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

Final Statement – PRRIP Sediment Augmentation Data Synthesis Compilation

On December 10, 2024, the PRRIP Governance Committee (GC) approved the following motion:

The Governance Committee approves the Technical Advisory Committee recommendation to accept the Sediment Augmentation Data Synthesis Compilation, revised by the Executive Director's Office in response to Peer Review comments, as FINAL. This revised document is now approved by the Governance Committee as final with the understanding it will be used for decision-making purposes, and with the understanding the revised document and all associated Peer Review materials will be made available to the public and posted on the Program website.

The final revised Sediment Augmentation Data Synthesis Compilation is attached as **Exhibit A**. The Peer Review Summary Report, including comments from three (3) Peer Reviewers and a comment/response matrix from the Executive Director's Office (EDO), is attached as **Exhibit B**

All further questions regarding the Sediment Augmentation Data Synthesis Compilation, its use, and the associated Peer Review should be directed to the EDO.

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -or- Program)
EXHIBIT A
Final PRRIP Sediment Augmentation Data Synthesis Compilation

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Data Synthesis Compilation

Sediment Augmentation

Prepared by staff of the Executive Director's Office for the Governance Committee of the Platte River Recovery Implementation Program

December 10, 2024

PREFACE

This document was prepared by the Executive Director's Office (EDO) of the Platte River Recovery Implementation Program ("Program" or "PRRIP"). The information and analyses presented herein are focused on informing the use of Program land, water, and fiscal resources to achieve the Program's long-term goal of improving and maintaining the associated habitats for the target species (interior least tern, piping plover, whooping crane, and pallid sturgeon). While the sediment regime and effect of sediment augmentation apply for the entire suite of target species, these actions have the highest potential to effect the channel planform as it relates to whooping crane habitat; as such, the Program has focused efforts on informing the relationship between sediment augmentation and the whooping crane management objective: contribute to the survival of whooping cranes by increasing habitat suitability and thus use of the Associated Habitat Reach (AHR) along the central Platte River in Nebraska. The Program has invested fourteen years in implementation of an adaptive management program (AMP) to reduce uncertainties about proposed management strategies and learn about river and species responses to management actions. During that time, the Program has implemented management actions, collected a large body of physical and species response data, and developed modeling and analysis tools to aid in the interpretation and synthesis of data.

Implementation of the Program's AMP has proceeded with the understanding that management uncertainties, expressed as hypotheses and summarized as Big Questions, encompass complex physical and ecological responses to limited treatments that occur within a larger ecosystem that cannot be controlled by the Program. The lack of experimental control and complexity of response precludes the sort of controlled experimental setting necessary to cleanly follow the strong inference path of testing alternative hypotheses by devising crucial experiments (Platt, 1964). Instead, adaptive management in the Platte River ecosystem must rely on a combination of monitoring of physical and biological response to management treatments, predictive modeling, and retrospective analyses (Walters, 1997).

One of the Program's primary management uncertainties is the need for long-term sediment (sand) augmentation. Due to significant variation and uncertainty in the sediment balance throughout the central Platte River, the Program focused its efforts at the upper end of the Associated Habitat Reach (AHR) to offset the largest and most well-known historical sediment deficit in the central Platte River due to clearwater hydropower return flows. Stakeholders have long been concerned that incision and narrowing due to erosion of sediment from the bed of the channel downstream of the return will migrate downstream and impact habitat suitability for the Program's target species. Efforts to quantify the magnitude of the sediment deficit and develop augmentation methods began soon after Program initiation in 2007. By 2016, Program stakeholders reached consensus that the best next step in evaluating sediment augmentation would be implementation of a full-scale sediment augmentation experiment immediately downstream of the hydropower return. The full-scale augmentation experiment was initiated in 2017 with augmentation occurring annually from 2017 through 2021. In 2022, the Executive Director's Office began analysis of the effectiveness of sediment augmentation, producing multiple lines of evidence across a range of spatial and temporal scales.

The results of our analyses are organized into a four-chapter synthesis report. The Executive Summary provides a condensed and consolidated summary of the findings presented in the following chapters. The Data Summary provides relevant information regarding all the sources of data used in our analyses. Chapter 1 provides history and context including a summarization of modeling and research conducted during the First Increment of the Program. Chapter 2 is comprised of retrospective analyses of spatial and temporal patterns of incision prior to initiation of the sediment augmentation experiment. Chapter 3 focuses on two-dimensional longitudinal channel response to sediment augmentation. Chapter 4 is comprised of an analysis of volumetric change in the period prior to and during the sediment augmentation experiment.

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CONTENTS

LIST OF ACRONYMS

1D	One dimensional
2D	Two dimensional
ADCP	Acoustic doppler current profilers
AHR	Associated Habitat Reach
AMP	Adaptive management plan
CNPPID	Central Nebraska Public Power and Irrigation District
CWR	Cottonwood Ranch
DEM	Digital elevation model
EDO	Executive Directors Office
EIS	Environmental impact statement
GAM	Generalized additive model
GAMM	Generalized additive mixed model
GC	Governance Committee
GGL	Geomorphic Grade Line
GSD	Ground Sample Distance
ISAC	Independent Scientific Advisory Committee
J2 Return	Johnson No. 2 Hydropower Return
KCD	Kearney Canal Diversion
LiDAR	Light Detection and Ranging
MUCW	Maximum unobstructed channel width
NE	Nebraska
PRRIP	Platte River Recovery Implementation Program, or Program
QSI	Quantum Spatial Inc.
REM	Relative elevation model
SED-VEG	Platte River Sediment Transport and Riparian Vegetation Model
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
Ft	Foot
cfs	Cubic feet per second
yd^3	Cubic yard

EXECUTIVE SUMMARY

E.1 Why did we conduct a sediment augmentation management experiment?

Extension Science Plan Big Question 3[1] asks if sediment augmentation is necessary to create and/or maintain suitable whooping crane habitat in the future. More specifically, clearwater hydropower return flows entering the south channel of the Platte between Lexington and Overton (the J2 Return Channel) have resulted in incision and narrowing in that reach. We hypothesized that annual sand augmentation of 60,000 to 80,000 tons (40,000 to 53,000 yd^3)[2] might be necessary to supply sediment in sufficient quantities to stabilize channel incision and prevent it from progressing downstream past the Overton Bridge and negatively impacting whooping crane habitat suitability.[3] Alternative hypotheses include the need for more or less sediment and/or alternate augmentation locations, as well as the hypothesis that incision is progressing slowly enough that it does not pose a threat to downstream habitat.

To answer this question, the Program initiated a full-scale sediment augmentation management experiment in 2017 that involves mechanically augmenting 40,000–60,000 yd^3 of sand into the channel immediately downstream of the J2 Return each year. A combination of transect surveys and LiDAR data has been analyzed to evaluate channel response to the increase in sediment supply. Preliminary findings, along with a map of the augmentation evaluation reach and features, follow.

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[1] Big Questions are priority uncertainties identified by policymakers. The answers to these questions will inform future decision-making.

[2] Earlier work computed sediment deficit and transport in units of tons, while current work is computed in cubic yards. In 2016, Twin Rivers Testing and Environmental determined an average sediment density and proposed 1 yd^3 would be equal to 1.5 T. This conversion rate was used to approximate volumes from sediment masses where necessary.

[3] The narrow, incised reach of the J2 Return Channel does not meet minimum habitat suitability requirements for whooping crane roosting habitat. If impacts progress downstream past the Overton Bridge, habitat suitability at the Cottonwood Ranch habitat complex will be negatively impacted.

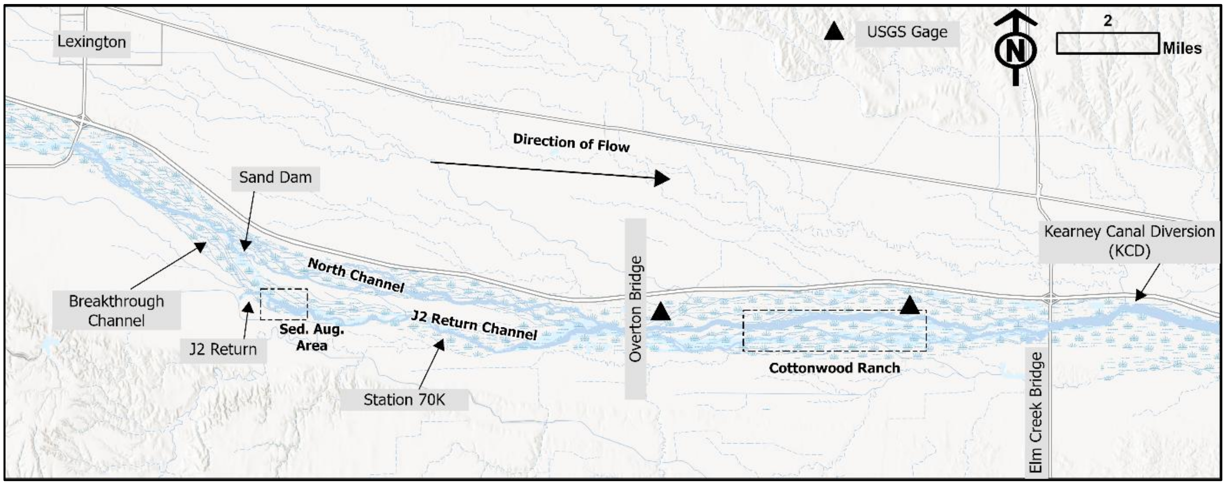

Figure E.1 Overview map of sediment augmentation evaluation reach and features. There is no permanent surface flow connection between the north channel and the upstream end of the J2 Return Channel.

E.2 What have we learned about historical degradation in the J2 Return Channel prior to augmentation?

The J2 Return began clearwater hydropower returns in 1942. Since then, J2 Return Channel has incised and its slope has decreased, diverging markedly from historical elevations (Figures 2.5-2.6; relative elevation model). Limited transect survey data prior to LiDAR gives an indication of the progression of this change. In 1989, transect data indicated that the thalweg below the return had incised 14 feet (0.3 ft/yr) below the floodplain, followed by an additional six feet of incision by 2002 (0.5 ft/yr). After this point, however, incision seems to have slowed with no measurable lowering between 2002 and 2016. This period of slowing incision coincided with a steady increase in sinuosity (i.e. more lateral channel movement).

Classic braided channels are multithreaded, where flow is separated by temporary, unvegetated sediment bars; meandering channels are single-threaded, sinuous and associated with pools along cut banks and riffles between subsequent pools; and wandering channels can be considered transitionary between braided and meandering. The shift from vertical incision to lateral migration may be linked to the channel slope dropping below the range needed to maintain a straight braided channel, causing it to transition to a wandering planform. Lateral erosion now comprises >50% of total erosion in the channel, supplying downstream reaches with sediment from bank material rather than bed material.

Overall, we assess that a wave of vertical incision propagated down through the study area after J2 Return began operations. In the early 2000s, the primary mechanism of channel degradation shifted from incision to lateral migration, with the highest intensity of migration occurring in upper half of the J2 Return Channel.

E.3 What have we learned about the J2 Return Channel during the sediment augmentation management experiment?

Mechanical augmentation operations began in 2017 and full-scale augmentation of 40,000–60,000 yd^3 occurred annually from 2018–2021.[4] Calculation of year-to-year volume change in the augmentation area indicates most augmented material was mobilized downstream out of the augmentation area annually. Annual comparisons of volume change downstream of the augmentation area found that rates of bed erosion decreased by 20,000–40,000 yd^3 (45%–60%) from the pre-augmentation period. This roughly equals the annual increase in sediment transported out of the sediment augmentation area (36,000 yd^3) during augmentation operations.

The decrease in bed erosion occurred in the first three miles downstream of the augmentation area. Bed elevations in that segment were stable to slightly aggradational. However, incision was observed farther down the J2 Return Channel. A 6,000 ft reach near Station 70,000 was identified as an area of interest where rapid channel consolidation and incision seems to be occurring. This area will continue to be monitored closely for evidence of transition from braided to wandering channel planforms.

These findings indicate that the annual augmentation volume was sufficient to offset approximately half the bed erosion in the J2 Return Channel Reach while bed erosion and possible planform change continued in the downstream half of the reach.

E.4 What have we learned about sediment balance downstream of Overton during the sediment augmentation management experiment?

When compared to the pre-augmentation period and normalized for discharge, we observed no major difference in the volume of bed erosion during the pre- and post-augmentation periods downstream of Overton Bridge. The one substantial difference we did observe was significant lateral erosion that occurred because of the prolonged peak flow event in 2015 which increased mean channel width by more than 200 ft. Channel widths have remained stable since.

Overall, we assess that effects of sediment augmentation were not detectable downstream of Overton Bridge. The reach continues to be dynamic and highly variable but generally stable and the increase in channel width that occurred during the pre-augmentation period has been maintained.[5]

E.5 What is our overall assessment of the performance of the sediment augmentation management experiment?

Augmentation operations reduced annual bed erosion in the J2 Return Channel by approximately 20,000–40,000 yd^3 (45%–60%) which is consistent with the 35,000 yd^3 increase in sediment transported out of the augmentation area following augmentation operations. Nonetheless, we observe continued incision and planform change midway down the J2 Return Channel (Station

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[4] Full-scale augmentation also occurred in 2022 but remote sensing data was not available in time to include in this analysis.

[5] Whooping crane habitat suitability in the CWR reach is being maintained at the highest level in 60-70 years.

70,000). In the absence of augmentation, we would expect bed erosion in the J2 Return Channel to return to pre-augmentation levels and for incision and planform change to accelerate near Station 70,000. We are unable to predict short term changes in the rate of incision because:

1) The absence of detailed thalweg elevation data during the pre-augmentation period (no topo-bathymetric LiDAR) prevented a detailed analysis of thalweg incision rates immediately prior to augmentation.
2) The absence of a complete hydrologic record in the J2 Return Channel obscures the relationship between flow and incision. This is being remedied for future analysis with the installation of a stream gage.

Regardless of these uncertainties we can say with confidence that there is a substantial sediment deficit in the J2 Return Channel that has, and continues to, impact channel form. At present the most serious planform impact (transition from braided to wandering) has not progressed downstream of Overton Bridge but may at some unknown point in the future. As such, mechanical augmentation at the upper end of the J2 Return Channel has been shown to reduce the sediment deficit, theoretically reducing future risk to downstream habitat. However, near- and long-term benefits are difficult to quantitatively predict in the light of data limitations described above. Additional data and monitoring may allow for better predictions that can more easily be weighed against the annual cost of augmenting sediment. Alternatives that allow for sediment replenishment without annual mechanical augmentation may offer a longer-term solution, though their effectiveness, when compared to recent mechanical augmentation efforts, is unknown.

DATA SUMMARY

The following section provides detailed information on the various types and sources of data used in this report.

D.1 Topographic and Bathymetric Elevation Data

D.1.1 Light Detection and Ranging (LiDAR) Data

The Program has collected high-resolution LiDAR data across the study area each year since 2009. The minimum specifications require LiDAR to be collected at a 2.3ft average ground sample distance (GSD) with greater than 2 pulses/m^2. Actual post spacing was often 4-8 pulses/m^2. Vertical topographic accuracy requirements for these acquisitions were less than 0.3 ft (3.6 inches), though delivered accuracies often achieved better (Table D.1). Prior to 2016, LiDAR was only collected over dry portions of the banks and riverbed. Wetted areas were "hydroflattened" to smooth and approximate the water surface elevation.

Starting in 2016, topo-bathymetric LiDAR was deployed which allowed for the collection of both topographic and bathymetric data. These acquisitions use near-infrared-wavelength lasers to collect topographic data in non-water areas and use water-penetrating green-wavelength lasers to collect bathymetry. Between 2016 and 2021 LiDAR elevation data were collected by Quantum Spatial Inc. (QSI) in either October or November (QSI, 2016- 2021). Annual survey and ground control points are used to calibrate new LiDAR surfaces and ensure consistency with past years. Bathymetric accuracy of the calibrated LiDAR surface is evaluated with check points captured in submerged areas of the channel at the time of LiDAR flights. Data is processed by QSI and delivered as 3-foot resolution elevation rasters. Tested accuracies for those rasters are shown in Table D.1. The accuracy values in Table D.1 represent the 95% confidence interval, as derived from the population of differences between field-measured and DEM values. Accuracy assessments are designed to meet the guidelines of the Federal Geographic Data Committee National Standard for Spatial Data Accuracy (FGDC, 1998). From 2016–2021 the accuracy assessment data indicate elevation values in wet areas had consistently higher uncertainty than dry areas across all years due to inherent differences in bathymetric and topographic LiDAR data acquisition and processing (Szafarczyk and Toś, 2022). As a result of deeper and more turbid water during the period of data collection, wet areas in 2019 had a higher vertical uncertainty value at 9 inches (Table D.1).

Table D.1. Vertical accuracy estimates for the LiDAR DEM surfaces from each year for wet and dry areas. Accuracy values represent 95% confidence in the estimate.

Year	Dry, Unvegetated Accuracy (in)	Wet Accuracy (in)
2009	3.0	NA
2012	1.6	NA
2016	1.7	3.1
2017	2.2	4.6
2018	1.2	4.2
2019	1.2	9.0
2020	2.2	3.1
2021	1.7	2.1

To enable evaluation of the pre-augmentation period, this report uses two years (2009 and 2012) of topographic-only LiDAR data and all years (2016-2021) of topo-bathymetric LiDAR. In 2009 and 2012, LiDAR collection occurred when river flows were low (see Table D.2) and water covered a small portion (~25%) of the active channel area, allowing for ~75% LiDAR coverage. The uncertainty in thalweg elevation and volume change created by these missing channel elevations will be discussed in Chapters 2 and 4.

Table D.2. Summary of LiDAR data used in analyses

	2009 and 2012		**2016 - 2021**	
LiDAR date, resolution	March 2009, November 2012, 2.3 ft GSD Topographic only		Fall (Oct or Nov), 2.3 ft GSD Topo-bathymetric	
Flow rate during LiDAR collection (cfs)	**J2 Return**	**Overton**	**J2 Return**	**Overton**
	0–134	200–400	90–2,000	250–2,400

D.1.2 Uncertainty Evaluation for Rasters of Difference

Several methods exist in literature for quantifying uncertainty from difference rasters including the use of fuzzy inference systems (Wheaton et al., 2010; Bangen et al., 2016) for systematic error and the use of probability thresholds to limit noise when quantifying total erosion or total deposition (Lane et. al., 2003). After careful analysis of our LiDAR data, we found that the distribution of error over the active channel approximates a normal distribution and does not portray evidence of systematic biases that would lead to significant over or under-estimation of changes in difference rasters. Given this finding, we elected to follow the example of Anderson, 2019 in which normally distributed positive and negative errors are assumed to cancel one another out, removing the need for thresholding.

To verify the absence of systematic error in topographic LiDAR as reported by the contractors, we extracted elevations from each DEM between 2016 and 2021 along roads within the study area (Figure D.1). These locations are stable and paved and expected to stay consistent such that any measured difference in DEM surface should represent error and not an actual change in elevation. Differences between the highest and lowest elevation extracted along the line are generally between 0.05 and 0.15 feet (0.6 to 1.8 inches) and standard deviations calculated for all years are around 0.05 feet (0.6 inches). These values represent the variability among surfaces due to LiDAR accuracy and DEM production methods. We can therefore confirm that the difference associated with acquisition and production accuracy and error between any two years' DEMs are generally less than 0.2 ft (2.5 inches) and in line with the accuracy as assessed by the contractor. We can also conclude there is no systematic bias to elevation error because at any given linear extraction location there is no consistency to the year that is the lowest or highest elevation (Figure D.1). For example, the 2021 survey (Figure D.1, orange line in Panels B-D) is the lowest elevation at Location 10, is around the average elevations at Location 1, and is relatively high in elevation at Location 15.

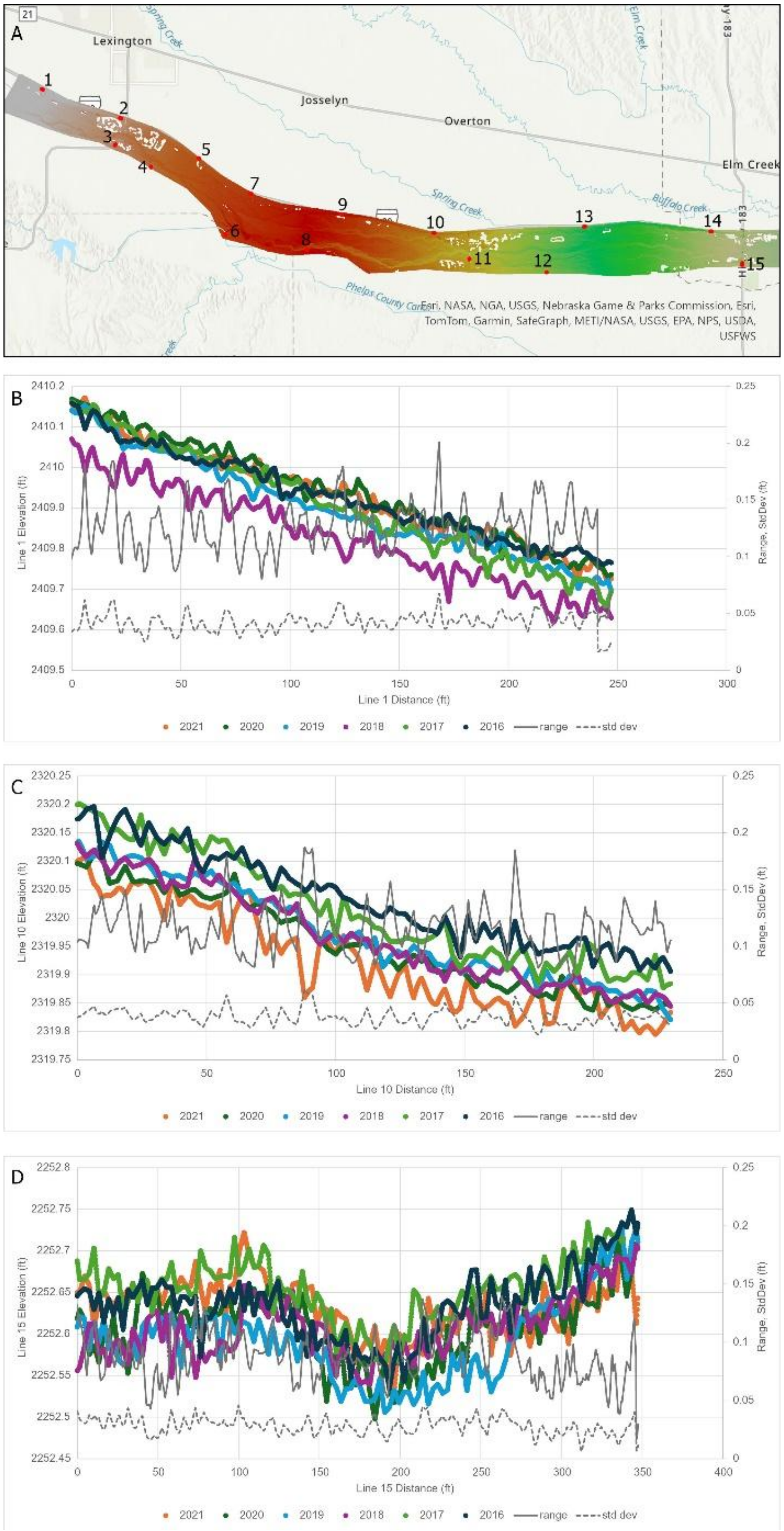

Figure D.1. Linear elevation extractions from three example paved surfaces (Location 1, Panel B; Location 10; Panel C, and Location 15, Panel D) in the study area (Panel A).

To verify the absence of systematic error in bathymetric LiDAR we examined the median average difference between bathymetric checkpoints and the DEM provided by the contractor. As shown in Table D.3, the median differences vary from slightly positive to slightly negative each year and remain within 1.5 inches of zero every year. This indicates that while the magnitude of LiDAR error is larger in inundated areas (Table D.1), there is no evidence of systematic error that would not average to zero.

Table D.3 Median difference of bathymetric checkpoints and LiDAR DEM.

Year	Number of Points	Median vertical error of bathymetric LiDAR (ft)
2016	140	-0.049
2017	288	0.03
2018	58	0.043
2019	128	-0.115
2020	251	0.013
2021	340	-0.036

We did observe systematic error due to vegetation changes in areas that experience plowing, tree clearing, mowing or haying vs. rest years for grasslands, or other major changes to vegetation height and cover that may be near or within typical accuracy estimates. These typical problem areas are rarely located within our area of interest for erosion and deposition (active channel), so by clipping the difference rasters to the active channel these areas are removed from our calculations. The full difference rasters presented in Appendix A demonstrate this vegetation bias and show where the active channel was clipped each year.

Following this post-processing effort to remove systematic error, and with the given reported accuracies, we believe it is reasonable to quantify change without using thresholds or other methods that may exclude data. Given the accuracy reports provided by the LiDAR contractor and our independent analysis of the DEM surfaces, we conclude that DEM elevation errors are small (< 0.2 ft or 2.5 inches). These results and reports thus suggest that it is reasonable to include the entire dataset in plots and calculations and that positive and negative errors should be canceled out (Anderson, 2019).

D.1.2 Pre-2016 Bathymetric Data

The primary data source for pre-2016 elevation data in the wetted portion of the channel was 2009–2016 systematic surveys of channel cross-section elevations conducted for the system-scale channel geomorphology and vegetation monitoring project (Tetra Tech, 2017). Prior to 2009 limited bathymetric survey data is available.

Repeat cross section data were collected by the United States Bureau of Reclamation (USBR) in 1989 and DJ&A consultants in 2002 (Holburn et al. 2006). These entities surveyed a total of 11 cross sections in 1989 between the J2 Return and KCD. Ten were repeated in 2002. A map of these cross section locations can be found in Chapter 2, Figure 2.7.

D.2 Hydrologic Data

Three sources of discharge data were used in our analyses. The furthest downstream, approximately 4.5 miles above the Kearney Canal Diversion (KCD) is the United States Geological Survey (USGS) Cottonwood Ranch Mid-Channel Gage (06768035) which measures stage and discharge of part of the river and was used solely for specific gage analysis (Section 2.5). A second USGS gage is located at the Overton Bridge (06768000) seven miles downstream of the J2 Return and ten miles upstream of the KCD. This gage captures the total flow immediately downstream of the confluence of the J2 Return Channel and the North Channel of the Platte. The period of record for the Overton stream gage extends from October 1, 1930, to present. However, the gage has been relocated several times and was moved to the present location on October 10, 1986. At the current location, operation has been continuous with one major datum adjustment (lowered by 2.0 ft) on September 30, 2004.

The third source data used in our analyses were records of discharge released from the Tri-County Supply Canal (Supply Canal) into the J2 Return Channel via the J2 Return. These records are provided by the Central Nebraska Public Power and Irrigation District (CNPPID). Typically, J2 Return releases represent the majority of total flow in the J2 Return Channel except for 100-300 cfs of baseflow. The exception to this is when high flows (~3,000 cfs) on the North Channel activate a channel that runs between the North and J2 Return Channels (the breakthrough channel, see Figure D.2). When the breakthrough channel is activated, an unknown but substantial quantity of flow is added to the J2 Return Channel. The breakthrough channel has periodically been blocked to prevent flow from entering and endangering a gas pipeline, however permanent closure of the channel is not currently allowed.

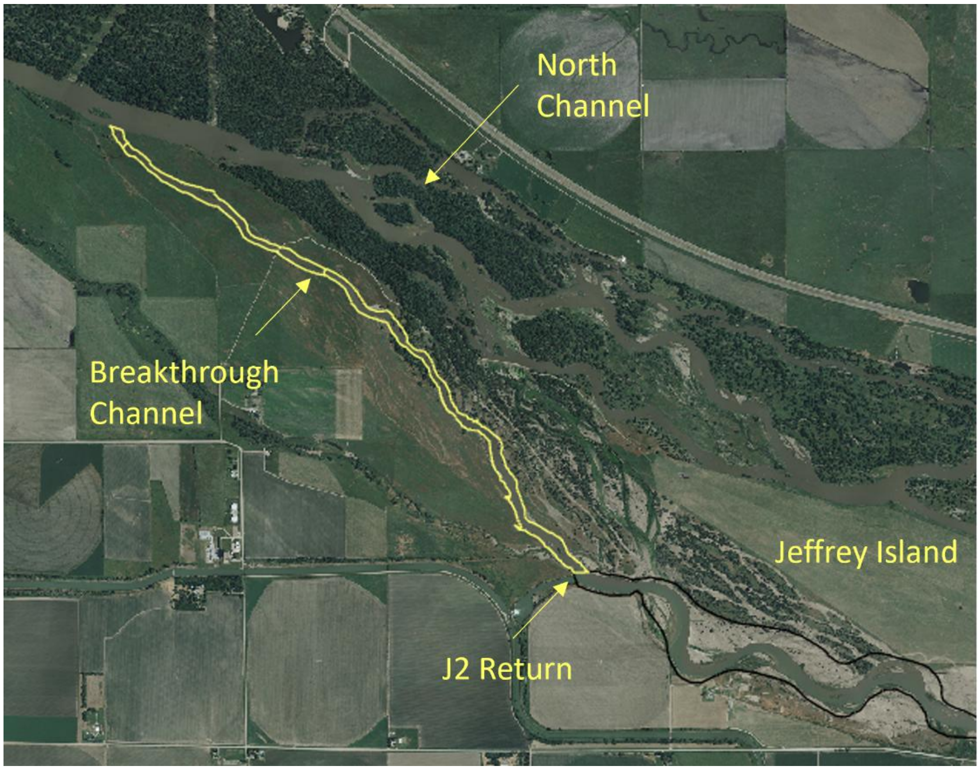

Figure D.2 Breakthrough channel connecting the North Channel to the J2 Return Channel during high flow conditions.

Figure D.3 presents 2009–2021 flow at the Overton Bridge (blue) alongside J2 Return releases (orange). J2 Return flows never exceeded 2,025 cfs during this period, whereas the Overton gage shows that there were several months in which mean flow was above 6,000 cfs. The peak daily flow of 15,300 cfs at Overton occurred in June of 2015. This flood had large geomorphic effects downstream of Overton such as high lateral erosion and channel widening (Section 3.6). As a result of the controlled hydrology from the J2 Return (except for occasional breakthrough channel activation), the J2 Return Channel does not experience floods as the North Channel does. This limits the ability of the channel to convey augmented sediment that is placed within the J2 Return Channel.

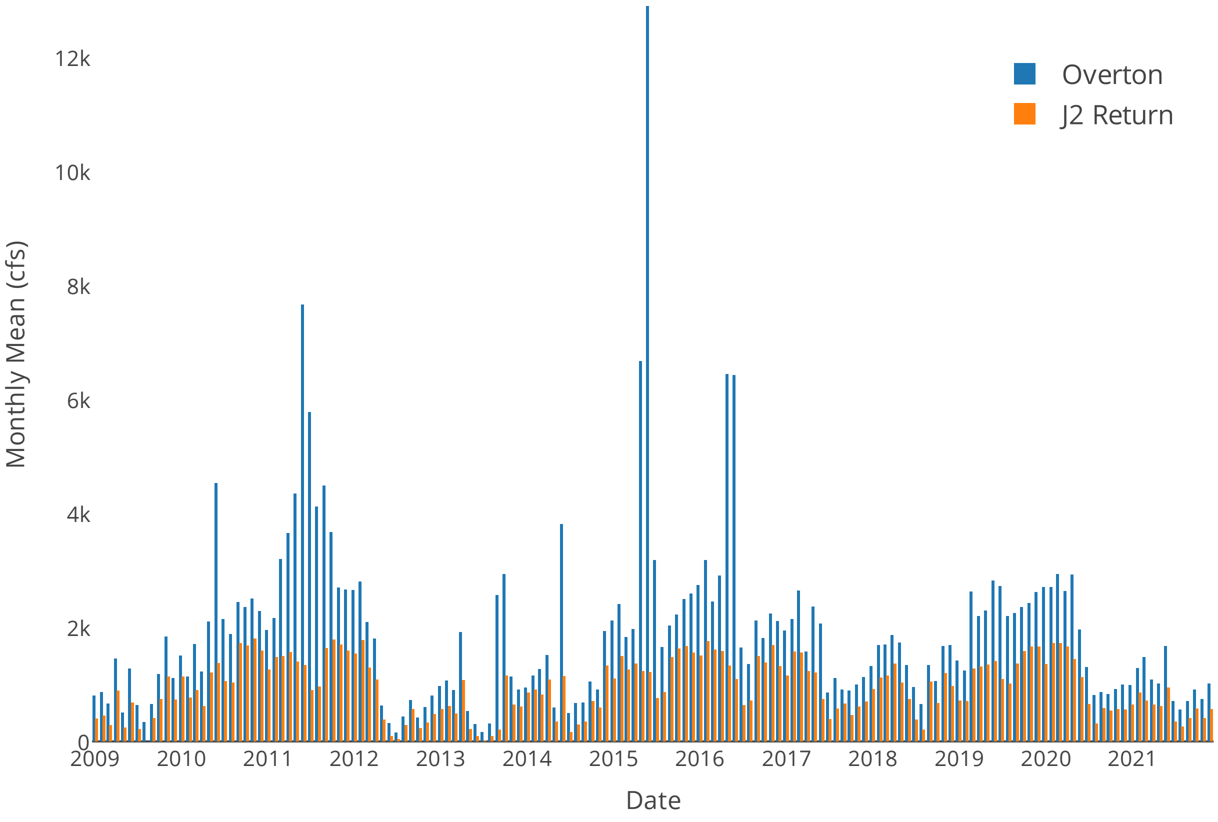

Figure D.3 Monthly mean discharge from CNPPID to the J2 Return Channel and at the USGS Overton gage from 2009 to 2021.

D.3 Hydraulic Models

D.3.1 Two-Dimensional Modeling

Since 2016, annual topo-bathymetric data has been used to update an SRH-2D (Lai, 2008) hydraulic model of the Associated Habitat Reach (AHR) that computes depth, velocity, and shear stress at each two-dimensional (2D) node over a range of in-channel flows (500 to 5,000 cfs). Each of the five model reaches has been calibrated, adjusting Manning's n to better match known data, and validated by comparing model results to measured water surface elevations. Water surface elevations were measured through field survey or LiDAR each year. Approximately 20 known water surface elevation points were collected each year at various flows and locations along the AHR. As shown in Table D.4, validated models predict water surface elevations with typical accuracies within one to two tenths of a foot.

Table D.4. Average difference between modeled and measured water surface elevation (ft) at sampled locations within SRH-2D model domains at various flows.

Model Reach	2016	2017	2018	2019	2020	2021
Grand Island to Chapman	0.01	NA	NA	0.18	-0.07	0.21
Shelton to Grand Island	0.02	-0.07	-0.09	0.09	-0.01	-0.11
Kearney to Shelton	-0.06	0.17	-0.04	-0.1	-0.06	0.01
Odessa to Kearney	NA	0.23	-0.07	0.13	-0.06	0.26
Overton to Odessa	-0.28	NA	-0.15	0.11	0.1	0.15
Lexington to Overton	NA	NA	0.14	0.06	-0.02	0.30

D.3.2 One-Dimensional Modeling

Prior to 2016, two one-dimensional (1D) hydraulic models were created, the first using 2009 LiDAR and survey data, the second using 2012 LiDAR and survey data. Both models were created using HEC-RAS with 78 cross-sections (PRRIP 2022a, HEC-RAS 2008) spaced an average of 1,165 ft apart through the study area. These models pre-dated topo-bathymetric LiDAR and relied on a combination of terrestrial LiDAR and supplemental field surveys. The models were calibrated using USGS rating curves at gage locations and LiDAR-measured water surface elevations at various locations along the AHR. The differences between published gage rating curves and modeled results were found to be within two tenths of a foot at all six gage locations and the average difference between LiDAR and modeled water surface elevations were found to be 0.04 feet (HDR, 2011).

D.4 Sediment Data

Detailed sediment analyses were conducted between 2009 and 2016 to estimate sediment deficits and desired augmentation volumes (The Flatwater Group 2010; Tetra Tech 2017). These included suspended and bedload monitoring and sieve grain size analysis. The sediment found in the Platte River is typically coarse to very coarse sand with a D50 of 0.5 to 2 mm. Sediment is coarser at the upstream end of the J2 Return Channel than it is on the North Channel or downstream of the North/J2 Return Channel confluence. At the time of this report, bed armoring has been observed but not measured on the upstream end of J2 (see Figure D.4. For a more thorough description of monitoring activities and results, see section 1.4.

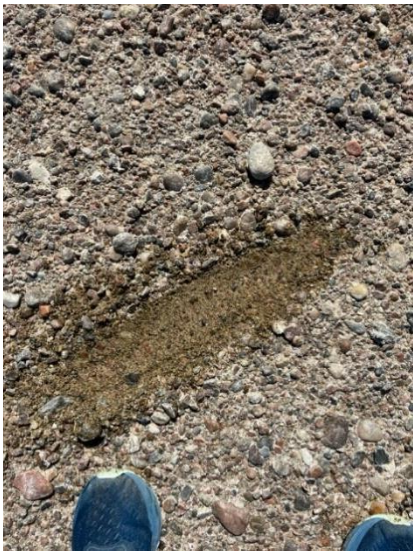

Figure D.4. Visual comparison of coarse armor layer overlaying finer sand on the channel bed approximately 500 feet downstream from the J2 Return

D.5 Aerial Imagery

High resolution (sub-1-meter pixel) aerial imagery collection has been commissioned by the Program annually or semi-annually since 2009. Products from these collections have typically included true-color as well as color-infrared (CIR) rasters. For this report we also made use of publicly available aerial imagery products pre-dating 2009. Sources for these images include the National Aerial Photography Program (NAPP), the United States Fish and Wildlife Service (USFWS), the Central Platte Natural Resources District (CPNRD), and the National Agricultural Imagery Program (NAIP). Table D.5 summarizes the year of collection, flow at the time of collection at the USGS Overton Gage, and the source of the imagery for each product used in this report.

Table D.5. Summary of aerial imagery sources and river flow at time of imagery capture.

	Average Overton Gage Flow on Collection Date (cfs)	Source
1988	2550	NAPP
1998	400	USFWS
2004	240	CPNRD
2007	285	NAIP
2009	1000	PRRIP
2010	310	PRRIP
2011	2800	PRRIP
2013	429	PRRIP
2014	264	PRRIP
2016	1120	PRRIP
2018	1550	PRRIP
2019	2400	PRRIP
2022	330	PRRIP

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CHAPTER 1 Sediment augmentation: History and Context

1.1 Abstract

Prior to implementation of a full-scale sediment augmentation experiment in 2017, the Platte River Recovery Implementation Program (PRRIP) and others have undertaken multiple monitoring, modeling and small-scale augmentation experiments to describe, quantify, and predict channel response to clearwater releases from the Johnson No. 2 Hydropower Return (J2 Return) near Lexington, NE. Since construction in the 1940s, the J2 Return has released sediment-free water into the south channel of the Platte River resulting in significant channel incision and planform change. This chapter summarizes findings from five decades of investigations leading up to full-scale augmentation. It also describes implementation of full-scale augmentation operations, with a focus on the location and volume of sediment augmentation.

1.2 Introduction

Water infrastructure often leads to longitudinal discontinuity of water and sediment in rivers (Wohl et al., 2015; Schmidt and Wilcock, 2008; Poff et al.; 1997, Kondolf 1997; Ligon et al., 1995). In response, rivers adjust toward new states of equilibrium after infrastructure-related disturbances to water and sediment supply (Howard, 1982). Adjustments to river planform, slope, width, and longitudinal profile occur abruptly at the sites of dams (Ward and Stanford, 1995), or in the case of our study area, the J2 Return. The J2 Return releases clear, sediment-free water into the south channel of the Platte River near Lexington, NE. River adjustments to lack of sediment supply extend and dissipate downstream for significant distances and tend to incise the upper portion of channel toward a convex profile (Smith and Mohrig, 2017; Graf, 2006; Williams, 1978). Over time, effects of the disturbance can propagate for large distances downstream (Smith and Mohrig, 2017). As a management strategy to balance the needs for human water use with river ecosystem function, sediment augmentation can help mitigate sediment imbalance that causes channel incision (Mortl and Cesare, 2021).

The Platte River Recovery Implementation Program (Program or PRRIP) is responsible for implementing certain aspects of the recovery plans for three threatened and endangered species including the highly endangered whooping crane (*Grus americana*). More specifically, the Program has a management objective to improve survival of whooping cranes during migration through increased use of the Associated Habitat Reach (AHR) of the Platte River in central Nebraska (PRRIP 2006a). This ninety-mile reach extends from Lexington, NE downstream to Chapman, NE and includes the Platte River channel and off-channel habitats within three and a half miles of the river (Figure 1.1).

Figure 1.1. Associated Habitat Reach (AHR) of the central Platte River in Nebraska extending from Lexington downstream to Chapman.

The Program has invested fourteen years implementing an adaptive management program to test strategies for increasing suitability of whooping crane habitat in the AHR. One area of focus has been the impact of a sediment deficit at the upstream end of the AHR on channel morphology. More specifically, channel incision and narrowing has occurred downstream of a clearwater hydropower return and Program stakeholders are concerned those impacts could progress downstream through time, impeding our ability to maintain the wide, unvegetated, braided river morphology that is suitable for whooping crane roosting. Concerns about incision emerged in the 1980s, approximately 40 years after the Johnson No. 2 Hydropower Return (J2 Return) began operations. Several investigations were conducted in the late 1990s and early 2000s to evaluate the magnitude of the deficit and develop the concept of sediment augmentation into a management action to be implemented during the First Increment of the Program (2007-2019).

During the First Increment of the Program, Adaptive Management Plan (AMP; PRRIP 2007) activities included additional monitoring, modeling, and evaluation of the feasibility and performance of various strategies to augment sediment. By 2016, Program decision makers advised by the Independent Science Advisory Committee (ISAC) concluded the best way to evaluate the performance of sediment augmentation was to initiate a full-scale sediment augmentation management experiment designed to offset the total sediment deficit downstream of the J2 Return. Implementation began in 2017 and annual augmentation continued through 2022.[6] Subsequent chapters of this document present analyses and interpretation of data collected prior to and during the sediment augmentation experiment. The objective of this introductory chapter is to provide an overview of the body of research and monitoring that led to implementation of full-scale augmentation. This begins with work leading up to Program initiation in 2007, including efforts to quantify the magnitude of the sediment deficit in the AHR

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[6] This analysis focuses on the period of 2017-2021 due to the lag time in remote sensing data processing.

and devise a sediment augmentation concept to be implemented under the AMP. We then transition to a description of adaptive management implementation efforts during the First Increment leading up to the full-scale augmentation experiment. The chapter concludes with an overview of full-scale augmentation including the location, timing, and magnitude of augmentation operations.

1.3 Pre-Program monitoring, modeling, and research 1978-2006

The first known discussion of sediment as a potential driver in morphologic change in the central Platte River occurs in Williams (1978). In that Geological Survey (USGS) Circular (781), Williams describes changes in width, braiding, sinuosity and bed aggradation/degradation in the North Platte and Platte Rivers in Nebraska over historical timeframes. Much of the publication focuses on large reductions in channel width that occurred in the decades following the initiation of reservoir construction in the North Platte River basin in the early 1900s. Williams focuses much of the publication on correlations between declining discharge and width metrics. However, he also included a specific gage analysis, noting that observed fluctuations in bed elevations at stream gage locations reflected complex regulation of both water and sediment delivery to the river.

In 1981, the USGS published a series of open-file reports describing sediment transport, channel morphology and other physical characteristics of various segments of the Platte River. Kircher (1981a) collected bedload and suspended sediment samples from segments of the South Platte, North Platte, and central Platte Rivers and used them to develop estimates of sediment transport and effective discharge for each segment (Kircher 1981b). Karlinger et al. (1981) explored the relationship between discharge, sediment, and channel width in the Central Platte, providing theoretical predictions of channel width adjustment to changes in sediment and flow. Finally, Crowley (1981) produced a detailed investigation of bedforms downstream of Grand Island, NE, characterizing the geometry and movement of macroforms as well as their relationship to channel narrowing.

In the late 1980s, O'Brien & Currier (1987) produced a report that explored changes in the morphology and vegetation in the Big Bend Reach of the Central Platte River.[7] The authors attempted to quantify magnitude of incision through comparison of historical quadrangle maps, concluding the channel had degraded three to ten feet from the late 1890s to the 1960s. Finally, the authors referenced several published works on empirical threshold relationships in alluvial channels (regime theory) and expressed concern that the reductions in flow and sediment supply in the Big Bend Reach could cause the channel to shift from a braided to meandering morphology. The authors concluded by recommending a complete analysis of sediment supply and transport capacity of the Central Platte.

In the early 1990s, basin stakeholders began the negotiations that ultimately led to the authorization of the Program in 2007. As part of those negotiations, a number of different investigations were initiated by the Platte River Environmental Impact Statement (EIS) Office and were published in the early 2000s. The first was a comprehensive evaluation of the physical history of the Central Platte River conducted by Simons and Associates (2000) which focused on

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[7] The Big Bend Reach roughly encompasses the 90-mile Associated Habitat Reach of the central Platte from Lexington, NE to Chapman, NE.

drivers of vegetation expansion into the channel in the 20th century. The authors noted that the bed of the Central Platte has coarsened over time and limited bed degradation has been observed. They ultimately concluded that sediment transport played a secondary role in channel narrowing, and that the channel bed was generally in a condition of dynamic equilibrium. Despite relegating sediment supply to a secondary factor in channel narrowing, the authors did (for the first time) introduce the concept of augmenting sediment to reduce bed degradation where it occurs. They recommended further analysis of potential relationships between augmentation, sediment transport, and riparian vegetation with a combined sediment transport and vegetation model developed by the United States Bureau of Reclamation (USBR).

Randle and Samad (2003) produced the first detailed evaluation of historical changes in sediment transport, reporting trends for the period of 1895-1999. Near the end of that report, the authors note that the main source of sediment between the J2 Return Channel and Overton was the bed and banks of the channel. They also noted that the thalweg was approximately 20 feet below the top of the right bank and had eroded six feet vertically between 1989 and 2002. These incision estimates were developed as part of a separate aggradation/degradation analysis by EIS Team published in 2006 (Holburn et. al. 2006). That work analyzed repeat channel cross section surveys to identify spatial and temporal trends in channel aggradation and degradation. The authors found a clear trend of degradation in a 25-mile reach from the J2 Return to Odessa. The most pronounced degradation occurred at the upstream end and gradually diminished until the difference in average annual change in cross-sectional area declined below 10 ft^2 which was assessed to be stable.

The major publication presenting the EIS Team's analysis and proposed restoration strategy was published in 2004. As with prior comprehensive assessments, Platte River Channel: History and Restoration (Murphy et al. 2004) discusses sediment along with other potential drivers of planform change. The authors discuss the theoretical progression of incision below the J2 Return, describing the process of winnowing of fine material from the riverbed, causing bed material in the reach that is incising to become significantly coarser through time. This process gradually results in armoring that limits the depth of channel incision at that location (assuming enough coarse material is available). Critically, the authors assessed that the process of incision would progress downstream until it was arrested by a combination of armoring and a decrease in local river slope.

Murphy et al. (2004) cited Graf (1998) and de Vries et.al. (1973) to predict how quickly channel incision would expand both vertically and downstream from the J2 Return under the theoretical assumption of steady flow and a channel bed of uniform sand. The figure of predicted incision through time is reproduced below as Figure 1.2. The figure predicts the progression of incision through the AHR and the authors note it could take centuries for the channel to reach equilibrium.

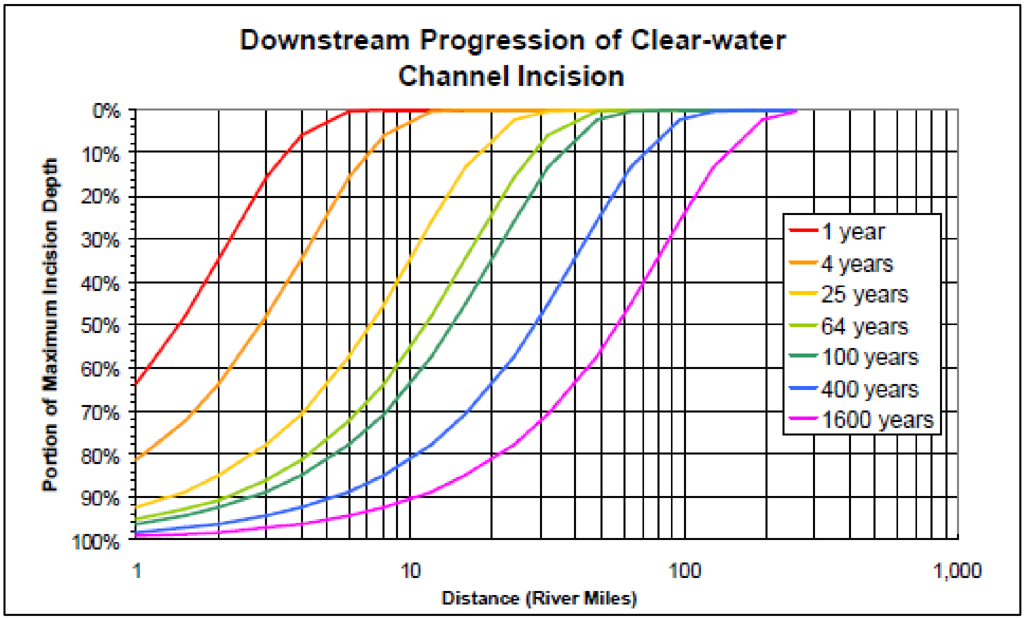

Figure 1.2. Reproduction of Figure 4.16 from Murphy et al (2004). Figure shows estimated progression of incision over time below the J2 Return.

As with prior EIS Team reports, the authors concluded that increased sediment supply is necessary to offset the deficit due to clearwater returns and to bring sediment supply into balance with cumulative sediment transport capacity of the river. The proposed solution was sand augmentation via mechanical pushing of island and bank material into the channel. This would have the effect of 1) increasing sediment supply and reducing median grain size of the riverbed, increasing bed mobility, and 2) widening the channel in augmentation reaches. Murphy et al. provided the hypothetical example of mechanically pushing 500 tons per day, or 100,000[8] yd^3 per year, requiring 20 acres of islands be leveled over the course of a year.

The EIS Team's final estimates of sediment deficit in the AHR and proposed volume of sediment augmentation were developed using an integrated hydraulic, sediment transport, and vegetation model called the Platte River Sediment Transport and Riparian Vegetation Model or SED-VEG model (Murphy et al. 2006). Model results indicated 85,000 to 175,000 tons (57,000 to 120,000 yd^3) of sediment were eroded annually from the bed and banks of J2 Return Channel, another 50,000 to 100,000 tons (35,000 to 70,000 yd^3) eroded annually from the bed and banks between the confluence with the North Channel and the Overton Bridge, and 180,000 tons (120,000 yd^3) eroded annually from the bed and banks of the river between Overton and Wood River 56 miles downstream.

Within the Program's AMP is the culmination of the EIS Team research described above. The AMP prescribes sediment augmentation as a management action to be tested under an adaptive management framework during the First Increment of the Program (2007-2019). Priority hypothesis Sediment 1 (reproduced as Figure 1.3) provides an overview of the magnitude and

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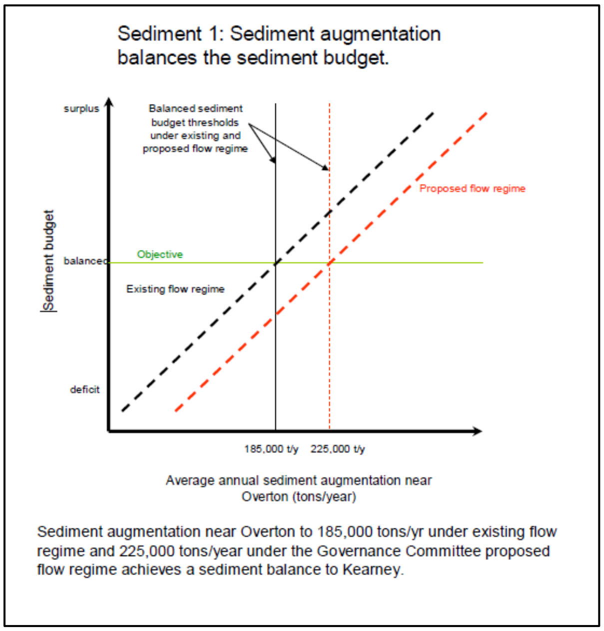
[8] Murphy et al. used a different volume to mass conversion factor.

hypothesized benefits of sediment augmentation. Specifically, annual mechanical augmentation of 185,000 tons (125,000 yd^3) of sediment near Overton under existing flow regime and 225,000 tons (150,000 yd^3) of sediment under the proposed flow regime[9] achieves sediment balance, eliminating the sediment deficit due to clearwater hydropower returns. Subsequent hypotheses (Sediment 2-4) predict increases in braiding and channel width due to augmentation.



Sediment 1: Sediment augmentation balances the sediment budget.

Sediment augmentation near Overton to 185,000 tons/yr under existing flow regime and 225,000 tons/year under the Governance Committee proposed flow regime achieves a sediment balance to Kearney.

Figure 1.3 Priority hypothesis Sediment 1 reproduced from the Program Adaptive Management Plan (PRRIP 2006).

1.4 Sediment augmentation research during the First Increment (2007-2016)

Following Program authorization in 2007, a team of consultants was retained to evaluate the feasibility of implementing sediment augmentation (The Flatwater Group 2010). The scope of work included development of an updated sediment transport model for the AHR[10] and evaluation of alternative methods and locations to implement the experiment. A baseline mobile bed sediment transport model was developed using the U.S. Army Corps of Engineers HEC-RAS program (HEC-RAS, 2008). It was then modified to represent and evaluate a range of sediment augmentation alternatives. Figure 1.4 is a recreation of baseline (no augmentation) sediment transport modeling results from the study. The modeled annual sediment deficit for the 12.5-year simulation period was 152,000 tons (100,000 yd^3).

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[9] Proposed flow regime refers to implementation of the Program's Water Action Plan designed to reduce deficits to United States Fish and Wildlife Service (USFWS) target flows by 130,000 – 150,000 acre-feet annually. Implementation of the Plan began in 2007. As of 2024, water projects are credited with reducing deficits by approximately 110,000 acre-feet annually. Water has been used to increase flow during whooping crane migration, during the summer to enhance baseflows, and to conduct vegetation scour/management experiments.

[10] The SED-VEG model was abandoned after Program authorization due to concerns about accuracy of model results and the custom/proprietary nature of the code which made it difficult to use.

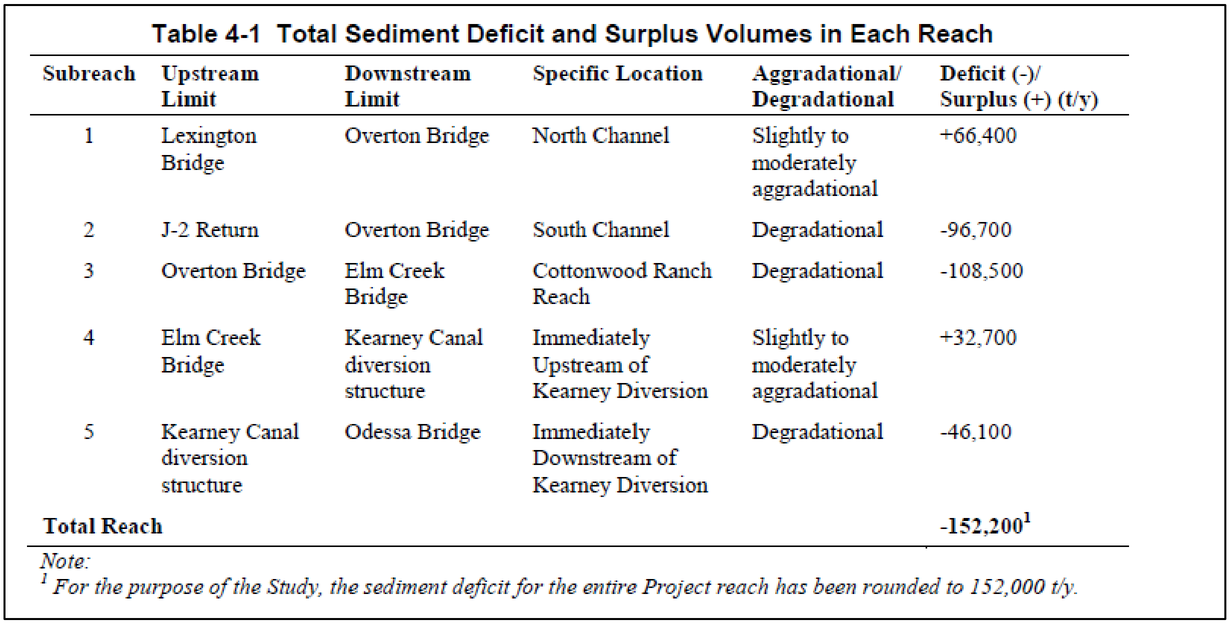

Table 4-1 Total Sediment Deficit and Surplus Volumes in Each Reach

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.*

Figure 1.4 Reproduction of Table 4-1 from The Flatwater Group (2010) providing baseline HEC-RAS sediment transport model results for the reach from Lexington, NE downstream to Odessa, NE.

Augmentation material gradations, sediment sources, methods of introducing sediment into the channel and augmentation locations were evaluated in the feasibility study. The report recommended two augmentation alternatives be implemented as part of a pilot-scale management experiment. The first alternative was similar to augmentation as proposed in the AMP. Bulldozers would push sediment from banks and islands (median grain size of 1.2 mm) into the channel, spreading the material across the width of channel to be mobilized by flow. This method had the benefit of widening the channel while augmenting sediment. The second alternative involved hydraulic mining of sediment from an existing gravel mine adjacent to the channel and screening it to produce a median grain size of 0.5mm. The screened sand and water slurry would then be pumped/piped directly into the channel. This alternative was similar to typical gravel mining operations with the expectation that unusable fines are discharged back into the mine.

Both augmentation alternatives were designed, permitted, and implemented in 2012–2013. Analysis of the alternatives concluded a year later (The Flatwater Group 2014). During the experiment, approximately 82,000 tons (55,000 yd^3) of hydraulically mined sand (D50 0.5 mm) were pumped into the lower end of the J2 Return Channel upstream of the confluence with the North Channel. Over 100,000 tons (70,000 yd^3) of overbank material (D50 of 1.2 mm) were bulldozed into the main channel downstream of the Overton Bridge at the upper end of the Cottonwood Ranch Habitat Complex. Monitoring was conducted during the experiment and used to assess the feasibility of augmentation methods as well as update sediment transport modeling and augmentation volume targets.

Implementation of mining/pumping and bulldozer augmentation revealed pros and cons for each augmentation method. Sand pumping maximized the volume of source material per surface area disturbed (material can be hydraulically mined to a depth of at least 40 ft) and allowed control of the gradation of the augmentation material. On the other hand, sand pumping had a much higher unit cost, low spatial flexibility due to the point source nature of the method, and it was difficult to match the augmentation rate to the channel transport capacity during low flows. Augmentation by bulldozer had a much lower unit cost and provided more flexibility in both location and placement of sediment, maximizing mobilization. Cons included low material volume per surface area disturbed and inability to control the sediment gradation.

The project team concluded that an annual average of 60,000 tons (40,000 yd^3) of annual augmentation (D50 of 1.2 mm) could be sustained in the lower portion of the J2 Return Channel without excess sediment accumulation. However, actual transport would range from 11,000 tons (7,000 yd^3) in dry years to 135,000 tons (90,000 yd^3) in wet years and rates would increase or decrease depending on material gradation. The volume of augmentation that could be sustained without excess sediment accumulation was lower than the model-derived annual sediment deficit between Overton and Elm Creek, which averaged 109,000 tons (73,000 yd^3) and ranged from 25,000 tons to 220,000 tons (17,000 to 150,000 yd^3).

The feasibility study team also modeled over-augmentation in the J2 Return Channel. Pumping 150,000 tons (100,000 yd^3) of sediment (D50 ~ 0.5 mm) annually into the J2 Return Channel was estimated to reduce the downstream deficit to approximately 43,000 tons (30,000 yd^3) on average. Using larger material from riverbanks (D50 ~ 1.2 mm), the deficit was reduced to 73,000 tons (50,000 yd^3) on average.

