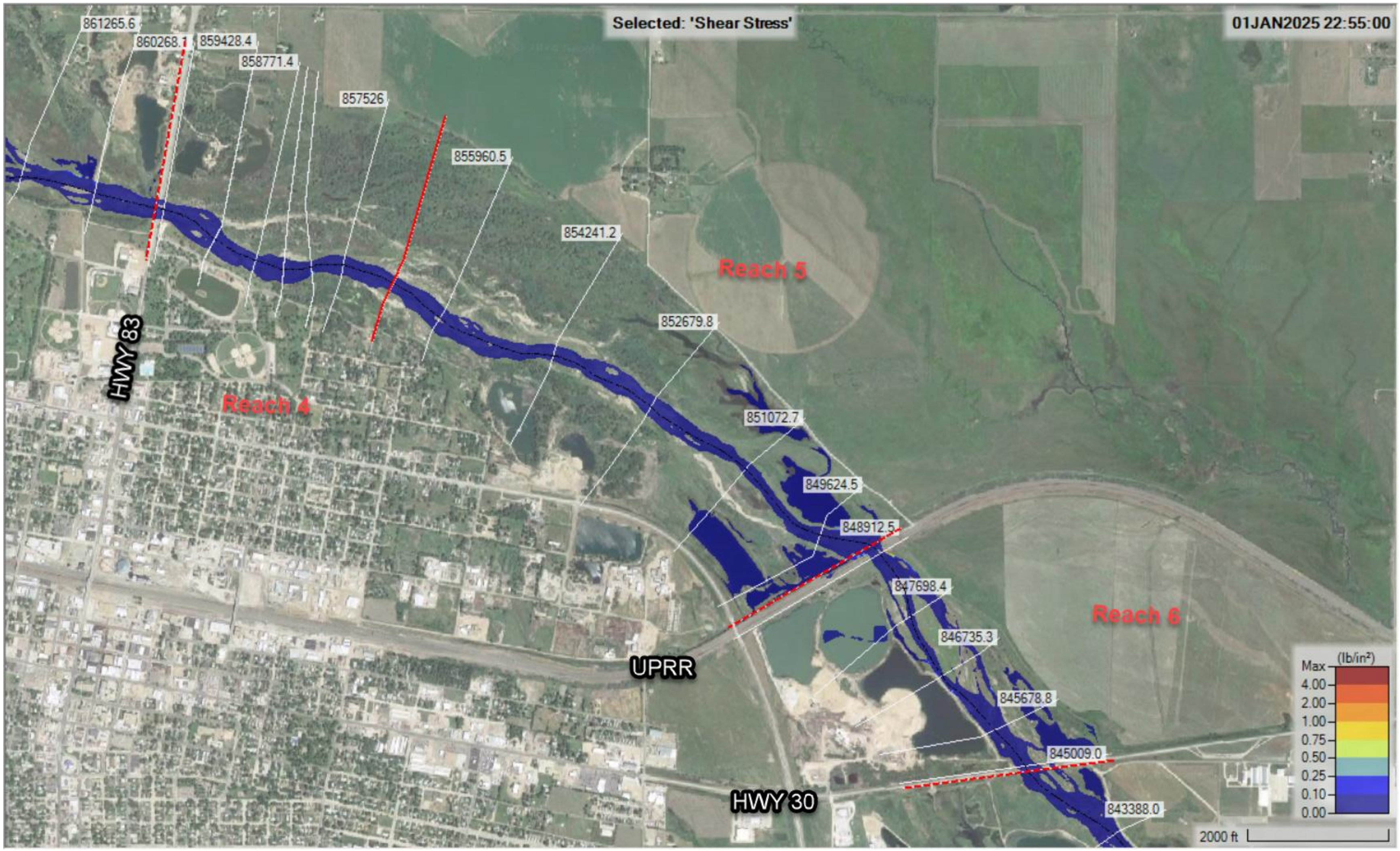



**Figure E-24 Shear Stress (lbs/ft2) Mapping 400 cfs – HWY 83 to HWY 30**


**Figure E-25 Shear Stress (lbs/ft2) Mapping 400 cfs – HWY 30 to Tri-County Diversion**

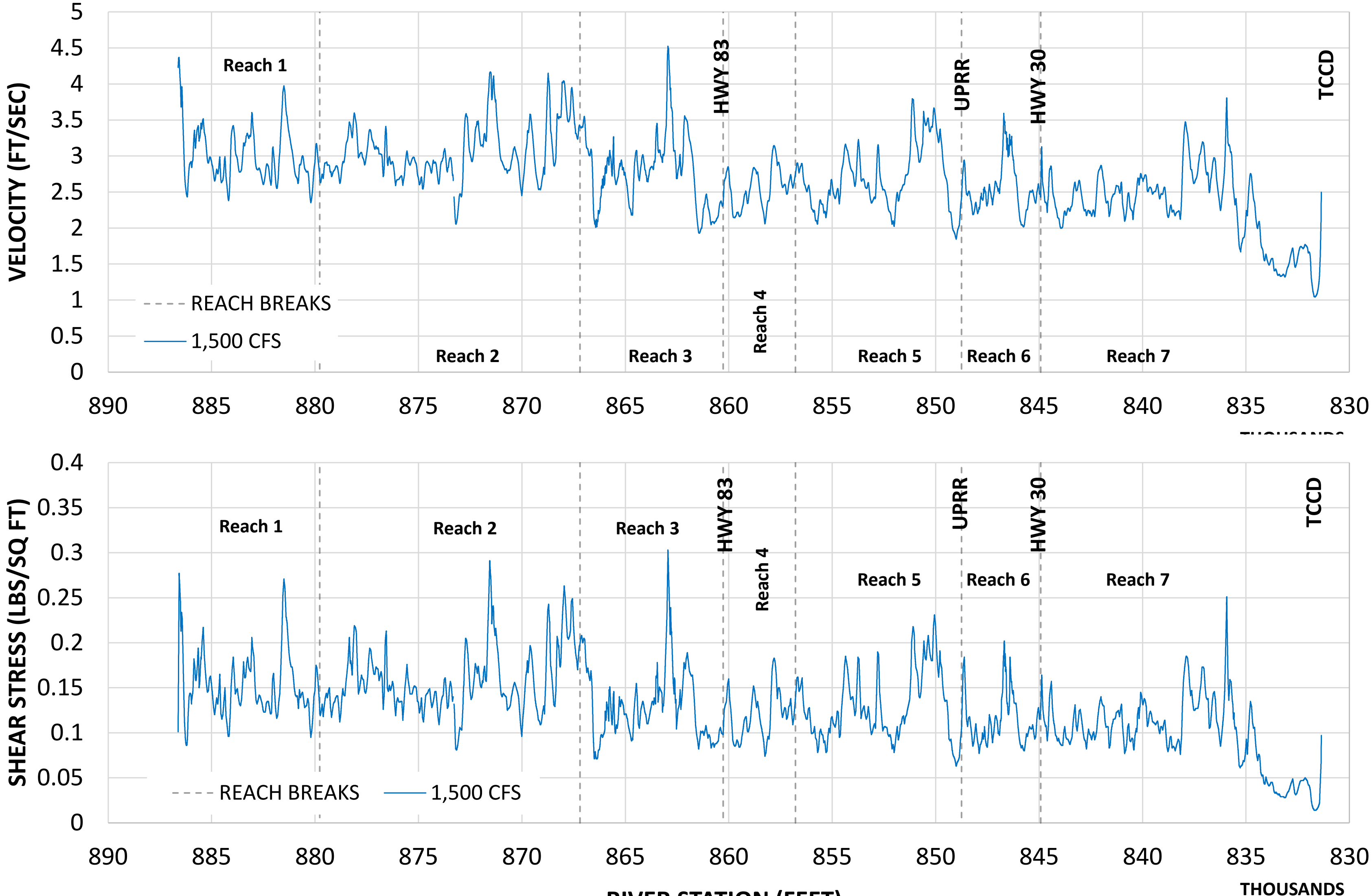



**Figure E-26 Channel Velocity and Shear Stress Profile – 1,500 cfs**

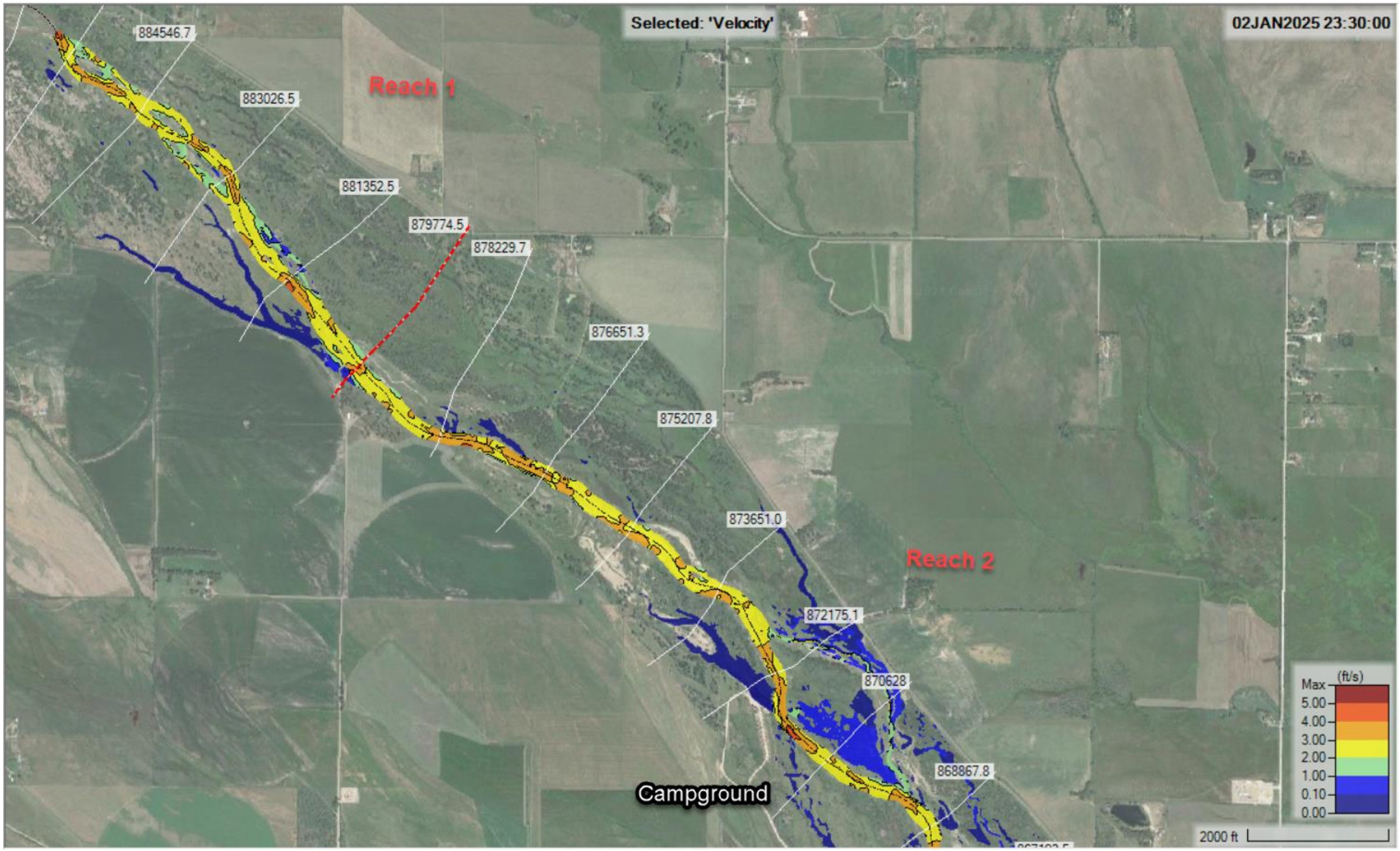



**Figure E-27 Velocity (ft/sec) Mapping 1,500 cfs – Reaches 1 and 2**

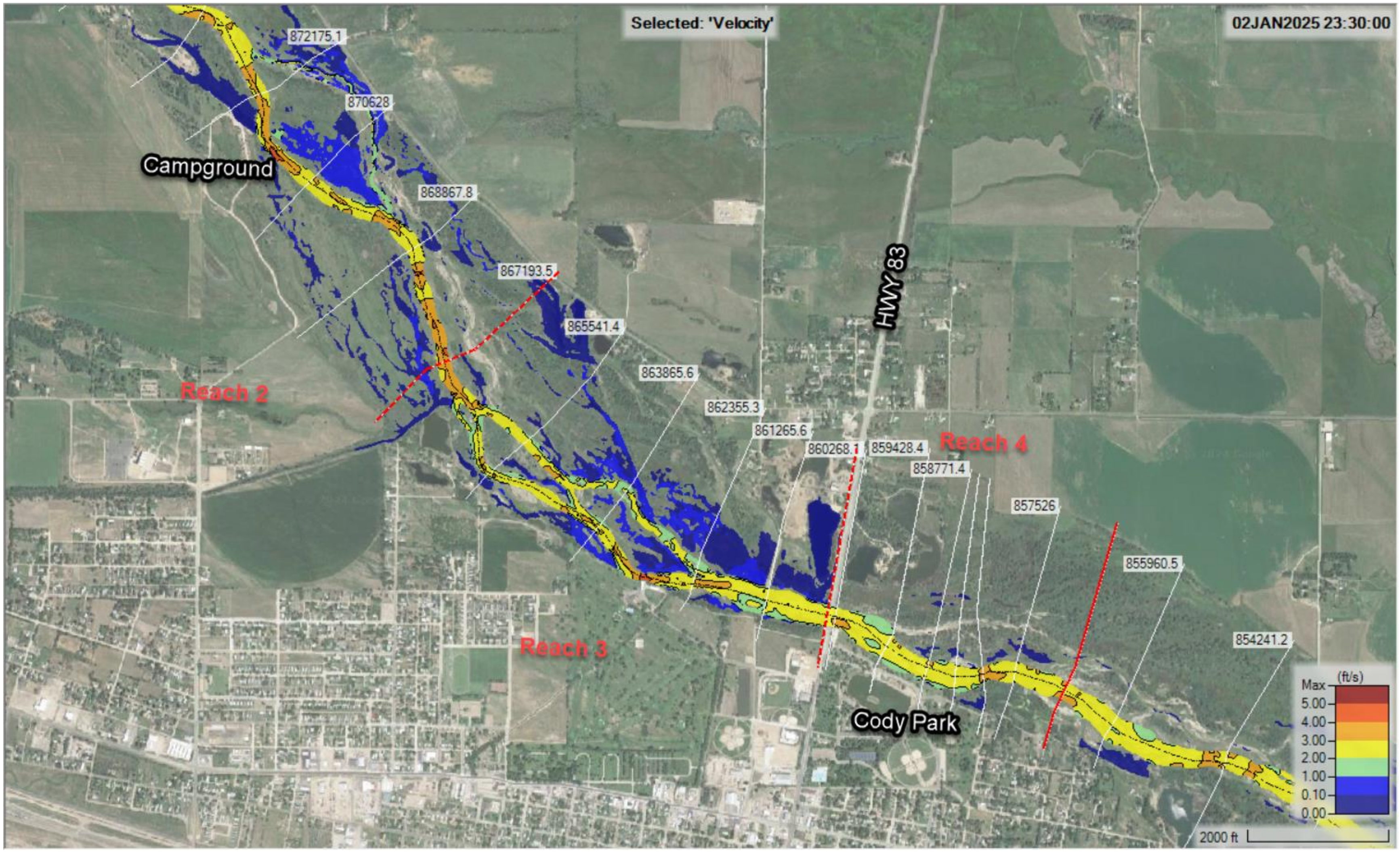



**Figure E-28 Velocity (ft/sec) Mapping 1,500 cfs – Campground to Cody Park**

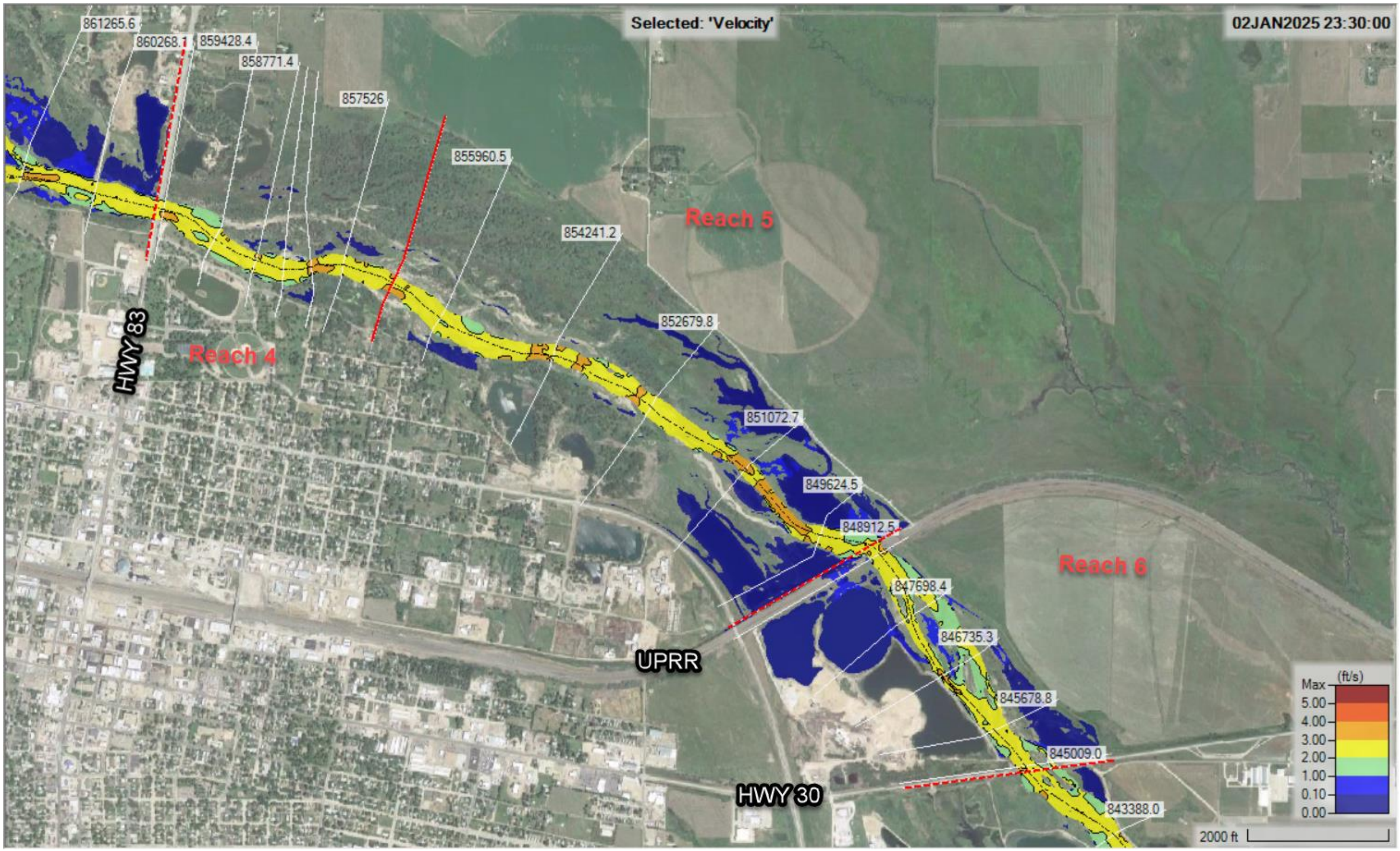



