PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -or- PROGRAM)

SEDIMENT AUGMENTATION EVALUATION

Amended on 2/6/2023

The following items were edited in sections III and V.

Section III	Section V
Table 6	Figures 15-18 (points changed near Elm Creek Bridge)
Table 7 Deleted, following tables renumbered.	Figures 21-22
Interpretations	Table 9
	Interpretations

I. Introduction

- **Authors of this presentation and future report**

Table 1. Sediment augmentation working group members and primary research topics.

Researcher	Topics
Sarah Fancher	Longitudinal profile, relative elevation model
Libby Casavant	Volume change, wetted width, braid index
Ed Weschler	Historical terrace imagery analysis, USBR transects
Jason Farnsworth	Sediment transport, volume change, historical context, specific gage analysis
Justin Brei	Sediment transport, volume change
Patrick Farrell	Specific gage analysis
Malinda Henry	Communications, study design

- **Purpose of sediment augmentation evaluation**
    - We aim to address Extension Big Question #3 from the science plan: Is sediment augmentation necessary to create and/or maintain suitable whooping crane habitat?

- **Structure of this outline: Lines of evidence to assess channel change and augmentation efficacy**
    - Review relevant reports and current conditions (Section II)
        - Compile previous work relating to sediment deficit and incision below the Johnson-2 Irrigation Return (J2 Return)
    - Quantify sediment inputs per year (Section III)
        - augmentation implementation volume and mass
        - cut-through channel sediment volume
    - Looking backward (Section IV)
        - Establish incision reference surface with the average floodplain elevation (Geomorphic Grade Line; GGL)
        - Evaluate pre-2017 channel incision
            - Terrace analysis (high uncertainty)
            - USBR transect surveys

        - Compare spatial and temporal rate of incision to Murphy et al. (2004; see Table 3)
    - Analyze spatial and temporal channel change since augmentation implementation (Section V)
        - Generate relative elevation models of 2016–2021 elevation relative to the GGL
        - Measure change in thalweg and average cross-sectional elevation 2016–2021
        - Quantify volume change with DEM differencing
            - Assess change with and without lateral erosion
    - Examine channel geometry, including metrics directly relevant to habitat (Section VI)
        - Slope, wetted width

- **Excerpt from the Science Plan, p. 50**

Extension Big Question #3: Is sediment augmentation necessary to create and/or maintain suitable* whooping crane habitat?

**Channels with ≥ 650 ft maximum width unobstructed by dense vegetation (MUCW) are highly suitable for whooping crane roosting.*

Management Hypothesis: Sediment augmentation is necessary to halt narrowing and incision in the south channel downstream of the J-2 Return.

X-Y Graph

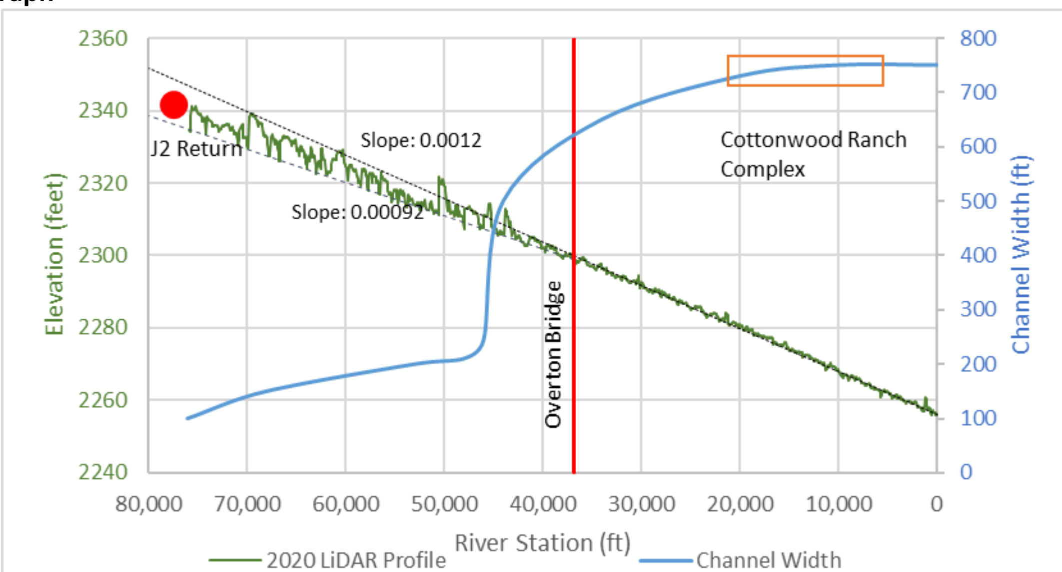

Figure 1. Full scale sediment augmentation (60,000 – 80,000 tons annually in south channel below J-2 Return) is necessary to offset the sediment deficit and halt narrowing and incision that has caused the upper portion of the south channel to transition to a narrow meandering planform, which is much less suitable for WC roosting. If incision is not halted, the affected reach will continue to expand downstream past the Overton bridge, reducing habitat suitability at the Cottonwood Ranch complex.

Alternative Hypotheses:

- More or less sediment must be augmented to offset the south channel deficit.
- Augmentation at alternative locations will halt narrowing and incision.
- Full scale augmentation is not feasible over the long term – not enough supply.
- Incision and narrowing progresses downstream so slowly that augmentation is not necessary.
- Mechanical channel widening will halt narrowing and incision at habitat complexes.

- **Explanation of stationing, spatial reference, and units**
  - Throughout this project, we use a stationed floodplain centerline that goes through the J2 Return reach with as few vertices as possible (Figure 2). Straight centerline does not align with sinuous streamflow but does follow the floodplain from west to east.
  - Station numbering is in units of feet and extends from station 0 at the Kearney Diversion Dam upstream to station 113,780 at the Lexington Bridge. Landmarks of interest and their associated stations are listed in Table and are called out on figures.
  - Although the stationed study area extends from Lexington Bridge to Kearney Canal diversion dam, analyses focused on the reach between the J2 Return and Kearney Canal diversion dam (KCDD).

Table 2. Landmarks in the study area and associated stations.

Landmark	**Station (ft)**
Lexington Bridge	113,780
Berm at upstream north/south channel split	101,890
J2 Return (Sand Dam is roughly same stationing)	91,955
Upstream extent of sediment augmentation area	89,360
Downstream extent of sediment augmentation area	84,000
North/south channel confluence	55,290
Overton Bridge	52,600
Cottonwood Ranch, upstream extent	39,925
Cottonwood Ranch, mid channel stream gage	25,120
Cottonwood Ranch, downstream extent	23,665
Elm Creek Bridge	8,395
Kearney Canal Diversion Dam	0

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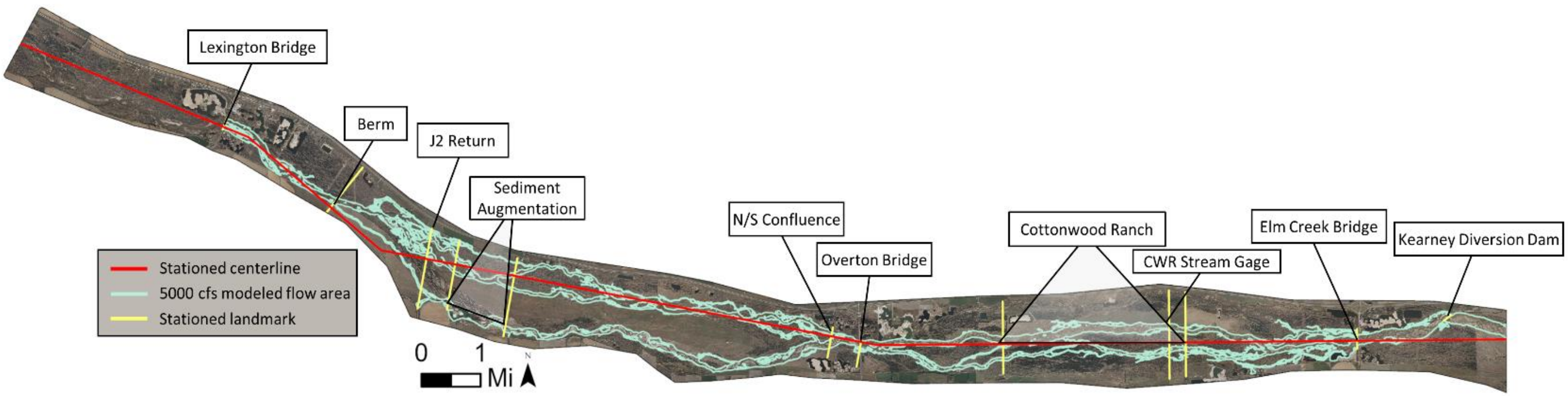

Figure 2. Study area for sediment augmentation evaluation. Landmarks are labelled and referenced to stationing in Table 2. Kearney Canal Diversion Dam (Station 0) and the Sand Dam (not labeled on this figure), a levee that disconnects the north and south channel, are pictured in Figure 3.

Figure 3. Kearney Diversion Dam (a) and the levee that disconnects the south channel, also called the “Sand Dam” (b). A portion of the breakthrough channel that is blocked with a berm at the upstream end is also shown in (b).

II. Summary of relevant literature and reports

Table 3. Past reports of incision, sediment deficit, and/or sediment augmentation in the Platte.

Reference	Main Findings
Williams, 1978. Case of the shrinking channels	• Fluctuations of stage/discharge relationships reflect regulation of water and sediment delivery to the river.
O'Brien and Currier, 1987. Channel morphology, channel maintenance, and riparian vegetation changes in the Big Bend Reach of the Platte River in NE	• Linked degradation (3-10 ft from 1890s to 1960s) to reduction in sediment supply based on comparison of quadrangle maps; • Concern that AHR shift from braided to meandering
Simons and Associates 2000. Physical history of the Platte River in NE: focusing upon flow, sediment transport, geomorphology, and vegetation	• AHR in the transfer zone downstream of the supply zone. Dams trap sediment and reduce flow. • 1990s sediment transport data suggests general stability/equilibrium • Introduced sediment augmentation as management action to reduce bed degradation
Randle et al., 2003. Platte River flow and sediment transport between North Platte & Grand Island 1895-1999	• From 1989 to 2002, channel eroded 6 ft at J2 Return and 1 ft at Kearney Canal Diversion 18 miles downstream
Murphy et al., 2004. The Platte River channel: history and restoration	• Erosion of fines coarsens bed material along a reach with history of channel incision • Armoring may limit depth of incision if there is enough coarse material in the bed to stop erosion; however, an armored bed also causes channel incision to progress downstream • Armoring and a resultant decrease in local river slope can eventually limit the depth of incision • Incision continues until the cumulative sediment supply balances transport capacity • Incision from clear-water releases at J2 Return may continue to progress slowly downstream • Incision wave propagation estimates (Graf 1998, de Vries et al. 1973) predict proportion of maximum incision depth through time with distance downstream in uniform sand (Figure 2) • Slow progression of the maximum incision depth could take centuries to reach equilibrium

	• Addition of island sand to the active channel would locally reduce median grain size, increase bed mobility, and shift planform toward wide and braided • If 500 tons per day of sand were added to the channel, the annual volume would be 100,000 yd^3 per year or 20 acres of island sand cut to 3 ft depth (2 mi^2 of island over 50 years). This amount is similar to sand dredged annually behind the Tri-County Diversion Dam and pumped into the channel downstream (Boyd, 1995)
Holburn et al., 2006. Trends of aggradation and degradation along the Central Platte River: 1985 to 2005	• Evidence of degradation in cross sections from river mile 247 to 225. Most degradation occurs upstream and diminishes with downstream distance. At RM 225.1 (Odessa), the difference in the average annual change in cross-sectional area is less than 10 ft^2 and was assigned a stable designation.
Murphy et al., 2006. Platte River Sediment Transport and Riparian Vegetation Model	• Estimates of net erosion annually (hydrology 1947-1994): o 85,000 to 175,000 tons from the bed and banks of the South Channel of Jeffreys Island o 125,000 to 370,000 tons from the North Channel (up to 170,000 tons from the bed and banks) o 50,000 to 100,000 tons from the bed and banks between Jeffreys Island (RM 241) and Overton (RM 239) o 45,000 tons exported from Plum Creek (RM 244) o 115,000 tons from tributaries downstream of Overton (RM 239) o 180,000 tons from the bed and banks of the river between Overton (RM 239)and Wood River (RM 183)
PRRIP Adaptive Management Plan	• Sediment is mechanically placed into the river from banks, islands and out-of-bank areas at a rate that will eliminate the sediment deficiency and restore a balanced sediment budget within the expected future flow regime. • Augmenting 225,000 tons annually will achieve sediment balance to Kearney • Sediment balance (in conjunction with consolidation & widening) will increase braiding index which will in turn increase unvegetated channel width

Flatwater, HDR Inc. & Tetra Tech 2010. Sediment augmentation experiment alternatives screening study	• HEC-6T Model: overall sediment deficit between the Lexington and Odessa bridges is approximately 152,000 t/y over the 12.5-year simulation period. • Augmentation Options: Push at CWR (1.2mm) & Pump at Dyer (0.5mm)
Flatwater, HDR Inc. & Tetra Tech 2014. Sediment Augmentation Final Pilot Study Report	• 82,000 tons pumped at Dyer & >100,000 tons pushed at CWR • The annual volume of augmentation that can be sustained at the Dyer Property without causing excess sediment accumulation in the South Channel between the outfall and the Overton Bridge would average about 60,000 tons and range from about 11,000 tons (based on the WY 2004 releases of about 87,000 ac-ft) to about 135,000 tons (based on the releases of approximately 1M ac-ft in WY 1999 and WY 2011). The rates would increase if a finer sediment gradation were pumped to the river and decrease if coarser sediment were used by amounts that depend on the actual input sediment gradation. • Modeling performed for the feasibility study using the flows that occurred during the 12.5-year period from WY 1990 through WY 2001 (Tetra Tech, 2010), the annual deficit between the Overton and Elm Creek Bridges averages about 109,000 tons and ranges from 25,000 tons to about 220,000 tons • Modeling indicates that pumping 150,000 tons of sediment per year to the river at the Cook and Dyer Property would reduce the existing approximately 109,000 ton average in-channel deficit in the Overton to Elm Creek reach to about 43,000 tons if finer material (D50 ~ 0.5 mm) were used for the augmentation and to about 73,000 tons if coarser material (D50=1.2 mm) were used
Tetra Tech 2015. 1-D model update	• There is relatively strong correlation between the volume of J-2 releases and the sediment deficit between Overton and RM 232 (Odessa). The data indicate that this part of the reach is approximately in-balance during years when J-2 releases are less than about 300,000 acre-feet, and the deficit increases to 80,000 tons to 100,000 tons, on average, when J-2 releases are in the range of 1M acre-feet • J2 Return flows result in a net change in the transport balance of about 55,000 tpy. By removing the J-2 flows, the in-channel deficit decreases from 92,000 tpy, on average, to 61,000 tpy, a

	reduction of about 40,000 tpy. Most of the indicated deficit occurs in the Cottonwood Ranch reach.
Tetra Tech 2017, Final 2009-2016 System-Scale Geomorphology and Vegetation Monitoring Report	• Evaluated sediment balance independently based on sediment transport measurements and repeat cross section surveys. • Evidence points to a general degradational tendency upstream from Shelton, while the balance between Shelton and Grand Island is unclear. • Based on the combined sediment transport and cross section monitoring data, the annual sediment deficit in the Overton to Kearney reach is most likely in the range of 50,000 tons to 75,000 tons. • Based on these results the net annual deficit in the Kearney to Shelton reach is likely in the range of 50,000 tons. • The survey data indicate a substantial sediment excess in the Shelton to Grand Island reach of about 194,000 tpy, on average, while the rating curves indicate an approximately 103,000 tpy deficit. As a result, these data do not provide a basis for concluding that a sediment imbalance exists in the Shelton to Grand Island.
2017 Full-Scale Sediment Augmentation	• Minimum 5 years: Push 60,000 – 80,000 T of sediment immediately downstream of J2 Return • Enough to generally offset sediment deficit… oversupply in low flow years and undersupply in wet years. • Collect LiDAR and attempt to identify sediment augmentation signal DS of augmentation location.

- General themes:
  - Upper half of AHR in sediment deficit to J2 Return (hungry water)
  - Without augmentation – J2 Return flows pick up sediment from channel bed and banks until at transport capacity. This causes incision and narrowing. Bed eventually armors causing trend to slowly move downstream. Could take centuries to reach equilibrium.
  - Sediment transport modeling (SEDVEG & HEC-6T) indicate mean annual sediment deficits on the order of 150,000 – 225,000 T
  - Modeling to isolate J2 Return flows indicates removing returns reduces deficit below Overton by 30,000-40,000 T (From >90,000 T to ~60,000 T).
  - Sediment transport measurements and cross-section surveys indicate a deficit from Overton – Kearney of 50,000-75,000 T.
  - Modeled sediment augmentation (1.2mm) upstream of Overton reduced sediment deficit by about 50% of augmented volume.
  - Overall: High variability in both modeled sediment transport and physical measurements led us to focus on the J2 Return reach. Most recent modeling & analyses

converged on the range of 60,000 – 80,000 T. Implement mechanical augmentation (more efficient) in that range and evaluate for signal.

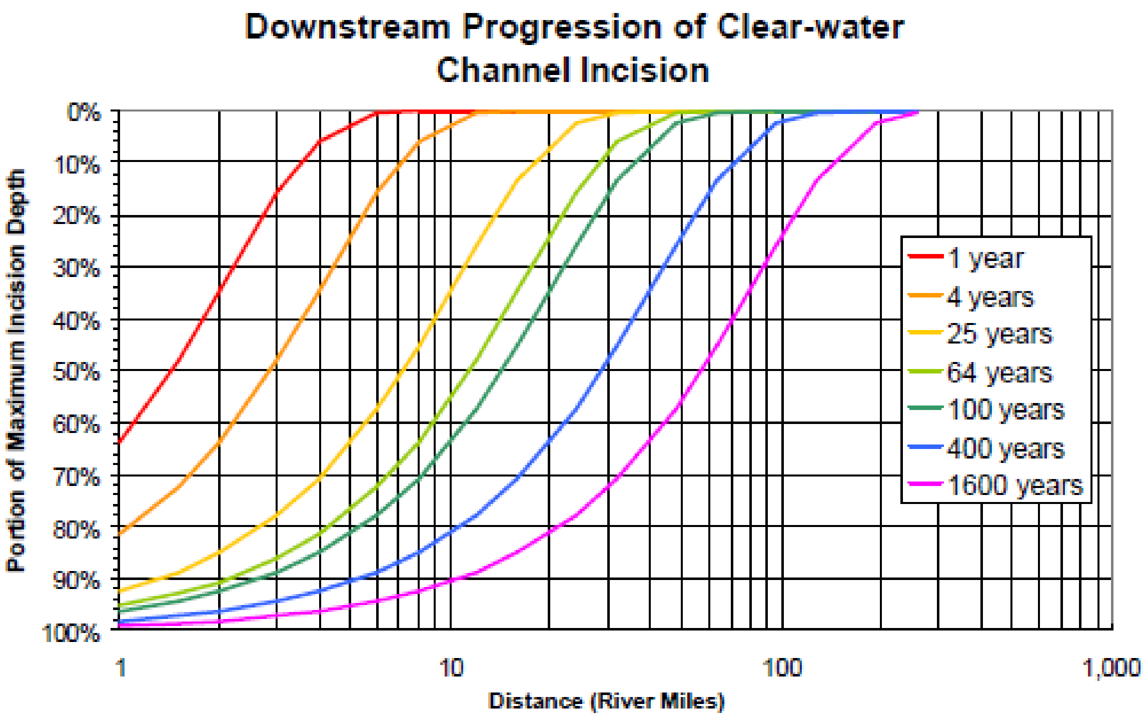

Figure 4. Downstream incision wave propagation estimates from Murphy et al. (2004).

