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

TO: PRRIP Governance Committee (GC)
FROM: Executive Director (ED)
SUBJECT: Refresher on Peak Flows & Unvegetated Channel Width
DATE: November 21, 2024

Background

At the October meeting, the Technical Advisory Committee (TAC) requested a refresher on the role of peak flows in maintenance of unvegetated channel width. This was a focus area for Program science during the First Increment. In 2018, the Program published research on the roles of hydrology, channel morphology and mechanical management in creation and maintenance of suitably-wide unvegetated channels for whooping crane roosting (Farnsworth et al. 2018). In addition, supplemental analyses are ongoing as part of the evaluation of the effectiveness of germination suppression flow releases. This memorandum provides brief summaries of these efforts.

2018 Investigation of Peak Flows

This research evaluated the influence of a range of hydrologic metrics, physical channel conditions, and mechanical management on the width of channel not obstructed by dense vegetation. This metric was referred to as total unobstructed channel width (TUCW). We employed quantile linear regression to identify and quantify the size effects of 11 primary variables on TUCW over the period of 2007 – 2015. The publication is included as **Attachment 1**. Key findings are presented below.

Key Findings

The 40-day peak discharge, defined as the highest average daily flow over a 40-day period, was identified as a primary predictor of TUCW in the study area during the analysis period. The analysis indicated that increases in 40-day peak flow lead to a corresponding increase in TUCW, supporting the role of sustained high flows in managing channel vegetation and maintaining habitat suitability. Specifically, for every 5 m^3/s (175 ft^3/s) increase in 40-day peak discharge, an approximate annual increase of 1.8 m (5.9 ft) in TUCW was observed.

A related metric maximum unvegated channel width (MUCW or MUOCW) is one of the best predictors of roosting habitat suitability for whooping cranes. MUCW is the widest continuous width of channel free of dense vegetation. For example, if a channel is completely free of vegetation, TUCW = MUCW. If there are any vegetated islands in the channel, TUCW > MUCW. Program research indicates that MUCW of 198 m (650 ft) or greater are highly suitable for whooping crane roosting. The 2018 research indicated that a 40-day peak discharge of approximately 200 m^3/s (13,000 cfs) was necessary to increase MUCW to 198 m.

The study also evaluated the effect of mechanical management actions such as disking and herbicide application. Disking and herbicide treatment were shown to increase TUCW by up to 41 m in some transects, suggesting that a combined strategy is most effective.

Limitations

The study covered a period (2007 – 2015) when the channel widened substantially. At the beginning of the study in 2007, much of the channel was occupied by phragmites, which colonized the reach during a prolonged drought. During the study period natural peak flows returned and intensive spraying and disking occurred throughout the reach. As a result, the analysis primarily captured physical process mechanisms responsible for increasing channel width. During the period of 2016 – 2020, the frequency and magnitude of peak flows decreased and the 2018 model predicted corresponding decreases in TUCW and MUCW. In reality, unvegetated channel width metrics remained fairly stable after 2015, indicating that modeling effort failed to capture some physical process that was maintaining width in the absence of sustained peak flows. Specifically, the Program hypothesized that channel inundation during the woody vegetation species germination period may prevent channel narrowing. This led the EDO to revisit channel width modeling during the Extension.

Machine Learning Modeling (Ongoing)

Beginning in 2020, the EDO transitioned to using machine learning approaches to modeling channel width. This work is ongoing as part of the experimental design and analysis approach for evaluation of germination suppression flow releases. **Attachment 2** is a summary of the modeling approach and preliminary results that was provided to the Program's Independent Science Advisory Committee (ISAC) in 2022. Preliminary results are described below.

Key Findings

The model was refined to focus solely on the management metric (MUCW) and predict change in MUCW from the previous as opposed to predicting MUCW. This provided more flexibility and better predictive capacity. The attachment provides more detail on refinements to the metrics and new modeling framework. Preliminary results reaffirm the importance of 1) magnitude of long-duration peak flows during the growing season[1] and 2) identified legacy effects of large peak flow events which appear to continue to influence MUCW several years after the event. Work on this modeling is ongoing. We expect to provide updated results to the TAC in 2025.

[1] The current year 40-day mean peak metric was replaced with 30-day mean June discharge in order to add flexibility for modeling germination suppression flows. Prior year 40-day mean peak discharges were added as new metrics.

Attachment 1 - Investigating whooping crane habitat in relation to hydrology, channel morphology and a water centric management strategy on the central Platte River, Nebraska

Heliyon

Received:
23 August 2018
Revised:
4 October 2018
Accepted:
10 October 2018

Cite as: Jason M. Farnsworth, David M. Baasch, Patrick D. Farrell, Chadwin B. Smith, Kevin L. Werbylo. Investigating whooping crane habitat in relation to hydrology, channel morphology and a water-centric management strategy on the central Platte River, Nebraska. Heliyon 4 (2018) e00851. doi: 10.1016/j.heliyon.2018.e00851

Investigating whooping crane habitat in relation to hydrology, channel morphology and a water-centric management strategy on the central Platte River, Nebraska