**Figure E-29 Velocity (ft/sec) Mapping 1,500 cfs – HWY 83 to HWY 30**

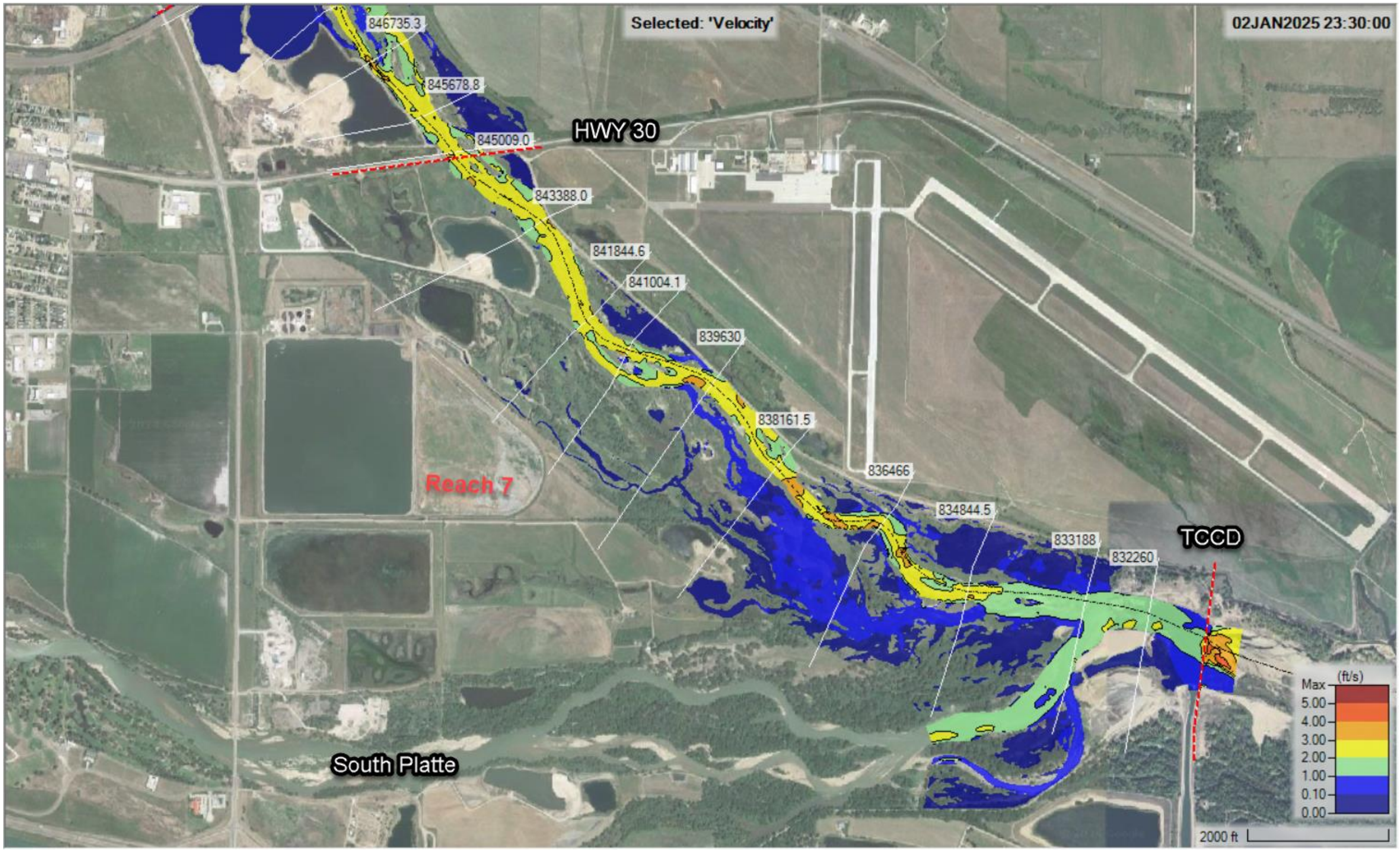



**Figure E-30 Velocity (ft/sec)   Mapping 1,500 cfs – HWY 30 to Tri-County Diversion**

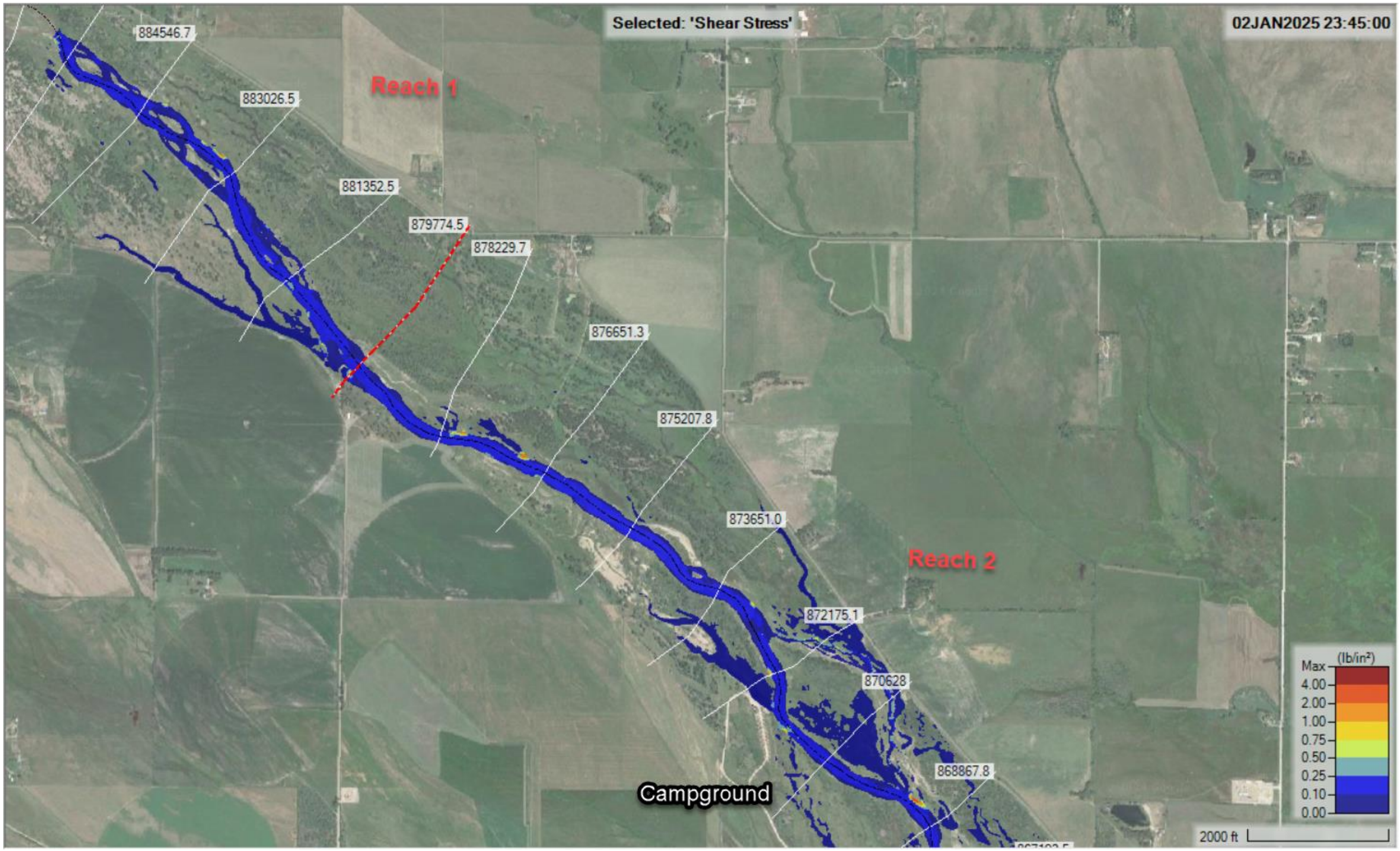



**Figure E-31 Shear Stress (lbs/ft2) Mapping 1,500 cfs – Reaches 1 and 2**

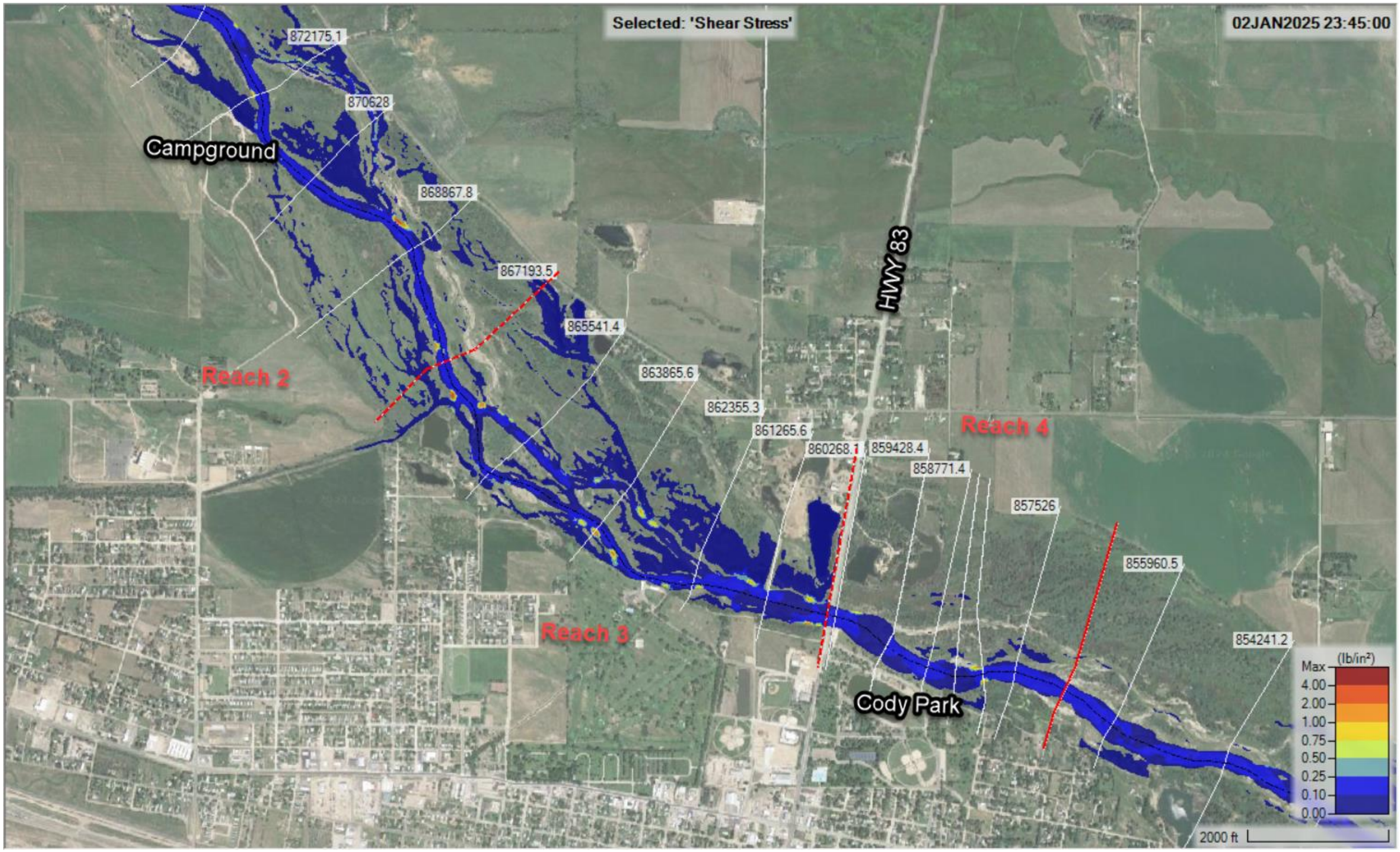



**Figure E-32 Shear Stress (lbs/ft2) Mapping 1,500 cfs – Campground to Cody Park**

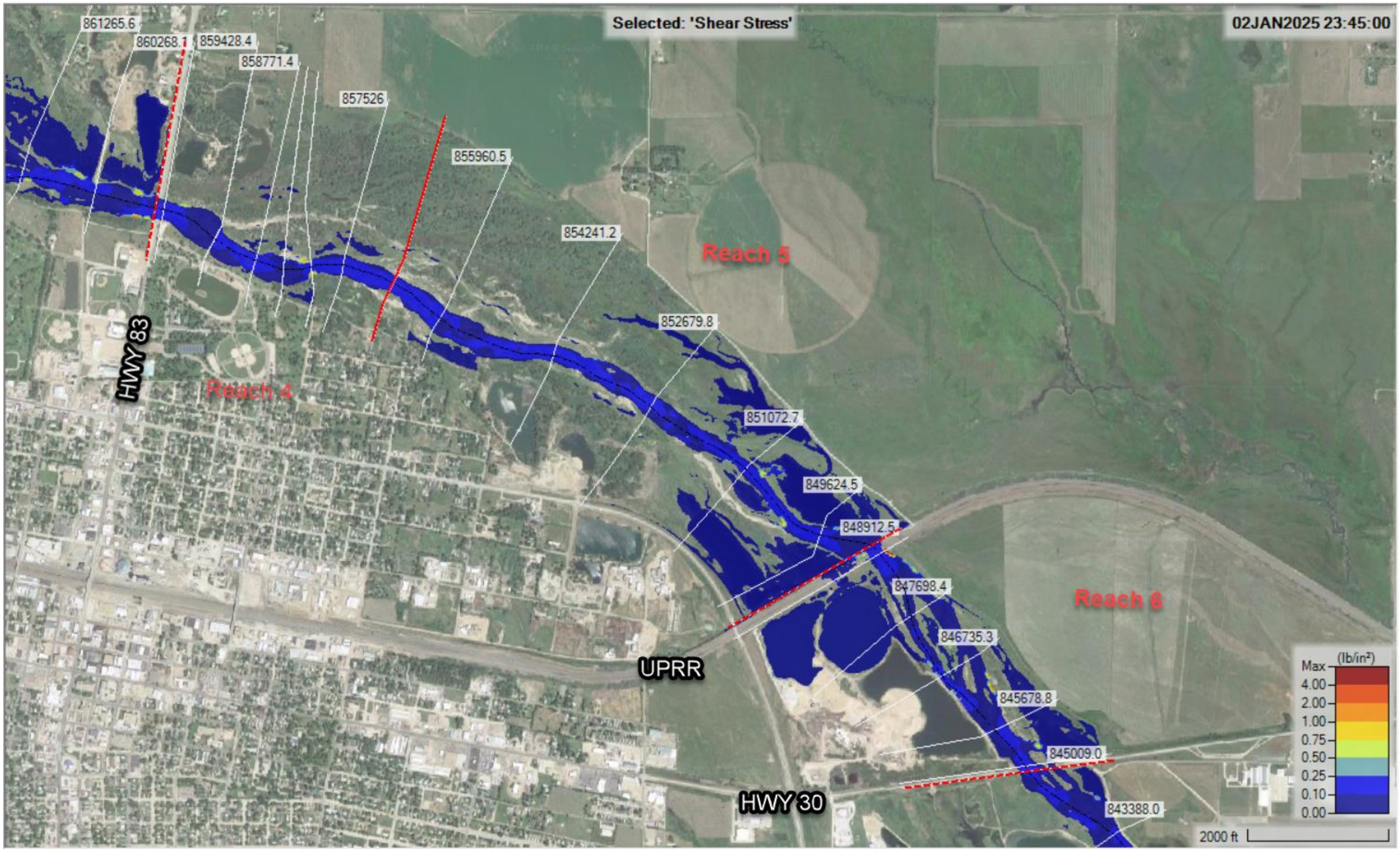



**Figure E-33 Shear Stress (lbs/ft2) Mapping 1,500 cfs – HWY 83 to HWY 30**

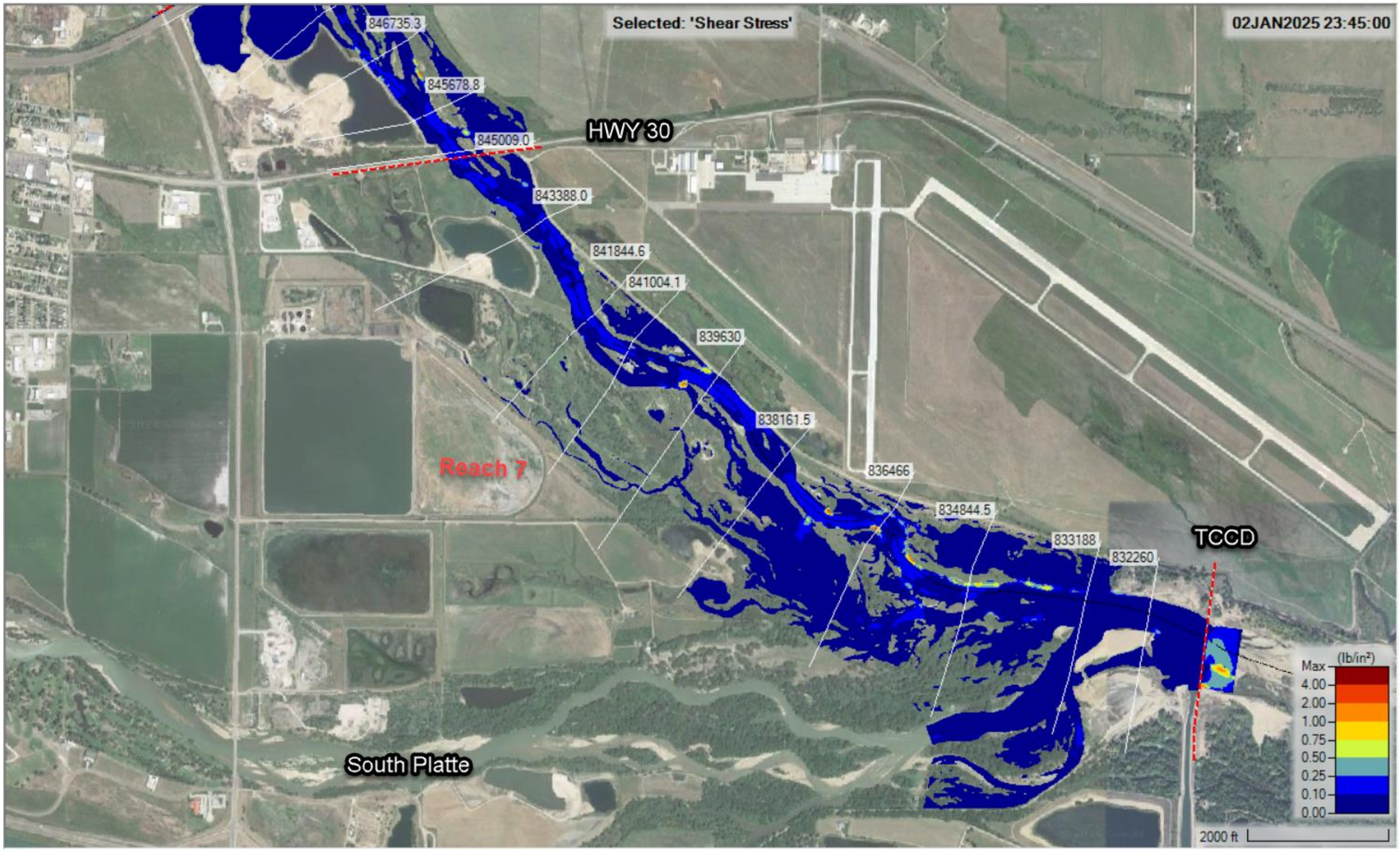