Table 4. Total sediment deficit and surplus volumes in reaches of the study area, from Flatwater, HDR, and Tetra Tech (2010).

Subreach	Upstream Limit	Downstream Limit	Specific Location	Aggradational/ Degradational	Deficit (-)/ Surplus (+) (t/y)
1	Lexington Bridge	Overton Bridge	North Channel	Slightly to moderately aggradational	+66,400
2	J-2 Return	Overton Bridge	South Channel	Degradational	-96,700
3	Overton Bridge	Elm Creek Bridge	Cottonwood Ranch Reach	Degradational	-108,500
4	Elm Creek Bridge	Kearney Canal diversion structure	Immediately Upstream of Kearney Diversion	Slightly to moderately aggradational	+32,700
5	Kearney Canal diversion structure	Odessa Bridge	Immediately Downstream of Kearney Diversion	Degradational	-46,100
Total Reach					**-152,200[1]**

Note:
[1] *For the purpose of the Study, the sediment deficit for the entire Project reach has been rounded to 152,000 t/y.*

III. Annual sediment inputs from augmentation area: sediment augmentation and breakthrough channel

- **Purpose**
  - The EDO is responsible for engineering design of annual full-scale sediment augmentation implementation.
  - Upstream of the J2 Return, a breakthrough channel extends from the berm that disconnects the north and south channel to the J2 reach (Figure 5).
  - The Sand Dam, different from the berm mentioned above, is a levee that disconnects the north and south channels (Figure 5).
  - Here, we approximate the augmentation and breakthrough channel sediment inputs.

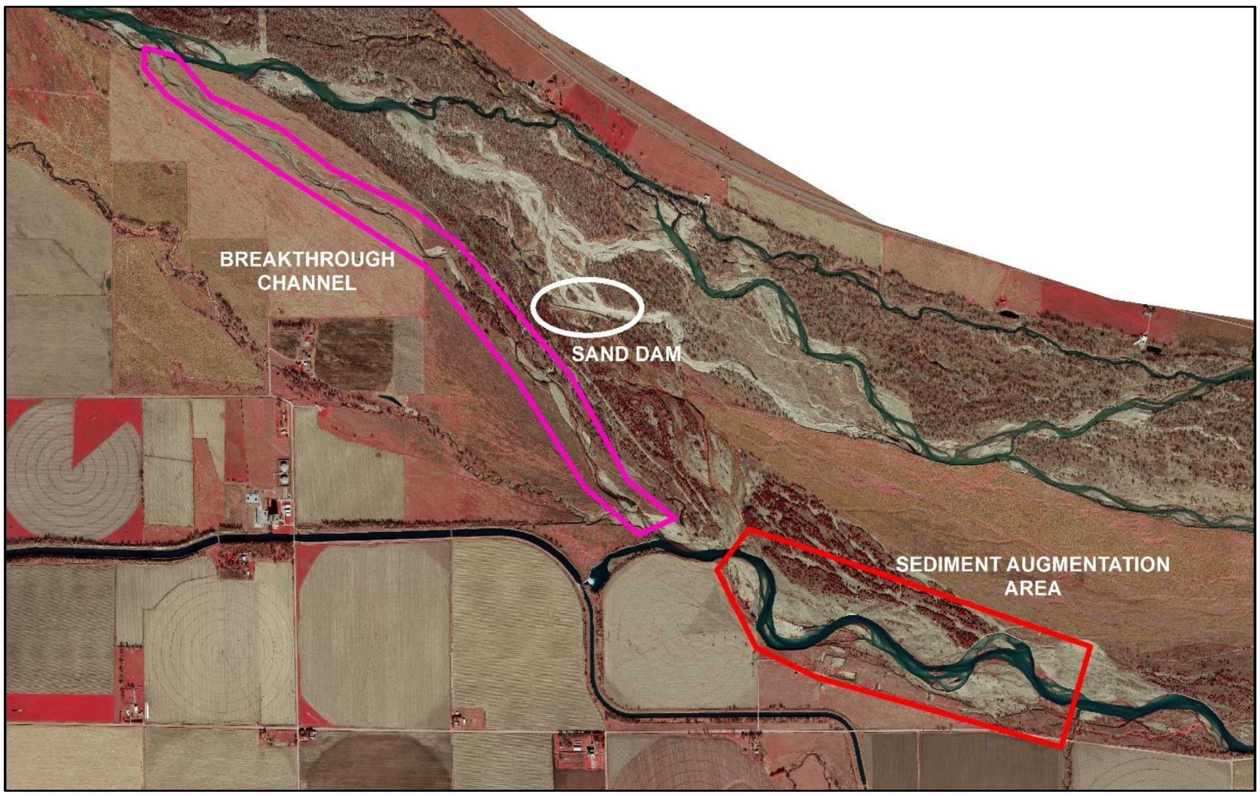

Figure 5. Location of sediment augmentation source area, breakthrough channel, and sand dam in relation to J2 Return.

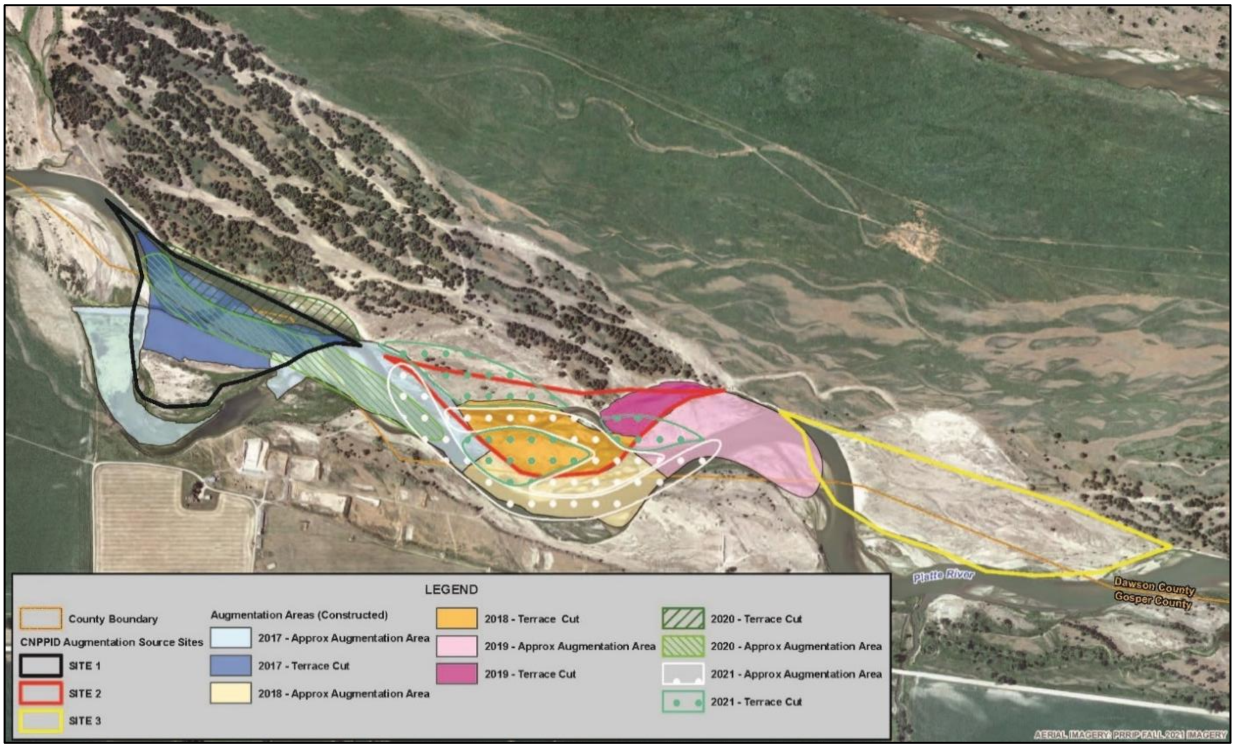

Figure 6. Sediment augmentation implementation area.

Table 5. Sediment Augmentation Project Tonnage - Based on HDR submittals to USACE

Year	Targeted Sediment Augmentation (tons)	Estimated Sediment Augmentation (tons)	Augmentation Dates
2017	115,000	120,000*	9/22/17-11/1/2017
2018	60,000	64,305	8/20/2018-10/1/2018
2019	60,000	63,500	9/10/2019-10/7/2019
2020	74,000	86,475	9/1/2020-9/25/2020
2021	80,100	76,982	9/1/2021-10/15/2021

*Majority into field and channel plug

Table 6. Volume estimates from construction planning and DEM differencing of augmentation and breakthrough channel sediment sources. The breakthrough channel is the remnant channel adjacent to the "sand dam," a berm that disconnects the north and south channels upstream of the J2 Return.

Year	Augmented Volume (CY)	Breakthrough Channel Eroded Volume (CY)	Breakthrough + Sed Aug Volume (CY)	Net Out of Sed Aug Area (J2 to Sta 84,000) (CY)	Net Out of Sed Aug Area (T)
10/17 to 10/16	23,000	71,637	94,637	-34,469	-51,704
10/18 to 10/17	42,870	61,075	103,945	-73,120	-109,681
10/19 to 10/18	42,333	19,944	62,277	-116,476	-174,715
10/20 to 10/19	57,650	NA	57,650	-42,228	-63,342
10/21-10/20	51,321	NA	51,321	-60,626	-90,940
10/16 to 10/21	**217,174**	**152,656**	**369,830**	**-326,921**	**-490,382**

- **Interpretations**
  - Sediment inputs upstream of Sta. 84,000 include 1) sediment eroded from the breakthrough channel upstream of J2 (2016-2019) and 2) sediment augmentation. Locations of these areas are shown in Figure 5.
  - Overall, during the period of 10/16 – 10/21, a total of **-326,921** CY (-490,382 T) was delivered downstream to South Channel below J-2 Return based on LiDAR volume change analysis. See annual volumes in Table 6.

IV. Looking Backward: Retrospective Analysis of Historical Incision Rates

- **Purpose**
  - Calculate floodplain surface elevation
  - Quantify historical incision magnitude and rate downstream J2 Return.
  - Compare incision magnitude and rates to Murphy et al. (2004) predictions.

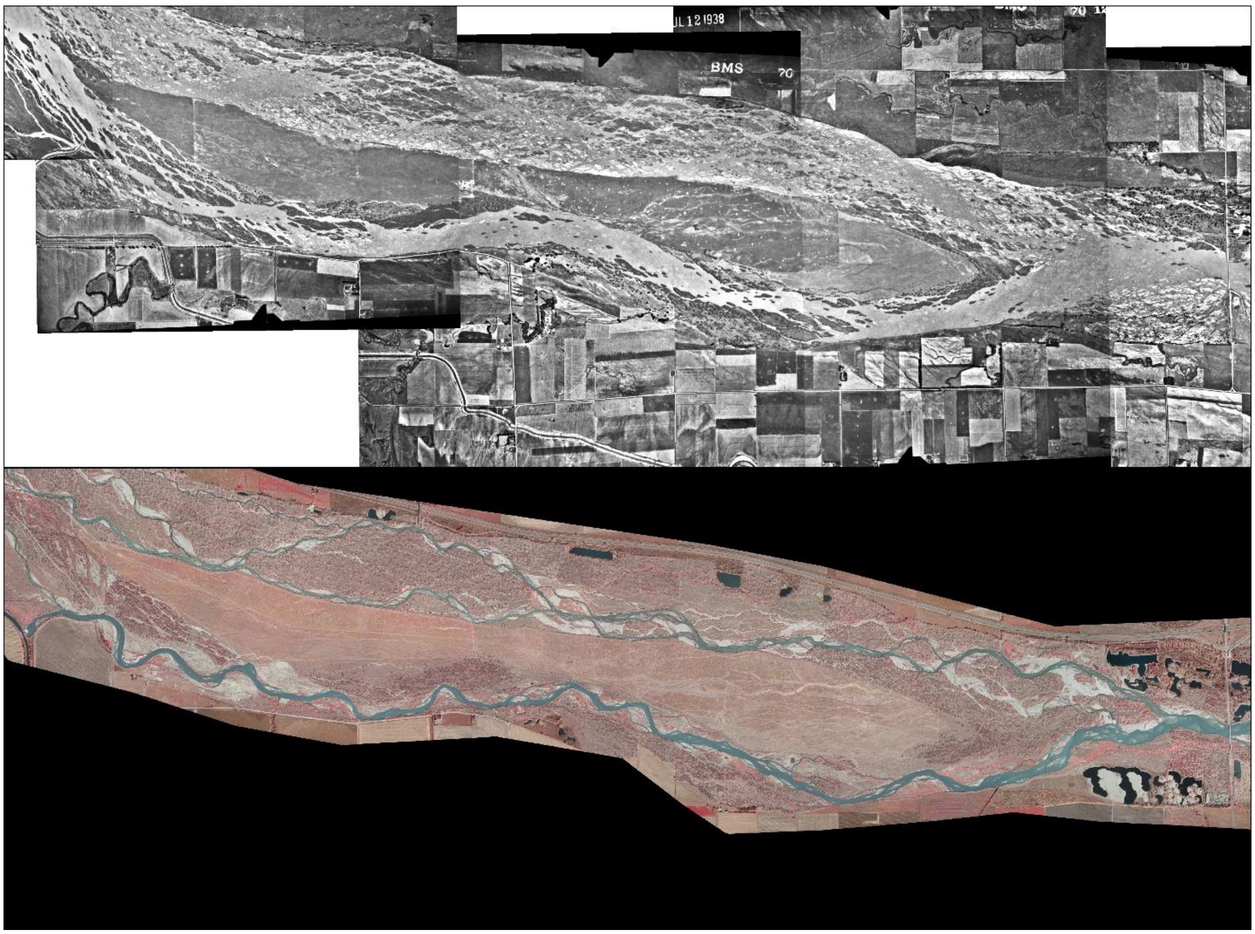

Figure 7. 1938 and 2016 channel from J-2 Return to Overton bridge. Prior to 1942, irrigation diversion located at current J-2 Return location.

- **Methods**
    - Geomorphic Grade Line (Powers et al., 2019)
        - The GGL is a regression of the valley floodplain elevation derived from transects across the entire floodplain every 5 ft from upstream of Lexington Bridge to Kearney Diversion Dam. Human made features (ponds, etc.) are not included in the data to create the regression. We used elevations from November 2021.
    - Historical imagery
        - Extracted elevations from abandoned channels at 24 cross sections spaced 4,000 feet
        - Estimated time of abandonment with imagery from 1938-1988, and calculated approximate incision rate with change in elevation per period of time between imagery
    - Bureau of Reclamation (USBR) Transects
        - Identified thalweg elevation and calculated mean cross section elevation.
        - Calculate incision rates at transect locations (Figure 6) between 1989 and 2002. These cross sections are sourced from Holburn et al. (2006).
        - Compared spatial and temporal rate of incision to Murphy et al. (2004) by plotting incision rates on top of incision wave propagation functions. Incision magnitudes were estimated as the difference between the GGL predicted elevation and the minimum and mean elevations of the 1989 and 2002 transects. The maximum incision depth is approximated as the difference between the GGL and 2021 LiDAR for the first 1,000 ft downstream of J2 Return. Maximum thalweg incision was 16.5 ft. Maximum of mean channel incision was 13.0 ft.

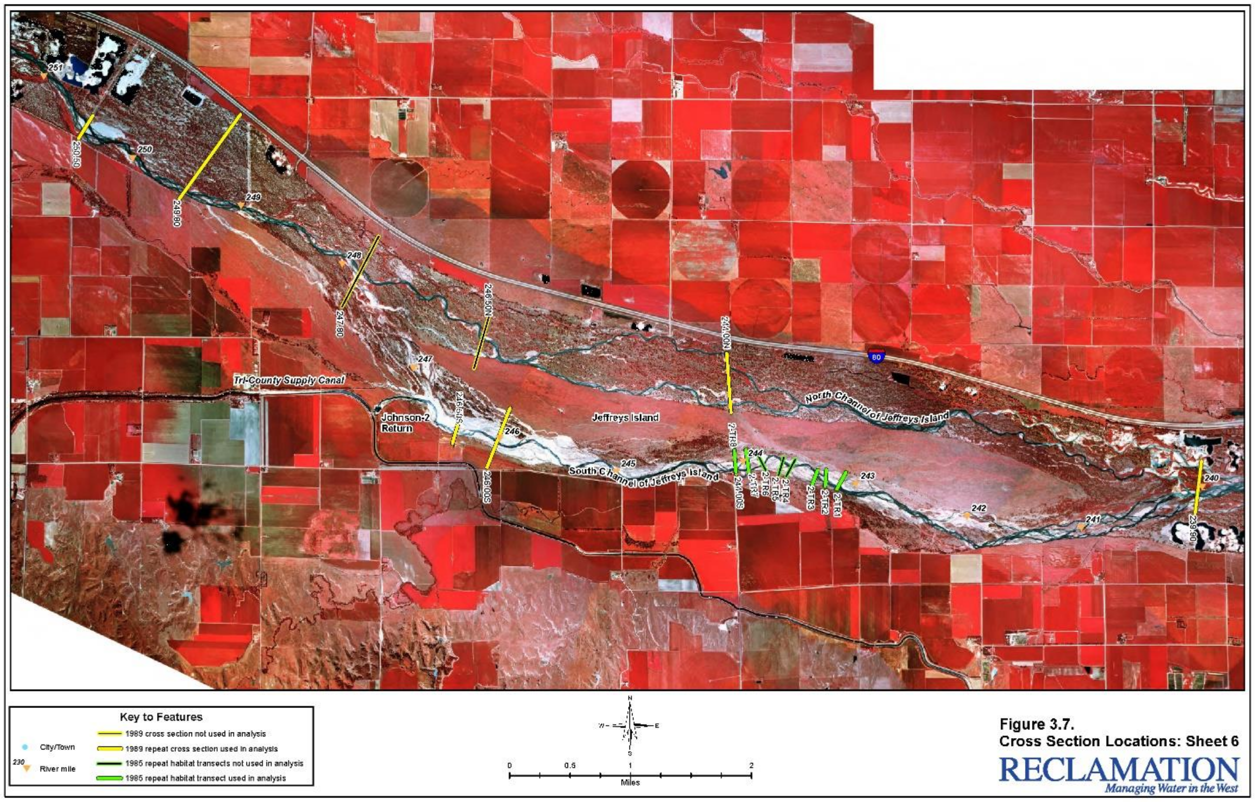

Figure 8. Locations of USBR transects.