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Abstract

The Flow-Sediment-Mechanical approach is one of two management strategies presented in the Platte River Recovery Implementation Program's (Program) Adaptive Management Plan to create and maintain suitable riverine habitat (≥200 m wide unobstructed channels) for whooping cranes (*Grus americana*). The Program's Flow-Sediment-Mechanical management strategy consists of sediment augmentation, mechanical vegetation clearing and channel widening, channel consolidation, and short duration high flow releases of 142−227 m^3/s for three to five days in two out of three years in order to increase the unvegetated width of the main channel and, by extension, create and maintain suitable habitat for whooping crane use. We examined the influence of a range of hydrologic and physical metrics on total unvegetated channel width (TUCW) and maximum unobstructed channel width (MUOCW) during the period of

https://doi.org/10.1016/j.heliyon.2018.e00851

2007−2015 and applied those findings to assess the performance of the Flow-Sediment-Mechanical management strategy for creating and maintaining whooping crane roosting habitat. Our investigation highlights uncertainties that are introduced when exploring the relationship between physical process drivers and species habitat metrics. We identified a strong positive relationship between peak flows and TUCW and MUOCW within the Associated Habitat Reach of the central Platte River. However, the peak discharge magnitude and duration needed to create highly favorable whooping crane roosting habitat within our study area are much greater than short duration high flow releases, as currently envisioned. We also found disking in combination with herbicide application to vegetated portions of the channel are effective for creating and maintaining highly favorable unobstructed channel widths for whooping cranes in all but the very driest years. As such, resource managers could prioritize the treatment of mid-channel islands that are vegetated to increase the suitability of roosting habitat for whooping cranes.

Keywords: Ecology, Environmental science, Hydrology

1. Introduction

Historically, the central Platte River in Nebraska, USA, exhibited a braided planform defined by very wide and sandy channels (Eschner et al., 1983). Mature woody vegetation was established mostly on islands of different sizes and maybe on the banks (Simmons and Associates, 2000). Significant upstream water extractions due to development began in the mid-19th Century and accelerated into the 20th Century. These extractions reduced flow through the central Platte, disturbed numerous geomorphic processes (Williams, 1978; O'Brien and Currier, 1987; Simons and Associates, 2000; Murphy et al., 2004; Tal et al., 2004; Schumm, 2005), and resulted in significant narrowing of the active channel area, evidenced by the encroachment of woody vegetation (Johnson, 1994). Consequently, the contemporary Platte River exhibits a braided to anastomosed planform defined by narrow sandy channels that are bound by large stands of mature woody vegetation.

The reduction in channel width of the central Platte River over time and the mechanisms driving this reduction have been studied extensively (Williams, 1978; O'Brien and Currier, 1987; Johnson, 1994; Simons and Associates Inc. 2000; Murphy et al., 2004; Schumm, 2005), often in the context of acknowledging a link between reach-wide reductions in channel width and reductions in habitat available for threatened or endangered species that use the channel, like the whooping crane (*Grus americana*). These linkages were first realized during many of the early whooping crane habitat selection studies performed on the central Platte River (Johnson, 1982; Lingle et al., 1984; Ziewitz, 1987;

https://doi.org/10.1016/j.heliyon.2018.e00851

Faanes and Bowman, 1992; Faanes, 1992; Faanes et al., 1992). During this time, the United States Fish and Wildlife Service (USFWS) and several conservation organizations became concerned that the widespread reductions in channel width (i.e., narrowing) were causing a decline in the availability and suitability of roosting habitat for the whooping crane (USFWS, 1978; PRRIP, 2006). This led the USFWS to issue jeopardy opinions for any basin water project that could reduce flow through the central Platte River and contribute to the ongoing narrowing of the channel.

In response, the Platte River Recovery Implementation Program (Program or PRRIP) was formed in 2006 and tasked, in part, with contributing to improved whooping crane survival by increasing the availability and suitability of whooping crane habitat along the central Platte River (i.e., creating and maintaining suitably-wide channel widths). The Program's Adaptive Management Plan, which was developed by experts, outlines two management strategies to create and maintain suitably-wide channel widths. The first is known as the Mechanical Creation and Maintenance strategy (PRRIP, 2006). It consists only of sustained mechanical interventions like in-channel vegetation removal via disking and herbicide application. The second management strategy is known as the Flow-Sediment-Mechanical strategy (PRRIP, 2006). As developed, it consists of: limited mechanical interventions to remove in-channel vegetation, flow consolidation into a single channel (which was eventually deemed unfeasible due to permitting and property rights constraints), sediment augmentation, and flow augmentation and management via prescribed releases. The mechanical interventions and sediment augmentation pieces of the FSM strategy have been implemented on the central Platte River since Program implementation in 2007 and, despite upstream channel capacity constraints and other factors preventing the Program from making specific releases prescribed in the Adaptive Management Plan, the natural hydrology in has provided a range of flow conditions including some that resemble the prescribed releases. Overall, the information gathered has been sufficient to begin to explore the effectiveness of the Flow-Sediment-Mechanical strategy at maintaining suitable channel widths for whooping cranes.