The Program paused sediment augmentation following completion of the pilot-scale management experiment while two other sediment-related efforts were concluded. The first was an update of sediment transport modeling to estimate the sediment deficit caused specifically by J2 Return flows (Tetra Tech 2015). This was accomplished by comparing sediment transport model results with and without J2 Return flows. The model indicated a relatively strong correlation between the volume of J2 releases and the sediment deficit downstream of the Overton Bridge. The reach was generally near balance during years when J2 releases were less than about 300,000 acre-feet, and the deficit increased to approximately 100,000 tons (70,000 yd^3) in years when J2 releases were in the range of 1,000,000 acre-feet. Eliminating J2 releases from the model reduced the average annual deficit downstream of Overton from 92,000 tons to 61,000 tons (60,000 to 40,000 yd^3), a reduction of 31,000 tons (20,000 yd^3) per year. Most of the remaining incision in the model occurred in the Cottonwood Ranch reach.

The second effort was the conclusion of an eight-year field-based monitoring program to assess system-scale changes in geomorphology and vegetation in the AHR (Tetra Tech 2017). Monitoring included repeat transect surveys of the channel, bed and bank material sampling, sediment transport measurements, and vegetation monitoring. Analyses of that data led to the conclusion that the annual sediment deficit in the Overton to Kearney reach was most likely in the range of 50,000 tons to 75,000 tons (30,000 to 50,000 yd^3). However, estimates of the deficit from cross section surveys and sediment transport estimates were highly variable with large confidence intervals, leading to low confidence in conclusions.

The ISAC provided feedback in 2014 and 2015 (ISAC 2014 and ISAC 2015) recommending that the Program implement large-scale augmentation in the reach immediately downstream of the J2 Return and intensively monitor channel response using multiple lines of evidence. The committee specifically mentioned application of geomorphic change detection techniques with Topo-bathymetric Light Detection and Ranging (LiDAR) data, analysis of trends in cross-sections and other geomorphic metrics through time, evaluation of the magnitude of change in the longitudinal profile, and specific gage analyses.

The Program's policy-making Governance Committee (GC) concurred with this advice and authorized the Executive Directors Office to design and implement a full-scale sediment augmentation experiment. That experiment commenced in 2017 with partial scale augmentation in that year[11] and full-scale augmentation in 2018-2021. The next section of Chapter 1 provides an overview of sediment augmentation implementation over the course of the management experiment.

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[11] More than the full-scale augmentation volume was moved during 2017, but the majority of that material was used to eliminate a meander bend and restore farmland that had been eroded. A berm was constructed to prevent the channel from continuing to migrate south towards a road and farmstead.

1.5 *Full-scale sediment augmentation management experiment (2017-2021)*

1.5.1 Sediment augmentation area

The Sediment augmentation sites are located in the J2 Return Channel, beginning approximately 0.75 miles downstream of the J2 Return and extending one mile east. This one-mile section includes three augmentation sites (Figure 1.5) that Central Nebraska Public Power and Irrigation District (CNPPID) has designated as available source sites for augmentation. These sites are bounded by the black, red, and yellow polygons in Figure 1.5. Since 2017, only two have been used for source material. Pending evaluation of results, augmentation may continue in a downstream direction with one more major grading site targeted in this upstream reach (Site 3 in Figure 1.5) before moving downstream to the Plum Creek Complex, approximately 4 miles further downstream.

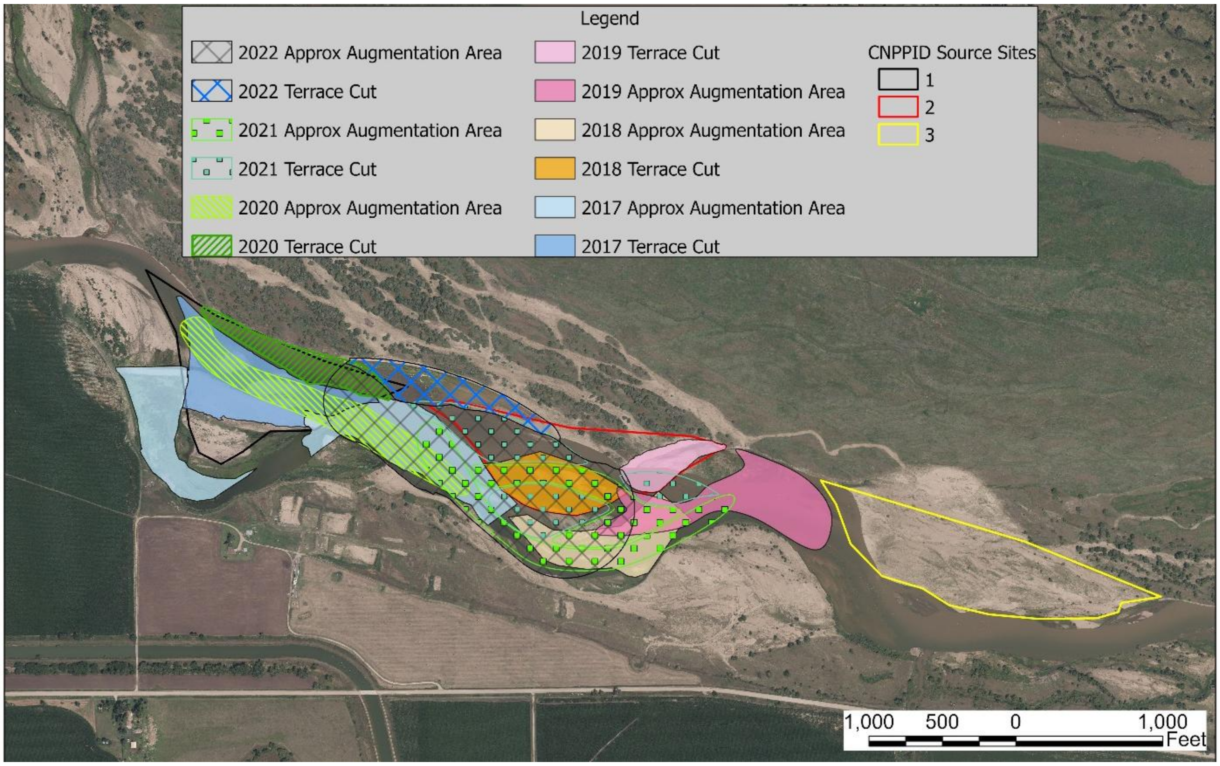


Figure 1.5 2017-2022 Augmentation Project Boundaries.

1.5.2 Timing

Sediment augmentation is implemented in the late summer/early fall each year to coincide with conducive flows out of the J2 Return. Summer low flows allow sediment to be staged, whereas long, high flow releases beginning in mid-September transport material away from the site. Due to CNPPID's hydropower production schedule, these high flow releases are interrupted by intermittent low flows. During these low flows, contractors can operate heavy equipment such as bulldozers and scrapers within the channel and stage more sediment for transport.

1.5.3 Design considerations

Alluvial material augmented to the riverbed is intended for transport downstream to mitigate sediment deficits. A full-scale sediment augmentation target was set between 60,000 to 80,000 tons (40,000–55,000 yd^3) per year over a design-life of 18 years of augmentation beginning along the high banks below the J2 Return (Figure 1.5).

To begin the design process, the existing stage range elevations within the chosen area must be calculated. These elevations are calculated by running hydraulic models at peak and low flows (1650 cfs and 300 cfs, respectively) typical for CNPPID hydrocycling during late summer/early fall. These values are used to guide excavation (cut) and augmentation area elevation targets.

To encourage natural erosion of high terraces on the north bank, an elevation near the average of the stage range is chosen as the final grade for the excavation area (terrace cut areas in Figure 1.5 from which the sediment is excavated). This allows occasional inundation during high flow events, during which some bank material will be removed. To prevent nominal stage increase within the reach, the augmentation area of the project is designed at an elevation near or below the lowest end of the stage range.

Given those elevation targets, the design volume of the project must be determined. System-scale monitoring data collected from 2009 to 2014 demonstrated that trends in aggradation-degradation are highly dependent on hydrology (Tetra Tech 2014). Knowing this, it is important to consider the hydrologic condition for the given design year. If it appears that there is a dry trend, CNPPID may operate in a conservation mode, releasing less flow into the J2 Return Channel. Under these conditions, design volume tends to be lower to match expected lower flows for sediment distribution. If it is a wet year, flow releases may be higher, allowing for the distribution of more material pushed into the channel.

Knowing elevation and volume targets, the last piece of the design equation is choosing an excavation area. Loading LiDAR data from the previous year into AutoCAD Civil3D (Autodesk, San Francisco, CA) provides an existing grade against which the design surfaces can be compared. By creating an approximate design surface set to the final grade elevation, volume differencing calculations can be run. Due to the variability of elevation along the existing grade surface, an iterative approach is necessary to adjust the excavation area until the “Cut” volume is approximately equal to the target value.

Given the possibility that flows may be too low for sediment transport during construction, it is important that there is enough area within the channel for the augmented material to be placed at the lowest stage elevation. An approximate design surface is created within the channel at the lowest stage elevation. This surface is compared to the existing grade and its area adjusted until “Fill” volume is approximately equal to “Cut” volume.

1.5.4 Sediment augmentation summaries

The design approach for 2017 and 2018 targeted 60,000 tons (40,000 yd^3) of immediate augmentation (Table 1.1), while encouraging the channel to continue to erode material out of the high terrace (north bank) on Jeffrey Island (PRRIP 2018). In fall of 2017, the upstream-most meander in the channel was cut off by excavating a pilot channel through an abandoned terrace and constructing a berm to shift the river to the north and mobilize sediment. 23,000 yd^3 were augmented to the main channel and 13,500 yd^3 of sediment were placed into the abandoned meander.

In fall of 2018, efforts moved downstream with the same target of 40,000 yd^3 and a more passive approach. By cutting down the next downstream bar, we were able to keep the sediment source on the adjacent high terraces on the left bank and encourage some deposition from upstream sources. The passive approach from 2018 was maintained in 2019, again with a target of 40,000 yd^3. This excavation was completed just downstream of the 2018 site. Construction can be seen in Figure 1.6. The 2020 design moved upstream, overlapping some of the original 2017 site. Due to Normal-to-Wet hydrologic conditions and high terraces on the site, the augmentation target was higher at 50,000 yd^3. The fall 2021 design also had a higher volume at 53,000 yd^3. This was due to the spread-out nature of the design, with 3 separate excavation sites being augmented into the channel. Augmentation in 2022 was designed in the same area as 2017 and 2020 since the high terraces of the area provided ample material for augmentation. With flows lower in 2022, the design volume was reduced to 45,000 yd^3.

Table 1.1 Sediment augmentation as-built volumes 2017-2022.

Year	Augmented (tons)	Sediment Augmentation Volume (yd^3)	Volume Leaving Sed Aug Area (yd^3)*
2017	34,500	23,000	34,500
2018	64,305	42,900	73,100
2019	63,500	42,300	116,500
2020	86,475	57,700	42,200
2021	76,982	51,300	60,600
2022	65,789	43,900	

*Volume change in augmentation area measured by differencing LiDAR elevations

Figure 1.6 Construction of 2019 Sediment Augmentation Project (42,300 yd^3).

1.6 First increment extension – Big Question #3

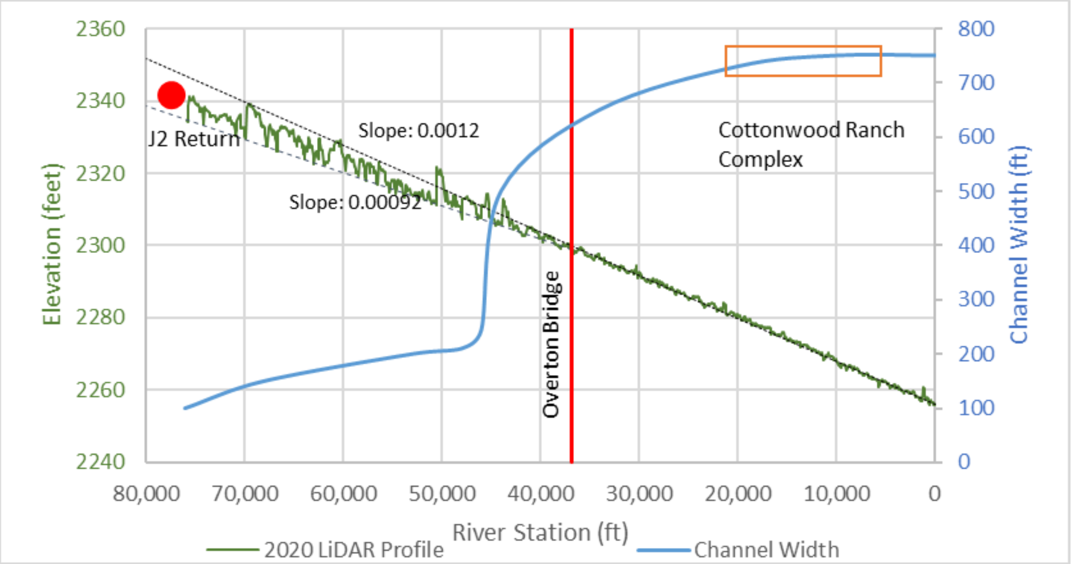
In 2015, Program stakeholders concluded that it was not possible to meet all Program Milestones prior to the end of the First Increment in 2019. This led to a negotiated 13-year extension of the Program referred to as First Increment Extension or just Extension. The first science priority in the Extension was an overhaul of the AMP to reflect current learning priorities, called the First Increment Extension Science Plan (PRRIP 2022). Extension Big Question #3 (Figure 1.7) and related management hypotheses focus on the sediment deficit below the J2 Return, progression of impacts due to the deficit, and potential consequences for whooping crane habitat downstream of Overton. The following chapters of this data synthesis present multiple lines of evidence to address this Big Question. Chapter 2 is a retrospective analysis of the magnitude and progression of incision through time, Chapter 3 evaluates longitudinal response to sediment augmentation, and Chapter 4 expands that evaluation into three-dimensions, exploring both vertical and lateral channel evolution in the periods before and after initiation of the full-scale augmentation management experiment.

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



Full scale sediment augmentation (60,000–80,000 tons annually in the south channel below J2 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.

Figure 1.7 Extension Big Question #3. South channel refers to the J2 Return Channel.

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CHAPTER 2 Evaluation of trends in incision prior to full-scale sediment augmentation

2.1 Abstract

The Platte River Recovery Implementation Program (PRRIP or Program) is concerned that incision and narrowing downstream of the J2 Return may continue to progress downstream, negatively impacting the suitability of roosting habitat for the highly endangered whooping crane (*Grus americana*). Evaluating historical patterns and rates of incision provides insight into the potential magnitude of future impacts in absence of long-term augmentation of sediment supply. We conducted retrospective analyses to evaluate spatial and temporal patterns of incision. This included comparing current channel topography to the historical channel elevation (relative elevation model), evaluation of incision trends at repeat transect survey locations, development of specific gage analyses at the Overton Bridge and Cottonwood Ranch mid-channel stream gages, and estimation of changes in channel sinuosity through time using aerial imagery. These analyses indicated a wave of vertical incision propagated down through the study area after J2 Return began operations in the early 1940s. In the early 2000s, the primary mechanism of channel degradation shifted from incision to lateral migration, with the highest intensity of migration occurring in upper half of the J2 Return Channel.

2.2 Introduction

As discussed in Chapter 1 of this data synthesis, since the 1980s, stakeholders of the Platte River Recovery Implementation Program (PRRIP or Program) have been concerned about channel degradation due to clearwater hydropower returns near Lexington, NE. During the First Increment of the Program, the Governance Committee (GC) initiated monitoring, modeling, and research projects to explore the magnitude and extent of the problem. Those efforts resulted in three major conclusions:

1) There is a persistent sediment deficit downstream of the J2 Return that has resulted in incision and narrowing of the segment of channel that extends from the J2 Return to the Overton Bridge (J2 Return Channel).
2) Downstream of the Overton Bridge, there was no discernable degradational trend during the period of 2009-2016.
3) Over time, the degradation (incision and narrowing) observed in the J2 Return Channel could progress downstream beyond the Overton Bridge, decreasing the proportion of the central Platte River suitable as habitat for whooping crane roosting.

In response to these findings, the Program initiated a full-scale sediment augmentation experiment in 2017 to test the hypothesis that offsetting the sediment deficit downstream of the J2 Return is necessary to halt downstream progression of channel degradation (Extension Big Question 3). Implicit in this hypothesis is an unquantified level of risk relating to the rate that degradation is progressing downstream absent augmentation as well as the relationship between incision magnitude and degradation of habitat suitability. The objective of this chapter is to evaluate the magnitude and rate of channel degradation in the decades prior to augmentation and compare to stakeholder predictions. This is accomplished through four retrospective analyses that rely on historical aerial imagery, stream gaging data, repeat channel transect surveys, and remote sensing topographic data collected prior to implementation of full-scale augmentation.

2.2.1 Study area

The focus area for this study encompasses the western portion of the Program's Associated Habitat Reach (AHR) extending from Lexington, NE downstream to the Kearney Canal Diversion (KCD), located two miles downstream of Elm Creek, NE. Figure 2.1 provides an overview of the study area including channel segments, stream gage locations, and landmarks referenced in this chapter.

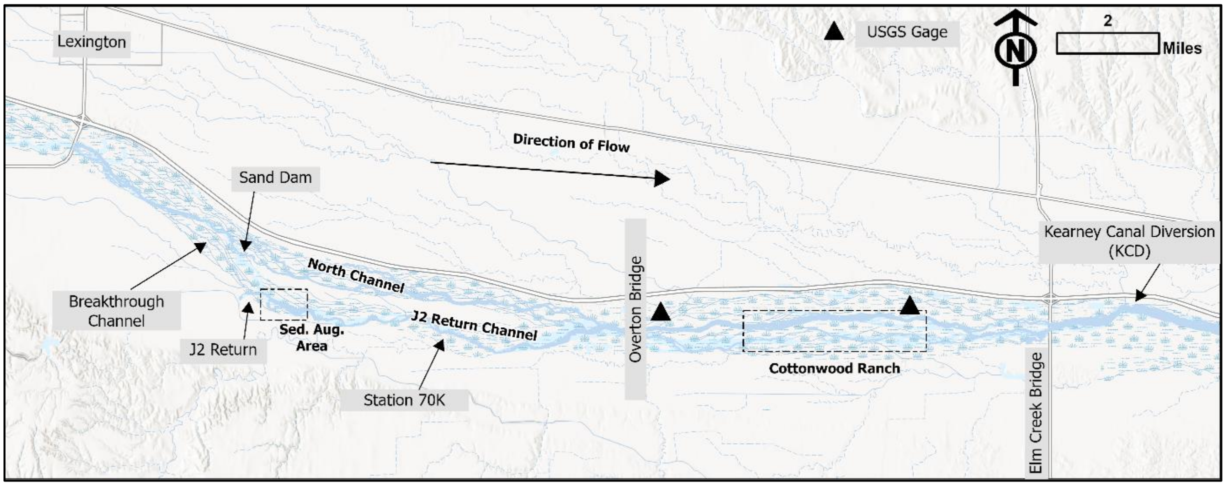

Figure 2.1. Map of the sediment augmentation study area including stream gage locations and landmarks of interest.

To provide consistent spatial referencing (stationing) for all longitudinal analyses, we delineated the approximate centerline of the floodplain from the KCD upstream to the Lexington bridge (Figure 2.2) and cut transects across the entire floodplain perpendicular to centerline at five-foot intervals. Stationing starts at 0 at KCD and ends at station 113,780 at the Lexington bridge. Stationing for important landmarks is provided in Table 2.1.

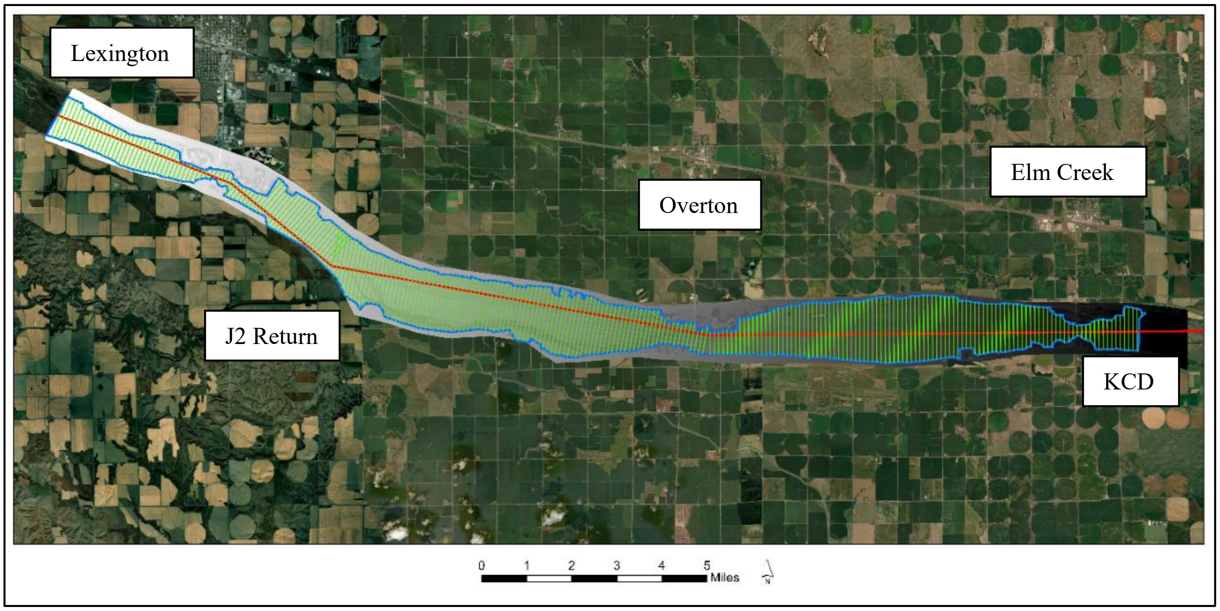

Figure 2.2. Floodplain centerline (red) and transects (green) through study area. Transects were generated perpendicular to centerline at five-foot intervals with example transects plotted at 500 ft spacing in this figure.

Table 2.1. Landmarks in the study area and associated stations.

Landmark	Station (ft)
Lexington Bridge	113,780
Berm at upstream North/J2 Return 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 Channel/J2 Return 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 (KCD)	0

2.2.2 Overview of analyses

As stated in the introduction, the objective of this chapter is to explore historical incision and planform change downstream of the J2 Return prior to the initiation of full-scale sediment augmentation in the fall of 2017. The J2 Return began operations in the early 1940s but there was little focus on channel incision in this reach until the 1980s. Consequently, historical data is limited primarily to historical aerial photography, limited repeat cross section surveys collected in the late 1980s and early 2000s, and stream gaging records. In this chapter we utilized these data in combination with contemporary remote sensing to explore patterns of channel incision through time. Specific analyses include:

1) development of a Geomorphic Grade Line and relative elevation model for 2016 to provide a snapshot of historical channel incision (relative to floodplain elevation) prior to implementation of full-scale augmentation,
2) analysis of historical repeat transect surveys and LiDAR data to evaluate spatial and temporal patterns of incision relative to those predicted in Murphy et al. (2004),
3) specific gage analyses at the Overton and Cottonwood Ranch Mid-Channel stream gages to identify temporal patterns of incision at those locations, and
4) estimation of channel sinuosity from aerial photography to quantify changes in channel length in the J2 Return Channel through time.

The results of these analyses are interpreted together to provide our assessment of spatial and temporal patterns of channel change prior to the implementation of the full-scale sediment augmentation management experiment and predict potential future patterns of incision in absence of augmentation.

2.3 Geomorphic Grade Line and relative elevation model

2.3.1 Methods

We utilized methods presented by Powers et al. (2019) to generate a Geomorphic Grade Line (GGL), or linear regression of valley slope. We found this approach to be appropriate in our context because the reach of interest consists of a single river that has fairly unrestricted flow and sediment transport. The Overton Bridge and KCD structures cause only small discontinuities in a localized area which were not significant enough to cause the GGL to deviate from a linear pattern. To create the GGL, we used 2021 Light Detection and Ranging (LiDAR) derived topography. First, we hand delineated the geographical extent of the existing floodplain. Mid-channel islands were not removed but human-made features like gravel mines, road embankments, and other development-related topographic features were clipped from the boundary. The fall 2021 LiDAR digital elevation model (DEM) was then sampled along transects at five-foot intervals within the floodplain, and we calculated average elevation for each transect (station). Mean transect elevations were regressed against station to establish the GGL for the study area. The GGL was used as the reference plane for development of a relative elevation model (REM) of the study area.

Relative elevation models (REMs) provide a way to visualize and quantify channel elevations without influence of the overall valley slope and are commonly used in river restoration to determine areas of cut and fill when regrading the valley bottom (Powers et al., 2019). To develop a REM, we first generated a raster of the GGL for the study area. We then differenced the fall 2016 LiDAR DEM and GGL (DEM – GGL) to calculate the elevation of each raster cell relative to the GGL.

The physical location or alignment of the thalweg was identified for each year (2016–2021) using the Hydrology Toolbox in ArcGIS Pro 2.9.3 to generate flow direction and flow accumulation rasters from annual DEMs derived from topo-bathymetric LiDAR. We delineated a stream network of connected flow paths in the channel and filtered the flow paths to select the highest stream order flow path through the study area to designate as the channel thalweg. Visual inspection of aerial imagery validated the use of these accumulated flow paths as reasonable thalweg lines except for 2018 and 2021, where thalwegs were originally routed in secondary channels. To maintain consistency with other years, we manually confined the alignment of the 2018 and 2021 thalwegs to the main channel using the highest order streamline in that fell within the main channel. The resulting thalweg lines were simplified to reduce extraneous vertices using the ArcGIS Pro 2.9.3 Simplify Line tool, the Douglas-Peucker algorithm, and a tolerance of 5 ft.

Thalweg lines were processed into longitudinal profiles by sampling DEM elevations at the intersection of the thalweg lines and stationed transects spaced every 5 ft perpendicular to the stationing centerline (transect methods are described in Chapter 2). We calculated at-a-station change in thalweg elevation between consecutive years and for the study period as a whole (2016–2021).

2.3.2 Results

The regression of average elevation versus river station (numbered downstream to upstream), or GGL, can be found in Figure 2.3. The slope of the GGL in the study area is 0.001276. Because stationing is from downstream to upstream, slope appears positive in the equation. The slope of the GGL is consistent with previous analyses of channel slope in the AHR (Murphy et al., 2004).

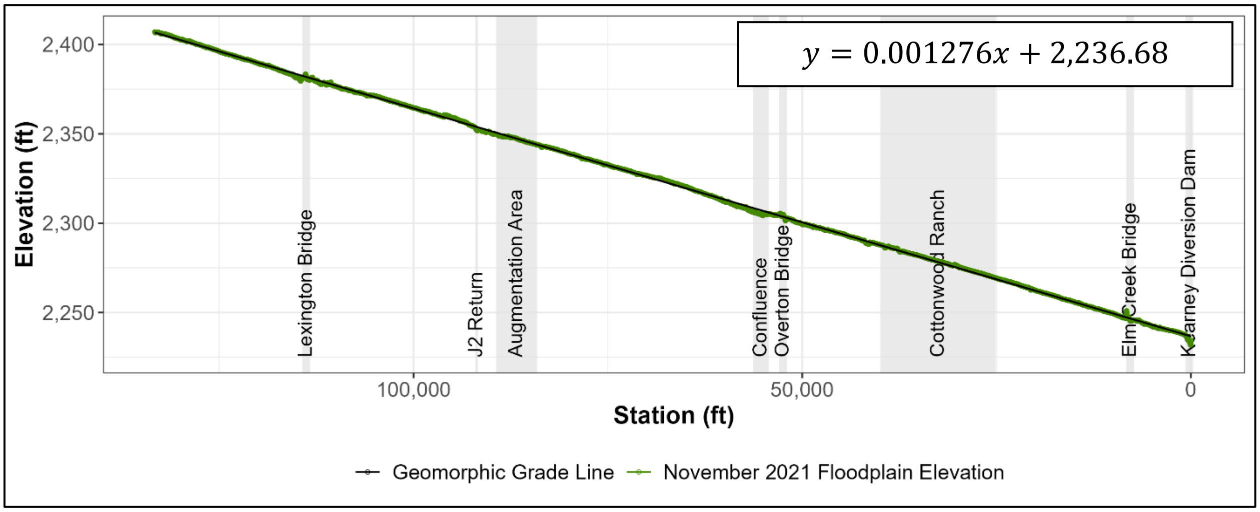

Figure 2.3. Geomorphic Grade Line (GGL) (black) of historical channel footprint in study area sensu Powers et al. (2019). Equation of the GGL presented in top right. Average elevation data sampled from 2021 LiDAR data (green).

The REM for 2016 is presented in Figure 2.5. A profile plot of REM elevations at lowest point in the channel (thalweg) is provided in Figure 2.6. The REM and REM thalweg profile provide a quantitative visualization of cumulative channel change downstream of the J2 Return to the extent that the GGL provides a good representation of pre-development channel elevations. As demonstrated in Figure 2.5, elevation deviation from GGL (incision) is greatest immediately downstream of the J2 Return (see field photos in Figure 2.4). Channel elevation in that segment in 2016 was on the order of 15–20 ft below GGL. In comparison, the relative elevation of the North Channel in that same area, which is not affected by hydropower return flows, was only 2–

4 ft below GGL. In the highly incised upper half of the J2 Return Channel, the REM also indicates a change in planform to a narrower channel with high sinuosity that is visible in relative elevations ranging from 10 ft to 22 ft below GGL. This pattern becomes less obvious as the magnitude of J2 Return Channel incision decreases in a downstream direction. At the confluence of the North Channel and J2 Return Channels 6.5 miles downstream of the return, most of the channel is 4–6 ft below GGL and braiding is apparent with a limited amount of incision progressing back up the North Channel. Downstream of the North and J2 Return Channel confluence, a limited amount of incision can be observed in the mile of channel downstream of the Overton Bridge. Beyond that, the REM indicates channel elevations are generally consistent relative to the GGL.

Figure 2.4. Field photos from July, 2024 depicting high eroding banks in the J2 Return Channel.

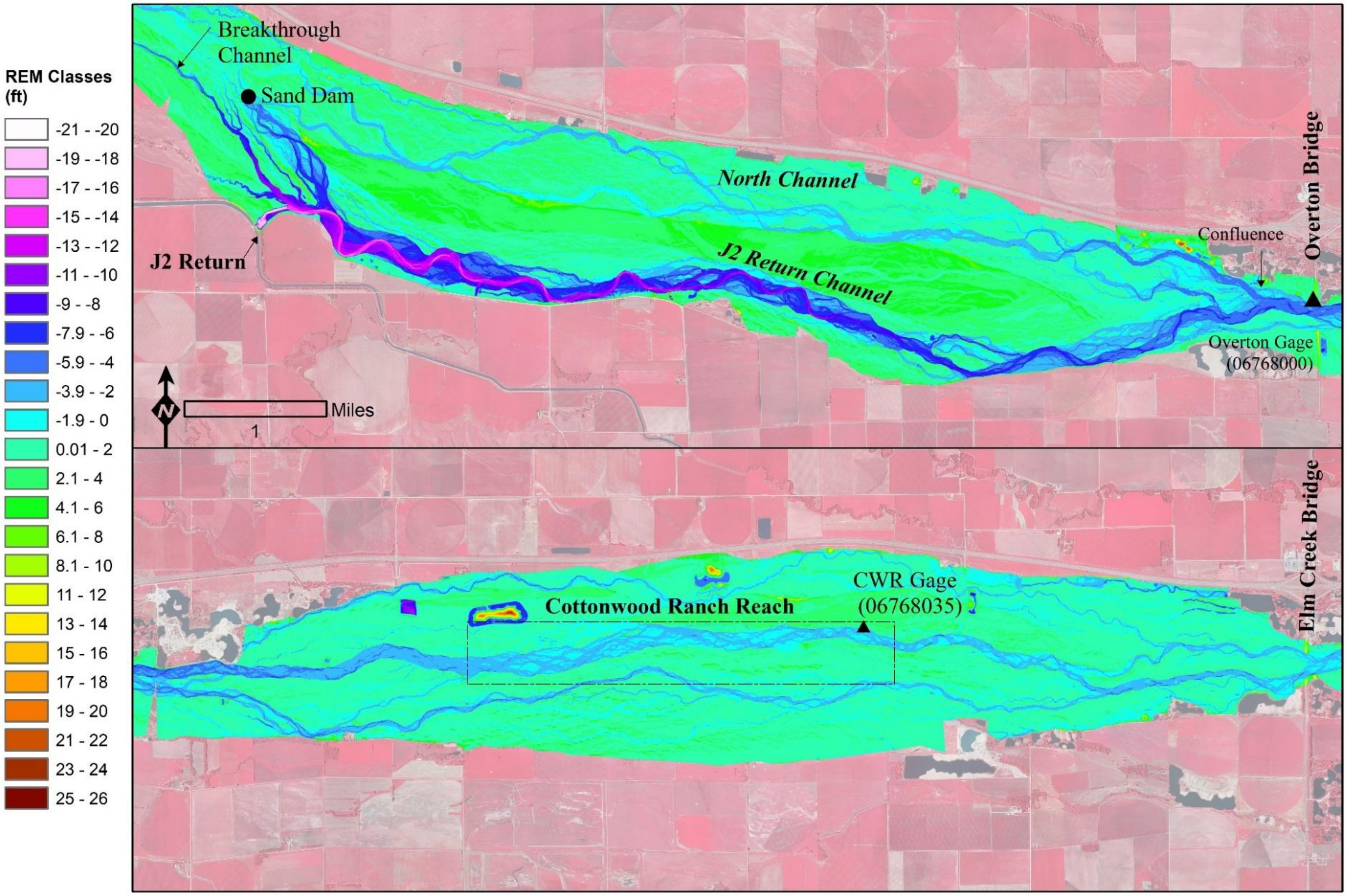

Figure 2.5. Relative elevation model (REM) of 2016 topo-bathymetry compared to the average elevation of the historical channel (GGL). The figure is split into J2 Return to Overton Bridge (top) and Overton Bridge to Elm Creek Bridge (bottom). Edges appear irregular due to clipping of ponds and other human-manipulated surfaces. Deviations from the GGL are much larger (10-20 ft below the floodplain) near the J2 Return and decrease to 1-6 ft below the floodplain toward the downstream extent of the study area.

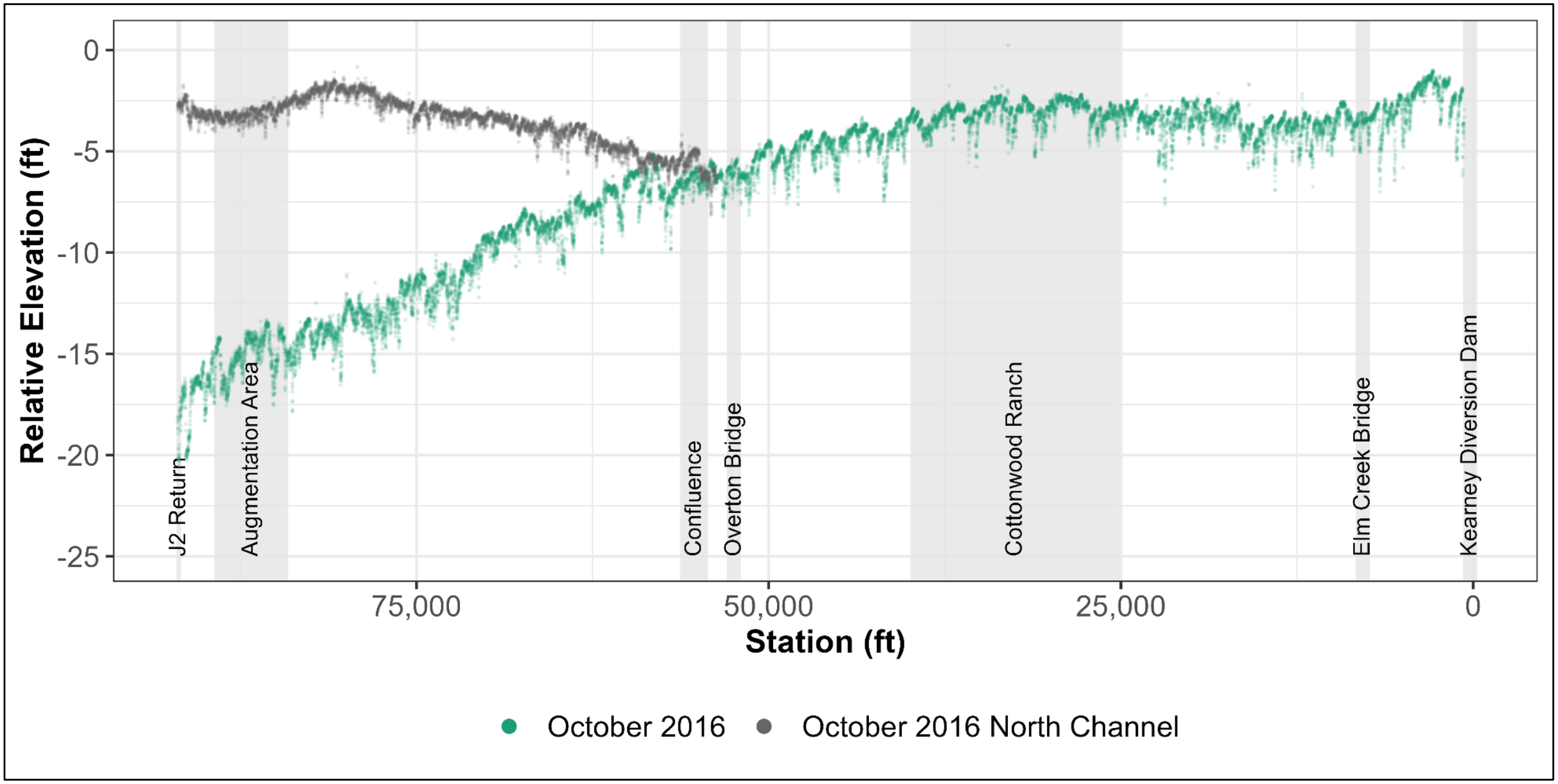

Figure 2.6. Elevation of deepest point (thalweg) in the North Channel (gray) and J2 Return/Main Channel (green) relative to Geomorphic Grade Line (GGL). The segment of channel immediately downstream of the J2 Return is incised on the order of 15–20 feet lower than the North Channel at the same station. Magnitude of incision decreases in a downstream direction with the thalweg becoming roughly parallel to GGL (GGL has a value of 0) near the upper end of the Cottonwood Ranch habitat complex. North Channel incision is also apparent upstream of the confluence of the North and J2 Return Channels.

2.4 Analysis of spatial and temporal trends in incision 1989-2016 relative to predictions

2.4.1 Methods

Murphy et al. (2004) included predictions of incision downstream of the J2 Return over time based on an incision wave propagation model (de Vries 1973), later referenced in Graf (1998). The model predicted downstream propagation of incision through time based on a ratio of incision downstream of the J2 Return relative to maximum incision at the return. According to Murphy et al. (2004), the maximum incision relative to the North Channel thalweg elevation in 2002 was 13.3 ft. We compared to the Murphy et al. (2004) predictions of downstream spread of incision by plotting incision as the difference in elevation from modified GGLs that match the elevations of the 2002 North Channel thalweg and mean cross-sectional elevations. We used 1989 and 2002 channel cross sections and 2016 LiDAR data to compare observed and predicted incision patterns (Figure 2.9).

Repeat cross section data used in this analysis were collected by the United States Bureau of Reclamation (USBR) in 1989 and DJ&A consultants in 2002 (Holburn et al. 2006). These entities surveyed a total of 11 cross sections in 1989 between the J2 Return and KCD (Figure 2.7.). Ten were repeated in 2002. We clipped the cross sections in ArcGIS to the extent of the active channel (5,000 cfs flow boundary) and calculated the minimum (thalweg) elevation and mean channel elevation at each survey cross section. The 2016 LiDAR DEM was also clipped and sampled to calculate thalweg and mean channel elevations at 5-foot intervals throughout the reach. Both mean and thalweg elevations were calculated and used in the analysis to evaluate maximum (thalweg) incision as well as general channel incision (mean). We used cubic (third order polynomial) regression to model full longitudinal profiles for thalweg and mean channel elevations from 1989 and 2002 with cross section data from 11 points in 1989 and 10 points in 2002 (Figure 2.8). Third order regression provided the best fit to the limited transect data and was consistent with the general shape of the 2016 LiDAR-derived profiles for mean cross-sectional elevation. We used a generalized additive mixed model (GAMM) for the 2016 thalweg elevations rather than a polynomial regression due to a more accurate fit. The methods for the GAMM are further described in Section 3.4.1. Note that this analysis is based on limited historical data and no uncertainty estimate is available for the 1989 or 2002 surveys.

Figure 2.7. Locations of USBR 1989 and 2002 survey cross-sections.

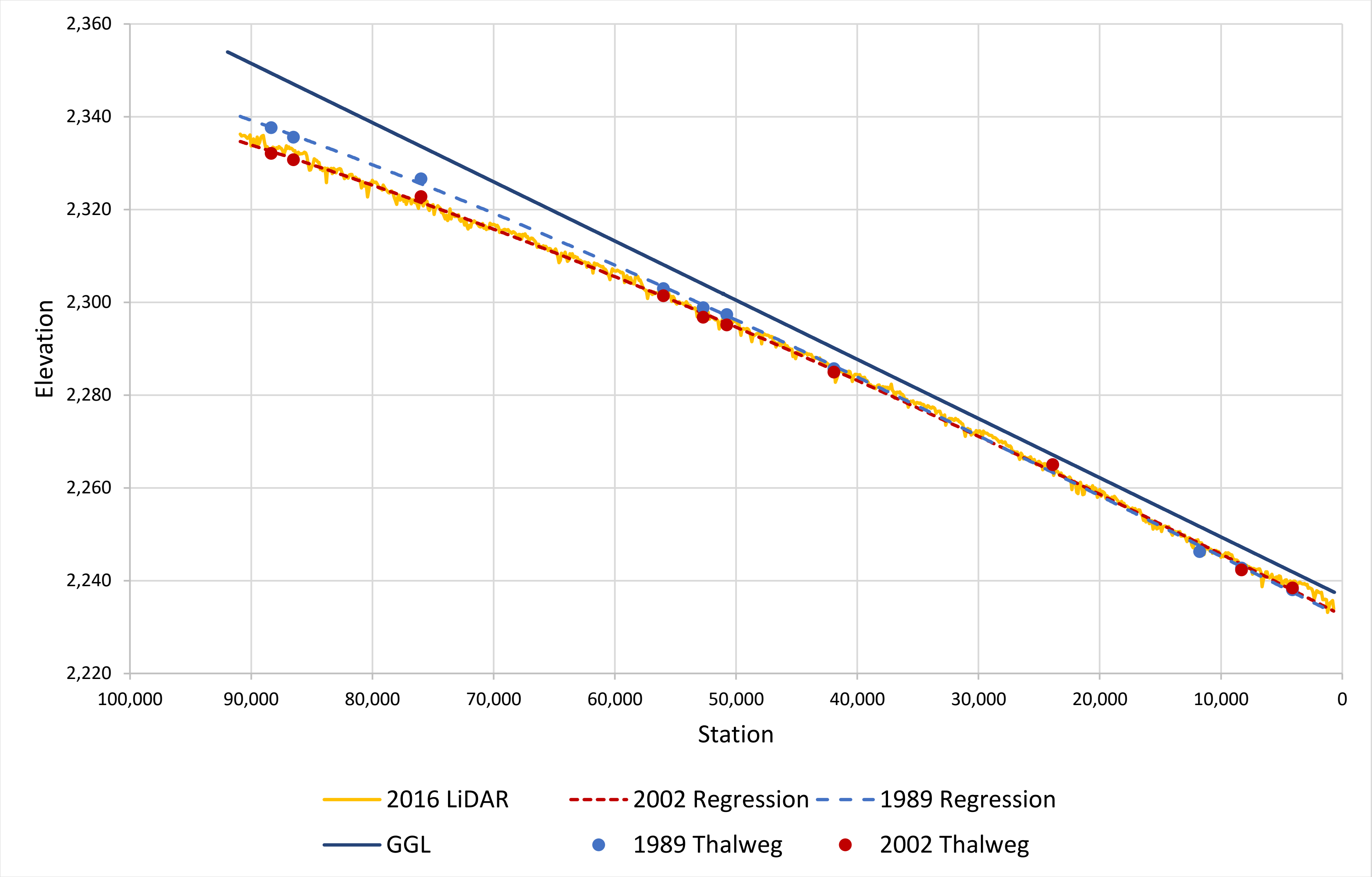

Figure 2.8. Modeled longitudinal profiles (cubic regression) of thalweg from 1989, 2002 cross section data. Profiles plotted with Geomorphic Grade Line (GGL) and thalweg profile from 2016 LiDAR data. Deviation from the GGL is evident between Stations 50,000 and 90,000 and increases between 1989 and 2002. No additional increase in deviation is observed between 2002 and 2016. Note that these findings are based on limited historical data and error estimates are not available.

Incision was calculated at 100 ft intervals by differencing profile elevation from modified GGLs for both the thalweg profile and the mean channel elevation profile. We used Murphy et al.'s (2004) maximum incision value of 13.3 ft below the 2002 North Channel thalweg for our maximum potential thalweg incision. To validate the use of this value, we confirmed that 2016 channel elevations remained approximately 13 ft below the original 2002 North Channel thalweg elevation at the original USBR transect location. Mean channel elevations from 2016 did not match the minimum mean channel elevation in 2002, so we used the 2016 minimum mean cross-sectional elevation for our maximum possible incision of mean channel elevation. The modified GGLs were based on the original GGL, but reduced in elevation by 3.59 ft to meet the 2002 North Channel thalweg elevation for thalweg comparisons, and reduced by 0.59 ft for mean elevations. The final step in recreating Murphy et al.'s incision plot was calculating proportion of maximum incision depth by dividing profile incision depth by maximum incision depth at each station.

2.4.2 Results

Comparisons of observed incision relative to Murphy et al. (2004) predictions are provided in Figure 2.9. The top panel (panel a) presents thalweg (minimum channel elevation) incision relative to Murphy et al.'s predictions. The bottom panel (panel b) presents mean channel incision relative to predictions. Both panels begin one mile downstream of the J2 Return and end at the KCD. The number of years in both plots reference years since J2 Return was constructed.

When observed incision is plotted on top of predictions, the observed extent of thalweg and mean channel incision propagation over the course of the 80 years since J2 Return operations began both fall between the 4-year and 25-year predictions for years 2002 and 2016. This indicates downstream propagation of incision has occurred substantially more slowly than predicted. Beyond the similarity in slower rate of observed progression of incision relative to predictions, the temporal incision patterns differ substantially.

The thalweg incision plot (panel a) indicates that approximately 55% of thalweg incision immediately downstream of the J2 Return occurred prior to 1989 and the remainder occurred prior to 2002. Between 2002 and 2016, the thalweg was stable, with little vertical incision occurring during that period. The mean channel elevation plot (panel b) indicates that mean channel incision did not stabilize after 2002, especially in the three-mile segment below the J2 Return, where mean channel elevation continued to decrease despite thalweg stability. Taken together, the panels indicate a shift from incision to erosion through lateral channel movement (lateral erosion) after 2002.

The 1989, 2002, and 2016 incision plots all terminate slightly less than 20 miles downstream of the J2 Return at the KCD. The plotted portion of maximum incision depth between approximately 10 and 20 miles downstream of the diversion is highly variable indicating inconsistent trends in that reach. This may be due to differing patterns of sediment accumulation and transport upstream or through KCD during wet and dry periods. A longer monitoring period may help to distinguish patterns of river dynamics from variability.

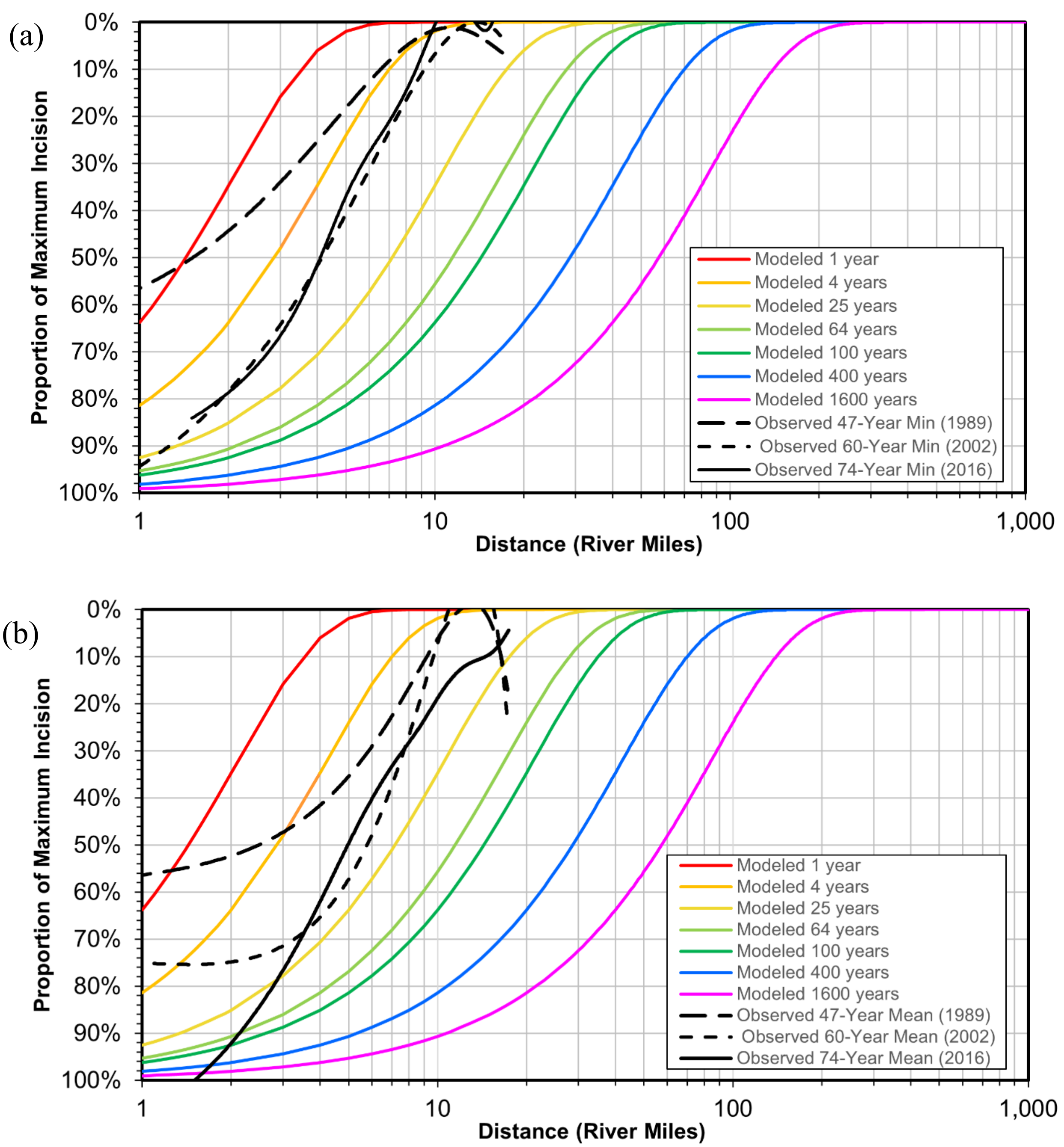

Figure 2.9. Channel incision estimates below J2 Return plotted on top of incision propagation estimates from Murphy et al. (2004). Minimum cross section elevation (thalweg) incision is shown in (a) and the mean channel elevation incision is shown in (b). Number of years represents years since operation started at J2 Return. Observed values from 1989 and 2002 were estimated with a 3rd order polynomial model through 10 transect locations, while 2016 observed

values are based on a Generalized Additive Mixed Model made with LiDAR data (thalweg) and a 3rd order polynomial through LiDAR data (mean).

Our use of Murphy et al.'s estimate of 13.3 ft for maximum thalweg incision below the North Channel allows for calculation of estimated thalweg elevation after 74 years (1942 to 2016) and subsequent comparison to 2016 LiDAR data (Figure 2.10). The model-predicted and measured thalweg elevation values diverge in the J2 Return Channel. The incision propagation model does not account for changes in channel slope, sinuosity, or sediment discharge through time, limiting its ability to predict the range of responses observed due to clearwater release from the J2 Return.

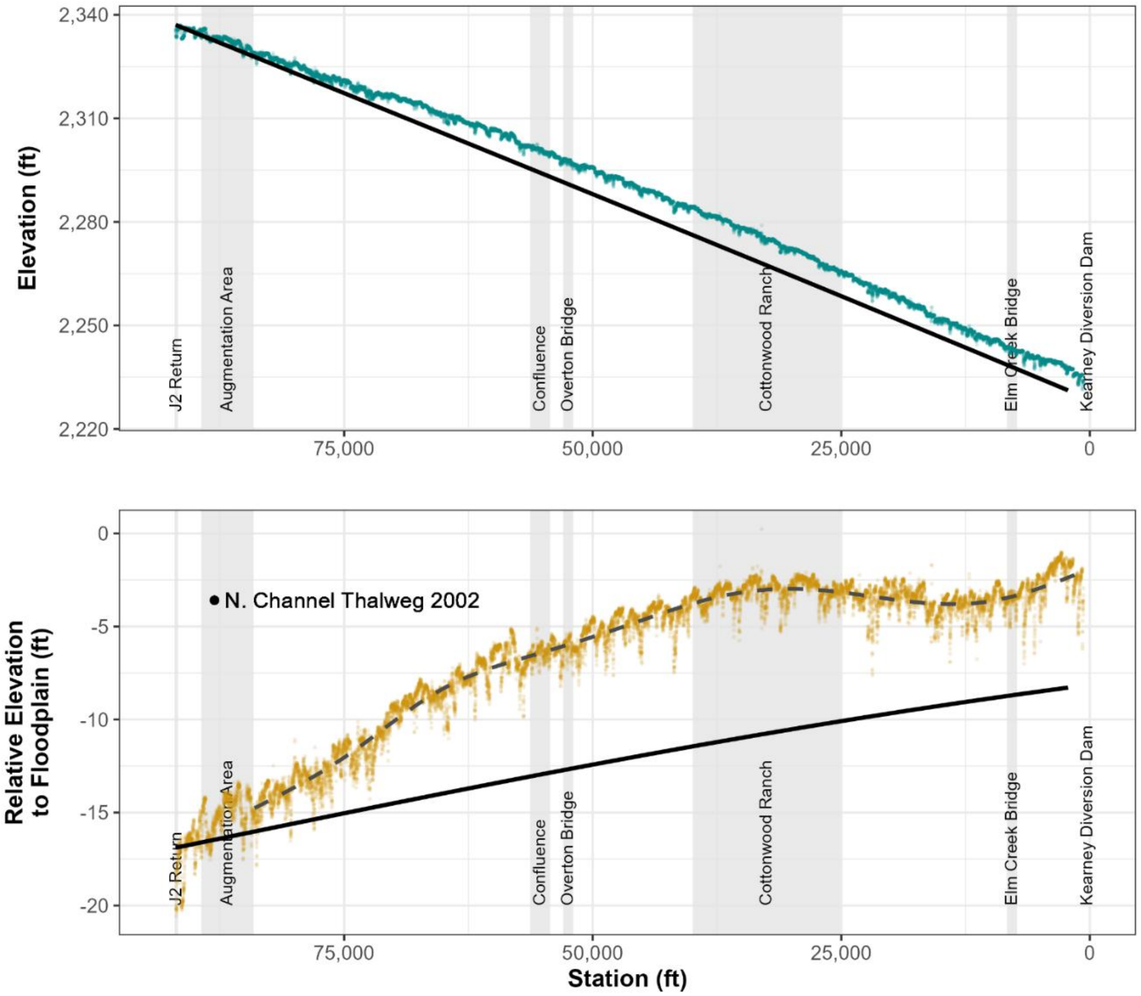

Figure 2.10. Observed and predicted channel thalweg elevations (a) and relative elevations to the floodplain (b) according to incision models presented in Murphy et al. (2004). The bold black lines in both plots show predicted elevations, while the dashed line in (b) is a modeled thalweg from a generalized additive mixed model (GAMM). We used a maximum potential thalweg incision value of 13.3 ft below the 2002 North Channel thalweg to be consistent with historical estimates.

2.5 Specific gage analysis

2.5.1 Methods

The presence of USGS stream gages at the Overton Bridge and the downstream end of Cottonwood Ranch (see location Figure 2.1) provide an opportunity to assess incision patterns through time at those locations via a specific gage analysis. Trends of increasing or decreasing water surface elevation at a constant discharge can be linked to a variety of complex processes and can be associated with geomorphic change, bridge/site modification, changes in sediment supply, and changes in roughness (vegetation dynamics). Increasing water surface elevation at a constant discharge through time is an indication that the channel at that location is aggradational, whether width changes or remains static. Declining water surface elevation could indicate several channel responses, including channel degradation alone or channel widening. In this study, we interpret decline in water surface elevations to be generally indicative of channel degradation.

Specific gage analyses can be conducted using either stage-discharge records or physical measurements that are used to develop and adjust stage-discharge rating curves. This analysis relies solely on physical measurement data to eliminate potential biasing related to stages that are estimated from rating curves (Samaranayake 2009, Biedenharn et al. 2017). Physical measurements include an unknown but low uncertainty in stage. Discharge at stage is estimated using current-meters or acoustic doppler current profilers (ADCP). USGS rates measurements as excellent, good, fair or poor, which correspond to potential errors of less than 2%, 5%, 8%, and greater than 8% respectively (Turnipseed and Sauer 2010). For the purpose of this analysis we filtered physical measurement data to remove measurements with poor ratings as well as all measurements in the months of December through February, which are often ice-affected.

Specific gage analyses examine trends in water surface elevation through time at a discharge. We chose to evaluate three discharges at each gage including the 10th and 50th percentile of mean daily discharge and median of instantaneous annual peak discharge during the period when physical measurements were available. These three discharges allowed us to evaluate trends in stage at low flows, normal flows, and at approximate bankfull discharge.

Most specific gage analyses involve development of simple linear regressions of stage through time for a range of discharges around a target discharge (Chen et al. 1999, Biedenharn et al. 2017). This is done to obtain a sufficient sample size to meet linear regression assumptions. For example, a specific gage analysis at 1,000 cfs would generally include all measurements collected from 800 to 1,200 cfs. If actual discharges are skewed above/below target through time, this approach can provide a biased estimate of stage change. Using simple linear regression also has other limitations including inability to model non-linear relationships and lack of meaningful estimates of uncertainty.

To address these issues, we developed generalized additive models (GAMs) for all physical measurement data at each gage with smoothed relationships limited to five degrees of freedom (Hastie and Tibshirani 1990). GAMs allowed us to estimate possible non-linear relationships of stage-discharge relationships using all appropriate physical measurement data. We then plotted the estimated relationships of stage-discharge for the three discharges described above with 95% confidence intervals.

2.5.2 Results

2.5.2.1 Overton Gage (06768000)

The period of record for the Overton stream gage extends from October 1, 1930, to present. However, the gage has been relocated several times and was moved to the present location on October 10, 1986. At the current location, operation has been continuous with one major datum adjustment (lowered by 2.0 ft) on September 30, 2004. Specific gage analysis results cover the period from October 1986 to present with an adjustment to bring the entire period of record onto a single datum. Figures 2.11 through 2.13 provide a time series of aerial imagery at the gage location.