**Figure E-34 Shear Stress (lbs/ft2) Mapping 1,500 cfs – HWY 30 to Tri-County Diversion**

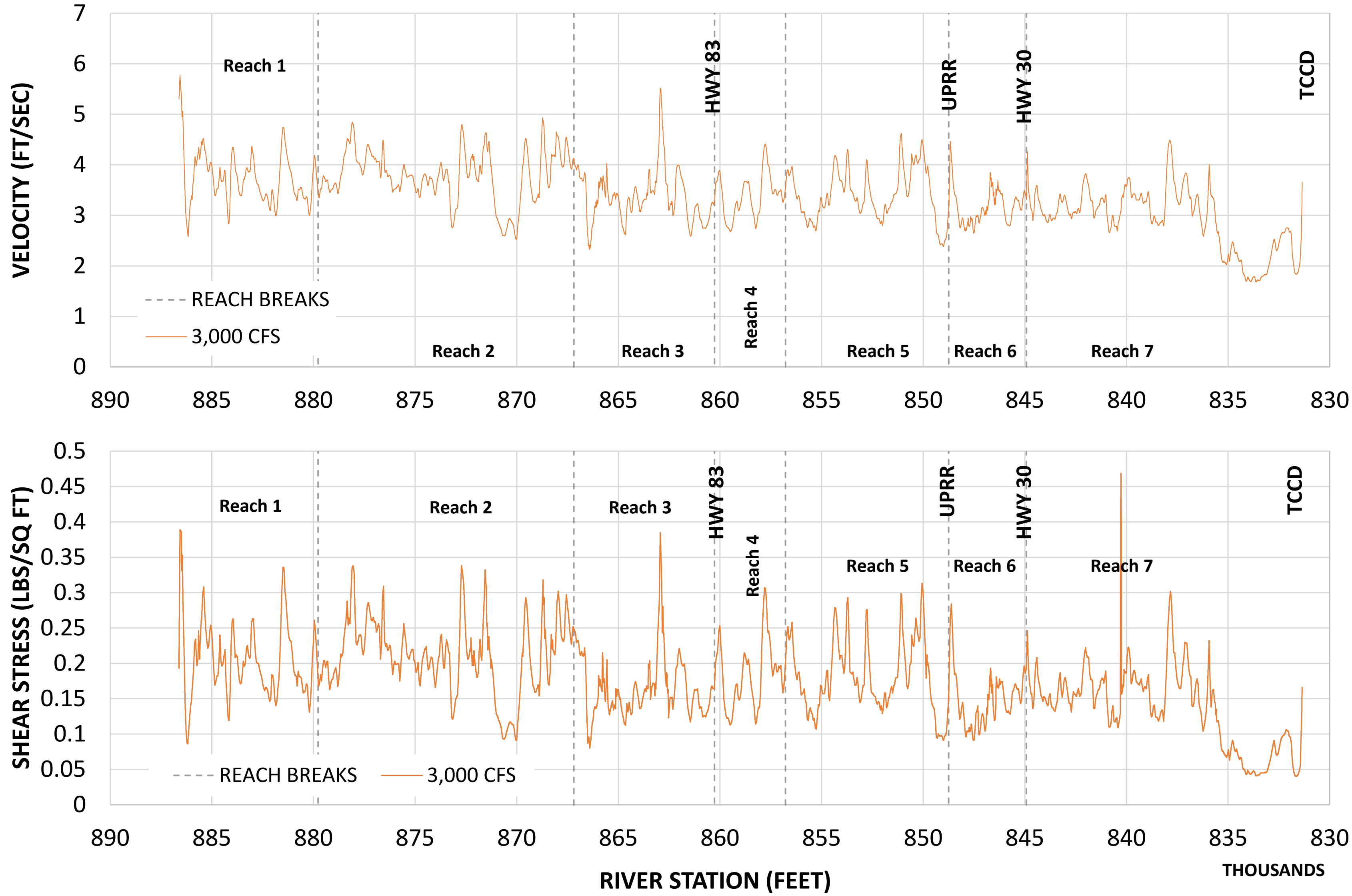



**Figure E-35 Channel Velocity and Shear Stress Profile – 3,000 cfs**

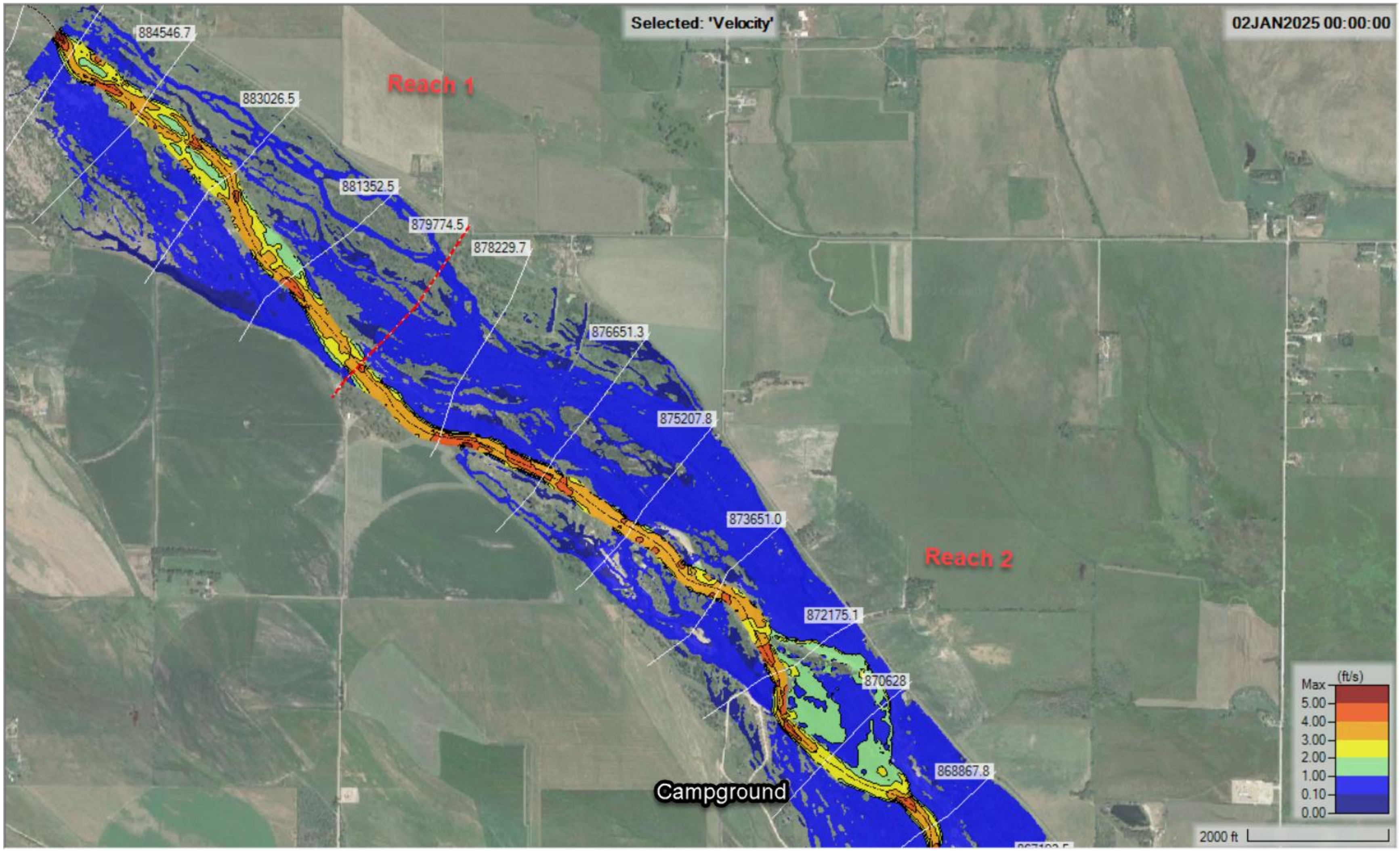



**Figure E-36 Velocity (ft/sec) Mapping 3,000 cfs – Reaches 1 and 2**

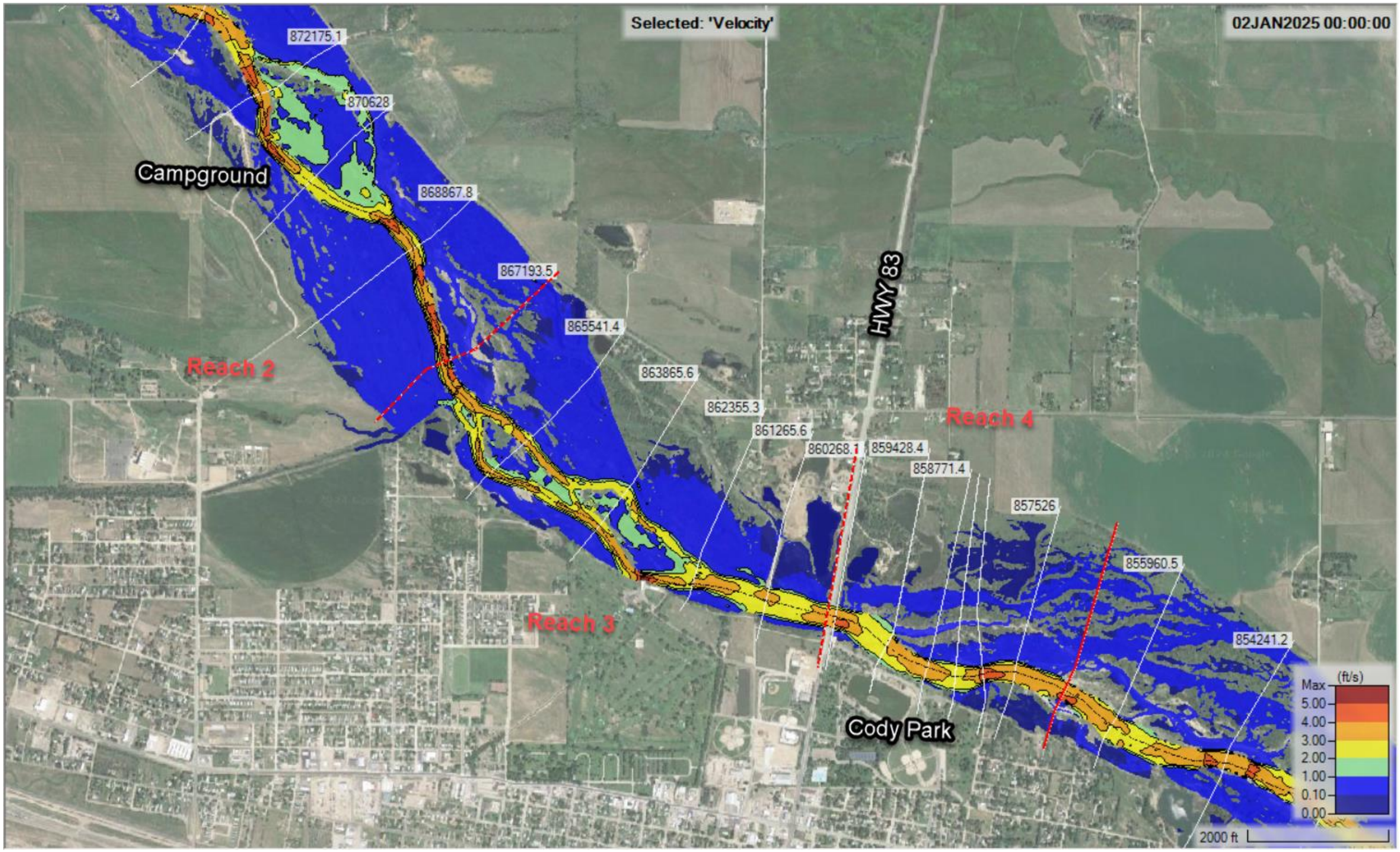



**Figure E-37 Velocity (ft/sec)   Mapping 3,000 cfs – Campground to Cody Park**

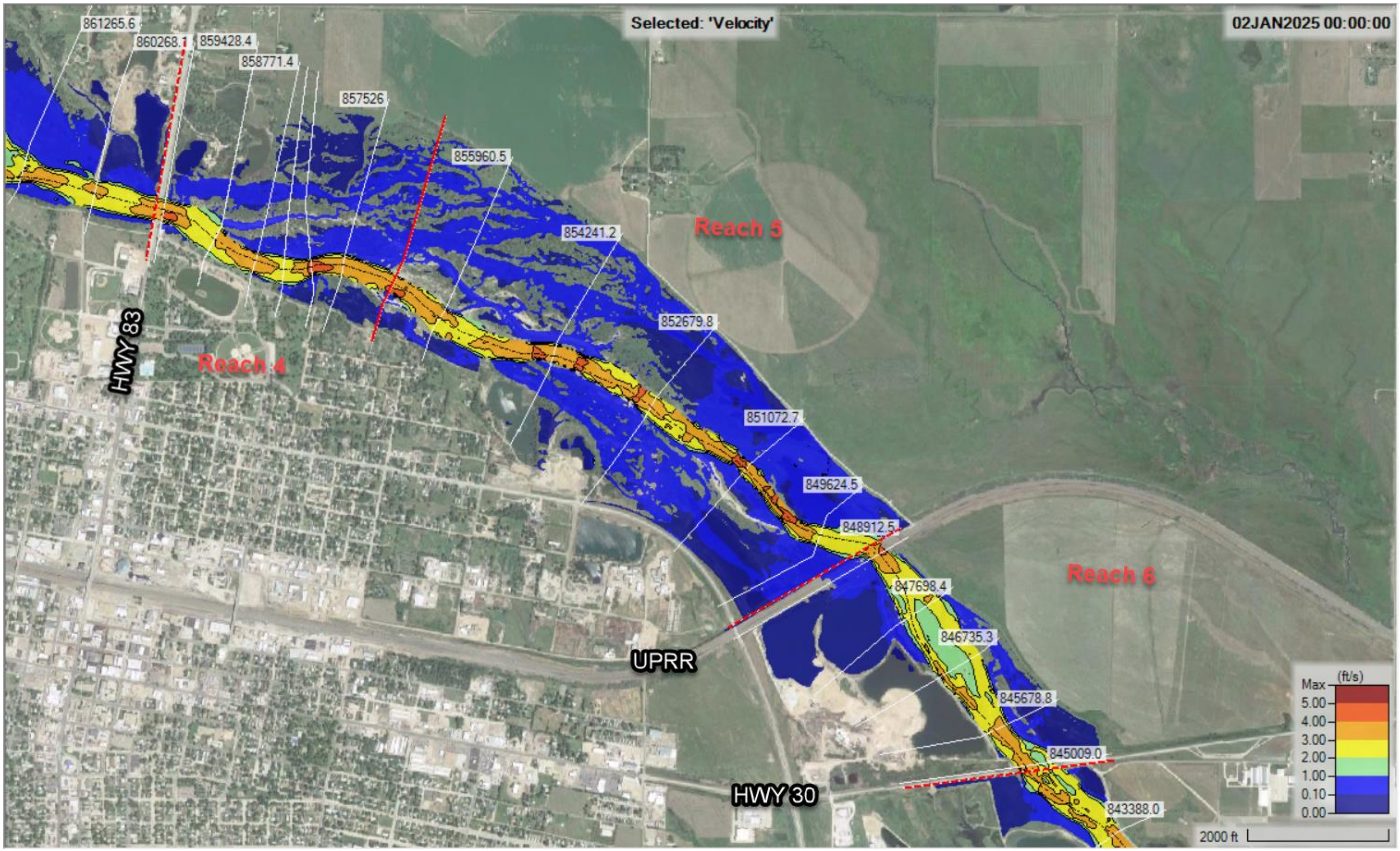



**Figure E-38 Velocity (ft/sec) Mapping 3,000 cfs – HWY 83 to HWY 30**

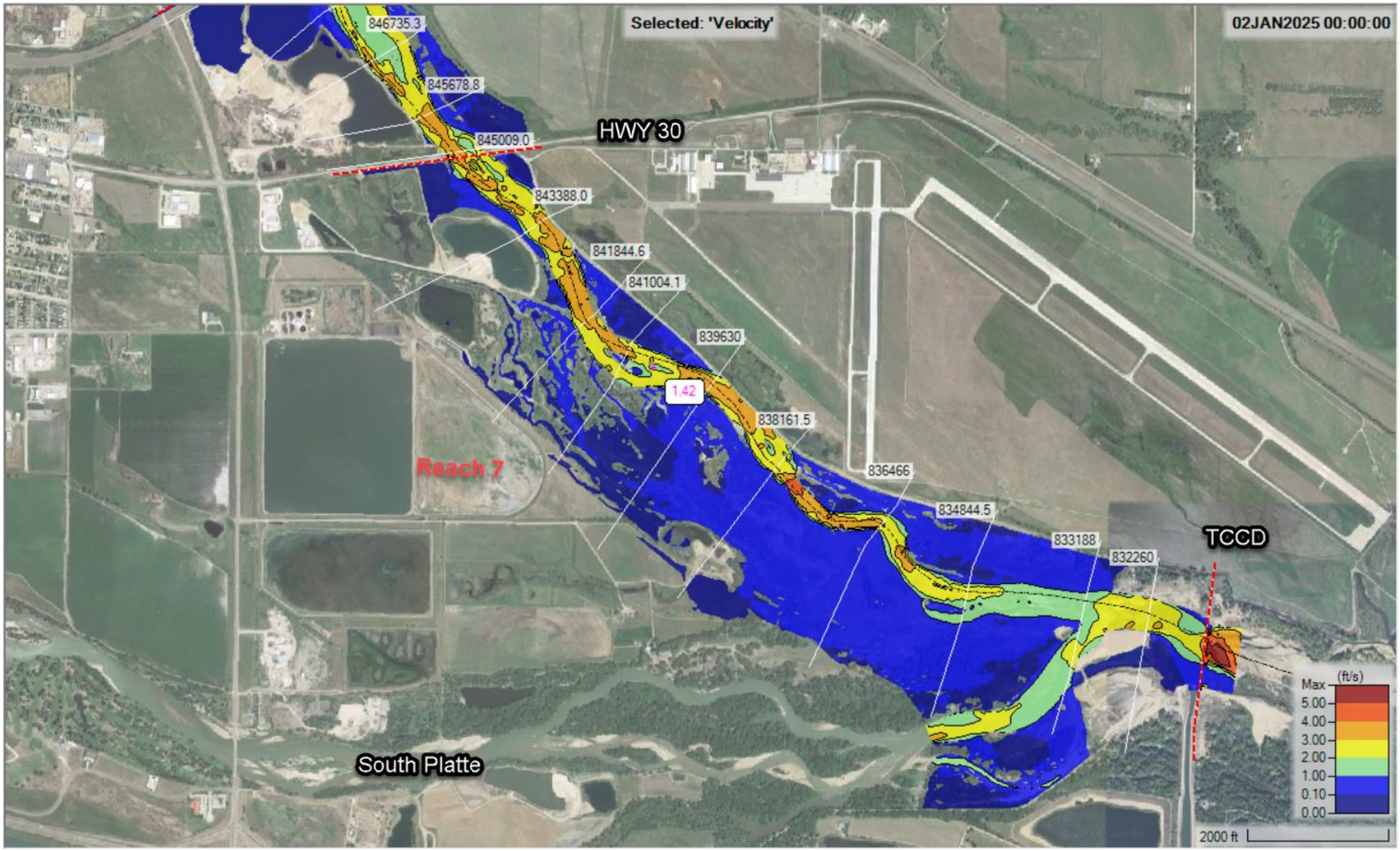