The objective of our study was to use the data collected by the Program to identify and quantify relationships between mechanical interventions, flow, and physical channel conditions on in-channel vegetation in the central Platte River. Here, we begin with a description of the methods, including a characterization of the study area, a description of the channel width metrics and a description of the statistical analyses. We then present the results and conclude with a discussion of the results as they relate to channel processes, the Flow-Sediment-Mechanical management strategy and ultimately roosting habitat for an iconic endangered species, the whooping crane.

https://doi.org/10.1016/j.heliyon.2018.e00851

2. Methods

2.1. Study area

The study area for this analysis was a 135-km reach of the central Platte River extending from Overton to Chapman, Nebraska (Fig. 1). This reach includes the critical habitat area for the whooping crane (USFWS, 1978). As is the case with the central Platte River as a whole, this reach is comprised of braided to anastomosed channels that have narrowed substantially over time. The historically active channels are now dominated by large stands of woody vegetation (Johnson, 1994), while the currently active channels tend to be slightly incised with many sandbars that are both unvegetated and covered with vegetation. These active channel bars are generally submerged by flows greater than about 35 m^3/s. Flows through the study reach can change by more than 50 m^3/s per day as they are heavily influenced by a hydropower return directly upstream of Overton and a diversion near Elm Creek (Fig. 1). The shallow nature of the channels produce width to depth ratios that range from approximately 50:1 to 300:1, depending on flow. The mean bed slope of the channel in the study area is approximately 0.12 cm/m, and the total drainage area at the Kearney stream gage is 136,077 km^2 (06770200).

2.2. Measurement of total unvegetated width and maximum unobstructed channel width

Our analysis focused on two channel width metrics: the maximum unobstructed channel width (MUOCW) and the total unvegetated channel width (TUCW). The MUOCW is an important predictor of whooping crane use (PRRIP, 2017) and is measured as the widest unvegetated width of the channel, including all bare-sand islands and water area between patches of dense vegetation. The TUCW includes all water and bare-sand area within the outer bank (i.e., historically active area) of

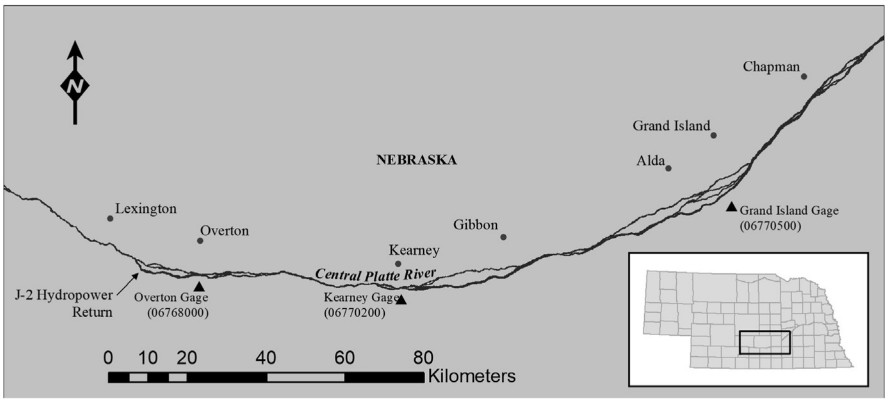

Fig. 1. Associated Habitat Reach of the central Platte River extending from Lexington downstream to Chapman, Nebraska. Locations of stream gages (triangles) used in our analyses are included as well.

https://doi.org/10.1016/j.heliyon.2018.e00851

the channel. In fully-consolidated channels free of in-channel vegetation, MUOCW and TUCW are equal. In channels with vegetated islands, MUOCW is smaller than TUCW and is highly dependent upon spatial location of vegetated islands (Fig. 2) and, consequently, the TUCW is not always representative of general channel width conditions. For example, if a wide portion of the channel is split by a very small island, the MUOCW would be approximately half of the TUCW. Including TUCW in the analysis eliminated this randomness in channel width measures associated with the MUOCW metric, allowing us to more easily evaluate the relationship between vegetation, physical processes, and Program management actions.

We used summer or fall aerial imagery collected annually during periods of low flow to photo-interpret TUCW and MUOCW throughout the study area during the period of 2007−2015. Unvegetated width metrics were delineated at a scale of 1 cm = 2,400 cm along 436 predefined transects using ESRI ArcMap Geographic Information System (GIS) software. Transects were oriented perpendicular to flow, were spaced at 305-m intervals along the channel throughout the study area and encompassed all channels in split-flow reaches (Fig. 2). Photo-interpretation of unvegetated width metrics was determined to provide generally acceptable measurement