- **Results**
  - Geomorphic Grade Line. Note the following equation is based on stationing from downstream to upstream.

Geomorphic Grade Line Regression: $y = 0.001276x + 2{,}236.68$

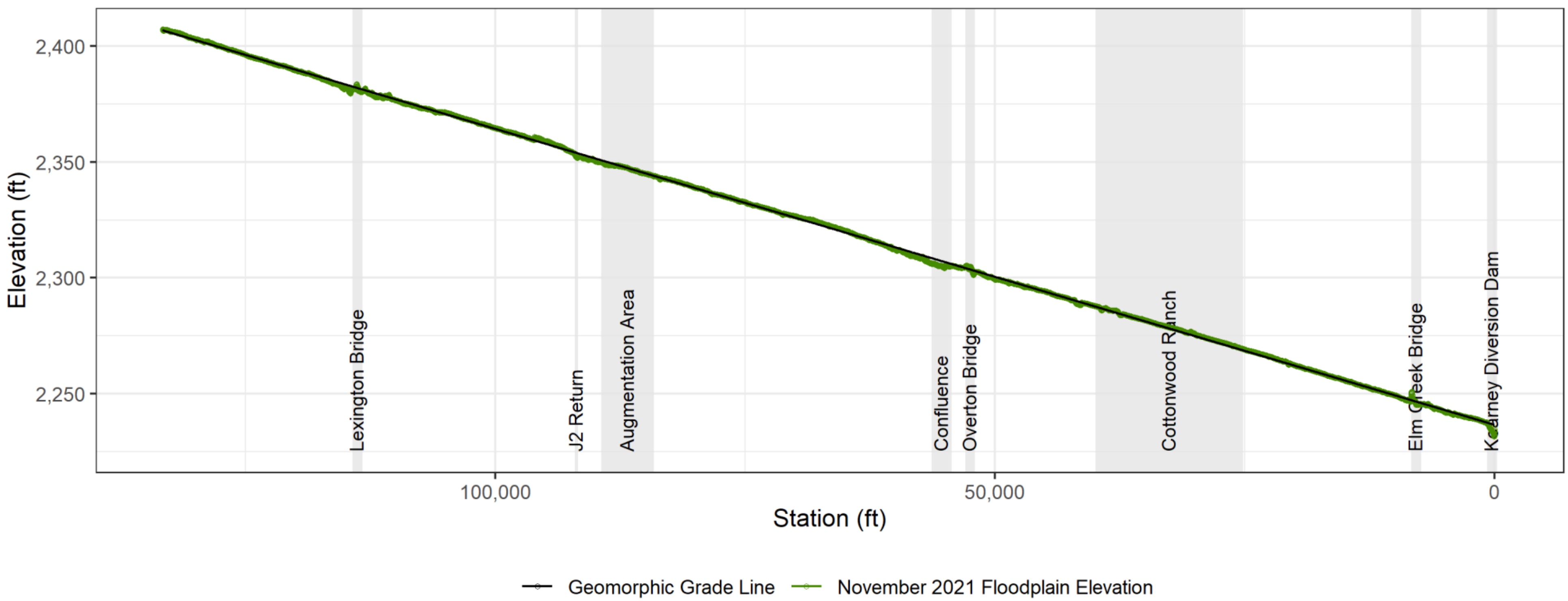

Figure 9. Average floodplain elevation data from 2021 (green) was used to determine the Geomorphic Grade Line regression sensu Powers et al. (2019).

- **Results continued**
  - Historical imagery analysis

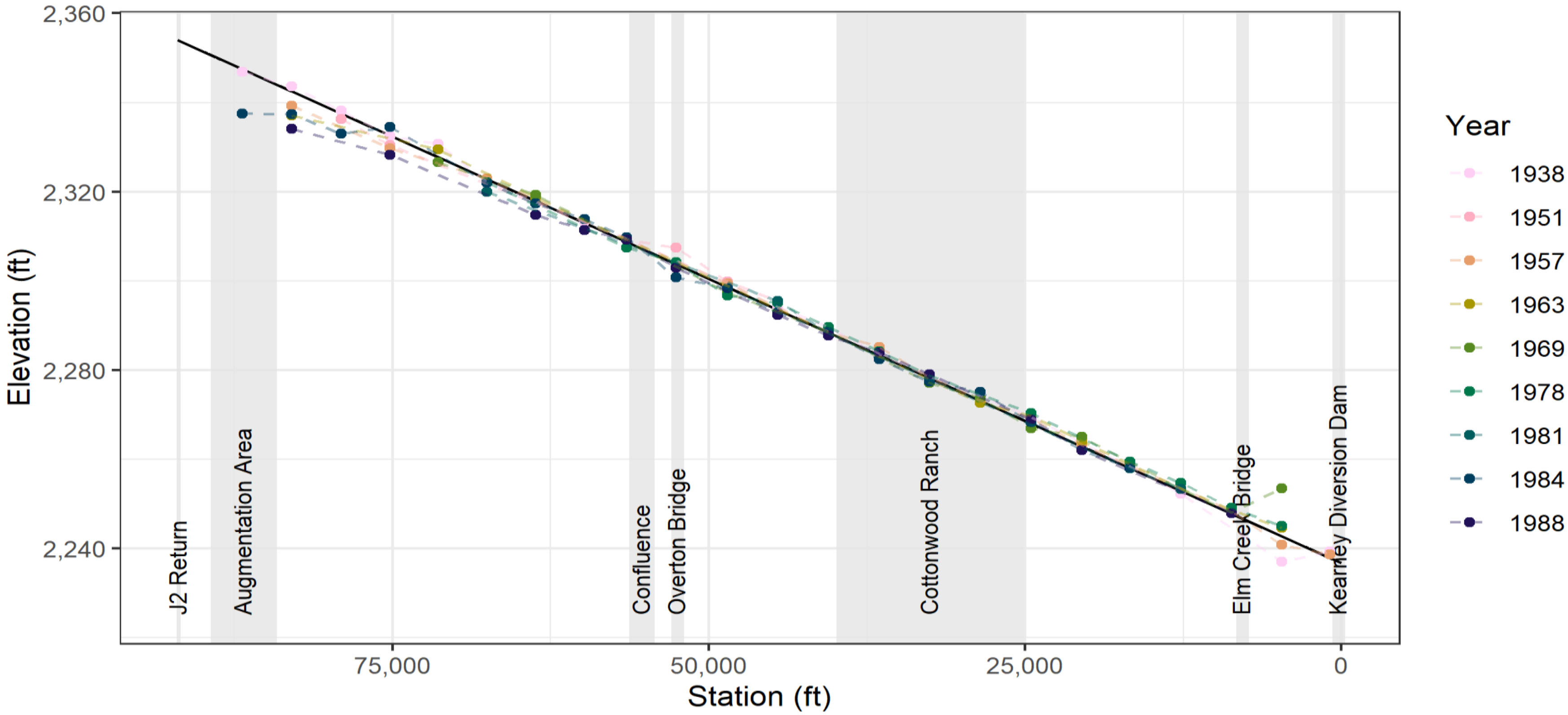

Figure 10. Historical terrace elevations from imagery analysis. A black line represents the Geomorphic Grade Line (GGL) with a slope of 0.001276.

- **Results continued**
    - USBR cross section analysis

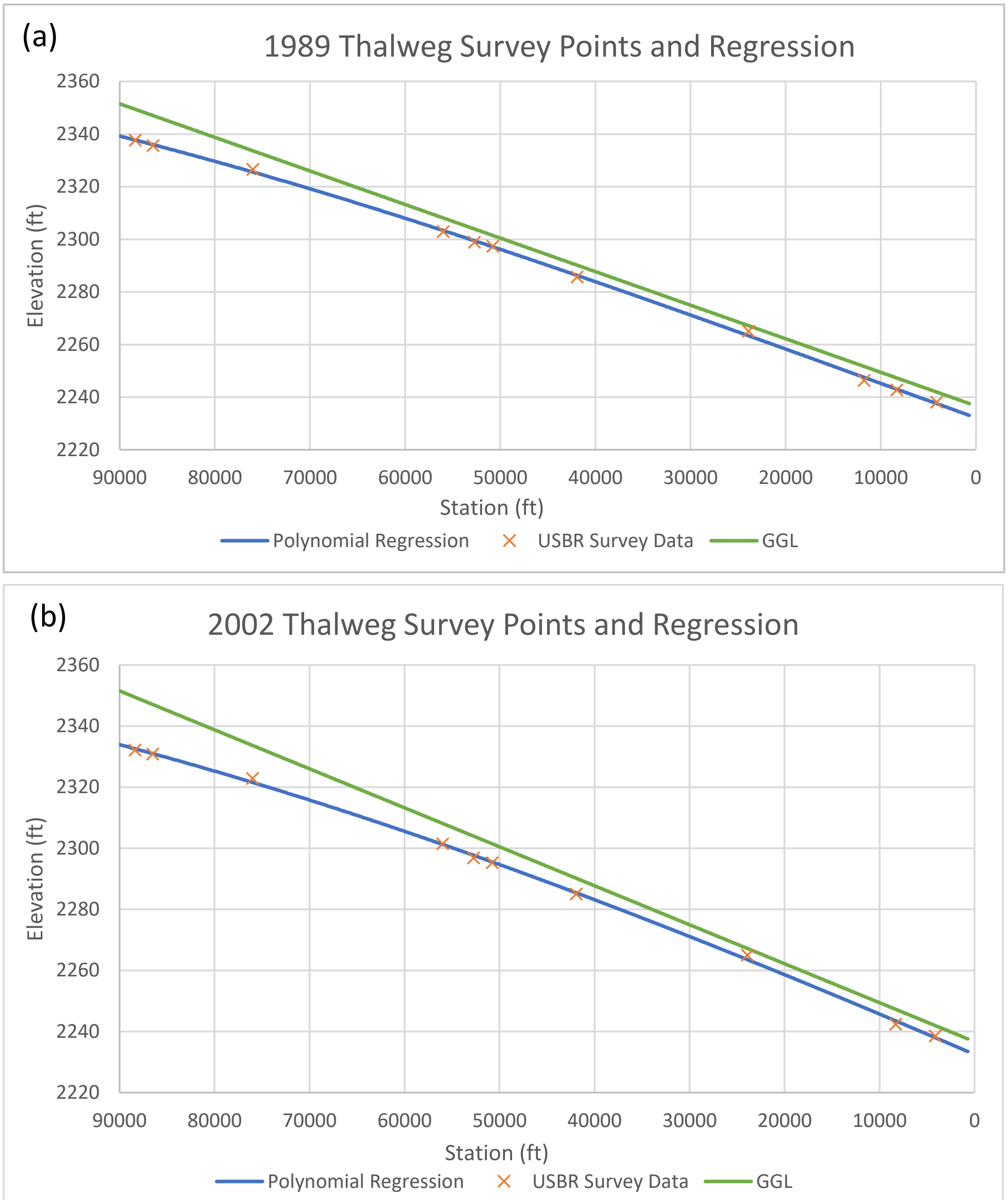

Figure 11. Bureau of Reclamation (USBR) thalweg (minimum cross section) elevations along stationing below J2 Return for 1989 (a) and 2002 (b). Blue lines are third-order polynomial relationships fit to the data. Green lines are the GGL.

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Table 7. Elevations of channel thalweg and average cross section in 1989 and 2002 from USBR transects.

USBR Cross Section Number	Longpro Station	Distance DS of J2 (mi)	Geomorphic Gradeline Elevation	1989 Average Elevation (5,000 cfs)	1989 Minimum Elevation (5,000cfs)	2002 Average Elevation (5,000cfs)	2002 Minimum Elevation (5,000cfs)
246.50S	88360	0.5	2349.4	2343.8	2337.6	2341.9	2332.1
246.00S	86505	0.8	2347.0	2338.9	2335.6	2337.3	2330.8
244.00D	76000	2.8	2333.6	2327.7	2326.6	2324.1	2322.8
239.9	55990	6.6	2308.1	2305.2	2302.9	2303.7	2301.4
239.3	52720	7.2	2303.9	2301.1	2298.9	2300.6	2296.8
239	50770	7.6	2301.4	2298.8	2297.4	2297.9	2295.2
237.5	41925	9.3	2290.2	2288.7	2285.7	2287.4	2284.9
233.8	23890	12.7	2267.2	2267.2	2265.0	2267.7	2265.0
231.5	11755	15.0	2251.7	2249.4	2246.3	N/A	N/A
230.8	8300	15.7	2247.3	2246.3	2242.7	2245.3	2242.3
230	4115	16.4	2241.9	2240.6	2238.1	2240.7	2238.5

- **Results continued**
    - Comparison of incision rates from USBR transects to Murphy et al., (2004)

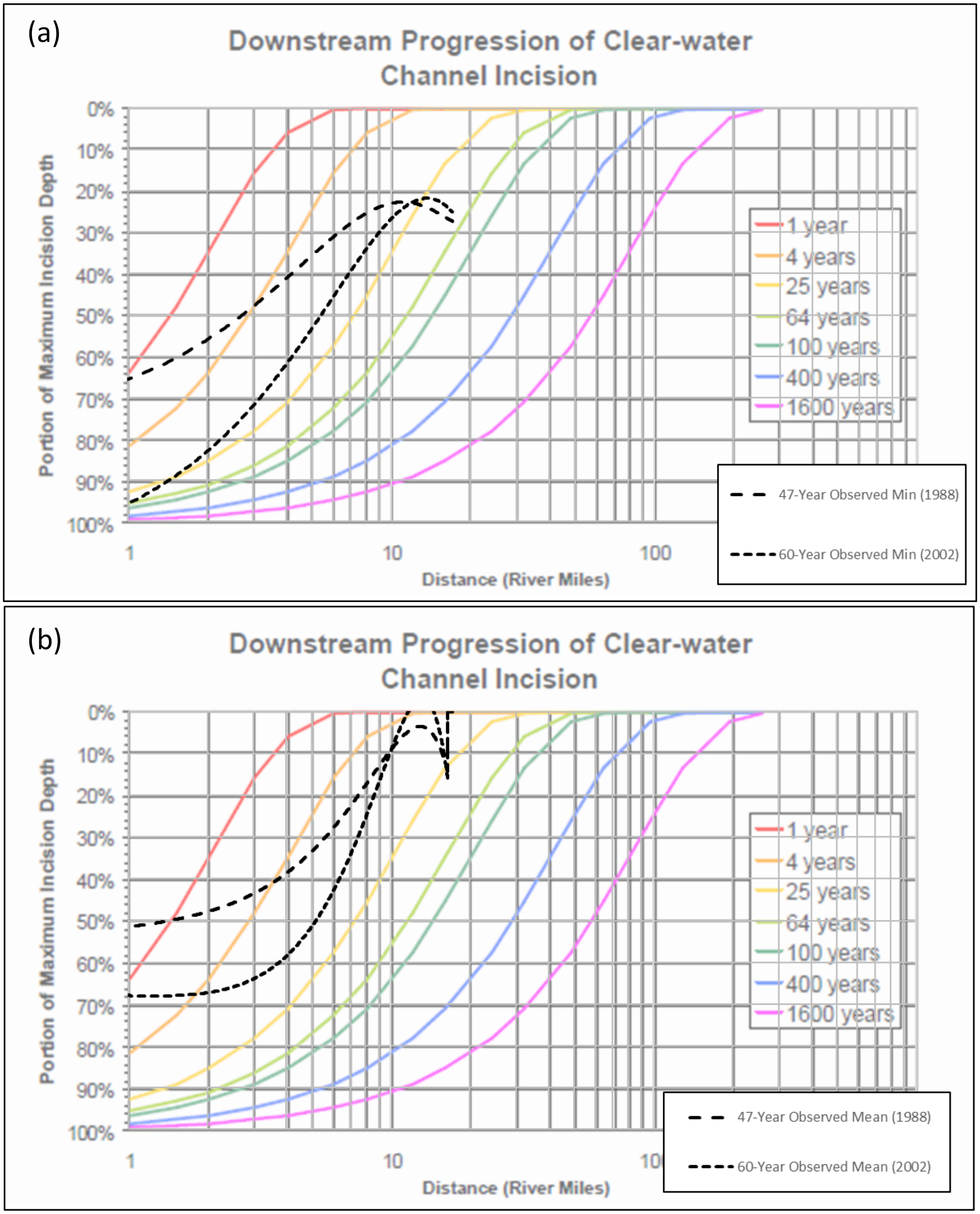

Figure 12. USBR transect data were plotted atop incision propagation estimates from Murphy et al. (2004). The minimum cross sectional elevation is shown in (a) and the average cross-sectional elevation is shown in (b). Number of years represents years since operation started at J2 Return.

- **Interpretations**
  - Geomorphic grade line
    - A linear regression adequately explains variability of the overall floodplain slope (R^2 = 0.99) and this line can be used in further analysis. Thalweg elevations typically fall a few feet below this line as expected.
  - Terrace mapping with historical aerial imagery
    - High uncertainty: sample size highly variable
    - Decreasing trend in magnitude of incision moving downstream from J2 Return
    - 1938 points fall along the GGL – add confidence in value of that analysis.
    - Overall: Less useful than we had hoped.
  - USBR cross section analysis
    - 3rd order polynomials seem to fit the data well in 1989 and 2002.
    - The channel incised between 1989 and 2002
  - Comparison to incision propagation estimates from Murphy et al. (2004)
    - Around 10 miles downstream of J2 Return, incision is near 0.
    - Our data show less incision than predicted for 47 and 60 years since operation began at J2. For example, the 60-year observed incision estimate falls between the predicted 4- and 25-year progression.
    - Fluctuations at the downstream end of our lines likely reflect grade control effects from the Kearney Diversion Dam.
    - **What other incision models might be useful?**
    - **What is the value of comparing our data to these predictions?**

V. Change since sediment augmentation implementation

- **Purpose**
  - Generate relative elevation models of 2016–2021 elevation relative to the average floodplain surface. This provides a visualization of change.
    - Sample and plot relative elevation along the thalweg
  - Measure change in thalweg and average cross-sectional elevation 2016–2021
    - Add thalweg and average cross-sectional change to incision propagation estimates from Murphy et al. (2004)
  - Estimate annual sediment transport capacity. Sediment monitoring, especially of bed material, is highly uncertain, as acknowledged in the Tetra Tech (2017; summary in Table 3) report.
  - Quantify volume change with DEM differencing
    - Assess change with and without lateral erosion
- **Methods**
  - Relative elevation models (REMs)
    - Subtracted LiDAR elevations from a raster of the predicted average floodplain surface (GGL)
    - Selected thalweg location each year with Arc HydroTools, where the thalweg is the lowest connected flowpath in the channel each year
    - Sampled relative elevation (and actual elevation, next section) from intersection between stationed 5 ft transects perpendicular to channel centerline and thalweg lines.
  - Thalweg and average cross-sectional elevation
    - Sampled thalweg elevation each year as described above for REM sampling
    - Clipped stationed transects to 5,000 cfs modeled flow boundary to confine area to active channels and calculated average elevation of each transect.
    - Plotted 2016 and 2021 proportions of max incision atop Murphy et al. (2004) plots.
  - Estimate sediment transport capacity
    - Estimated annual sediment transport capacity with Tetra Tech (2017) sediment transport relationships and mean daily flow data at Darr & Overton gages.
  - Volumetric change
    - Differenced DEMs from each year with no thresholding
    - Divided south channel study area into 900 ft rectangles, then clipped rectangles to a hand-delineated sampling area based on 5,000 cfs modeled flow polygon.
    - Summed differences * area within each sample area to calculate volumetric change
    - Separated volumetric changes due to lateral erosion with a buffer around channel banks.