**Figure E-39 Velocity (ft/sec) Mapping 3,000 cfs – HWY 30 to Tri-County Diversion**

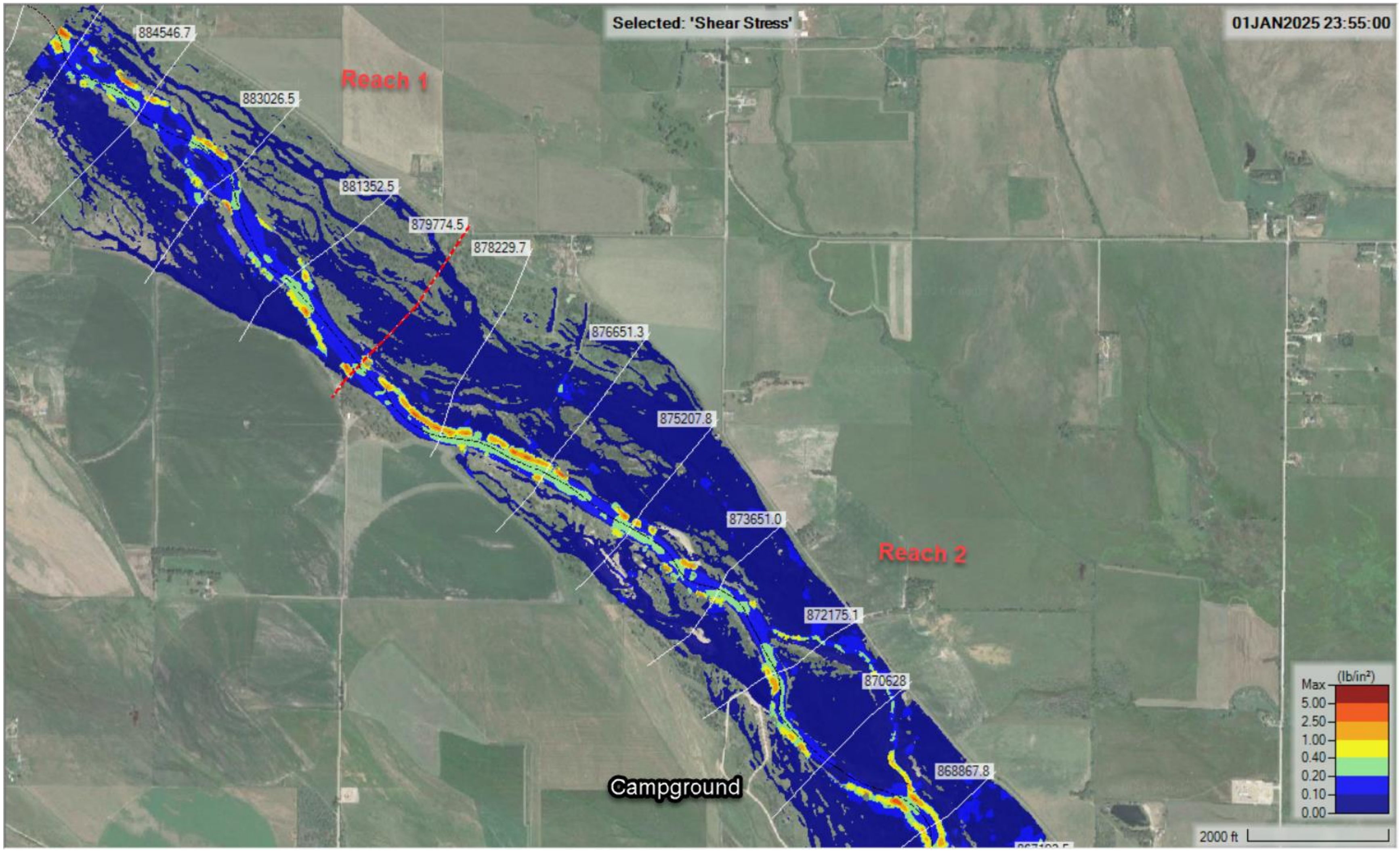



**Figure E-40 Shear Stress (lbs/ft2) Mapping 3,000 cfs – Reaches 1 and 2**

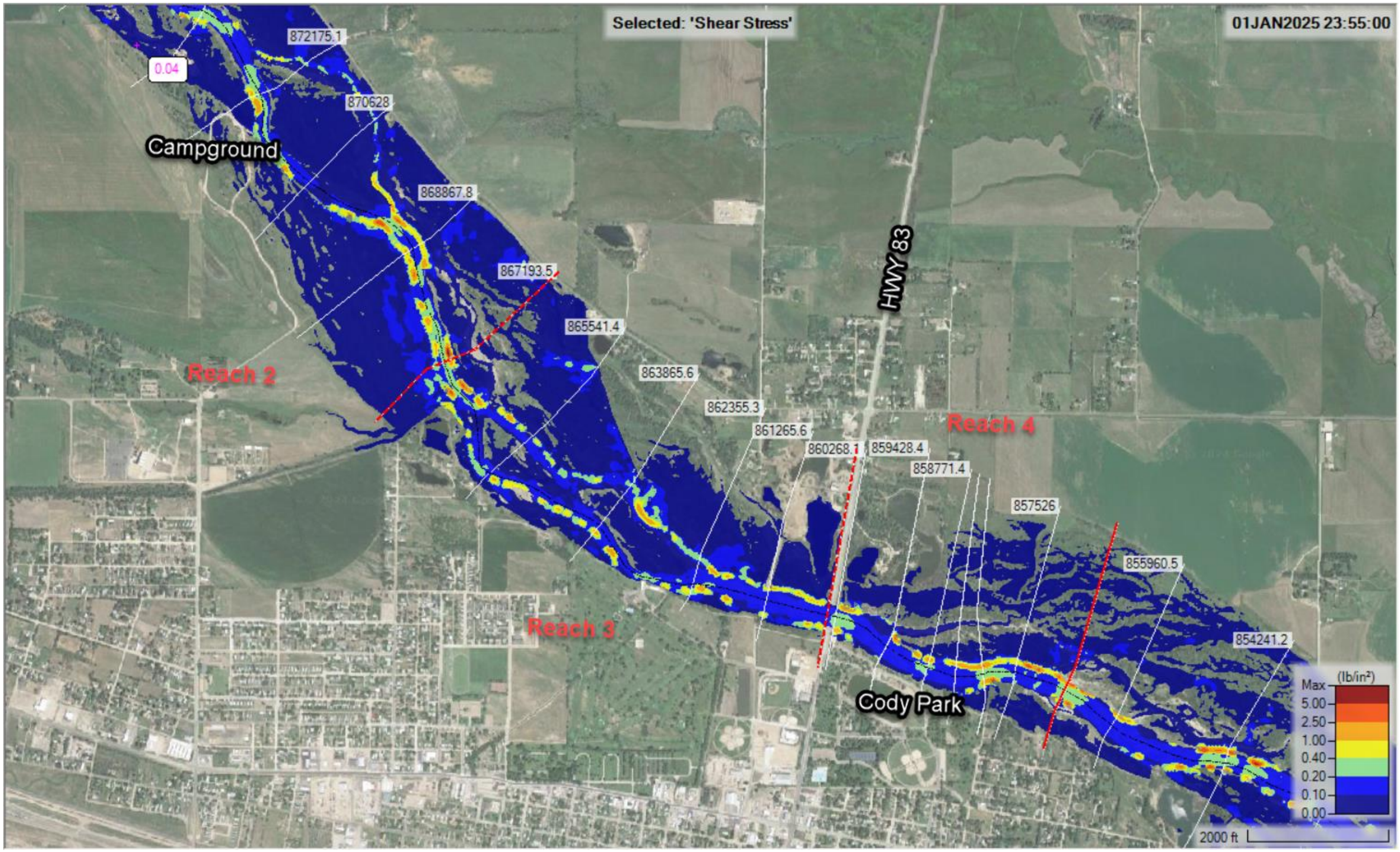



**Figure E-41 Shear Stress (lbs/ft2) Mapping 3,000 cfs – Campground to Cody Park**

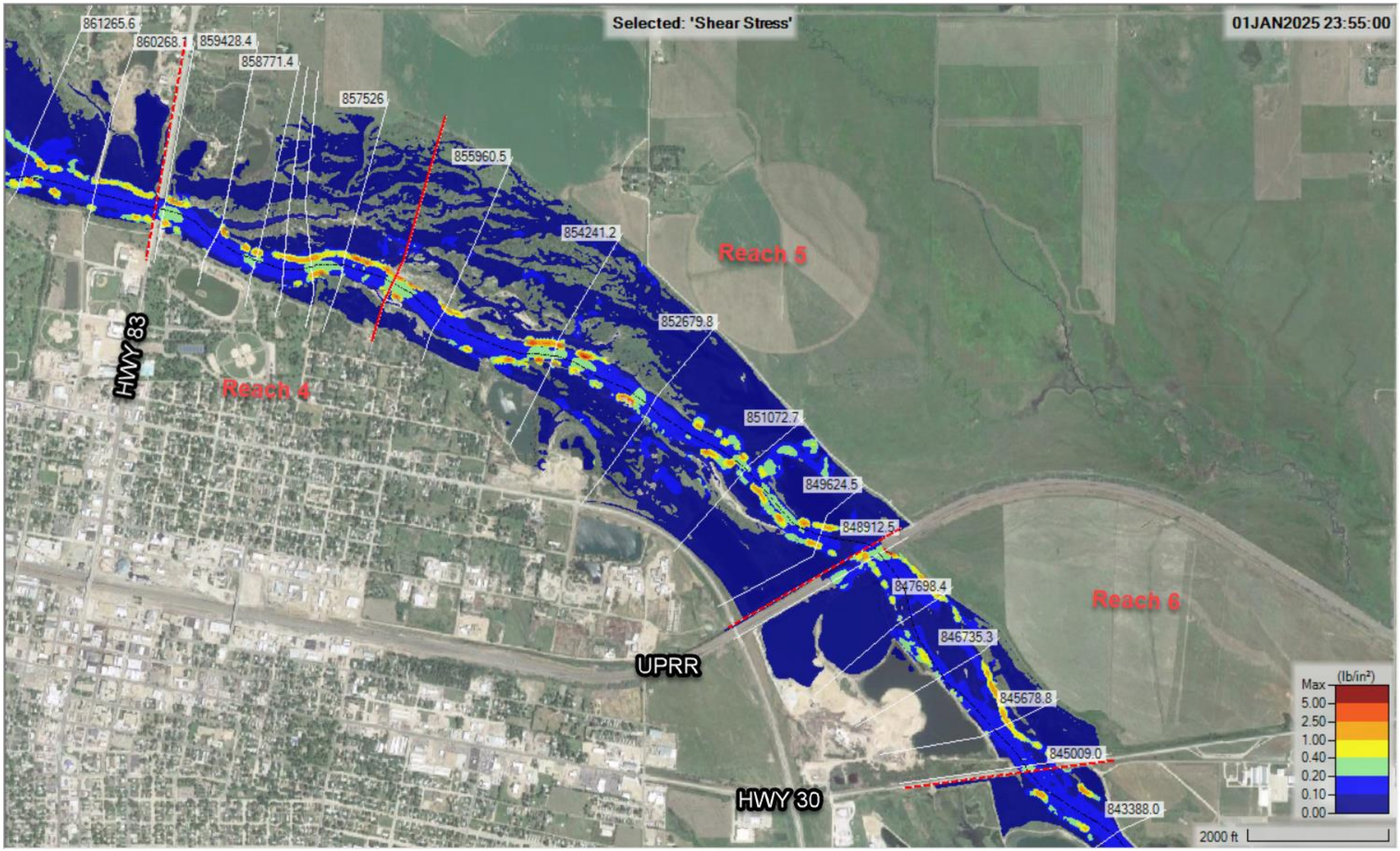



**Figure E-42 Shear Stress (lbs/ft2) Mapping 3,000 cfs – HWY 83 to HWY 30**

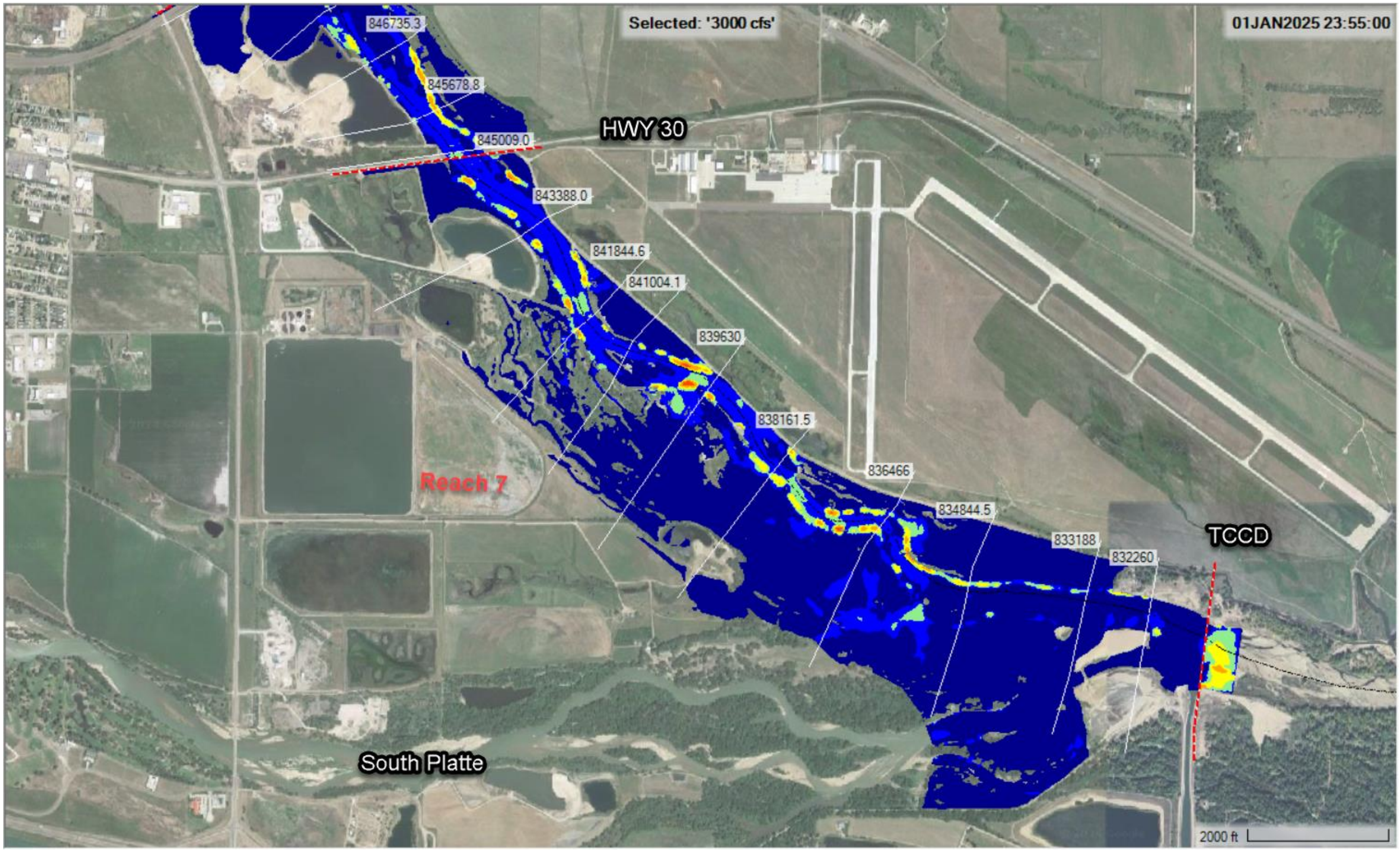
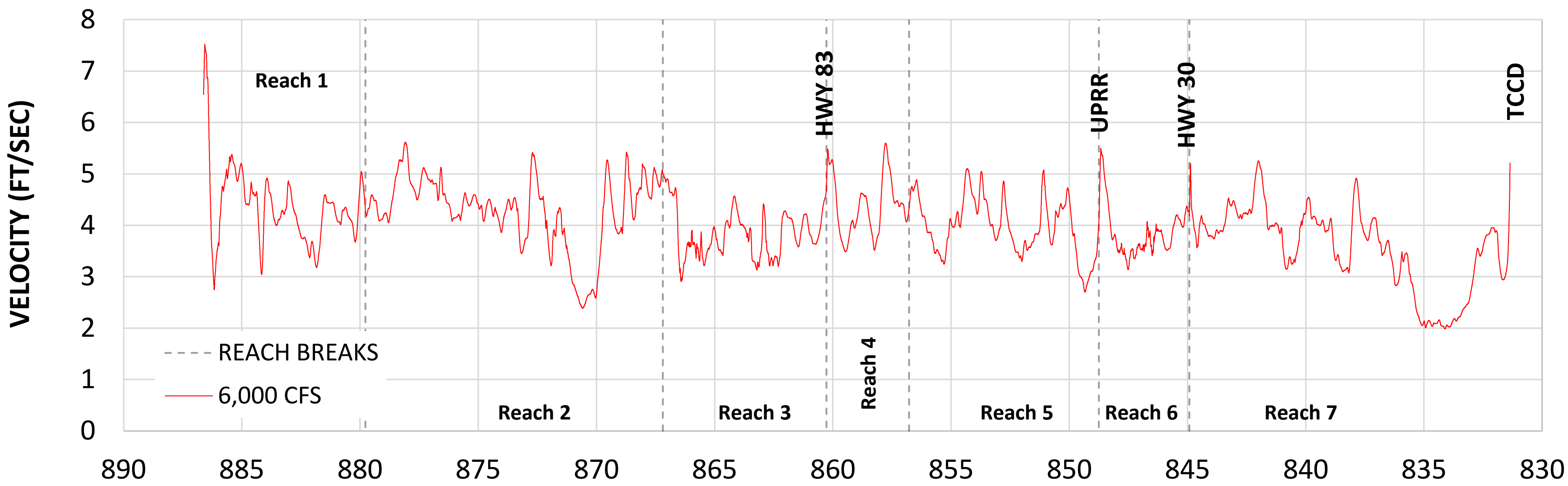