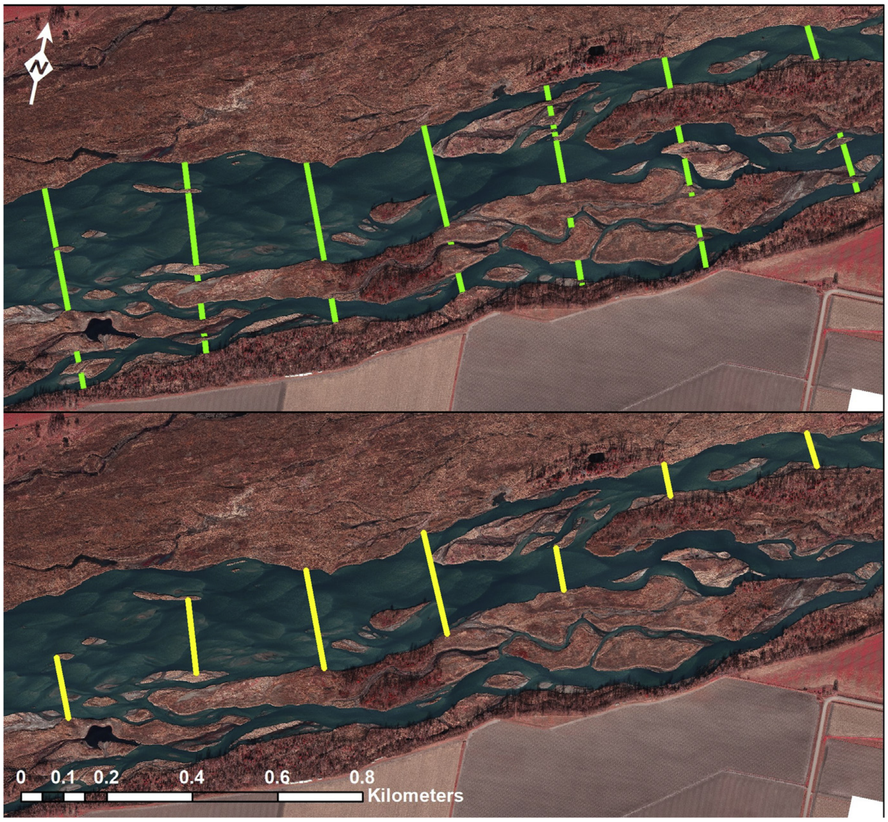

Fig. 2. Examples of total unvegetated channel width (TUCW; top) and maximum width of channel unobstructed by vegetation (MUOCW; bottom) delineations.

https://doi.org/10.1016/j.heliyon.2018.e00851

accuracy based on previous comparisons of field-measured and photo-interpreted unvegetated width measurements in the study area (i.e., average differences of less than plus or minus 10 m, when evaluating average widths of about 160−240 m; Werbylo et al., 2016).

2.3. Model metrics and statistical analyses

A total of 11 primary hydrologic, geomorphic, and management variables were identified based on our review of the literature, proposed Flow-Sediment-Mechanical management actions, and our knowledge of ongoing activities in the study area (Table 1; Supplementary Data). We performed 2 multiple quantile linear regression analyses to identify and quantify size effects of these variables on TUCW and MUOCW within the study area during the period of 2007−2015.

Transects were subset spatially to utilize every fifth transect location to minimize autocorrelation and provide enough information for a robust statistical analysis. We used a quantile regression analysis because our dataset contained heterogeneous variances and obvious bias due to unmeasured variables, which made traditional least squares linear regression inappropriate (Rosenbaum, 1995; Terrell et al., 1996; Cade et al., 1999; Cade, 2003). Quantile regression provides a more comprehensive view of variable relationships by estimating multiple rates of change (i.e., slopes) throughout the distribution of the response variable (Koenker and Bassett, 1978).

Due to the high number of possible covariate combinations, especially due to uncertainty of the best peak and minimum flow durations to predict TUCW and MUOCW, we utilized Akaike's Information Criterion (AIC) and quantile regression goodness of fit for a given quantile in a five-step model selection process (PRRIP, 2017). Local Interpretation of quantile regression goodness of fit was developed to be analogous to interpretation of least squares regression coefficient of determination (Koenker and Machado, 1999). Similar multi-step AIC model selection efforts have been observed in ecological modeling efforts (Baasch et al., 2010; McGowan et al., 2011; Catlin et al., 2015). The model selection steps and goodness of fit measurements were analyzed where the quantile value (τ) was 0.5 and no covariates were included together in models if absolute Spearman correlation was $\geq$0.5. We utilized this multi-step selection process to: 1) identify the most important peak discharge duration; 2) identify the influence of previous year's peak discharge; 3) identify the most important minimum discharge duration; 4) identify best overall hydrologic variable; and 5) produce and evaluate final models with the best hydrologic variable and *a priori* non-hydrologic variables. Within each model selection step, the best model was identified as the most parsimonious model with a delta AIC $\leq$2.0. Model coefficient confidence intervals were produced with an inverted rank test (Koenker, 1994) and the 0.05 and 0.95 response quantiles were used to produce 90% prediction intervals to evaluate the suitability of habitat for whooping cranes.

https://doi.org/10.1016/j.heliyon.2018.e00851

Table 1. Hydrologic, geomorphic and management variables included in our regression analyses for total unvegetated channel width (TUCW) and maximum unobstructed channel width (MUOCW) for the period of 2007−2015. Type, units of measurement and a description of data acquisition are included for each metric.