- **Results**
  - Relative elevation models, J2 to Overton Bridge

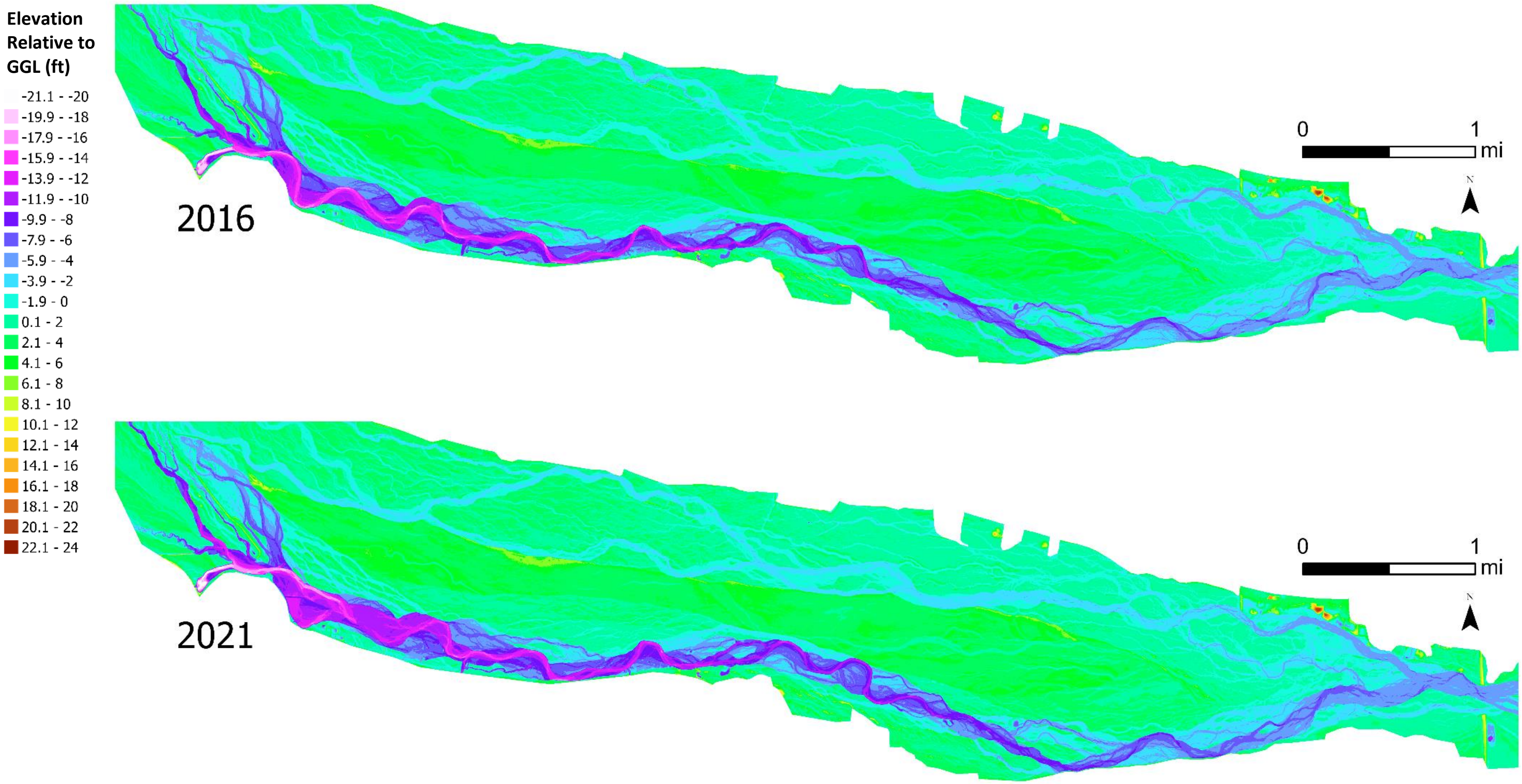

Figure 13. Relative elevation models of 2016 and 2021 elevation compared to the average floodplain surface (GGL). The region pictured is from the J2 Return to Overton Bridge. Edges appear irregular due to clipping of ponds and other human-manipulated surfaces.

- **Results continued**
    - Relative elevation models through Cottonwood Ranch downstream of Overton Bridge.

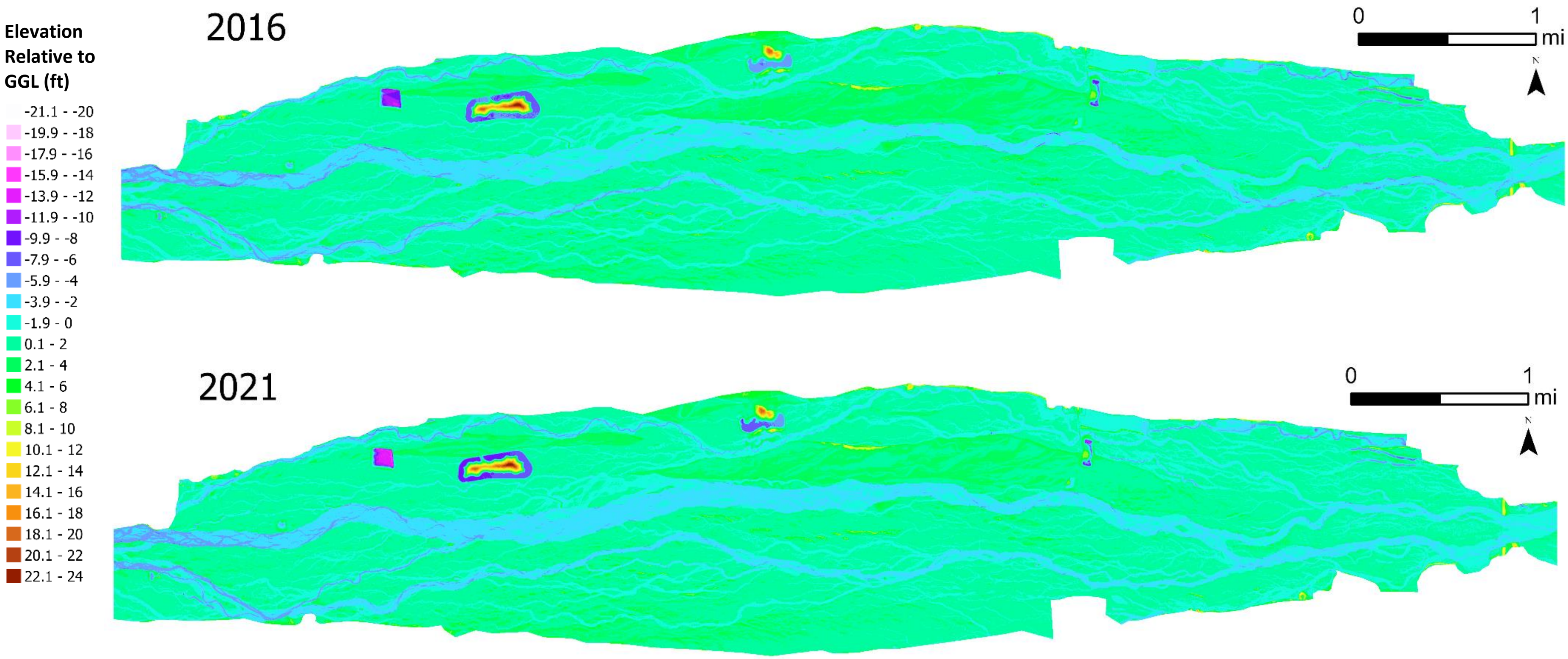

Figure 14. Relative elevation models of 2016 and 2021 elevation compared to the average floodplain surface (GGL). The region pictured surrounds Cottonwood Ranch and ends downstream of Elm Creek Bridge. Edges appear irregular due to clipping of ponds and other human-manipulated surfaces.

- **Results continued**
    - Relative elevation of channel thalweg, 2016 and 2021

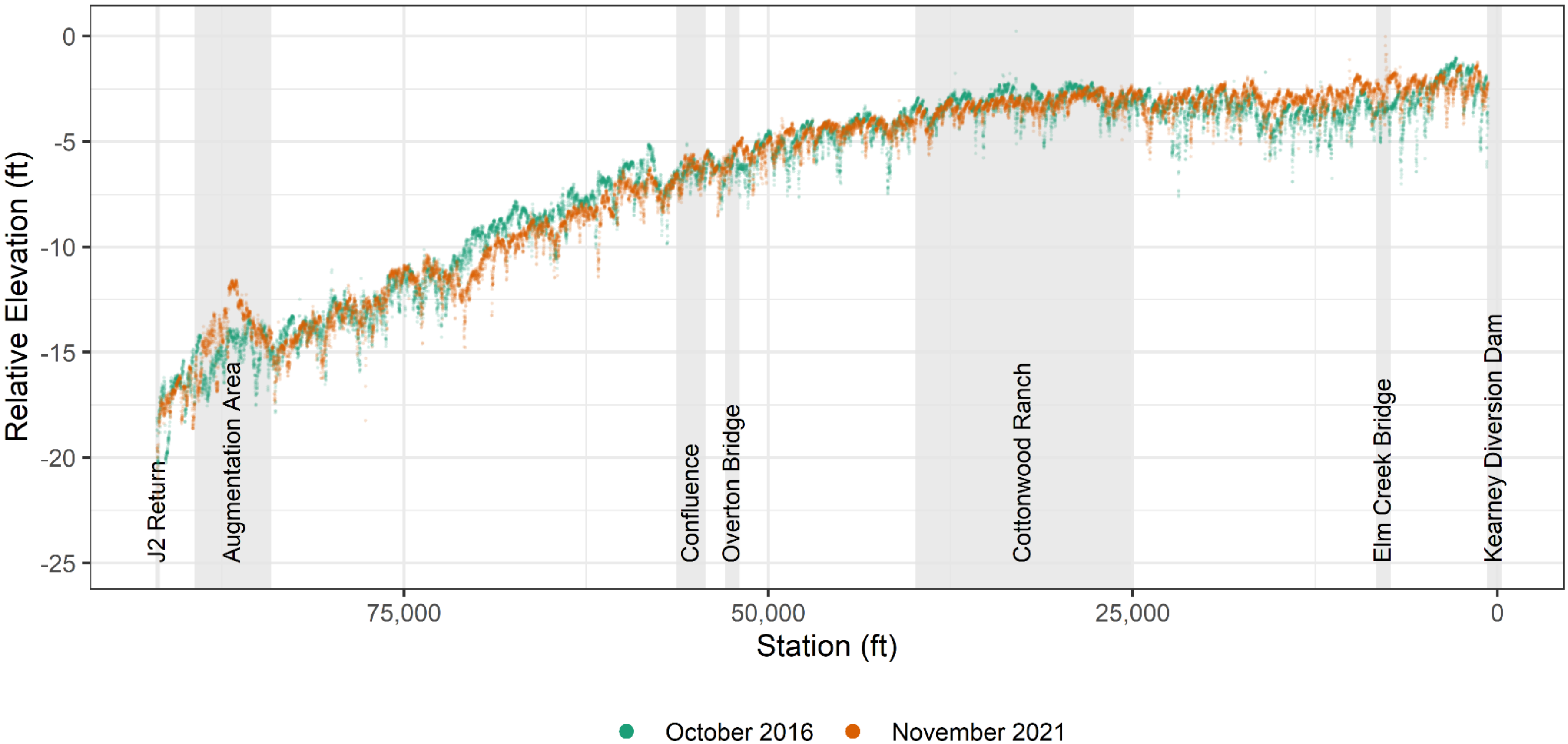

Figure 15. Relative elevation of channel thalweg compared to the Geomorphic Grade Line (GGL) in 2016 and 2021.

- **Results continued**
    - Longitudinal profile of channel thalweg, 2016 and 2021

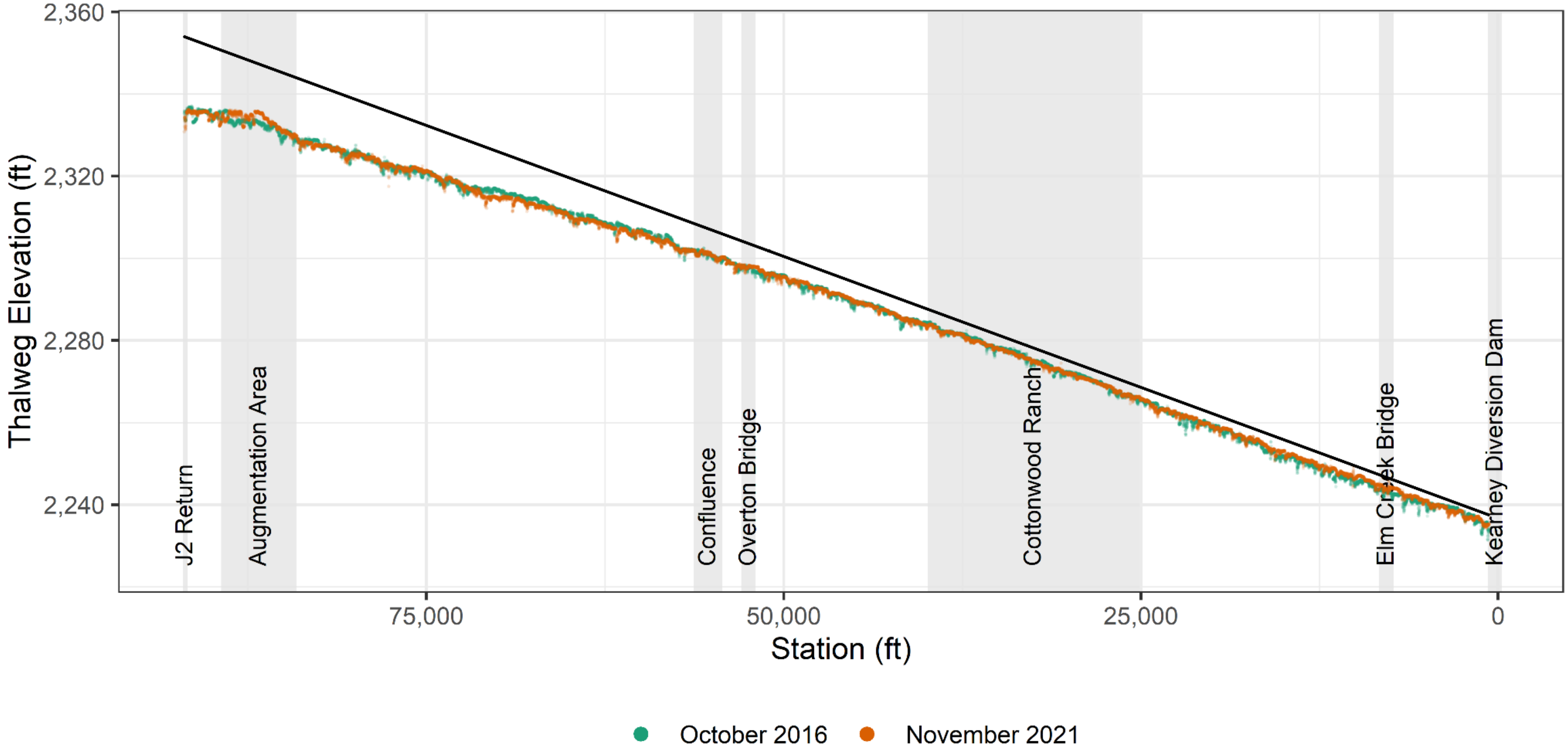

Figure 16. Longitudinal profile of thalweg elevation in 2016 and 2021. The black line is the geomorphic grade line (GGL), or average floodplain surface.

- **Results continued**
    - Longitudinal profile of average cross-sectional elevation, 2016 and 2021

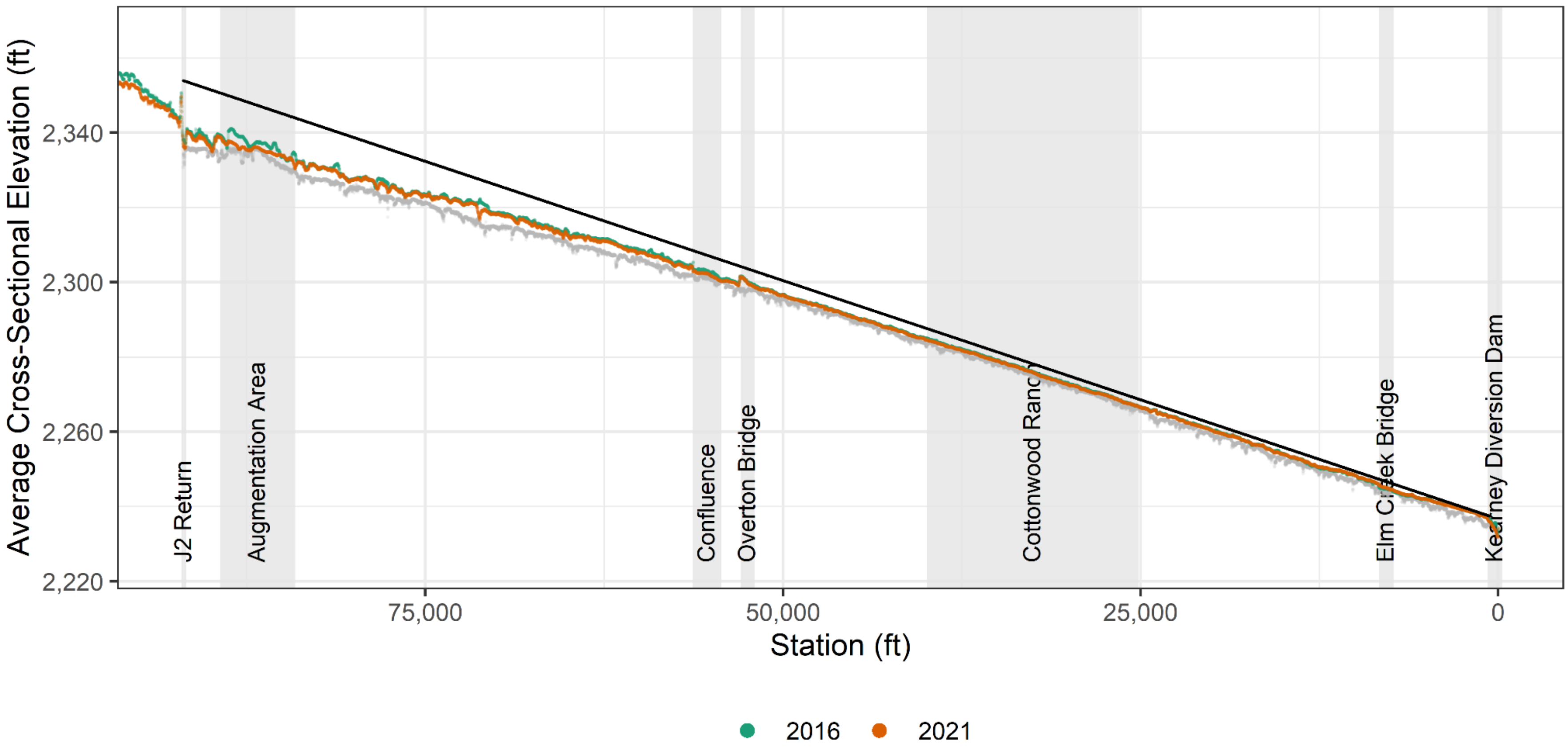

Figure 17. Longitudinal profile of average cross-sectional elevation in 2016 and 2021. The black line is the geomorphic grade line (GGL), or average floodplain surface. Thalweg elevation in 2021 is shown in light grey for reference.