**Figure E-43 Shear Stress (lbs/ft2)  Mapping 3,000 cfs – HWY 30 to Tri-County Diversion**



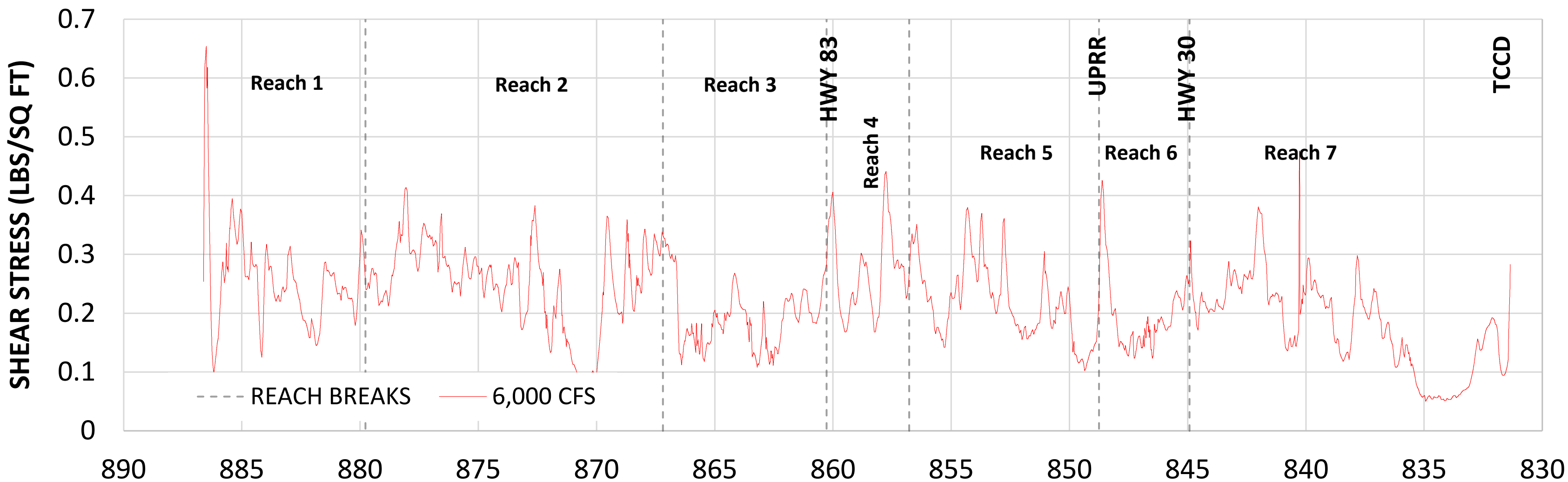




**Figure E-44 Channel Velocity and Shear Stress Profile – 6,000 cfs**

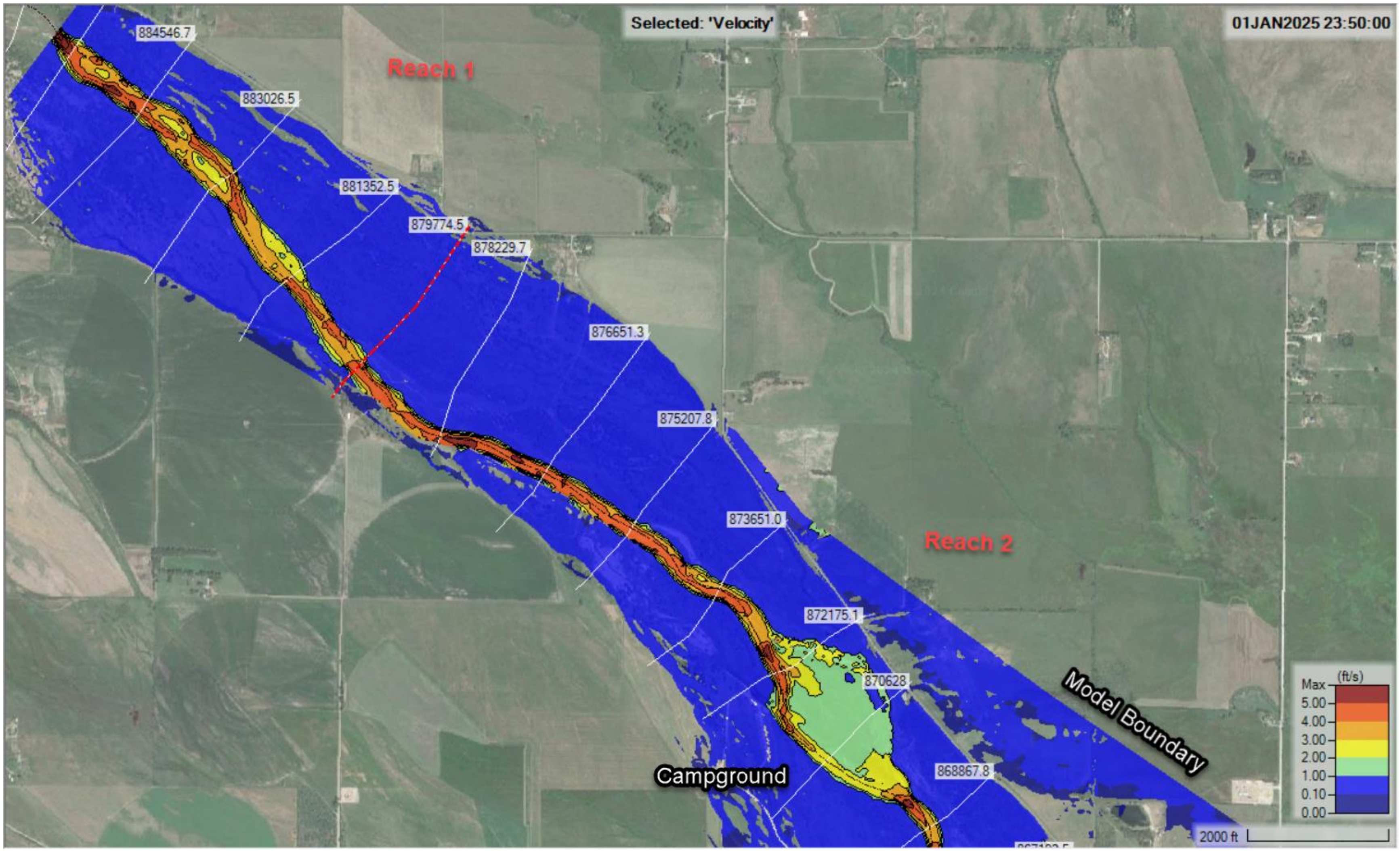



**Figure E-45 Velocity (ft/sec) Mapping 6,000 cfs – Reaches 1 and 2**

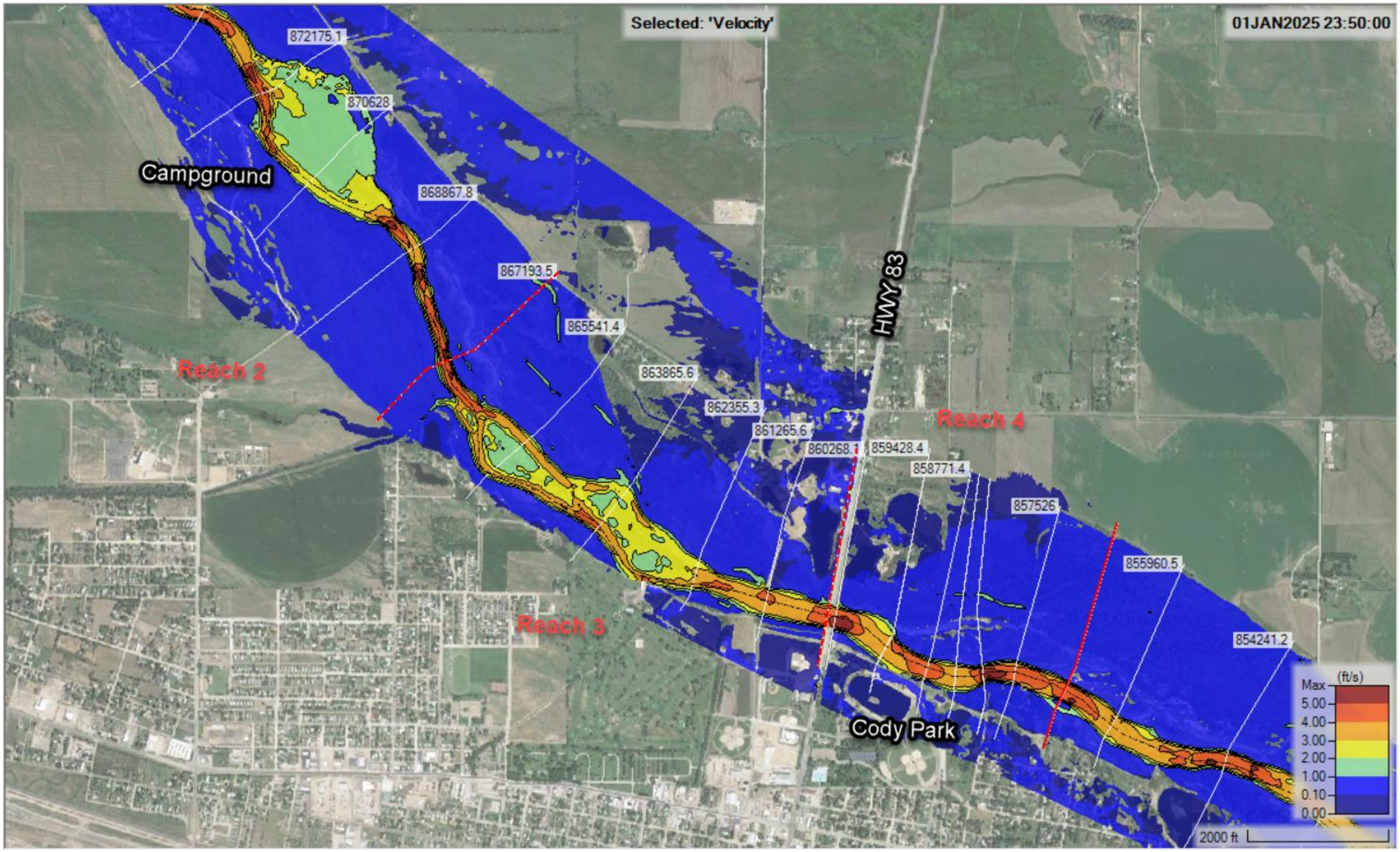



**Figure E-46 Velocity (ft/sec) Mapping 6,000 cfs – Campground to Cody Park**

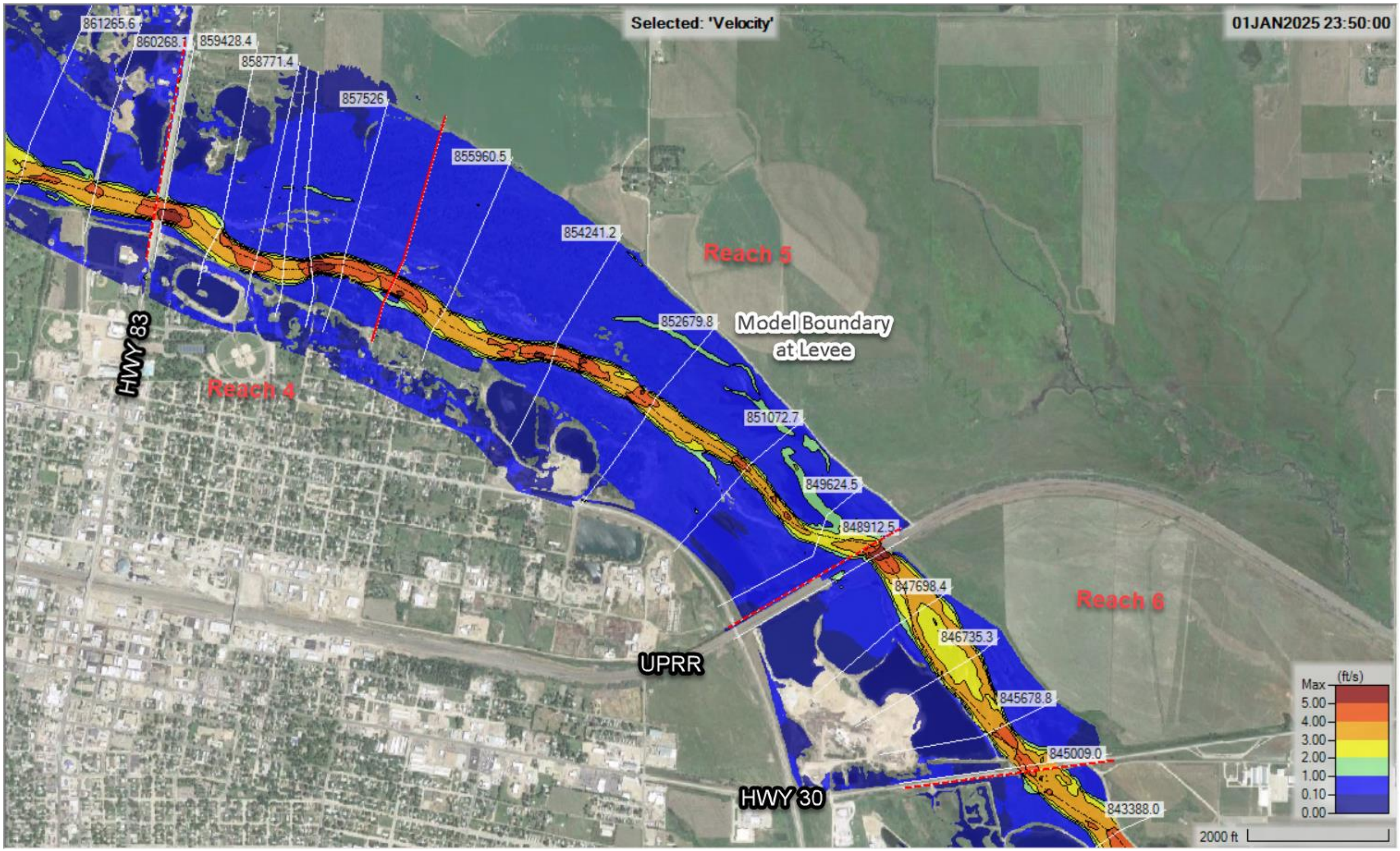



**Figure E-47 Velocity (ft/sec) Mapping 6,000 cfs – HWY 83 to HWY 30**

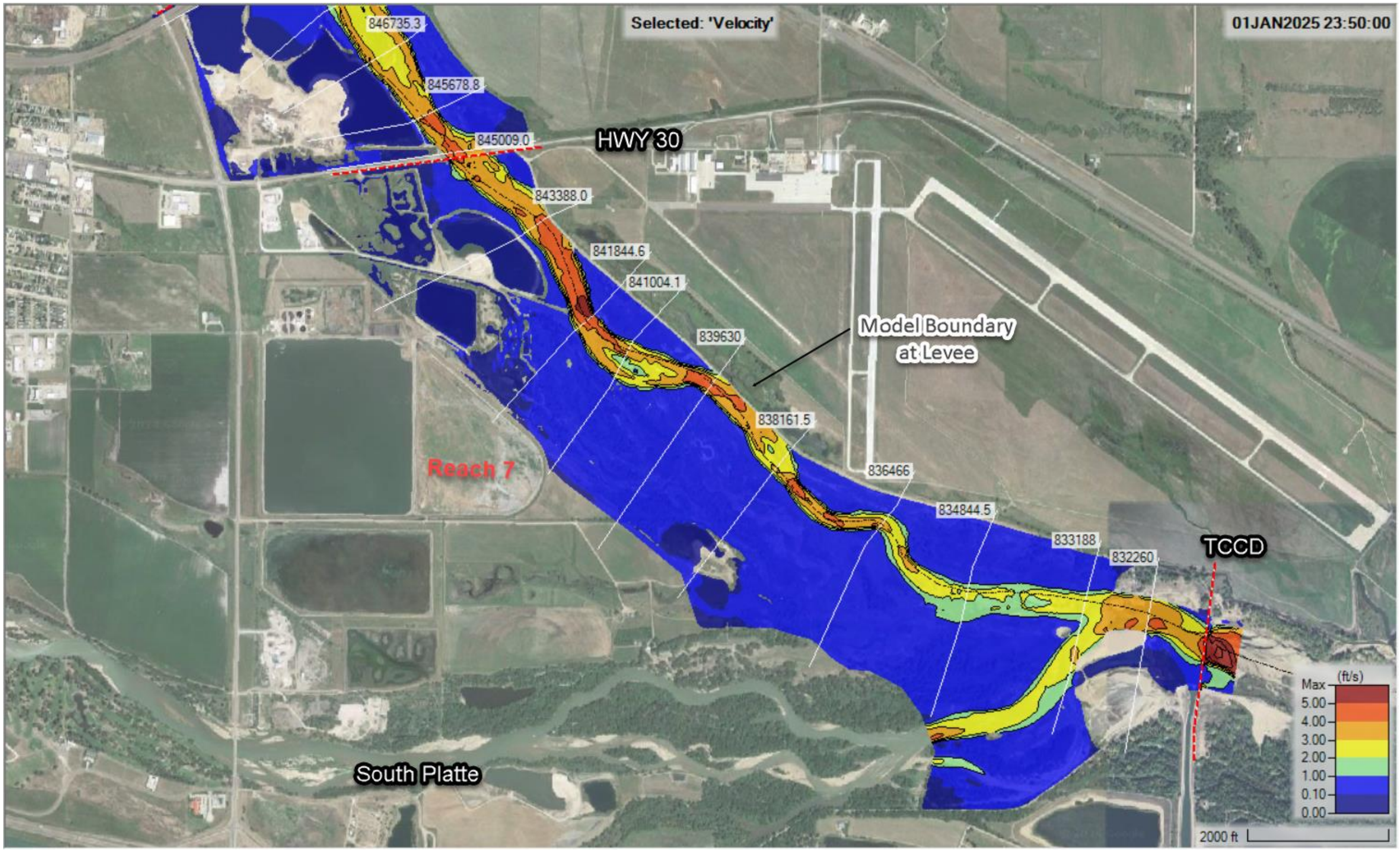