Metric	Type	Units	Description
Peak Discharge	Hydrologic	m^3/s	Mean daily discharge records were obtained from www.water.usgs.gov for the three United States Geological Survey (USGS) stream gages located in the study area (Fig. 1). Annual hydrologic metrics were calculated for each transect by linear interpolation from the nearest gage. Mean annual peak discharges were identified for 1, 3, 5, 10, 20, 30, 40, 50, and 60-day durations.
Peak Discharge + Previous Year Peak Effect	Hydrologic	m^3/s	Mean annual peak discharge + a percentage of peak discharge from previous year. Metric intended to identify peak discharge effects across multiple years. Previous year peak effects included 0%, 20%, 40%, 60%, 80%, and 100% of previous year peak discharge.
Minimum Discharge	Hydrologic	m^3/s	Mean annual minimum discharge events were identified for 10, 20, 30, and 40-day durations.
Mean June Discharge	Hydrologic	m^3/s	Mean daily discharge during the month of June.
Mean Growing Season Discharge	Hydrologic	m^3/s	Mean daily discharge during the portion of the year when vegetation is actively germinating and growing in the channel. Growing season is defined as 15-April through 15-August.
Wetted Width at Bankfull Discharge	Geomorphic	m	Wetted width of the channel at bankfull discharge. Metric included to represent “vegetation ratchet” control on width adjustment potential. Widths were delineated from June 2011 aerial imagery, which was flown at near bankfull discharge. Areas of shallow overbank flow were omitted.
Main Channel Wetted Width	Geomorphic	m	Wetted width of the main channel at bankfull discharge. Metric included to represent “vegetation ratchet” control on width adjustment potential. Widths were delineated from June 2011 aerial imagery, which was flown at near bankfull discharge. Areas of shallow overbank flow were omitted.
Median Grain Size	Geomorphic	mm	Average of median bed and bar material grain size during the period of 2009−2014 at Program pure panel anchor point locations. Transect grain size was identified based on nearest anchor point.

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Table 1. (*Continued*)

Metric	Type	Units	Description
Channel Slope	Geomorphic	Dimensionless	Mean channel slope for 1.61-kilometer reach centered on each transect. Slopes calculated from 2009 longitudinal profile of the study area.
River Kilometer	Geomorphic	km	General metric included to represent general effect of declining sediment deficit from west to east.
Annual Disking	Management	Categorical	Annual delineations of disking and herbicide application were used to classify transects in GIS as to whether these management actions were applied. If any portion of a transect was intersected by the disking polygon, the transect was considered disked. If any portion of a transect was intersected by an herbicide polygon, the transect was considered to be treated with herbicide.
Annual Herbicide	Management	Categorical	

2.4. Application of the final MUOCW model to evaluate the flow-sediment-mechanical management strategy

The final MUOCW model was used to assess the potential performance of the Flow-Sediment-Mechanical management strategy at maintaining suitable channel widths at a hypothetical channel reach location given observed hydrology during the period of 1998−2015. The hypothetic reach was assumed to have a main channel bankfull width of 305 m and a median bed material grain size of 0.9 mm. Annual MUOCW was first calculated given observed hydrology during the period of 1998−2015 at the Overton stream gage (06768000). Observed hydrology was then altered to add a series of flow prescriptions described in the Program's Adaptive Management Plan (PRRIP, 2006). These flows are referred to as short duration high flows and are events of 227 m^3/s for three days in approximately two out of three years. Short duration high flow releases were not added in wet years or the years immediately following the two highest discharge years (1999 and 2011). Specifically, short duration high flow implementation was added in 1998, 2001, 2002, 2004, 2005, and 2007. In all cases the short duration high flow hydrograph included two to three days of up-ramping flows, three days at a discharge of 227 m^3/s and two to three days of down-ramping flows following the peak. Ramping duration depended on observed discharge with longer ramping duration under low discharge conditions. MUOCWs predicted under full short duration high flow implementation were compared to those predicted given observed hydrology to assess the ability of short duration high flow releases to increase MUOCW and maintain unobstructed channel widths that were found to be highly suitable for whooping crane use (PRRIP, 2017).

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3. Results

3.1. Total unvegetated channel width and maximum unobstructed channel width

TUCW and MUOCW followed similar trend patterns from 2007−2015. The lowest average values for each width measurement were observed in 2007 and the highest was in 2015 (Table 2). From 2008−2014, mean and median MUOCW values were observed to have little variation where the difference between the maximum and minimum value was 33 m for mean and 27 m for median observations. Likewise, from 2008−2014, mean and median TUCW values were observed to have little variation, where the difference between the maximum and minimum value was 67 m for mean and median observations (Table 2).

3.2. Metrics found to influence total unvegetated channel width

A summary of important annual flow, geomorphic and management variable values in relation to mean TUCW and MUOCW are presented in Table 2. Forty-day peak discharge ranged from 36.48 m^3/s to 453.07 m^3/s and generally occurred between early May and early July. Wetted width ranged from 149 m to 595 m. Disking was somewhat variable during the analysis period, ranging from a low of 0% of transects being disked in 2011 to a high of 41% of transects in 2008 in the study area. The proportion of transects sprayed was low in 2007 and 2008, prior to the commencement of reach-wide phragmites spraying efforts. At full-scale implementation, up to 83% of transects were sprayed in a single year.