228 • **Results continued**

229 ○ Differences in thalweg and average cross-sectional elevation, 2016-2021.

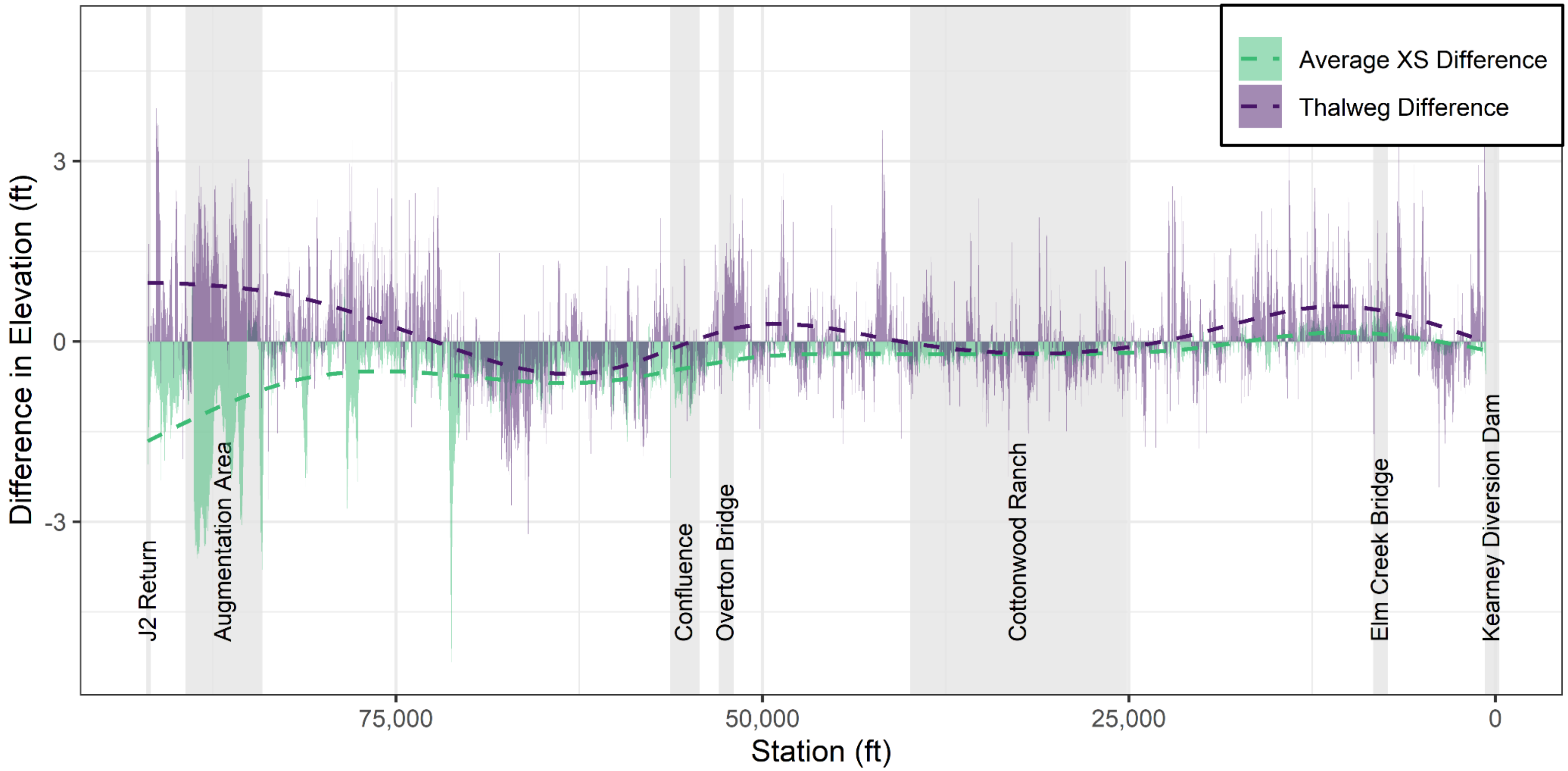

Figure 18. Differences in thalweg and average cross-sectional elevation from 2016 to 2021. A line depicting general trends was estimated with a generalized additive model.

- **Results continued**
  - Comparison of 2016 and 2021 thalweg and cross-sectional incision (relative to GGL) to plots by Murphy et al. (2004).

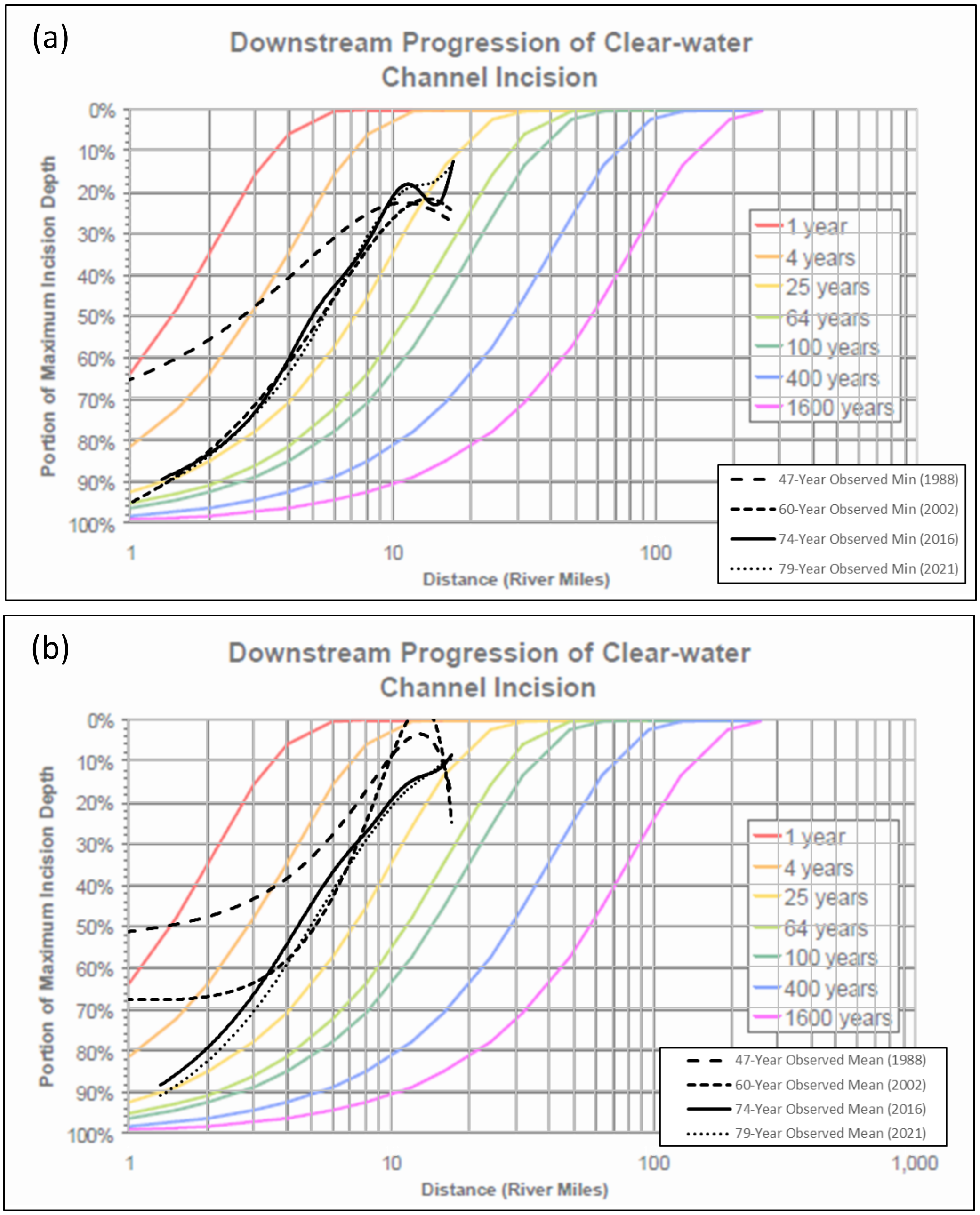

Figure 19. Thalweg (a) and average cross-sectional (b) incision plotted with incision estimates from Murphy et al. (2004). USBR transect data from 1988 and 2002 are included on the graph for reference to Section III.

- **Results continued:**
    - Annual sediment transport capacity estimates

Table 8. Sediment transport calculations via equations from Tetra Tech (2017). Estimates are in US tons and Q = discharge.

Date Range	DARR				OVERTON			
	Mean Q (cfs)	Bedload (T)	Suspended (T)	Total (T)	Mean Q (cfs)	Bedload (T)	Suspended (T)	Total (T)
10/19/16 - 10/14/17	504	86,000	238,000	324,000	1,786	308,000	338,000	646,000
10/15/17 - 10/5/18	245	30,000	101,000	131,000	1,284	205,000	201,000	406,000
10/6/18 - 11/15/19	469	81,000	237,000	318,000	2,075	399,000	454,000	853,000
11/16/19 - 10/10/20	447	63,000	186,000	249,000	2,128	345,000	395,000	740,000
10/11/20 - 11/3/21	220	30,000	98,000	128,000	1,014	168,000	157,000	325,000
Average	**377**	**58,000**	**172,000**	**230,000**	**1657**	**285,000**	**309,000**	**594,000**

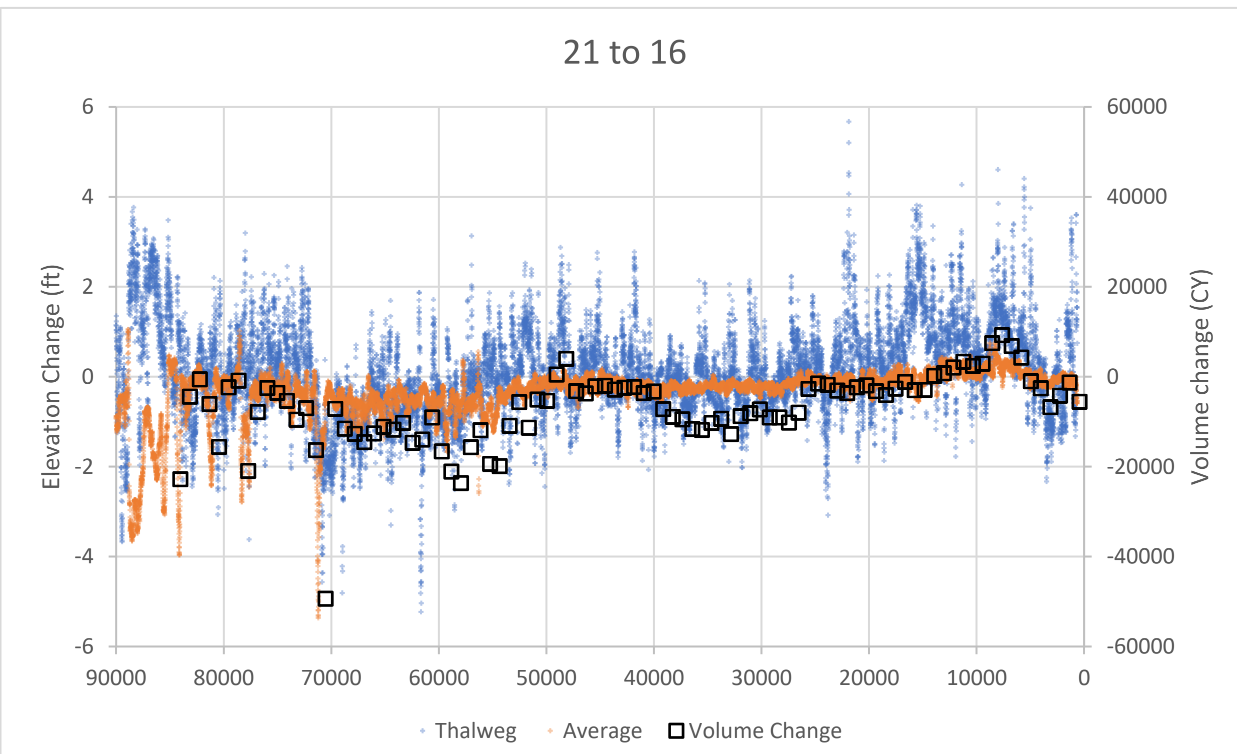

Figure 20. Volumetric, thalweg, and average cross-sectional elevation change between 2016 and 2021. A steeply eroding bank at the outside of a meander bend exists just upstream of Station 70,000.

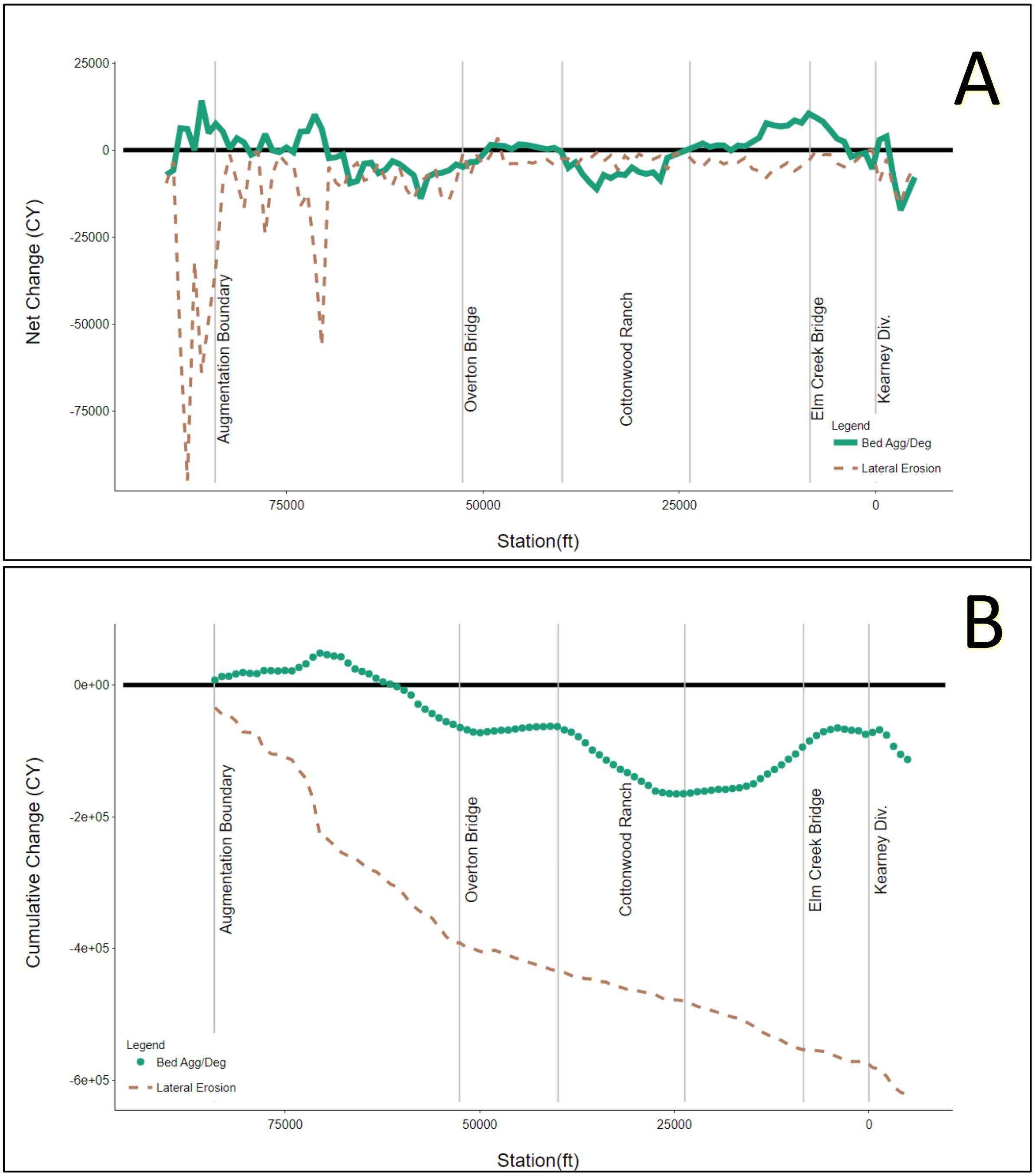

Figure 21. Net (A) and Cumulative (B) volume change from 2016 to 2021. Green lines indicate bed aggradation and degradation without lateral erosion. Brown lines show lateral erosion. Note the steeply eroding bank outside of a meander bend at Station 70,000 in both charts.

Table 9. Volume change estimates from DEM Differencing with lateral erosion separated. Positive changes are in green and negative changes are in orange.