**Figure E-48 Velocity (ft/sec) Mapping 6,000 cfs – HWY 30 to Tri-County Diversion**

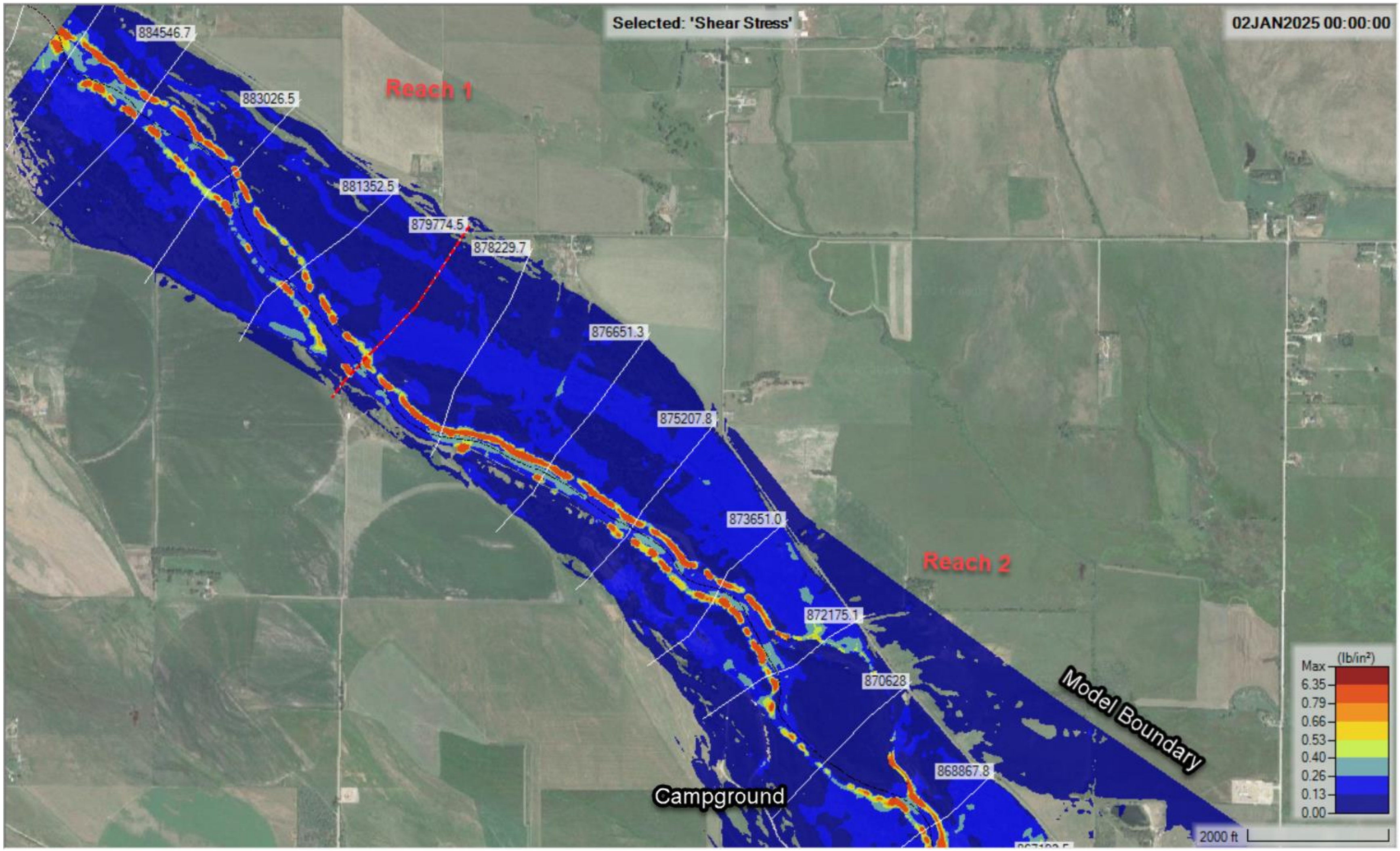



**Figure E-49 Shear Stress (lbs/ft2) Mapping 6,000 cfs – Reaches 1 and 2**

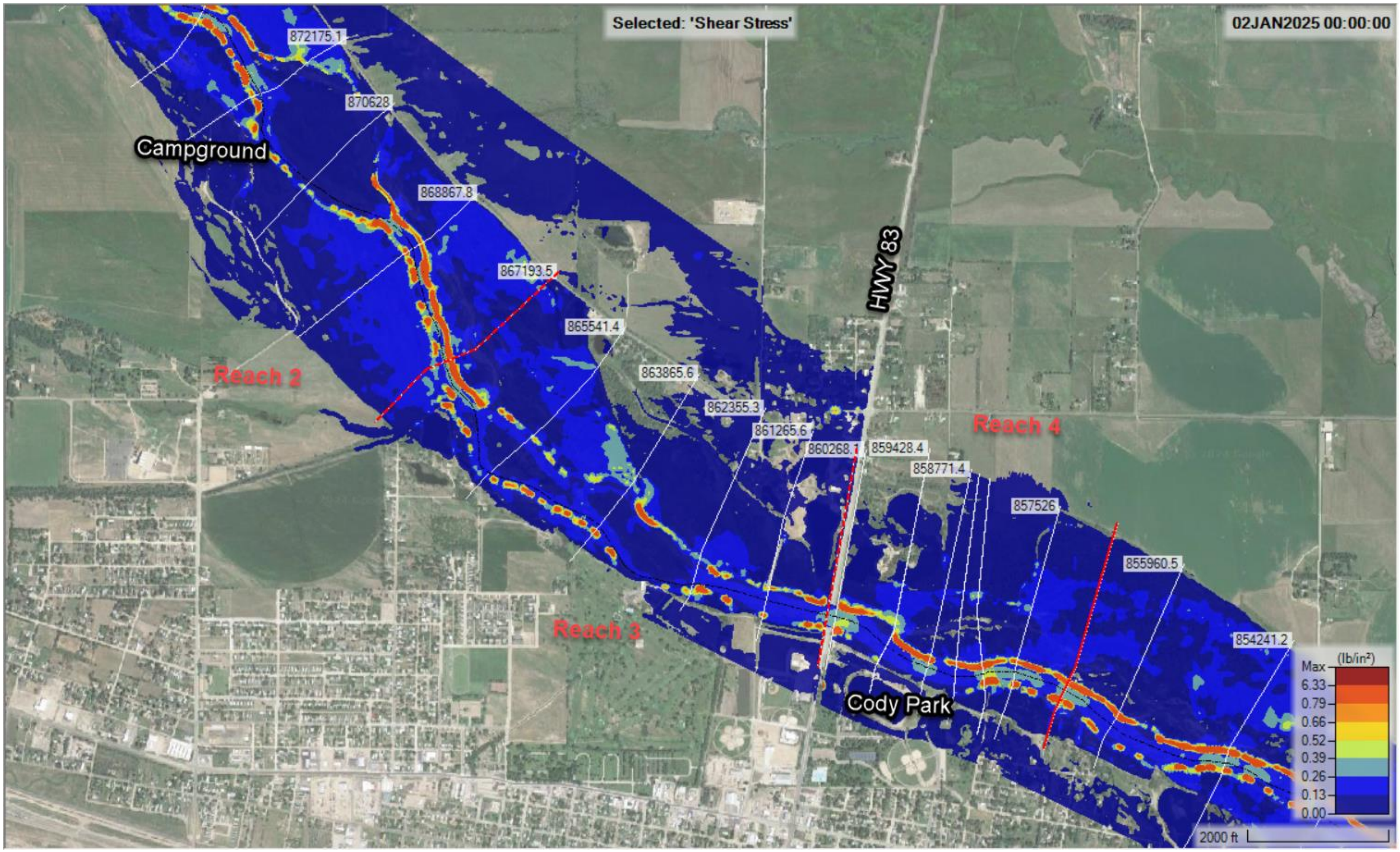



**Figure E-50 Shear Stress (lbs/ft2) Mapping 6,000 cfs – Campground to Cody Park**

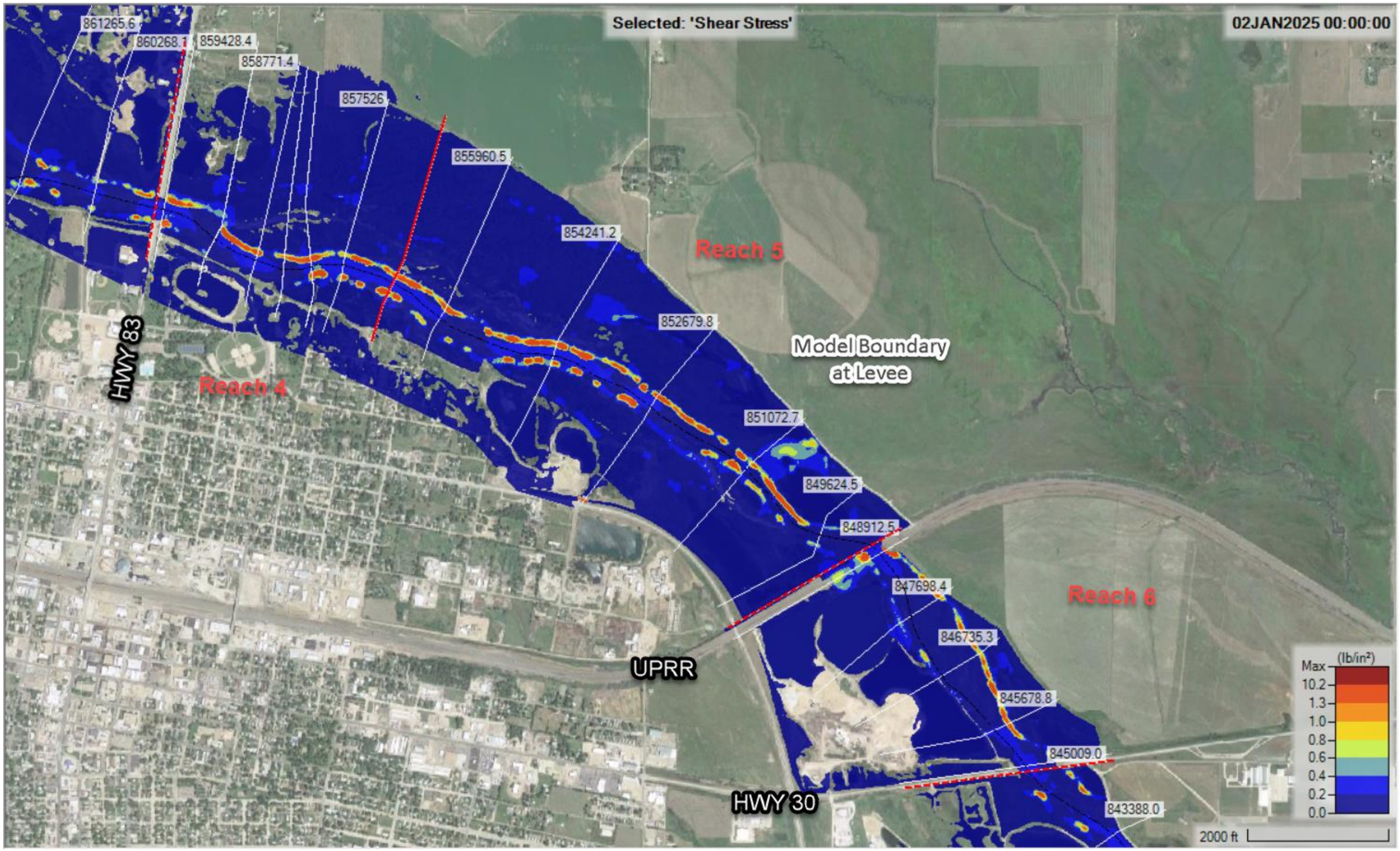



**Figure E-51 Shear Stress (lbs/ft2) Mapping 6,000  cfs – HWY 83 to HWY 30**

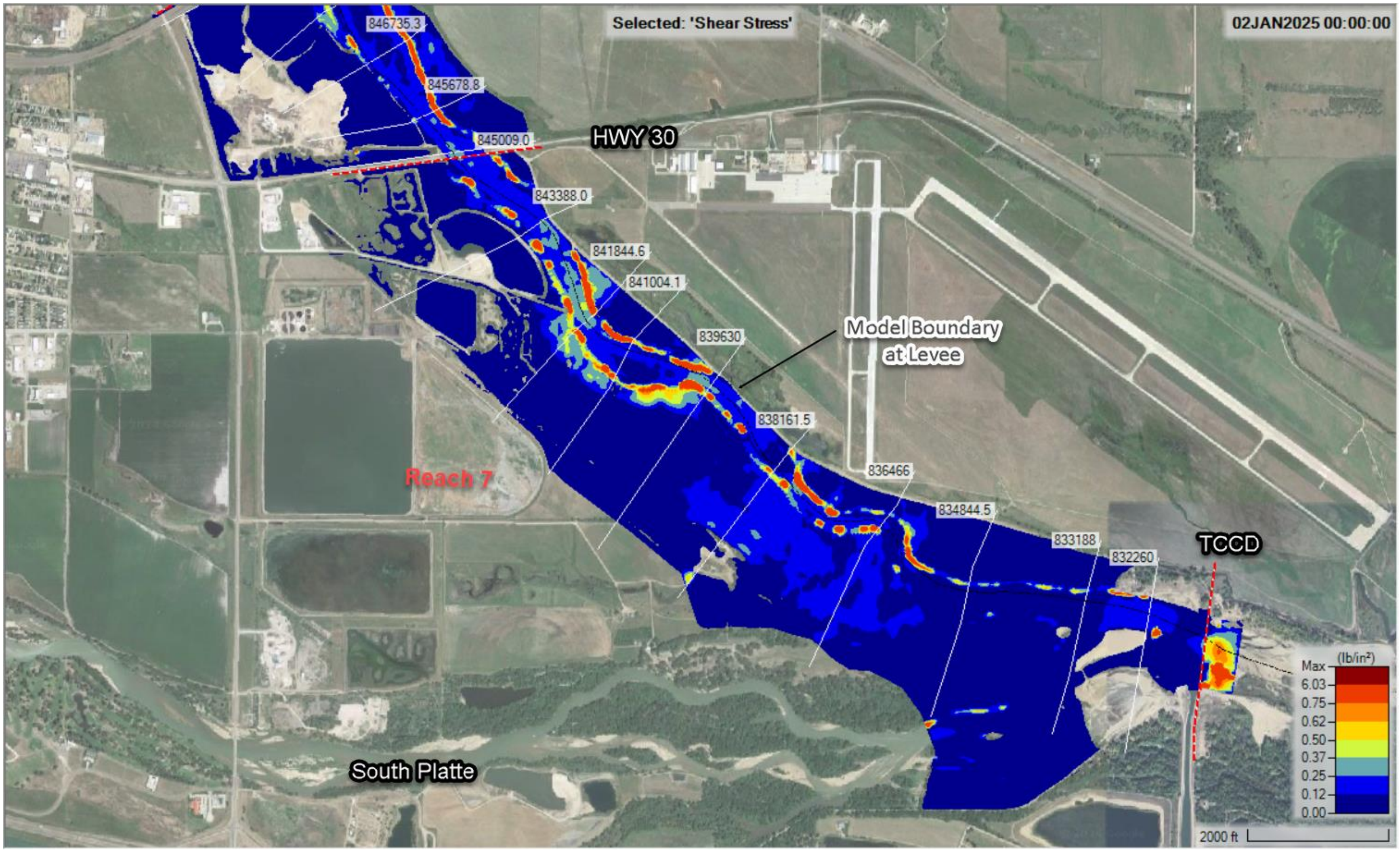
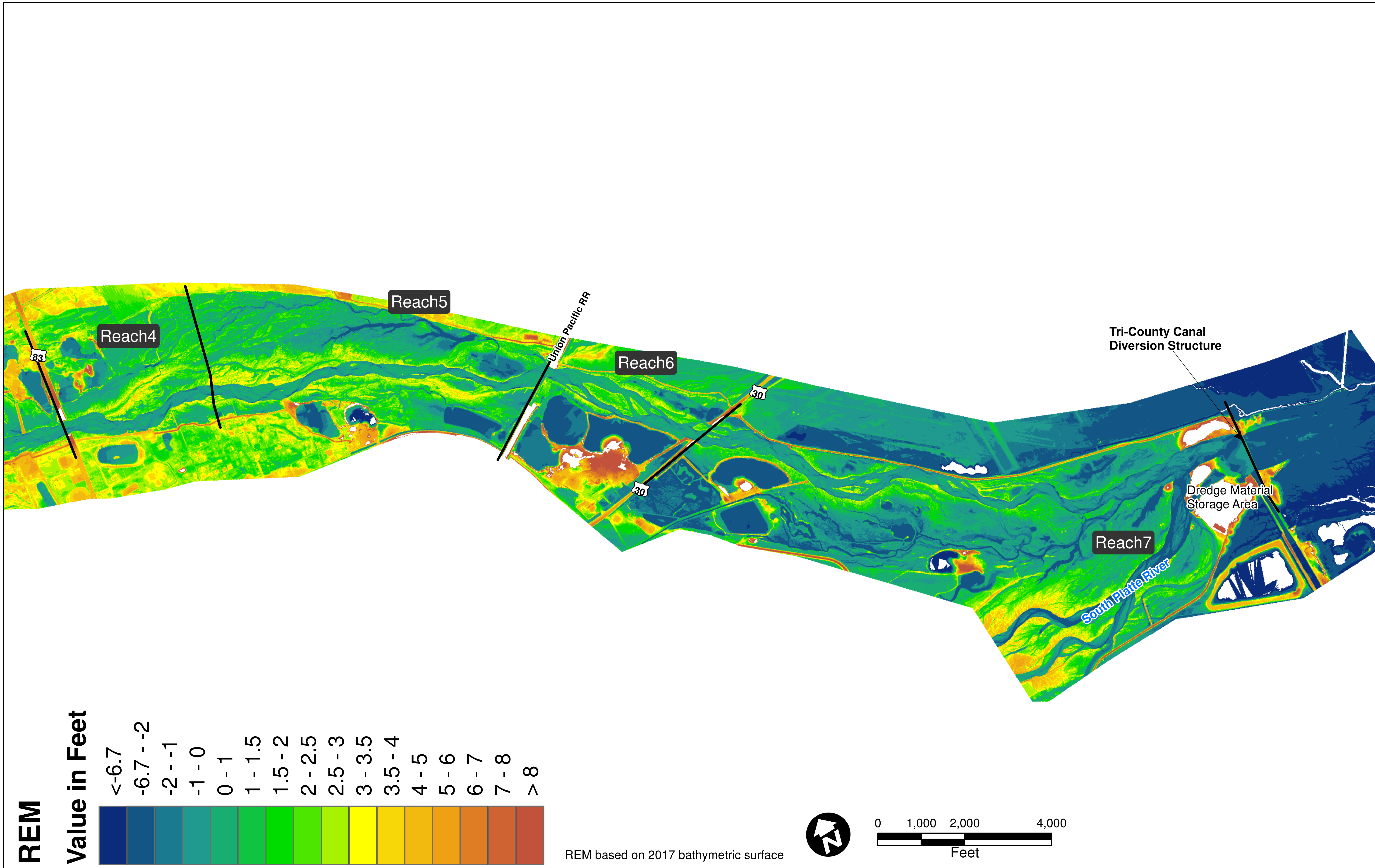