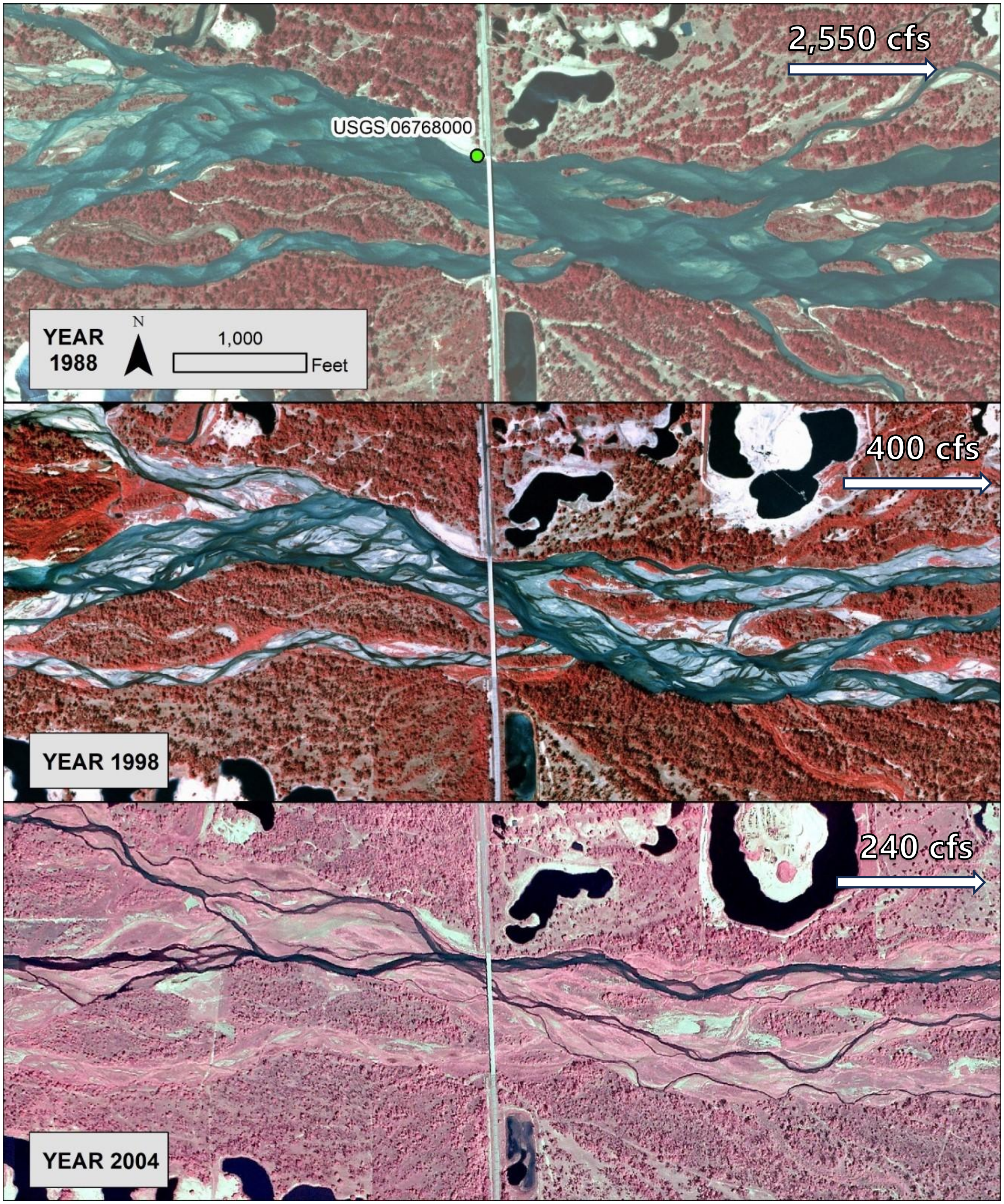

Figure 2.11. Imagery at Overton Gage (USGS 06768000) 1998 through 2004.

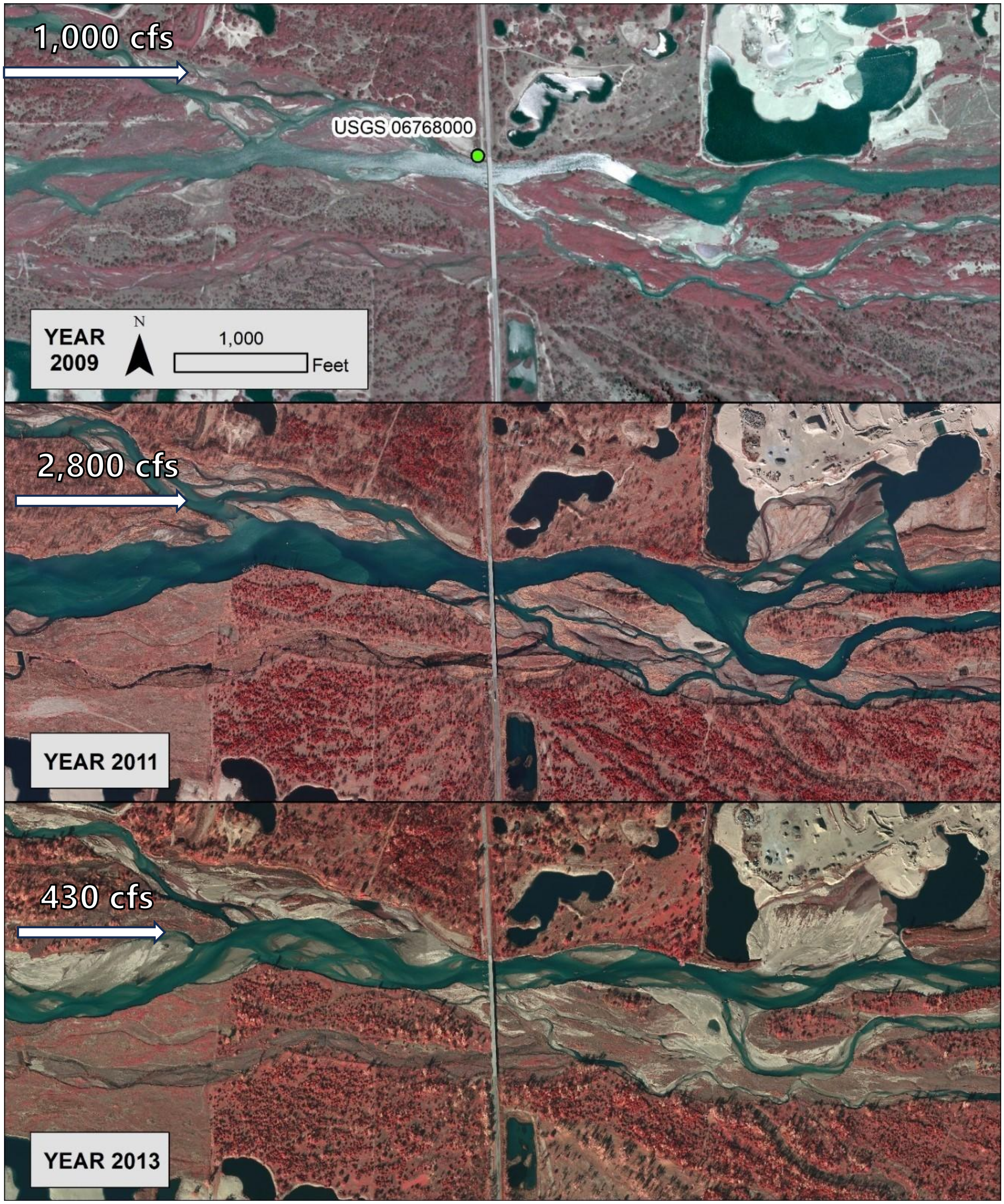

Figure 2.12. Imagery at Overton Gage (USGS 06768000) 2009 through 2013.

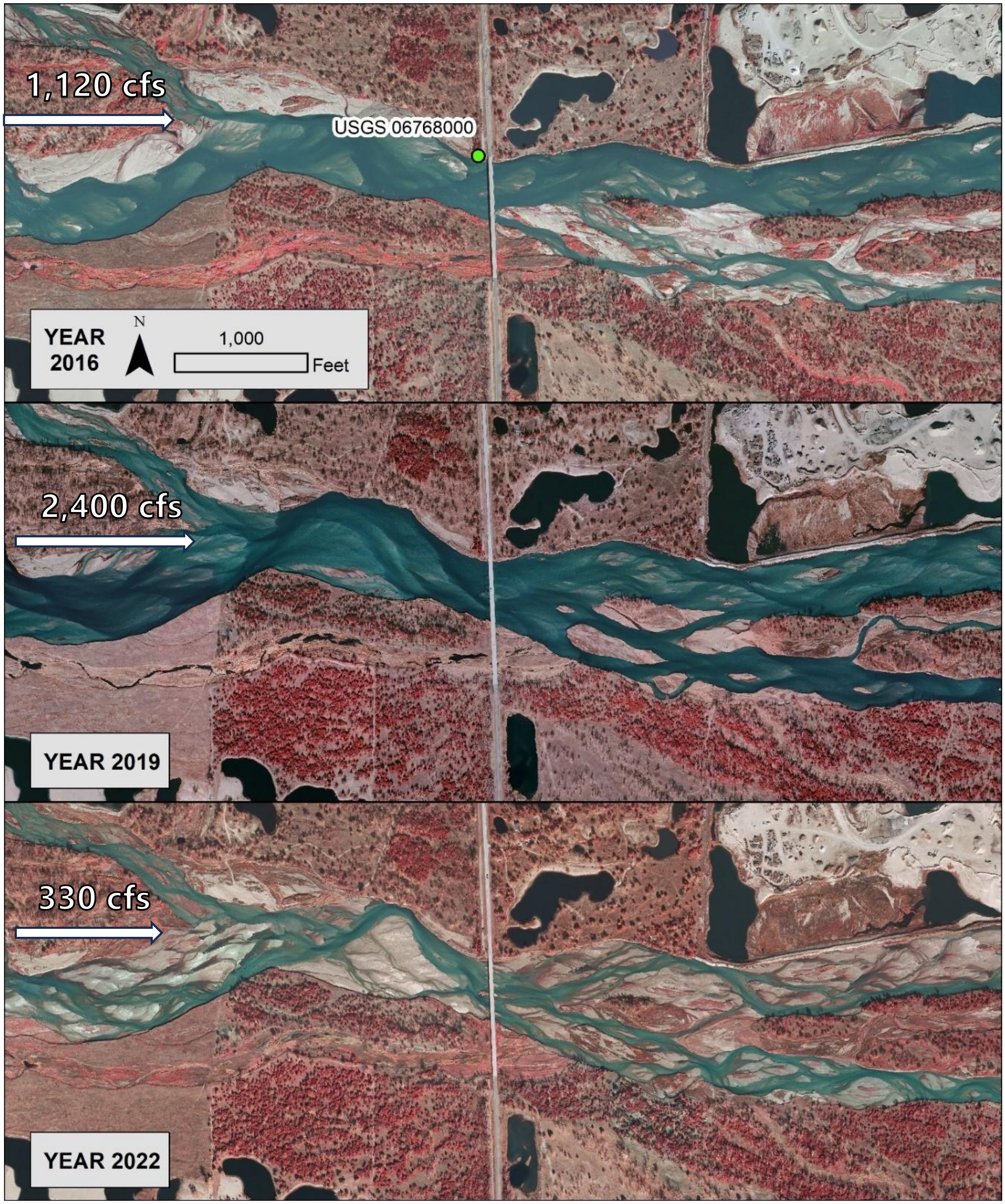

Figure 2.13. Imagery at Overton Gage (USGS 06768000) 2016 through 2022.

Figure 2.14 provides physical stage measurement data for the study period at the current Overton gage location along with trailing 30-day mean discharge. In the figure, stages are binned by discharge. The measurement data indicates slight decline in stage for discharges below 3,000 cfs until the late 1990s when the decline began to accelerate, especially at lower discharges. The trend of declining stage continued through approximately 2013 when it reversed and stage began to increase at low discharges (<1,000 cfs). Stage trends at higher discharges are less clear but appear to indicate a long term decline.

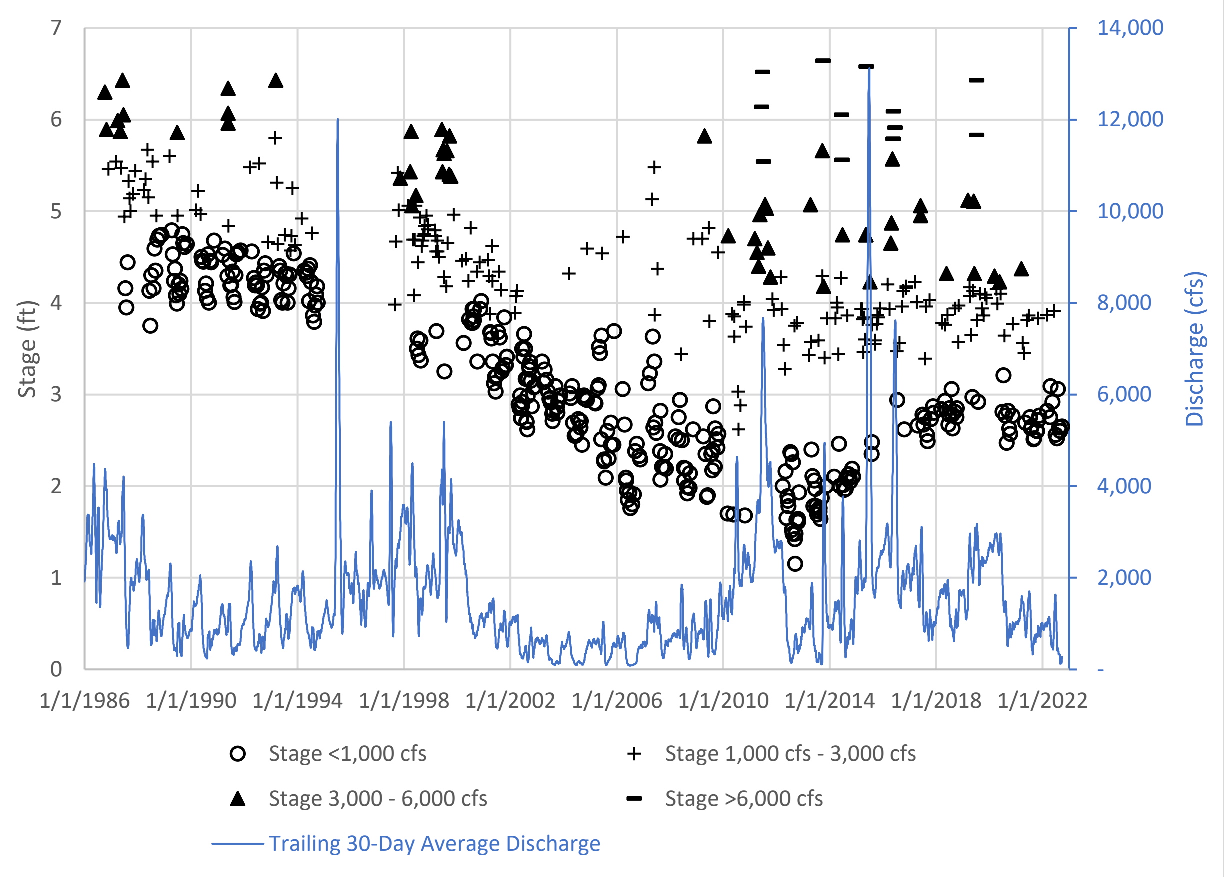

Figure 2.14. Physical measurement stage data at Overton Gage (USGS 06768000) and trailing 30-day average discharge. Presence of stage measurements in flow ranges above corresponding discharge on this figure reflect use of 30-day average trailing discharge.

Figure 2.15 provides specific gage analysis results. The specific gage analysis indicates decreasing stage at the Overton Bridge at low and median discharges from 1986-2013 with a total magnitude of approximately two feet. That trend is reversed in 2014 with stage increasing, especially at the 10th percentile discharge. Stage at the median annual peak discharge has declined throughout the period of record. This indicates that approximately two feet of incision occurred at the bridge between 1990 to 2014 with the greatest rate of change in the 2000s.

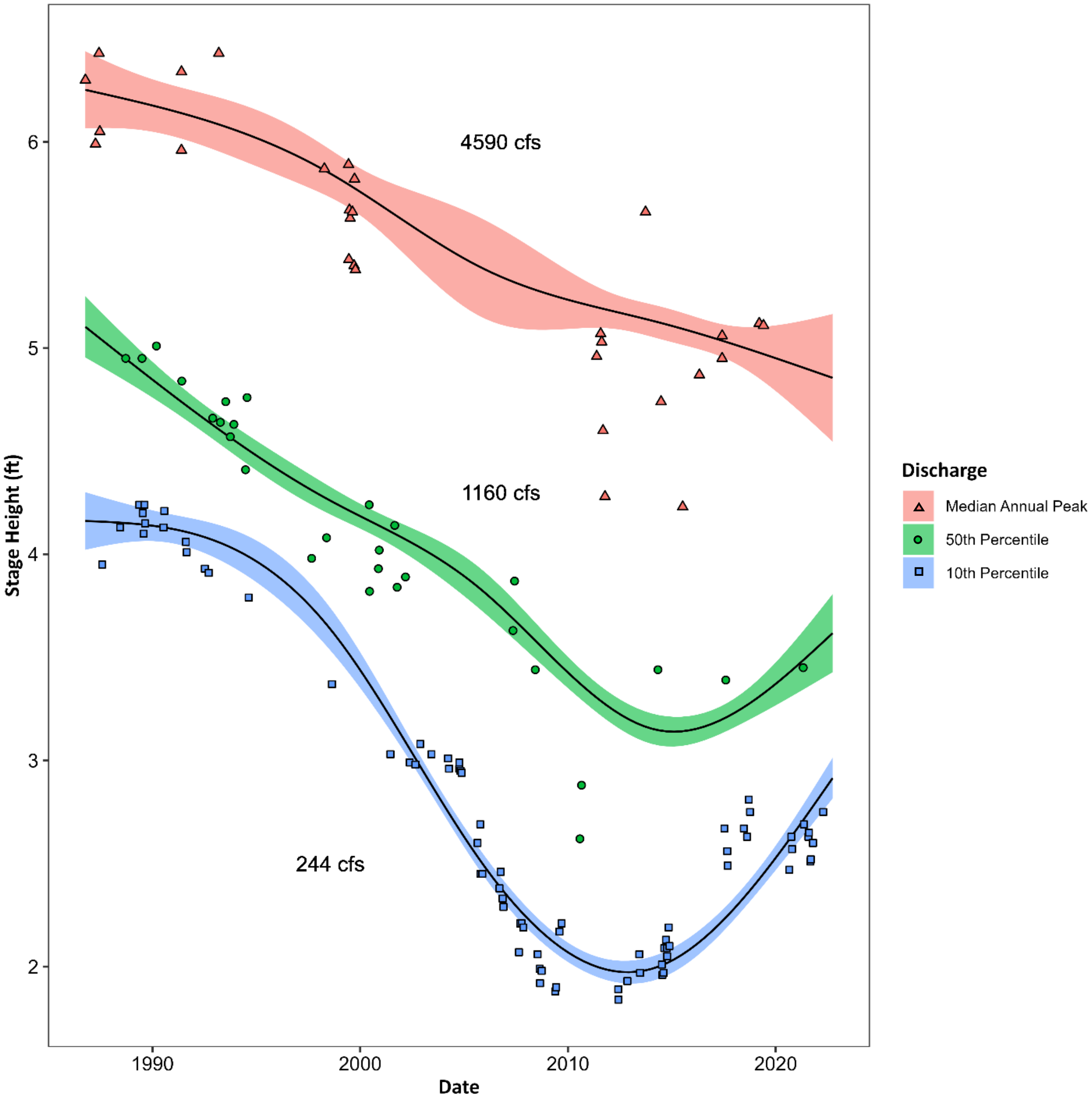

Figure 2.15. Specific Gage analysis for Overton Gage (USGS 06768000) at 10th percentile discharge of 244 cfs, median discharge of 1,160 cfs, and median annual peak discharge of 4,590 cfs. Shaded regions represent 95% confidence intervals for each discharge. Results indicate that elevations at this gage have decreased since 1986, though a rebound may be occurring beginning in 2013.

2.5.2.2 Cottonwood Ranch Mid-Channel Gage (06768035)

The period of record for the Cottonwood Ranch Mid-Channel stream gage extends from October 1, 2001 to present. The gage has operated at the current location through that entire period and there have been no datum adjustments. Figures 2.16 and 2.17 provide a time series of aerial imagery at the gage location.

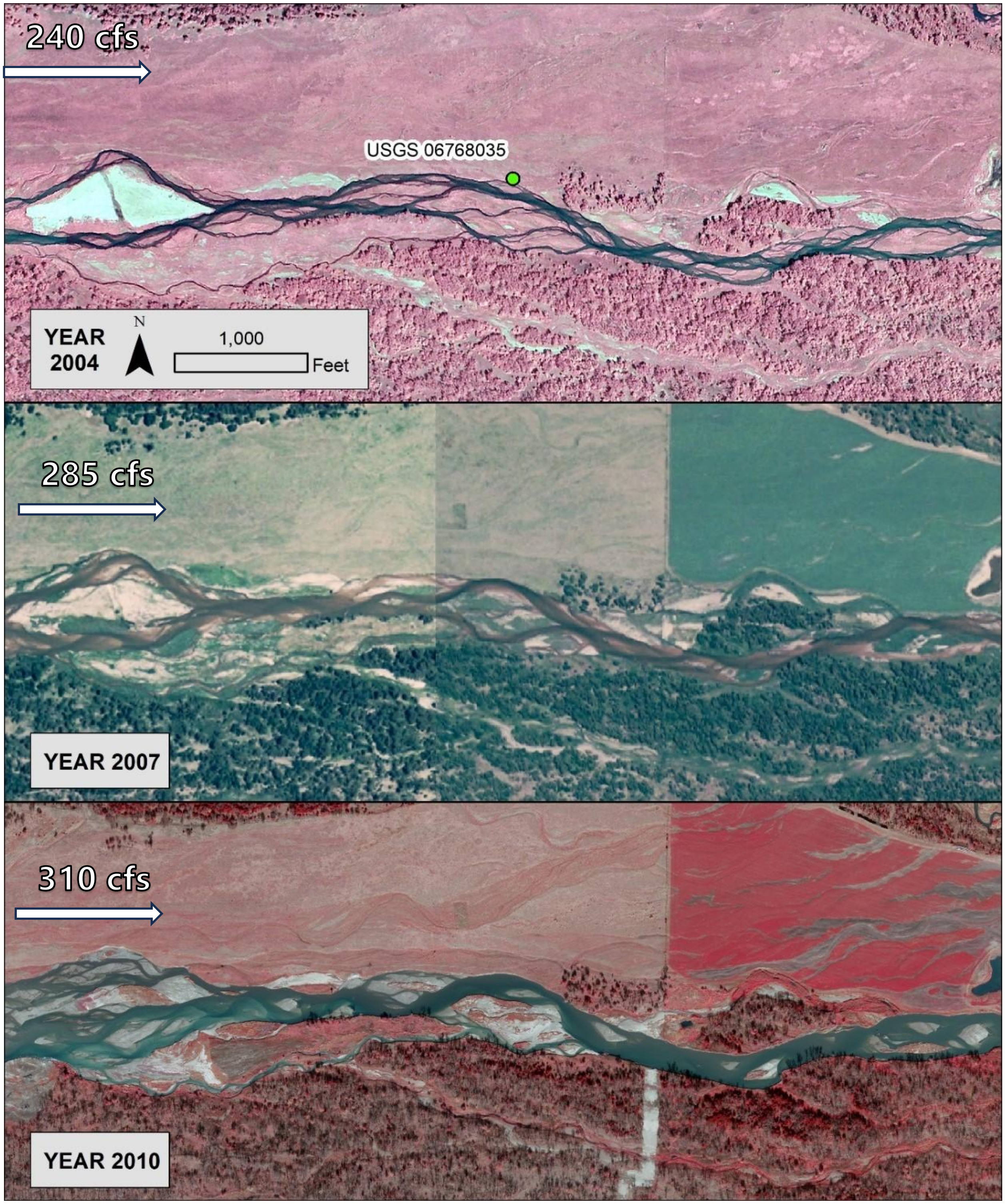

Figure 2.16. Imagery at Cottonwood Ranch Mid-Channel Gage (USGS 06768035) 2004 through 2010.

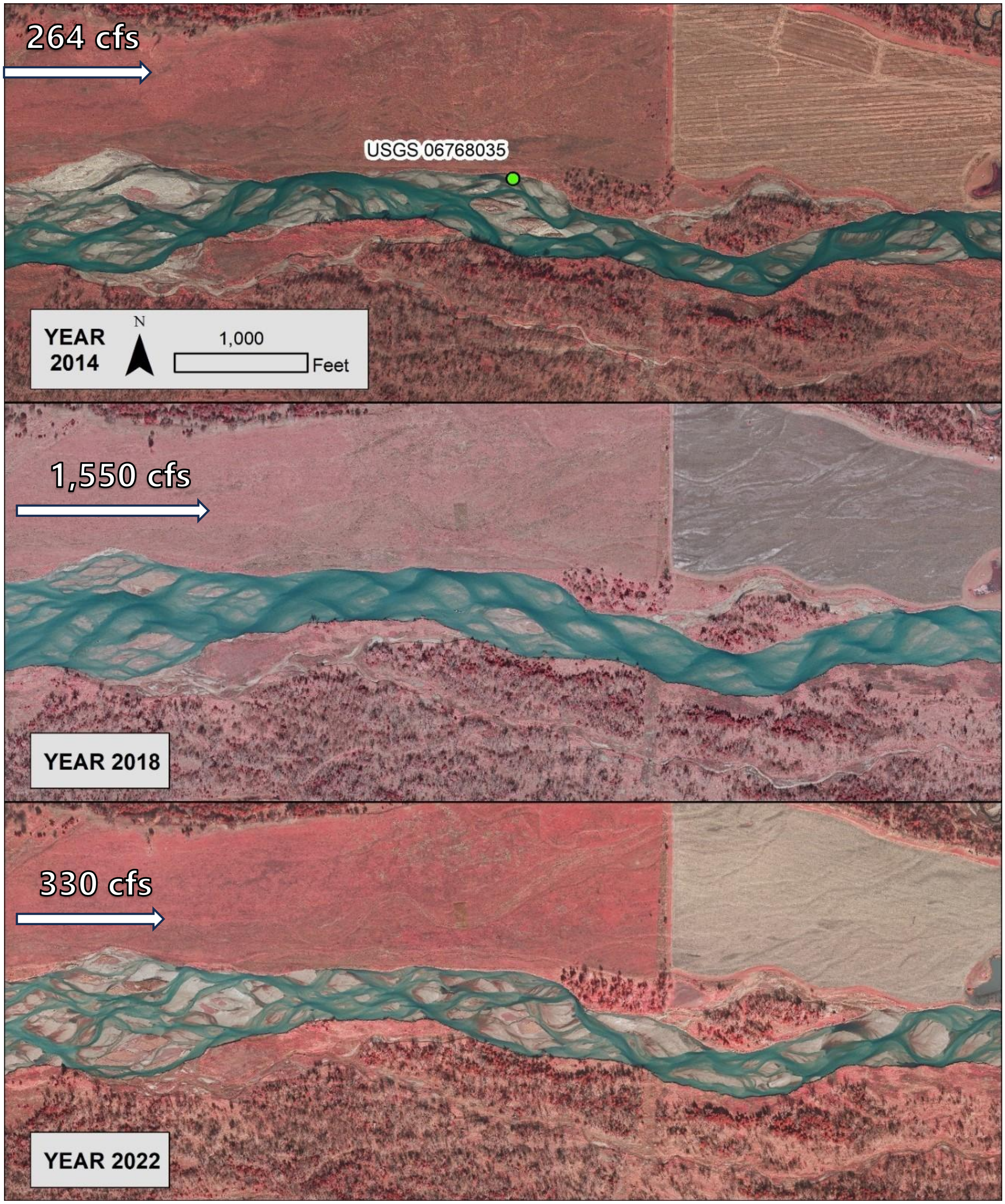

Figure 2.17. Imagery at Cottonwood Ranch Mid-Channel Gage (USGS 06768035) 2014 through 2022.

Figure 2.18 provides physical stage measurement data for the period of record at Cottonwood Ranch Mid-Channel gage along with trailing 30-day mean discharge. The raw stage measurements indicate relative stability at low discharges (<1,000 cfs) until 2007, increasing stage from 2007 to 2011, and stability since 2012. The lack of stage measurements at discharges exceeding 3,000 cfs limit ability to interpret trends in stage for peak flows.

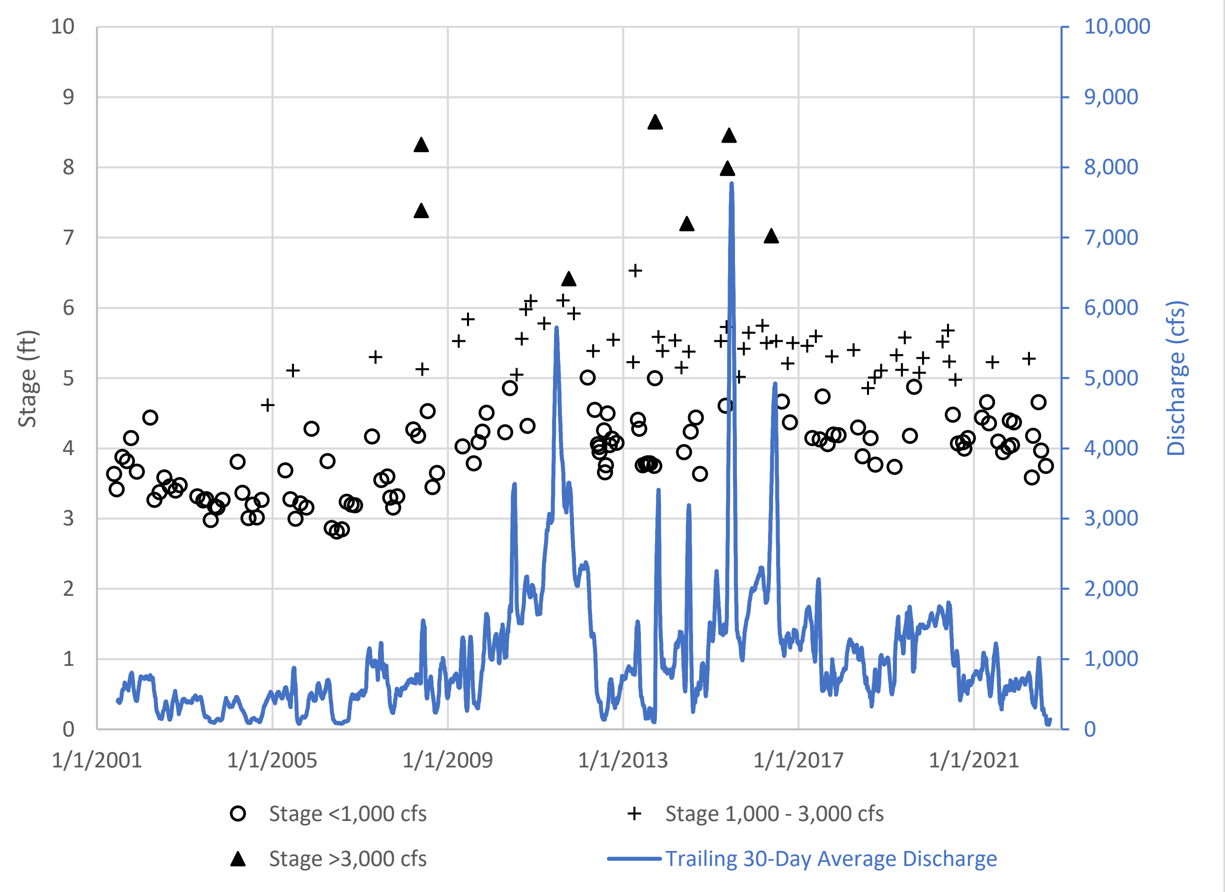

Figure 2.18. Physical measurement stage data at Cottonwood Ranch Mid-Channel gage (06768035) and trailing 30-day average discharge.

Figure 2.19 provides specific gage analysis results. The specific gage analysis indicates stable to slightly increasing stage at low and median discharges during the period of record. There are an inadequate number of stage measurements at the median annual peak discharge to establish any trends in stage at approximate bankfull discharges.

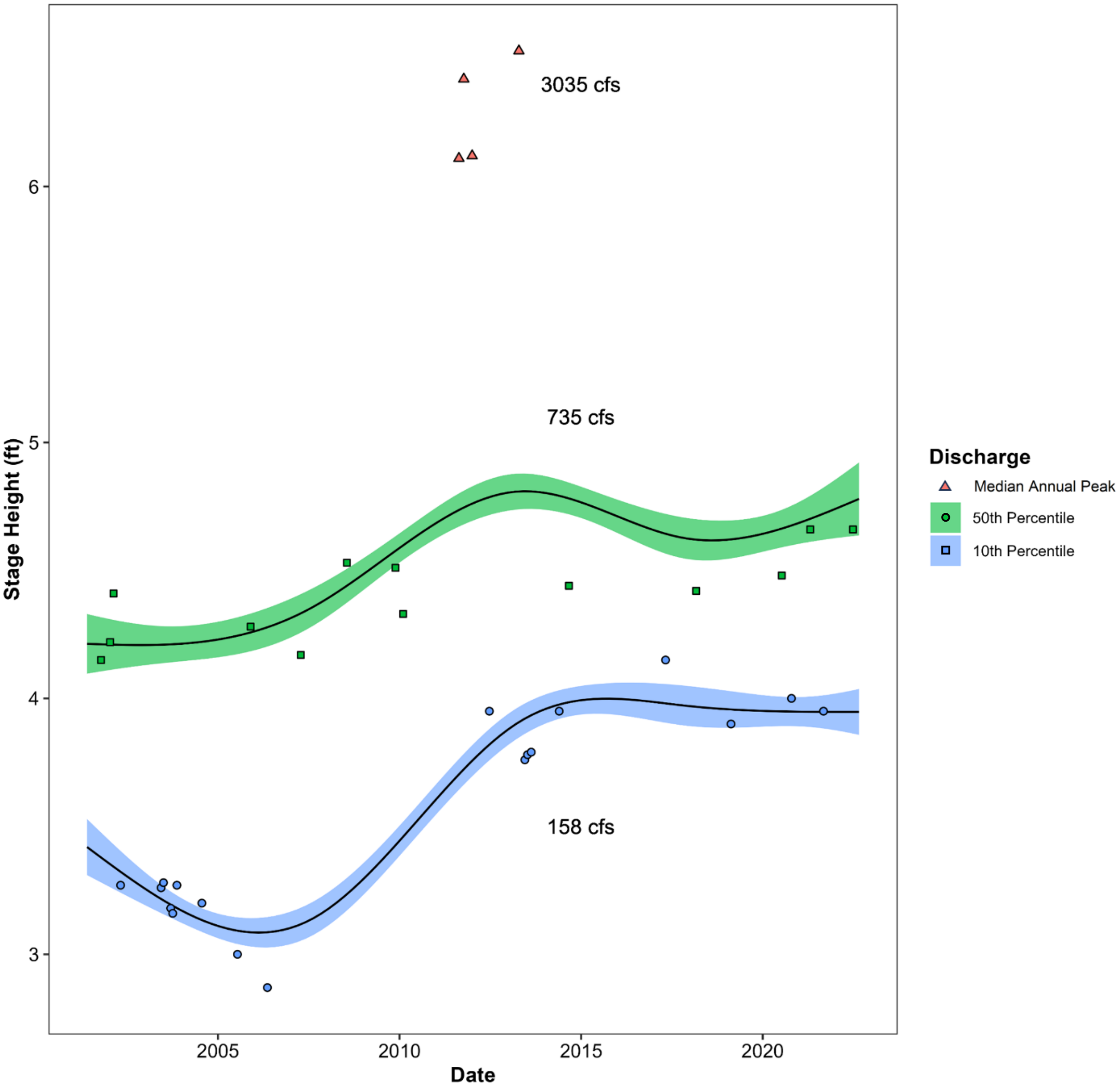

Figure 2.19. Specific Gage analysis for Cottonwood Ranch Mid-Channel Gage (USGS 06768035) at 10th percentile discharge of 158 cfs, median discharge of 735 cfs, and median annual peak discharge 3,035 cfs. Shaded regions represent 95% confidence intervals for each discharge. Results indicate that elevation at this gage increased slightly until approximately 2012 and 2015 for median and 10th percentile discharge, respectively, and remained relatively stable afterward.

2.6 *Channel sinuosity upstream of the Overton Bridge*

2.6.1 Methods

As discussed in Section 2.3, the REM appears to show a shift in channel geometry upstream of the Overton Bridge, especially in the upper half of the J2 Return Channel. In that section, the channel shifted from a braided planform (historically) to narrower and more sinuous wandering form. The results of the incision analysis presented in Section 2.4 indicated minimal vertical incision after 2002 with continuing decline in mean channel elevation in the upper portion of the reach. Taken together, these findings indicate that after 2002 the channel adjustment is occurring primarily through lateral channel movement with increasing meander intensity.

We quantified this increase in meandering by estimating annual sinuosity in the reach between the J2 Return and Overton Bridge using aerial imagery. The first step in this analysis involved hand-delineating channel length by tracing the thalweg from the Overton Bridge to the J2 Return in a series of primarily color-infrared imagery spanning the period of 1969 to 2016. Imagery series captured at high discharge were not included as the thalweg could not be identified. We then calculated straight-line distances between the starting and ending points of each year's thalweg and divided total thalweg channel length by the straight-line distance producing an estimate of sinuosity for each year/image.

2.6.2 Results

Sinuosity analysis results are presented in Figure 2.20. Sinuosity ranged from 1.1 – 1.15 during the late 1960s through the late 1990s. Sinuosity began to increase in the early 2000s with that trend continuing up to the initiation of full-scale sediment augmentation in 2017. Many systems of stream classification (Leopold and Wolman, 1957; Rosgen, 1994; Fryirs, K. & Brierley, G, 2005) include measures of sinuosity as part of their distinction between braided and meandering streams or rivers. In these systems, threshold sinuosity to transition from a braided to meandering channel ranges from 1.2 -1.5. By 2016, mean sinuosity in the J2 Return Channel had increased to the lower end of this threshold, consistent with a transition toward a meandering planform.

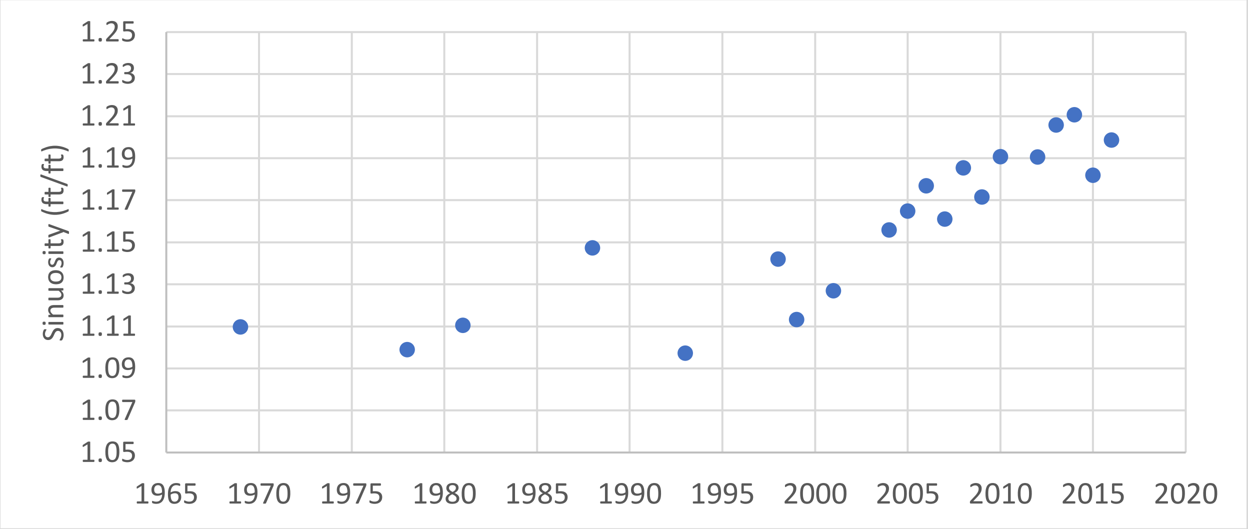

Figure 2.20. Ratio of total channel length to straight-line length (sinuosity) between the J2

Return and the Overton Bridge 1969 to 2016. Figure shows an increase in sinuosity starting in the early 2000s.

2.7 Discussion

The Program's Extension Big Question 3 asks whether augmentation is necessary to keep incision and narrowing from progressing downstream past the Overton Bridge and negatively impacting the suitability of habitat for whooping cranes. The retrospective analyses presented above provide information about historical incision patterns in the study area. The first analysis (2016 REM) indicates there has been approximately 16 ft of incision immediately downstream of the J2 Return. The magnitude of incision declines to about four ft at the confluence of the North and J2 Return Channels near the Overton Bridge and is negligible at the upper end of the Cottonwood Ranch habitat complex. Patterns of incision that can be observed in the REM also indicate the most incised segment in the J2 Return Channel (upper half) has transitioned from braided to a wandering planform that is narrower with higher sinuosity.

Thalweg and mean channel elevation profiles created from 1989 and 2002 repeat cross section surveys, along with 2016 LiDAR profiles, indicate that incision stabilized by the early 2000s. The 2016 and 2002 channel thalweg profiles are topographically similar along the interpolated profile between the ten available thalweg points from 2002. However, comparison of mean channel profiles indicates mean channel elevation continued to decline in the reach downstream of the J2 Return, signaling a shift from a pattern of vertical incision to lateral migration. This is consistent with the trend of increasing sinuosity upstream of the Overton Bridge starting in the early 2000s.

The specific gage analysis at the Overton Bridge indicated approximately two ft of incision occurred at the bridge between 1990 to 2014 with the greatest rate of change in the 2000s. After 2014, stage increased somewhat at the 10th percentile flow (low flow) increasing back to early 2000s levels by 2016. The similarity in low flow stage in early 2000s and 2016 is consistent with the similarity in 2002 and 2016 thalweg profiles but it should be noted that the profile analysis misses the cycle of incision followed by deposition that was observed in the gage data. The specific gage at Cottonwood Ranch indicates that reach has been stable to slightly aggradational since the mid-2000s. However, it should be noted that pilot-scale sediment augmentation occurred one mile upstream of the Overton gage in late 2012 and early 2013 and a considerable amount of channel widening though mechanical augmentation occurred upstream of that gage on Cottonwood Ranch during the period of 2005-2013. Those actions likely affected trends in stage at the gage locations.

Beyond documenting incision rates and patterns, the Program is interested in the rate of incision progression. How long until incision and narrowing progress downstream of Overton and that segment begins to transition to the wandering channel observed below the J2 Return? A change from braided to wandering or even meandering planform could indicate the system is in disequilibrium, or could be a normal, equilibrium response to shifts in sediment supply as meandering rivers are usually associated with less bedload transport than braided or wandering rivers of equal size. These analyses indicate that vertical incision slowed dramatically by 2002 with the channel continuing to evolve via increasing meandering (lateral migration) in the three-mile reach below the J2 Return. This shift from vertical to lateral change was likely caused by a number of factors, including but not limited to: a decrease in channel slope, armoring of the channel bed in the J2 Return Channel that limited vertical incision, and degradation of the channel below the root depth of bank vegetation which increased bank erodibility.

Overall, the retrospective analyses indicated the first wave of channel degradation (vertical incision) appears to have propagated down through the study area by 2002 with a total magnitude of incision of 16 feet at the J2 Return, four ft at the Overton Bridge and negligible incision at the upper end of Cottonwood Ranch. The second wave of channel degradation via lateral migration has been dominant since the early 2000s. The second wave relationships between incision, channel slope, and planform evolution are explored further in Chapters 3 and 4.

2.8 References

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CHAPTER 3 Evaluation of longitudinal change after sediment augmentation in the Central Platte River, NE, USA

3.1 Abstract

In this chapter we evaluated changes from a two-dimensional perspective with planform and profile analyses. This approach allowed us to target specific variables that are either hydrologically important or offer direct comparison with historical data. Implementation of annual REMs highlighted areas of aggradation and incision, and led to the identification of Station 70,000 as an area of active transition from braided to wandering planforms. Using changepoint analysis we found that average channel aggradation may be negatively correlated with flow in the J2 Return Channel and positively correlated with flow downstream of Overton Bridge. We compared wetted width and sinuosity to pre-augmentation data and found that both have increased over the past decades. Sinuosity appears to be continuing to increase gradually, while wetted width appears stable in more recent years. The spatial pattern of wetted width increasing in the downstream direction closely mirrors the spatial pattern of thalweg slope.

3.2 Introduction

In this chapter, our objective is to examine changes in our reach of interest since augmentation began from a two-dimensional perspective and evaluate the role of sediment augmentation in relation to these changes. This involved analysis of planform and profile data during the first five years of sediment augmentation implementation, (2017–2021), and the year prior to beginning augmentation (2016) during which topo-bathymetric data was also collected. Planform analyses made use of this data and pre-augmentation topographic-only LiDAR and aerial imagery. In the following sections, we present methods and results for analysis of annual relative elevation models (REMs), longitudinal analyses of thalweg elevation and mean channel elevation, and planform analyses of wetted width and sinuosity. We follow with a more detailed evaluation of channel incision and planform change near the midpoint between augmentation and the Overton Bridge (Station 70,000).

3.3 Relative elevation model

In Chapter 2, we introduced the relative elevation model (REM) as a tool to visualize channel planform and incision relative to the elevation of the floodplain. That chapter discussed incision patterns prior to augmentation. In this chapter, we extended the REM analysis through the augmentation experiment to evaluate change during augmentation.

3.3.1 Methods

We developed annual (2016–2021) REMs of channel topography relative to average floodplain elevation using the methods described in Chapter 2 derived from Powers et al. (2019). REMs were generated by differencing annual LiDAR from the Geomorphic Grade Line (GGL) surface that approximates the elevation of the valley-scale floodplain in the reach. The resulting REM rasters were classified into two-foot intervals to observe topographic changes during the sediment augmentation experiment.

3.3.2 Results

The 2016 and 2021 REMs for the segments of the study area upstream and downstream of the Overton Bridge are included in Figure 3.1 and Figure 3.2. In general, the pattern of incision downstream of the J2 Return extends the length of the J2 Return Channel to the Overton Bridge (Figure 3.1). Headcutting (incision) is present in the lower section of the North Channel, in the breakthrough channel upstream of the J2 Return, and in the sand-dammed channel that was formerly connected to the North Channel (Figure E.1). This headcutting is due to the elevation of the affected channel segments adjusting to match the base level of the incising J2 Return Channel.

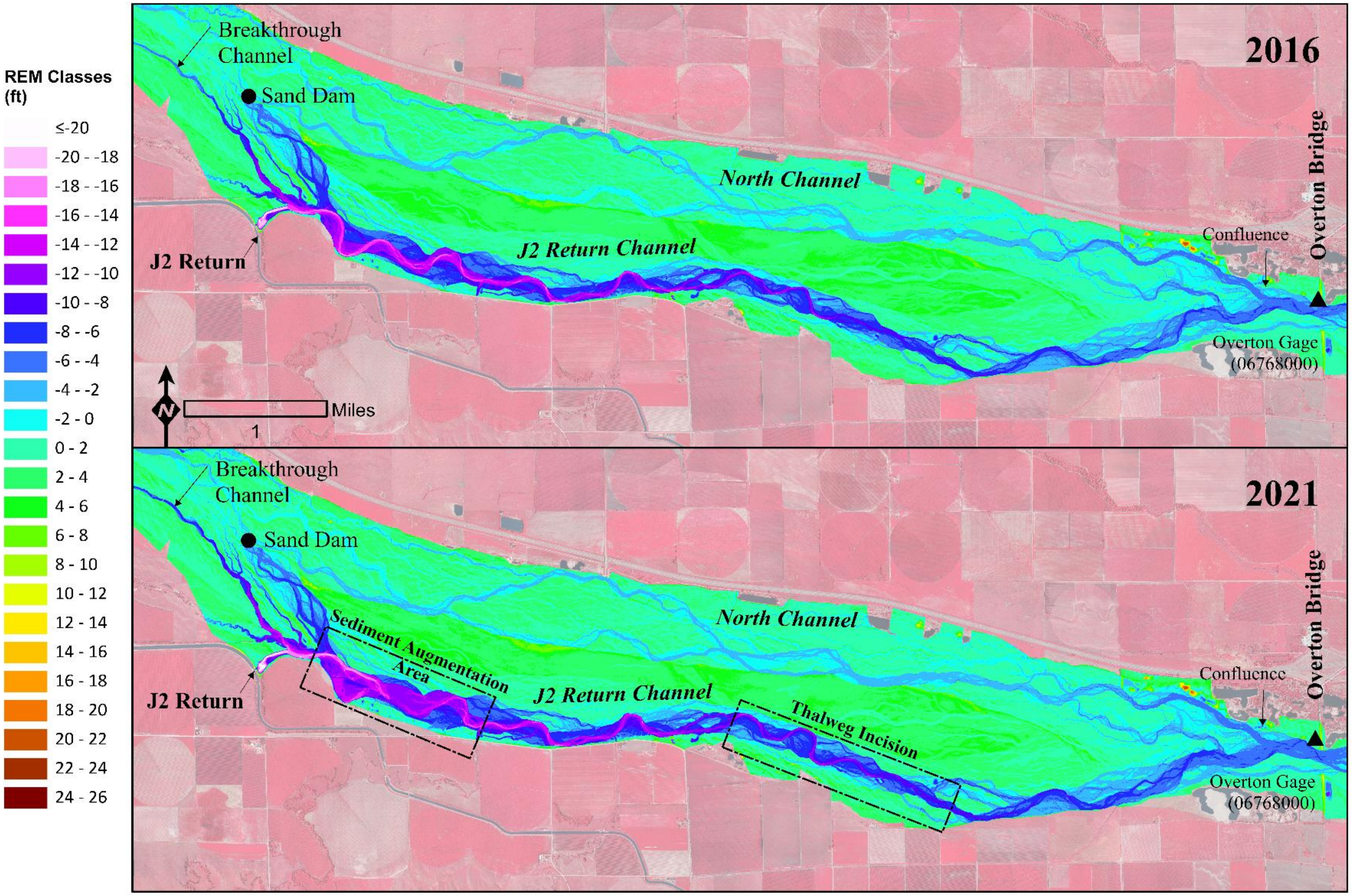

Figure 3.1. Relative elevation models (REMs) of the portion of the study area upstream of Overton in 2016 (top) and 2021 (bottom). The topographic signature of sediment augmentation is apparent in the 2021 REM as is a segment of thalweg incision midway between the J2 Return and Overton Bridge. More change occurred from 2016-2021 upstream of Overton Bridge than downstream (comparing Figure 3.1 to Figure 3.2 below).

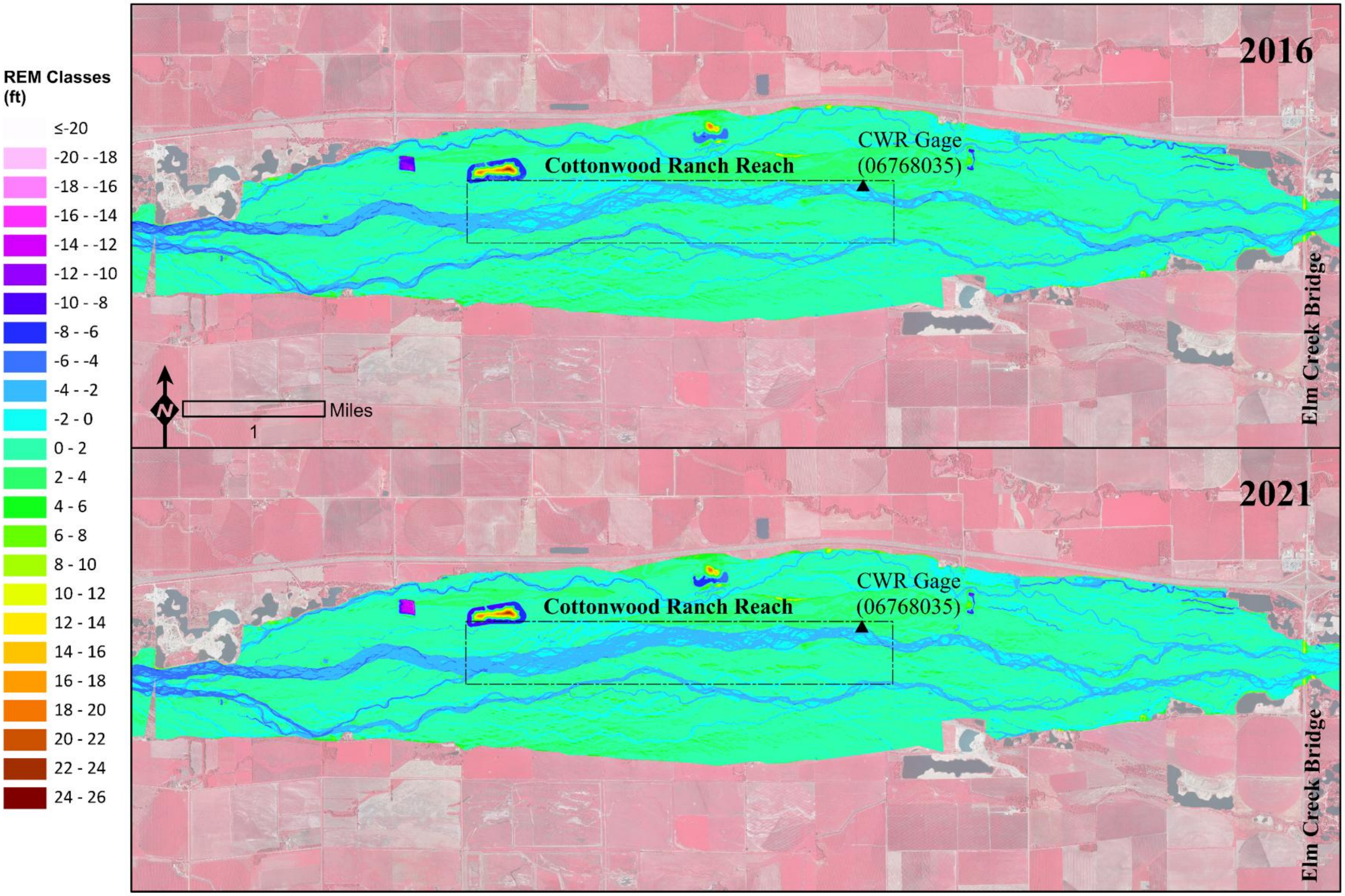

Figure 3.2. Relative elevation models (REMs) of the portion of the study area downstream of Overton to the Elm Creek Bridge in 2016 and 2021. Large changes to relative elevation are not apparent in this reach.

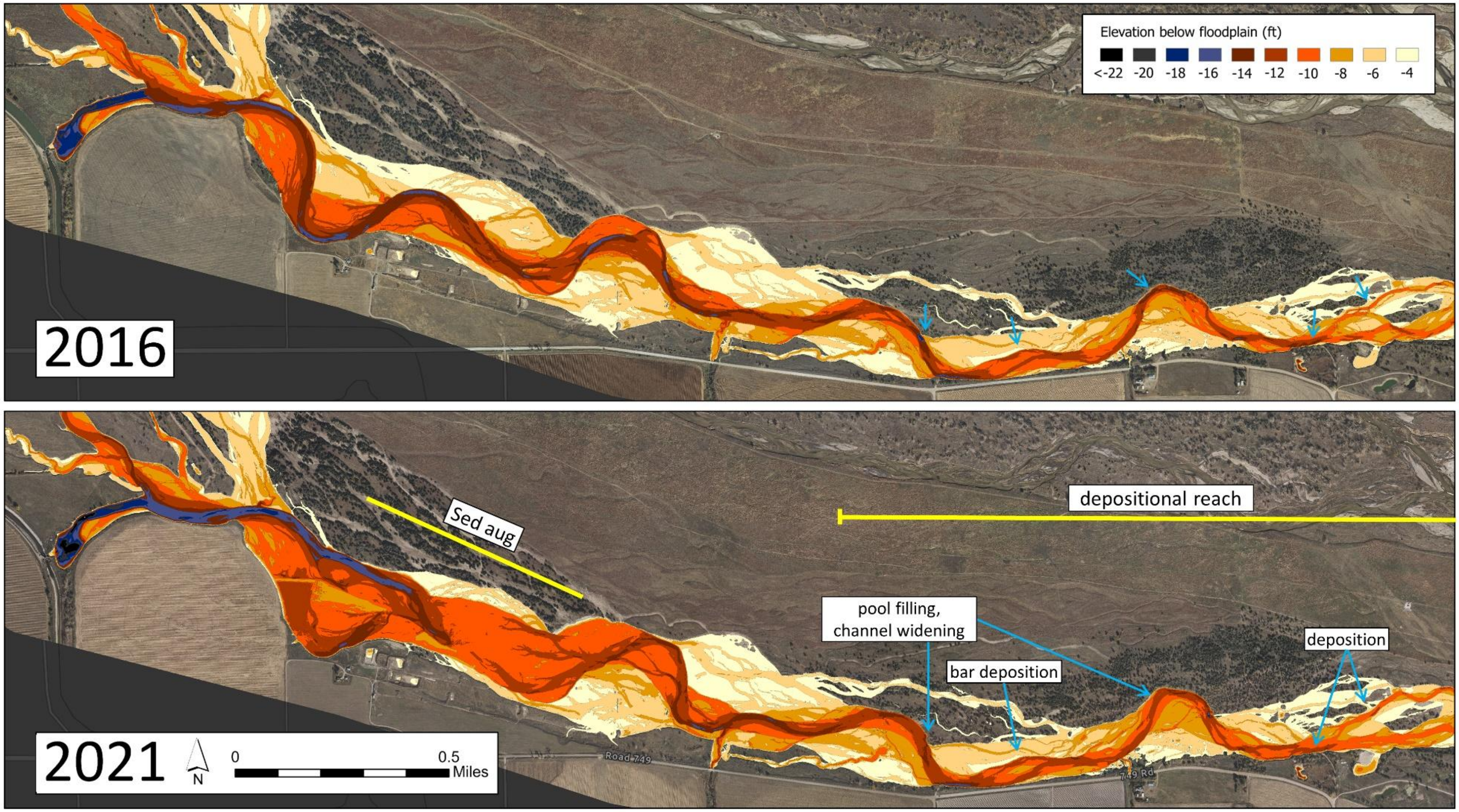

Figure 3.3. Annotated relative elevation model of the sediment augmentation area and downstream. The color scale illustrates four feet or more below the average floodplain and omits higher elevations. Incision occurred upstream of augmentation (blue) and deposition occurred downstream of augmentation.

When comparing 2016 and 2021 REMs upstream of Overton, changes are apparent in the J2 Return Channel. The scars of sediment augmentation projects are visible in the farthest upstream area, most notably the 2017 project which blocked a meander to protect private property, shifting the thalweg north (see Section 1.5.4). This shortening of the thalweg caused local erosion that is abruptly arrested by deposition from augmentation projects that occurred just downstream (Figure 3.3). Downstream of the augmentation area, deposition occurred in the form of pool filling, channel widening, and bar deposition (Figure 3.3). Midway through the J2 Return Channel, an area of thalweg incision extends toward the Overton Bridge (Figure 3.1).

Below Overton Bridge (Figure 3.2), a small amount of pronounced incision is present downstream of the bridge but subsides near the upstream boundary of Cottonwood Ranch with thalweg elevation stabilizing at approximately 3 ft below the GGL. Despite year-by-year variations in the REMs of this reach, there is no signature of prolonged substantial change in relative elevations.

Given most channel change during the sediment augmentation experiment occurred in the segment upstream of the Overton Bridge, all annual REMs for that area are plotted together in Figure 3.4 with a continuous color scale ranging from -1 ft to -29 ft below GGL. In the sediment augmentation area, the sediment source locations for annual augmentation operations along the left (North) bank are apparent starting near the upper end of the augmentation area in 2017 and moving downstream through 2019. Augmentation operations subsequently moved back upstream in 2020 and 2021. Downstream, the area of channel incision and planform transition is located near Station 70,000 (Figure 3.4, outlined in yellow). Meandering intensity progressively increased in that area from 2016–2021.