	Downstream augmentation boundary to Overton Bridge			Overton Bridge to Kearney Diversion Dam		
Year	**Total Volume Change (yd^3)**	**Lateral Erosion (yd^3)**	**Bed Agg/Deg[a] (yd^3)**	**Total Volume Change (yd^3)**	**Lateral Erosion (yd^3)**	**Bed Agg/Deg (yd^3)**
2017-2016	-119,727	-99,822	-19,900	7,420	-25,874	33,294
2018-2017	-91,262	-75,130	-16,100	-131,298	-42,402	-88,896
2019-2018	-124,036	-104,235	-19,800	-75,918	-76,623	705
2020-2019	-77,462	-54,386	-23,100	11,611	-21,540	33,151
2021-2020	-38,039	-57,940	19,900	-14,821	-13,552	-1,269
2021-2016	-450,526	-320,175	-64,600	-203,006	-179,990	-10,241

[a]Bed Agg/Deg indicates total volume change minus lateral erosion.

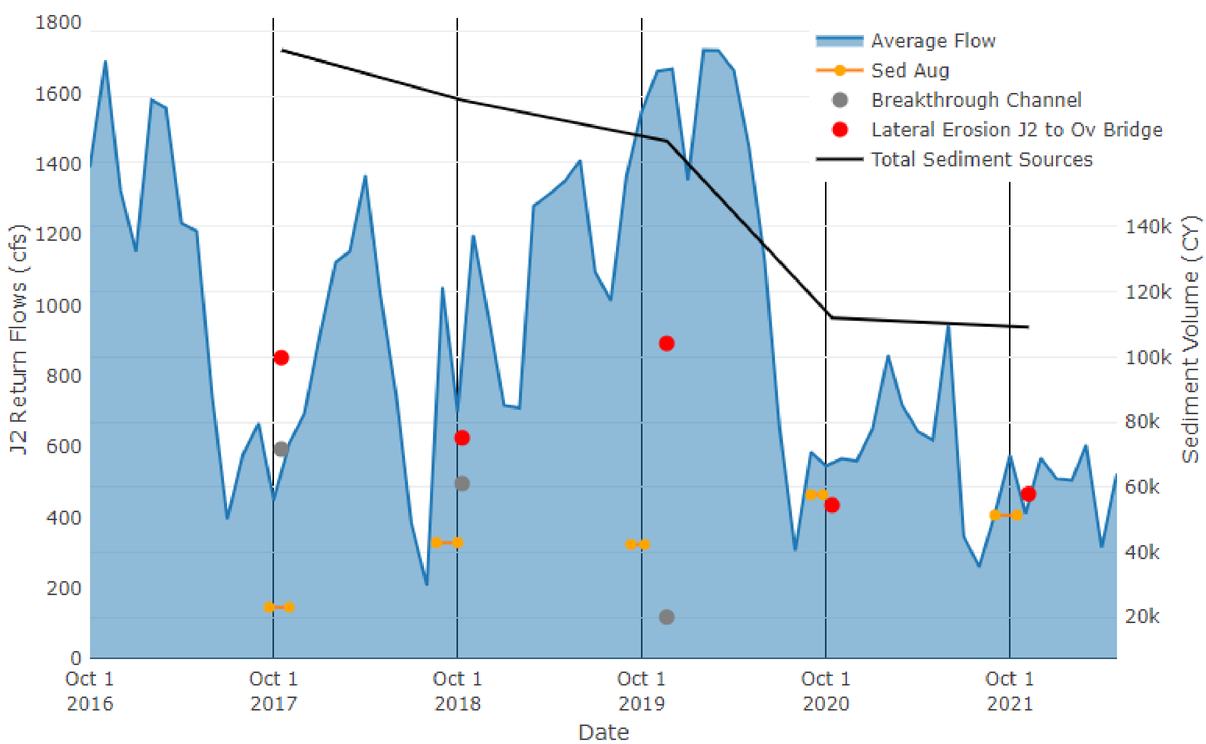

Figure 22. Monthly average flows from the J2 Return with all known sediment inputs to the reach from J2 Return to Overton Bridge. These include sediment augmentation (orange bars indicate dates), erosion from the breakthrough channel near J2 Return that was active in 2016-2019, and sediment from lateral erosion contributed along the reach. The black line shows the sum of all three inputs for each year.

- **Interpretations**
  - Relative elevation models (REMs)
    - Visually from the spatial REM, there appears to be incision between Station 70,000 and the N/S Channel confluence.
    - The profile of relative elevation along the thalweg appears to reach a threshold before relatively stabilizing. From J2 to Cottonwood Ranch, the relationship curves up to the threshold.
      - **How can we mathematically model this relationship?**
  - Thalweg and average cross-sectional elevation
    - 2016–2021 lowering of the channel thalweg is present between station 70,000 and the confluence with the North Channel
    - 2016-2021 aggradation is present downstream of Cottonwood Ranch to downstream of the Elm Creek Bridge
    - The slope of the thalweg gradually approaches the slope of the GGL, although the thalweg is a few feet below the GGL, as expected
    - There is higher variability in average cross sectional elevation upstream of the Overton Bridge.
    - Average cross-sectional elevations lowered in the J2 to Overton reach, especially in the first few miles. This could be partially due to lateral erosion.
    - The average cross-sectional and thalweg elevations seem to converge closer to one another downstream of Overton Bridge, and especially in Cottonwood Ranch.
    - **Should we consider the difference between average cross-sectional and thalweg elevations as a metric to assess channel change?**
    - **Should we consider variance of average cross-sectional elevation longitudinally?**
    - **How do we quantify the "end" of the incision-affected reach with our data?**
  - The difference between the years 2016 and 2021 show a few combinations of change: loss in both average cross section and thalweg, gain in thalweg but loss in average cross section, and both gaining.
    - **Should we categorize combined changes in both thalweg and average cross section, and associate them with geomorphic processes? If so, how do we determine what level of change is significant?**

  - Volumetric change
    - Based on rates derived from sediment sampling (Tetra Tech, 2017), the mean annual transport during the past 5 years at the Darr gage on the north channel above the J2 Return confluence is 230,000 T. At the Overton Bridge gage downstream of the confluence the mean annual transport is 594,000 T. This indicates a 364,000 T increase in transport capacity due to flow from the J2 Return.
    - High lateral erosion and corresponding bed aggradation in first third of study reach. Lateral erosion decreases downstream of meander bends through the rest of the reach (Fig 21A).
    - Excluding lateral erosion, year to year bed agg/deg (Table 9) shows that the reach upstream of the Overton Bridge has been relatively stable during the augmentation period. Volume changes are small compared to the estimated reach deficit of 55,000 CY (Tetra Tech, 2015). Things are a bit more variable downstream of Overton

Bridge, with one year of very high degradation (2017 to 2018) and several years of net aggradation. **This unexplained degradation warrants further monitoring.**

- **Is it reasonable to consider the total volume change leaving an upstream reach as volume delivered (input) to the downstream reach?**

VI. Relationship to target species habitat metrics

- **Purpose**
  - Wetted width, channel slope, and channel planform are important indicators of habitat. Measuring changes in these metrics through time will help determine potential changes in habitat suitability within our study area. Although the reach below J2 Return is considered a "corridor of sacrifice," it is our responsibility to ensure channel degradation does not spread to habitat management areas such as Cottonwood Ranch.
  - The purpose of sediment augmentation is to prevent the wandering planform from moving downstream.
- **Methods**
  - Wetted width
    - Flow area at 2,000 cfs was derived from a 2D hydrodynamic model. We obtained cross sections every 500 ft within the boundary of this flow area and measured the wetted width.
  - Slope
    - A cubic spline regression was used to model the longitudinal profile of the channel thalweg. Using the output of this regression as a representation of channel thalweg elevation through space, we calculated the slope of the thalweg in a moving window of 50 ft.

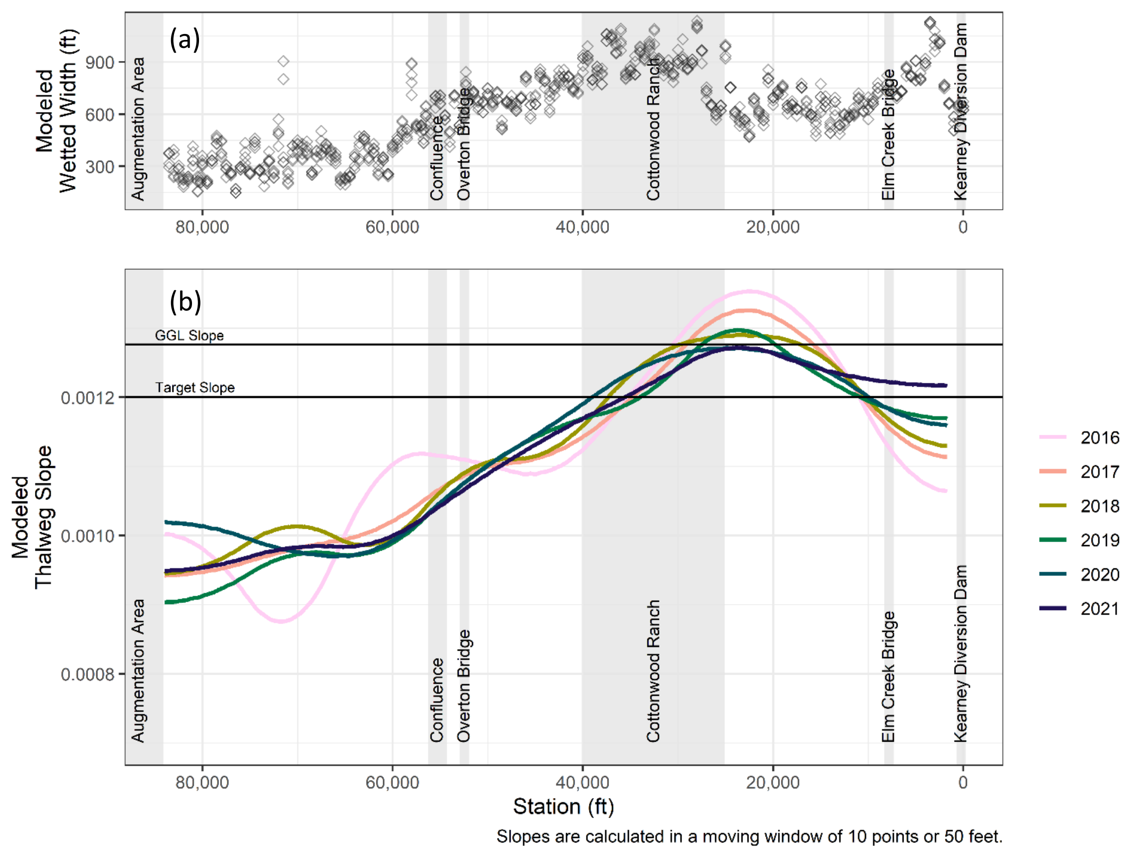

Figure 23. Modeled wetted channel (a) and channel slope (b) with distance downstream.

- **Interpretations**
  - Wetted Width
    - Wetted width does not appear to change much through time. We used a flow boundary of 2,000 cfs.
      - **Would a lower, more common flow (e.g., 1,200 cfs be more appropriate to assess change?)**
  - Slope
    - The slope presented is model-estimated slope based on a regression.
      - **Would assessment of true channel slope, which is highly variable, be meaningful?**
    - Slope appears to stabilize with time.
      - **How can we measure and quantify the change or stabilization of slope?**
    - The channel appears to shift from a wandering to braided planform at a slope of about 0.001.
      - **How do we quantitatively reconcile channel planform with slope or other variables?**
      - **Generally, how do we quantify inflection points or thresholds so that we can examine change through time?**
  - We are in progress to quantify braid index and BRI*.
    - **What other habitat metrics should we consider?**

VII. Conclusion

- **General Interpretations and Questions**
  - **How can we incorporate year-to-year flow variability into our analyses?**
  - Comparison to Murphy et al. (2004) plots
    - The south channel incision rate is much slower than Murphy et al. (2004) predicted.
    - Thalweg elevation and slope appear to have been relatively stable since 2002 when compared to 1989 data.
  - Mean channel elevation continues to drop in first three miles downstream of J2 Return as lateral migration mines sediment out of historical channel footprint.
  - Channel seems to be stable downstream of Overton Bridge since the beginning of sediment augmentation
  - Lateral migration may dominate the sourcing of sediment in the J2 to Overton Bridge reach, along with sediment augmentation. Sediment budgeting under current conditions may help determine the proportion of sediment contributions.
  - **What would happen in the absence of sediment augmentation? For example, would there be more lateral erosion? More incision?**
  - In general, augmenting the south channel sediment supply seems beneficial, but it is difficult to quantify changes due to sediment augmentation
  - Moving forward, we could consider less intensive supply options, for example:
    - Encourage lateral erosion (or at least don't stabilize)
    - Build a sand dam sediment bypass at the berm that disconnects the south channel. This dam would allow sediment to pass through during high flow.
    - **What other options could we consider?**

Selected References

Please see Table 3 for report summaries. A full References section will be included in the final Sediment Augmentation Evaluation Report.

Graf, W. 1998. Fluvial Hydraulics, Flow and Transport Processes in Channels of Simple Geometry. John Wiley & Sons, New York, New York, 681 pp.

Murphy, P.J., Randle, T.J., Fotherby, L.M. and Daraio, J.A. 2004. Platte River channel: history and restoration. Denver, Colorado: US Bureau of Reclamation.

Powers, P.D., Helstab, M. and Niezgoda, S.L. 2019. A process-based approach to restoring depositional river valleys to Stage 0, an anastomosing channel network. River Research and Applications 35(1): 3-13.

Appendix A: Specific Gage Analysis

- **History of specific gage analyses**
    - Strengths
        - Long term record of physical measurements of river stage and discharge at a location. Specific gage allows use of that data to infer trends in aggradation/degradation over time.
    - Weaknesses
        - Data quality: measurements of discharge include unknown error that has likely changed over time in relation to improvements in measuring devices.
        - Methods: many specific gage analyses have not used appropriate statistical techniques and have been justly criticized.
        - Interpretation: Limited to the physical location of the gage(s). Useful as an indicator but not diagnostic.
- **Purpose**
    - In relation to sediment augmentation, specific gage analysis provides empirical evidence of pre/post augmentation add/deg trends at the Overton Bridge as well as for other gage locations in the central and lower Platte. Other gages are useful in assessing comparative stability.
- **Methods**
    - General Methods – ONLY use physical stage/discharge measurements. This eliminates additional uncertainty of methods that rely on discharge estimates derived from rating curves.
    - Physical Measurement Data from USGS – used entire period of record available at current physical gage location (with datum adjustments).
        - No uncertainty on date
        - Unknown but low uncertainty on stage.
        - The USGS rates current-meter discharge measurements as excellent, good, fair, or poor, which correspond to potential errors of less than 2, 5, 8, and greater than 8 percent, respectively. (https://pubs.usgs.gov/tm/tm3-a8/tm3a8.pdf)
            - Note – average assumed to be +-5%.
            - Note – Post-2014 USGS solely uses ADCP units for discharge measurements. Substantially improves accuracy.
        - For the purpose of this analysis filtered data to remove measurements with poor rating as well as Dec – Feb measurements that are often ice-affected.
    - Gage Locations
        - Platte at Overton, CWR Mid-Channel, Kearney, Grand Island, North Bend, Ashland, Louisville.
    - Analysis discharges:
        - 10th Percentile mean daily discharge during period of physical measurements – low flow channel
        - 50th Percentile mean daily discharge during period of physical measurements – general channel
        - Median of instantaneous annual peak discharge – approximate bankfull

- Regression
  - Most specific gage analyses are linear regressions using a range of discharges around the target.
    - If actual discharges are skewed above/below target through time, can provide a biased estimate of stage change.
    - Relationships are sometimes non-linear
    - No uncertainty estimates
    - Used general additive models for each gage with smoothing.
    - Limited to 5 degrees of freedom for each gage model (Hastie and Tibshirani 1990).

- **Results**
  - Overton (06768000)
    - https://waterdata.usgs.gov/nwis/inventory/?site_no=06768000&agency_cd=USGS
    - Period of Record: 10/1/1930 to present
      - Limitation – Moved to present location on 10/7/1986 and datum adjusted 2.0 ft lower on 9/30/2004.
    - Physical Measurements:
      - 10/7/1986 to current: 799
      - Filtered for quality: 610
  - Cottonwood Ranch Mid-Channel (06768035)
    - https://waterdata.usgs.gov/nwis/inventory/?site_no=06768035&agency_cd=USGS
    - Period of Record: 10/1/2001 to Present
    - Physical Measurements: 241
      - Filtered for quality: 178
      - Discharge range 56 cfs to 8520 cfs

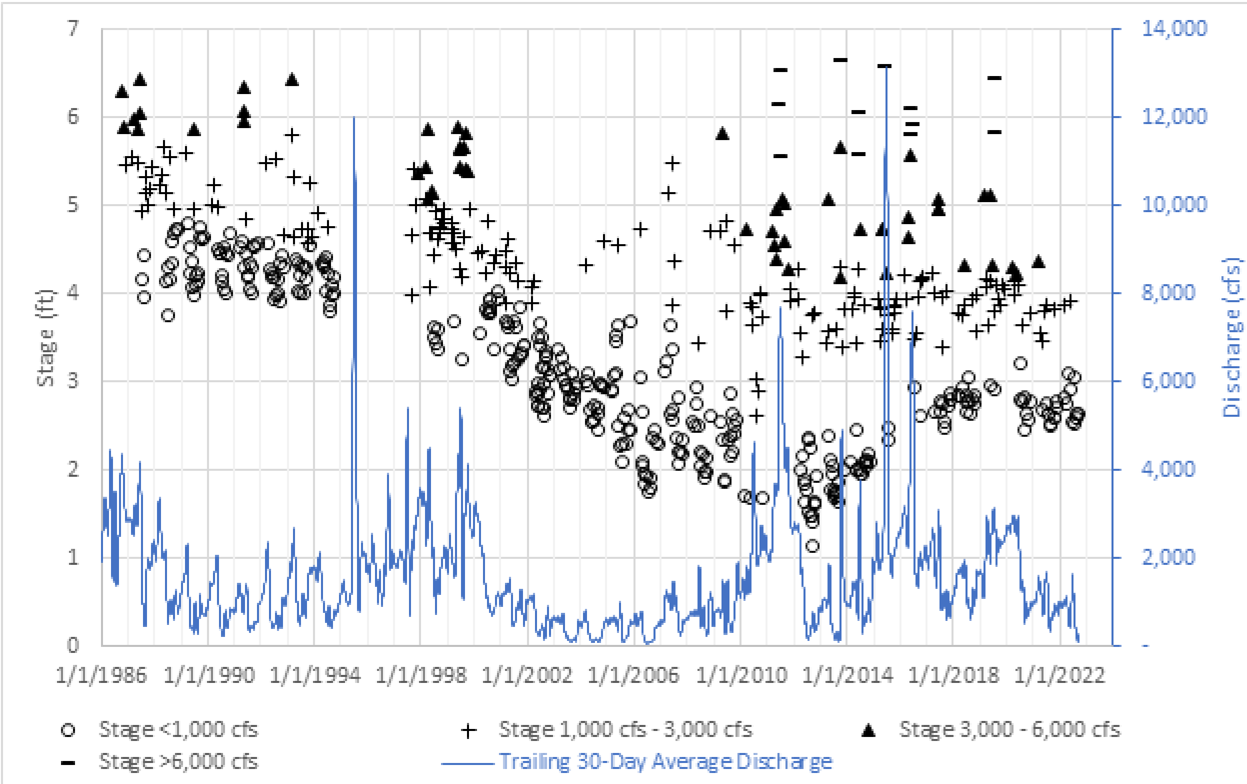

Figure A.1. Physical measurement stage data at Overton Gage (USGS 06768000) and trailing 30-day average discharge