We found TUCW was best explained by 40-day duration peak discharge, disking, herbicide application, and wetted width of the channel at bankfull discharge (Table 3); all of which were incorporated in one of two models that carried substantial model weight ($w > 0.40$). AIC values indicate our top model was ∼437 AIC units lower than a model that only included 40-day peak discharge and ∼850 AIC unit lower than the null model. All variables had a positive effect on TUCW from 2007−2015 (Table 4). The formula of the top model to explain TUCW at the 0.5 quantile ($\tau = 0.5$) was noted as:

$$TUCW = -19.10 + 0.36\beta 1 + 35.49\beta 2 + 5.52\beta 3 + 0.55\beta 4 \quad (1)$$

where β1 was the mean 40-day duration peak discharge, β2 and β3 were categorical variables based on whether or not herbicide or disking were applied within the previous year respectively, and β4 was a measure of the wetted width of all channel segments at bankfull discharge.

Besides the effects of 40-day peak discharge, beta values generally increased from low to high quantiles of TUCW. For instance, at the 0.05 quantile, disking increased TUCW by 6.2 m and herbicide increased TUCW by 9.0 m on average. At the 0.95

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Table 2. Summary of important flow, geomorphic and management metric values from 2007 to 2015 in relation to mean and median total unvegetated channel width (TUCW) and mean and median unobstructed channel width (MUOCW) by 1.61-km reach of river within the Associated Habitat Reach (study area), 2007−2015. 40-day peak discharge was calculated as the maximum 40-day running average of mean daily discharge during the year.

Year	40 Day Peak Discharge (m^3/s)	Bankfull Wetted Width (m)[1]	Median Grain Size (mm)[2]	% of Transects Disked	% of Transects Sprayed	Mean TUCW (m)	Median TUCW (m)	Mean MUOCW (m)	Median MUOCW (m)
2007	57	318	0.93	33%	0%	174	170	92	79
2008	108			41%	5%	219	222	135	117
2009	60			10%	13%	198	196	114	104
2010	146			5%	77%	201	199	125	106
2011	231			0%	44%	265	263	147	131
2012	83			9%	81%	212	211	138	120
2013	104			11%	71%	220	219	147	128
2014	83			18%	74%	218	216	131	114
2015	354			0%	83%	321	313	191	175

[1] Bankfull width measurements were derived from 2011 aerial imagery.

[2] Median grain size was calculated as the average of measurements from 2009−2014. We assumed bankfull width and median grain size were relatively stable at individual transects from 2007−2015.

https://doi.org/10.1016/j.heliyon.2018.e00851

Table 3. Akaike's Information Criterion (AIC) model selection results of annual total unvegetated channel width (TUCW) in the Associated Habitat Reach (study area), 2007−2015. ΔAIC represents the change in AIC value from the top-ranked model, AICw represents the probability each model is the best given the models tested, and R[1] equals the goodness of fit for the given quantile ($\tau = 0.5$).

Metrics	AIC	ΔAIC	AICw	R[1]
40-Day Peak + Disking + Herbicide + Wetted Width	8321.29	0.00	1.00	0.42
40-Day Peak + Disking + Herbicide + Median Grain Size	8580.94	259.65	0.00	0.32
40-Day Peak + Disking + Herbicide + River Km	8586.18	264.89	0.00	0.32
40-Day Peak + Disking + Herbicide	8704.14	382.85	0.00	0.26
40-Day Peak	8757.37	436.08	0.00	0.23
Wetted Width	8758.16	436.87	0.00	0.23
River Kilometer	8911.56	590.27	0.00	0.15
Median Grain Size	8956.55	635.26	0.00	0.13
Disking + Herbicide	9122.29	801.00	0.00	0.03
Null	9171.79	850.50	0.00	0.13

[1] Null model was used to test the hypothesis that unobstructed channel width remained constant from 2007−2015.

Table 4. Multiple quantile regression beta estimates in the top model from the total unobstructed channel width (TUCW) model selection process.

Quantile	Intercept	40-Day Peak Discharge	Disking	Herbicide	Wetted Width
0.05	−39.33	0.340	6.18	8.95	0.39
0.10	−39.61	0.387	17.53	9.80	0.42
0.25	−30.14	0.389	32.94	7.91	0.47
0.50	−19.10	0.359	35.49	5.52	0.55
0.75	−7.24	0.364	31.31	7.17	0.61
0.90	5.55	0.339	39.39	11.82	0.67
0.95	21.03	0.340	67.03	23.54	0.66

quantile, disking increased TUCW by 67.0 m and herbicide increased TUCW by 23.5 m on average (Table 4).

Based on the results of our top quantile regression model at the 0.5 quantile, for each 5-m^3/s increase in 40-day peak discharge, on average, we would expect a 1.8 m (95% CI = 1.7−2.0 m) increase in TUCW annually when no disking or herbicide treatment was applied and wetted width at bankfull discharge was held at its median value (Fig. 3). When transects were disked, on average, TUCW was 35.5 m (95% CI = 26.2−42.9 m) wider than at transects where no disking occurred within the previous year. When transects were disked and herbicide was applied, on average,