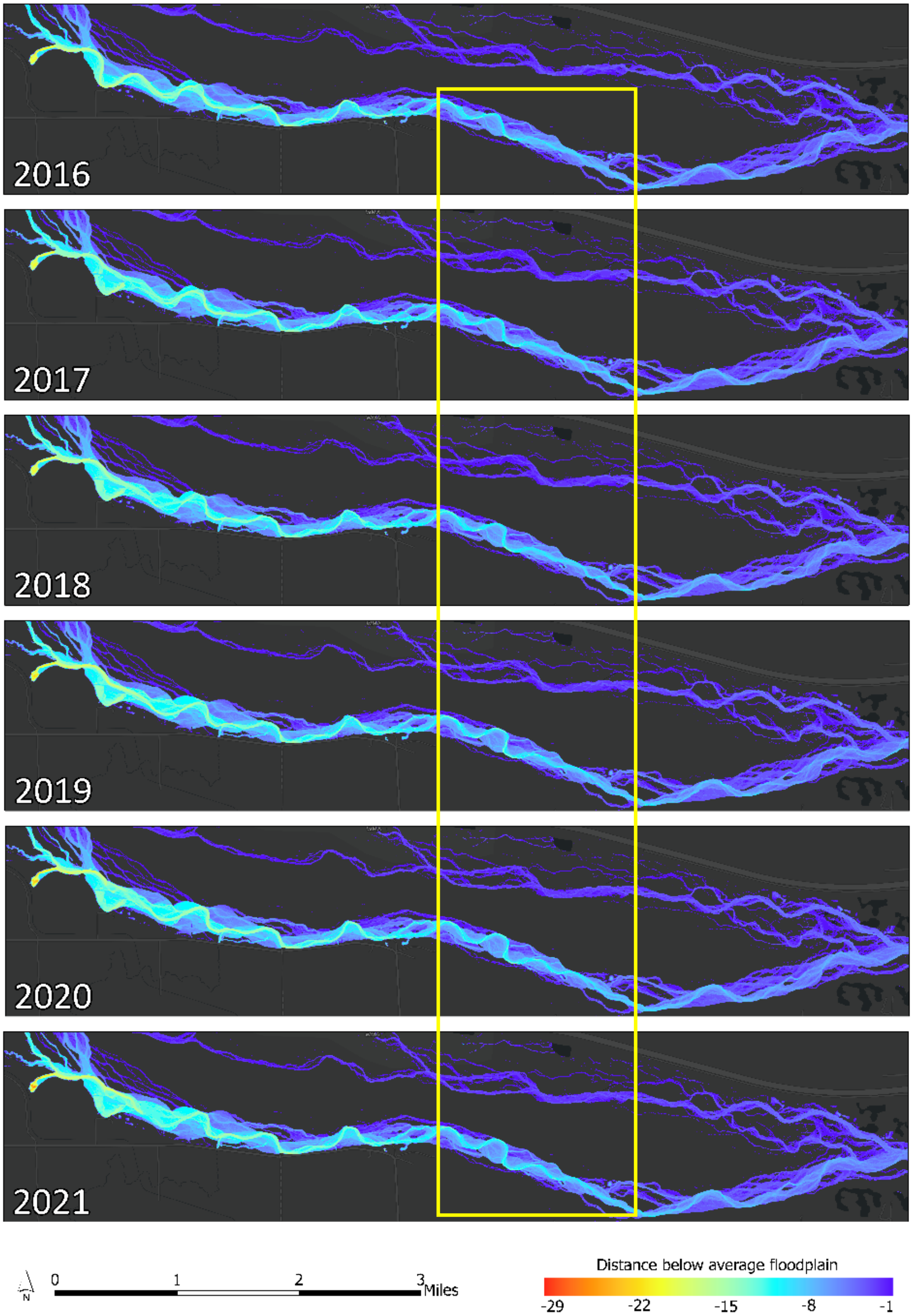

Figure 3.4. Annual relative elevation models (REMs) of the J2 Return Channel (2016 to 2021). Meander development and thalweg incision can be observed near Station 70,000 (yellow box).

3.4 Longitudinal profile of channel thalweg 2016–2021

While visual comparison of REMs is useful for identification of areas of changes during sediment augmentation, longitudinal profiles of the deepest point of the channel (thalweg) provide a more specific numerical measure of spatial and temporal patterns of aggradation or degradation during the sediment augmentation experiment. As discussed in Section D.1, LiDAR elevations in wet areas such as the channel thalweg are less accurate than LiDAR over dry areas (< 0.2 ft). Typical wet error was found to be within 0.3 ft of checkpoints and within 0.75 ft of checkpoints in 2019 due to higher flow and turbidity in that year. This error should be born in mind, however, we believe our conclusions are still valid despite the additional uncertainty.

3.4.1 Methods

Annual thalwegs were delineated for each year of analysis using methods described in Section 2.3.1.

Changepoint analysis, a method of detecting statistically similar segments, was used to identify patterns in measured changes in mean thalweg elevations for the reach extending from the downstream end of the sediment augmentation area (Station 84,000) to Station 15,000[12]. Changepoints were calculated using the changepoint package in R version 4.2.2 (Killick et al., 2022; R Core Team 2022; Killick & Eckley 2014). We used the Pruned Exact Linear Time (PELT) method to detect multiple changepoints of sample mean, and the Changepoints for a Range of Penalties (CROPS) process to determine a manual penalty value of 200 on the log likelihood scale with diagnostic plots (Haynes et al., 2017 Killick et al., 2012). PELT is a dynamic programming technique that sequentially and iteratively optimizes changepoint locations, and CROPS automatically calculates all changepoint locations according to a variety of penalty values to assist with optimal penalty selection.

3.4.2 Results

Figure 3.5 provides annual thalweg alignments for 2016–2021. Annual alignments in the upper half of the J2 Return Channel were consistent, except for several expanding meanders and the sediment augmentation area where thalweg location has been manipulated. The planform transition from single thread wandering (upstream) to braided (downstream) is also apparent in Figure 3.5. Approximately two miles upstream of the Overton Bridge, annual alignments begin to diverge with annual differences increasing spatially with channel width and braiding intensity. Annual differences are most apparent in the Cottonwood Ranch Reach in the Overton to Elm Creek Bridge segment and in the reach immediately upstream of the KCD (below the Elm Creek Bridge).

The longitudinal profiles for 2016 and 2021 are plotted in Figure 3.6 along with the Geomorphic Grade Line (GGL) for the study area. Both longitudinal profiles are convex in shape, with slope increasing in a downstream direction, away from the area of maximum incision immediately below the J2 Return. Differences in 2016 and 2021 thalweg profiles are apparent in the sediment augmentation area (upstream of Station 84,000) where the 2021 thalweg is higher than 2016 because of augmentation operations. Downstream in the J2 Return Channel, a segment between Stations 72,000 and 66,000 shows incision relative to the rest of the channel. Below the Overton

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[12] Analysis ended at Station 15,000 to eliminate backwater effects from the Kearney Canal Diversion.

Bridge, thalweg elevations appear to have been stable through Cottonwood Ranch and increased upstream of the Elm Creek Bridge (Station 25,000 to 15,000), indicating the bed aggraded in that area. Thalweg slopes did not vary much between 2016 and 2021 when examined at a reach scale. At smaller scales, slope changes were apparent due to local thalweg change, but we did not observe a pattern of steepening or flattening on the J2 Return Channel during this period. The gradual shift from shallow slopes in the J2 Return Channel (0.00075 to 0.00095 ft/ft) to steeper slopes downstream of the North Channel confluence to the KCD (0.00106 to 0.00111 ft/ft) appears to be stable or changing too gradually to observe over this timescale (Figure 3.6).

Figure 3.7 provides annual thalweg profiles for the J2 Return Channel smoothed using 1,005 ft centered running average elevations to highlight annual profile changes. Thalweg elevations in the sediment augmentation area generally increased during the augmentation experiment as sediment from floodplain terraces was mechanically spread across the active channel. Downstream near Station 70,000, the highest magnitude of incision occurred between 2018 and 2019, with more stability from 2019 through 2021. We explore this segment in greater detail in Section 3.8.

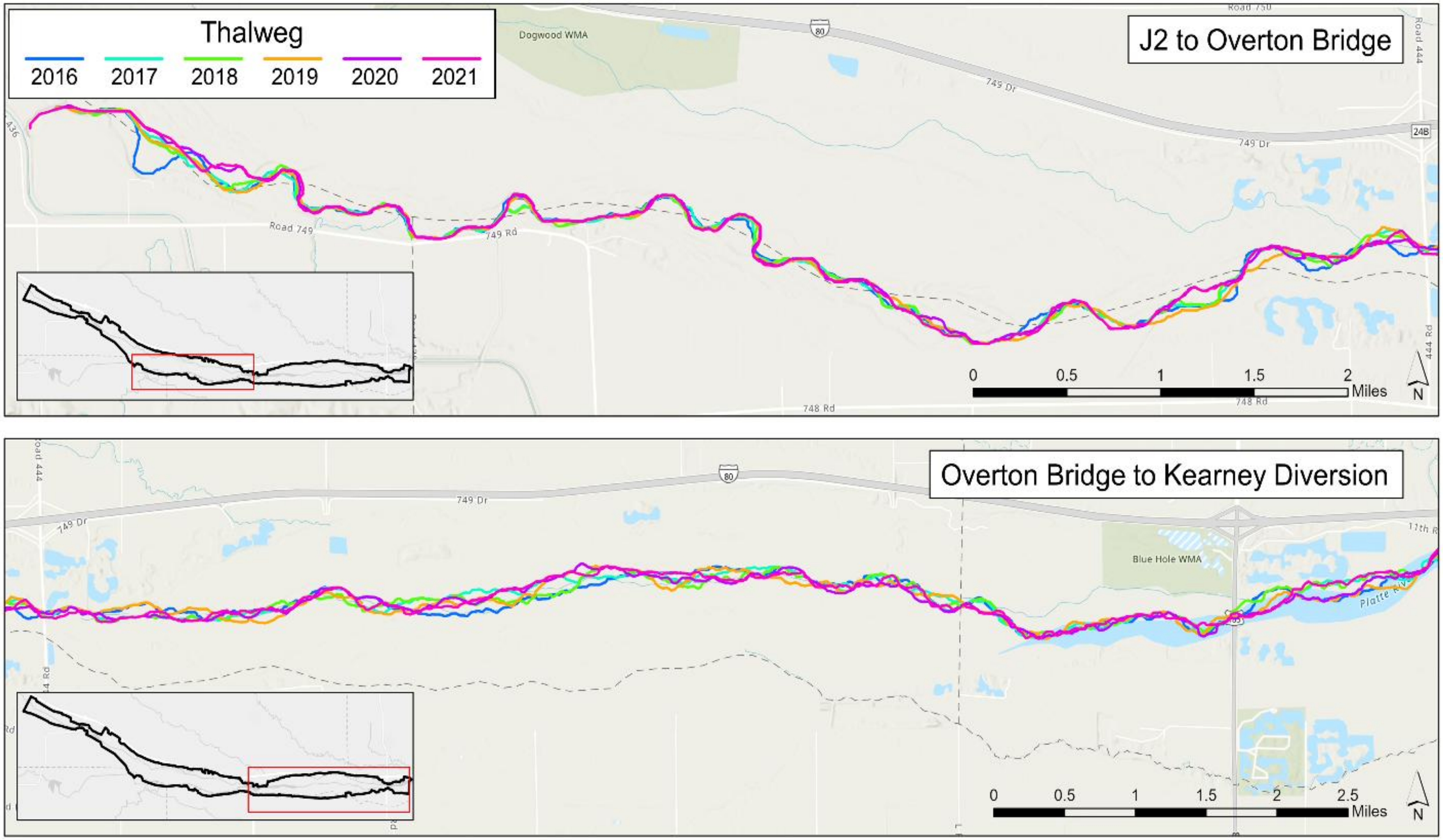

Figure 3.5. Annual thalweg alignments (2016–2021) derived from flow accumulation rasters. In the top panel, the transition from wandering to braided planform is present midway through the J2 Return Channel.

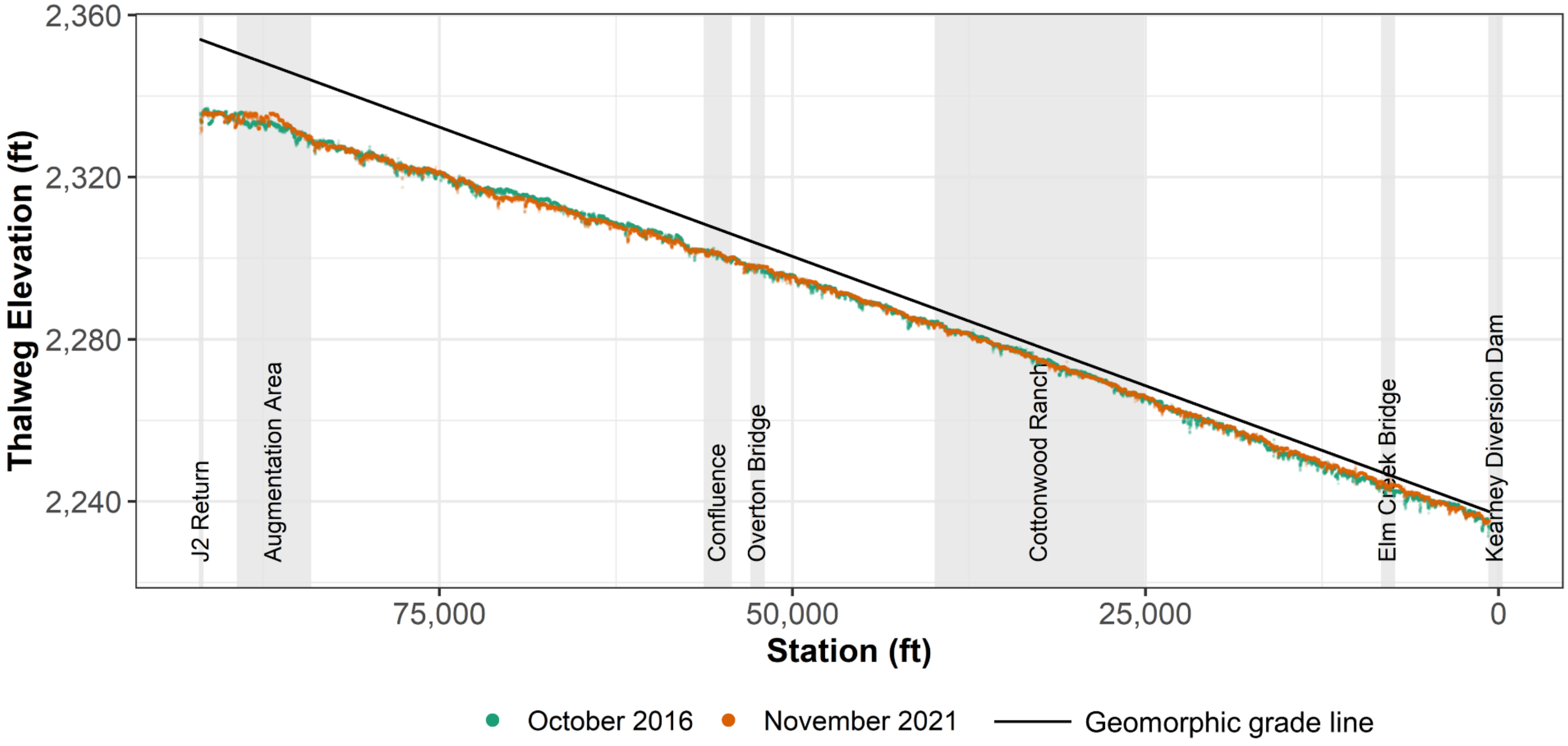

Figure 3.6. Longitudinal profile of thalweg elevation in 2016 (green) and 2021 (orange). The Geomorphic Grade Line (GGL) is shown in black as a reference for the magnitude of channel incision.

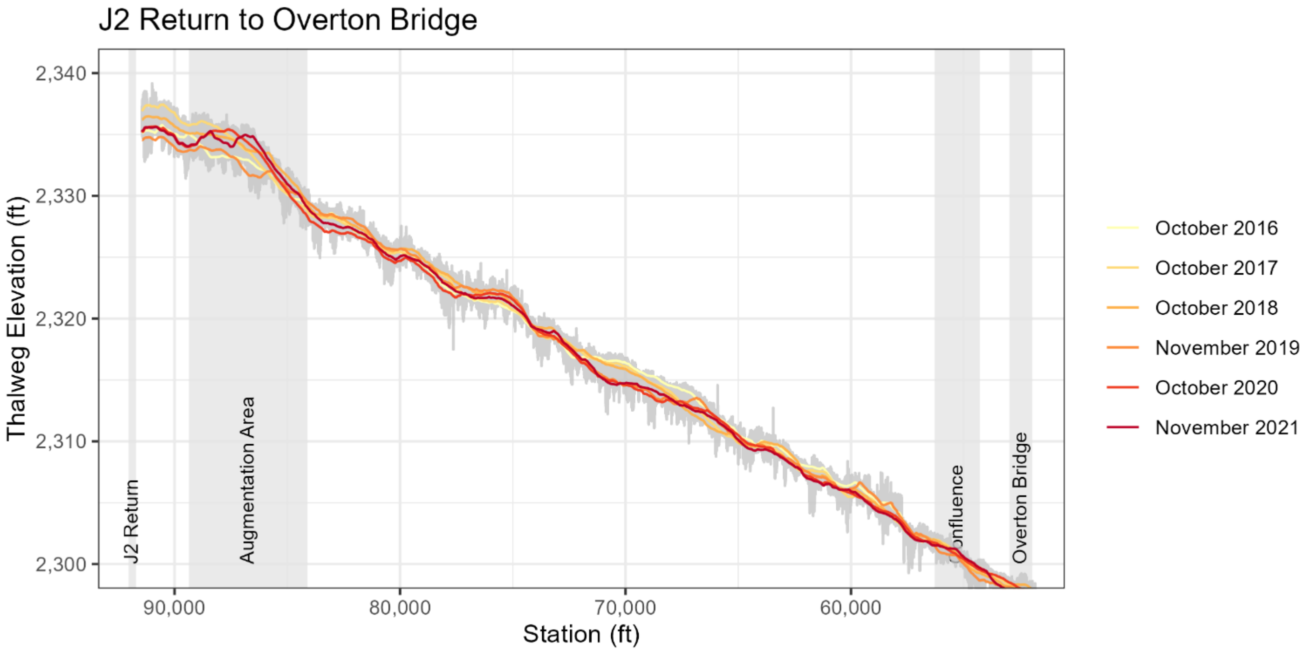

Figure 3.7. 2016–2021 annual moving average (1,005 ft) longitudinal profiles between J2 Return and Overton Bridge. Grey area behind profiles indicates the range of values for 2016–2021. Progressive thalweg aggradation is apparent in the sediment augmentation area and progressive degradation is apparent downstream in the vicinity of Station 70,000.

Segments of mean change derived from the changepoint analysis for the entire augmentation period (2016–2021) are presented in Figure 3.8 and mean change values are provided in Table 3.1. After five years of augmentation, mean change in thalweg elevation in the first 2.3 miles downstream of the augmentation area ranged from -0.3 to +0.4 ft. This is followed by an approximately one-mile reach with the most prominent incisional trend in the study area. The incisional reach extends from roughly Station 72,000 downstream to Station 66,000 with mean thalweg incision of -1.3 ft. The thalweg also incised in the reach immediately downstream with mean thalweg elevation loss of -0.64 ft. Continuing downstream, the channel transitioned to slight aggradation (+0.2 ft) near the J2 Return Channel confluence with the North Channel. Near Cottonwood Ranch, mean change shifted to slight thalweg incision (-0.2 ft). Downstream of Cottonwood Ranch, thalweg elevation increased by an average of 0.5 ft.

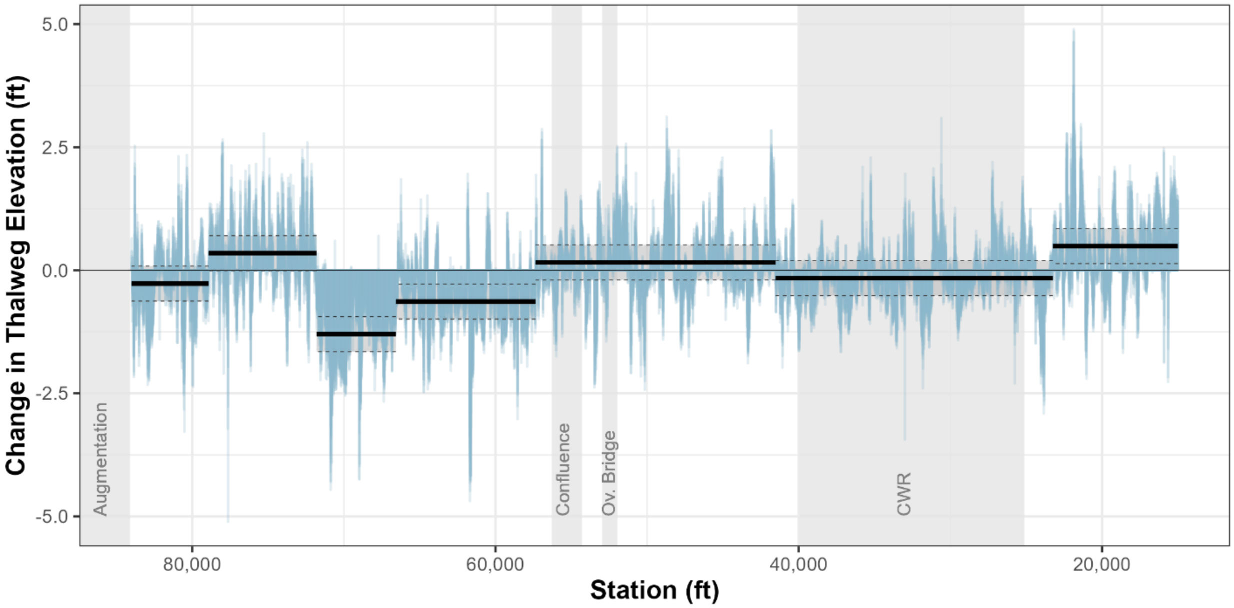

Figure 3.8 2016–2021 thalweg changepoint analysis results. Differences in thalweg elevations shown in blue. Mean segment change values shown in black. Negative numbers indicate thalweg incision and positive indicate thalweg aggradation. Shaded areas with bounding dotted lines represent the propagated error from LiDAR collection for 2016 and 2021 (0.356 ft).

Table 3.1. 2016–2021 thalweg changepoint analysis results.

Station Range	Segment Length (mi)	Thalweg Elevation Change (ft)		
		Mean	Minimum	Maximum
84,000–78,915	1.0	-0.3	-2.3	4.9
78,915–71,805	1.3	0.4	-3.4	3.1
71,805–66,570	1.0	-1.3	-2.4	3.1
66,570–57,360	1.7	-0.6	-4.7	2.0
57,360–41,520	3.0	0.2	-4.5	0.7
41,520–23,240	3.5	-0.2	-5.1	2.8
23,240–15,000	1.6	0.5	-3.3	2.5

Changepoint analyses were also utilized to detect segments of mean change for each set of consecutive years during the augmentation experiment to evaluate inter-annual variability (Figure 3.9). In the J2 Return Channel, the segment around Station 70,000 shows persistent loss from 2016 to 2019, with the most loss occurring in 2019. The thalweg was stable in that area in 2020 and aggraded slightly in 2021. Downstream of the Overton Bridge, the annual changepoints indicate relative thalweg stability. Table 3.2 shows annual mean thalweg changes summarized by their location either upstream or downstream of Overton Bridge. See Section D.2 for further discussion on flow data.

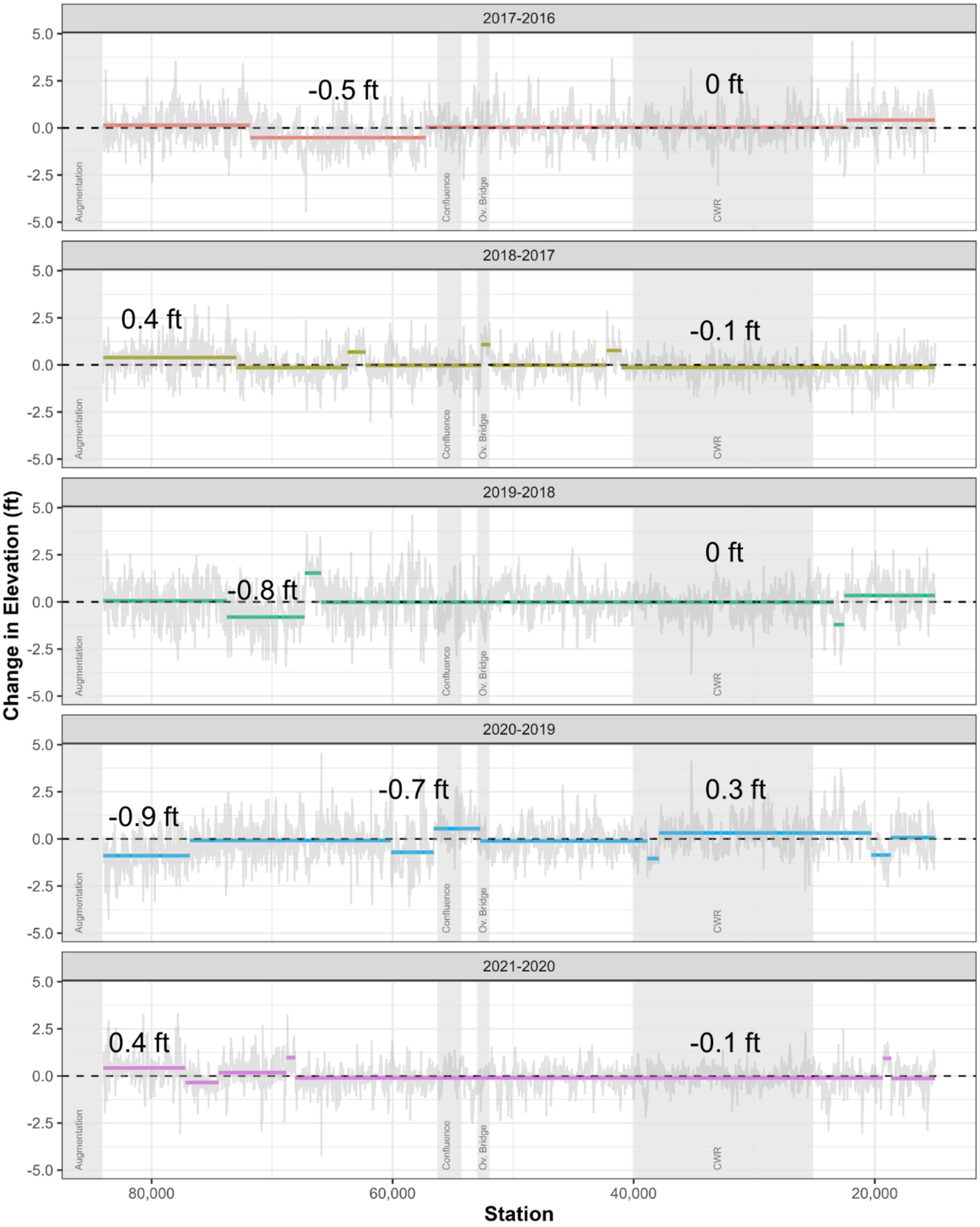

Figure 3.9. Annual changepoint analysis results of change in thalweg elevation between years. Colored lines show mean change values of changepoint segments. Light grey lines show at-a-station thalweg elevation difference.

Table 3.2. Average thalweg changes upstream and downstream of Overton Bridge with mean flow for comparison.

Year	Mean Thalweg Change (ft)		Mean Discharge at Overton Bridge (cfs)	Mean J2 Return Flow (cfs)
	J2 Return Channel	Downstream of Overton		
2016–2017	-0.17	0.11	1,780	1,099
2017–2018	0.13	-0.05	1,289	807
2018–2019	-0.10	0.04	2,082	1,155
2019–2020	-0.26	0.05	2,127	1,225
2020–2021	0.04	-0.06	1,008	589

3.5 Longitudinal profile of mean channel elevation 2016–2021

Longitudinal profiles of thalweg elevations are useful in evaluating incision and slope change during the sediment augmentation experiment. However, they only describe changes to the deepest part of the channel. We also examined longitudinal profiles of average cross-sectional elevation to quantify dispersed channel change beyond the thalweg.

3.5.1 Methods

To calculate average cross-sectional elevation, we first clipped stationed channel transects to confine them to the active channel, defined as the portion of the channel wetted at a discharge of 2,500 cfs in the J2 Return Channel and 2,500 cfs in the North Channel. This results in a total flow of 5,000 cfs downstream of the J2 Return and North Channel Confluence. These flows represent the approximate bankfull (50% probability) flow for the reach. Wetted area was modeled for each year with SRH-2D (Lai, 2008), using 2016–2021 LiDAR (PRRIP 2022b). Flow area polygons for each year were merged into a single polygon capturing the entire wetted area during the management experiment. After transects were clipped to the limits of the active channel, we sampled LiDAR DEM elevations at 3 ft intervals along each clipped transect and calculated the average elevation. Mean elevations were plotted by station for each year. At-a-station differences were calculated for each pair of consecutive years from 2016 through 2021, and for the difference between 2021 and 2016. Increases in mean channel elevation indicate aggradation due to depositing material. Material sources in this case include sediment augmentation, lateral erosion, and upstream transport. The merged polygon used to clip our transects includes inactive floodplain elevations that may have been incorporated into the active floodplain via lateral erosion over the course of the study period. As a result, reductions in mean channel elevation through time can be the result of either lateral erosion or bed erosion.

3.5.2 Results

The longitudinal profiles of average cross-sectional elevation for 2016 and 2021 are plotted in Figure 3.10 along with the GGL. Like the channel thalweg, the longitudinal profile of average cross-sectional elevation diverges from the GGL due to incision downstream of J2 Return. Maximum divergence from the GGL occurs near the J2 Return. The profile gradually converges with the GGL in a downstream direction. Through the Cottonwood Ranch Reach, the average cross-sectional elevation is nearly parallel with the GGL and close to the predicted GGL elevation. Downstream of Station 12,000 (near Elm Creek Bridge) the profile of mean elevation converges with GGL due to the backwater effect and consequent upstream aggradational influence of the KCD. The average elevation in the sediment augmentation area (above Station 84,000) decreased between 2016 and 2021 as a result of augmentation (Figure 3.10). Station 71,250 also experienced a decrease in mean elevation. Overall, elevation change from 2016 to 2021 was more evident in the J2 Return Channel than downstream of Overton Bridge.

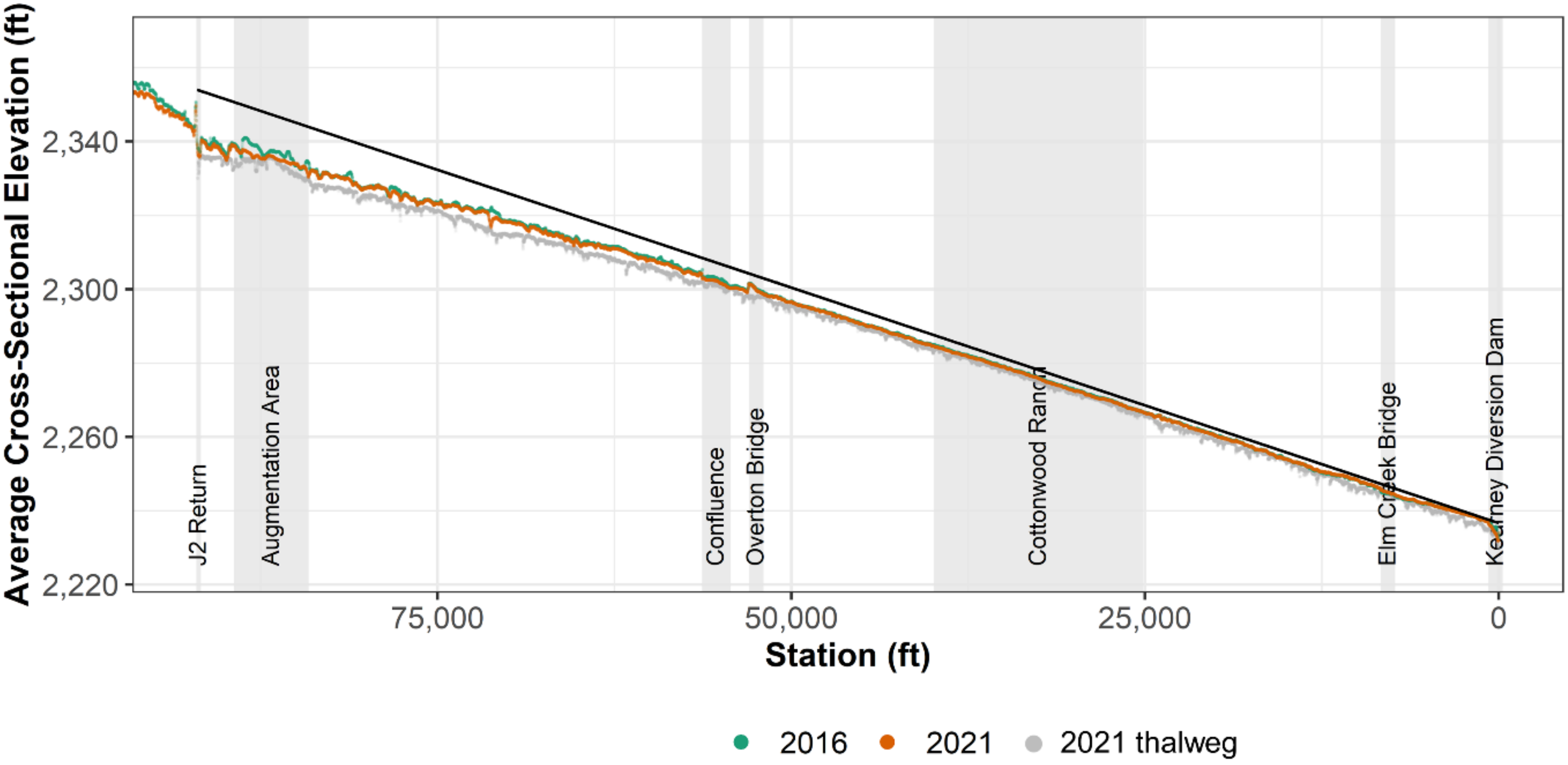

Figure 3.10. Average cross-sectional elevation longitudinal profile. The geomorphic grade line and 2021 thalweg are shown for reference.

Figure 3.11 provides annual mean channel elevation profiles for the J2 Return Channel smoothed using 1,005 ft centered running average elevations to highlight annual profile changes. Mean channel elevation decreased in the sediment augmentation area through the augmentation experiment due to mechanical removal of sediment from floodplain terraces and placement into the active channel. Downstream of the augmentation area, areas of large progressive decline in mean channel elevation are apparent near Stations 82,000, 78,000 and 72,000. These are areas with meanders that are actively migrating via lateral erosion of cutbanks and deposition on point bars. Progressive decline is also a pattern downstream of 72,000 to Overton Bridge between 2016 and 2021.

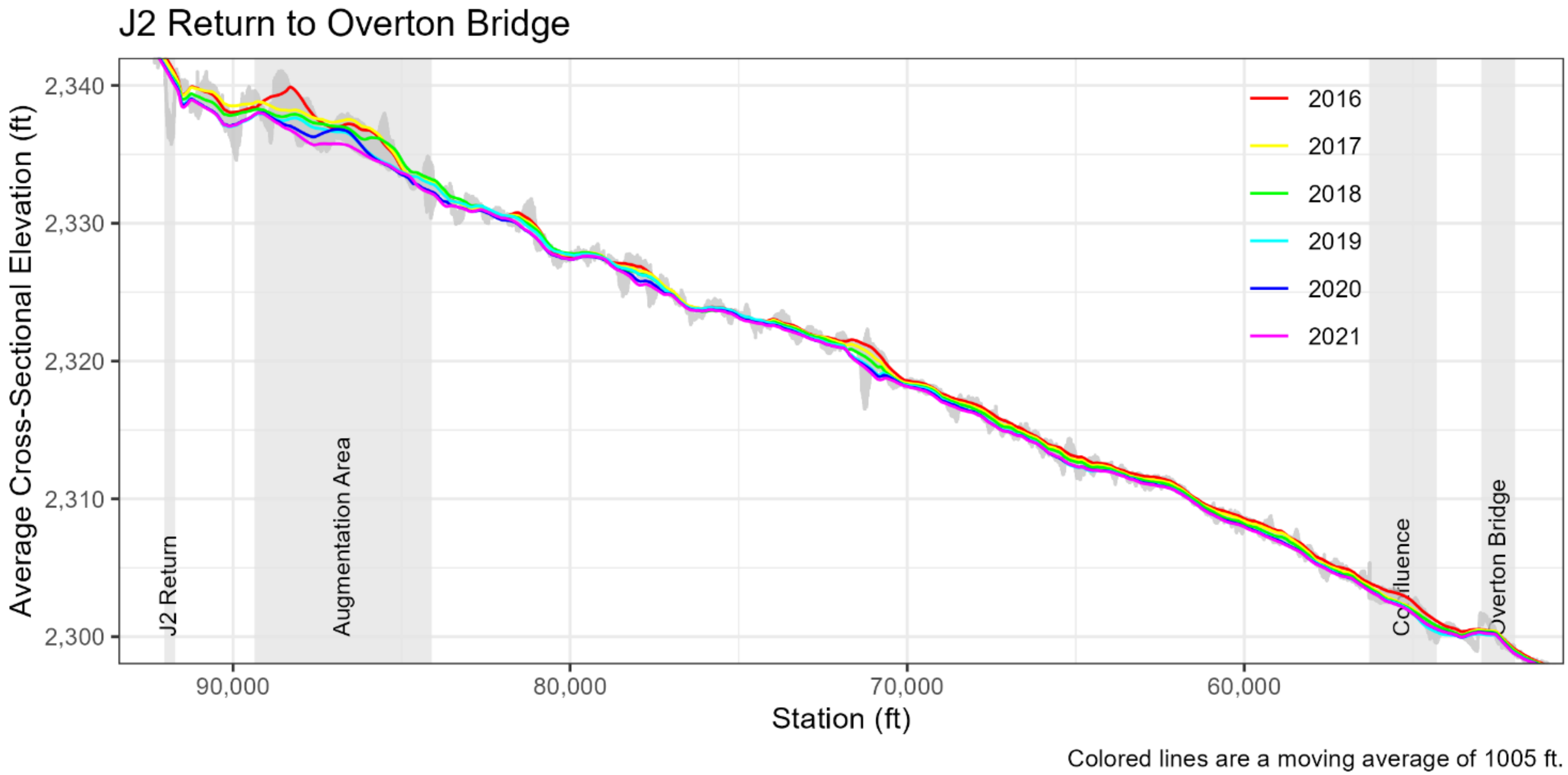

Figure 3.11. Average cross-sectional elevation longitudinal profile in the J2 Return channel. Colored lines are a moving average of 1005 ft and grey lines show the range of values for 2016–2021.

Combining thalweg and mean channel elevation changes into one figure (3.12) provides a comprehensive view of in-channel changes during the augmentation experiment. General degradation can be detected when both thalweg and average elevations decrease (see Station 72,000 to Overton Bridge), while lateral erosion or channel widening can be detected by a decrease in average elevations accompanied by increase in thalweg elevations (see the augmentation area). Downstream of Overton Bridge, changes in average and thalweg elevations are not strongly positive or negative until station 25,000 where aggradation is indicated. These patterns of erosion and deposition can be more directly assessed through a three-dimensional analysis of volume change that discriminates between lateral and bed erosion. That analysis is presented in Chapter 4.

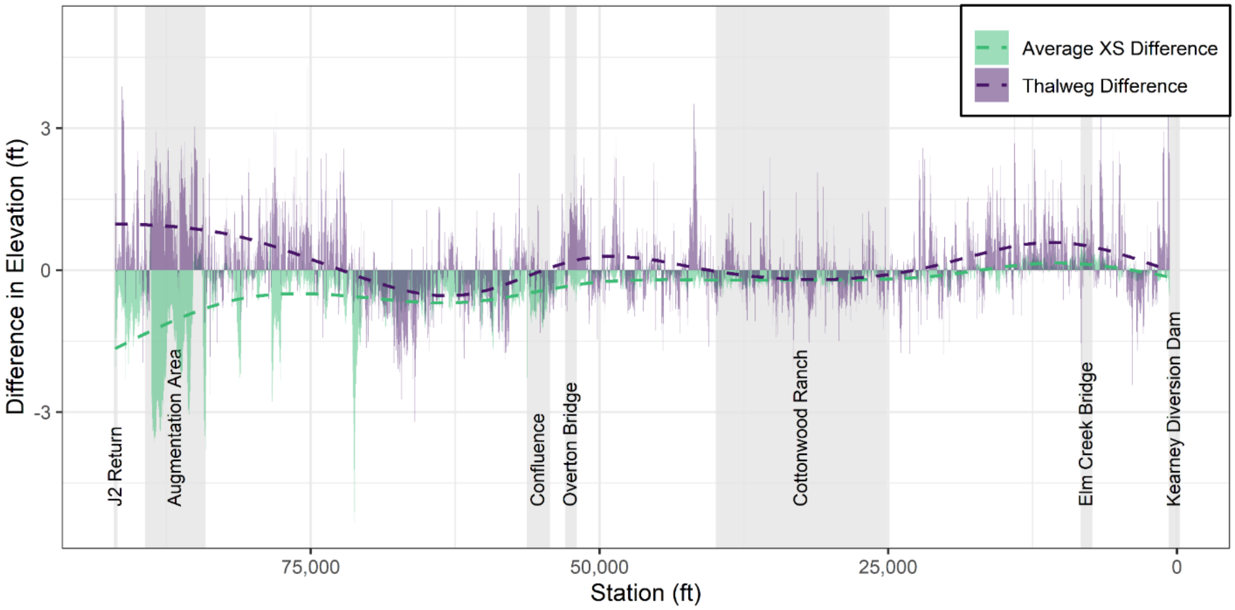

Figure 3.12. Differences in thalweg and average cross-sectional elevation from 2016 to 2021. A line depicting general trends was estimated with a generalized additive model.

3.6 *Wetted Width*

As discussed previously, a portion of the J2 Return Channel transitioned from a historically wide braided planform to a narrow wandering planform over several decades after the J2 Return began operations in the 1940s. Evaluating spatial and temporal trends in wetted width, or the width of channel inundated by water during a reference flow, provides clues about the progression of incision and narrowing in the J2 Return Channel as well as potential effects of sediment augmentation.

3.6.1 Methods

Analyses of wetted widths are necessarily tied to one or more reference flows. For this analysis, we used a flow of 2,000 cfs to remain consistent with ongoing system-scale monitoring efforts (PRRIP EDO, 2022a). In general, 2,000 cfs is the approximate flow in the J2 Return Channel when the return is operating at full capacity.[13] Downstream of Overton, a flow of 2,000 cfs was chosen for system-scale analyses of wetted width as it is sufficient to inundate bedforms and fill the entire channel without overtopping banks.

Wetted widths prior to and during the augmentation experiment were modeled using a combination of one-dimensional (1D) and two-dimensional (2D) hydraulic models of the study area. Wetted widths in 2009 and 2012 were modeled in 1D HEC-RAS at 78 cross-sections (PRRIP 2022a, HEC-RAS 2008) spaced an average of 1,165 ft apart through the study area. These models pre-dated topo-bathymetric LiDAR and relied on a combination of terrestrial LiDAR and supplemental field surveys. Once topo-bathymetric LiDAR were available in 2016, the Program shifted to annual two-dimensional hydraulic modeling using the Bureau of Reclamation SRH-2D modeling platform (Lai 2008) See Section D.3 for further discussion of hydraulic models, calibration, and validation. To provide for a direct comparison of HEC-RAS and SRH-2D wetted widths, we clipped HEC-RAS cross station lines to SRH-2D water surface polygons (2016, 2017, 2021) which allowed us to report 2D wetted widths at 1D cross section locations. Statistical tests of differences between mean width in three reaches (augmentation area, J2 Return Channel, and downstream of Overton) were completed with the emmeans package in R version 4.2.2 (Lenth 2023).

3.6.2 Results

The results of the wetted width analysis can be viewed as a continuum from upstream to downstream (Figure 3.13) or broken into three reaches and averaged (Table 3.3). The first reach is from the J2 Return to the downstream boundary of the augmentation area. This is the reach in which the channel was mechanically widened by bulldozing terraces and spreading the terrace sediment over the channel bed. Because of augmentation activities, widths in this reach increased dramatically in 2017, the first year of sediment augmentation. The second reach extends from the downstream boundary of the augmentation area to the Overton Bridge. This reach shows year-to-year width variations, but on average no progressive widening or narrowing (Table 3.3). In this reach, Tukey-adjusted pairwise comparisons of mean width between years do not reveal significant change in sequential years but do detect a significant difference between 2009 and 2016 wetted widths, with 2009 having higher width on average in the J2 Return Channel between stations 84,000 and 55,000 (mean difference 120 ft, $p<0.025$ at the 95% confidence level). Pre-2016 widths are derived from a 1D model while post-2016 widths are derived from a 2D model. While this inconsistency should not obfuscate large changes, it precludes fine-scale analysis of year-to-year variation. Downstream of the Overton Bridge, the channel receives water inputs from both the J2 Return Channel and the North Channel, making it subject to natural high flow events in a way that the J2 Return Channel is not. A high flow event in 2015 had a large morphological impact on the reach downstream of Overton including substantial bank erosion (Figure 3.14). The result of this event can be seen in the 50% increase in width from 2012 to 2016 below the confluence. This increase in width was maintained with additional slight increases during the sediment augmentation experiment. These width increases had a positive impact on Whooping Crane habitat.

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[13] J2 Return flow of approximately 1,800 cfs and an additional 200 cfs of groundwater return flows.

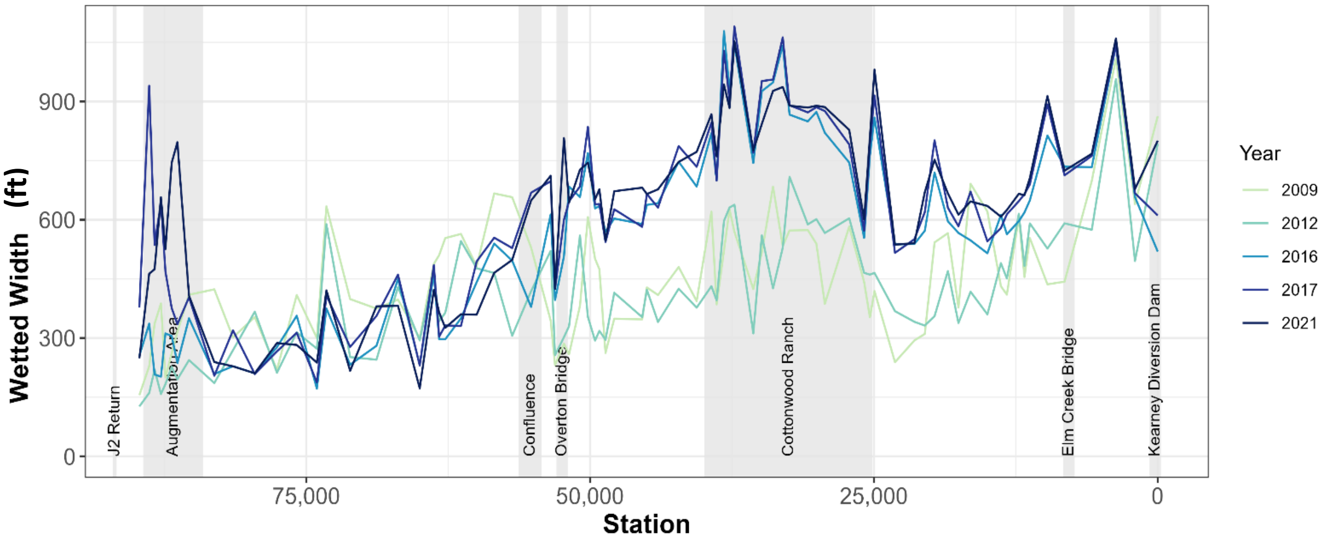

Figure 3.13 Wetted width at HEC-RAS cross-sections in 2009–2021 at a flow of 2,000 cfs. Widening due to augmentation (2017, 2021) is visible upstream of the Augmentation Boundary and widening due to the 2015 flood visible downstream of Overton Bridge.

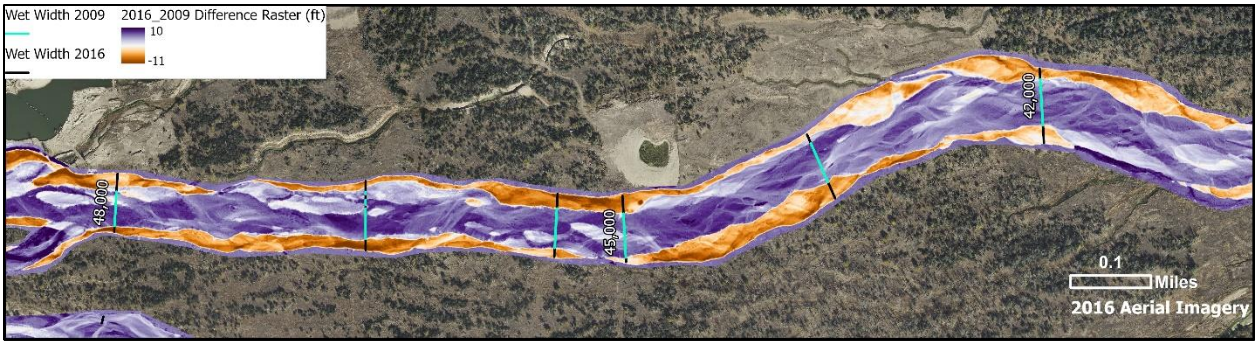

Figure 3.14 Significant channel widening is evidenced in the 2016 to 2009 difference raster by the regular pattern of erosion (orange) along channel banks between stations 48,000 and 42,000. This pattern begins at the confluence of the J2 Return and North Channels and continues to Elm Creek Bridge. Year by year comparison of LiDAR data indicates that the majority of the widening occurred in 2015.

Table 3.3 Mean wetted width and standard deviation (SD) in three reaches, measured at 78 HEC-RAS cross-section locations. Augmentation beginning in 2017 increased width in Reach 1. Flooding in 2015 caused Reach 3 to widen between 2012 and 2016.

	Reach 1 J2 to Augmentation Boundary		**Reach 2 Augmentation Boundary to Overton**		**Reach 3 Overton to KCD**	
Year	**Mean (ft)**	**SD (ft)**	**Mean (ft)**	**SD (ft)**	**Mean (ft)**	**SD (ft)**
2009	290	90	440	130	490	150
2012	190	40	360	120	480	140
2016	280	60	350	120	720	160
2017	510	200	380	150	740	150
2021	540	180	360	140	760	130

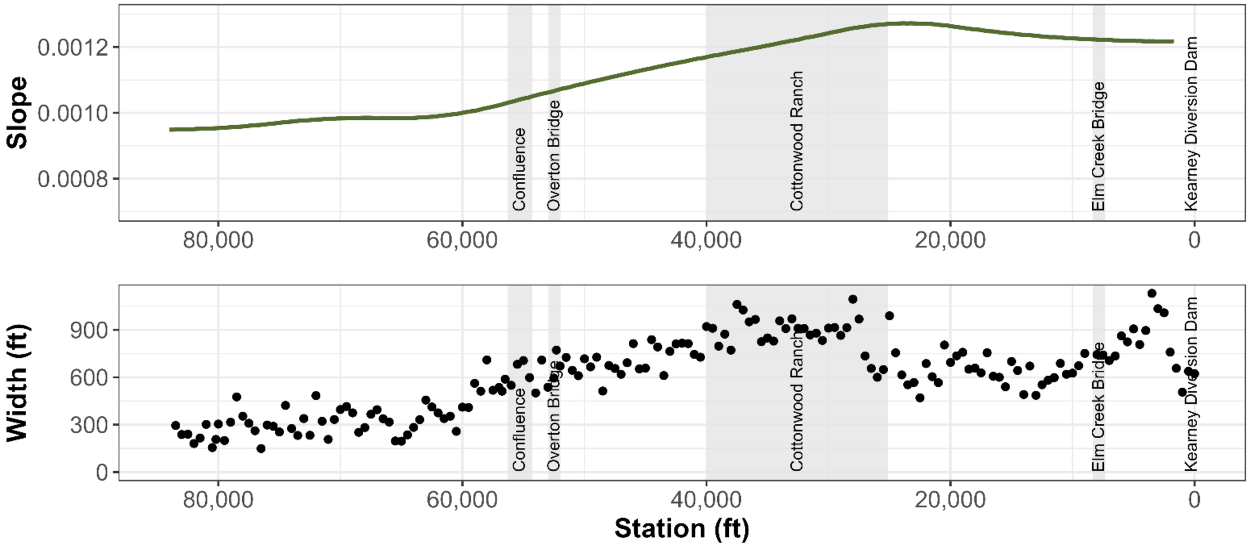

Figure 3.15. 2021 channel slope of the GAMM-modeled thalweg (top) and wetted width at 2,000 cfs (bottom). Width and slope increase together between Station 60,000 and 30,000.

We compared 2021 wetted width with channel slope to examine slope-width relationships in the study area (Figure 3.15). To reduce noise in our slope data, we used a Generalized Additive Mixed Model (GAMM) with a sampling distance of 100 ft to fit a line to the thalweg profile and calculated slope with a moving window. In 2021, there is an upward inflection in both slope and wetted width near Station 60,000. Between Station 60,000 and 30,000, both width and slope appear to increase together. Below Station 30,000, both width and slope decrease. However, width decreases more substantially than slope. This mirrored pattern suggests links between slope and width behavior; however, we acknowledge that many other variables such as flow and sediment supply are likely impacting these characteristics.

3.7 Sinuosity of the J2 Return Channel

Similar to wetted width, evaluating spatial and temporal trends in sinuosity provides clues about the progression of incision and narrowing in the J2 Return Channel as well as potential effects of sediment augmentation.

3.7.1 Methods

We analyzed pre-augmentation changes in channel sinuosity in the J2 Return Channel between 1969 and 2016 using hand-delineated channel thalwegs from aerial imagery (see Chapter 2). For the analysis of post-augmentation sinuosity, we used geoprocessing techniques described in Section 2.3.1 to delineate thalwegs from topo-bathymetric LiDAR. These lines were then smoothed in ArcGIS Pro version 3.0.3 using polynomial approximation with an exponential kernel smoothing algorithm and a tolerance of 300 ft. We compared the smoothed LiDAR-derived thalwegs to hand-delineations for overlapping years and found results to be similar, although hand-delineations yielded a higher average sinuosity by 0.01. Therefore, we plot and interpret sinuosity derived from both methods together.

3.7.2 Results

Sinuosity results are presented in Figure 3.16. Prior to initiation of sediment augmentation, sinuosity of the J2 Return Channel had increased steadily, though with low magnitude, since the early 2000s. Sinuosity declined in 2017 due to the construction of a meander cutoff immediately below the J2 Return (see Chapter 1). The cutoff rerouted the channel to avoid erosion of private property and straightened the alignment of the channel, decreasing length by about 1,300 ft. After 2017, sinuosity continued to increase throughout the duration of the augmentation management experiment. This is due to the continued development of meanders in the wandering segment of channel. The increase in sinuosity of the J2 Return Channel is not dramatic but the pattern shows a consistent increase in recent decades that is evidence for the onset and development of the observed changes in channel pattern. While sinuosity is not high enough to signify the existence of a clear and consistent transition to meandering, the trend in sinuosity increase supports visual analysis that this transition has begun and could continue.

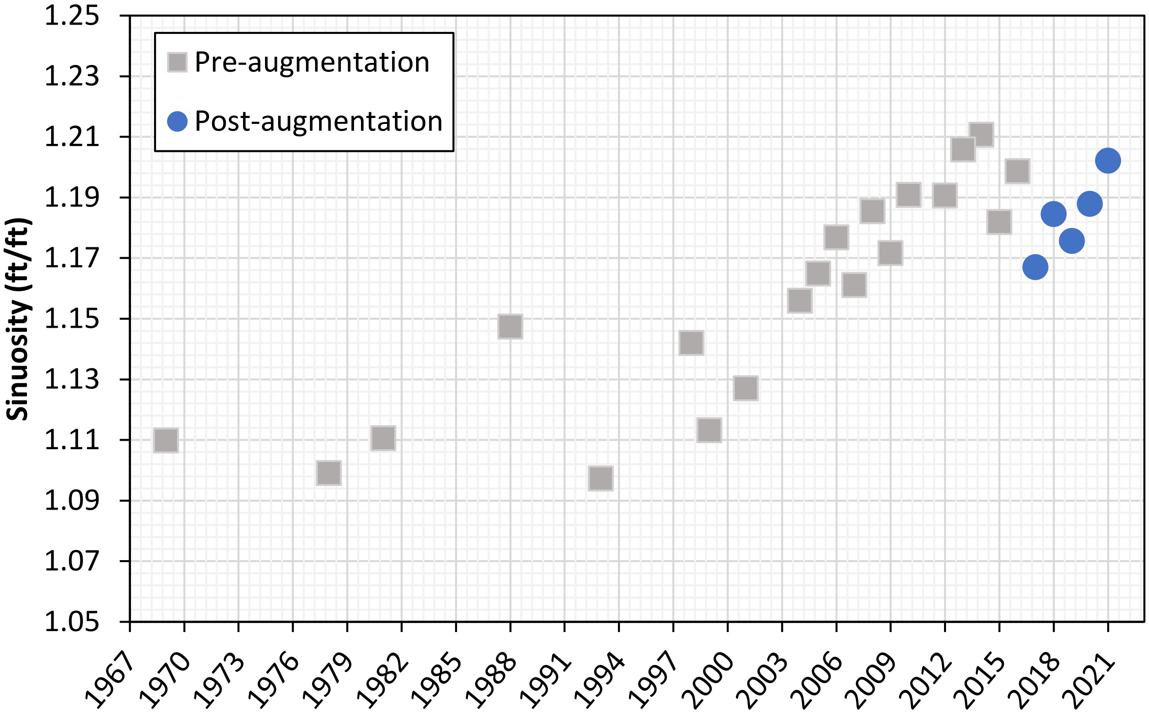

Figure 3.16 Ratio of thalweg to straight-line length (sinuosity) in the J2 Return Channel between 1969 and 2021. Figure shows a trend in increasing sinuosity beginning in the early 2000s. Sinuosity declined in 2017 due to the construction of a meander cutoff as part of augmentation operations. Despite the cutoff, the trend of increasing sinuosity continued during the augmentation experiment.

3.8 Focused analysis of incision in the vicinity of Station 70,000

We identified a reach of river extending from Station 72,000 to 65,000 that required deeper investigation due to higher magnitude of change relative to other river segments. The reach is referred to as Reach 70,000 due to its proximity to River Station 70,000. In addition to a more detailed evaluation of prior analyses, we measured six channel cross sections from LiDAR data in this reach to provide a cross-sectional view of channel change during the augmentation experiment.

A detailed plot of 2016 and 2021 longitudinal profiles of the thalweg, 1,005 ft centered moving average thalweg elevations, and GAMM-predicted thalweg elevations (see section 3.6.2) is presented in Figure 3.17 with planview alignments presented as a reference in Figure 3.18. Comparison of the profiles indicates at-a-station change was highly variable with the highest magnitude of incision near Station 71,000 at the apex of a meander. Overall, the modeled thalweg profiles indicate significant incision of the thalweg beginning at Station 73,000 and ending at approximately Station 57,000. Within this reach the maximum magnitude of modeled thalweg incision (> 2 ft) occurred in the vicinity of Station 70,000.

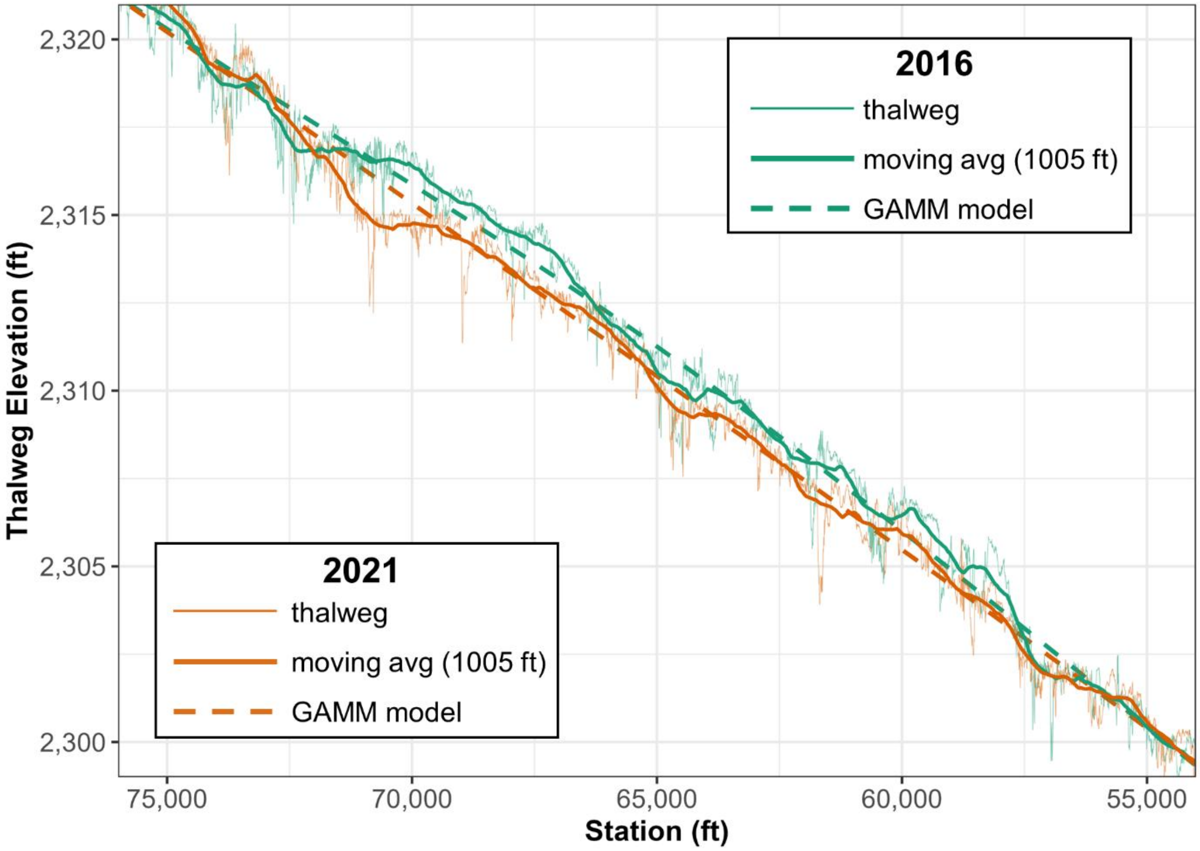

Figure 3.17. Longitudinal thalweg profiles and thalweg models (GAMMs) for 2016 and 2021 between Station 75,000 and 55,000.