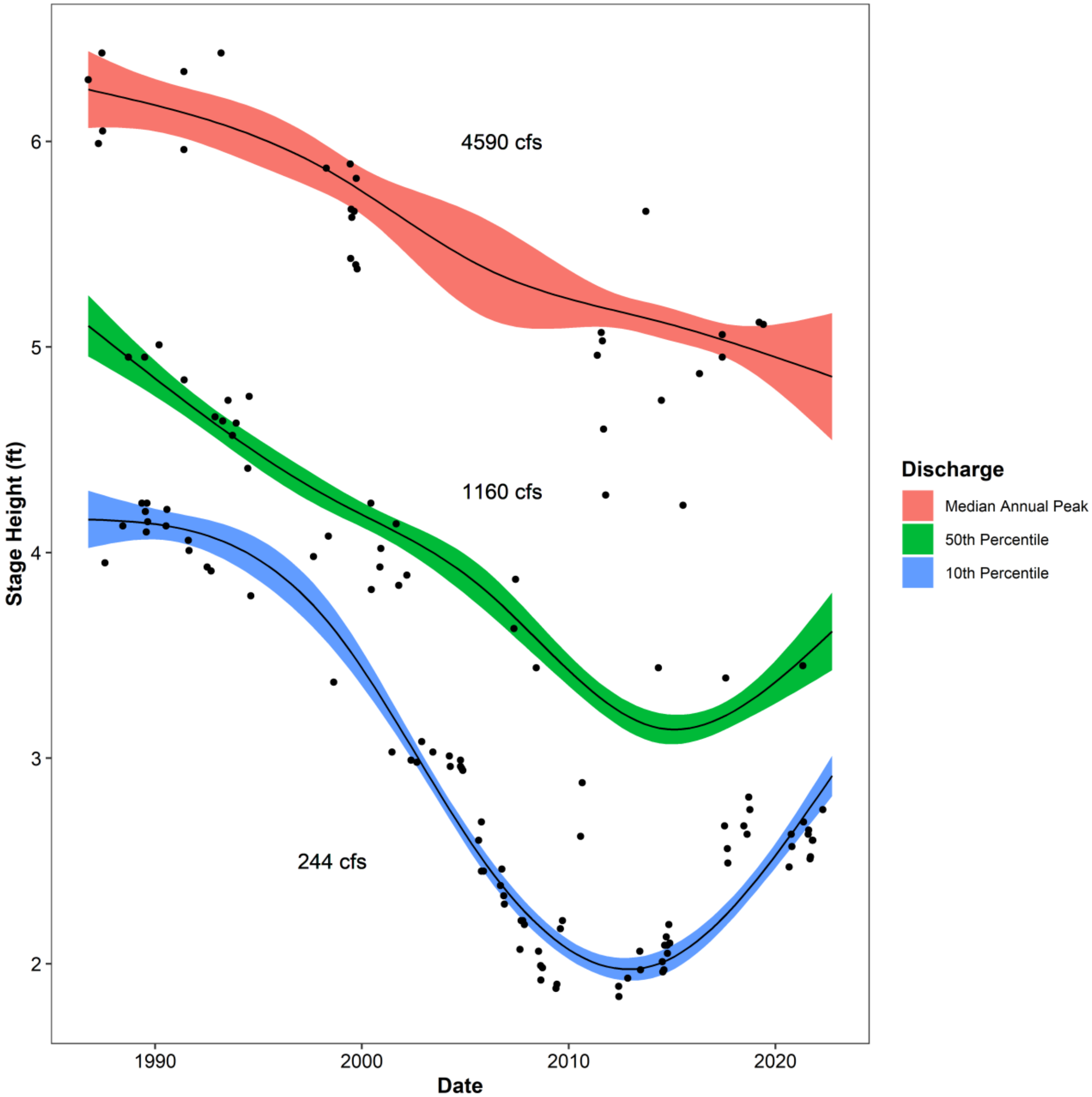

Figure A.2. Specific Gage analysis for Overton Gage (USGS 06768000) at 10th percentile discharge of 244 cfs, median discharge of 1,160 cfs, and median annual peak discharge of 4,590 cfs.

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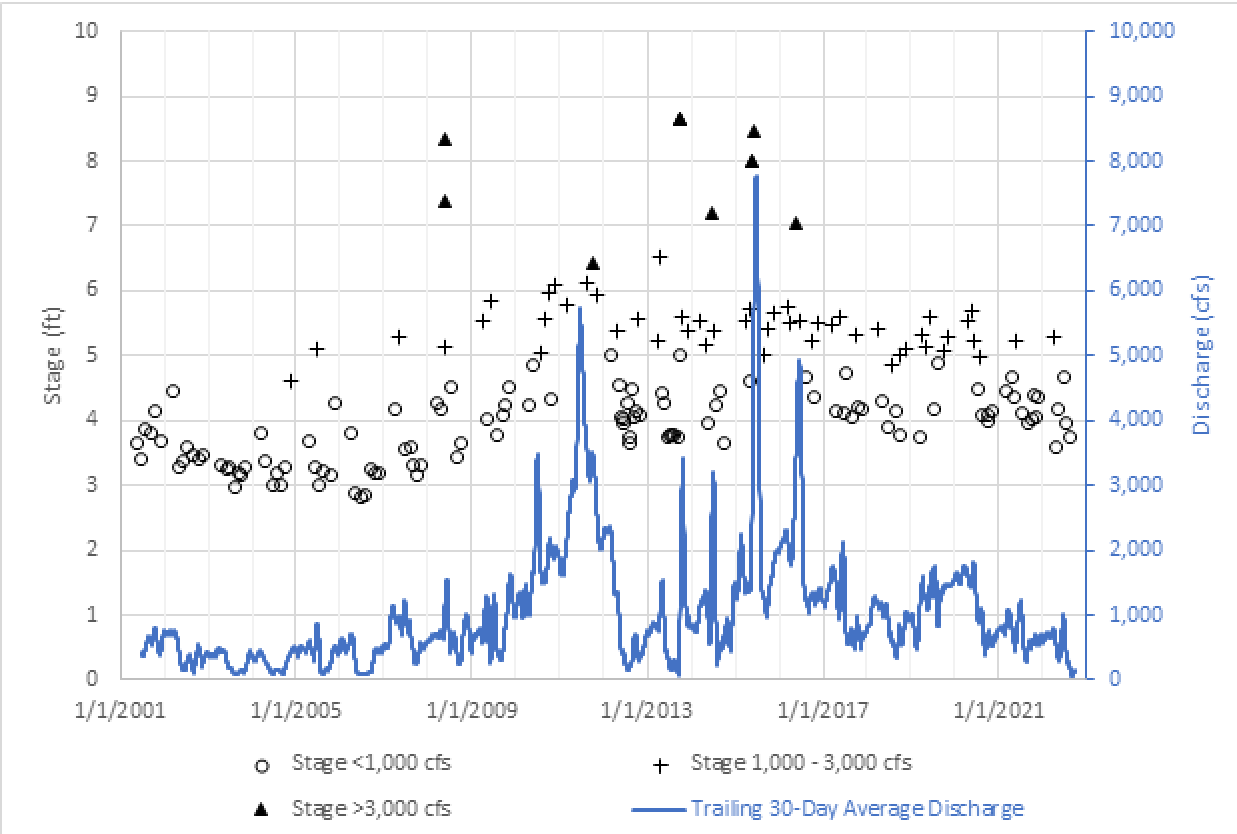

Figure A.3. Physical measurement stage data at Cottonwood Ranch Mid-Channel gage (06768035) and trailing 30-day average discharge.

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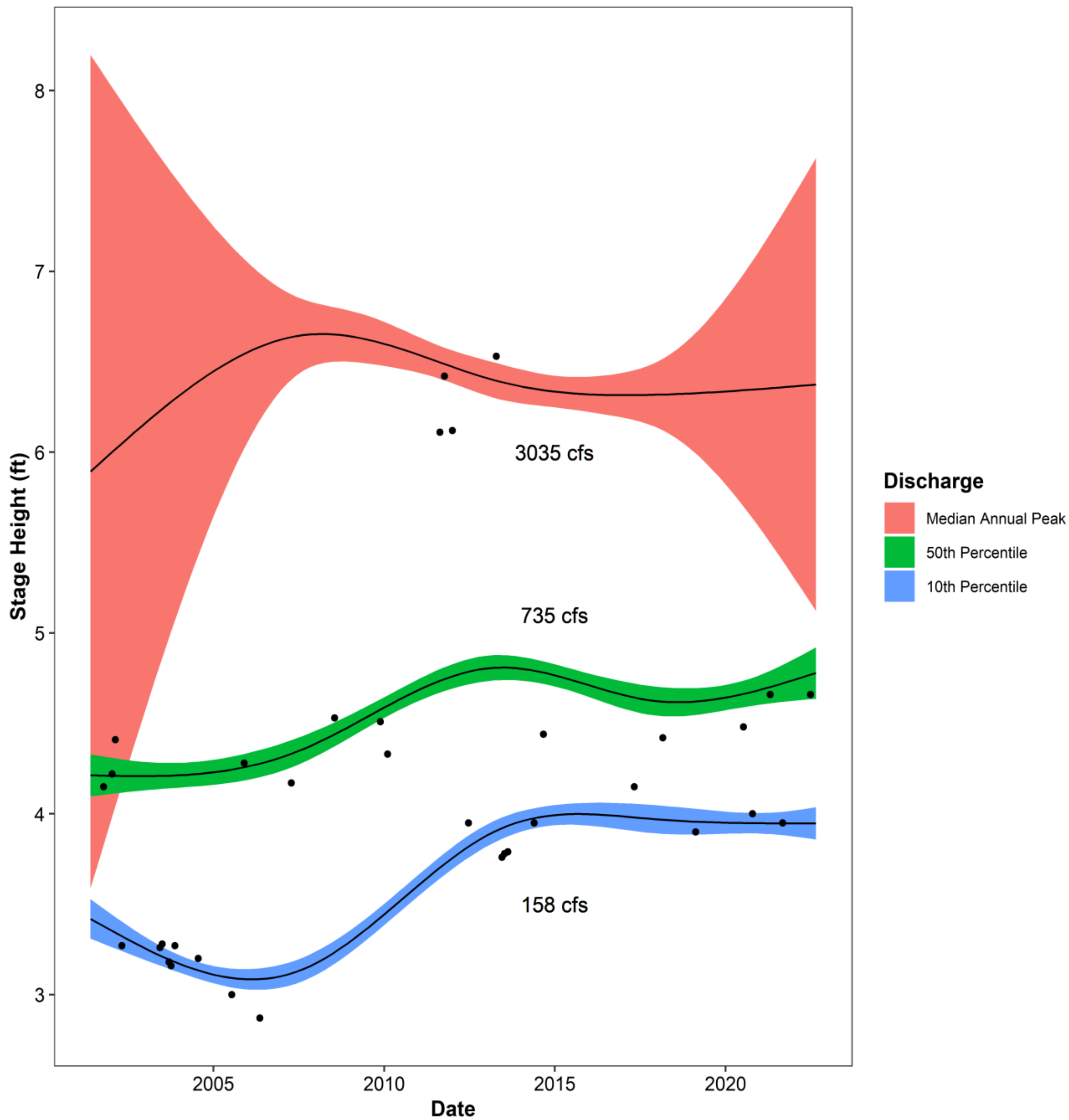

Figure A.5. Specific Gage analysis for Cottonwood Ranch Mid-Channel Gage (USGS 06768035) at 10th percentile discharge of 158 cfs, median discharge of 735 cfs, and median annual peak discharge 3,035 cfs.

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477 • OTHER GAGES FOR GENERAL COMPARISON

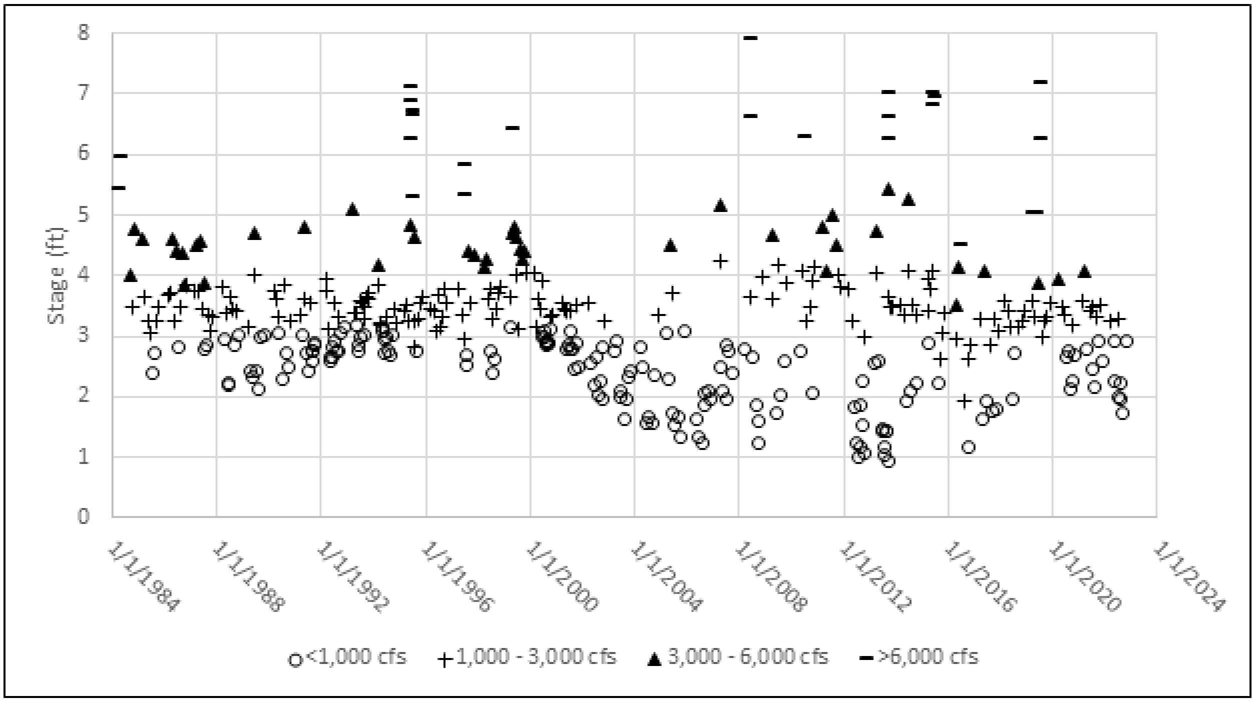


Figure A.6. Physical stage measurements Platte River at Kearney (USGS 06770200) for period of 1984– 2022.

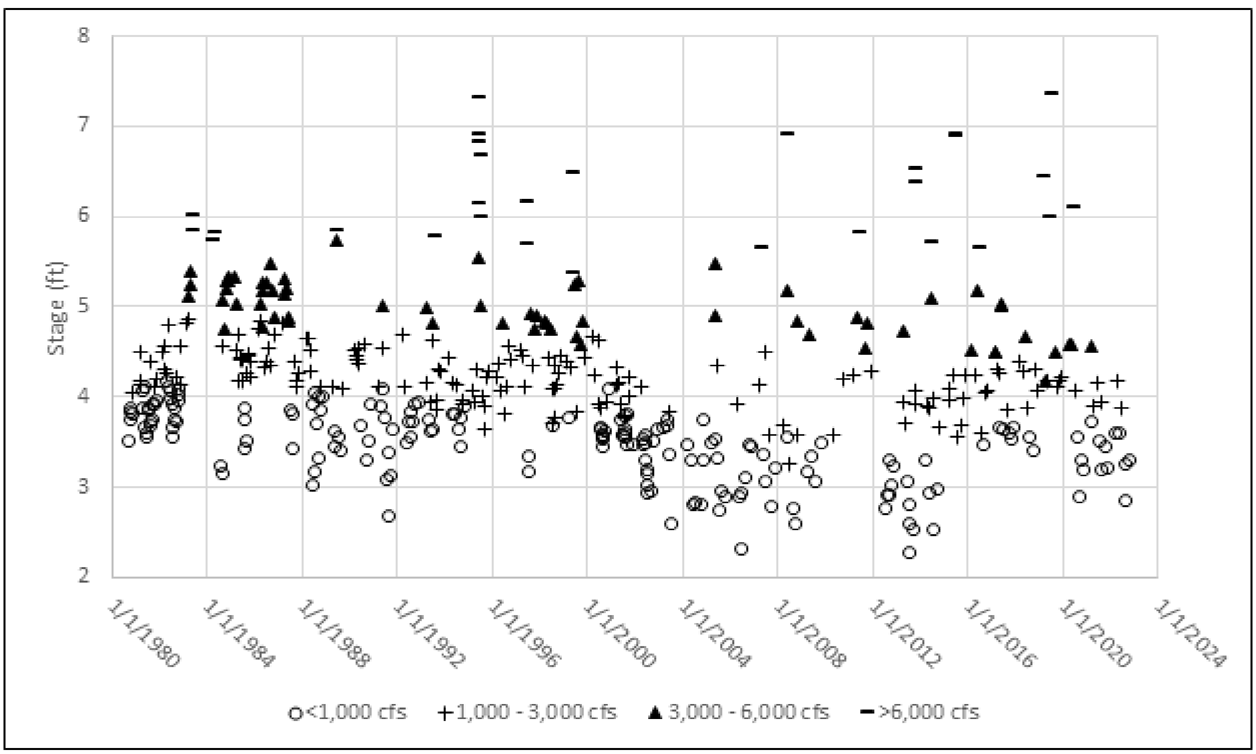


Figure A.7. Physical stage measurements Platte River at Grand Island (USGS 06770200) for period of 1980– 2022.