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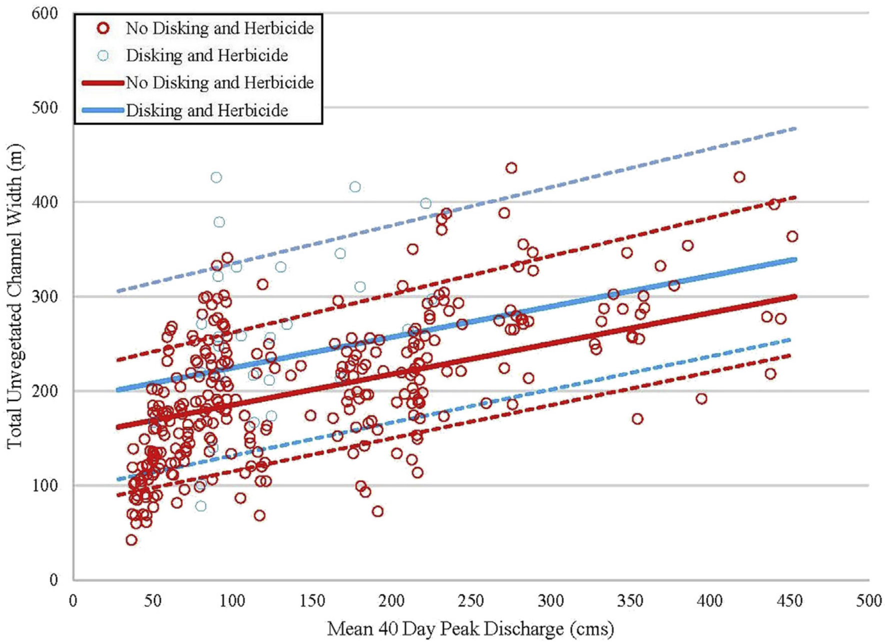

Fig. 3. Predicted relationships of total unvegetated channel width (TUCW) to 40-day peak discharge at transects in the Associated Habitat Reach (study area) without (red) or with (blue) management actions from 2007−2015. Dashed lines represent 90% quantile regression prediction intervals and points display the subset of measured TUCWs at transects used in quantile regression analyses. Points represent transects where no management actions (red) or disking and herbicide (blue) occurred.

TUCW was 41.0 m (95% CI = 24.0−55.3 m) wider than transects where no other management actions occurred in the previous year. For each 30-m increase in wetted width at bankfull discharge, on average, we would expect a 19.9 m (95% CI = 16.57−22.20 m) increase in TUCW annually.

We compared observed and predicted TUCW at each transect for each year. Utilizing the linear model and betas previously stated at the 0.5 quantile, 45% of TUCW predictions were within 30 m and 76% of predictions were within 60 m of actual values observed from 2007−2015. Only two years, 2007 and 2010, were found to contain mean errors >10% of observed values (Table 5).

3.3. Metrics found to influence maximum unvegetated channel width

We found MUOCW was best explained by 40-day duration peak discharge and wetted width of the main channel (Table 6). Disking and herbicide application were also included in the top MUOCW model. AIC values indicated our top model was ∼109 AIC units lower than a model that only included 40-day peak discharge and ∼240 AIC unit lower than the null model. All variables had a positive effect on

 https://doi.org/10.1016/j.heliyon.2018.e00851

Table 5. Comparison of mean observed and predicted total unvegetated channel width (TUCW) in Associated Habitat Reach (study area) for the period of 2007−2015 using a 0.5 quantile regression. Parentheses indicated 90% quantile regression prediction intervals.

Year	Observed Mean TUCW (m)	Predicted Mean TUCW (m)	Mean Error (m)	Mean Error as % of Observed TUCW
2007	174	204 (122−289)	30 (−52−114)	17 (−30−66)
2008	219	237 (151−323)	17 (−69−103)	8 (−31−47)
2009	198	185 (111−265)	−13 (−87−67)	−6 (−44−34)
2010	201	225 (153−314)	24 (−48−112)	12 (−24−56)
2011	265	247 (174−326)	−18 (−91−62)	−7 (−34−23)
2012	212	195 (123−287)	−17 (−89−75)	−8 (−42−35)
2013	220	229 (154−317)	9 (−66−97)	4 (−30−44)
2014	218	218 (142−310)	0 (−76−92)	0 (−35−42)
2015	321	302 (227−386)	−19 (−94−64)	−6 (−29−20)

Table 6. Akaike's Information Criterion (AIC) model selection results of annual maximum unobstructed channel width (MUOCW) in the Associated Habitat Reach (study area), 2007−2015. R^1 equals the goodness of fit for the given quantile ($\tau = 0.5$).

Combined Models	AIC	ΔAIC	Likelihood	AICw	R^1
40-Day Peak + Disking + Herbicide + Main Channel Wetted Width	8724.67	0.00	1.00	1.00	0.15
40-Day Peak + Disking + Herbicide + Median Grain Size	8776.88	52.21	0.00	0.00	0.12
40-Day Peak + Disking + Herbicide	8781.04	56.37	0.00	0.00	0.11
40-Day Peak + Disking + Herbicide + River Kilometer	8781.53	56.86	0.00	0.00	0.11
40-Day Peak	8834.08	109.40	0.00	0.00	0.08
Main Channel Wetted Width	8878.00	153.33	0.00	0.00	0.05
Median Grain Size	8894.74	170.07	0.00	0.00	0.04
Disking + Herbicide	8904.45	179.78	0.00	0.00	0.04
River Kilometer	8910.60	185.92	0.00	0.00	0.04
Null	8964.58	239.91	0.00	0.00	0.00

MUOCW from 2007−2015. The formula of the top model used to explain MUOCW at the 0.5 quantile ($\tau = 0.5$) was noted as:

$$UOCW = 27.96 + 0.24\beta 1 + 39.31\beta 2 + 8.48\beta 3 + 0.18\beta 4 \quad (2)$$

 https://doi.org/10.1016/j.heliyon.2018.e00851

where β1 was the mean 40-day duration peak discharge, β2 and β3 were categorical variables based on whether or not herbicide or disking were applied within the previous year, respectively, and β4 referred only to the main channel and not the total wetted width of all channels at bankfull discharge.