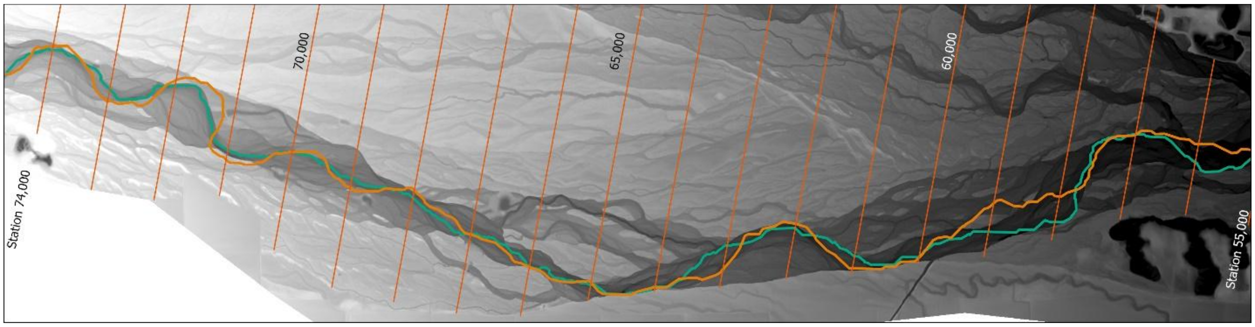

Figure 3.18. Planview of thalweg alignments in 2016 (green) and 2021 (orange) between station 74,000 and 55,000.

Annotated Reach 70,000 REMs for 2016 and 2021 are presented in Figure 3.19. The REMs indicate intensification of the existing meander and formation of a new meander just downstream of Station 70,000. Incision is apparent in the downstream extension of the eight ft and ten ft REM classes between 2016 and 2021. Figure 3.20 provides the location of cross sections between Station 71,580 and 68,940 within 2016 and 2021 aerial imagery.

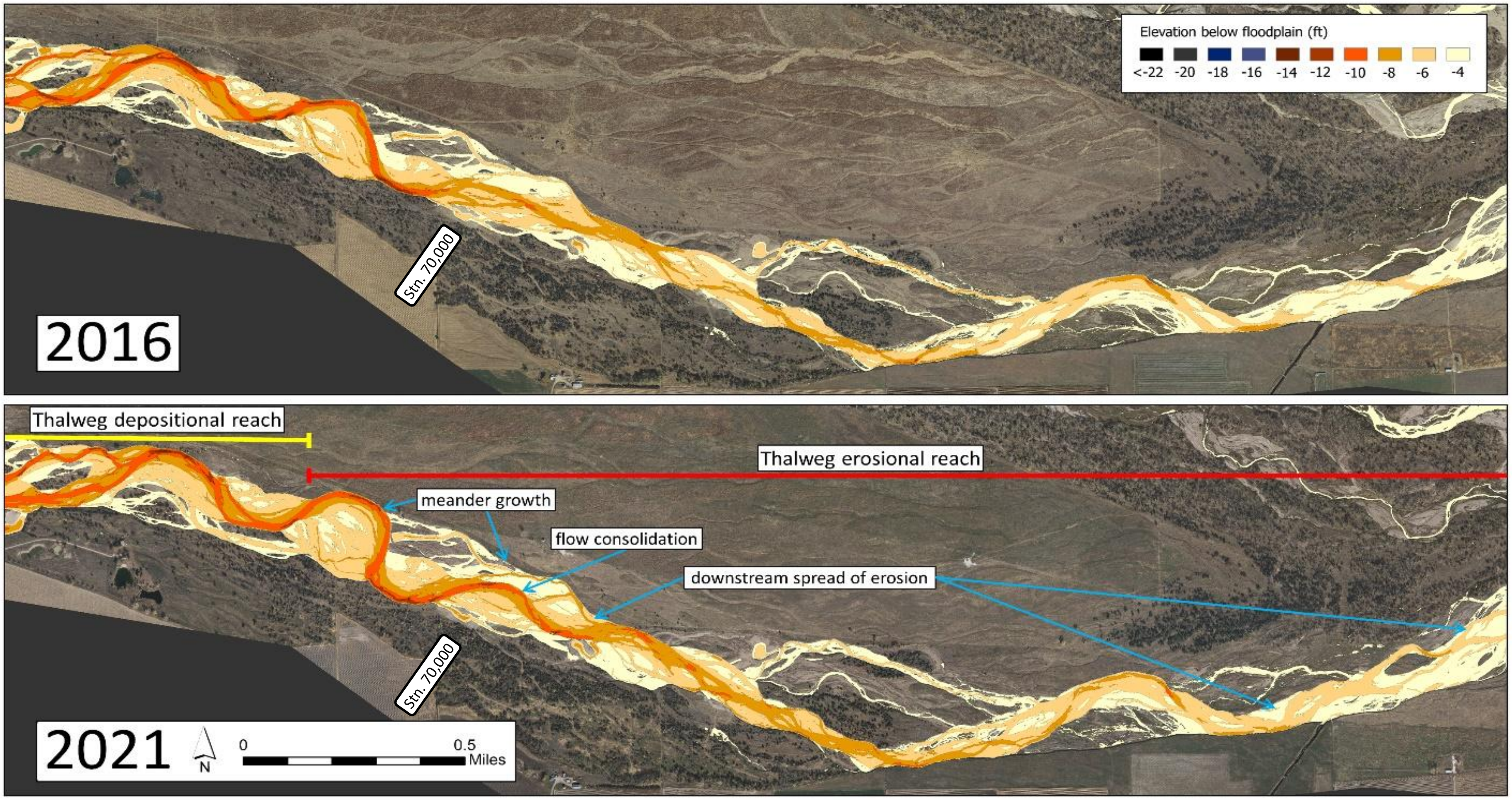

Figure 3.19. Annotated relative elevation models (REMs) of the downstream section of J2 Return Channel ending at Station 58,000. The relative elevation model is contoured into 2 ft intervals below -4 ft relative to the floodplain. Blue arrows in the bottom panel highlight changes since sediment augmentation. Yellow and red lines indicate regions of erosion and deposition detected by changepoint analysis.

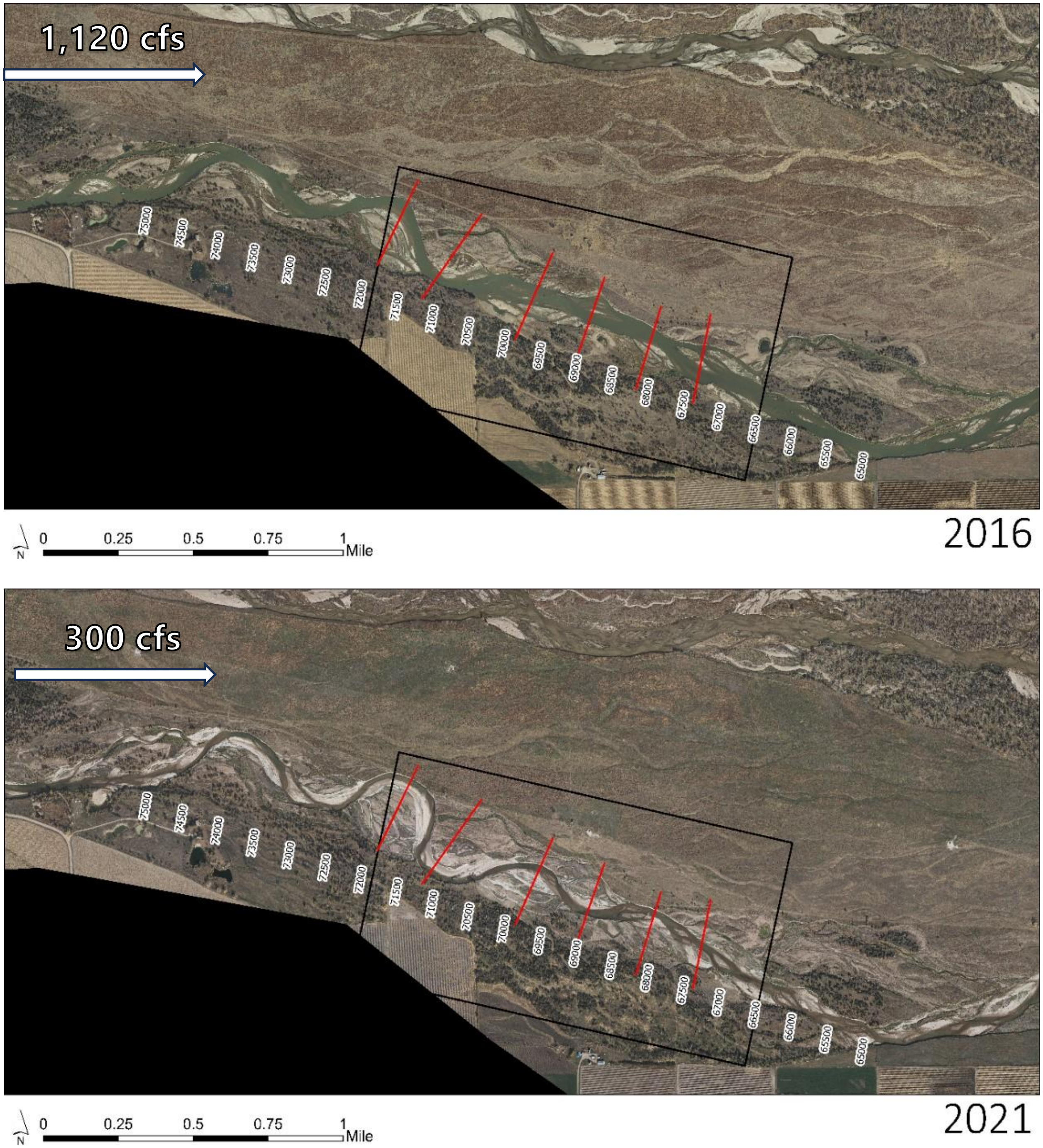

Figure 3.20. Aerial imagery of Reach 70,000 in 2016 (top) and 2021 (bottom). A black rectangle extends from Station 71,835 to Station 66,435 and delineates the reach with the most change. Cross section locations are noted in red.

LiDAR-derived transect plots for the six cross sections between Station 71,580 and 68,940 are provided in Figure 3.21. All cross sections show some degree of lateral erosion between 2016 and 2021. This is most apparent at Station 71,580, 71,070, 68,940 and 68,050 transects which are all located at or near the apices of developing meanders. In terms of thalweg incision, the three most upstream cross sections experienced the highest magnitudes of incision in 2019 with some thalweg infilling in subsequent years. The three downstream cross sections did not experience thalweg infilling after 2019. Change in channel geometry at the furthest downstream cross section (67,355) indicates a planform shift at that location in 2019 with the development of an incised low flow channel near the midpoint of the cross section that persisted through 2021.

Figure 3.21. Cross sections viewed from river left to right, looking in the downstream direction at 6 locations in Reach 70,000 of the J2 Return Channel.

Sinuosity in Reach 70,000, calculated as thalweg length within the black rectangle in Figure 3.19, increased from 2016 to 2021 (Figure 3.22a). This is evident in REMs and aerial imagery as

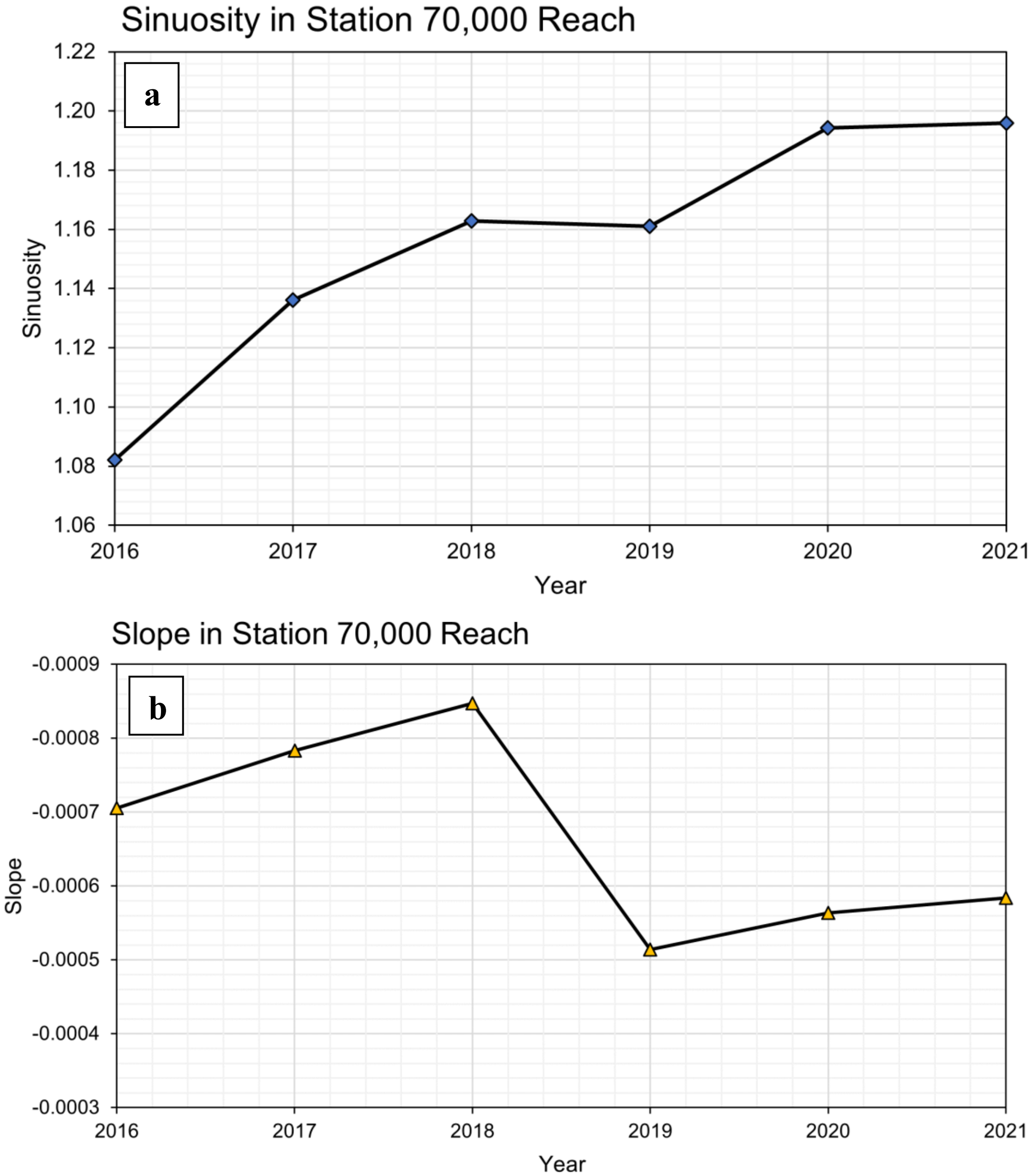

Figure 3.22. (a) Sinuosity of Reach 70,000, measured in the area delineated by the black rectangle in Figure 3.20. Sinuosity is the ratio of along-channel distance to straight line distance. (b) Slope of reach 70,000, measured as the slope of a linear regression between elevation and along-thalweg distance within the black rectangle in Figure 3.20.

meanders expanded during this period (Figures 3.19–3.20). Over the same period, channel slope decreased in this area due to events in 2019, although slight increases occurred before and after 2019 (Figure 3.22b).

This area is evolving and appears to have been the focal point of incision and planform change in the J2 Return Channel during the sediment augmentation experiment. The pace of this migration should be monitored, especially in absence of sediment augmentation, to evaluate how the channel continues to evolve.

3.9 Discussion

To evaluate sediment augmentation effectiveness since sediment augmentation began below the J2 Return, we examined longitudinal change starting in 2016, the year immediately prior to sediment augmentation. Analyses extended through 2021 to incorporate the first five years of the sediment augmentation management experiment. Using results from relative elevation to the floodplain, thalweg elevation, average cross-sectional elevation, and channel geometry, we found evidence of an aggradational augmentation response in the upper portion of the J2 Return Channel. The lower portion of the J2 Return Channel degraded during augmentation, especially as a result of high flows in 2019. Downstream of Overton Bridge, minor aggradation and degradation was observed at much smaller magnitudes than in the J2 Return Channel.

Upstream of Station 70,000 (the first 2.3 miles below sediment augmentation), the channel elevation increased. Sediment inputs during this time formed bars, decreased pool depths, and generally aggraded the channel. Though low magnitude when averaged through the reach, this gain in elevation could be partially attributed to sediment augmentation efforts, with some additional sediment inputs from the breakthrough channel prior to 2019. The breakthrough channel is described in D.2 and discussed further in Chapter 4.

Moving downstream of the aggradational reach within the J2 Return Channel, the remaining length of the reach upstream of the North Channel confluence continued to degrade during the first few years of the sediment augmentation experiment. Thalweg and average cross-sectional elevation decreased, and the reach surrounding Station 70,000 experienced the most negative change. Within this reach, meanders grew and migrated downstream. Although already incising, the reach experienced a large magnitude incisional event in 2019. Since 2019, when high flows occurred and the breakthrough channel berm was repaired (Section D.2), bed elevations in this reach have been stable though sinuosity has continued to increase.

Annual changes to thalweg planform patterns depict many areas along the J2 Return Channel where meanders are actively evolving as concentrated flows cut into unconsolidated banks (Figure 3.5). This lateral migration recruits additional sediment to the channel and is therefore not considered a negative outcome, but increased lateral migration can result in lowered channel slope, which in turn may affect planform. In the remaining braided section of the J2 Return Channel, both width and slope increase steadily in the downstream direction but have not changed much in the past five years. As meanders continue to expand and add channel length in this vicinity, slope is expected to decrease and planform transition will continue shifting further downstream. It is possible that upstream portions of the J2 Return Channel have adjusted to a relatively constant slope that yields a consistent wandering planform and may not evolve further under the current discharge and sediment regime. However, without sediment augmentation or regular contributions from the breakthrough channel, the previously adjusted channel length is subject to additional change.

Changes downstream of Overton Bridge were generally subtle and lower magnitude than changes within the J2 Return Channel. Some bars dissipated during the study period. This change could be attributed to low magnitude degradation and management actions (e.g. vegetation disking in 2018) between 2016 and 2021. Generally, the reach downstream of Overton retained high wetted widths since 2015 with little to no detectable change in channel elevations and geometry. The channel is aggrading upstream of Elm Creek Bridge. This aggradation is potentially associated with the buildup of sediment upstream of the constriction at Elm Creek Bridge and behind KCD.

The J2 Return Channel, especially Reach 70,000, is sensitive to high flows and experienced overall average loss in elevation during the three highest flow years within the study period (2016–2017, 2018–2019, and 2019–2020; Table 3.2; Section D.2). During the two drier years (2017–2018 and 2020–2021), elevation gained on average in the J2 Return Channel. During all years measured, reach-averaged losses and gains have opposite signs in the J2 Return Channel versus downstream of Overton Bridge, i.e., when the J2 Return Channel experiences elevation loss, the channel downstream of Overton experiences elevation gain. Losses versus gains relative to flow magnitudes are reversed within the reach downstream of Overton Bridge. During lower flow years, the channel degraded downstream of Overton, and during high flow years the channel aggraded (Table 3.2). This behavior may assist future assessment of the general fate of augmented sediment. We hypothesize that during dry years, more augmented sediment remains within the J2 Return Channel, and during wet years more sediment (both augmented and stored) is transported downstream of Overton. Because the system upstream of Overton Bridge continues to receive insufficient sediment supply for sediment balance, high sediment transport years lead to channel degradation and threat of planform migration downstream within the J2 Return Channel. Though incision may be present in the J2 Return Channel during years with high flow, high transport years also yield important sediment inputs to downstream habitat. We will continue to evaluate this hypothesis as we collect more years of data on the system

A primary goal of sediment augmentation is to halt downstream progression of incision and narrowing. The transition from wandering to braided planform is roughly 3 miles upstream of Overton Bridge (see E.2 for our definition of these planform types). Here, our evaluation of channel planform and cross-sections indicated that the downstream end of the wandering planform reach migrated roughly 2,000 ft downstream during the augmentation experiment. This length estimate of channel planform migration over 5 years, and the approximate distance of 3 miles downstream to Overton Bridge, indicate that a wandering planform could migrate to the Overton Bridge on the order of 40 years. Though this estimate is general, it implies that the timescale for complete planform transition of the J2 Return Channel is decadal. Incision and planform change are measurable threats to habitat downstream of the Overton Bridge, but the confluence with the North Channel provides significant sediment inputs which are not quantified in this study. Analogous to sediment inputs from tributary confluences (Benda et al., 2004), water and sediment inputs from the North Channel offset some of the risk associated with incision caused by the J2 Return. Thus, related channel changes downstream of the confluence are likely to occur at a slower pace than within the J2 Return Channel.

Future analyses to advance our understanding of channel behavior downstream of the J2 Return include more detailed analysis of changes in channel width and slope, quantification of lateral migration of the channel thalweg, and statistical or morphodynamic models to relate channel response to sediment supply and flow. There are limitations to examining change with one metric at a time longitudinally. For example, confining analysis of change within the channel thalweg leads to continued uncertainty regarding the active channel and floodplain outside of the deepest portion of the channel and omits information about overbank deposition and secondary flow paths. Thus, we extend our analyses in the following chapter with examination of volume change to quantify sediment erosion and deposition within the study reach.

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CHAPTER 4 Volume change analysis

4.1 *Abstract*

We used topo-bathymetric elevation data to calculate volumes of sediment that deposited or eroded between the Johnson No. 2 Hydropower Return (J2 Return) and the Kearney Canal Diversion (KCD). Using hydraulic modeling results, we separated lateral erosion from bed aggradation and degradation. We found that the study reach became less degradational in years since sediment augmentation began. Bed erosion has decreased 45% to 60% upstream of Overton Bridge. Our data indicate that a combination of hydrology, natural sediment sources, and augmented sediment have played a role in this reduction.

4.2 *Introduction*

As discussed in Chapter 1, the Platte River Recovery Implementation Program (PRRIP or Program) attempted to estimate the sediment deficit in the Program's Associated Habitat Reach (AHR) created by the J2 Return structure using various measured and theoretical sediment transport functions that tie transport to flow. The estimated deficit ranged from 50,000 tons per year (35,000 yd^3/yr) between Overton Bridge and Kearney (Tetra Tech, 2017), to a 109,000 tons per year (73,000 yd^3/yr) deficit between Overton and Elm Creek (The Flatwater Group, Inc, 2010). The 2017 estimate is less than half that of the 2010 estimate, despite covering a longer stretch of river with no major sediment sources. This disparity underlines the uncertainty and difficulty in comparing theoretical and field sediment data.

The Program began a full-scale sediment augmentation management experiment in 2017 with the purpose of offsetting the deficit and assessing effectiveness of augmentation in stabilizing the J2 Return Channel. Specifically, the Program began to augment 60,000–80,000 tons (40,000 – 60,000 yd^3) of sediment immediately downstream of the J2 Return each year. Effectiveness is assessed using Light Detection and Ranging (LiDAR) topographic data and hydraulic modeling data to measure actual volumetric change in our study area. This application of the morphological method (Ashmore and Church, 1998; Anderson, 2019; Vericat, et al., 2017), makes the most of our high-resolution LiDAR data to calculate change under known (or mostly known) circumstances.

Chapter 3 focuses on evaluation of longitudinal change in channel morphology during full-scale augmentation operations. Two of the primary limitations of that effort were 1) inability to quantify sediment flux through the study area and 2) lack of differentiation between lateral and bed erosion. Lateral erosion is sediment removal from banks and islands due to horizontal stress, while bed erosion is sediment removal from the riverbed due to vertical stress. Lateral erosion is a natural result of channel migration or width adjustment due to increased flow. With lateral erosion, sediment that was previously stored in the bank is added to the system. This sediment is incorporated into downstream bars and may reduce downstream deficits. In this way, lateral erosion is fundamentally different from bed erosion which signals channel deepening and further disconnection from the floodplain.

In this chapter, we expand LiDAR-derived longitudinal analysis into three-dimensional estimates of annual volume change during the sediment augmentation experiment that differentiate between bed and lateral erosion. To increase the utility of our findings, we also expanded the analysis to include the years of 2009–2016 prior to augmentation activities. During that period, the Program collected topographic bare earth LiDAR. From 2016 to present, bathymetric LiDAR has been collected. Topo-bathymetric LiDAR penetrates the water surface and returns highly accurate estimations of the river bottom. Lack of bathymetry prior to 2016 adds uncertainty to volume change estimates, which is described in more detail below. Throughout this chapter, volume change estimates for 2009–2016 are referred to as Pre-Augmentation. Annual estimates during the augmentation experiment are referred to as Post-Augmentation.

Table 4.1 shows the amount of sediment that was made available for transport via augmentation in each year. The volume for 2017 is lower than other years because some excavated sediment was used to restore eroded cropland and construct a berm to arrest lateral erosion that was threatening a home along the south bank. Volumes were calculated using LiDAR differencing methods described in the following section of this chapter.

In years when the breakthrough channel was active, large amounts of sediment were also eroded and transported into J2 Return Channel in approximately the same location as the mechanical augmentation. The volume of sediment contributed via the breakthrough channel was calculated using the same method of analyzing difference rasters that was used across the entire study reach (see Section 4.3.2). Prior to annual topo-bathymetric data collection beginning in 2016, volume change below water surface is calculated as a range of values (Section 4.3.2). Prior to augmentation, the only known source of sediment to the J2 Return Channel was the breakthrough channel which contributed an annual average of 32,800–33,500 yd^3 between 2009 and 2016 (Table 4.1, Figure 4.1). Years in which augmentation and breakthrough channel activation both occurred had the highest sediment inputs, with a maximum of 104,000 yd^3 in the 2017–2018 year.

Table 4.1 Sediment added to the J2 Return Channel.

	Breakthrough Channel Volume (yd^3)	Augmented Volume (yd^3)	Total (yd^3)
2009 – 2016	262,000–268,300	0	262,000–268,300
2016 – 2017	71,600	23,000	94,600
2017 – 2018	61,100	42,900	104,000
2018 – 2019	19,900	42,300	62,200
2019 – 2020	0	57,700	57,700
2020 – 2021	0	51,300	51,300

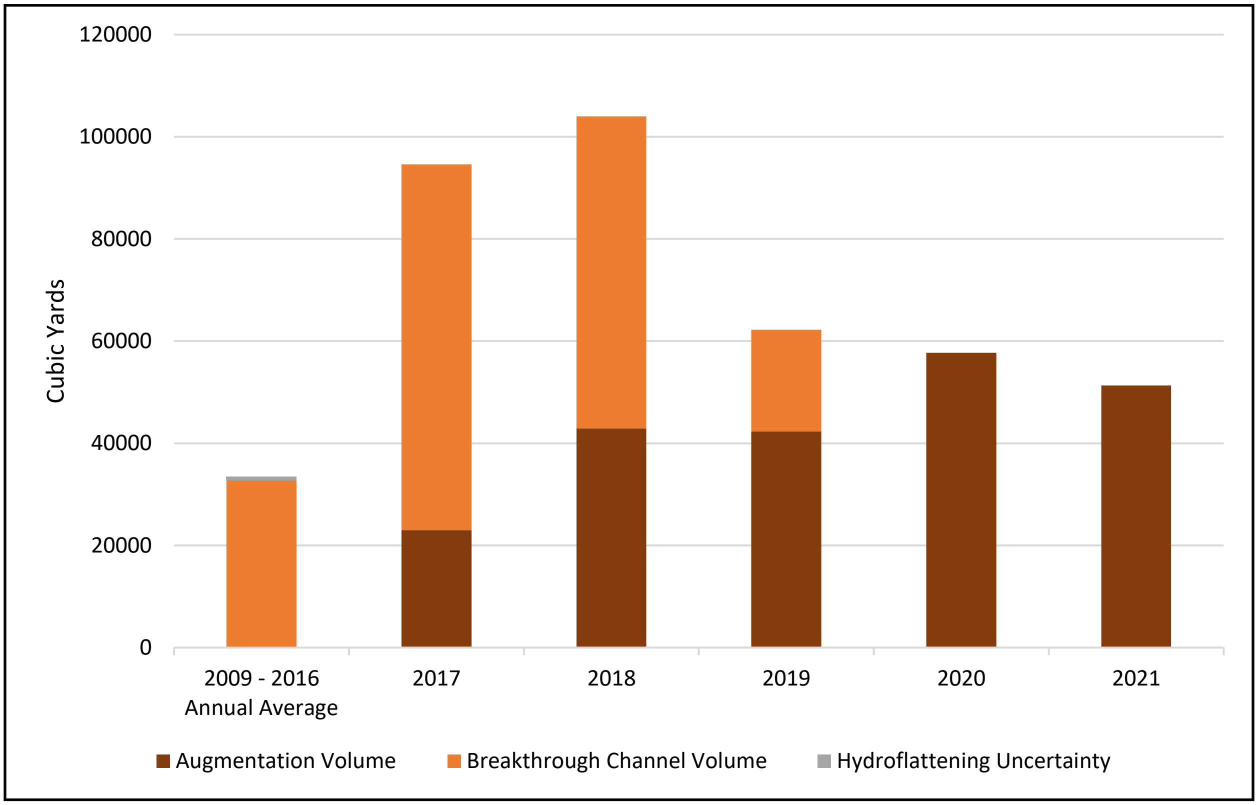

Figure 4.1 Sediment added to the J2 Return Channel downstream of the return through erosion in the breakthrough channel (orange) and sediment augmentation (brown).

4.3 *Methods*

4.3.1 Volume change (LiDAR raster differencing)

Annual volume change estimates were developed via LiDAR raster differencing. We created annual difference elevation rasters by subtracting the earlier year from the more recent year. We then clipped the difference rasters to the active channel (Figure 4.2; Appendix A) to remove dry floodplain areas that were not altered by flow. Removing these areas improved our accuracy because we found non-random error in LiDAR data for many floodplain areas due to year-to-year changes in vegetation. The active channel clip area was based on the hydraulic modeling results (see Section D.3) that identified the active flow conveyance area. These areas were then manually widened in places to include areas of bank failure that were not wet. The hydraulic model results represented an approximate bankfull discharge of 2,500 cfs in the J2 Return Channel and 2,500 cfs in the North Channel, resulting in 5,000 cfs in the reach downstream of the confluence. The active channel changes every year, so delineations are unique for each analysis year.

To convert 1D model results to 2D water extent polygons for pre-augmentation years 2009 and 2012, we exported water surface elevation (WSE) data to ArcGIS using HEC-GeoRAS (HEC-RAS, 2008) and created a digital triangulated irregular network (TIN) of the water surface. We then subtracted LiDAR data from the TIN of the modeled WSE, producing a raster of positive depth values where the ground was below the water surface. We then manually removed puddles, abandoned channels, and other low-lying areas that were not hydraulically connected to the river. The full set of differenced rasters and their clipped area extents can be seen in Appendix A.

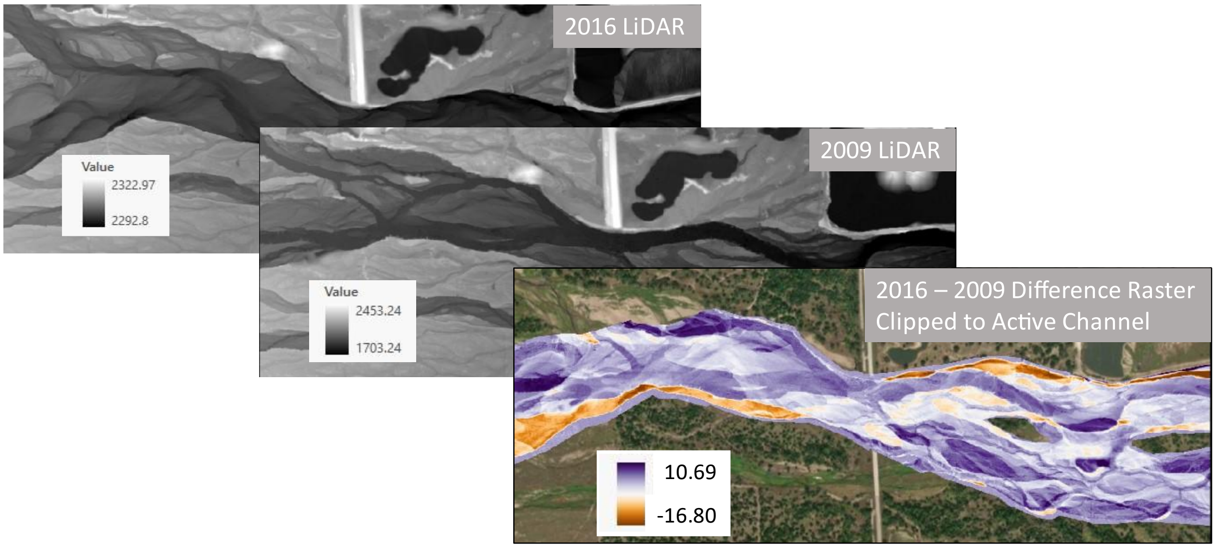

Figure 4.2. Example of raster differencing and clipping to the active channel at the Overton Bridge. 2009 elevations were subtracted from the 2016 elevations, resulting in a raster ranging from 10.69 ft of aggradation (purple) to 16.80 ft of erosion (orange).

In 2009, LiDAR rasters were hydroflattened within the wetted areas so change is presented as a range of possible values based on potential erosion and aggradation below the 2009 water surface. The hydroflattened areas often experienced aggradation as the channel migrated during the intervening years. In the 2016–2009 difference raster, this resulted in a net positive change above the 2009 hydroflattened elevation, meaning that the channel below the 2009 water surface filled in completely with sediment in many places. Based on the 2009 hydraulic model, the average depth of flow on the date of LiDAR collection was one ft. Multiplying this by the hydroflattened area gives a total underwater volume of 156,000 yd^3 in the J2 Return Channel reach. We used this estimate to represent maximum potential aggradation not accounted for during raster subtraction due to missing bathymetry data in the 2009 LiDAR.

We defined lateral erosion as areas that experienced bank erosion or failure due to hydraulic activity. Following this erosion, previously dry areas become accessible to flow. To identify these “newly wet” areas and thus areas of lateral erosion, we converted HEC-RAS and SRH-2D modeled water extents into 3x3 ft WSE raster grids (Figure 4.3A). We then intersected the rasters (2,500 cfs in the J2 Return Channel and 5,000 cfs below the North Channel confluence) and identified cells where water was newly present to create a mask of lateral erosion for each difference raster (Figure 4.3B).

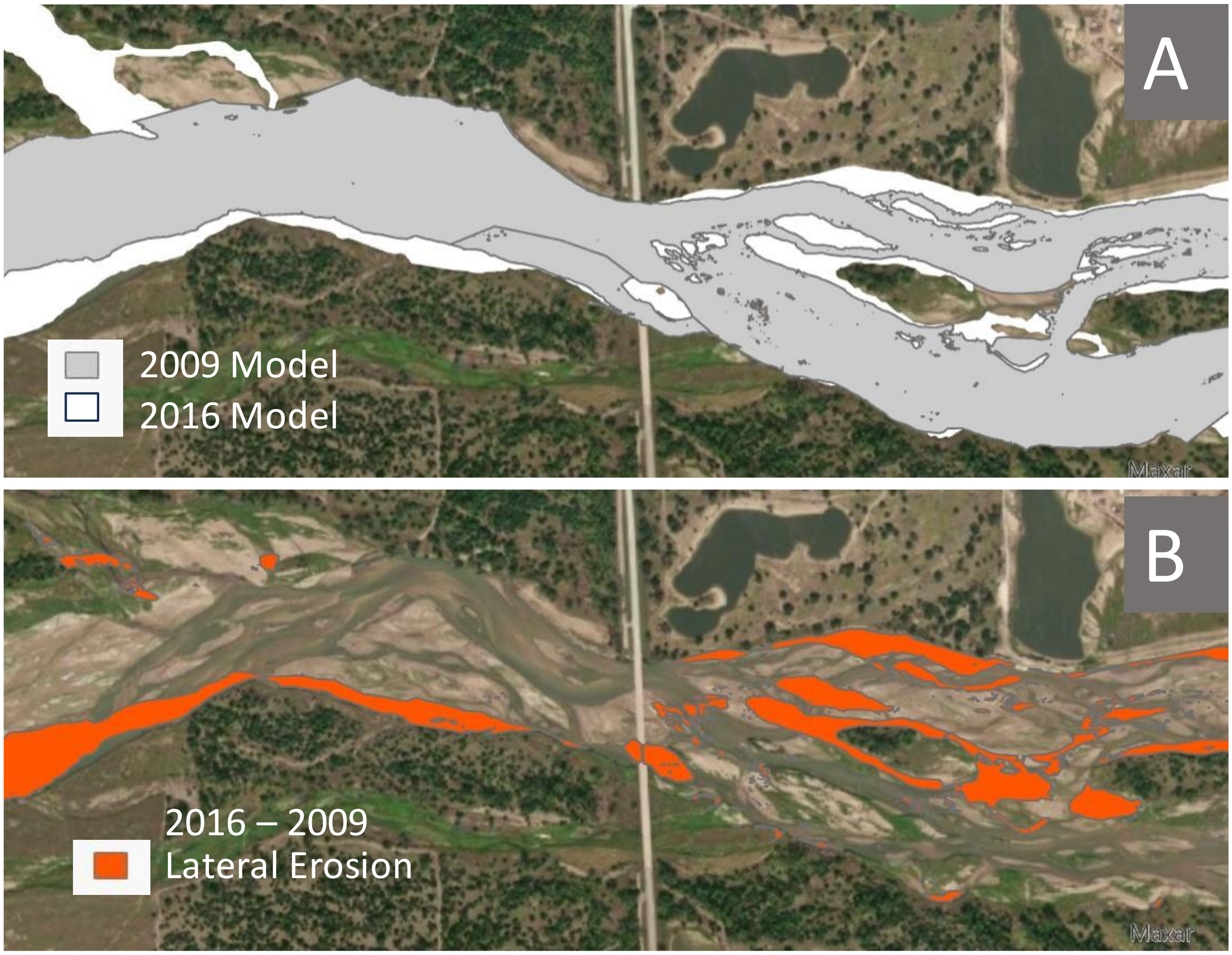

Figure 4.3. Lateral erosion was delineated by differencing hydraulic model results (A) and isolating newly wet areas (B).

Based on results of the System Scale Monitoring Report (PRRIP EDO, 2022b), the average wetted width of the J2 Return Channel is 450 feet. We chose to quantify sediment volume flux from year to year at a resolution of approximately two channel widths (900 feet) along the study reach. To accomplish this, we generated 900-foot-wide rectangles along the channel centerline that encompassed the entire channel. Using these rectangles as regions and values from the difference rasters clipped to the active main channel, we then summarized the data in each region using the ArcGIS Pro Zonal Statistics as Table tool (Figure 4.4). The sum of raster values in each region was multiplied by the area of the difference raster cell (9 ft^2) to compute the change in volume for that region. This sum includes all volume change including lateral erosion. We then used the same process to calculate volume change under the lateral erosion masks. Bed erosion was quantified by subtracting the lateral erosion quantity from the total volume difference for each region.

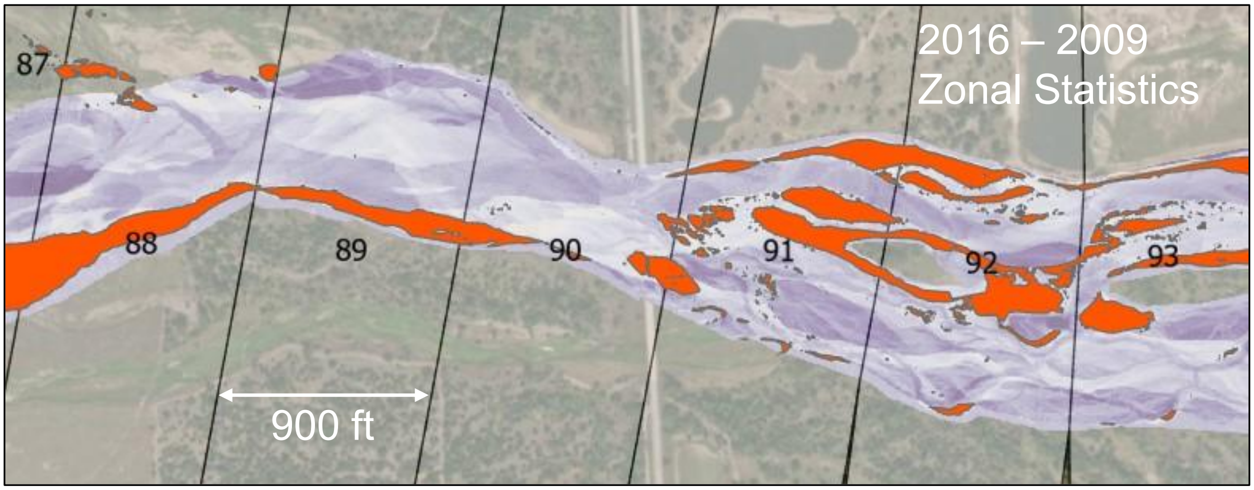

Figure 4.4. Using the zonal statistics tool, elevation differences in each 900-ft wide zone were summed. Zones are bounded in black and numbered 87-93 in this figure. The sums were then converted from ft to ft^3 by multiplying the elevation difference by the raster cell area (9 ft^2). The process was repeated to look only within the lateral erosion mask, shown in orange, to obtain the volume of lateral erosion in each zone.

4.3.2 Flow normalization of volume change

In most instances, volume change is divided by the number of years over which the change occurred. Another method to examine the volume change is to normalize the results by flow rather than year. This type of normalization allows us to control for the exponential relationship between flow and sediment transport, meaning that we can observe results without needing to account separately for wet and dry years. This procedure can only be used for normalization of volume change downstream of Overton Bridge because we do not have a complete set of flow data for the upstream reach due to ungaged flow from the breakthrough channel.

Normalization by flow was calculated by dividing volume change by the q dividend (Equation 4.1). The q dividend is the square of the flow volume that passed through the channel during the time that the volume change occurred. It is calculated by converting the daily mean flow rate to units of cubic yards per day, then squaring this value. Finally, the squared values are summed, and the resulting quantity is in units of $1/yd^3$. Sediment transport capacity is often related to a power function of flow, with common exponents ranging from 1.4 to 2.4 (Julien & Simons, 1985). For the purposes of this analysis, we chose an exponent of 2.0 as recommended by our Independent Science Advisory Committee (ISAC, 2023).

Equation 4.1 $$q\ dividend = \sum Q^2$$

4.4 Results

4.4.1 Pre- and post-augmentation volume change results

To understand the relative influence of sediment augmentation on volume change and sediment flux within the study area, it is helpful to compare data grouped into pre- and post-augmentation time periods. The earliest Program LiDAR data was collected in 2009 and the first augmentation project occurred in the fall of 2017, prior to LiDAR collection. Therefore, our pre-augmentation period spans 2009–2016 and post-augmentation spans 2016–2021. Given the different lengths of these timespans, results have been annualized or normalized by flow for easier comparison.

The net volume change at each station is shown in Figure 4.5, while Figure 4.6 shows the cumulative, or running sum, of volume change beginning at the downstream end of the sediment augmentation area. Figure 4.5A shows that total volume change was primarily negative (degradational) over the full reach for both time periods. Much of this negative change can be attributed to lateral erosion (Figure 4.5B). Sediment augmentation and lateral erosion both produced concentrated signatures in the J2 Return Channel due to mechanical widening and evolving meanders. When lateral erosion is subtracted from total change, the remaining volume can be attributed to changes that occurred in the channel bed (Figure 4.5C). Bed changes were a mix of positive (aggradational) and negative (degradational) across the reach.

In the post-augmentation period, areas of aggradation included the upstream end of the reach to Station 70,000 and downstream near the Elm Creek Bridge. In the pre-augmentation period, the reach upstream of the Overton Bridge was primarily negative, but the uncertainty due to the absence of 2009 bathymetry prevents a clear conclusion on the downstream reach. Viewing net change in relation to channel station is helpful for observing variability and identifying specific areas of interest, however, summing change over a longer reach can give more concise conclusions. Table 4.2 gives the sum of volume changes upstream and downstream of Overton Bridge. Sums in the upstream reach do not include change in the augmentation project area, instead focusing on non-mechanical change downstream of the projects. Figure 4.6 shows the running sum of change over the full area of interest.

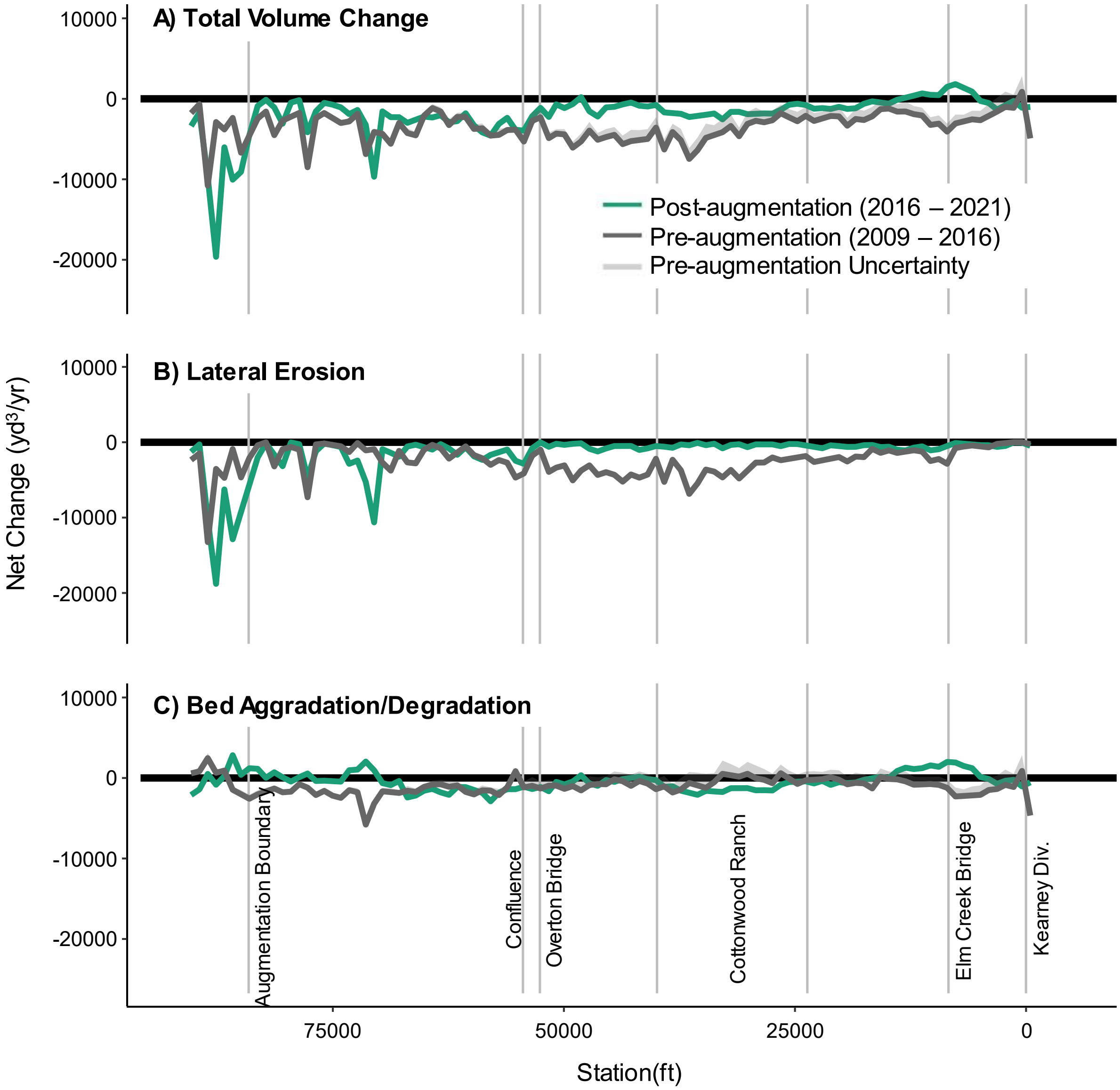

Figure 4.5. Net volume change per year by station. The figure shows the total volume change (A), which is the sum of the lateral erosion (B) and the bed aggradation/degradation (C). Upstream of Overton Bridge lateral erosion was high both pre- and post-augmentation while bed degradation reduced. Downstream of Overton Bridge much less lateral erosion occurred post-augmentation while bed volume change fluctuated around zero during both periods.

Table 4.2. Pre- and post-augmentation volume change broken into two reaches. Negative values indicate net degradation for the reach. Orange cells indicate an increase in degradation from pre- to post-augmentation, while green cells indicate a decrease in degradation.

	Augmentation Boundary to Overton Bridge (yd^3/yr)		Overton Bridge to KCD (yd^3/yr)	
	Pre-Augmentation	Post-Augmentation	Pre-Augmentation	Post-Augmentation
Lateral	-63,000	-65,800	-154,400	-29,600
Bed	-59,700 to -42,000	-23,000	-46,100 to 23,700	-21,500
Total	-122,700 to -105,000	-88,800	-200,400 to -130,700	-51,100

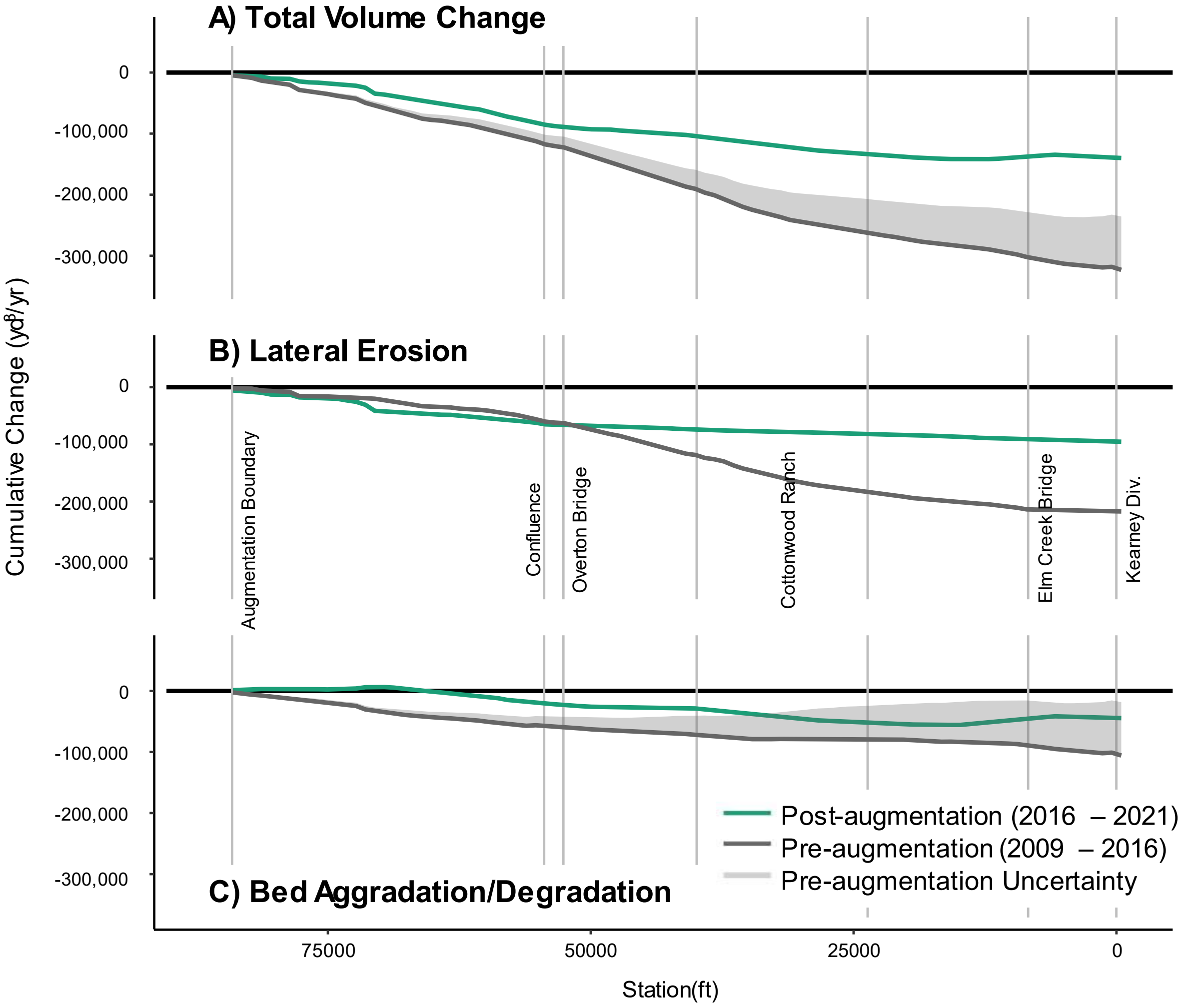

Figure 4.6. Cumulative volume change in the pre- and post-augmentation time periods. Lines represent the running sum of all change starting at the downstream end of augmentation projects. Gray shaded area represents the uncertainty in the pre-augmentation period due to lacking bathymetry data.

While volume change remained negative in the post-augmentation period, Table 4.2 and Figures 4.5 and 4.6 show that this change became less negative compared to pre-augmentation. Upstream of the Overton Bridge, the channel bed was degrading at a rate of 0.8 to 1.1 in/yr, averaged over the total area. After augmentation, this rate decreased to 0.4 in/yr, a decrease of 45% to 60% while lateral erosion had a slight increase of 4%. Downstream of the bridge a large reduction in lateral (80%) and total degradation (61%–75%) was observed. At KCD, total volume change and lateral erosion were lower during the post-augmentation period, while the difference in bed degradation is within the uncertainty for the pre-augmentation period.

4.4.2 Flow-normalized volume change results

Given sediment transport increases nonlinearly with flow, it can be helpful to remove flow variability from the analysis to compare volume change under approximately equal flow conditions. For example, given equal flow, we would expect an unstable reach to change more than a stable one. As will be further discussed in Section 4.4.3, the pre-augmentation period experienced greater flow than the post-augmentation period, and Figure 4.7A shows that the pre-augmentation period also experienced greater total volume change. Figure 4.7B shows that when these results are normalized by flow, the difference between pre- and post-augmentation values shrinks to be within the uncertainty bounds over most of the reach[14]. The contrast between change normalized by flow (Figure 4.7B) and change not normalized by flow (Figure 4.7A) This indicates that flow is a primary factor in the reduction in downstream volume change in the post-augmentation period. This further suggests that the reach has not become more or less prone to erosion with time. It continues to be degradational on average, with the magnitude of degradation varying with flow.

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[14] Note that flow normalized data is only available downstream of Overton Bridge due to incomplete flow data upstream of the bridge.

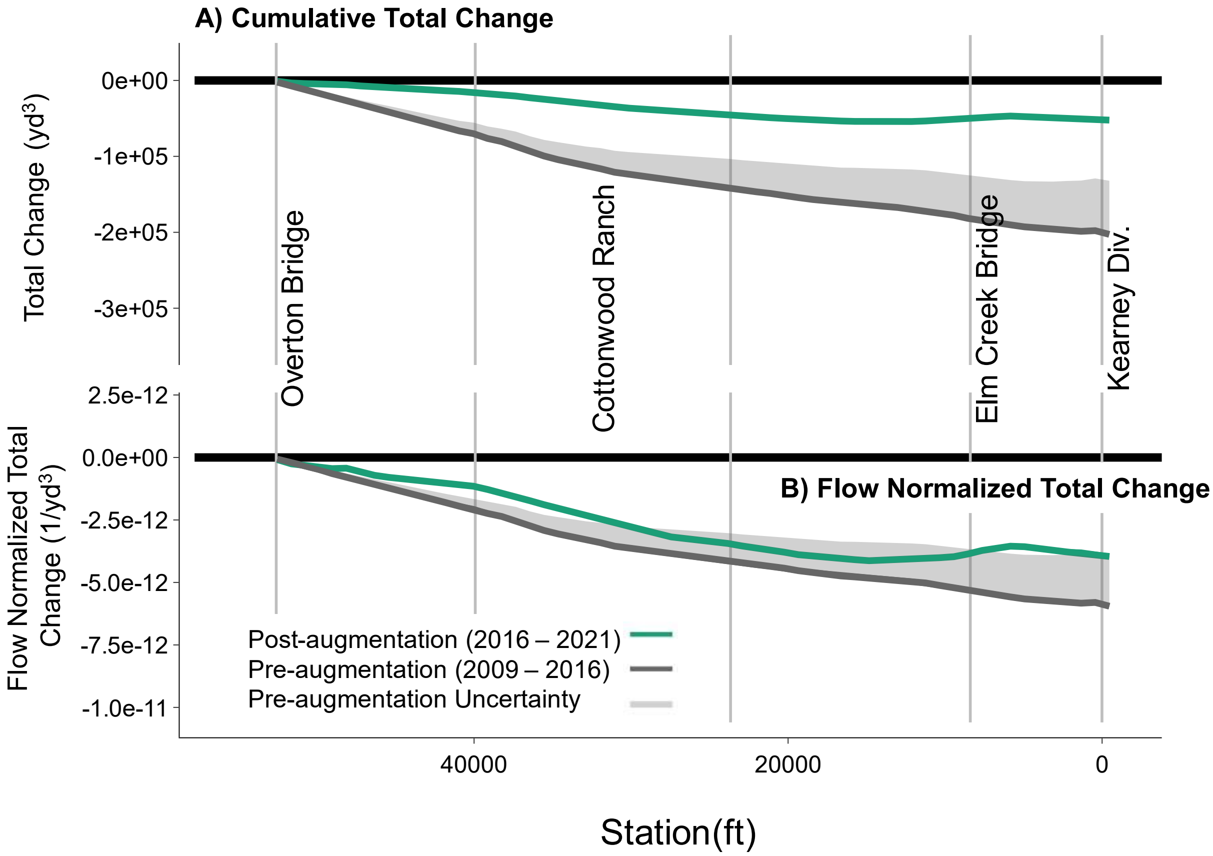

Figure 4.7. Cumulative total volume change downstream of the Overton Bridge. Values in panel B are normalized by flow at the Overton USGS gage, while values in A are not. Normalizing by flow reduces the difference between pre- and post-augmentation volume change.

4.4.3 Effectiveness of sediment augmentation

Our analysis indicates that conditions became less degradational in our study area since the implementation of sediment augmentation. To isolate the part that sediment augmentation played in this improvement, we must consider the other main variable in our system, flow. Downstream from the confluence of the J2 Return Channel and the North Channel, the Overton Bridge USGS gage shows that the pre- and post-augmentation periods were distinct. Figure D.4 shows that monthly average flow exceeded 6,000 cfs five times in the pre-augmentation period and not once in the post-augmentation period. In addition, the high flow event in June of 2015 brought a maximum daily flow of 15,300cfs, much higher than the maximum daily flow of 9,750cfs during the drier post-augmentation period (Table 4.3).

Table 4.3 Summary of flow during the pre and post-augmentation periods.