- GAGE IMAGERY SERIES

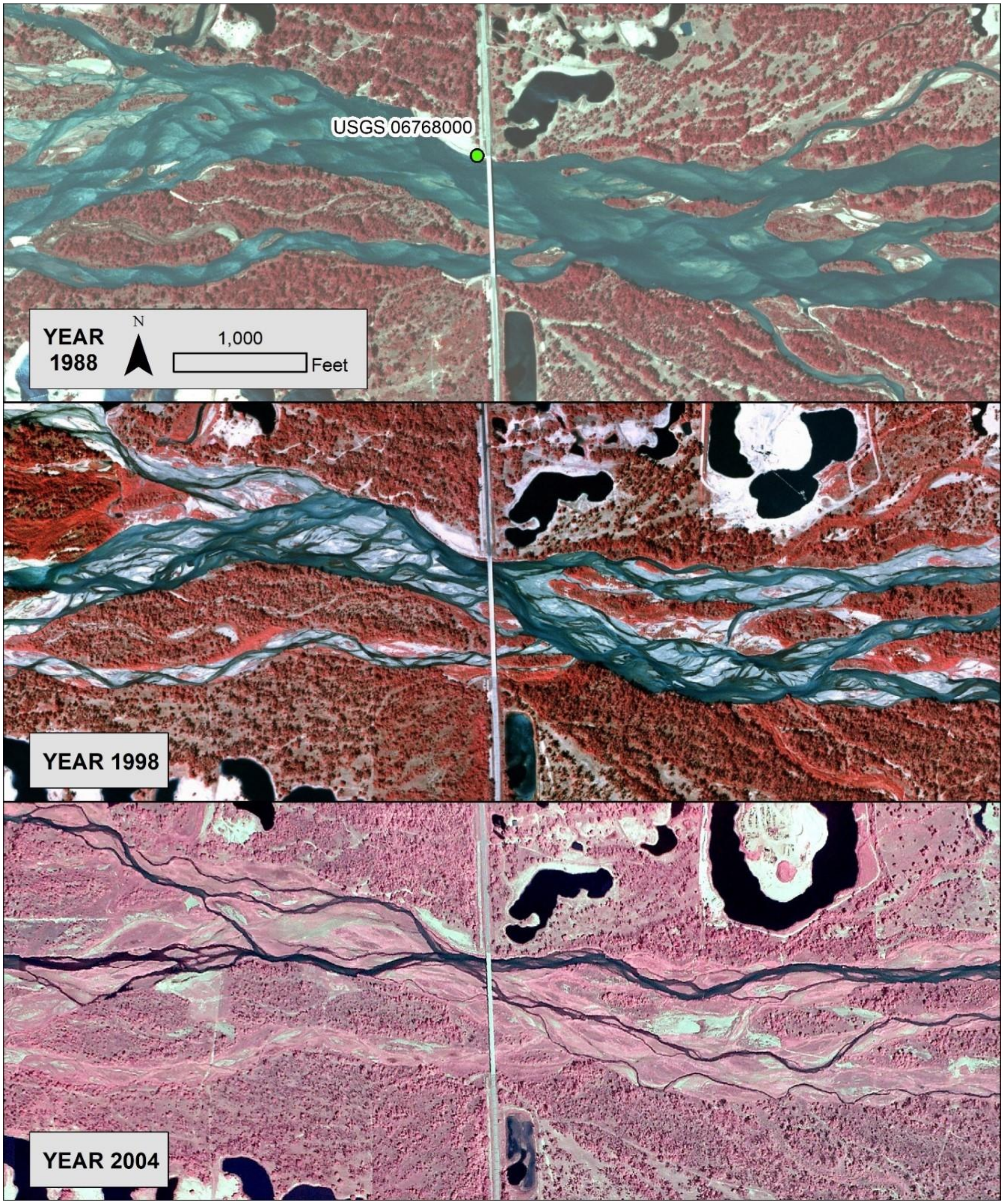


Figure A.8. Imagery at Overton Gage (USGS 06768000) 1998 through 2004.

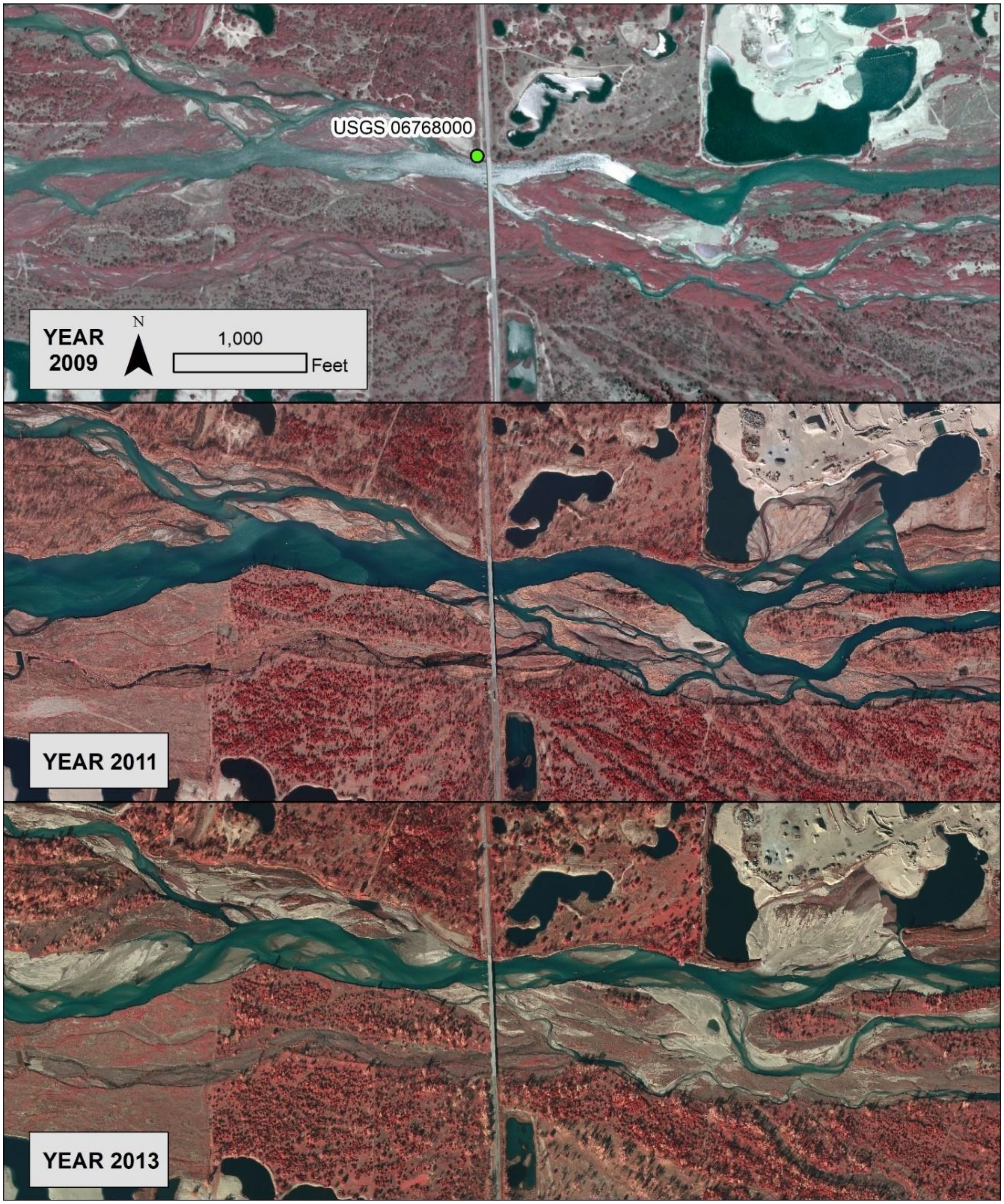
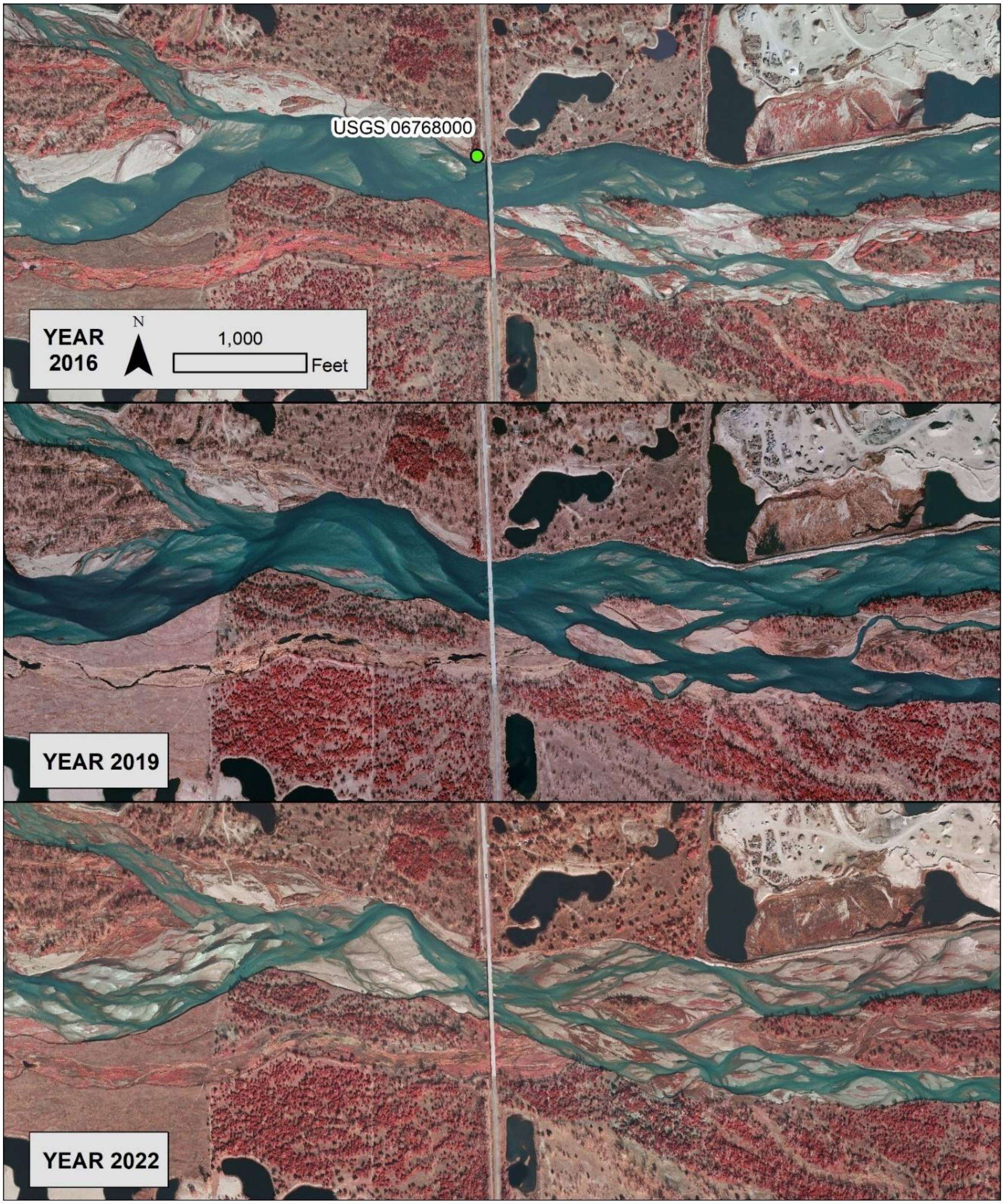


Figure A.9. Imagery at Overton Gage (USGS 06768000) 2009 through 2013.



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487 **Figure A.10.** Imagery at Overton Gage (USGS 06768000) 2016 through 2022.

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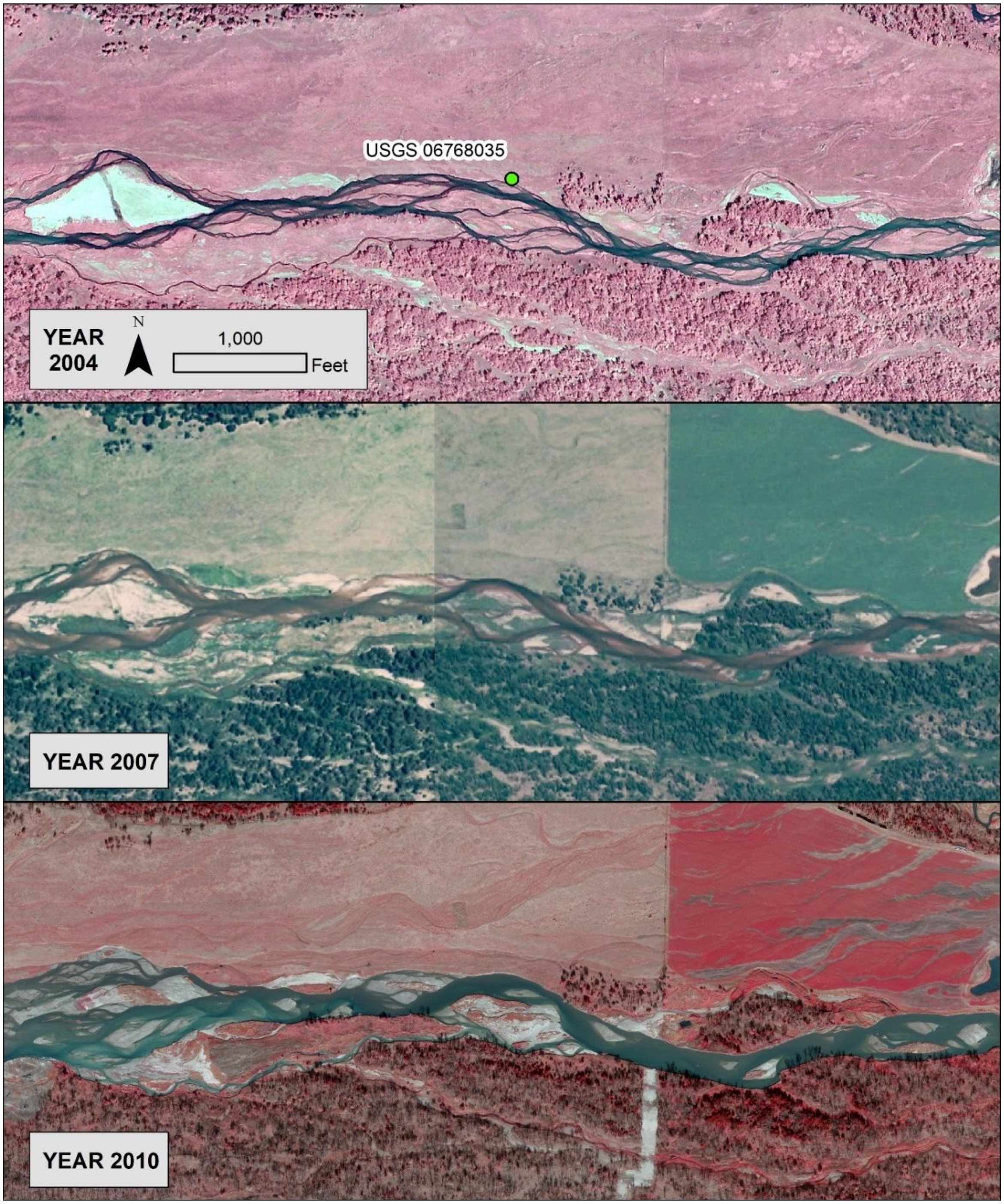

489 **Figure A.11.** Imagery at Cottonwood Ranch Mid-Channel Gage (USGS 06768035) 2004 through 2010.

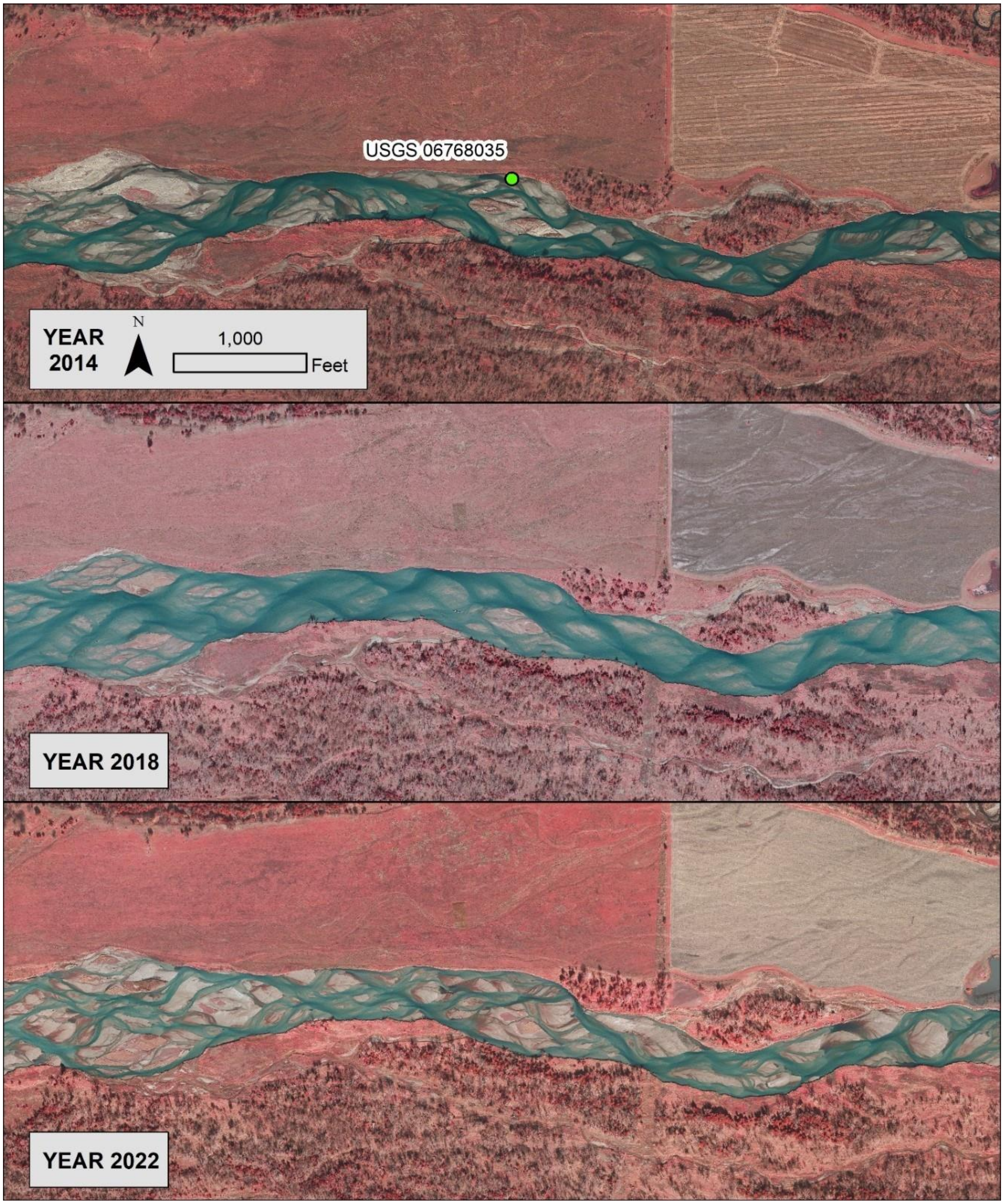

Figure A.12. Imagery at Cottonwood Ranch Mid-Channel Gage (USGS 06768035) 2014 through 2022.