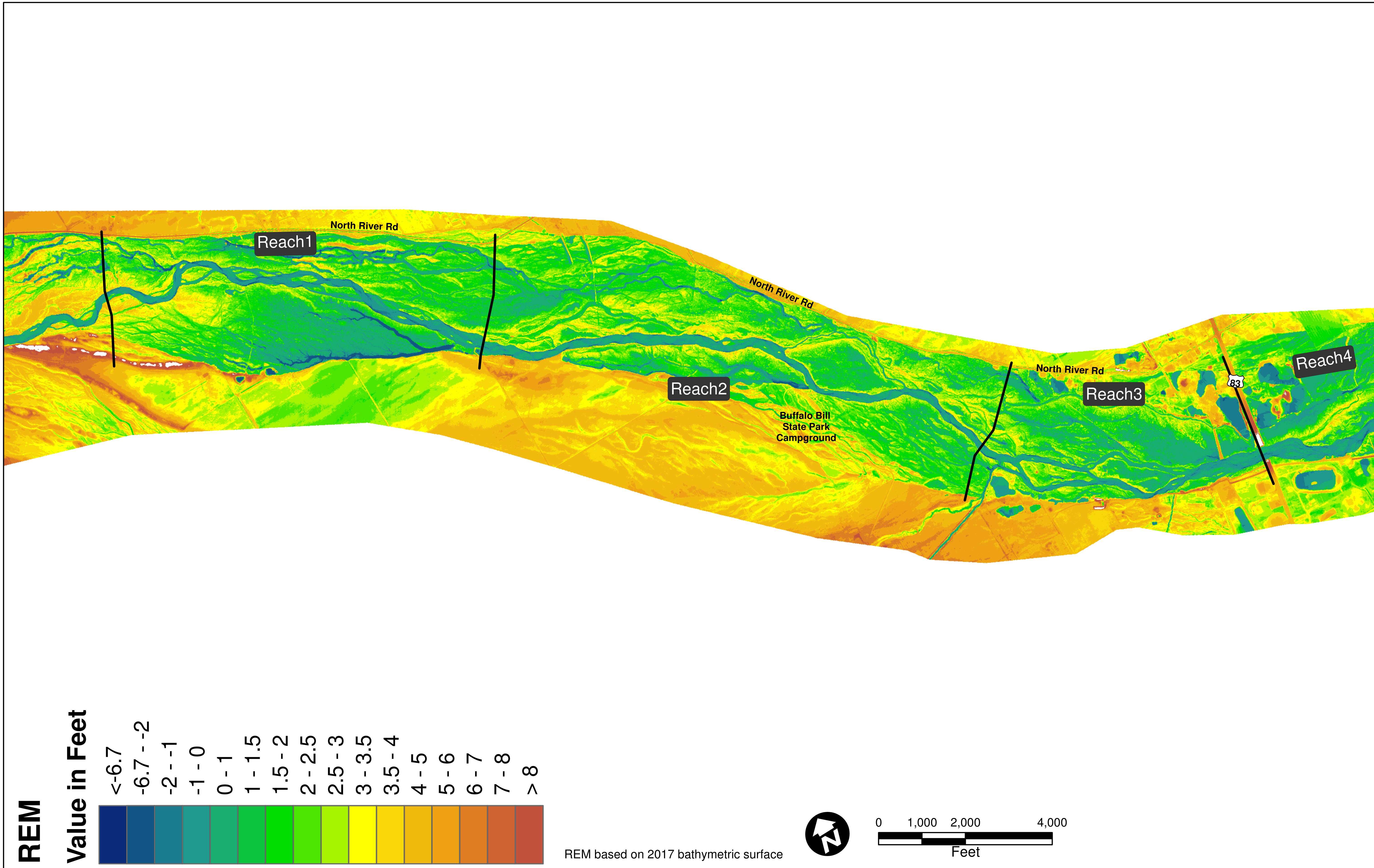

**Figure E-52 Shear Stress (lbs/ft2) Mapping 6,000 cfs – HWY 30 to Tri-County Diversion**

# APPENDIX F. RELATIVE ELEVATION MODEL

# Relative Elevation Model Downstream of US 83

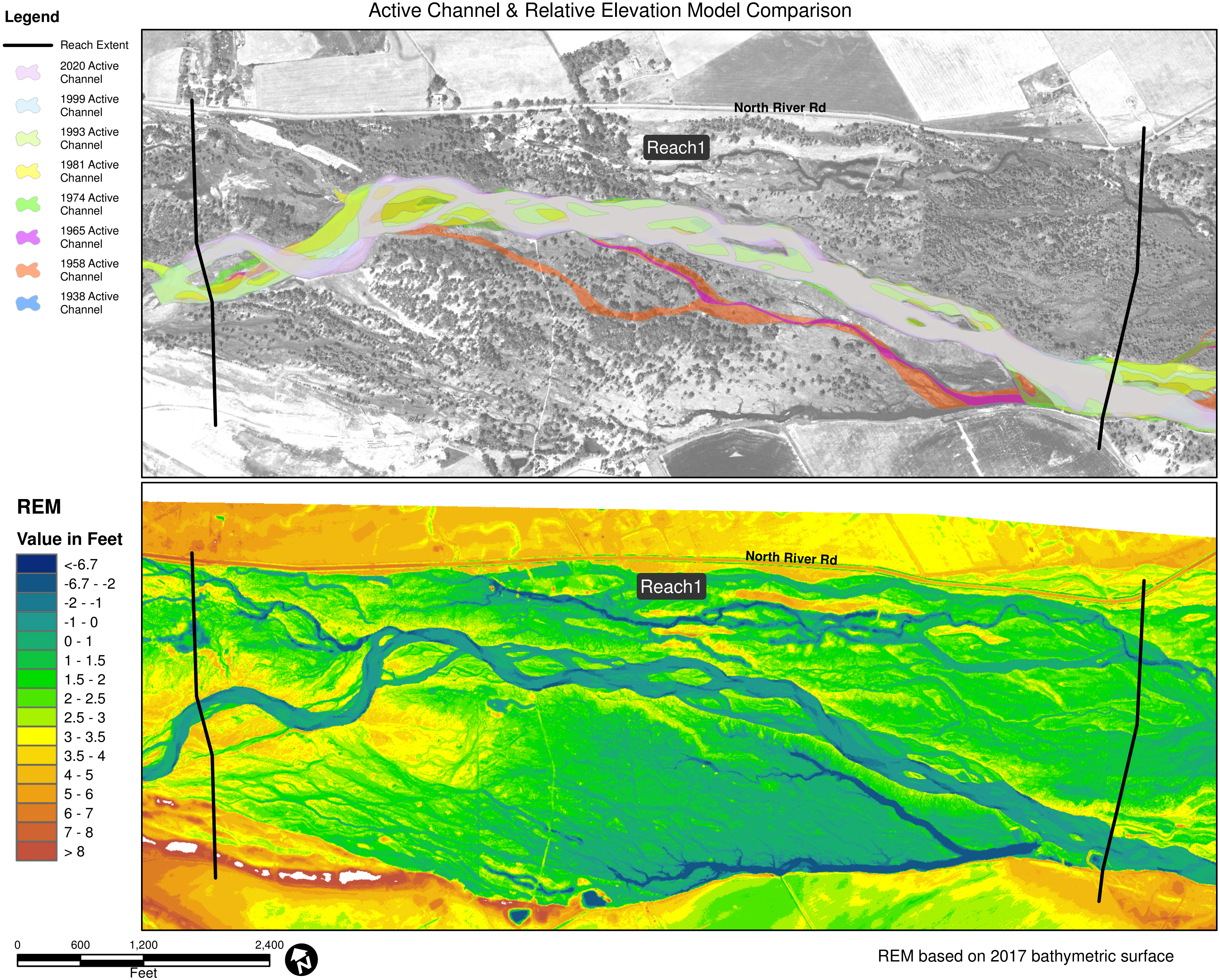


# Relative Elevation Model Upstream of US 83



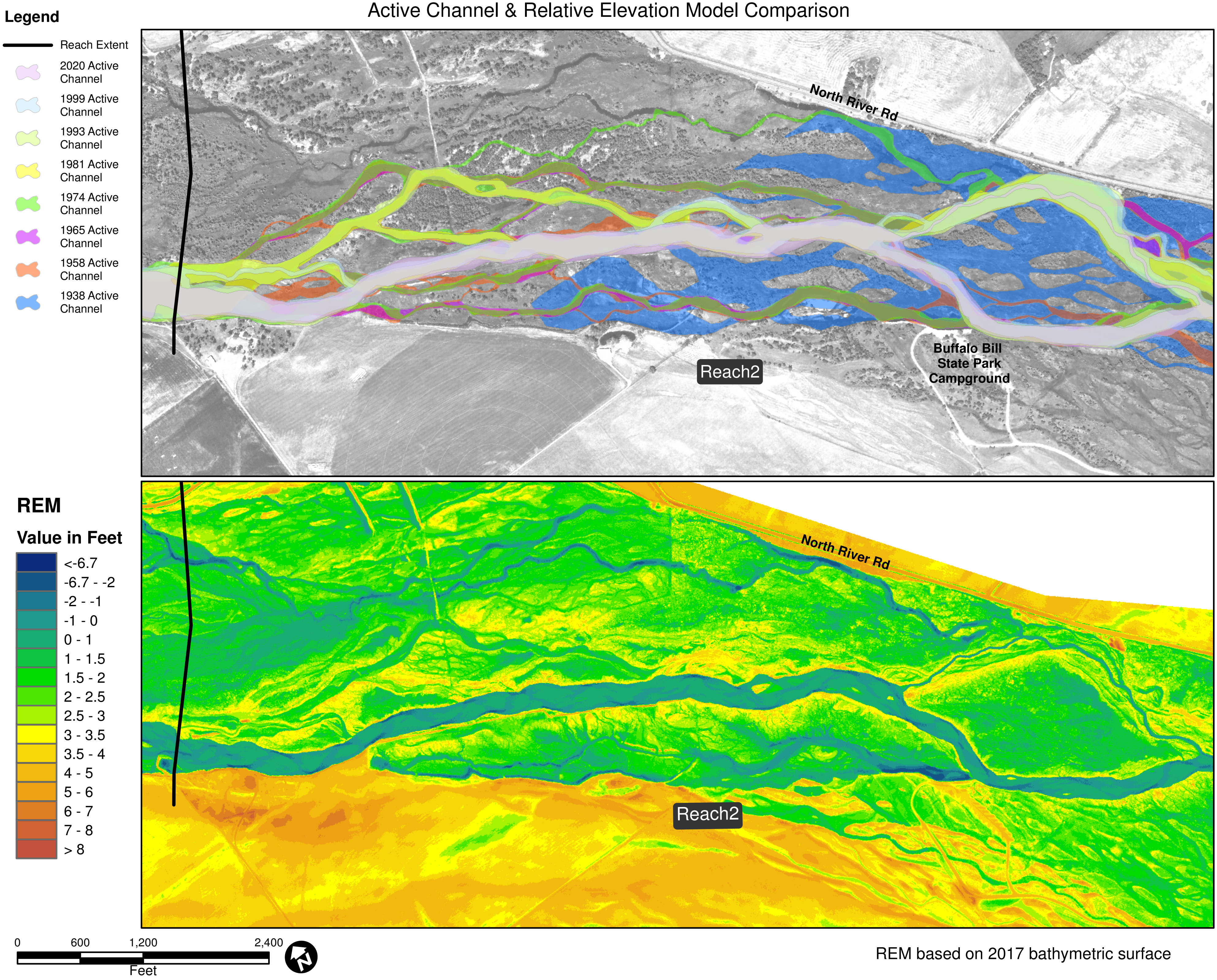
# APPENDIX G. RELATIVE ELEVATION MODEL AND ACTIVE CHANNEL EVOLUTION BY REACH

Active Channel & Relative Elevation Model Comparison



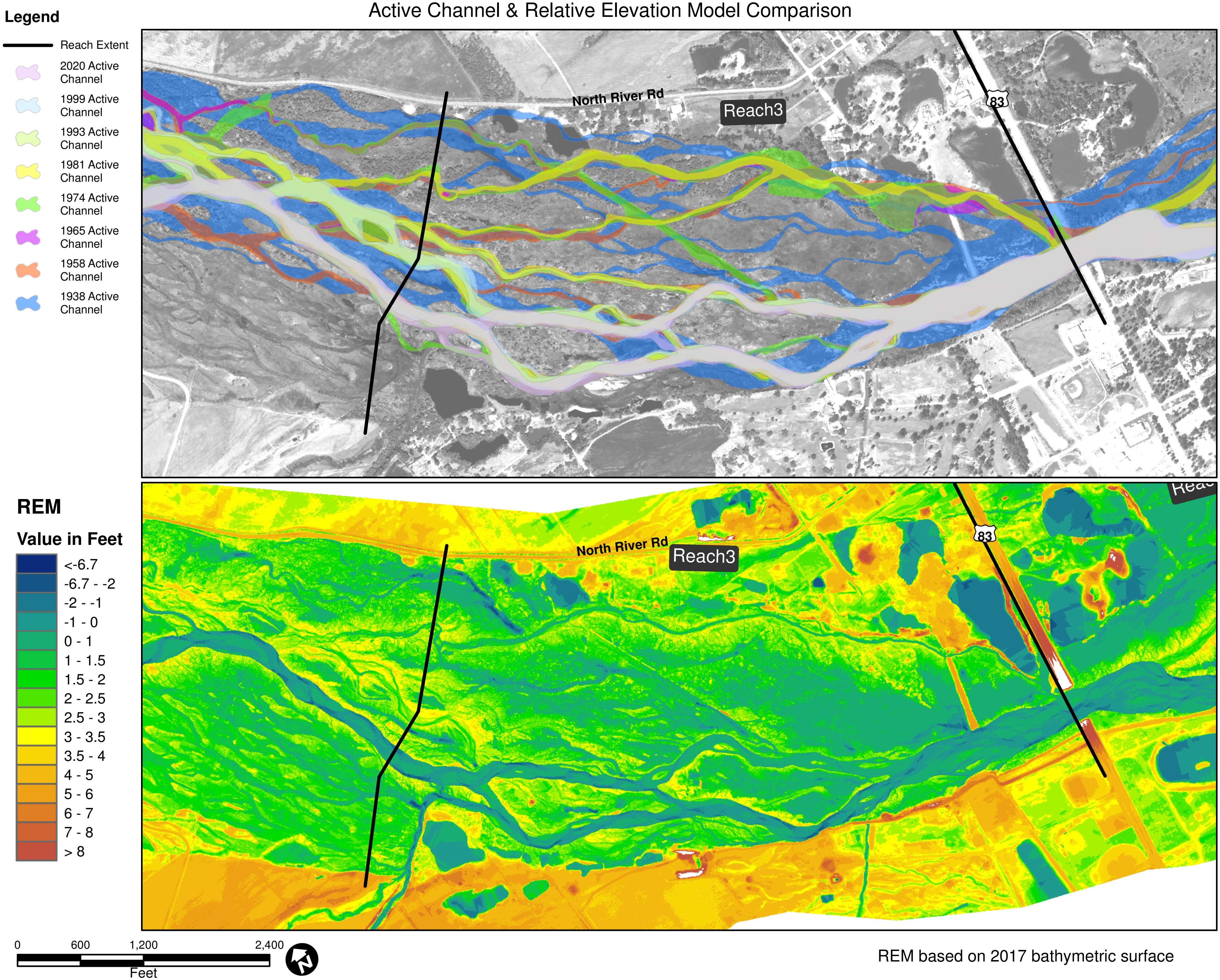

REM based on 2017 bathymetric surface

## Active Channel & Relative Elevation Model Comparison




REM based on 2017 bathymetric surface

Active Channel & Relative Elevation Model Comparison

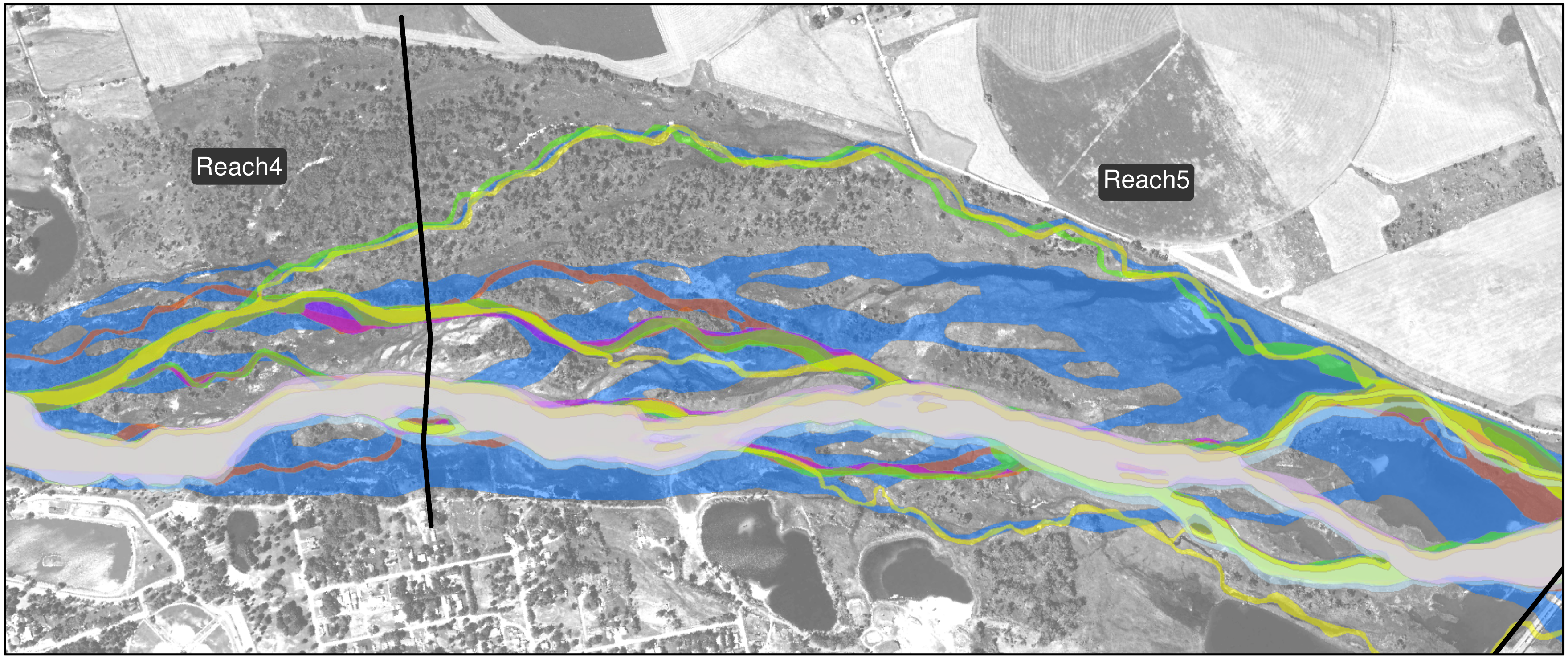



REM based on 2017 bathymetric surface

## Active Channel & Relative Elevation Model Comparison

**Legend**

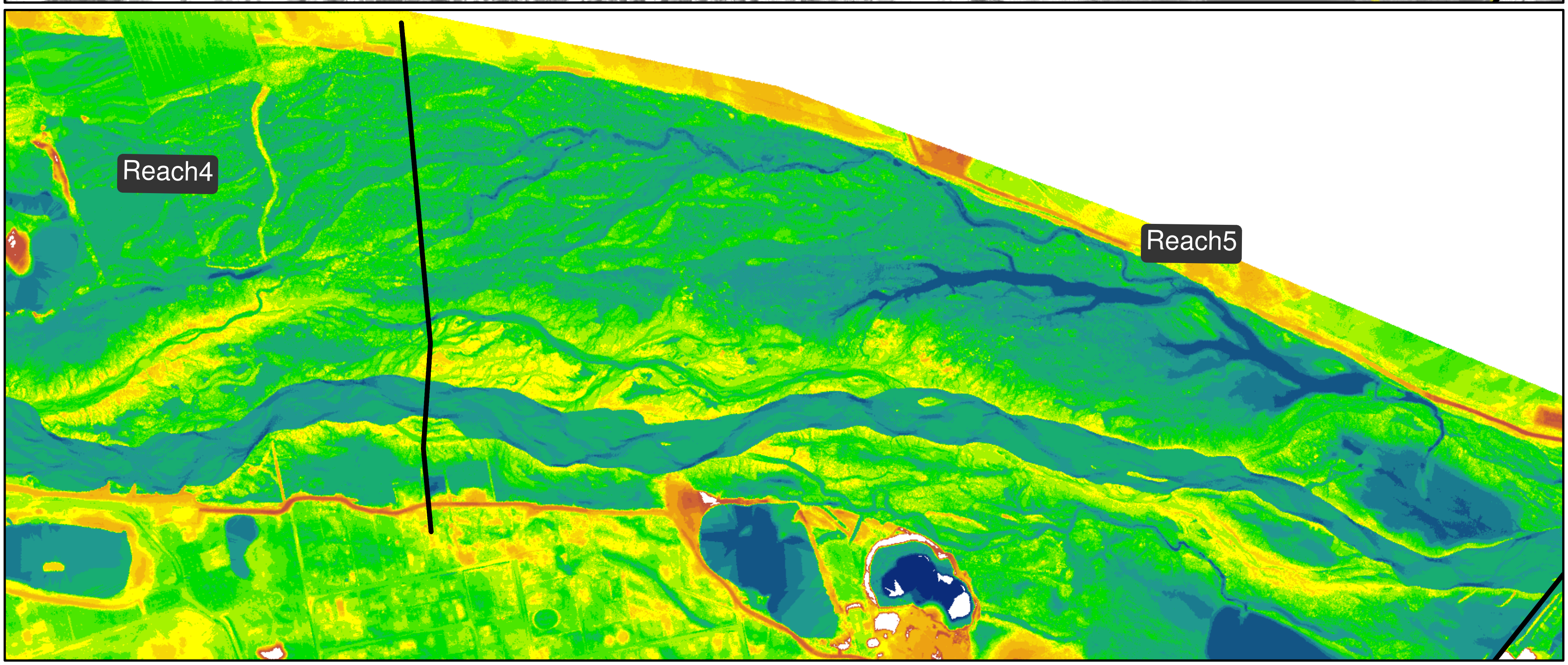
- Reach Extent
- 2020 Active Channel
- 1999 Active Channel
- 1993 Active Channel
- 1981 Active Channel
- 1974 Active Channel
- 1965 Active Channel
- 1958 Active Channel
- 1938 Active Channel




**REM**

**Value in Feet**

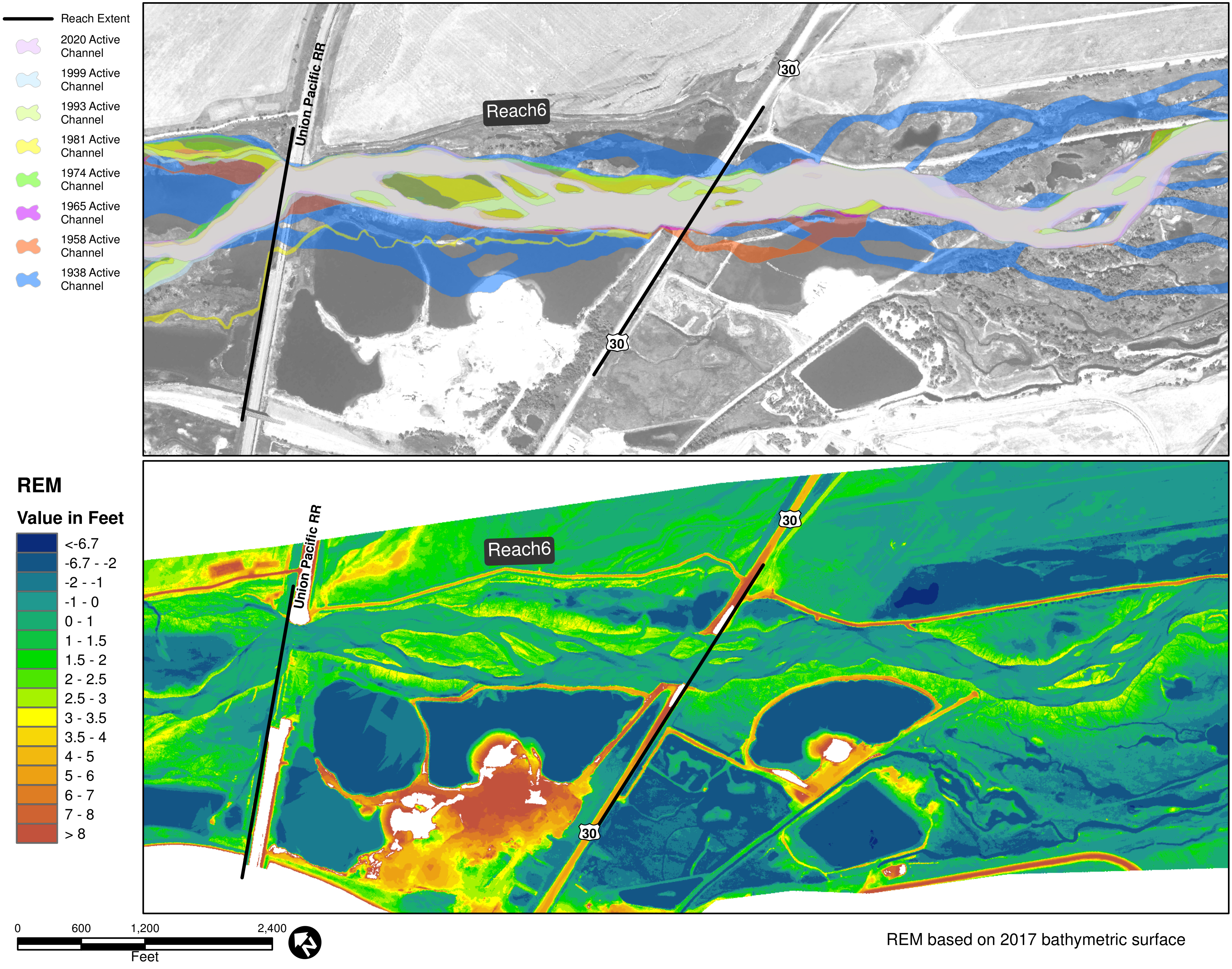
- <-6.7
- -6.7 - -2
- -2 - -1
- -1 - 0
- 0 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- > 8