	Pre-augmentation		Post-Augmentation	
	J2 Return	Overton Bridge	J2 Return	Overton Bridge
Average Daily Flow (cfs)	960	2,150	970	1,650
Maximum Daily Flow (cfs)	2,030	15,300	1,780	9,750

These differences in flow make it difficult to isolate the effect of sediment augmentation. Fortunately, our full flow record at the Overton gage allows us to approximate volumetric change on the downstream reach independent of flow (Figure 4.7B). Doing so indicates that degradation potential was similar on this reach pre- and post-augmentation. While the post-augmentation change is slightly less degradational in a few locations, the differences are small enough to be within the uncertainty bounds over most of the reach. The high lateral erosion (Table 4.2) and large increases to wetted width (see Chapter 3) in the pre-augmentation period also point towards high flow events being the main driver of change rather than augmentation project sediment. Channel-forming events such as the flood in 2015 caused high lateral erosion, which in turn introduced new sediment to the riverbed. Without high flow events, the post-augmentation period saw only 20% of the pre-augmentation annual lateral erosion downstream of the Overton Bridge.

Upstream of Overton Bridge, flow entering the J2 Return Channel is typically regulated and ranges from 0 to 2,000 cfs. The average release from the Supply Canal was very similar in the pre- and post-augmentation periods (Table 4.3). This indicates that the additional sediment introduced to the system via sediment augmentation projects is likely a key factor in the reduction in bed degradation and total degradation observed in the J2 Return Channel. Figure 4.8 shows the relative volumes of sediment that eroded from the most upstream part of the J2 Return Channel where augmentation projects have occurred (orange). In the post augmentation period, the amount of sediment that eroded, including what was augmented, from the upstream reach increased by 35,500–38,300 yd^3/yr. Given that flow was similar in the post-augmentation period, this increase in erosion can be attributed to an increased availability of sediment (23,000 to 57,700 yd^3/yr) from sediment augmentation and the breakthrough channel, see Figure 4.1). Relative to this, we see a decrease in bed erosion from downstream of the augmentation area to the Overton Bridge of 16,200 to 33,900 yd^3 per year. The similarity between the values of the upstream increase and downstream decrease in erosion indicates that sediment is leaving the augmentation area and reducing bed degradation downstream.

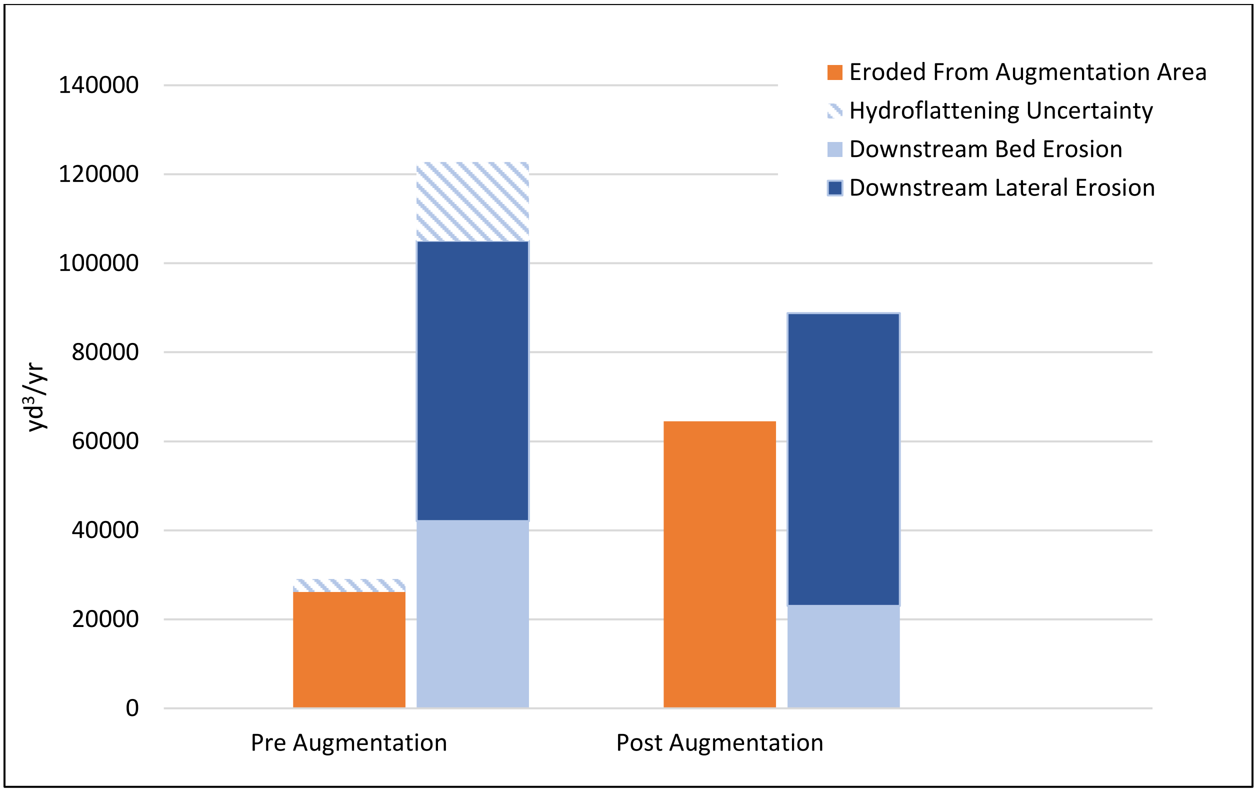

Figure 4.8 Volumes eroded from the J2 Return Channel upstream and within the augmentation project area (orange), and downstream of augmentation projects to the Overton Bridge (blue) in pre- and post-augmentation periods. In the post augmentation period, upstream sediment supply increased and downstream bed erosion decreased. The similarity between the values of increase and decrease indicate that sediment is leaving the augmentation area and reducing bed erosion downstream.

4.4.4 Year-by-Year Volume Change During Augmentation

In the post-augmentation period, annual topo-bathymetric LiDAR data enables a year-by-year examination of volume change. Table 4.4 shows there is high variation, but generally less degradation was observed in the most recent two years when the breakthrough channel has been closed. Examining the year-by-year post-augmentation data spatially (Figures 4.9 and 4.10), it is possible to see an expanding zone of positive change just downstream of the augmentation boundary from 2016–2019 (4.11a). This signal is not evident in 2019–2021, perhaps becoming more dispersed as total degradation is reduced in those years.

Table 4.4 Post-augmentation year-by-year volume change divided into two reaches at Overton Bridge. Negative values are in parentheses and indicate net degradation or erosion.

	Downstream augmentation boundary to Overton Bridge			Overton Bridge to KCD		
	Total Volume Change (yd^3)	**Lateral Erosion (yd^3)**	**Bed Agg/Deg (yd^3)**	**Total Volume Change (yd^3)**	**Lateral Erosion (yd^3)**	**Bed Agg/Deg (yd^3)**
2017-2016	(117,200)	(76,800)	(40,300)	18,500	(23,300)	41,800
2018-2017	(91,100)	(39,300)	(51,800)	(170,300)	(18,300)	(152,000)
2019-2018	(123,800)	(73,900)	(49,900)	(116,300)	(50,300)	(66,000)
2020-2019	(77,500)	(40,200)	(37,400)	12,100	(26,600)	38,700
2021-2020	(38,900)	(41,600)	2,700	(2,100)	(300)	(1,900)

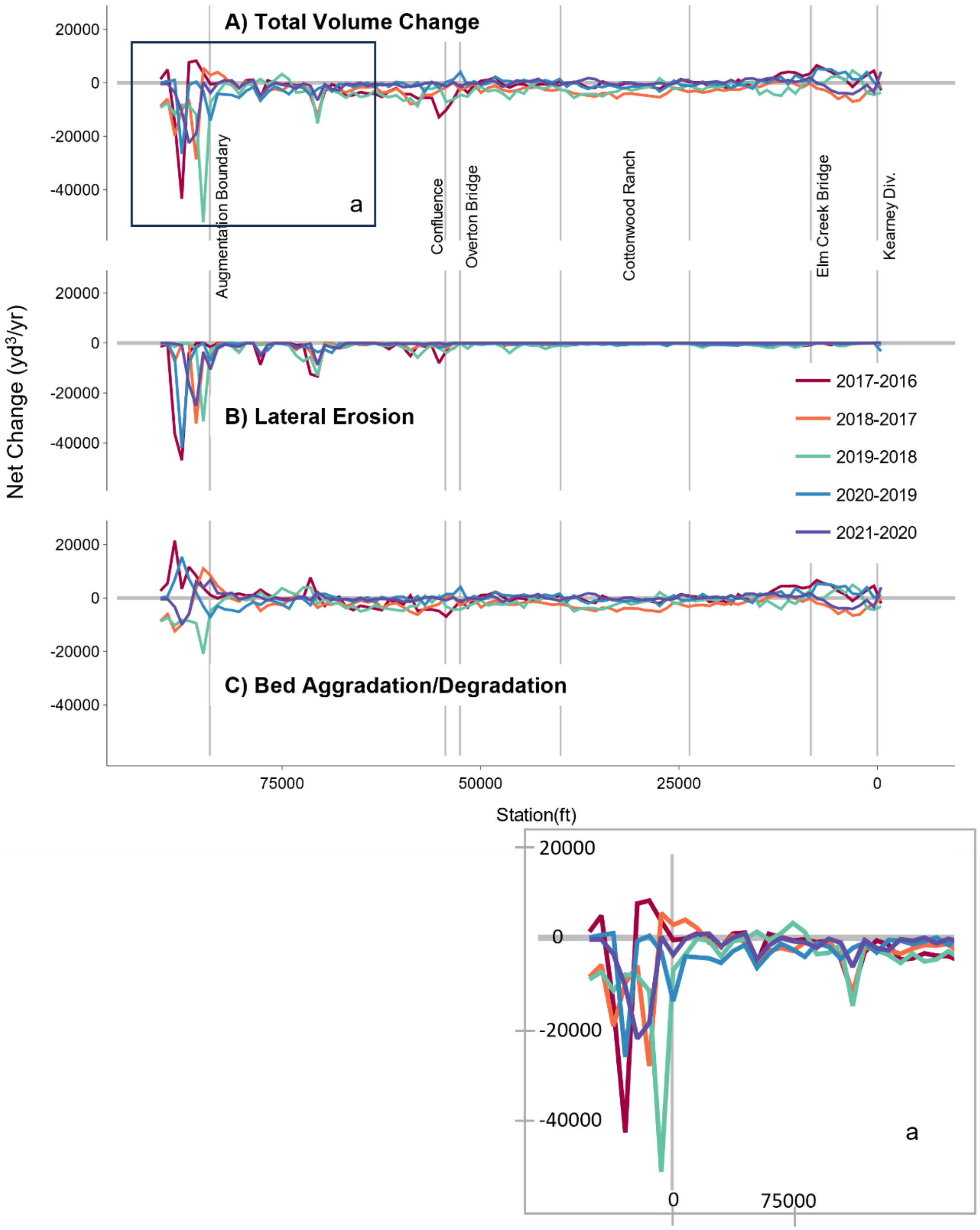

Figure 4.9 Post-augmentation year-by-year net volume change. Inset ‘a’ depicts positive volume change that moves downstream from the augmentation zone in 2016 to 2019. This pattern is disrupted in 2019-2021, perhaps becoming more dispersed as total degradation is reduced in those years.

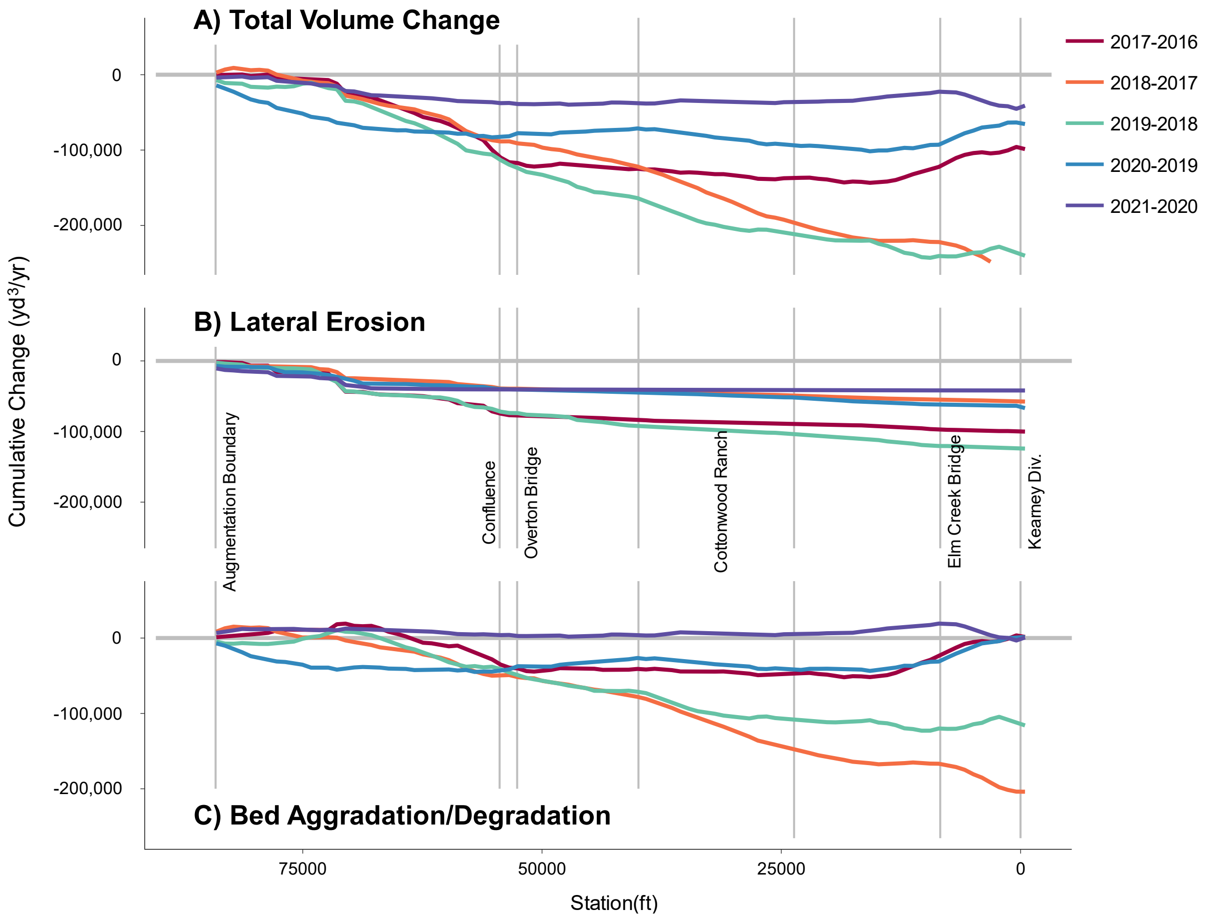

Figure 4.10 Cumulative year-by-year volume change in the post-augmentation period. (A) Lines represent the running sum of all change starting at the downstream end of augmentation projects. The nearly flat lines downstream of Overton Bridge indicate very little lateral erosion occurred (B). Steep slopes indicate high local change, such as the high bed degradation at Cottonwood Ranch from 2017–2019 (C).

Noise due to varying flow and sediment inputs makes the year-by-year data difficult to interpret. General trends seem to be decreasing degradation in the reach upstream of Overton Bridge, though higher flows in 2019 seem to have caused more bed degradation in the 2020–2019 year. Some years (2016 - 2018) have a distinct hump that is likely the signature of augmentation and breakthrough sediment moving downstream (Figure 4.9 inset ‘a’), but in other years no distinct signature is visible and a more dispersed reduction in erosion can be seen. While the reach downstream of Overton Bridge is largely stable, there is year-by-year variation here as well. The steep negative slope in the Cottonwood Ranch area (Figure 4.10) in 2017–2019 shows that this area was degradational during that time, likely due to disking activities in 2018 and higher flow in 2019 (Figure D.4). After the large-scale lateral erosion that occurred in the flood of 2015, very little additional lateral erosion occurred in the downstream reach during the drier post-augmentation period. This can be observed from the nearly flat slope of lines in Figure 4.10B.

4.5 Discussion

In our full-scale augmentation experiment we evaluated whether 60,000–80,000 tons (40,000–60,000 yd^3) of sediment placed immediately downstream of the J2 Return each year could offset the sediment deficit sufficiently to stabilize the J2 Return Channel and prevent incision from progressing downstream. In this chapter we evaluated the effectiveness of augmentation via the morphological approach, using LiDAR data (constrained by hydraulic modeling) to measure actual volumetric change during the experiment. Our findings indicate that the J2 Return Channel remained degradational during the experiment, but bed erosion was reduced, and some areas of aggradation were observed in the first three miles downstream of augmentation. We also found that a large portion of sediment supply in the J2 Return Channel came from lateral erosion of channel banks. Finally, we found that the net volume change downstream of the J2 Return Channel between Overton Bridge and the KCD is dynamic but stable, with no observable signal from augmentation.

In terms of quantitative change, bed degradation in the J2 Return Channel decreased by 45%–60% during the augmentation experiment. We attribute this reduction to augmentation activities because the decrease in erosion (approx. 20,000 to 40,000 yd^3/yr) was roughly equal to the augmented material leaving the sediment augmentation project area. The movement of augmented material downstream away from the augmentation area is visible in Fig. 4.11. Given full-scale sediment augmentation arrested approximately half of bed degradation in the J2 Return Channel, the volume, location of augmentation, grain-size distribution, or other design factors may need to be adjusted to address the continued incision in the lower half of the channel. Doubling the annual augmentation volume could hypothetically offset remaining bed degradation, but mechanically augmenting 80,000–120,000 yd^3/yr may incur challenges in terms of cost, physical supply, and ability to mobilize the sediment. The Program's current United States Corps of Engineers (USACE) Section 404 permit identifies seven sites from which sediment can be sourced with varying degrees of difficulty. At the current rate of augmentation, these sites have enough sediment for a total of 21 more augmentation projects. Without alteration to the existing permit, doubling the volume of augmented sediment would reduce the number of potential projects by half, with four years of source material from Jeffrey Island and six years of source material from more challenging sites along Plum Creek.

Downstream of Overton Bridge, volume change analysis indicates a dynamic channel with a high degree of spatial and temporal variability during the augmentation period. Spatially, the reach from the Overton Bridge to CWR was stable to slightly aggradational, the CWR reach was slightly degradational, and the reach from CWR to the KCD structure was aggradational during augmentation years. Temporally, the channel bed (excluding lateral erosion) between Overton and KCD was net aggradational or relatively stable in three out of five years, but degradational from 2017–2019. When compared to the pre-augmentation period and normalized for discharge, we observed no major difference in bed erosion during the pre- and post-augmentation periods downstream of Overton Bridge.

The one difference we did observe was substantial lateral erosion that occurred because of the prolonged peak flow event in 2015 which increased mean channel width by more than 200 ft. Channel widths have remained stable since 2015, despite much lower flows in recent years (Chapter 3).

Overall, sediment augmentation reduced bed degradation in the J2 Return Channel, but there was no pre- and post-augmentation difference in sediment balance downstream of Overton within the limits of our uncertainty from hydroflattened DEMs. Much of the sediment supply in the J2 Return Channel originates from lateral erosion, which recruits stored sediment from the banks. Theoretically, degradation will continue to slowly progress downstream toward the Overton Bridge and will negatively impact habitat at an unknown point in the future. As such, some form of permanent ongoing augmentation in J2 Return Channel is necessary to reduce future risk to downstream habitat, but near- and long-term benefits are difficult to quantify and weigh against the annual cost of augmenting sediment. Accordingly, it may be necessary to evaluate alternatives that allow for some degree of long-term sediment replenishment into the J2 Return Channel without the cost and supply limitations of ongoing mechanical augmentation. This includes alternatives like retrofitting of the Jeffrey Island Sand Dam to pass sediment into the J2 Return Channel in a controlled manner. Investigations into passive sediment replenishment and augmentation alternatives will likely begin in late 2023.

4.6 References

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

EXHIBIT B

Peer Review Summary Report for the PRRIP Sediment Augmentation Data Synthesis Compilation

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -or- Program) Peer Review Summary Report – Sediment Augmentation Data Synthesis Compilation

1.0 Introduction

This document provides an overview of a formal, independent, external scientific peer review conducted for the Platte River Recovery Implementation Program ("PRRIP" -or- "Program"). The peer reviewed document is titled "PRRIP Sediment Augmentation Data Synthesis Compilation" prepared by the Program's Executive Director's Office (EDO) using Program data and analysis.

1.1 Background

One of the Program's primary management uncertainties is the need for long-term sediment (sand) augmentation at the upper end of the Associated Habitat Reach (AHR) to offset a sediment deficit due to clearwater hydropower return flows. Stakeholders have long been concerned that incision and narrowing due to mining of sediment from the bed and banks of the channel downstream of the hydropower return will migrate downstream and impact habitat suitability for the Program's four target species (whooping crane, piping plover, interior least tern [now de-listed], and pallid sturgeon). Efforts to quantify the magnitude of the sediment deficit and develop augmentation methods began soon after Program initiation in 2007. By 2016, Program stakeholders reached consensus that the best next step in evaluating sediment augmentation would be implementation of a full-scale sediment augmentation experiment immediately downstream of the hydropower return. The full-scale augmentation experiment was initiated in 2017 with augmentation occurring annually from 2017 through 2021. In 2022, the EDO began analysis of the effectiveness of sediment augmentation, producing multiple lines of evidence across a range of spatial and temporal scales. The Sediment Augmentation Data Synthesis Compilation is a roll-up of this multi-scalar analysis and is intended to provide a framework for the Program to assess the results of sediment augmentation so far and the implications for decision-making related to sediment augmentation throughout the remainder of the Program's First Increment Extension (2020-2032) and beyond.

The Program sought an independent peer review of the Sediment Augmentation Data Synthesis Compilation. Pending internal feedback and the results of the peer review regarding the significance and relevance of methods and results presented in the Sediment Augmentation Data Synthesis Compilation, the intent is to prepare a manuscript for publication that incorporates parts of the overall report.

1.2 Purpose and Scope of Peer Review

The purpose of the peer review was to provide a formal, independent, external scientific review of the information presented in the Sediment Augmentation Data Synthesis Compilation. Reviewers were charged with evaluating the scientific merit of the document's technical analyses and conclusions, ensuring that any scientific uncertainties are clearly identified and characterized and that the potential implications of the uncertainties for the technical conclusions drawn are clear. Specifically, the PRRIP requested reviewers consider and respond to the questions listed below, at a minimum, in their reviews:

General Questions:

1. Does the Sediment Augmentation Data Synthesis Compilation adequately address the overall objective – to synthesize multiple lines of evidence from the Program's full-scale sediment augmentation experiment to assess overall results and provide useful information for decision-making related to future sediment augmentation management actions?

2. Do the authors draw reasonable and scientifically sound conclusions from the information presented? If not, please identify those that are not and the specifics of each situation.

3. Are there any <u>seminal</u> peer-reviewed scientific papers omitted from consideration that would contribute to alternate conclusions that are scientifically sound? Please identify any such papers including citations.

4. Are the statistical methods and modeling tools used valid and current, and are the associated results presented in a manner useful to Program decision-makers?

5. Are potential biases, errors, or uncertainties appropriately considered within the methods sections and then discussed in the results and conclusion sections?

Technical Questions:

6. LiDAR data was processed to remove non-random error to the degree possible. Accordingly, two- and three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?

7. Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?

In addition to providing written comments and responses to the General and Technical questions above, each reviewer was charged with providing a separate comprehensive rating and recommendation utilizing the following format:

RATING

Please score each aspect of this set of chapters using the following rating system:
1 = Excellent; 2 = Very Good; 3 = Good; 4 = Fair; 5 = Poor

Category	**Rating**
Scientific soundness	______
Degree to which conclusions are supported by the data	______
Organization and clarity	______
Cohesiveness of conclusions	______
Conciseness	______
Important to objectives of the Program	______

RECOMMENDATION **(Check One)**

Accept ______

Accept with revisions ______

Unacceptable ______

If a peer reviewer checked “Accept with Revisions” or “Unacceptable,” that reviewer was directed to **explicitly state** what changes would be required to change the recommendation to “Accept.” This is a critical step in ensuring the Program understands potential fatal flaws or major areas of revision that must be addressed before finalizing these documents and seeking Governance Committee (GC) approval.

2.0 Peer Review Process

Dr. Chadwin Smith of the EDO facilitated the peer review process for the PRRIP. The process included the following steps:

1) Develop a Scope of Work for the peer review.
2) Identify potential peer review candidates; contact all candidates and screen for expertise criteria and potential conflicts of interest; obtain biographical sketches and CVs/resumes for all candidates.
3) Work with the PRRIP Peer Review Selection Panel to vet all candidates and recommend three (3) reviewers for the Peer Review Panel to be approved by the GC.
4) Communicate with all candidates regarding the Peer Review Panel selection process and contract with the appointed peer reviewers.
5) Distribute peer review materials to each reviewer and conduct individual virtual discussions with the peer reviewers to discuss the review scope and documents and to address any questions.
6) Develop a Peer Review Summary Report providing an overview of all review comments and a trackable spreadsheet of all specific technical comments. This includes working with EDO staff to identify key issues identified by reviewers and proposed responses to key issues and all specific technical comments.
7) Discuss Peer Review Summary Report and proposed document changes/edits with the PRRIP Technical Advisory Committee (TAC), recommend additional changes/edits, and finalize for review by Peer Review Panel.
8) *As warranted*, elicit Peer Review Panel reaction (via electronic responses and/or virtual meeting) to proposed changes/responses to Sediment Augmentation Data Synthesis Compilation indicating acceptance or rejection of changes.
9) Discuss responses from the Peer Review Panel with the TAC and recommend final changes to Sediment Augmentation Data Synthesis Compilation for GC consideration.
10) Seek GC approval of final Peer Review Summary Report including a revised Sediment Augmentation Data Synthesis Compilation, post for public distribution via the PRRIP website.

2.1 Selection of Reviewers

The PRRIP requested peer review candidates comprising the following areas of expertise: sediment augmentation and management; sediment transport data collection and modeling; and utilization of LiDAR and other tools to evaluate large datasets over time (including dealing with topographic change and uncertainty). The following is a brief summary of the process used by Dr. Smith to identify potential peer reviewers for the Sediment Augmentation Data Synthesis Compilation with a background in one or more of these broad categories of expertise:

Step 1 – Develop a Peer Review Scope of Work.

Dr. Smith developed a Peer Review Scope of Work for the Sediment Augmentation Data Synthesis Compilation in consultation with EDO staff and members of the TAC. The Scope of Work includes background information on the Sediment Augmentation Data Synthesis Compilation, specific questions to be addressed by each peer reviewer, and a peer review ranking process.

Step 2 – Solicit peer review candidates.

Peer review candidates were solicited in the following manner:

- Dr. Smith's personal expertise network.
- Recommendations from the PRRIP Executive Director and EDO staff.
- Recommendations from members of the PRRIP TAC.
- Candidates previously vetted by the PRRIP ISAC Selection Panel for consideration as an ISAC members for the open fluvial geomorphology seat on the ISAC in 2023.
- Identification of subject matter experts in government, academic, and industry fields from current publications on sediment augmentation, management, and evaluation (preferably in braided river systems); sediment transport data collection and modeling; and utilization of LiDAR and other tools to evaluate large datasets over time.
- Peer review candidates were contacted to determine their interest, availability, and willingness to serve. This contact was conducted electronically and by phone. Each candidate was provided with a copy of the Scope of Work and Dr. Smith discussed the anticipated peer review schedule, desired experience, and potential conflicts of interest with all candidates.

Step 3 – Obtain information from each peer review candidate.

Prospective candidates were asked to provide a short biographical statement and their most current CV. All candidates indicated the peer review schedule was acceptable and that they would be able to sign the Program's Certification Regarding Lobbying and the Program's Peer Reviewer Conflict of Interest Form.

In November 2023, Dr. Smith (EDO) submitted a Peer Review Candidate Report to the Peer Review Selection Panel. The Candidate Report identified ten (10) individuals contacted about the peer review, six (6) of which were presented as a candidates. Based on the recommendation of the Peer Review Selection Panel, in December 2023 the GC appointed the following individuals to the Sediment Augmentation Data Synthesis Compilation Peer Review Panel:

		Expertise Area(s)		
Name	**Affiliation**	*Sediment Augmentation, Management, & Evaluation (braided rivers)*	*Sediment Transport Data Collection & Modelling*	*LiDAR & Other Tools for Large Datasets; Topographic Change and Uncertainty*
James Brasington, Ph.D.	University of Canterbury (NZ)	**X**	**X**	**X**
Mark Smith, Ph.D.	University of Leeds (UK)		**X**	**X**
Richard Williams, Ph.D.	University of Glasgow (Scotland)	**X**	**X**	**X**

2.2 Document Review and Peer Review Report Development

In January 2024, Dr. Smith (EDO) transmitted all review-related documents to and held individual virtual meetings with all three (3) peer reviewers. The reviewers conducted their independent desktop reviews between February and May 2024. Peer reviewers submitted the following deliverables:

1) Responses to the General and Technical Questions identified in the Scope of Work.
2) Ratings of the WEST report and synthesis chapters in five different categories, as well as an overall recommendation for acceptance.
3) Specific comments on the text of the Sediment Augmentation Data Synthesis Compilation.

This Peer Review Summary Report provides a general summary of the reviewers' responses to the General and Technical Questions and their rankings of the Sediment Augmentation Data Synthesis Compilation. **Appendix A** includes the full set of comments from each reviewer and **Appendix B** includes all specific comments and responses from the EDO to each of those comments compiled into a matrix. As described in the PRRIP Peer Review Guidelines and addressed in the Peer Review Scope of Work, all three (3) reviewers chose to have their review comments attributed throughout the peer review process.

3.0 Peer Review Results

Below are summaries of the individual reviewers' responses to the five (5) General Questions (Section 3.1) and two (2) Technical Questions (Section 3.2) posed by the PRRIP. These summaries are not intended to be comprehensive, rather they attempt to capture an overview of the reviewers' primary comments. Ratings and Recommendations relating to acceptability of the report are summarized in Section 3.3.

3.1 Reponses to General Questions

1. *Does the Sediment Augmentation Data Synthesis Compilation adequately address the overall objective – to synthesize multiple lines of evidence from the Program's full-scale sediment augmentation experiment to assess overall results and provide useful information for decision-making related to future sediment augmentation management actions?*

<u>Brasington</u> – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

Smith – Yes. This is a well presented and well-compiled report of an interesting management implementation. A data-rich approach is taken, and the data are interrogated thoroughly and appropriately. The use of multiple lines of evidence that each confirm a clear outcome adds further support to the conclusions made. My comments above are mainly focused on increasing the clarity and adding further contextual information to support decision-makers, but I endorse the findings made here.

Williams – Overall, I consider that the report has the correct overall experimental framework to address the Big Science Question: "Is sediment augmentation necessary to create and/or maintain suitable whooping crane habitat?" In particular, it presents a wide-ranging set of different lines of evidence. However, I do consider that there are a number of issues that require clarification or additional supporting analyses that could help to support some methodological assumptions that have been made, including the characterisation of uncertainty in the volumetric change estimates. I recommend that the Executive Summary is carefully revisited following any revisions and, in particular, a graphical diagram that summarises the various conclusions for different segments of the river may help to summarise the information for decision makers.

2. *Do the authors draw reasonable and scientifically sound conclusions from the information presented? If not, please identify those that are not and the specifics of each situation.*

Brasington – This report is an impressive and comprehensive examination of an ambitious field experiment. In recent decades, sediment augmentation has emerged a well-established intervention that aims to address the physical and ecological consequences of impounding and regulating natural river flow regimes. Few attempts to achieve this, however, have been designed as effectively and scrutinized as robustly as detailed here. The approach taken is distinctive, and I would argue world-leading, for its application of powerful emerging technologies. The acquisition and interrogation of dense topobathymetric lidar covering a 6-year period provides an unparalleled, data rich lens through which to assess this intervention. While I have some technical questions over the precise approach to the volumetric change analysis and uncertainty estimation, I find the broad geomorphological interpretation astute and compelling.

Smith – Yes. The data are clearly presented and support the conclusions made. While I have minor suggestions regarding data presentation of the volume change results, these are simply to give further confidence that systematic errors are not problematic. The fact that the evidence presented by the volumetric change analysis confirms previous thalweg-based analysis suggests that none of this would adjust the overall conclusions made.

Williams – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

3. *Are there any seminal peer-reviewed scientific papers omitted from consideration that would contribute to alternate conclusions that are scientifically sound? Please identify any such papers including citations.*

Brasington – Additional references integrated into comments.

Smith – I suggest that the overall conclusions are scientifically sound. The citations I present in this document regarding DEM differencing (Wheaton et al., 2010; Brasington et al., 2012; Smith et al., 2015) and sediment budget segregation (Wheaton et al., 2013 in minor comments below) are simply alternative approaches to some of the methodological choices here.
Williams – A reference list to the associated citations is provided below. I note that the report doesn't contextualise the effects of sediment augmentation with other global examples; this would be likely required for publication and the authors may wish to consider broader contextualisation for this report. As a starting point, I would recommend the review by Staentzel et al. (2020).

4. *Are the statistical methods and modeling tools used valid and current, and are the associated results presented in a manner useful to Program decision-makers?*

Brasington – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

Smith – Yes. There are no issues here. The most complex statistics (GAMMs) are well explained and represented visually. Overall, the report takes a visual approach to representing the data which are also quantified into summary statistics. It is very clear. There were few details on the modelling methods used, though these were often not the core of the analysis, but rather provided a step of the analysis (e.g., to identify a wetted area for given discharge). I was a little unclear as to where in the workflow these models were used and their impact on the final findings (see main comment above), but again I should reiterate that I do not think this has any impact on the conclusions.

Williams – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

5. *Are potential biases, errors, or uncertainties appropriately considered within the methods sections and then discussed in the results and conclusion sections?*

Brasington – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

Smith – More discussion of these for the volumetric change analysis chapter would be useful (see main comment 6 above). The relative magnitude of different uncertainties relative to the differences observed could be better articulated. I should add that I see no cause for concern, rather it is in the interest of clear reporting to do so. Presenting DEMs of Difference would add further confidence that there exist no outstanding systematic errors in the data.

Williams – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

3.2 Responses to Technical Questions

6. *LiDAR data was processed to remove non-random error to the degree possible. Accordingly, two- and three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?*

Brasington – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

Smith – There is a precedent here (Anderson, 2019) which is cited by the report. While it is not my preferred method, I think it is appropriate for the scale of the study. The largest assumptions in the report arise from the calculation of sediment volume changes from the 2009 LiDAR data that had no bathymetric component (P90). The report clearly flags the uncertainty arising from this (e.g., P94) but would likely be the most open to criticism. As described in my comments above, I would like to see more DEMs of Difference to help clarify visually that no residual systematic errors remain.

Williams – The reporting of vertical errors before and after post-processing to minimise systematic errors is not sufficiently detailed for me to be able to assess the effectiveness of this correction (see comment g above). It would also be useful to know more about the roughness (i.e. grain size) of the active channel to discern what the influence of roughness may be on the character of the LiDAR derived surface. I also envisage that the presence (and likely removal) of vegetation from the LiDAR derived surfaces (e.g. sparsely vegetated bars) will also contribute uncertainty that is more spatially variable in character than that which has been systematically corrected. In my experience, I have conducted and reviewed very few sediment budgeting analyses that haven't quantified uncertainties, often although not always using the types of probabilistic thresholding approaches reviewed by Vericat et al. (2017). Although the authors cite Anderson (2019), Anderson still argues that estimated uncertainty bounds should be part of a quantitative estimate of volumetric or mean change (second bullet point in the conclusion e.g. Figure 11 and Table III of Anderson's (2019) example). I recommend that either Vericat et al.'s (2017) and/or Anderson's (2019) approaches could be used to characterise uncertainty and enable more rigorous assessment of whether some of the observed changes are indistinguishable from zero within uncertainty.

7. *Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?*

Brasington – Answered throughout general and specific comments on Sediment Augmentation Data Synthesis Compilation.

Smith – I can see that this method makes intuitive sense and is defensible. My previous experience was with the method described by Wheaton et al. (2013) of segregating the sediment budget by mechanism. The approach implemented here has the benefit of simplicity and would likely result in the same outcome. As per my minor comment (below) on P85, some visual example of this segregation process would be helpful as the description of the methods here was quite brief.

Williams – See comment (h) above for my answer to this question. In summary, the approach used may be appropriate, but I would like to see a comparison to manual expert interpretation to enable a quantitative assessment of the quality of its ability to segment this type of geomorphic change.

3.3 Ratings and Recommendations

Reviewers rated the Sediment Augmentation Data Synthesis Compilation using the following PRRIP rating system: 1 = Excellent; 2 = Very Good; 3 = Good; 4 = Fair; 5 = Poor. **Table 3-1** summarizes each reviewer's ratings.

Table 3-1. Peer reviewers' comprehensive ratings of the Sediment Augmentation Data Synthesis Compilation, by category.

Category	Brasington	Smith[1]	Williams[2]
Scientific soundness	1	2	3
Degree to which conclusions are supported by the data	1	2	3
Organization and clarity	1	3	2
Cohesiveness and clarity	1	2	2.5
Conciseness	1	3	3
Important to objectives of the Program	1	2	1
Rating Average	1	2.3	2.4

<u>Initial Recommendations</u>

The peer reviewers were asked to provide their recommendation to either accept the Sediment Augmentation Data Synthesis Compilation, accept it with revisions, or deem the report unacceptable. *<u>All three reviewers initially recommended the Sediment Augmentation Data Synthesis Compilation be accepted with revisions.</u>* To accept the Sediment Augmentation Data Synthesis Compilation, the peer reviewers suggested the following key revisions:

<u>Brasington:</u>

I have raised a number of discussion points through this review, the most significant of which relate to the DEM differencing methods employed in Chapter 4 and, in particular, the absence of formal quantification of volumetric change uncertainty. I appreciate the approach taken by the team in this regard but would encourage them to consider the range of options available to compute the residual systematic error and to incorporate this within the presentation of the results.

<u>Smith:</u>

1. **Context**. Comments 1-3 all deal with background context. These were things I felt would enable decision makers to better interpret the evidence provided. Some text on the catchment, flows, history, etc., would be useful, but I recognize that this may not be appropriate for the intended use of the report.
2. **Structure**. I would try to split out result description and interpretation where possible. I realize this is challenging in places. A brief summary section to directly relate key conclusions back to the underlying evidence presented would be helpful here (either at the end of the document or making better use of the existing Executive Summary). The description of the data collection (i.e., LiDAR, flow gauges and related data) could be expanded, separated out from results description and interpretation and moved earlier in the document.

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[1] Smith transposed the rating scale (e.g., Categories rated a "4" should instead be rated a "2" etc.). Those transpositions have been fixed in Table 3-1, the original ratings remain in his comment set.

[2] Williams transposed the rating scale (e.g., Categories rated a "4" should instead be rated a "2" etc.). Those transpositions have been fixed in Table 3-1, the original ratings remain in his comment set.

3. **Volumetric changes**. The LiDAR volumetric changes section would benefit from presentation of DEMs of Difference to visually identify any residual systematic errors. Consideration of the relative magnitude of potential errors would also be useful alongside the magnitude of observed topographic changes. See the main comments 6-7 above.
4. **Minor points**. I have a number of minor points below. While these don't all require action, it would be good if they could be considered.

Williams:

1. **Scientific Soundness.** An enormous amount of effort has been spent acquiring, processing and interpreting data. However, I consider that some clarifications are needed, which would enable this score to be increased.
2. **Degree to which conclusions are supported by data.** These are generally sound, but I consider clarifications are needed to ensure that conclusions are appropriate. Addressing these would enable this score to be increased.
3. **Conciseness.** See comments on presenting a clearer contextualisation, organising methods in one place, and using more cross-referencing to avoid repetition.

Final Recommendations

After the EDO edited the Sediment Augmentation Data Synthesis Compilation following peer review, and after those proposed edits were discussed with the PRRIP Technical Advisory Committee (TAC), Dr. Smith (EDO) contacted all three peer reviewers to assess whether they would change their initial recommendations of "Accept with Revisions" to "Accept" based on the proposed edits. ***All three reviewers agreed to revise their initial recommendations from "Accept with Revisions" to "Accept".*** Below are the responses from each reviewer on this question:

James Brasington:

I think your team has made an excellent response to a series of fulsome reviews. From my perspective, perhaps the most significant contributions lie in the provision of additional information and data to evaluate the co-registration and uncertainties associated with the sequential lidar series. These data answer my principal questions around the assessment of systematic differences and how that analysis should be used to support sediment budgeting. Examination of the 2022-2021 data reveal that thresholding is unlikely to bias the modelled pattern of net change and the segregated models of change presented in the technical appendix provide a good rationale for sticking to the methods used originally. That said, the appendix provides useful information on the segregated changes that offer some additional clarity of the scale of erosion and deposition. This feels like an expedient but scientifically justifiable way forward. Beyond this, the matrix of reviewers comments provides an effective summary of how the principal points raised have been addressed. The responses are well-reasoned and I concur with the changes made and as well as those resisted. The net result is a well-polished, scientifically credible analysis that would stand the rigours of peer review and publication. I commend the team of the approach you've pursued. To my view, the PRRIP is an exemplar of how high quality, evidence-based analysis that leverages state-of-the-art tools is being used to guide complex environmental management problems. This report makes an excellent contribution to this effort.

Mark Smith:

Once again thanks for the clear documents, especially the summary report and comment matrix. I have been through these carefully, alongside the addenda. I am happy to move my rating to "Accept" based on these thorough revisions. While I did not re-read the whole data synthesis document, I did enjoy seeing the Data Summary, field photos and elevation change maps in particular. Do let me know if you need anything more detailed from me at this point – but my impression was this short statement was all that is required. Thank you for taking the time to review and respond to all the comments. I appreciate not all were appropriate for this particular document, so thanks too for effectively screening out these.

Richard Williams:

I have now read through all four documents provided:

- Appendix E. Thank you for providing a thorough response document. I see you have been selective with the comments that you have incorporated into the revised version of the report and it is good to see open justifications and explanation. I note that the vertical dimensions of some cells means that some text cannot be read. I recommend checking your formatting.
- Data synthesis compilation – I found the overall presentation and quality of the description to have improved. I found one typo - P2L22. Space missing after "D.1."
- Technical Addenda – No comments.

Overall, subject to the above minor corrections, I am happy to change my recommendation to "accept." I am pleased to see that my comments were helpful and thank your colleagues for considering them. In addition to the value of your report, I would welcome seeing this transposed into a manuscript for an international audience – it's a unique dataset worthy of the world seeing to help improve river health. ***Editorial Note:*** *All of these corrections have been made in the final Sediment Augmentation Data Synthesis Compilation.*

3.4 Other Specific Comments

In reviewing the results of the peer review and evaluating potential responses to specific comments, EDO staff identified four (4) key comments regarding analysis and methods that received particular attention in the process of editing the Sediment Augmentation Data Synthesis Compilation and in discussion with the TAC and the PRRIP Independent Scientific Advisory Committee (ISAC). **Table 3.2** provides more detail on those key comments:

Table 3.2. Key peer review comments on analysis and methods, and proposed EDO responses.

1. LiDAR and Raster Differencing Uncertainty
We requested feedback on our decision not to threshold our LiDAR data or quantify/account for error in our two- and three-dimensional analyses. Most reviewers understood our reasoning but wanted to be shown more clearly a) what the error was and b) how much thresholding/not thresholding would have altered results. For example, Brasington asked us to include more details and evidence regarding the LiDAR contractor's removal of systematic errors, while Williams pointed out that Anderson 2019 (which we cite) "argues that estimated uncertainty bounds should be part of a quantitative estimate of volumetric mean change" and suggests that we characterize uncertainty using either Anderson 2019 or Vericat 2017 approaches.

EDO Response:

EDO Response: We agree with this advice and have several ideas for how to address it.

Methodological Details: We will present a more thorough description of how the LiDAR contractor collected, verified, and post-processed the data.

Systematic Error: We will test for residual systematic error in our post-processed LiDAR by showing year-to-year elevation changes at known stable points (Figure 1). Year-to-year elevation change on interstates and other stable features should be very small and normally distributed around zero. We will also investigate magnitudes of error where in-channel vegetation changed year-to-year based on Brasington's comment that the conversion from vegetation height to bare-earth elevation may be prone to systematic errors.

2. Lateral Erosion Delineation Method

We asked reviewers to consider whether our method of separating lateral erosion from bed aggradation/degradation was appropriate. While most found the method appropriate, Williams asked that we evaluate how the method works compared to "expert manual interpretation" as used in Wheaton et al. 2013.

EDO Response:

We will address this by comparing our more automated method of hydraulic model result differencing with the Wheaton method on two small reaches of river in order to validate the automated method. Staff will independently delineate lateral erosion by hand using differenced rasters and aerial imagery, after first reviewing a manually delineated test reach. The test reach will help the staff agree upon the process and definitions, while the independent delineation will allow an examination of the effect of individual bias in manual interpretation. Areas of hand delineated lateral erosion will be compared with the area delineated in our report. We expect to visually compare the locations and intensity of lateral erosion predicted by our systematic remote sensing process and the manual interpretation. We will also quantify and compare the volumes predicted by both methods.

3. Analyze the North Channel as a control reach

Williams suggested we conduct geomorphic analyses (wetted width, sinuosity, longitudinal profiling, etc.) on the north channel to serve as a comparison to the J2 Channel. The reasoning behind the suggestion is that these two branches of the same river have many similarities, but only the J2 Channel has been impacted by the hydropower return, so the North Channel may act as a "control reach".

EDO Response:

While we agree that further examination of the North Channel would be interesting, we do not predict that it would add meaningfully to the conclusions of our report. This is mainly because the North Channel and J2 Channel differ not only in sediment inputs (clearwater return vs. natural regime) but also in flow variation and magnitude. For decades, the J2 Channel has experienced little variation in flow while the North Channel has experienced frequent very low flows and several floods (Figure 2). If the North Channel represented the J2 channel but with a natural sediment regime (i.e., no clearwater discharge), then comparisons between the wetted width, sinuosity, longitudinal profiles, and other variables between the two channels would provide helpful information on the impact of the changes in sediment transport regime since the

beginning of J2 Return flows. However, we propose that the North Channel is in practice a poor control to isolate the impact of sediment transport differences.
4. Volume Change Analysis
Brasington and Williams commented on our approach to summing bed volume change in each region to compute net change rather than providing the raw values of aggradation and degradation similar to Vericat, 2017. Williams suggested that it would be "beneficial to more extensively segregate erosion and deposition."
EDO Response:
We are currently uncertain of what the benefit of this segregated accounting would be for our stakeholders. To address a different comment from Brasington we are planning to add more figures of year-to-year LiDAR differenced rasters (Figure 3). We believe these additional figures may also help to add context to our "net change" values by visually depicting the areas of aggradation and degradation on the channel bed.

All other comments provided by each peer reviewer can be read in full in **Appendix A**. Specific comments have been pulled out into a matrix spreadsheet in **Appendix B** and organized by Reviewer (alphabetical), Comment Number, Type, Topic, Chapter, Page, Line, Comment/Paraphrase, and Proposed EDO Response. Each comment is included fully or is paraphrase to save space, and a proposed response from the EDO is provided for further discussion with the TAC.

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PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -or- Program)
APPENDIX A – Compiled Peer Reviewer (3) Comments

REPORT: SEDIMENT AUGMENTATION DATA SYNTHESIS COMPILATION, DRAFT, 27 NOV 2023
REVIEWER: PROFESSOR JAMES BRASINGTON, UNIVERSITY OF CANTERBURY, NZ
DATE: 26th APRIL 2024

1. SCOPE OF WORK

The PRRIP contracted this review to provide independent, critical but constructive feedback of this analysis of the Program's Sediment Augmentation experiment. The review is designed to examine specifically the scientific soundness of the work undertaken; the technical analyses performed; the conclusions drawn; and their presentation in this report.

Particular attention is drawn to five areas for general assessment (paraphrased below as):

(1) Does the Sediment Augmentation Data Synthesis Compilation use adequately multiple lines of evidence to assess the results of the augmentation experiment;

(2) Do the authors draw reasonable and scientifically sound conclusions;

(3) Are there seminal papers that have not been adequately considered and may have contributed to alternative conclusions;

(4) Are the statistical methods and modelling tools used appropriate and current; and

(5) Are potential biases, errors and uncertainties considered and discussed appropriately.

The reviewer's attention was also drawn to two further specific technical questions:

(6) LiDAR (sic.) data was processed to remove non-random error to the degree possible. Accordingly, two and three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?; and

(7) Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?

2. GENERAL COMMENTS

This report is an impressive and comprehensive examination of an ambitious field experiment. In recent decades, sediment augmentation has emerged a well-established intervention that aims to address the physical and ecological consequences of impounding and regulating natural river flow regimes. Few attempts to achieve this, however, have been designed as effectively and scrutinized as robustly as detailed here.

The approach taken is distinctive, and I would argue world-leading, for its application of powerful emerging technologies. The acquisition and interrogation of dense topobathymetric lidar covering a 6-year period provides an unparalleled, data rich lens through which to assess this intervention. While I have some technical questions over the precise approach to the volumetric change analysis and uncertainty estimation, I find the broad geomorphological interpretation astute and compelling.

Ultimately, the study demonstrates the complexity in insolating and explaining system-scale responses in a natural, open system over (what are logistically impressive, but nonetheless) short environmental timescales.

3. OVERVIEW AND STRUCTURE OF THE REPORT

The report is structured into four chapters, preceded by an Executive Summary. This opening summary synthesizes the findings of the study though a series of fundamental questions (E.1 – E.5, p. 8-10) that address directly the principal information needed to guide future decision-making.

Following this, the first chapter introduces the hydro-physiographic setting of the AHR and outlines initial modelling used to design the sediment augmentation experiment. Chapter 2 then provides a detailed evaluation of longitudinal trends in river response prior to augmentation. This chapter brings together multiple lines of evidence spanning a range of timescales to quantify incisional trends within the AHR. It clearly quantifies and explains the switch from vertical channel incision to lateral channel migration in response to declining bed slope and armouring of the bed of the J2 channel. Chapter 3 extends this analysis into the post-augmentation phase of the experiment (2017-2022), with a particular focus on longitudinal trends of thalweg and mean (active-) bed level responses. The methods used build effectively on those presented in Chapter 2 and focus principally on 1D longitudinal metrics of channel adjustment.

Chapter 4 provides the most refined analysis, drawing the spatially-rich, topobathymetric DEMs of the AHR. These are used to quantify the width-integrated, longitudinal distribution of net geomorphic change. The methods used are generally well-described and insightful. There are key hallmarks of excellence, for example, the use of numerical hydrodynamic simulations to segment geomorphic changes into lateral bank migration and vertical bed adjustment; and use of a discharge weighted normalization to compare changes before and after augmentation under varying flow conditions. As described in the sections that follow, I am sympathetic to the arguments against the application of thresholds to quantify erosion and aggradation volumes explicitly, however, I would argue that the treatment of uncertainties in the lidar models is somewhat superficial. This could be expanded and used to build a more comprehensive treatment of volumetric uncertainty that scales with area and puts the observed longitudinal trends of volumetric change within more robust statistical bounds. This will help to consolidate the broad findings of Chapter 4 and assist in the presentation of information to the key decision makers.

I have no doubt that the authors are well-aware that the current section, table and figure referencing needs to be updated and unified. The new referencing will then need to be married with the Table of Contents (TOC) on pages 4-6 and supported by a lists of tables and figures following the TOC. Aside from this, I found the report to be very well written and presented throughout. The text is succinct, effectively structured. The methods, results and inferences clearly demarcated and discussed critically. The figures are presented to a high standard and where appropriate, maps and spatial data are scaled, orientated and labelled clearly. In a small number of cases, individual captioning could be improved, and this is highlighted in the chapter reviews that follow.

The report draws comprehensively on the literature. This is used to support not just the justification and elaboration of methods but is also used to contextualize the results and substantiate the conclusions. Again, where relevant, additional supporting literature is highlighted below.

The review that follows examines each chapter in sequence and highlights specific questions/comments using the line numbers, table and figure referencing used in the draft document supplied. The executive summary is reviewed last, and my recommendations are presented at the end of this review. In line with the SOW and summary above, I have focused most of my attention on the technical methods and interpretations presented in Chapters 2, 3 and 4.

4. CHAPTER 1

Chapter 1 provides the introductory historical and geographical context, explains and justifies the selection and design of the augmentation experiment. The report reviews a range of studies from the literature that have sought to quantify incision associated with clearwater return flows from the J2 outlet and date back to Williams (1978).

A key focus of this chapter is the discussion of an early model of channel incision associated with clearwater flows published by Murphy et al. (2004). This study predicts the downstream propagation of a wave of incision, that is only arrested when the local rate of sediment transport falls in response to armouring of the bed and decreasing slope. The authors note that this model is based on assumptions of uniform sand and steady flow – factors that as described in Chapter 2 – are likely to explain the difference between this hypothetical model and the slower rate of wave propagation observed in reality. The review then clearly describes how these initial conclusions were refined through the development of the initial (SED-VEG) and then updated (HEC-RAS) numerical simulation tools to predict the annual sediment deficit in the AHR. Details of the modelling are not discussed (having been published elsewhere), but the spatial pattern of the predict sediment deficit is carefully presented, and used to frame the initial 2012-2013 augmentation experiment.

Experience during this trial is discussed and the report builds on this to justify the approach adopted for the large-scale augmentation experiment in 2017-2022. The selection of bulldozing material in late summer/early fall from the reach shown in Figure 0.5 (page 19) is well-presented. This assessment involved a careful appraisal of sediment availability, the development of design surfaces and used a reflexive approach that adapts to flow conditions.

Comments/suggestions:

This is a well-written chapter with few suggested changes or comments. The only points I would raise are:

4.1 Figure 0.5 (page 19) does not have a scale bar and the legend would be better placed at the top of the image rather than obscuring the channel. This is a complicated map, with multiple, overlapping layers – could it be simplified with better rendering? The caption also relies on an acronym and should really be able to stand in isolation (which is does not at present).

4.2 In the discussion of the as-built augmentation volumes (p 21, lines 279-298), while there is reference to adapting the volumes to flow conditions, the role of the Breakthrough Channel as an additional source of material is not discussed. This is reviewed in Chapter 4, but it may be useful to signpost this discussion here.

5. CHAPTER 2

This chapter seeks to create baseline information on the dynamics of channel adjustment across the AHR prior to the start of large-scale sediment augmentation in 2017. A methodology is presented that very effectively draws together multiple lines of evidence and triangulates results to shine a light on the system-scale behaviour. These methods include: the geomorphic interpretation of airborne lidar surveys; integration of these data with historical section surveys; reconstruction of at-a-section bed level change via specific gauge analysis; and an assessment of changing planform geometry. This is an impressive array of techniques that are brought to examine and quantify trends in river behaviour. In concert, they create a robust baseline against which changes during the augmentation experiment can be set.

A central tool to assess current and historical trends in the morphology of the AHR is the development of the Geomorphic Grade Line (GGL) as discussed in Section 1.9 (p. 28 onwards). The method is well described and the production of a Relative Elevation Model (REMs) for 2016 provides a powerful lens on longitudinal patterns. Specifically, this approach enables quantification of the current channel morphology relative to the average elevation of wider valley floor. This is an established tool to interpret channel and floodplain morphology that maximises the rich 3D information in remotely sensed river models (see Brasington et al., 2003 doi.org/10.1016/S0169-555X(02)00320-3; Westaway et al., 2003 doi.org/10.1080/01431160110113070 for some early examples of the approach)

Both thalweg elevation (deepest point in a section) and the mean bed level (averaged over the active channel) are compared to this regional sloping datum. Figure 2.6 shows thalweg elevations relative to the GGL and is a visually compelling summary diagram that captures succinctly the state of the system in 2016. It is an exemplar communication tool. This approach is then extended by integrating thalweg elevations from cross-section survey data in 1989 and 2002, enabling a deeper perspective on the progression of incision over a >25 year period.

Together, the resulting data provides the necessary spatiotemporal information on channel incision that are required to test the forecasts of Murphy et al. (2004) discussed in Chapter 1. The net result is effectively summarized in Figure 2.8. This is a fantastic insight, which clearly demonstrates how the downstream wave of incision appears to have been arrested significantly quicker than forecast. It also reveals how thalweg depths stabilized by 2002, but that mean active bed level continued to decline until the last snapshot analysed in 2016. This difference reflects a change in the mode of channel adjustment, with a shift from vertical incision to lateral migration and the development of a dynamic meandering planform. The result is further supported by the analysis of sinuosity presented in 1.12 (page 47).

Evidence of incision below Overton Bridge is less clear from the lines of evidence discussed above. Thalweg elevations in this reach below the confluence rise gradually (from c. 6 ft at the bridge) downstream before stabilizing (at c. 3-4 ft) at the upper boundary of the Cottonwood Ranch reach. In the absence of repeat sections through this lower reach, the team have used specific gauge analysis also known as constant-discharge analysis to interpret long-term trends in bed level at the two rated sections – Overton Bridge and at the downstream end of Cottonwood Ranch.

This approach aims to infer changes in bathymetry through trends in water surface elevation (stage) at a given discharge. The methods used are well described (albeit not perhaps as well complemented by references to the literature – see comments below), and it is important to recognize that signals of changing stage are not unambiguously tied to a specific morphological change. Compensating changes in width, bed elevation, slope and roughness mean may lead to complex relationships that could be misinterpreted. This point is well-made (p.37, lines 52-57) although could have been expanded using examples from the literature (see for example Criss and Shock, 2001, https://doi.org/10.1130/0091-7613(2001)029<0875:FETFC>2.0.CO;2; Pinter et al., 2006 doi.org/10.1016/j.jhydrol.2006.06.013).

The approach taken here uses three reference discharges, representing an appropriate range of flow conditions from the duration curve, including an index for bankfull discharge. Appropriate statistical models are fitted to stage-discharge relationships around each reference discharge and trends derived for Overton back to 1988 and Cottonwood Ranch back to 2001. The results for Overton are interesting, implying c. 2 ft of incision to 2014, most of which occurred after 2000. At Cottonwood Ranch, the reach appears to have been stable or even net aggradational.

The interpretation of the results is supported by false colour composite imagery for each site, dating back to 1988 and 2004 for Overton and Cottonwood respectively. Interpretation of planform imagery is notorious complex, given the discharge dependency, and it would have been useful to determine and label the estimated discharge associated with these images (Figures 2.9-2.11 and 2.14-2.15). However, when the images are taken together with the specific gauge analysis (again as two complementary lines of evidence), the interpretations are justified, and the value of the gauge analysis to identify of cycles of incision is well made.

Comments/suggestions:

This chapter is very well designed and presented. Multiple approaches are used to detect and decipher trends in the incisional history of the AHR. Combining these results consolidates their interpretation and represents a very high standard of science. There are few specific suggestions I would make, but offer the following comments/suggestions:

5.1 There is no discussion of bed texture/substrate changes in the chapter. As the authors note, the arresting of incision is likely to reflect a combination of factors, including armouring, reduced slope and also exposure of poorly reinforced bank material. Do the authors have any insight into the principal driver of the changing nature of bed adjustment – and specifically – could the revised HEC-RAS sediment routing model discussed in Chapter 1 be used to isolate the significance of the controls?

5.2 The description of specific gauge analysis could benefit from some specific examples from the literature that describe how this approach has been used elsewhere and illustrates the complexities of deciphering bed level change from stage. I have suggested a couple of key examples (above) and there any many more.

5.3 What is perhaps of more interest, is the potential to explore extending this analysis in the future with new data from the Surface Water and Ocean Topography (SWOT) mission. The shortwave radar interferometry that represents the mainstay of this mission has the potential to provide consistent high frequency (7-11 day) measurements of water level, extent and slope at longitudinal spacing equivalent to one channel width. While the scale of the wetted width of the Platte falls at the observational limits of SWOT, these new data may offer the opportunity relax the requirement to focus adjustment solely at the gauged sections and provide an insight into streamwise variations in channel response. See Shaperow et al., (2019 - doi.org/10.1029/2019WR024938) for further discussion.

5.4 As discussed above, labelling the relevant discharge associated with the images presented in Figures 2.9-2.11 and 2.14-2.15 would support their interpretation.

6. CHAPTER 3

This chapter extends elements of the framework used in Chapter 2 to examine longitudinal patterns of channel morphological response through 2016-2021. This epoch represents a one-year lead before the large-scale augmentation began in 2017, but terminates a year before the experiment ended (2022). It's not clear why the period of assessment terminates before the end of the augmentation, but I presume this is when (2022) work on this report commenced? The focus again largely divides the AHR into the J2 reach to Overton Bridge and then Overton to KCD. The toolkit used to assess the pattern of river adjustment relies on multiple lines of evidence as described in Chapter 2, though here there is a greater reliance on formal statistical methods to identify variations in longitudinal response, for example, changepoint analysis (space-series segmentation) and piecemeal modelling of long profiles using a variety of GAMs. The bulk of the analyses are derived from a collection of six topobathymetric lidar surveys of the AHR commissioned to capture the system in late summer/fall each year. This is an impressive dataset and – as highlighted previously – sets this work apart in terms its data rich assessment framework.

The use of changepoint analysis to segment longitudinal patterns of channel adjustment is revealing. This provides an excellent framework to identify discrete, localized trends in incision/aggradation. In addition to direct morphological metrics (thalweg elevations; mean bed levels; local slope), numerical hydrodynamic modelling (HEC-RAS and SRH-2D) is used to predict the effects of changing morphology of downstream wetted width at a reference discharge of 2,000 cfs. This flow represents the operating capacity of the J2 return channel and is sufficient to inundate bedforms and the full channel from Overton to KCD. The analysis integrates results from earlier 1D HEC-RAS modelling (for 2009 and 2012) with SRH-2D models parameterized using topobathy lidar from 2016, 2017 and 2021 (through the augmentation period). The modelling provides insights into the hydro-ecological functioning of the system and is an excellent tool to interpret changes riverscape condition. Intriguingly, the analysis revealed the importance of natural flow events, and particular the role of the high flow event in 2015. This event has clearly played a critical role in reshaping the morphology below the J2 confluence; resulting in a 50% expansion of wetted width at the reference 2000 cfs level. This active width appears to have been sustained through the augmentation period.

The summary conclusions appear to be well justified, with multiple lines of evidence proving an effective means to reinforce the key inferences. A key insight from the analysis is that while there is evidence of an aggradational response within and immediately downstream of the augmentation area, incision and planform change continued to progress downstream in the lower J2 channel during the augmentation experiment. In this lower reach, significant lateral migration of the channel was evident, resulting in the decline mean bed levels and reduced channel gradient. The rate of progression was, however, relatively slow and, if consistent over time, would imply a decadal timescale for complete transformation to a wandering planform of the J2 channel downstream to Overton Bridge.

The reach below Overton appears to be more resilient to change. In part this reflects sediment inputs from the North Channel, but also evidence that upstream incision in the J2 channel correlates with downstream aggradation below the confluence. This latter pattern appears to be strongly linked to transport capacity, with sediment stored in the J2 reach in dry years and more transported downstream (supporting aggradation) in wet years.

The correlation between channel wetted width and gradient and the inference that a slope threshold of 0.001 is associated with the transition between wandering and braiding planform dynamics is interesting. It is tempting to suggest this threshold is a discriminant index of flow strength, i.e., specific stream power or mean bed shear stress. However, other factors may be just as critical in the maintenance of braiding and could confound this singular interpretation – notably variations in upstream sediment supply (below the North Channel confluence) and bank strength. Additionally, this relationship is presented only for one reference flow condition (2000 cfs). As bed adjustment occurs over a much wider range of flows in sand-bed channels, it may be hazardous consider a single particular flow association. In summary, I would be cautious of using threshold slope relationships in a specific management context.

Overall, the methods used are well described and conclusions justified. The following are a small number of specific comments/questions and/or suggestions for additions or changes:

6.1 The use of terrain based hydrological analysis to derive thalweg depths was not discussed in Chapter 2 in associated with Figures 2.6 and 2.7. Was the same approached used there, in which case it may make more sense to shift the description on page 57 back to Chapter 2. Alternatively, was this approach only used here, and applied as a means to estimate the thalweg alignments and local slope gradients – both of which requiring continuous, spatially contiguous elevation series?

6.2 Figure 3.5 is too small – enhance this plot by presenting as a single page.

6.3 The caption of Figure 3.16 is disconnected from the figure itself (page 72/73).

6.4 It would be useful to plot the timeseries of thalweg alignments around station 70,000 as an accompaniment to Figure 3.18.

6.5 The discharge at the time of capture for the aerial imagery shown for 2016 and 2021 in Figure 3.2 clearly differs. I would be useful to back out the discharge for the two acquisition dates and add this to the images as a label or as a note in the caption

6.6 Treat discriminant slope relationships with caution as per my comments above.

7. CHAPTER 4

In Chapter 4, the assessment of the augmentation experiment is extended to consider net volumetric change over the AHR. The supporting data are measured using DEM differencing methods, making full use of the 3D information in the series of the topobathymetric DEMs. These data offer important insights into the geomorphic processes driving evolution of the AHR and enable direct linkages between the volumes of material entering the reach via augmentation or natural supply (via the breakthrough channel), and the volumes of stored, eroded and transferred longitudinally.

Overall, I find the methods used here to be well-executed and carefully considered. The conclusions are intriguing, in particular the finding that the bed degradation of the J2 channel decreased by between 45-60% of the pre-augmentation rate. Volumetrically this decline is calculated to be approximately equal to the volume of material transferred downstream from the augmentation zone. This correspondence raises the question of whether the ultimate goal of arresting degradation in the J2 channel could be achieved by (at least) doubling the rate of managed supply. This inference is supported by the apparent downstream connectivity revealed by supply from the augmentation zone and mean bed level adjustment show in Figure 0.11 (p. 102).

This is possibly the most significant conclusion of the entire study from a future management perspective. However, while this appears to offer an attractive forward trajectory, the chapter also reveals the confounding influence of flow and sediment supply through the breakthrough channel during the early years of the experiment. While it's difficult to evaluate the relative roles of these 'natural' and 'anthropogenic' drivers, it does seem likely that continuing attempts to address the sediment deficit in the J2 channel may potentially mitigate the impacts of incision in the lower reach of the channel, and potentially delay or even prevent incision progressing downstream of the North Channel confluence. Uncertainty in predicting future channel adjustment is further complicated by the potential for autogenic stabilization of the lower J2 channel through the process of continuing lateral migration and a concomitant reduction in channel gradient.

While the conclusions of the chapter are, I feel, largely justified and well presented, the scope of this review asked specific questions regarding the methodologies used. There are four components to the work that I feel are important to discuss in this context:

7.1 DEM differencing methods

The approach to DEM differencing applied herein follows the philosophy described in Anderson (2019 – see also Anderson and Pitlick, 2014 - doi:10.1002/2013JF002933). Briefly, Anderson (2019) argues that for the analysis of NET VOLUMETRIC CHANGE it is advisable to neglect the presence of normally distributed random DEM errors as, in summation, these cancel out and contribute negligibly to the overall uncertainty estimation. A caveat, is that this dependency relies on a large sampling interval, and is appropriate only when considering net change integrated over relative large areas – as applied here (where changes are integrated over downstream units equal to c. two-channel widths).

Anderson (ibid.) also argues that the – more conventional – use of detection thresholds to distinguish significant vertical changes from 'random noise' may actually create systematic bias in estimates of volumetric change. This holds true particularly when the vertical magnitude of changes is unevenly distributed about zero. Fluvial processes are an important case in point, as a common observation is that erosional processes are characterized by a signature of localized but deep (high magnitude) scour, whereas aggradation is more typically associated with comparatively shallow (low vertical magnitude) but widely-dispersed sheets of material – see the discussion in Brasington et al., 2003 (referenced above) and also Vericat et al., (2017 – cited within the report). The application of thresholds to distinguish significant changes may, therefore, distort the calculation of net volumetric change by preferentially disregarding shallow – aggradational – changes, while 'retaining' deeper, erosional signatures of bed adjustment. This point is well made on p. 93, and I concur with this judgement for the estimation of NET volumetric or mean bed level changes.

Following the logic of Anderson (2019) the dominant term in an uncertainty assessment of DEM change is, therefore, the presence of uncorrected systematic errors. Briefly, he demonstrates that these errors will scale linearly with the area over which volumetric changes are integrated. When changes are incrementally summed downstream – for example in the estimation of cumulative volumetric change shown in Figure 0.9 (p. 97) – the uncertainty bounds around this sum will grow in proportion to the integration area scaled by the systematic vertical uncertainty.

Where I might raise an orange flag in the current analysis, is that such systematic errors appear to have been largely neglected on the basis of two actions:

a) Limiting the analysis to an area of interest representing the time-integrated active channel. This is justified as an attempt to focus the calculation of net volumetric change within areas where fluvial processes are dominant. This will eliminate the influence of lidar related artefacts such as differential vegetation penetration, that might otherwise dominate volumetric budgeting over wider areas; and
b) By arguing that common artefacts in lidar-derived DEMs, associated with uncertainties in the POS (position and orientation solution – or trajectory) were eliminated by refined processing undertaken by QSI in which the 2019 surface was used as a datum to calibrate the navigation solution for the remaining surfaces.

With regards to (a) ... restricting the net volume change calculations to a hydrodynamically defined AOI is good practice, and I fully endorse this approach. However, to argue that this will mitigate systematic lidar related uncertainties such as vegetation penetration is to ignore the presence of significant bar top vegetation cover within this AOI – as shown clearly in Figure 0.5 on p. 91. A similar logic applies to the accuracy of bed elevations in the subaerial and subaqueous areas of the survey – which have significantly different vertical accuracy assessments as shown in Table 0.3 on p.93. It is, in my view, highly likely that the ability to detect vertical changes reliably will be strongly conditioned by these surface cover effects (vegetated/unvegetated, wet/dry) and the direction of the surface cover changes. Ignoring these effects, would – following Anderson – only be justified when the units of volumetric integration (the 2-channel width cells) contain comparable proportions of these various cover types and the confusion matrix of change-types is balanced.

With regards to (b) ... calibration of the lidar models to a common reference datum is good practice. This approach seeks to ensure accurate georegistration of the surfaces to a consistent internal measure used throughout the analysis – rather than relying solely on independent geodetic control of each model. The ‘flightline-dependent tilts’ referred to on page 93 (and also rather loosely by Anderson, 2019) comprise two components. The first of these are global boresight parameters representing the alignment angles, mirror optics and time differences between the laser scanner and inertial navigation unit. The second component represents time-varying uncertainties in the POS that are associated with high frequency GNSS positional errors and the inertial measurement of acceleration and orientation. While it is arguably possible to minimize the global boresight error through co-registration (i.e., reducing the mean difference to zero), the time varying component of the POS uncertainty will always propagate into the estimation of sensor position and attitude. This uncertainty will then be compounded further by errors in the range estimation associated with the laser scanner itself. These effects are usually solved by using information content in two overlapping point clouds to define time-varying adjustments to the boresight that serve to minimize differences along individual trajectories.

The source of elevation uncertainties does not end here and may be magnified further along the lidar processing and DEM generation chain. Variations in point density, slant angle, classification of the point cloud and ultimately the interpolators used, including the presence/absence of breakline data, all impact the quality and accuracy of a terrain model systematically. To assume that all such systematic errors have been corrected (as asserted on p. 93) without demonstrating this is hard to justify and difficult to believe.

Addressing the above sources of uncertainty is far from straightforward! Previous work has argued for the application of rigorous forward uncertainty estimation of uncertainty to quantify the full error budget on a pulse-by-pulse basis. This approach extends the methods used for the total estimation of uncertainty used in terrestrial laser scanning – see for example Lui et al., 2021 (https://doi.org/10.1016/j.autcon.2021.103673) building on Lichti et al., (2005 DOI.ORG/10.1061/(ASCE)0733-9453(2005)131:4(135)). A similar philosophy is used to support the quality assessment of multibeam echosounder (MBES) data via the calculation of total propagated uncertainty (TPU). Such approaches will not however, account for the effects of variable point density, slant angle, classification (including vegetation penetration) errors and subsequent interpolation.

In practice therefore, these combined effects are more typically assessed empirically. A common approach is through the examination of vertical and horizontal errors associated with what are presumed to be stable, reference surfaces. This assessment should focus on the DEMs produced (cf point clouds) as these integrate all of the above effects.

The analysis reported here could be strengthened by quantifying the magnitude and direction of systematic differences between DEMs, estimated by a computing DEM differences over areas presumed to be unchanged through the analysis period. This could be achieved relatively easily, by selecting a set of hard surfaces (roads, bridge decks), as well as roughened areas and areas under vegetation cover outside the active channel and extracting a large set of elevation differences taken from multiple, (spatially dispersed) independent test areas. The resulting sample errors could then be quantified either as empirical confidence intervals, or under assumptions, in terms of the mean error, SDE and RMSE. These metrics provide a practical insight into the typical magnitude of elevation differences between stable surfaces and offer evidence for systematic directional effects.

This approach is essentially that used in Anderson (2019). We could debate whether this analysis actually quantifies 'systematic' errors, but it is a means to approximate the uncertainty that cannot be eliminated in DEM differencing. Following Anderson, if this error term is then assumed to be spatially uniform (!), it will scale linearly with the integration area over which net change is calculated. The uncertainty used to provide local confidence intervals for each integration area and integrated into the longitudinal plots such as Figure 0.7 (p. 95) and used to derive the cumulative downstream uncertainty for the analysis plotted in Figure 0.9 (p.98) > see for example Anderson (2019) Figure 11.

An alternative approach that may also shed some additional light on systematic errors within a single survey (as opposed to co-registeration errors), would be examine the strip-matching results that QSI should have produced as part of their data deliverables. This metric examines the statistics of elevation variability in the overlapping regions of individual flightlines, and provides a useful indication of the magnitude of unresolved boresight errors and their spatial distribution.

As an indication of what an additional focus on uncertainty might reveal, take the total cumulative change shown (2021-2016) between the augmentation boundary to Overton shown (Figure 0.8 and Table 0.4 p.96/97). This is currently reported as -88,800 yd^3/yr. I don't have the AOI to hand, but let's assume the active channel is 450 ft wide (p. 91) and length of the reach is 32,000 ft (Table 2.1, p. 28). The integration area for the cumulative sum is therefore c. 1,599,998 y^2. If we take a vertical systematic error equal to c. 2 in (0.0555 yd), the total volumetric uncertainty over this area would be +-88,889 yd^2. While these numbers are only indicative, they serve to contextualize the cumulative sums of net volumetric change presented in Table 0.4.

7.2 Net Change Versus Erosion/Deposition Volumes

The approach of Anderson (2019) – neglecting random errors – is appropriate when computing net volumetric change. Net negative or positive volume of change, are not, however, equal to volumes of erosion or deposition. The actual volumes of the negative/positive changes will be larger than any net change, and moreover, should be treated with care to isolate changes that can (in this case) be distinguished from random errors.

I am therefore, a little confused how the values presented in Figure 0.10 have been estimated? This table shows the 'volumes eroded' from the J2 channel within and downstream of the augmentation area – both pre- and post-augmentation. It is a little unclear whether this is a rather 'loose' description and has somehow been derived from the net negative volume change, or whether the actual values of erosion have been estimated here by DEM differencing. If the latter, details of how thresholds have or have not been applied requires discussion, and it obviously opens questions about whether/how this approach to change detection generates net volume changes that differs from the results presented elsewhere. There is a clear potential to 'let the cat of the bag' here and the details of this needs to be clarified – especially given the significance of the erosional volumes relative to the augmentation volume.

7.3 Lateral Erosion versus Bed Aggradation/Incision

The use of numerical hydrodynamic model simulations to segment changes that into patterns of fluvial adjustment that represent lateral channel migration versus vertical bed deformation/transfer is an excellent approach. The discharge ranges used also appear appropriate.

The methods used here aim for a similar outcome to that of Llena et al., (2024 - doi.org/10.1130/B36720.1) in their analysis of channel adjustment and planform change in the Marecchia River, Italy. In their case, however, segmentation was based on geomorphic mapping and assessments of river confinement. That approach is in turn, a simplification of the method used by Wheaton et al., (2013 - doi.org/10.1002/jgrf.20060) to segment changes into specific braiding processes, defined by discrete morphodynamic signatures. These papers could provide a useful discussion of alternative approaches to segmenting DEMs of difference. An important distinction with this adjacent work, however, is their use of DEM differencing thresholding techniques, which permit direct assessment of volumes of erosion and scour and an insight into the geomorphic processes acting.

The only concern I have in this regard, is that the absence of graphical plots of DEM differences for each period precludes a qualitative assessment of the validity of this approach. I can't really see why these plots are not included in this Chapter as they would provide an important visual lens to interpret key changes within the AHR.

7.4 Normalization of Volumetric Change by Discharge

To compare the scale of pre- and post-augmentation volumetric change, the total volumetric change budgets are normalized not by time, but by the cumulative sum of Q^2. This is another excellent approach, as it reflects directly the potential geomorphic work over these two periods. This is an important contribution, that accounts for variability in flow between the two periods and the exponent used in the sum is fair reflection of the driver of transport processes in sand bed rivers.

Beyond these major discussion points, some smaller comments include:

7.5 As highlighted above (6.3) DoDs for the full sequence should be presented in full page map formats, extending the exemplar plot of Figure 0.4;

7.6 Figure 0.1 needs to contain a scale bar and ideally an insight to reveal its location;

7.7 The same is true for Figure 0.5.

7.8 What are the vertical accuracy metrics reported in Table 0.3? Are these empirical confidence intervals or 2 x the standard deviation of error. It would also be normal practice to identify any bias (via a mean error term). If the individual DEMs have been co-registered to 2019 (as discussed on p. 93) then it is unlikely that the mean error (by comparison for RTK GNSS observations) would be zero;

7.9 As discussed in 6.1 above, if a systematic uncertainty term is computed and assumed to scale linearly with the integration area, the models of longitudinal net volumetric change (i.e., Figure 0.7) could be presented as envelope curves, the width of which will largely reflect the area of the AOI within each 900 ft cell.

8. SUMMARY

Overall, this is a very well executed and interpreted analysis of the augmentation experiment. The work has been carefully designed, rigorously completed and draws on a world-class dataset. The methods used reflect the state-of-the-art in fluvial geomorphology and geomorphometry.

I have raised a number of discussion points through this review, the most significant of which relate to the DEM differencing methods employed in Chapter 4 and, in particular, the absence of formal quantification of volumetric change uncertainty. I appreciate the approach taken by the team in this regard but would encourage them to consider the range of options available to compute the residual systematic error and to incorporate this within the presentation of the results.

9. REVIEW SCORES AND RECOMMENDATION

CATEGORY	RATING
Scientific soundness	1
Degree to which conclusions are supported by the data	1
Organization and clarity	1
Cohesiveness of conclusions	1
Conciseness	1
Important to objectives of the Program	1

RECOMMENDATION	
Accept	
Accept with revisions	x
Unacceptable	

Dr Mark W. Smith, University of Leeds, Leeds, UK.

Review of Platte River Recovery Implementation Program (PRRIP) Sediment augmentation data synthesis compilation

The 'Sediment augmentation data synthesis compilation' is a detailed and well-presented body of evidence regarding the efficacy of a long-term sediment augmentation experiment. An impressive dataset has been compiled, detailing a number of lines of evidence which generally support the conclusions made. Evidence is primarily derived from LiDAR surveys, aerial imagery and flow gauge data. Each chapter presents numerous lines of evidence with generally support the overall conclusions of the report. The challenges of a real-world natural experiment are well articulated (P2). The authors correctly note that an experimental control is not possible given the nature of the Big Question articulated. Moreover, while subject to uncertainty, the flow normalization methods (P98) go some way towards correcting for the variable conditions experienced in the pre- and post-augmentation periods.

Incision of the J2 Return Channel since 1984 has been triggered by clearwater hydropower returns. The extent and magnitude of the incision of the J2 Return Channel is clearly and unambiguously presented (P31, P32). The channel degradation is supported further by specific gauge analysis (P41) which also shows that the pronounced incision has not progressed as far downstream as Cottonwood Ranch (P45). Prior to sediment augmentation, incision seems to have given way to lateral migration as the primary mechanism of channel change, especially in the upper portion of the channel (P34, P70). Sinuosity here has also increased (P47). The magnitude of sediment supply via lateral erosion is comparable to that of the sediment augmentation.

Despite extensive sediment augmentation, the incision of the J2 Return Channel has continued to progress downstream (P52, P62), especially in high flow years (P63). Fortunately, there is clear evidence that disturbance has not propagated downstream of Overton bridge (P53, P62). Direct comparison of pre- and during sediment augmentation periods is challenging owing to the different hydrological conditions. There was a decrease in bed erosion by 45-60% upstream of Overton Bridge since sediment augmentation; however, correction for changing conditions for this via flow normalization shows little difference in volume change before and after the augmentation (P98). It is hard to evaluate the specific effect of augmentation on the incision, though there is limited evidence for some positive effect at the upper reach. Whether it can stop the downstream progression of that incision is unclear.

Main Comments

Here, I expand on a few main comments arising from my review of the document. These relate primarily to the evidence presented in the compilation document. I'm mindful that program decision makers will need to make decisions regarding future management strategies based on this evidence. My comments and suggestions are therefore presented with this in mind and aim to maximise the utility of this document.

More specific comments (detailing page and line numbers) are provided at the end of this document.

1. Catchment Perspective and History

History and context of the PRRIP is well detailed in Chapter 1. It would be useful (especially for those of us previously unfamiliar with the catchment) to see a little more context of the broader catchment and its history. For instance, very limited information is provided as to the upstream catchment. This is relevant to the question at hand as it provides information on water and sediment fluxes expected and what may have been experienced in the past. From what I could gather, the water of the J2 Return Channel was taken from the Platte River just downstream of the confluence of the north and south branches near North Platte. It then runs through a series of reservoirs before being returned to the channel as a clearwater flow at the J2 Return Channel. I would be interested to know the approximate magnitude of the abstraction near North Platte.

Also, the historical development of the channel system is important context. Prior to the diversion for reservoirs and HEP, was the J2 Return Channel just a branch of the main Platte River (perhaps the downstream extension of the breakthrough channel that naturally forms)? I did a bit of searching and found a 1951 aerial image that showed a much stronger linkage between the 'North' channel and the J2 Return Channel here. In fact, the North Channel seemed to contain relatively little flow by comparison, though it is hard to tell for sure in the black and white image. The longer-term decline in discharge and channel narrowing since 1865 presented by Williams (1978) (seemingly arising from upstream reservoirs and irrigation) is briefly mentioned in Chapter 1, and also provides useful context with which to interpret measured channel behaviours in response to these clearwater flows.

While none of this information changes any conclusions of the report, these are questions I find myself asking when considering optimum future management plans. A paragraph or two in the 'History and Context' could readily provide this information.

2. Channel Fluxes
I realise there is a lack of information here, but also a general idea of the relative magnitudes of flows in the North Channel and the J2 Return Channel would be helpful up-front. This is most clearly presented on P88 (and the North Channel flows can be estimated by subtraction), but it is useful background through which to assess the findings.

The reason for such information is to get a better idea of the more natural sediment budget here. Are there no direct sediment transport measurements? Are there any estimates of sedimentation rates in the upstream reservoirs? These field measurements would give a better idea of the volume of sediment needed to provide balance to the channel reach. I realise that these data simply may not exist, but it would be useful to identify this data gap somewhere in the document.

3. Field Photographs and Observations
The value of seeing imagery of the river on or close to the ground cannot be underestimated. For example, the image on P22 really helps to set the scene. It was surprising to see so few images of these river systems, aside from aerial imagery. Descriptions often refer to incision (e.g., in the description of the REM on P30). I'd be interested to see these cuts in the field to get a better handle on how the system is changing.

4. Separation of Methods, Results and Discussion
I would encourage a clearer separation of Methods, Results description and Interpretation of data (see also point 6 below on Data collection). The latter two categories are often quite mixed in Chapters 2-4. There is of course an argument to mix these together (it is generally a matter of preference). Likewise, ensure all methods are fully described prior to the results section. The general structure is to provide the Methods/Results of each line of evidence used within each chapter. Perhaps a short Discussion section too would help isolate interpretation from the description?

Generally though, the report structure is clear. The section and figure numbering issue on my copy did confuse it a little, but this will not be an issue in a finalised version.

5. Chapter 3 Rationale
Given the excellent LiDAR dataset assembled, I found myself excited for the identification of areas of erosion and deposition and a volumetric analysis. Prior to this (in Chapter 4), Chapter 3 isolates several key measurements from these LiDAR data and provides a detailed analysis (e.g., thalweg profile, channel width, channel slope, sinuosity). The rationale for reducing the data in this way would be useful to articulate, presumably: (i) for more targeted analysis of hydrologically important variables; and (ii) more direct comparison with pre-augmentation data and trends (Chapter 2).

Many of the same conclusions were, of course, repeated in Chapter 4, as expected given the same underlying LiDAR dataset. Chapter 3 is the longest chapter in the report and the key messages and findings (and how the contribution is different to other chapters) got slightly confused to me on first reading.

6. Data Collection and LiDAR Methods

The LiDAR data sources are described briefly here (P85). It would be informative and transparent to see more specifications of the LiDAR system used, dates of data capture, target flying height, (etc.). Overall, the description of this data collection was rather brief. It also comes quite late in a document (P85) which first presents Relative Elevation Models (REMs) derived from these data from P31 onwards. A section detailing all data collated in the report (e.g., LiDAR, GPS ground control, gauge data) and description of that data collection might be useful earlier in the document.

The project takes the approach of Anderson (2019) and does not threshold DEMs to a minimum Level of Detection (LoD) before calculating erosion/deposition volumes. Given the scale of the systems under evaluation, I have no issue with this approach and, in general, am convinced by the main interpretations of these data.

I would be interested to see more details regarding these systematic errors. Data were post-processed to correct for flightline errors (but not 2009). What were the magnitude of changes arising from this post-processing? Vegetation changes are recognised but not directly considered. Disking of vegetated bars in the Cottonwood ranch is mentioned (P55): did this show up on any DEM of Difference? See comment 7 below.

Generally, it seems that the LiDAR data are accurate to within 3 inches on stable non-vegetated surfaces, perhaps lower where vegetation is present and up to 9 inches in wet areas. Generally, I would expect these to be a reasonable overall error estimate, though in the presence of steep surface features (e.g., banks) the sub-grid variability in elevations might also be of a similar magnitude or even more in isolated grid cells.

The mixture of models and LiDAR data became confusing (e.g., P71). It became hard to identify exactly what output data these models were being used to compute. A flow chart of the method and how LiDAR and models were used to determine key outputs might be informative and add clarity to the overall data processing workflow thereby improving reproducibility.

Perhaps the method that requires the most careful description and cautious interpretation is the calculation of sediment volume changes from the 2009 LiDAR data that had no bathymetric component. I can follow the logic of taking the mean modelled depth and assuming fill below the water surface to give a maximum possible value. However, of all steps this method (P90) seems most open to criticism. Thankfully, ranges are presented and the shortcomings of this approach are acknowledged fully and on reflection I do not believe this method and associated uncertainties change the key conclusions. Still, any attempt to prove the limited impact of this assumption is welcome.

7. Presenting and interpreting DEMs of Difference

The most surprising thing about Chapter 4 was the absence of DEMs of Difference (DoDs). Only one is presented (P90) as part of a demonstration of the method. These data products are extremely useful to evaluate any potential issues arising from systematic errors identified (described above). Moreover, all discussion appears to describe ‘net’ change in the system, while absolute magnitudes and locations of erosion and deposition are not presented. Presumably, this is because of the need to implement a minimum level of detection to compute such estimates reliably (again though, there is precedent here: Wheaton et al., 2010; Brasington et al., 2012; Smith et al., 2015). A minLoD could be computed from sub-grid elevation variability (if available) or simply the error metrics reported on P93 (though these would be conservative where vegetation is present). To be clear, I don’t think calculation of the absolute magnitudes is necessary, but I do think some presentation of the DEMs of Difference adds confidence to the approach, would clearly indicate any systematic errors in the data and gives a richer understanding of the nature and pattern of geomorphic changes in the river (even if this can only be presented by differencing the first and last available survey).

Related to that, I wonder about the style of geomorphic change. Are these big localised changes, or more evenly spread out? A DoD reveals this, as does creation of a histogram of change (plotting the frequency of grid cells that experience different levels of elevation changes) see the citations earlier in this comment. Overall, these analyses yield both greater insight into the processes and greater confidence in the data. I would encourage the addition of these analyses.

8. Summary section

A Summary section would be useful or further specifics could be added to the existing Executive Summary. While the Executive Summary gives an overview of the findings, linking back these findings to specific lines of evidence (e.g., Figures, Tables) makes it easier to see how justified these conclusions are. This is best placed at the end of the document. Such references could equally be added to the Executive Summary (as in P8, L22). While I feel that the evidence compiled in the report supports the key overall conclusions of the document, I note that a few lines in the Executive Summary (e.g., P9, L51-52) push the interpretation a little further than the rest of the document (see my response to General Question 2 below). I would suggest caution here, or at least making these clear links back to the line of evidence from which each statement is derived.

9. Relationship of changes to habitat suitability

To finish on a few broader comments (see also comment 10), the data compilation does a good job of presenting channel changes both before and during sediment augmentation. The stated purpose of this is to preserve habitats of target species. However, the link between these changes and species habitat is only loosely made. What is the relationship between incision and habitat suitability? Likewise, the identification of pronounced channel widening at Cottonwood Ranch (seemingly against a backdrop of long-term channel narrowing presented by Williams, 1978) seemed like it might be good news, though I could not be sure. It seems likely that such interpretation is beyond the scope of this data compilation but seemed lacking given the focus on Extension Big Question #3 (P23).

10. Broader thoughts

Appropriate questions are raised in the Executive Summary. There remain many unknowns here. It does seem that the incision is still migrating downstream despite sediment augmentation, but I agree with the suggestion in the report that this migration rate will likely slow once it reaches the main channel and the impact of floods and variable flows/sediment input buffers the incision.

It leaves the question of what to do about the J2 Return Channel. I recognise the broader management context here too (e.g., the need to refill the meander and so locally steepen the reach to protect the building on the right bank). The suggestions of shifting augmentation location downstream and passive augmentation had been raised in my mind too. The breakthrough channel is something that also keeps raising itself. The longer-term history of the channel seems to suggest that more flows were once routed through the J2 Return Channel as recently as the 1950s (from the aerial photograph I found). The fact that when this breakthrough occurred it “periodically conveyed a substantial volume of flow and sediment” (P86) it does identify itself as a naturally dynamic component of the system and something that would fully convey the augmented sediment. However, the suggestion of the report is that the 2019 breakthrough event was the main driver of increased incision in that year. Given the 15 ft elevation difference that now exists between channels (P32) as a result of degradation, such breakthroughs do seem likely in future.

The focus on the transition between meandering channels and braided sections is also interesting and seems relevant given the focus on habitat protection. While not to be taken exactly (there are many qualifiers and complications), I found myself considering the old Leopold & Wolman (1957) graph that roughly identifies a threshold between meandering and braiding. Again, I wouldn’t focus on the specifics here, but even plotting the ‘bankfull’ discharge level (median annual peak) at Overton (downstream of the confluence) and we are close to/below the threshold line for either the old or new slopes. The 2500 cfs used to estimate the bankfull discharge of the J2 Return Channel (P90) would plot below this and sit firmly in the meandering section. Clearly, the braided reaches of the river (e.g., the onset of braiding at Station 60,000 at the point of high slope in 2016) show that the Leopold & Wolman (1957) relation is not exactly correct (and there are many examples in the literature where braided sections plot below the threshold line), but it also indicates that braiding might not be sustainable (or stable) in the J2 Return Channel at the present levels of return flow. These observations should be placed into the long-term context of discharge decline in the reach from irrigation, etc. (see comment 1 above).

General Questions

1. **Does the Sediment Augmentation Data Synthesis Compilation adequately address the overall objective – to synthesize multiple lines of evidence from the Program's full-scale sediment augmentation experiment to assess overall results and provide useful information for decision-making related to future sediment augmentation management actions?**
   Yes. This is a well presented and well-compiled report of an interesting management implementation. A data-rich approach is taken and the data are interrogated thoroughly and appropriately. The use of multiple lines of evidence that each confirm a clear outcome adds further support to the conclusions made. My comments above are mainly focused on increasing the clarity and adding further contextual information to support decision-makers, but I endorse the findings made here.

2. **Do the authors draw reasonable and scientifically sound conclusions from the information presented? If not, please identify those that are not and the specifics of each situation.**
   Yes. The data are clearly presented and support the conclusions made. While I have minor suggestions regarding data presentation of the volume change results, these are simply to give further confidence that systematic errors are not problematic. The fact that the evidence presented by the volumetric change analysis confirms previous thalweg-based analysis suggests that none of this would adjust the overall conclusions made.

   The line in the Executive Summary (P9, L52) that half the bed erosion was offset by sediment augmentation might be a little strong given the results from flow normalization (P95-97) and should perhaps be stated more conservatively. At the reach scale to Overton bridge, it may be true since it seems sediment has not been mobilised this far and has been added into the system, but whether or not it is protecting against incision I'm unsure. I'm not 100% clear where the evidence is that the incising channel may be recovering slightly (L51). These few lines are the only such instances I can identify.

3. **Are there any seminal peer-reviewed scientific papers omitted from consideration that would contribute to alternate conclusions that are scientifically sound? Please identify any such papers including citations**.
   I suggest that the overall conclusions are scientifically sound. The citations I present in this document regarding DEM differencing (Wheaton et al., 2010; Brasington et al., 2012; Smith et al., 2015) and sediment budget segregation (Wheaton et al., 2013 in minor comments below) are simply alternative approaches to some of the methodological choices here.

4. **Are the statistical methods and modeling tools used valid and current, and are the associated results presented in a manner useful to Program decision-makers?**
   Yes. There are no issues here. The most complex statistics (GAMMs) are well explained and represented visually. Overall, the report takes a visual approach to representing the data which are also quantified into summary statistics. It is very clear. There were few details on the modelling methods used, though these were often not the core of the analysis, but rather provided a step of the analysis (e.g., to identify a wetted area for given discharge). I was a little unclear as to where in the workflow these models were used and their impact on the final findings (see main comment above), but again I should reiterate that I do not think this has any impact on the conclusions.

5. **Are potential biases, errors, or uncertainties appropriately considered within the methods sections and then discussed in the results and conclusion sections**?
   More discussion of these for the volumetric change analysis chapter would be useful (see main comment 6 above). The relative magnitude of different uncertainties relative to the differences observed could be better articulated. I should add that I see no cause for concern, rather it is in the interest of clear reporting to do so. Presenting DEMs of Difference would add further confidence that there exist no outstanding systematic errors in the data.

Technical Questions

6. **LiDAR data was processed to remove non-random error to the degree possible. Accordingly, two- and three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?**
   There is a precedent here (Anderson, 2019) which is cited by the report. While it is not my preferred method, I think it is appropriate for the scale of the study. The largest assumptions in the report arise from the calculation of sediment volume changes from the 2009 LiDAR data that had no bathymetric component (P90). The report clearly flags the uncertainty arising from this (e.g., P94) but would likely be the most open to criticism. As described in my comments above, I would like to see more DEMs of Difference to help clarify visually that no residual systematic errors remain.

7. **Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?**
   I can see that this method makes intuitive sense and is defensible. My previous experience was with the method described by Wheaton et al. (2013) of segregating the sediment budget by mechanism. The approach implemented here has the benefit of simplicity and would likely result in the same outcome. As per my minor comment (below) on P85, some visual example of this segregation process would be helpful as the description of the methods here was quite brief.

Peer Review Rating & Recommendation

Category	**Rating**
Scientific soundness	4
Degree to which conclusions are supported by the data	4
Organization and clarity	3
Cohesiveness of conclusions	4
Conciseness	3

I wasn't sure how to interpret the below category. I assume it reflects the degree to which the report addresses the program's objective (though I note it does not address habitat directly)?

Important to objectives of the Program	4

RECOMMENDATION	**(Check One)**
Accept	
Accept with revisions	x
Unacceptable	

Suggested revisions:

My suggested revisions relate to by 'Main Comments' above.

1. **Context**. Comments 1-3 all deal with background context. These were things I felt would enable decision makers to better interpret the evidence provided. Some text on the catchment, flows, history, etc., would be useful, but I recognise that this may not be appropriate for the intended use of the report.
2. **Structure**. I would try to split out result description and interpretation where possible. I realise this is challenging in places. A brief summary section to directly relate key conclusions back to the underlying evidence presented would be helpful here (either at the end of the document or making better use of the existing Executive Summary). The description of the data collection (i.e., LiDAR, flow gauges and related data) could be expanded, separated out from results description and interpretation and moved earlier in the document.
3. **Volumetric changes**. The LiDAR volumetric changes section would benefit from presentation of DEMs of Difference to visually identify any residual systematic errors. Consideration of the relative magnitude of potential errors would also be useful alongside the magnitude of observed topographic changes. See the main comments 6-7 above.
4. **Minor points**. I have a number of minor points below. While these don't all require action, it would be good if they could be considered.

Minor points

Presentation: this was mentioned to me beforehand, but the figure/section numbering of the report is non-sequential. It was also mentioned that the pagination of the pdf I reviewed may be different from other versions. My apologies if my page numbers below are a little off.

P2, L30: 'mining' of sediment invokes some kind of human sand/gravel mining. Is this what is intended here?

P8: there is some issue here with the conversion between tons and cubic yards. The footnote indicates that $1\ T = 1.5\ yd^3$. However, the conversion applied on L7 is different, with seemingly the opposite ratio applied ($1.5\ T = 1\ yd^3$). It would be also useful to see the data on the sediment density; however, this does not change the study conclusions.

P8 and P27: presumably this is false colour image (there are several through the document)? Perhaps indicate flow direction. Also, perhaps indicate station 70,000 which is referenced in the Executive Summary.

P9, L25: how far downstream did the 6 ft of incision reach by 2002?

P9, footnote 5: what is NPPD?

P12: why is the map not to scale?

P16: what is the 'proposed flow regime'? Presumably this is a higher flow, relating to the values in the footnote?

P23: two slopes are presented in the graph. What are these?

P28, L81: what is meant by 'pre-development channel'?

P29: clarify that the equation is for the black GGL line. Does this include the J2 return channel and land in-between (I'm just wondering why the convexity is not apparent)? What was Murphy's slope estimate and how exactly does it compare?

P30: are there any field observations of these bank heights (or even measured directly from LiDAR)?

P31: this Figure is very convincing.

P33, L20: it would be good to see these cross-section locations.

P36: the incision measurements are not as severe as modelled by Murphy et al. (2004), though I suppose these new lines would shift down if the same maximum incision depth was used. How would it compare then?

P37, L55: would channel narrowing not *increase* the water elevation for a given discharge?

P41: I assume the presence of triangles (for example) on the graph, where this discharge is well below the triangle stage range, simply reflects the use of the 30-day trailing mean discharge? Perhaps note this in the caption to explain this.

P41, L105: typo 'dischargers'

P41, L116: I deleted an earlier comment about providing a check on channel width using aerial photographs owing to the clearly variable stage. This variability also complicates the interpretation presented here. Overall though, the key point is that the channel is not widening (which I agree with).

P47, L161: 'attempted to'?

P50, L40: four analyses? The following text suggests three, though it is hard to identify exactly what they are.

P55, L12: some of these differences are hard to see in Figure 3.3. I know we are waiting for the subsequent volume chapter, but a difference map of the two models would allow these patterns/changes to be seen more clearly. Likewise, On P56, I cannot see the meander development especially clearly in this comparison of REMs (whereas a DEM of Difference would be very clear).

L58, L75: I need a little bit of clarity on the point being made here. What might the effect be on the calculated slopes? If migration has taken place, would the horizontal distance used in the slope equation be a lot out? Or is this really minor given the migration rates and intervals used (is it 100 ft like the prior analysis)? Without this information, I can't really judge how limiting this assumption is in the slope calculations.

P60: an 'elevation distance from grade line' plot might help discriminate between these two lines a little.

P65: it is interesting to see the slope variability smoothing out between 2016 and 2021 and the onset of braiding at the higher slope location (Station 60,000).

P66, L66: why use two separate discharge levels either side of Overton to clip the transects? Could a more consistent approach be used (e.g., stage when the gage reading was X)? Presumably, the approach taken was simpler to implement, but did it result in a discontinuity at Overton?

P66, L70: a 'single' polygon used for all years. Was this a union of all wetted areas?

P69, L9: is there any deposition taking place on the inside of these migrating meanders?

P71: I found the modelling aspect of the wetted width calculation a little tricky to follow.

P71: the figure really highlights the main problem reach where there are some narrowing or static widths (around 75,000). Surely the increases in width around cottonwood are good? Though it is hard to tell without any identification of impacts on habitats.

P72, L89: the text suggests a nonlinear relationship between slope and width, yet Pearson correlation used. It might be nice to see this relationship. Which direction is the relationship?

P73, L118: "continued to increase"… the real increase from Figure 3.17 seems to be prior to 2012, though following the straightening of the meander, there has been a gradual increase… I doubt this would be statistically significant. Also, is sinuosity not hard to interpret when there is so much braiding. Why was there no braiding index considered? Finally, P72 notes both manual and LiDAR-derived thalwegs… which is shown in the Figure?

P81, L90: there's reason to suspect that the wandering planform migration would slow or cease beyond the confluence.

P85, L62: typo "3three"

P85: some details on the specific LiDAR system used would be informative.

P85, L68: perhaps clarify here that the 1D models were in HEC-RAS.

P85: the partitioning of lateral erosion and bed changes seems clear to me, though an image might help to clarify/demonstrate exactly how this was done. I'm also mindful of mentioning the method of segmenting sediment budgets presented in Wheaton et al. (2013) which could be simplified and applied here. To be clear though, I think the method used would be adequate.

P90, L140: what might be the effect of the disking of vegetation mentioned previously?

P90: the use of 2009 data when no bathymetry was available is slightly challenging. My understanding is that model estimates suggested an average depth of 1 ft and this is used to estimate subsequent sediment aggradation below the water level of the survey. I agree this gives a maximum possible value, but I'd exercise caution in how this value is interpreted. To be fair, this is reflected in the results description (e.g., P94).

P95: exactly how were these uncertainties calculated? I suggest dedicating a short section in the methods to clearly articulating this. No uncertainty in upstream reach? Is it within the thickness of the line?

P98: this flow normalization is good to see. Of course, it is sensitive to the choice of exponent on the *q* divided (P92).

P99, L336: when describing erosion here, is the net erosion? I assume so. Likewise for the Figure on P100.

P103: it would be useful to have a comment about the very different pattern of volume change in 2019/20 in the most upstream portion of the reach. Is this related to the closure of the breakthrough or just the higher flows that year mobilising more of the augmented sediment?

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PRRIP Sediment Augmentation Data Synthesis Compilation – Peer Review

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28 March 2024

Introduction

First, I would like to thank the authors of this report ("PRRIP – EDO Review Draft) dated 27 November 2023) for providing a report that has relatively few minor typographic errors and is generally laid out to a high standard. This has eased my review and enabled me to focus primarily upon the scientific methods, results and interpretation. Second, I would like to comment that I consider the work that has been conducted to be well focused upon investigating what is a challenging applied river management problem both for these reaches of the Platte River and for many other global rivers that are characterised by similar pressures due to the consequences of dams. Acquiring system-scale data to monitor changes in river morphology is not straightforward, and neither is the interpretation of the often relatively short timescale (i.e. annual- to decadal-scale) observations that are often characterised by events that cannot be controlled, such as different magnitude high flows. Thus, I would like to comment that I think it is a testament to the authors of this report and the broader Program that the "Big Question" that this report focuses upon is being investigated with the acquisition and interpretation of observational data, with the ultimate objective of maintaining or improving the health of river habitat.

My review, below, is organised into a set of sections. Each section includes my comments on the report's content and recommendations for consideration, throughout this section I include answers to many of the General and Technical Questions. In the subsequent two sections I provide a summary of my answers to the General and Technical Questions (which includes cross-reference back to the detailed thematically organised information), and my rating and recommendation. I am, of course, happy to provide any further details or clarifications as needed; please just get in touch with me.

Specific comments and recommendations on the report

1. Geomorphological overview of the study area

I am not familiar with this river. Whilst the report provides an overview of the history and context of sediment augmentation, in order for me to interpret the results it would have been useful to have further contextual information about the study reach itself. Specifically, I recommend that a contextual section could include information on:

- Topographic context, and natural and anthropogenic confinement: It would be useful to provide a summary of any natural/anthropogenic confinement along the study area. I was particularly interested in the role of natural (e.g. topographic narrowing of the valley bottom) or anthropogenic (e.g. bridge infrastructure) narrowing at Overton Bridge, which may play a significant role in controlling the flux of sediment through this section of river, and thus the degradation/aggradation dynamics (and associated timescales) in the reaches upstream and downstream. It would be useful to provide a detrended (relative elevation model) that extends beyond the active channel (i.e. across the adjacent floodplain) to assist with this contextualisation. This may also help to reveal high bars; from the satellite imagery in the figures it also appears that there are some areas with high, vegetated bars that have previously been geomorphologically worked by the river but are not used for agriculture. It would also be useful to understand the geomorphology of the river downstream from the Kearney Canal Diversion; are there any downstream pressures that may propagate up to the Cottonwood Ranch Reach that may influence the morphodynamics of the study area?
- Grain size: Do you have surface / sub-surface grain size information for different reaches? If so, what are the downstream / bar-scale patterns? This is important since the report refers to bed armouring as a consequence of “hungry water” winnowing fines.
- Vegetation: There are various references to the root systems of vegetation and their relation to bank erosion susceptibility. It would be useful to have a description of the colonisation of bars and banks with vegetation, any seasonal dynamics, and any management interventions.
- Anthropogenic management interventions: In the report there is reference to a (i) meander straightening; (ii) blocking of a “breakthrough” channel; (iii) mechanical augmentation upstream of Overton gage during 2005-2013 (P48 L206); (iv) “disking” of vegetated bars in Cottonwood Ranch in 2018 (P55 L19). I consider these management interventions, which take place prior to or within the timeframe of sediment augmentation, to also be important to the interpretation of the river’s morphodynamics in response to management actions. Rather than introducing and referring to these activities in the results sections, I recommend that these (and any other) management activities are described in a contextual section and are carefully interpreted in the overall executive summary. If there are also “historical” management activities that have taken place upstream, within the study area, or immediately downstream, which may have influenced morphodynamics, then I also recommend that these are summarised.

2. Figure quality

Figures are generally produced to a good standard but a number of enhancements could be made to help interpretation, particularly for readers not already familiar with the geographic context of the river:

- Choice of colours on charts for points/lines showing different years. A wide variety of different colours are used on different charts; interpretation would be easier if a consistent palette was used throughout the report, which is also accessible for people with colour-vision deficiencies (Crameri et al., 2020).
- Consistent inclusion of geographic features on maps. Many charts (e.g. Figure 2.6) include a consistent set of geographic features (e.g. JT Return, Augmentation Area, Overton Bridge etc); it would be useful if these features were also consistently shown on all maps; this positioning would help data interpret by enabling easy cross-referencing between figures.
- Add a "flow direction" arrow to all maps.
- Consider using identical extents and scales for similar maps (e.g. why do the extents for Figures 2.1 and 2.2 need to be different – it makes it hard to cross-compare them).

3. Methodological description

Chapters 2, 3 and 4 of the report present analyses that are dependent upon some common datasets but details on the characteristics of these datasets are not always immediately available (e.g. vertical errors associated with dry and wet areas of airborne LiDAR surveys) until a latter section. I recommend organising the report so that a section that provides information on datasets is provided at the outset, before these data are used for analysis. It would also be useful if a hydrograph was presented earlier (e.g. it would be useful to support Section 1.5.2, P20 L240).

4. Review of Chapter 2: Evaluation of trends in incision prior to full-scale sediment augmentation

Below, a review of each of the components of this chapter is provided. The review focuses upon queries or points of clarification. Overall, the material below is intended, for this chapter, to answer the following questions required for the peer review:

- Are statistical methods and modelling tools valid and current?
- Are associated results presented in a manner that is useful to program decision makers?
- Are potential biases, errors or uncertainties appropriately considered with the methods sections and then discussed in the results and conclusions sections?
- Do the authors draw reasonable and scientifically sound conclusions from the information presented?

This chapter uses four approaches (listed below) to evaluate trends in incision prior to full-scale sediment augmentation. The "Discussion" section (which I consider could be more appropriate titled "summary") of this section clearly communicates the overall findings, which are drawn from a generally appropriate set of methods and data analysis (although see comments below). This analysis enables the quantification of: the magnitude of incision immediately downstream of the J2 return (from REM analysis); the timing of changes in the rate of incision along the study area (from cross-section analysis); higher-temporal resolution analysis of degradation/aggradation dynamics at two observation points (Overton; Cottonwood Ranch gages); and analysis of channel sinuosity upstream of Overton Bridge. Based on the data presented, I consider the interpretation of the nature of, and causes of, planform change to be appropriate (P48 L214-216) but recommend that: (i) there is a comment on on whether the transition is from braided to meandering or whether there is a wandering state, since a wandering planform is referred to in subsequent sections of the report; and (ii) that there is a broader desk-based conceptual interpretation of what a change in planform pattern may mean for differences in the rate of sediment transport and thus supply (with/without augmentation) from this reach to the reach downstream of Overton Bridge (i.e. what are the typical capacities of braided / wandering river types for conveying sediment versus meandering rive types) (see e.g. Church, 2002).

Geomorphic Grade Line and relative elevation model

Use of geomorphic grade line is appropriate for analysis of a continuous length of river where there are no perturbations that may cause "natural" deviations from a linear trend (e.g. influx of sediment from a tributary, a choke point caused by a topographic constriction, adjustment to a sediment wave caused by landsliding upstream, baselevel adjustment propagating from downstream). I have suggested a broader geomorphic contextualisation above but consider that this approach is appropriate overall, subject to these caveats. However, it would be useful if the authors added a sentence or two to more fully justify why this approach is valid for this river (insert on P29 L104).

With respect to the data used for this analysis, my comment above on providing an overview of the LiDAR dataset in an overarching methods section, at an earlier point in the report, is of relevance here. It would also be useful if reference to the 2016 "topography" explicitly states that this topography includes representation of both wet and dry topography (assuming it came from the topo-bathy LiDAR dataset)

Analysis of trends in incision 1989-2016 relative to predictions

I consider the fit of a third order (cubic) regression to be ok to model the trend in the longitudinal thalwegs for 1989 and 2002 but note that there are some potential subsequent cases of potentially overfitting trend curves to data later in the report (see below) rather than letting the data "speak for itself". Whilst there are only two sample years available from the cross-section data, and it is know that there is inter-year variability, I agree with the interpretation of Figure 2.7 that there is a signal of different elevations between stations 50,000 and 90,000 between 1989 and 2002-2016. Shading could be provided around each line to indicate the elevation uncertainty in the different survey techniques, potentially drawing on Bangen et al. (2014) for cross-section surveys and the error analysis for "wet" areas in the 2016 LiDAR survey (presented in Chapter 4). This would enable further interpretation of the point (e.g. at station 50,000 or 60,000 etc) at which the signal is clear from potential survey noise.

I sympathise with the authors with their challenge of reproducing results from a previous study (see data reproducibility recommendation below) and consider that the comparison of modelling and observed datasets (Figure 2.8) is appropriate. I consider that the model predictions from the Murphy et al. (2004) study are rather "crisp" in nature and the summary chart doesn't well present the uncertainties that may be associated with the different predictions (e.g. due to flow variability; uncertainty in grain size; vegetation dynamics etc). I recommend that the comparison (Section 1.10.2 P35) between the observations and predictions could be edited to place less emphasis on the model potentially being "correct" (i.e. the truth) and rather emphasizing what the limitations to the model are in terms of its conceptualisation, assumptions and data inputs relative to the dynamics of the river and what interpretation of the observations allows. I recommend that any reference to a "longer study period" (P35 L39) explicitly focuses on how further monitoring may allow the river to express its dynamics though interpretation of the observational data rather than any inferences to improving the model-observation comparison.

Gage analysis

This method and data analysis makes good use of two relatively high temporal frequency, long temporal duration gage datasets. I have a number of comments / questions / recommendations for consideration:

- Methodological approach: Why was water surface elevation (i.e. stage height) interpreted and not any bed level information from ratings? Are the latter available. I'd be curious to know whether these gages were included in Slater et al.'s analysis of USGS station data; if so, what do their results show? If not, why couldn't the data be included in Slater et al.'s analysis? This may explain why bed level can't be used here?
- Overall, I found the interpretation of the stage height data for the 10th percentile, median discharge and median annual peak discharge (Figures 2.13 and 2.17) to be more valuable for interpretation of the river's dynamics at the two gage locations than the segmentation of data into four flow stages (e.g. Figure 2.12). However, it was useful to see the full hydrograph in Figure 2.12 (see recommendation about providing more contextual information early in the report, above).
- Can you further expand the reasons for water surface elevation change (P37 L52) to include local change change and roughness change?
- Interpretation of planform change shown in Figures 2.9 to 2.11 and Figures 2.14 to 2.15: I consider that interpretation of planform changes from satellite imagery is very important for the interpretation of river channel change but I think that a clearer presentation of these results is required, which may involve finding imagery from alternative months for each year. What is the source of this imagery; Landsat imagery? Can the caption include detail of why these years are being compared; what is the reason for showing these data (you refer the dynamics that are interpreted on P41 L116-117)? Can you label the figures with your interpretation of changes? Is it worth extending this analysis for the whole study area (it can be done automatically e.g. in Google Earth Engine; Boothroyd et al., 2021) and including this as a separate methods/results section (it's beyond gage analysis), noting that planform change is considered in chapter 4. Would it be useful to digitise low flow wet channel (from image acquisitions with relatively consistent flow, if possible, and active channel (i.e. wet and dry; Boothroyd et al., 2021) extents and make a transparent GIS overlap to compare these data? The wetted extent for each year varies considerably which makes it hard to make any comparisons about the position of the primary anabranch or the extent active channel, can you select images that have similar discharges or, in the very least, label the discharge at the time of image acquisition. At present, I consider that these figures may be a potential source of confusion for decision-makers that may not understand the reasons for the differences.
- Does interpretation of planform change (e.g. switching of anabranches, changes in anabranch widths) in the multi-thread sections (particularly Cottonwood) influence the consistency of interpretations of gage data, particularly for low flows?

Channel sinuosity

This analysis builds on the interpretation of planform change presented within the gage analysis section. I have a few queries on this data analysis:

- Can you provide information on the specific satellite (P47 L164) and the imagery dates (as an appendix?); are the thalweg lines available (digital supplement?)
- How was imagery selected for each year? Similar month, similar discharge?
- Earlier in the report there is an argument presented that there is a shift in river type (broadly from braided to meandering); is it possible to also calculate a braiding index (if imagery with a similar discharge can be selected) to provide further a line of evidence associated with this, and in particular whether the river has transitioned to wandering or meandering (P47 L175-6)?
- Is there value in interpreting sinuosity / braiding intensity of the North Channel as a "control" to compare to the J2 Return Channel?

5. Review of Chapter 3: Evaluation of longitudinal change after sediment augmentation

The review of Chapter 3 takes a similar form to Chapter 2; a review of each of the components of this chapter is provided, focusing upon queries or points of clarification. Overall, the material below is intended, for this chapter, to answer the same four questions outlined above that are required for the peer review.

The objective of this chapter is to examine longitudinal changes between the J2 return and KCD during the first five years of sediment augmentation (2017-2021). In the introduction, I recommend that: (i) explicit reference is made to all LiDAR from 2016 onwards being topo-bathymetric LiDAR that represents both wet and dry topography (assuming this is correct, as described in Chapter 4) and (ii) a more precise/expansive description of "more detailed evaluation" is provided (P51 L43). The suite of methods and associated results shed light on the longitudinal dynamics of the study area. The discussion (P80; section 1.23) is organised well for interpretation by decision makers since it begins by interpreting the results in a downstream sequence. However this section could be improved by considering the following: (i) linking to an overview contextual section that includes details on e.g. the high flow record (to help interpretation of comment on 2019 high flows – P80 L34), breakthrough channel closure (P80 L47-8); (ii) developing of a conceptual/schematic diagram/cartoon to summarise the findings (this could also integrate findings from other chapters and be presented in the executive summary); (iii) conducting an analysis of the longitudinal dynamics of the North Channel, to contextualise the findings for the J2 Return Channel (P40 L92) and improve the certainty associated with the statement about confluence inputs on P81 L92 as these are important for sediment supply downstream of Overton Bridge; and (iv) providing more commentary on the relative merits, scope and feasibility of different future analyses (P81; L97) – I consider that the changes in channel width and slope are already good but this could be enhanced with multi-temporal satellite imagery analysis, lateral thalweg migration quantification could be achieved with various GIS tools, and morphodynamic modelling is potentially financially expensive and subject to considerable uncertainty albeit depending on the questions that are posed.

Relative elevation model

This analysis is both appropriate and rigorous but reporting could be improved by providing clarity on a number of aspects:

- P51 L54. Is “in general” correct; is “For all” more precise?
- P51 L62-3. A channel type change to “wandering planform” is described for the upper end of the J2 Return Channel. Ensure that this is consistent with the meandering to braiding transition noted in the previous chapter; is wandering described here because it is just for the upper end of the J2 Return Channel? That’s factually fine but I suggest that these different transitions are explicitly summarised in the Executive Summary and whenever they are referred to in the report the time range and geographic extent are explicitly noted, to prevent any confusion or mis-interpretation.
- Are elevations associated with the extent of the North Channel excluded from any subsequent quantitative analysis of the dynamics of the J2 Return Channel? The full extent, including both Channels, is shown on Figure 3.1 and I’m concerned that if the North Channel is not excluded then the morphodynamics of that Channel may influence (even bias) any interpretation of data from the J2 Return Channel. It would be worth making a note about this on the figure caption and in the methods.
- Figure 3.3. Interpretation of the differences between these figures gets very close to a map of elevation change (next chapter); it may be worth cross-referencing the subsequent figure that shows elevation change or adding this as another horizontal pane at the bottom of this figure. Text associated with this section actually starts to interpret channel (i.e. volumetric) change. This can be inferred but without a DEM of Difference is this the best place for this interpretation (rather than the next chapter?) Indeed, there is a risk that a decision maker is shown too many plots that are close to showing the same thing, so the relationship between this section of the chapter and the volume analysis should be carefully considered. Nevertheless, comparison of the 2016 and 2021 REMs sheds light on horizontal changes between these times.
- P55 L17-18. There is no data to support this comment on the differing proportions for different categories. Can a histogram be added to the side of each REM in Figure 3.3?
- P55 L19. “Disked” isn’t a term I was previously familiar with, although I accept it may be commonly used in the local area. Perhaps provide a brief explanation. This management intervention is also noted above with respect to providing an overview of management actions.
- Figure 3.4. This is a really nice set of data to work with to investigate this problem; it’s rare to see system-scale topographic-bathymetric datasets of this temporal frequency.

Longitudinal profile of channel thalweg 2016-2021

The position of the thalwegs was automatically detected, then manually corrected in some instances, using a contemporary, and appropriate, GIS topographic analysis tool. Longitudinal slopes were “smoothed” using GAMM. Changepoint analysis was then applied to detect statistically similar segments. I agree that it was appropriate to maintain a common station reference system for the comparison (P58 L75). I have the following comments on this section:

- Consider the logical sequence of the methods section: I think the slope smoothing (i.e. producing the data that will be analysed) should be presented before the changepoint analysis.
- Consider whether some of the differences quoted (e.g. 0.2 ft; P61 L12 / L14) are within the range of uncertainty in the wet area accuracy of the LiDAR (P93 Table 0.3).
- Table 3.1: Consider presenting lower and upper quartiles as well or instead of minima/maxima as minima/maxima can be misleading if there are outliers.

- Figure 3.10: Could a statistical test be used to determine whether there is statistically significant difference between the 2016 and 2021 Thalweg Models? This would help to shed light on my next two comments.
- Reflect upon how the results are phrased and whether some of the small changes in slope are likely a signal or close being similar to the magnitude of noise in the observations. I think that the larger changes in Figure 3.8 are compelling but that interpretation of the small magnitude changes needs to be undertaken carefully.
- Double check that the magnitude of difference between 2016 and 2017 modelled thalweg slopes is correct upstream of Overton Bridge (Figure 3.11). In the caption it would be valuable to concisely explain the channel changes that caused these differences.