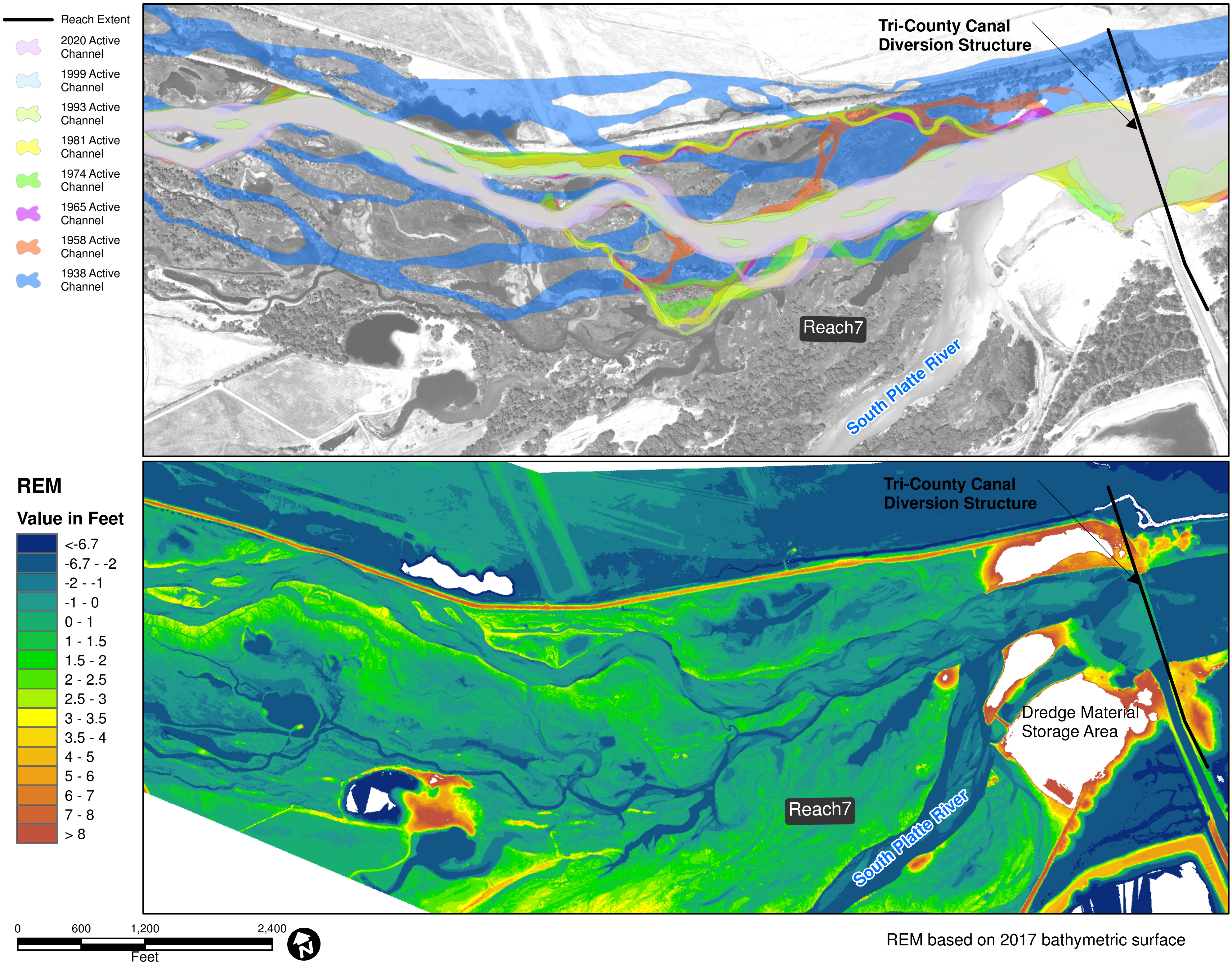

0 600 1,200 2,400
Feet

REM based on 2017 bathymetric surface

## Active Channel & Relative Elevation Model Comparison

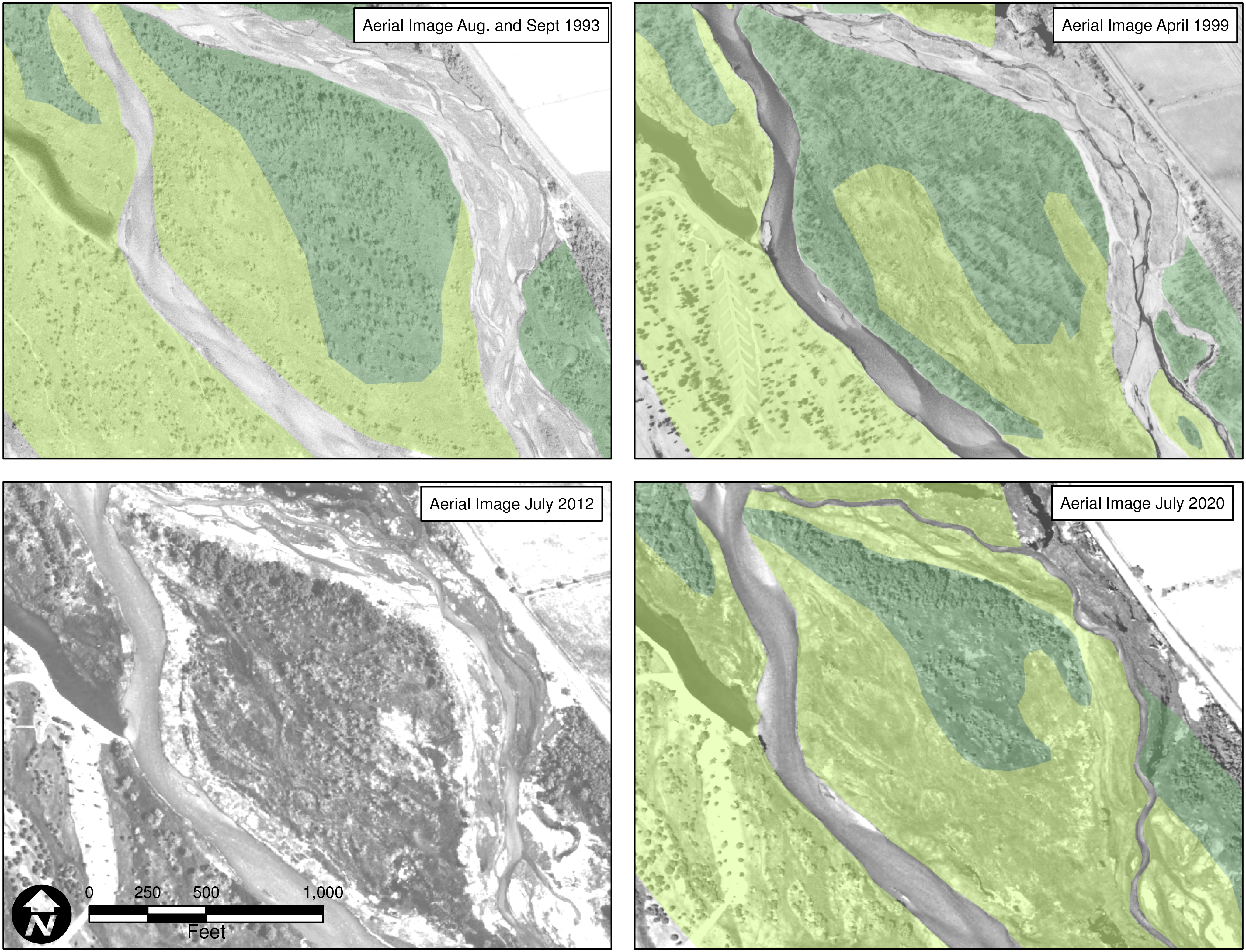


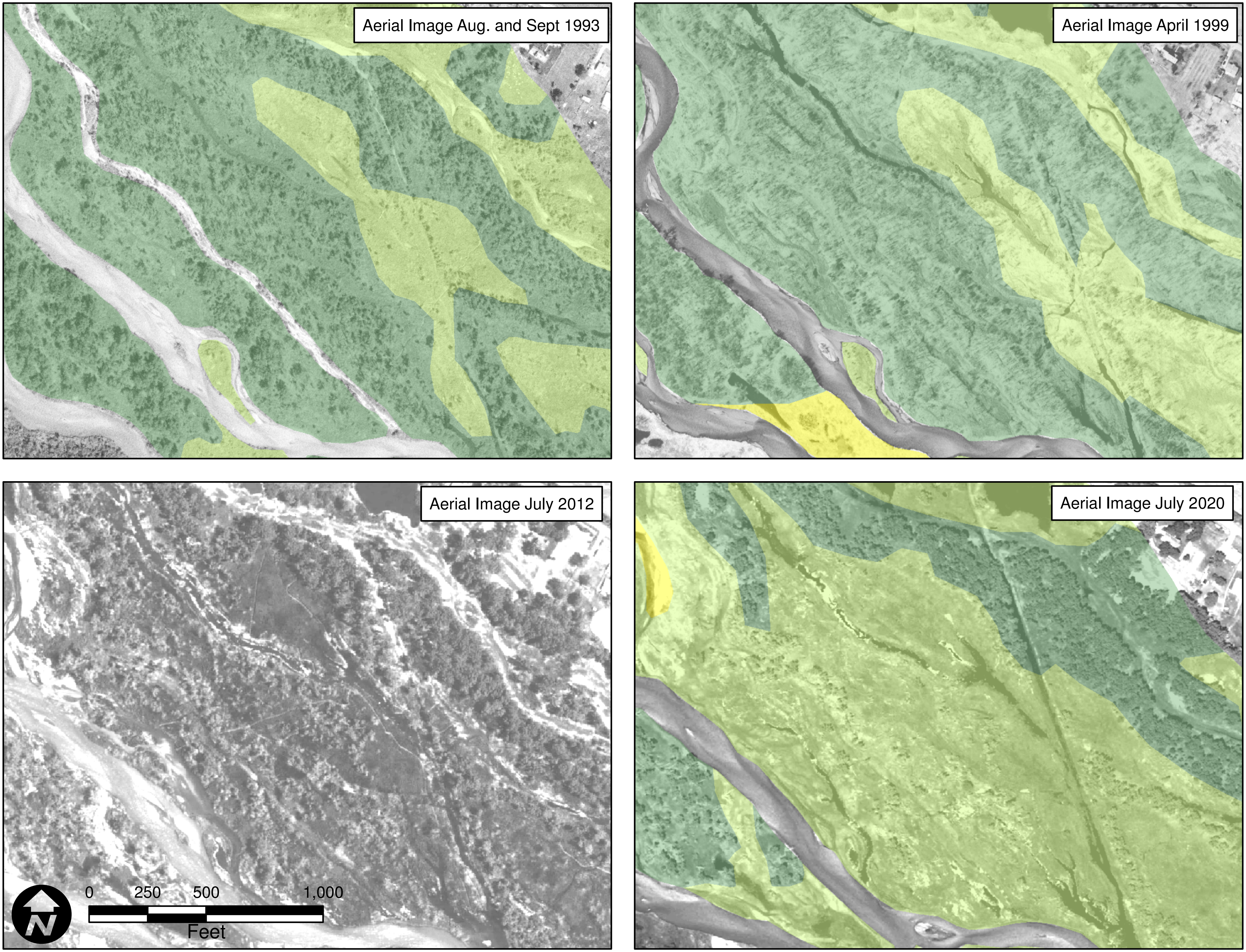
Active Channel & Relative Elevation Model Comparison

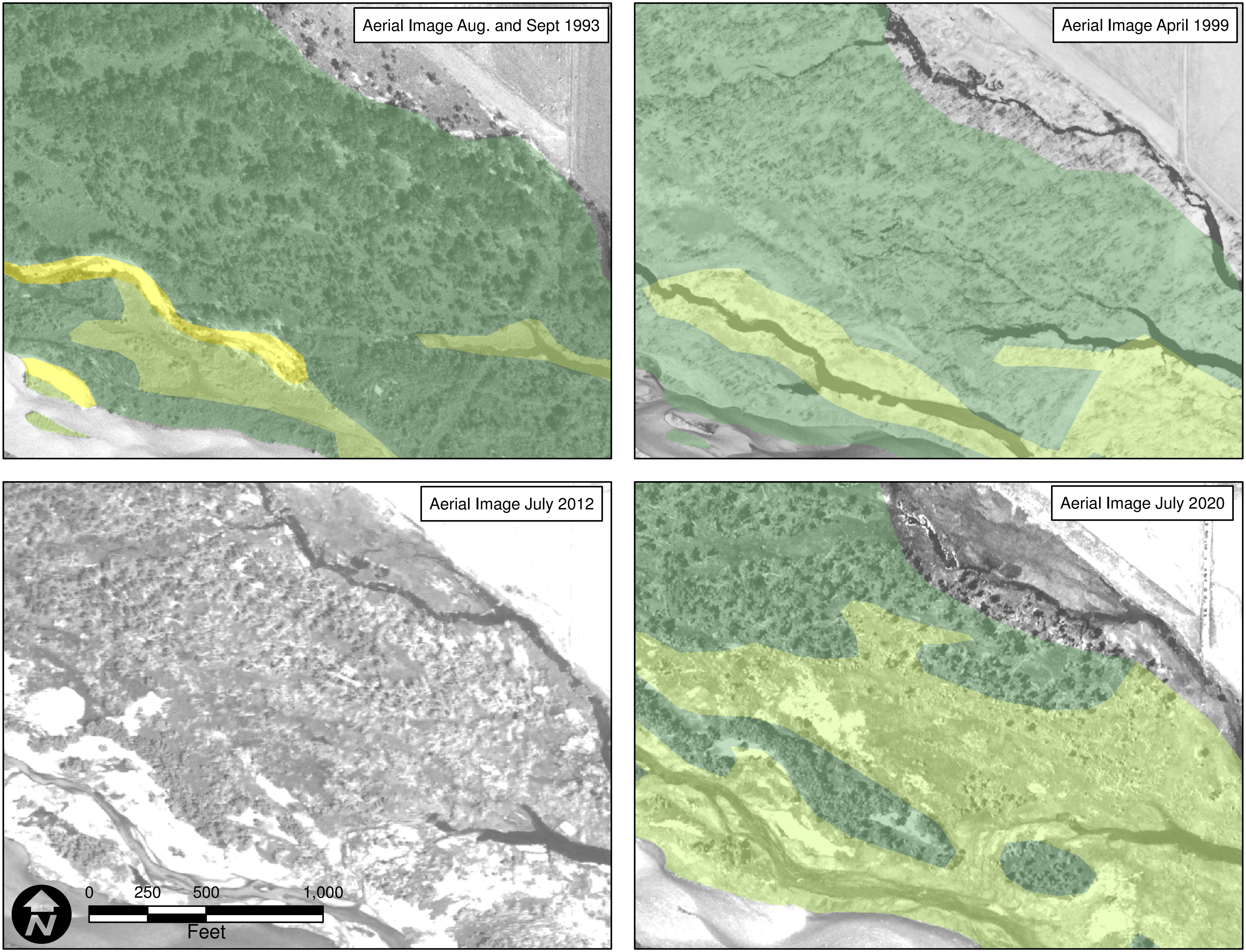



REM based on 2017 bathymetric surface

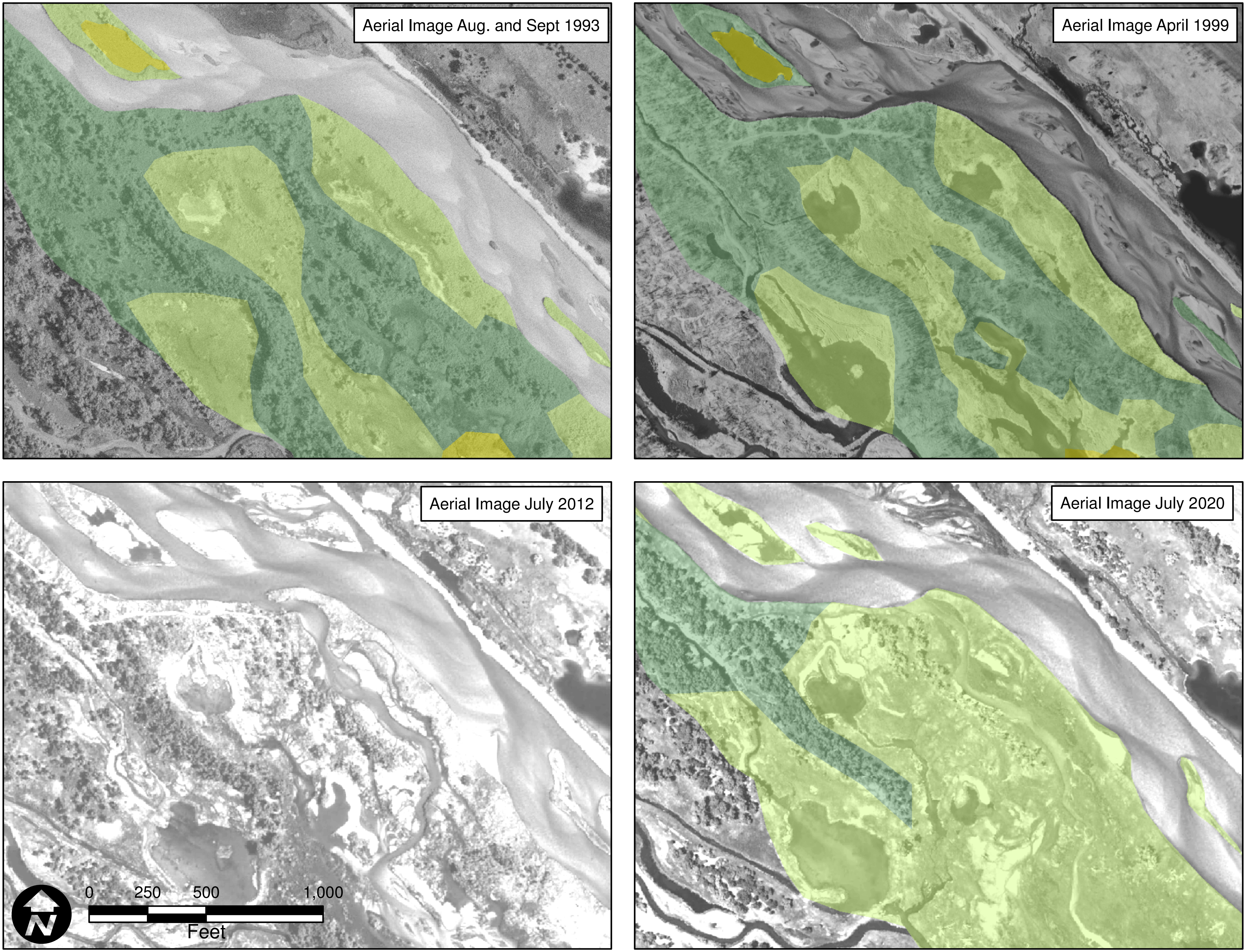
# APPENDIX H. VEGETATION COVER COMPARISON 1993 - 2020


Aerial Image Aug. and Sept 1993
Aerial Image April 1999
Aerial Image July 2012
Aerial Image July 2020
0
250
500
1,000
Feet
N


Aerial Image Aug. and Sept 1993
Aerial Image April 1999
Aerial Image July 2012
0
250
500
1,000
Feet
Aerial Image July 2020



Aerial Image Aug. and Sept 1993
Aerial Image April 1999
Aerial Image July 2012
Aerial Image July 2020
0
250
500
1,000
Feet


Aerial Image Aug. and Sept 1993
Aerial Image April 1999
Aerial Image July 2012
Aerial Image July 2020
0
250
500
1,000
Feet
N