Longitudinal profile of mean channel elevation 2016-2021

For this analysis, change in elevation was considered across the whole active river rather than just along the thalweg. This approach to analysis is thus more similar to a volumetric change analysis (Chapter 4) than a thalweg analysis. This is an important component of the analysis since for multi-thread, labile rivers a considerable amount of channel change can occur outwith the primary anabranch and change can also be associated with width and bed variation. I have a number of comments and questions about this analysis:

- Are elevations associated with the North Channel removed from this analysis?
- Why were 2,500 and 5,000 cfs selected? Is there a physical basis for these values? From figure 2.12, I note that these values exclude many Annual Maximum flows. To contextualise and aid interpretation, it would be useful to see a figure showing the inundation area associated with these flows (from 2D model predictions?).
- P66 L76-77. Processes associated with degradation are explained but not those associated with aggradation.
- P67 L81. Is it really convex, or actually predominantly linear?
- Figure 3.13. From c.72,000 ft station to Overton Bridge there is a consistent pattern of average cross-sectional elevation; this is compelling for analysis of the overall trend.
- P69 L24: Is this interpretation of "stable to widening" correct, particularly the "stable" aspect? It would be useful to see a figure similar to Figure 3.13 for the extent downstream of Overtop Bridge; is the average XS difference shown in Figure 3.14 that much different for this reach than for Cottonwood Reach? Greater cross-referencing to the evidence would help here.

Wetted Width

Hydraulic numerical modelling was used to predict inundation area along the study area for selected years. Models before 2016 were constrained by available topographic information and were thus 1D. Models for 2016 and thereafter were 2D as LiDAR data was available. These numerical modelling approaches are appropriate for the nature of the river and the available data. I have a number of comments and questions about this analysis:

- Why was a value of 2,000 cfs used here (compared to 2,500 and 5,000 cfs used in the previous section).
- Were any of the numerical models calibrated / validated with observation data? How well do they perform? A range of metrics are available to assess 2D hydraulic model predictions;

Section 2.51 of Masafu et al. (2024) provides a summary of some of these techniques. If information is available in other reports then a summary of model performance would be valuable here.

- Figure 3.15 shows a large difference between 2012 and 2016. The interpretation (P71 L57-75) focuses upon a large flood event in 2015 causing substantial change downstream of Overton. I think further evidence to clarify the magnitude of this change is warranted. (i) Does analysis of satellite imagery (e.g. Chapter 2 comparisons of imagery) agree with this? (ii) This change is coincident with a change from 1D to 2D numerical modelling and a change in both how flow is numerically simulated and how maps are plotted in GIS. It would be useful to know how sensitive the model predictions are to this change; an appropriate way to evaluate this would be to use the 2016 LiDAR survey to provide topography for a 1D HEC-RAS model to assess how predicted wetted widths compare to the SRH-2D model/
- Figure 3.15: What is the unit on the y axis?
- P71 L66-68. It is good to see this statistical comparison; I encourage this approach elsewhere, where viable.
- Figure 3.16: This is a good summary figure for characterising 2021.

Sinuosity of the J2 Return Channel

This is a comparably short section. I don't have any comments or items needing clarification.

Analysis of incision in the vicinity of Station 70,000

This section includes a detailed analysis of one reach of the study area. Figure 3.19 is nicely interpreted; the overlay on the imagery is clear. I have one query:

- Figure 3.20. I think the discharges for 2016 and 2021 are different. Can the discharges be labelled or imagery with similar discharge be found (see an earlier comment about this for figures in Chapter 2).

6. **Review of Chapter 4: Volume change analysis**

The review of Chapter 3 takes a similar form to that for Chapters 2 and 3; a review of each of the components of this chapter is provided, focusing upon queries or points of clarification. The material below is intended, for this chapter, to answer the same questions outlined in the introduction to the review of Chapter 2. However, an additional section focuses on answering Technical Questions 6 and 7.

Review

This chapter presents a volumetric change analysis, using two topographic LiDAR surveys obtained in 2009 and 2012, and six topographic-bathymetric LiDAR surveys obtained between 2016 and 2021. The reported dry and wet accuracies of the LiDAR surveys (Table 0.3) are typical of similar surveys reported in academic literature. Systematic error between surveys was minimised by post-processing LiDAR using a common LiDAR flight as a control. This enables varies analysis, the most salient of which I consider to be the longitudinal analysis of volumetric change, presented in Figure 0.8 (P97). This figure also shows cumulative change segmented by the processes of lateral erosion and bed aggradation/degradation. It is valuable to try to distinguish the causal mechanisms for channel change but I do have some comments and questions associated with this approach:

a. P84 L24. Earlier literature could be cited to refer to the morphological approach. See Vericat et al. (2017), which you already cite, for relevant references.
b. P84 L34-35. Similar to a comment above for Chapter 3, I think it would also be useful to refer to depositional mechanisms here; not all processes in the reach are degradational (as the analysis in this chapter also evidences).
c. P85 L50. Can you refer to the range of actual errors (Table 0.3 P93) rather than typical errors reported in literature? I accept you do this later in this section, and in Table 0.3, but I think these different values could cause confusion to a reader that isn't technically proficient in LiDAR capture/analysis.
d. P85 Section 1.27.1.2 "Hydraulic data". This is an example (together with the LiDAR data) of where there could be cross-referencing through the report and the report could be made more concise by organising common methods into one location (see earlier comments on this). Similarly, I found the material on P87 L97-104 and P88 L109-130 to be rather contextual and more suitable for an introduction rather than methods section.
e. Table 0.2. How were these volumes calculated?
f. P90 L150. Can you provide more information on what hydroflattening means, targeted at a decision maker reader? This is important for the subsequent interpretation, as it is an important source of bias. I think that there is considerable uncertainty associated with the assumption of a constant depth along the river to correct for this (P90 L150-159) and the uncertainties associated with this assumption should be more clearly explained in table and figure captions (rather than just labelling it) and also in the interpretive text that explain results from this assumption.
g. For the LiDAR post-processing, how effective were any filters to remove vegetation or other objects from the DEMs? How many samples points were acquired to assess the accuracies reported in Table 0.3 (P93); what were their distribution? What is the median grain size in the reach and how does this compare to the reported vertical errors (i.e. what is the roughness of the dry, unvegetated topographic surface)? Does the table of wet/dry errors measure errors before or after LiDAR were post-processed to "minimise" systematic error. It would be really useful to see a comparison of the errors before and after this post-processing step, if a suitable number and spatial distribution of "check" points are available.
h. The segmentation of the "lateral erosion" component of the volumetric budget relies upon differencing hydraulic model results. Based on Figure 0.5 it is likely that this method works reasonably where there is bank erosion on either the left or right bank of the active channel (i.e. where banks are relatively high) but I would question how consistent and effective this approach is along anabranches within the active channel where topographic variation is of a lower magnitude. Would manual interpretation of the DEMs of Difference also be valuable (e.g. in a similar manner to Wheaton et al., 2013); lateral erosion usually has a longitudinally extensive "shape" and a relatively large vertical magnitude relative to "patches" of geomorphic change caused by other geomorphic mechanisms. A verification of the hydraulic modelling differencing approach could be conducted by comparing this automated approach to expert manual interpretation.

i. Aside from "lateral erosion", all other changes are "lumped" together whether they are associated with erosion or deposition. To interpret the dynamics of the study area, I think it would be beneficial to more extensively segregate erosion and deposition within this residual class (e.g. on the bottom panel of Figure 0.8 showing erosion and deposition separately as well as the net).
j. Figure 0.11: The sub-figure is missing vertical and horizontal scales; its presentational quality needs to be improved.
k. Interpretation on P104 L394-395. "Dynamic but stable with no observable signal from augmentation". Do you know that all sediment generated from augmentation has been deposited in upstream reaches; a cumulative, segmented budget similar to that shown in Figure 5.2 in Vericat et al. (2017) would enable you to quantitatively analyse where sediment is being stored along sub-reaches.

Answers to Technical Questions

LiDAR data was processed to remove non-random error to the degree possible. Accordingly, two and three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?

The reporting of vertical errors before and after post-processing to minimise systematic errors is not sufficiently detailed for me to be able to assess the effectiveness of this correction (see comment g above). It would also be useful to know more about the roughness (i.e. grain size) of the active channel to discern what the influence of roughness may be on the character of the LiDAR derived surface. I also envisage that the presence (and likely removal) of vegetation from the LiDAR derived surfaces (e.g. sparsely vegetated bars) will also contribute uncertainty that is more spatially variable in character than that which has been systematically corrected. In my experience, I have conducted and reviewed very few sediment budgeting analyses that haven't quantified uncertainties, often although not always using the types of probabilistic thresholding approaches reviewed by Vericat et al. (2017). Although the authors cite Anderson (2019), Anderson still argues that estimated uncertainty bounds should be part of a quantitative estimate of volumetric or mean change (second bullet point in the conclusion e.g. Figure 11 and Table III of Anderson's (2019) example). I recommend that either Vericat et al.'s (2017) and/or Anderson's (2019) approaches could be used to characterise uncertainty and enable more rigorous assessment of whether some of the observed changes are indistinguishable from zero within uncertainty.

Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?

See comment (h) above for my answer to this question. In summary, the approach used may be appropriate but I would like to see a comparison to manual expert interpretation to enable a quantitative assessment of the quality of its ability to segment this type of geomorphic change.

7. **Reproducibility**

It is clear that some modelling results that have been undertaken for previous reports are not accessible and/or not reproducible. Are there plans to ensure that the data and analysis that has been undertaken for this report are long-term digitally accessible?

8. Publication, and space to move and augmentation sustainability

I consider that the results presented in this report would be of interest to both the scientific and applied river management community. I know that the authors are considering dissemination in a journal format. With appropriate contextualisation, I consider that the data and interpretation would be suitable for journals such as *Water Resources Research* or *River Management and Applications*.

Below are some broader comments. These are related to the broader contextualisation of the challenge and/or consequences of the findings. They may be useful here or for the framing of a manuscript (see below).

Space to move: One section of the report notes management interventions to prevent geomorphic change adjacent to a property. Lateral erosion is identified as a key mechanism for sediment generation but this commonly requires space for a river to move. Interesting recent reviews on this topic include Nelson et al. (2024) and Brierley et al. (2023).

Sustainability of augmentation areas: My interpretation of Figure 0.5 is that the 2017-2022 source of sediment from the augmentation areas is material from unvegetated / sparsely vegetated river bars. This material is being "pushed" into the low flow channel. How sustainable is this source (I note that there are other areas where material can be obtained from)? What are the longer-term consequences for "natural" replenishment of these areas and the morphological adjustment of this reach? During a normal (i.e. without dam controls) range of flow variability bars will be inundated and are key sources and stores of sediment; their functioning in this reach will likely be changed as a consequence of topographic lowering albeit within the context of the flows that they are now exposed to. Does this limit how hydropeaking along the J2 Return Channel could, if viable, be used as a possible approach to mobilise sediment in this reach (I note from Figure 0.2, P88 that large flows can be conveyed down this channel e.g. in 2015). The final page of the report discusses dam retrofitting to enable sediment bypassing; this is an interesting idea that could mitigate the challenge of where to obtain material for sediment augmentation.

9. Minor comments

- Section numbering: something has gone wrong and most sections start "0." I use the likely erroneous section numbering that is in the main report document (rather than the contents page numbering, which I think is correct) to refer to particular sections in my comments above.
- Page (P) 8. Section E.1. Consider changing the start of this sentence – it's a big leap for a reader with no prior knowledge to be expected to know what a Big Question is.
- P8 Line (L) 18. Can the caption be expanded to provide more context for the summary.
- P8 L21. More context on the river before hydropower impacts is needed.
- P9 L38-39. Reference to the high flow dynamics during these years would be useful.

- P9 L43. An average is then presented then a range. Need to be consistent or provide greater explanation of these different formats.
- P9 L56. Is the word “specific” needed?
- P16 L140. When will the proposed flow regime be implemented? More context needed.
- P18 L222. What are the “other” geomorphic metrics?
- P27 L48. These places aren’t marked on the maps, or different acronyms are used; see comment above on consistency in geographic reference points on figures.
- P50 L31. This paragraph is relatively general at this stage of the report. The overall aim of the report doesn’t need to be repeated, you can go straight to the chapter objective (next paragraph). Edits such as this will help to make the report more concise.

Answers to general and technical questions

General questions

Does the Sediment Augmentation Data Synthesis Compilation adequately address the overall objective – to synthesize multiple lines of evidence from the Program's full-scale sediment augmentation experiment to assess overall results and provide useful information for decision making related to future sediment augmentation management actions?

Overall, I consider that the report has the correct overall experimental framework to address the Big Science Question: "Is sediment augmentation necessary to create and/or maintain suitable whooping crane habitat?" In particular, it presents a wide ranging set of different lines of evidence. However, I do consider that there are a number of issues that require clarification or additional supporting analyses that could help to support some methodological assumptions that have been made, including the characterisation of uncertainty in the volumetric change estimates. I recommend that the Executive Summary is carefully revisited following any revisions and, in particular, a graphical diagram that summarises the various conclusions for different segments of the river may help to summarise the information for decision makers.

Do the authors draw reasonable and scientifically sound conclusions from the information presented? If not, please identify those that are not and the specifics of each situation.

This question has been addressed in the section titled "Specific comments and recommendations on the report".

Are there any seminal peer-reviewed scientific papers omitted from consideration that would contribute to alternate conclusions that are scientifically sound? Please identify any such paper including citations.

This question has been addressed in the section titled "Specific comments and recommendations on the report" and a reference list to the associated citations is provided below. I note that the report doesn't contextualise the effects of sediment augmentation with other global examples; this would be likely required for publication and the authors may wish to consider broader contextualisation for this report. As a starting point, I would recommend the review by Staentzel et al. (2020).

Are the statistical methods and modeling tools used valid and current, and are the associated result presented in a manner useful to Program decision-makers?

This question has been addressed in the section titled "Specific comments and recommendations on the report".

Are potential biases, errors, or uncertainties appropriately considered within the methods sections and then discussed in the results and conclusion sections?

This question has been addressed in the section titled "Specific comments and recommendations on the report".

Technical Questions:

LiDAR data was processed to remove non-random error to the degree possible. Accordingly, twoand three-dimensional change analyses did not utilize methods (e.g., thresholding) to quantify and/or *account for error. Was that an appropriate approach? Would you suggest an alternative approach to quantifying and addressing error?*

Is the method used to separate lateral erosion from bed aggradation/degradation appropriate? Would you suggest any alternative method be utilized?

Both these questions have been addressed in the sub-section on Chapter 4 within the section titled "Specific comments and recommendations on the report"

Rating and recommendation

I note that I don't have a definition for what the different categories mean, so my interpretation of them is thus subjective. However, I hope that the relative differences between my ratings for different sections helps to differentiate where I consider the overall strengths and limitations lie. I have provided brief justification for my ratings.

Scientific soundness = **3**

- An enormous amount of effort has been spent acquiring, processing and interpreting data. However I consider that some clarifications are needed, which would enable this score to be increased.

Degree to which conclusions are supported by data = **3**

- These are generally sound but I consider clarifications are needed to ensure that conclusions are appropriate. Addressing these would enable this score to be increased.

Organisation and clarity = **4**

Cohesiveness of conclusions = **3.5**

Conciseness = **3**

- See comments on presenting a clearer contextualisation, organising methods in one place and using more cross-referencing to avoid repetition.

Important to objectives of the program = **5**

- As noted at the very start of my report, I consider the data that has been acquired and overall monitoring strategy to be excellent and state of the art for this applied management problem.

Recommendation: **Accept with revisions**

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PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -or- Program)
APPENDIX B – Peer Review Comment/Response Matrix

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Smith	8	Figure	BQ3	1	23		Two slopes are presented in the graph. What are these?	no change made to report	The higher slope (0.0012) was the slope of the linear regression downstream of Overton Bridge, while the lower slope (0.00092) was the slope of the linear regression from J2 to Overton Bridge. This analysis was done prior to the work presented in this report, so exact values and methods for determining these values may vary from what is presented in later chapters.
Williams	Ch. 2d iii	Text	Braid Index	2	47	175-6	Earlier in the report there is an argument presented that there is a shift in river type (broadly from braided to meandering); is it possible to also calculate a braiding index (if imagery with a similar discharge can be selected) to provide further a line of evidence associated with this, and in particular whether the river has transitioned to wandering or meandering (P47 L175-6)?	no change made to report	We have explored different ways to characterize braiding, including a new entropic braiding index (Tejedor, Alejandro, et al. "The entropic Braiding Index (eBI): A robust metric to account for the diversity of channel scales in multi-thread rivers." Geophysical Research Letters 49.16 (2022): e2022GL099681). We are considering the best way to add more thorough planform characterization for future reports but we think that including more and more complicated planform assessments in the current report without rigorous testing and comparison with literature could distract from current results or lead to faulty conclusions.
Brasington	4.2	Organization	Breakthrough	1	21	279-298	Breakthrough intro should be moved before this section	change made to report	Moved to Data Section
Williams	Ch. 4a iv	Organization	Breakthrough	4	87	97-104	Put in introduction/methods	change made to report	Moved to Data Summary Section
Brasington	6.3	Figure	Caption	3	72/73	Fig 3.16	Caption disconnected	change made to report	Fixed
Smith	21	Figure	Ch. 3	3	55	12	Some of these differences are hard to see in Figure 3.3. I know we are waiting for the subsequent volume chapter, but a difference map of the two models would allow these patterns/changes to be seen more clearly. Likewise, On P56, I cannot see the meander development especially clearly in this comparison of REMs (whereas a DEM of Difference would be very clear).	change made to report	Edited text to remove items that cannot be seen from given figures. These are either unimportant to overall conclusions, or will be discussed later
Williams	Ch. 3a iv	Figure	Ch. 3	3		Fig 3.3	Interpretation is very similar to volume change figures. Needed? Show both in same place?	no change made to report	Agree that some analyses in this report may be redundant, partly because we were piloting many new analyses for this study. Some will likely be discontinued in the future, but we will include in this report for a full record of what we have done to date. Any work published for a wider audience will be more focused/paired down
Smith	Big Picture: Main Comment 5	Organization	Ch. 3	3			Articulate the rationale for Ch. 3 (length and content). Chapter 4 analyses contain similar conclusions. Rationale could include i) more targeted analysis of hydrologically important variables; ii) more direct comparison with pre-aug data	change made to report	Rewrote the abstract, and parts of the introduction and discussion to address this comment. In chapter 3 we evaluated changes from a two-dimensional perspective with planform and profile analyses. This approach allowed us to target specific variables that are either hydrologically important or offer direct comparison with historical data. We acknowledge it is a chapter with many different analyses and findings that would be paired down/focused in a more concise journal writeup of our work
Williams	Ch. 3b v	Text/Stats	Changepoint	3			Reflect upon how the results are phrased and whether some of the small changes in slope are likely a signal or close being similar to the magnitude of noise in the observations. I think that the larger changes in Figure 3.8 are compelling but that interpretation of the small magnitude changes needs to be undertaken carefully.	change made to report	Slope is now discussed in combination with thalweg profiles and regarding Figure 3.15. Several figures and some discussion was removed from the report. After review, we determined that we have over-interpreted spatial and temporal changes in slope and have thus pivoted to showing the simplest - but most certain - conclusion that we can make about slope: the J2 channel has a lower slope than the channel downstream of Overton. We will continue to consider and work on how to relate slope to process/landform in J2, with particular attention to comparison among other parts of the Platte.
Smith	36	Text	Cite fig and ref	4 Methods	85		The partitioning of lateral erosion and bed changes seems clear to me, though an image might help to clarify/demonstrate exactly how this was done. I'm also mindful of mentioning the method of segmenting sediment budgets presented in Wheaton et al. (2013) which could be simplified and applied here. To be clear though, I think the method used would be adequate.	no change made to report	see Fig. 4.6, and yes we are planning to try sediment flux/budgeting in future work. See addenda for volume change segregated by aggradation/degradation as opposed to the net change presented in the report.
Smith	2	Math	CY to T conversion	Exec Summary	8		There is some issue here with the conversion between tons and cubic yards. The footnote indicates that 1 T = 1.5 yd3. However, the conversion applied on L7 is different, with seemingly the opposite ratio applied (1.5 T = 1 yd3). It would be also useful to see the data on the sediment density; however, this does not change the study conclusions.	change made to report	Fixed - we had the ratio listed backwards
Smith	Big Picture: Main Comment 6	Organization	Data Collection/Lidar	1			Provide more LiDAR specs earlier in the report. Currently on pg. 85 after REMs are presented (pg 31). Data section detailing all data could be useful	change made to report	See new Data Summary section

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Smith	34	Text	Data Collection/Lidar	4	85		Some details on the specific LiDAR system used would be informative.	change made to report	This is now in the new Data Summary Section.
Williams	Ch. 4a iii	Text	Data Collection/Lidar	4	85	50	State actual errors reported in lit rather than typical	change made to report	Addressed accuracy in new data summary section D.1.
Williams	Ch. 4 a vii	Text	Data Collection/Lidar	4	93	Table 0.3	For the LiDAR post-processing, how effective were any filters to remove vegetation or other objects from the DEMs? How many samples points were acquired to assess the accuracies reported in Table 0.3 (P93); what were their distribution? What is the median grain size in the reach and how does this compare to the reported vertical errors (i.e. what is the roughness of the dry, unvegetated topographic surface)? Does the table of wet/dry errors measure errors before or after LiDAR were post-processed to “minimise” systematic error. It would be really useful to see a comparison of the errors before and after this post-processing step, if a suitable number and spatial distribution of “check” points are available.	change made to report	Additional details on LiDAR collection over vegetated surfaces and grain size has been added to D.1. D50 = 0.5 to 2 mm. Vertical accuracy is assessed using ~700 ground control points captured in 2020 (see LiDAR addendum) and 58 to 340 bathy check points depending on the year. All error is reported after post-processing is complete.
Brasington	7.8	Text/Stats	Data Collection/LiDAR	4	93	Table 0.3	Further describe vertical accuracy methods from QSI	change made to report	See Data Summary Section and LiDAR addendum
Williams	3	Organization	Data Summary	throughout			Create a section that provides information on datasets at the outset, before these data are used for analysis. It would also be useful if a hydrograph was presented earlier (e.g. it would be useful to support Section 1.5.2, P20 L240).	change made to report	There is now a Data Summary section at the beginning of our report
Smith	27	Text/Analysis	Deposition patterns	3	69	9	Is there any deposition taking place on the inside of these migrating meanders?	change made to report	There is indeed deposition on point bars to go with erosion at cutbanks and we have clarified this sentence.
Williams	Ch. 3 Discussion ii	Figure	Discussion	3			Section would be improved by developing of a conceptual/schematic diagram/cartoon to summarise the findings (this could also integrate findings from other chapters and be presented in the executive summary)	no change made to report	We appreciate this suggestion and will consider it for future work.
Williams	Ch. 3 Discussion i	Text	Discussion	3			Linking to an overview contextual section that includes details on e.g. the high flow record (to help interpretation of comment on 2019 high flows – P80 L34), breakthrough channel closure (P80 L47-8)	change made to report	Added several references to the Data Section and ES
Williams	Ch. 3 iv	Text	Discussion	3			Providing more commentary on the relative merits, scope and feasibility of different future analyses (P81; L97) – I consider that the changes in channel width and slope are already good but this could be enhanced with multi-temporal satellite imagery analysis, lateral thalweg migration quantification could be achieved with various GIS tools, and morphodynamic modelling is potentially financially expensive and subject to considerable uncertainty albeit depending on the questions that are posed.	no change made to report	These suggestions are being considered or applied in our ongoing monitoring
Williams	Ch. 3a vi	Text	Disking	3	55	19	Define disking	no change made to report	We use a tractor to pull a disk harrow across areas of vegetation to be removed. Disks cut and turn soil to depths of 6" to 1'. The term is common for this audience.
Smith	37	Text	Disking	4 Methods	90	140	What might be the effect of the disking of vegetation mentioned previously?	no change made to report	Disking removes vegetation and may locally raise and lower ground elevations by small amounts. It also increases erodibility. Because bare-earth LiDAR is used, it should not have a strong impact on elevations apart from potential error. See data section
Smith	Big Picture: Main Comment 6	Figure	DoDs	1			Show details of systemic errors? (DoDs)	change made to report	See Appendix A for DoD figures. We have added a Data Summary section which provides a check of our DEM data accuracy, reports on errors, and more convincingly justifies our decision to not threshold our data. We have also provided you with a supplemental addendum on this subject depicting a histogram of channel elevation change and showing these are not biased in a particular direction (e.g. not towards erosion or deposition) in the ranges that would be impacted by thresholding (< about 3 inches) . In the report we added a figure to support these findings that show errors in DEM surface in paved locations are small and random
Brasington	7.1	Text/Analysis	DoDs	4			It's not enough to say we removed systematic error without demonstrating. Show variation over areas that are assumed to be unchanged. Also effect of in-channel veg change? Or stripmatching from QSI	change made to report	Addressed accuracy and thresholding in new data section D.1. and LiDAR addendum

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Williams	Tech Q 1	Text/Analysis	DoDs	4			Although the authors cite Anderson (2019), Anderson still argues that estimated uncertainty bounds should be part of a quantitative estimate of volumetric or mean change (second bullet point in the conclusion e.g. Figure 11 and Table III of Anderson's (2019) example). Use Vericat 2017 or Anderson 2019 to characterise uncertainty and whether some changes are within range of uncertainty	change made to report	Addressed accuracy and thresholding in new data section D.1.2. and LiDAR addendum
Brasington	7.9	Text/Analysis	DoDs	4	95	Fig. 0.7	If a systematic uncertainty term is computed and assumed to scale linearly with the integration area, the models of longitudinal net volumetric change (i.e., Figure 0.7) could be presented as envelope curves, the width of which will largely reflect the area of the AOI within each 900 ft cell.	change made to report	We have given more careful consideration to how we deal with systematic uncertainty in section D.1
Smith	Big Picture: Main Comment 6	Text/Analysis	DoDs	4			No issue with Anderson (2019) threshold approach.	no change made to report	
Smith	Big Picture: Main Comment 7	Figure	DoDs	throughout			Show more DoDs	change made to report	We have addressed this comment by adding a full set of DoDs in an appendix (A) for the J2 Return Channel reach.
Smith	7.5	Figure	DoDs	throughout/appendix			As highlighted above (6.3) DoDs for the full sequence should be presented in full page map formats, extending the exemplar plot of Figure 0.4	change made to report	We have addressed this comment by adding a full set of DoDs in an appendix (A) for the J2 Return Channel reach.
Brasington	6.2	Figure	Enlarge	3		Fig. 3.5	Present as a single page	change made to report	Moved Fig. 3.5 to single page
Smith	Big Picture: Main Comment 3	Figure	Field Photos	Throughout/Appendix			Provide more field photos such as on P22. Especially of incision/ other things discussed	change made to report	Added to incision discussion, Figure 2.5
Williams	2b	Figure	Figure	throughout			Consistent inclusion of geographic features on maps. Many charts (e.g. Figure 2.6) include a consistent set of geographic features (e.g. JT Return, Augmentation Area, Overton Bridge etc); it would be useful if these features were also consistently shown on all maps; this positioning would help data interpret by enabling easy cross-referencing between figures.	change made to report	Overview map has been replaced to address these and other comments (E.1, 2.1)
Williams	2c	Figure	Figure	throughout			Add a "flow direction" arrow to all maps.	change made to report	Added to figures where appropriate
Smith	13	Figure	Figure	2	33	20	It would be good to see these cross-section locations.	change made to report	Added map (Fig 2.7)
Williams	2a	Figure	Figure	throughout			Choice of colours on charts for points/lines showing different years. A wide variety of different colours are used on different charts; interpretation would be easier if a consistent palette was used throughout the report, which is also accessible for people with colour-vision deficiencies (Crameri et al., 2020).	no change made to report	Agree this is a good approach and we will incorporate it into future work.
Smith	23	Figure	Figure	3	60		An 'elevation distance from grade line' plot might help discriminate between these two lines a little.	no change made to report	Fig. 3.8 provides a differential comparison of 2016 and 2021 thalweg elevations as part of the changepoint analysis
Smith	40	Text	Flow Normalization	4 Methods	98		This flow normalization is good to see. Of course, it is sensitive to the choice of exponent on the q divided (P92).	no change made to report	Agreed.
Williams	Ch. 2 c iii	Text	Gage Analysis	2	37	52	Can you further expand the reasons for water surface elevation change (P37 L52) to include local change and roughness change?	change made to report	Modified sentence to say: Trends of increasing or decreasing water surface elevation at a constant discharge can be linked to a variety of complex processes and can be associated with bridge/site modification, changes in sediment supply, and changes in roughness (vegetation dynamics).
Williams	Ch. 2c v	Text	Gage Analysis	2			Does interpretation of planform change (e.g. switching of anabranches, changes in anabranch widths) in the multi-thread sections (particularly Cottonwood) influence the consistency of interpretations of gage data, particularly for low flows?	no change made to report	Yes. The dynamic nature of the multi-threaded channel creates "noise" in stage measurements at low discharges. This was part of the rationale for using GAMMs to develop long-term relationships and plotting the relationships along with the measurement data to get a sense of variability and confidence in modeled stage through time.
Williams	Ch. 2 c i	Text/Analysis	Gage Analysis	2			Methodological approach: Why was water surface elevation (i.e. stage height) interpreted and not any bed level information from ratings? Are the latter available. I'd be curious to know whether these gages were included in Slater et al.'s analysis of USGS station data; if so, what do their results show? If not, why couldn't the data be included in Slater et al.'s analysis? This may explain why bed level can't be used here?	no change made to report	These gages were not included in the Slater analysis. We agree that using flow area, velocity, and width to enhance our analysis would be beneficial if we revisit specific gage analysis in the future, however, we do not intend to add more to this analysis for this report.
Williams	Ch. 2 a	Text	GGL	2	29	104	Justify use of GGL (no perturbations/tribs/chokepoints to interrupt)	change made to report	Added language to 2.3.1

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Williams	Ch. 2 a	Text	GGL	2		fig 2.5 caption	Change reference to 2016 "topography" to include bathy	change made to report	edited
Smith	10	Text/Figure	GGL	2.9	29		Clarify that the equation is for the black GGL line. Does this include the J2 return channel and land in-between (I'm just wondering why the convexity is not apparent)? What was Murphy's slope estimate and how exactly does it compare?	change made to report	Updated Fig. 2.3 caption. Yes the cross sections are depicted in Figure 2.2 and cover everything from the north bank of the north channel to the south bank of the J2 Channel. There is enough floodplain elevation data in this extent to reduce the impact of J2 slope on the overall GGL slope.
Smith	26	Text	GIS	3 Methods	66	70	A 'single' polygon used for all years. Was this a union of all wetted areas?	no change made to report	yes
Smith	Big Picture: Main Comment 9	Text	Habitat	throughout			Make stronger connection between channel change and habitat. Characterize things more clearly as good or bad for habitat	change made to report	Clarified this in wetted width discussion
Williams	Ch. 2 b	Figure	Historical Trends	2	Fig 2.7		Whilst there are only two sample years available from the cross-section data, and it is known that there is inter-year variability, I agree with the interpretation of Figure 2.7 that there is a signal of different elevations between stations 50,000 and 90,000 between 1989 and 2002-2016. Shading could be provided around each line to indicate the elevation uncertainty in the different survey techniques, potentially drawing on Bangen et al. (2014) for cross-section surveys and the error analysis for "wet" areas in the 2016 LiDAR survey (presented in Chapter 4). This would enable further interpretation of the point (e.g. at station 50,000 or 60,000 etc.) at which the signal is clear from potential survey noise.	change made to report	We agree this would be a more robust way of demonstrating the uncertainty of measurements. We don't have information on the vertical accuracy of the historical cross-section surveys and had trouble identifying a way to show elevation uncertainty that wasn't arbitrary. Instead, we modified the text to acknowledge this limitation. See caption on Figure 2.8
Williams	Ch. 3d ii	Text	Hydraulic Model	3			Were any of the numerical models calibrated / validated with observation data? How well do they perform? A range of metrics are available to assess 2D hydraulic model predictions; Section 2.51 of Masafu et al. (2024) provides a summary of some of these techniques. If information is available in other reports then a summary of model performance would be valuable here.	change made to report	Calibration and validation details can now be found in section D.3
Smith		Text	Hydraulic Model	3 Methods	66	66	Why use two separate discharge levels either side of Overton to clip the transects? Could a more consistent approach be used (e.g., stage when the gage reading was X)? Presumably, the approach taken was simpler to implement, but did it result in a discontinuity at Overton?	change made to report	Because the J2 Return channel and North Channel do not typically have an upstream connection, this reach must be modeled with 2 upstream boundary conditions. We selected flows that approximate a realistic bankfull flow in they system (i.e. 2500 at J2 Return and 2500 in the North Channel) These flows then combine near Overton Bridge to create the 5000 cfs flow for the rest of the reach. This has been clarified in the report.
Williams	Reproducibility	Text	Hydraulic Model	3, 4			It is clear that some modelling results that have been undertaken for previous reports are not accessible and/or not reproducible. Are there plans to ensure that the data and analysis that has been undertaken for this report are long-term digitally accessible?	change made to report	Previous models are accessible, however we did confront challenges in comparing results from 1D models based on transect surveys to 2D models based on LiDAR bathymetry. We have added more detailed background on our models in sections D.3 and 3.6.1
Smith	35	Text	Hydraulic Model	4 Methods	85	68	Perhaps clarify here that the 1D models were in HEC-RAS.	change made to report	This is now noted in section D.3
Smith	Big Picture: Main Comment 6	Text/Figure	Hydraulic Model	Ch. 3,4 Methods			A flow chart of the method and how LiDAR and models were used to determine key outputs might be informative and add clarity to the overall data processing workflow thereby improving reproducibility	no change made to report	We do not believe that a flowchart is needed for the intended audience but will consider this for wider publication.
Williams	Ch. 4a iv	Organization	Hydro Data	4	85	1.27.1.2	"Hydraulic data". This is an example (together with the LiDAR data) of where there could be cross-referencing through the report and the report could be made more concise by organising common methods into one location (see earlier comments on this). Similarly, I found the material on P87 L97-104 and P88 L109-130 to be rather contextual and more suitable for an introduction rather than methods section.	change made to report	This has been addressed by moving hydraulic, hydrologic, and other introductory/contextual information to the new Data Summary Section
Williams	Ch. 2c iv	Figure	Imagery	2			Imagery should be more carefully evaluated and cited	change made to report	We added information on imagery data used to section D.5 and added flow labels to imagery figures
Williams	Ch. 2d i	Figure	Imagery	2	47	164	Can you provide information on the specific satellite (P47 L164) and the imagery dates (as an appendix?); are the thalweg lines available (digital supplement?)	change made to report	Information on aerial imagery added to Section D.5. No satellite imagery used. Data is available upon request.
Brasington	5.4	Figure	Imagery	2	2.9-2.11	2.9-2.11; 2.14-2.15	Label discharge in figures	change made to report	Added flow and flow direction label on all aerial imagery

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Williams	Ch. 2d ii	Text	Imagery	2			How was imagery selected for each year? Similar month, similar discharge?	no change made to report	Prior to 2011 - used highest resolution CIR imagery available. 2011 - present, used Program's annual fall imagery flown in October or November.
Brasington	6.5	Figure	Imagery	3		3.20	The discharge at the time of capture for the aerial imagery shown for 2016 and 2021 in Figure 3.2 clearly differs. I would be useful to back out the discharge for the two acquisition dates and add this to the images as a label or as a note in the caption	change made to report	Added flow and flow direction labels to Figure 3.20
Williams	Ch. 3f i	Figure	Imagery	3	Fig 3.20		I think the discharges for 2016 and 2021 are different. Can the discharges be labelled or imagery with similar discharge be found (see an earlier comment about this for figures in Chapter 2).	change made to report	Added flow and flow direction labels to Figure 3.20
Williams	1c	Text	Introduction	1			Vegetation: There are various references to the root systems of vegetation and their relation to bank erosion susceptibility. It would be useful to have a description of the colonization of bars and banks with vegetation, any seasonal dynamics, and any management interventions .	no change made to report	Our intention was to very broadly state that vegetation exists on channel boundaries, and while a full-scale investigation of the vegetative characteristics is no doubt interesting and important we feel it is beyond the scope of the current report. Moving forward, we are investigating the impact of roots and trees on cutbank erosion patterns and rates with lidar and drones, and we hope to develop a stronger connection among flow, form, and vegetation.
Williams	VIII	Text	Introduction	1	16	140	When will proposed flow regime be implemented? More context	change made to report	Added text to footnote 10: Proposed flow regime refers to implementation of the Program's Water Action Plan designed to reduce deficits to United States Fish and Wildlife Service (USFWS) target flows by 130,000 – 150,000 acre-feet annually. Implementation of the Plan began in 2007. As of 2024, water projects are credited with reducing deficits by approximately 110,000 acre-feet annually. Water has been used to increase flow during whooping crane migration, during the summer to enhance baseflows, and to conduct vegetation scour/management experiments.
Williams	IX	Text	Introduction	1	18	222	What are the "other" geomorphic metrics?	no change made to report	There was no additional specificity. The EDO was tasked with exploring appropriate metrics.
Williams	1d	Text	Introduction	1			Summarize all historical management actions earlier in the report. Include meander straightening, blocking breakthrough channel, mechanical augmentation, disking.	change made to report	Description of augmentation projects (including 2017 straightening) is in 1.5.4. Added a reference and breakthrough channel description added to D.2
Brasington	4.1	Figure	Introduction	1	19	Fig 0.5	No scale bar and legend obscures channel. Maybe rendering better? Remove acronym in caption	change made to report	Fig 1.5 in revised report
Smith	7	Text	Introduction	1	16		what is the 'proposed flow regime'? Presumably this is a higher flow, relating to the values in the footnote?	change made to report	The specific flow regime was the implementation of USFWS target flows. Clarification added to footnote 10.
Smith	Big Picture: Main Comment 1	Text	Introduction	1			Provide more information the catchment/ canal system. How much is abstracted at N. Platte? Pre-canal history of the J2 Channel and flow decreases	no change made to report	We will note this for publication to a wider audience, but do not consider it necessary for the current audience of this report.
Williams	Ch. 3 Intro i	Text	Introduction	3			Make explicit reference to 2016 onwards topobathy and pre-2016 to 2009 topo only	change made to report	clarified
Williams	Ch. 3 Intro ii	Text	Introduction	3	51	43	More precise/expansive description of "more detailed evaluation"	change made to report	added
Williams	Ch. 3c iii	Text	Introduction	3	66	76-77	Describe aggradational processes	change made to report	Added "Increases in mean channel elevation indicate aggradation due to depositing material. Material sources in this case include sediment augmentation, lateral erosion, and upstream transport."
Williams	XI	Text	Introduction	3	50	31	This paragraph is relatively general at this stage of the report. The overall aim of the report doesn't need to be repeated, you can go straight to the chapter objective (next paragraph). Edits such as this will help to make the report more concise.	change made to report	Agree, moved paragraph to ch. 1
Smith	20	Text	Introduction	3	50	40	Four analyses? The following text suggests three, though it is hard to identify exactly what they are.	change made to report	Agree that this was unclear. Rephrased the sentence
Williams	Ch. 4a i	References	Introduction	4	84	24	See Vericat 2017 for earlier references to cite	change made to report	Rephrased, added Ashmore and Church 1998
Williams	Ch. 4a ii	Text	Introduction	4	84	34-35	Describe aggradational processes	no change made to report	Added in chapter 3, but doesn't fit in the context of this paragraph
Williams	IV	Text	Introduction	Exec Summary	8	21	More context on the river before hydropower impacts is needed.	no change made to report	Executive Summary is aimed at an audience already familiar with the river. More context is provided further in the report
Williams	V	Text	Introduction	Exec Summary	9	38-39	Reference to the high flow dynamics during these years would be useful	no change made to report	Executive Summary is aimed at an audience already familiar with the river. More context is provided further in the report
Williams	VI	Text	Introduction	Exec Summary	9	43	An average is presented then a range. Need to be consistent or provide greater explanation of these different formats.	change made to report	Updated text to provide a range for both components
Williams	VII	Text	Introduction	Exec Summary	9	56	Is the word specific needed?	no change made to report	Yes, this is consistent with how we refer to this analysis later

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Williams	II	Text	Introduction	Exec Summary	8	E.1	Define Big Question	change made to report	Add footnote: Big Questions are priority uncertainties identified by policymakers. The answers to these questions will inform future decision-making.
Smith	4	Text	Introduction	Exec Summary	9	25	How far downstream did the 6 ft of incision reach by 2002?	no change made to report	Approximately 4000 feet based on available data points (Figure 2.8)
Smith	5	Text	Introduction	Exec Summary	9	fn 5	What is NPPD?	change made to report	Nebraska Public Power District. Defined in text
Williams	Ch. 4 a viii	Text/Analysis	Lateral Erosion	4			Does lateral erosion method work along anabranches within the active channel where topo variation is smaller? Could compare with Wheaton et al. 2013 method or "expert manual interpretation" to check	Data Provided	Using this suggestion we had two experts within the Program manually delineate lateral erosion in two example locations (wandering section and braided section) between two different time periods. We have included figures and tables that justify moving forward with our automated procedure in the Lateral Erosion Addendum
Brasington	7.3	Text/Figure	Lateral Erosion	4			Cite similar work (listed) and provide more DoD plots	change made to report	We have reviewed citations but no additions made to this section. Added full set of DoDs for the upper study reach as Appendix A
Williams	Ch. 3b i	Organization	Long Pro	3			Consider the logical sequence of the methods section: I think the slope smoothing (i.e. producing the data that will be analysed) should be presented before the changepoint analysis.	change made to report	Moved thalweg generation and simplification methods from Section 3.7.1 to 2.3.1 (prior to changepoint). Changepoint analysis not done using the GAMM-modeled thalweg data so GAMM is described where first referenced in 3.6.2 and also used for Sta. 70,000 analysis (section 3.8)
Williams	Ch. 3b ii	Text	Long Pro	3	61	12-14	Consider whether some of the differences quoted (e.g. 0.2 ft; P61 L12 / L14) are within the range of uncertainty in the wet area accuracy of the LiDAR (P93 Table 0.3).	change made to report	We estimate that wet LiDAR accuracy (95% confidence) ranged from 0.17 to 0.25 ft in 2016 and 2021 (Table D.1), therefore conclusions about changes of 0.2ft may be affected by error. However, we have shown in Table D.3 that error is overall normally distributed. An average change of 0.2 ft over many points considered in the changepoint analysis is therefore likely representing real elevation change.
Williams	Ch. 3b iii	Text/Stats	Long Pro	3	table 3.1		Consider quartiles instead of min/max	no change made to report	We think our simplistic descriptive stats are easier to interpret and we are not sure what additional benefit adding quartiles would provide to the average reader.
Williams	Ch. 3b iv	Text/Stats	Long Pro	3	Fig 3.10		Figure 3.10: Could a statistical test be used to determine whether there is statistically significant difference between the 2016 and 2021 Thalweg Models? This would help to shed light on my next two comments.	change made to report	We removed this figure based on this and other comments regarding slope analysis
Williams	Ch. 2 b	Text	Murphy	2			I recommend that the comparison (Section 1.10.2 P35) between the observations and predictions could be edited to place less emphasis on the model potentially being “correct” (i.e. the truth) and rather emphasizing what the limitations to the model are in terms of its conceptualisation, assumptions and data inputs relative to the dynamics of the river and what interpretation of the observations allows.	change made to report	Agreed, changed text to clarify on pg. 55 ln8-10
Williams	Ch. 2 b	Text	Murphy	2	35	39	Focus on how further monitoring may allow the river to express its dynamics	change made to report	edited text
Smith	14	Text	Murphy	2	36		the incision measurements are not as severe as modelled by Murphy et al. (2004), though I suppose these new lines would shift down if the same maximum incision depth was used. How would it compare then?	change made to report	We redid this analysis with the same maximum depth/Murphy method to make this an apples-to-apples comparison. It did not change the outcome of the analysis.
Williams	Ch. 2d iv	Text	North Channel	2			Is there value in interpreting sinuosity / braiding intensity of the North Channel as a “control” to compare to the J2 Return Channel?	no change made to report	We like the suggestion of using a control reach to better place morphological changes in J2 into context, but we do not think the North channel is a strong candidate due to many decades of considerably different flow regime. We are exploring how best to use other parts of the Platte for adding context to J2 and will pursue this concept in future work.
Williams	Ch. 3 Discussion iii	Text	North Channel	3	81	97	Consider conducting an analysis of the longitudinal dynamics of the North Channel, to contextualise the findings for the J2 Return Channel (P40 L92) and improve the certainty associated with the statement about confluence inputs on P81 L92 as these are important for sediment supply downstream of Overton Bridge;	no change made to report	We like the suggestion of using a control reach to better place morphological changes in J2 into context, but we do not think the North channel is a strong candidate due to many decades of considerably different flow regime. We are exploring how best to use other parts of the Platte for adding context to J2 and will pursue this concept in future work.
Smith	Big Picture: Main Comment 4	Organization	Organization	throughout			Prefers clearer separation of Methods and Results. Suggests short discussion section to help isolate interpretation from description	no change made to report	Considered alternate structures but prefer existing organization
Smith	7.6	Figure	Overview Map	1		Fig. 0.1, 0.5	Add a scale bar and inset location map	change made to report	Replaced these figures (E.1 and 1.5), inset not required for this audience

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Williams	X	Figure	Overview Map	2	27	48	These places aren't marked on the maps, or different acronyms are used; see comment above on consistency in geographic reference points on figures.	change made to report	Overview map has been replaced to address these and other comments (E.1 and 2.1)
Williams	III	Text	Overview Map	Exec Summary	8	18	Expand caption to provide more context for the summary	change made to report	caption edited
Smith	3	Figure	Overview Map	Exec Summary	8	27	Presumably this is false colour image (there are several through the document)? Perhaps indicate flow direction. Also, perhaps indicate station 70,000 which is referenced in the Executive Summary.	change made to report	Yes, this is color infrared (CIR) imagery. Figure updated based on this and other comments (E.1)
Williams	2d	Figure	Overview Map	throughout			Consider using identical extents and scales for similar maps (e.g. why do the extents for Figures 2.1 and 2.2 need to be different – it makes it hard to cross-compare them).	change made to report	Overview map has been replaced to address these and other comments (E.1, 2.1)
Smith	11	Text	Photos	2	30		Are there any field observations of these bank heights (or even measured directly from LiDAR)?	change made to report	Yes. Added photos of incision (Fig. 2.4)
Williams	Ch. 2 i, ii	Text	Planform Change	2	48	216	Comment on whether the transition is from braided to meandering or whether there is a wandering state, since a wandering planform is referred to in subsequent sections of the report; and (ii) Discuss what are the typical capacities of braided / wandering river types for conveying sediment versus meandering rive types) (see e.g. Church, 2002).	change made to report	Added text in Section E.2 and 2.7.
Williams	Ch. 3a ii	Text	Planform Change	3	51	62-3	Explicitly summarize meandering, wandering, braided definitions in Exec Summary	change made to report	We have added explicit definitions to section E.2.
Smith	Big Picture: Main Comment 9	Text	Planform Change	1 or 3 Intro			Consider adding Leo&Wolman(1957) or other braiding thresholds discussion	no change made to report	We note a reference to this seminal paper is already included in section 2.6.2. We think the idea of thresholds in planform is well established and think a detailed discussion of these papers (and more recent ones (e.g. Kleinhans and van den Berg, 2011) are interesting but beyond the scope of the report.
Williams	Ch. 4a vi	Text	Pre-Aug Data	4	90	150	Define hydroflattening. Important source of bias should be explained/ assumptions listed in table and figure captions	change made to report	Defined in Data Summary Section; Uncertainty shown and labeled in all figures involving 2009 LiDAR.
Smith	38	Text	Pre-Aug Data	4 Methods	90		The use of 2009 data when no bathymetry was available is slightly challenging. My understanding is that model estimates suggested an average depth of 1 ft and this is used to estimate subsequent sediment aggradation below the water level of the survey. I agree this gives a maximum possible value, but I'd exercise caution in how this value is interpreted. To be fair, this is reflected in the results description (e.g., P94).	no change made to report	Agreed
Smith	39	Text	Pre-Aug Data	4 Methods	95		Exactly how were these uncertainties calculated? I suggest dedicating a short section in the methods to clearly articulating this. No uncertainty in upstream reach? Is it within the thickness of the line?	no change made to report	Uncertainty is calculated at each station by adding the potential aggradation volume (calculated as described in the methods section) to the volume change.
Williams	Ch. 3a v	Figure	REM	3	55	17-18	There is no data to support this comment on the differing proportions for different categories. Can a histogram be added to the side of each REM in Figure 3.3?	change made to report	Removed this statement as the conclusion is not supported by other analyses.
Williams	Ch. 3a iii	Text	REM	3			Are elevations associated with the extent of the North Channel excluded from any subsequent quantitative analysis of the dynamics of the J2 Return Channel? The full extent, including both Channels, is shown on Figure 3.1 and I'm concerned that if the North Channel is not excluded then the morphodynamics of that Channel may influence (even bias) any interpretation of data from the J2 Return Channel. It would be worth making a note about this on the figure caption and in the methods.	no change made to report	The North Channel is excluded from sinuosity , wetted width and mean channel elevation analyses. It is included in the GGL computation.
Williams	Ch. 3a i	Text	REM	3	51	54	Is "in general" correct; is "For all" more precise?	change made to report	Removed "in general"
Smith	6	Figure	Scale	Exec Summary	12		Why is the map not to scale?	change made to report	Figure has been updated (1.1)

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Williams	Ch. 4a v	Text	Sed volumes	4	Table 0.2		How were volumes calculated?	change made to report	Volumes were calculated using the method described in the next section. This was clarified in the report text.
Williams	1b	Text	Sediment Data	1			Grain size: Do you have surface / sub-surface grain size information for different reaches? If so, what are the downstream / bar-scale patterns? This is important since the report refers to bed armouring as a consequence of "hungry water" winnowing fines.	change made to report	No armoring data available, but field photo added along with general grain size information to section D.4
Smith	Big Picture: Main Comment 2	Organization	Sediment Data	1			Provide flow summary (N and J2) earlier. Currently on P88. Any direct sed trans measurements? Sed rates in US reservoirs? If so provide upfront	change made to report	Hydrology and sediment are now discussed in the Data Summary Section.
Brasington	5.1	Text/Analysis	Sediment Data	2			There is no discussion of bed texture/substrate changes in the chapter. As the authors note, the arresting of incision is likely to reflect a combination of factors, including armouring, reduced slope and also exposure of poorly reinforced bank material. Do the authors have any insight into the principal driver of the changing nature of bed adjustment – and specifically – could the revised HEC-RAS sediment routing model discussed in Chapter 1 be used to isolate the significance of the controls?	change made to report	A brief description of sediment size is now provided in D.4. We are currently working with consultants on improved mobile bed models of this system that may help us address these uncertainties
Williams	Ch. 4a iv	Organization	Sediment Data	4	88	109-130	Put in introduction/methods	change made to report	Moved to Data Summary section
Smith	31	Text/Figure	Sinuosity	3 Methods/Discussion	73	118	"Continued to increase"... the real increase from Figure 3.17 seems to be prior to 2012, though following the straightening of the meander, there has been a gradual increase... I doubt this would be statistically significant. Also, is sinuosity not hard to interpret when there is so much braiding. Why was there no braiding index considered? Finally, P72 notes both manual and LiDAR-derived thalwegs... which is shown in the Figure?	change made to report	We think the general trend in increase in sinuosity is important, though we do concede the value of this increase is small. However, since sinuosity is nearly one to begin with, even small increases can be important to note the onset of wandering and eventually meandering. We have clarified this with some edited text. In addition, we think a rigorous assessment of statistical significance would be both difficult with such a small dataset and potentially distract from the point - that sinuosity numerically confirms visual analysis of planform changes. Our goal is to highlight evidence that confirms recent planform changes and could inform potential future changes. Additional analyses of planform changes - for example, comparison of J2 with other parts of the Platte - could indeed benefit from statistical tests and we appreciate the suggestion moving forward.
Brasington	6.6	Text	Slope/Width Relationship	3	72/73		Interesting, but be cautious of conclusion as other factors may be just as critical for maintaining a braided channel (sed supply, bank strength, various flows)	change made to report	Agree, removed the paragraph on the relation between the two factors.
Smith	30	Text/Stats	Slopes	3 Discussion	72	89	The text suggests a nonlinear relationship between slope and width, yet Pearson correlation used. It might be nice to see this relationship. Which direction is the relationship?	change made to report	We have removed Fig 3.11 and slope is now discussed in combination with thalweg profile (3.4.2, pg 80,ln3-8) and regarding Fig. 3.15
Williams	Ch. 3b vi	Analysis/Figure	Slopes	3	Fig 3.11		Double check that the magnitude of difference between 2016 and 2017 modelled thalweg slopes is correct upstream of Overton Bridge (Figure 3.11). In the caption it would be valuable to concisely explain the channel changes that caused these differences.	change made to report	We have removed Fig 3.11 and slope is now discussed in combination with thalweg profile (3.4.2, pg 80,ln3-8) and regarding Fig. 3.15
Smith	22	Text/Analysis	Slopes	3	58	75	I need a little bit of clarity on the point being made here. What might the effect be on the calculated slopes? If migration has taken place, would the horizontal distance used in the slope equation be a lot out? Or is this really minor given the migration rates and intervals used (is it 100 ft like the prior analysis)? Without this information, I can't really judge how limiting this assumption is in the slope calculations.	change made to report	We have removed Fig 3.11 and slope is now discussed in combination with thalweg profile (3.4.2, pg 80,ln3-8) and regarding Fig. 3.15

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Smith	16	Figure	Specific Gage	2	41	Figure 2.12	I assume the presence of triangles (for example) on the graph, where this discharge is well below the triangle stage range, simply reflects the use of the 30-day trailing mean discharge? Perhaps note this in the caption to explain this.	change made to report	That is correct. Text added to caption: Presence of stage measurements in flow ranges above corresponding discharge on this figure reflect use of 30-day average trailing discharge.
Brasington	6.1	Organization	Thalwegs	3	57		Thalweg delineation methods were used for Figs. 2.6 and 2.7 as well. Should those methods go in Ch. 2?	change made to report	Moved thalweg generation and simplification methods from Section 3.7.1 to 2.3.1.
Brasington	6.4	Figure	Thalwegs	3		Fig. 3.18	Plot timeseries of thalweg alignments around 70K as accompaniment	change made to report	Created planview figure of thalweg alignments around 70K (Fig. 3.18)
Smith	17	Text	Typo	2	41	105	typo 'dischargers'	change made to report	fixed
Smith	19	Text	Typo	2	47	161	'attempted to'?	change made to report	fixed
Smith	33	Text	Typo	4	85	62	typo "3three"	change made to report	fixed
Williams	I	Text	Typo	Throughout			Fix numbering	change made to report	Apologies for the many numbering issues. They should be addressed in the current version
Brasington	7.2	Text/Analysis	Volume Change	4		Fig. 0.10	Further describe how "volume eroded" values computed vs. net change	Data Provided	Segmented aggradation and degradation figures are provided as an addendum
Williams	Ch.4 a xi	Text/Analysis	Volume Change	4	104	394-395	Dynamic but stable with no observable signal from augmentation". Do you know that all sediment generated from augmentation has been deposited in upstream reaches; a cumulative, segmented budget similar to that shown in Figure 5.2 in Vericat et al. (2017) would enable you to quantitatively analyse where sediment is being stored along sub-reaches.	Data Provided	Segmented aggradation and degradation figures are provided in this package. We plan to examine sediment flux and budget analyses in future work
Williams	Ch.4 a x	Figure	Volume Change	4		Fig. 0.11	Add vert and horizontal scales to inset	change made to report	Edited Figure 4.9
Williams	Ch. 4 a ix	Text/Analysis	Volume Change	4			Aside from "lateral erosion", all other changes are "lumped" together whether they are associated with erosion or deposition. To interpret the dynamics of the study area, I think it would be beneficial to more extensively segregate erosion and deposition within this residual class (e.g. on the bottom panel of Figure 0.8 showing erosion and deposition separately as well as the net).	Data Provided	Segmented aggradation and degradation figures are provided as an addendum
Smith	42	Text	Volume Change	4 Discussion	103		It would be useful to have a comment about the very different pattern of volume change in 2019/20 in the most upstream portion of the reach. Is this related to the closure of the breakthrough or just the higher flows that year mobilising more of the augmented sediment?	no change made to report	see Fig 4.11 caption. Without exact flow data in the upstream reach, can't point to an exact cause.
Williams	Ch. 3d iv	Figure	Wetted Width	3	3.15		What is the unit on the y axis?	change made to report	Added FT to y axis unit on Fig 3.13
Williams	Ch. 3d iii	Text/Figure	Wetted Width	3			Show that Sat imagery confirms large change following 2015 (not due to HEC-RAS/SRH switch)	change made to report	Added figure 3.14
Williams	Ch. 3d i	Text	Wetted Width	3			Why was a value of 2,000 cfs used here (compared to 2,500 and 5,000 cfs used in the previous section).	no change made to report	2,000 cfs was used here for consistency with previous wetted width data sets that are reported across the entire Associated Habitat Reach. (3.6.1)
Smith	28	Text	Wetted Width	3	71		I found the modelling aspect of the wetted width calculation a little tricky to follow.	no change made to report	We do not know what specifically should be changed in response to this comment but we recognize that we had to use a mismatch of 1D and 2D models. We will consider how to make the modeling aspect of this work easier to understand in future reports.
Smith	29	Text	Wetted Width	3 Discussion	71		The figure really highlights the main problem reach where there are some narrowing or static widths (around 75,000). Surely the increases in width around cottonwood are good? Though it is hard to tell without any identification of impacts on habitats.	change made to report	Added "these width increases had a positive impact on WC habitat"
Brasington	5.3	Text/Analysis	Wetted Width	2			SWOT data?	no change made to report	With this suggestion we tested these data and we confirm that the width of the river is at the observational limits - especially when flows are low. In some cases the water surface slope is only represented by less than 2 pixels, and we found there to be substantial lateral and downstream variation with such marginal data. However, we will consider using SWOT in the future especially during large flood flows and we remain excited for future uses of this and other similar remote data.
Smith	9	Text	Wording	1	28	81	What is meant by 'pre-development channel'?	change made to report	Agree this was unclear, removed this term from text.
Smith	15	Text	Wording	2	37	55	would channel narrowing not *increase* the water elevation for a given discharge?	change made to report	Agree with comment, removed narrowing example from sentence

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Reviewer	Comment	Type	Topic	Chapter/Section	Page	Line	Comment / Paraphrase	Addressed?	Response (Text or peg and line#)
Smith	41	Text	Wording	4	99	336	When describing erosion here, is it net erosion? I assume so. Likewise for the Figure on P100.	no change made to report	Correct
Smith	Big Picture: Main Comment 8	Text	Wording	Exec Summary	9	51-52	Interpretation pushed further than rest of document. Cite specific figures/ results here and throughout section	change made to report	We have reviewed our wording in this section, but we also emphasize that we think our language is appropriate for our audience - softening language too much, or making statements less firm, should only be done when the conclusions or results are weak and warrant it.
Smith	1	Text	Wording	Preface	2	30	'Mining' of sediment invokes some kind of human sand/gravel mining. Is this what is intended here?	change made to report	No. Changed text to "erosion of sediment"
Williams	Ch. 3c v	Text	XS Ave Pro	3	Fig 3.13		From c.72,000 ft station to Overton Bridge there is a consistent pattern of average cross-sectional elevation; this is compelling for analysis of the overall trend.	change made to report	Agreed! Added to 3.5.2 results text
Williams	Ch. 3c vi	Text	XS Ave Pro	3	69	24	Greater cross-referencing to the evidence would help here.	change made to report	Added more references to specific sections in the discussion and throughout this chapter.
Williams	Ch. 3c ii	Hydraulic Modeling	XS Ave Pro	3			Why were 2,500 and 5,000 cfs selected? Is there a physical basis for these values? From figure 2.12, I note that these values exclude many Annual Maximum flows. To contextualise and aid interpretation, it would be useful to see a figure showing the inundation area associated with these flows (from 2D model predictions?).	change made to report	Added explanation that these are the approximate bankfull flows for the reach above and below the confluence. See 3.5.1
Williams	Ch. 3c i	Text	XS Ave Pro	3			Is N. Channel excluded from XS Ave Profile calcs?	no change made to report	Yes
Williams	Ch. 3c iv	Text	XS Ave Pro	3	67	81	Convex or linear?	change made to report	Fig. 3.10. agree doesn't look obviously convex, reworded to deviation from GGL
Smith	12	Figure		2	31	Fig. 2.5	This figure is very convincing.	no change made to report	Thank you