Besides the effects of 40-day peak discharge, other beta values generally increased from low to high quantiles. For example, at the 0.05 quantile, disking increased MUOCW by 6.3 m and herbicide increased MUOCW by 5.0 m on average. At the 0.95 quantile, on average, disking increased MUCW by 61.9 m and herbicide increased MUCW by 14.5 m (Table 7). Based on the results of our top quantile regression model at the 0.5 quantile, for each 30-m^3/s increase in 40-day peak discharge, on average, we would expect a 7.3 m (95% CI = 5.8−8.3 m) annual increase in MUOCW, when no disking or herbicide treatment was applied and bankfull wetted width was held at its median value (Fig. 4). For each 30-m increase in bankfull wetted width of the main channel, on average, we would expect a 5.3 m (95% CI = 4.0−7.2 m) increase in MUOCW. When transects were disked, on average, MUOCW was 39.3 m (95% CI = 28.3−52.1 m) wider than transects where no disking occurred within the previous year. When both disking and herbicide were applied, on average, we found transects were 47.8 m (95% CI = 30.0−68.2 m) wider than transects where no management actions occurred in the previous year.

We used several analyses to validate the accuracy of the top MUOCW model we identified through the AIC model selection process. Utilizing the MUOCW linear model and betas previously stated for the 0.5 quantile, 36% of MUOCW predictions were within 30 m and 66% were within 60 m of actual values observed from 2007−2015. Once again, overestimating MUOCW was of special concern since narrower than predicted MUOCWs would potentially have more negative consequences for habitat suitability for whooping cranes than underestimations. Only 36% percent of MUOCW predictions were overestimated by more than 30 m and 17% were overestimated by more than 60 m. We also compared mean observed

Table 7. Beta estimates for the maximum unobstructed channel width (MUOCW), multiple quantile regression model selection process.

Quantile	Intercept	40-Day Peak Discharge	Disking	Herbicide	Main Channel Wetted Width
0.05	22.176	0.113	6.326	5.030	0.045
0.10	33.819	0.092	8.077	6.603	0.039
0.25	32.477	0.143	36.560	8.443	0.092
0.50	27.959	0.244	39.310	8.484	0.175
0.75	24.612	0.227	53.733	18.315	0.391
0.90	16.774	0.214	43.221	10.453	0.647
0.95	31.619	0.175	61.892	14.512	0.700

https://doi.org/10.1016/j.heliyon.2018.e00851

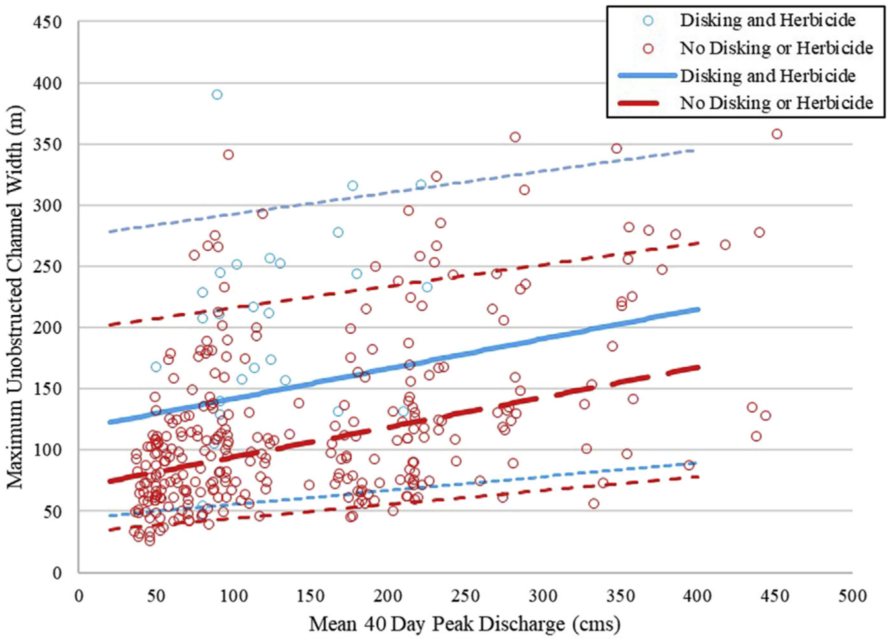

Fig. 4. Predicted relationships of maximum unobstructed channel width (MUOCW) to 40-day peak discharge at transects with (blue) or without (red) management actions in the Associated Habitat Reach (study area) from 2007−2015. Dashed lines represent 90% quantile regression prediction intervals and points display the subset of measured MUOCWs at transects used in regression analyses. Points represent transects where no management actions (red) or disking and herbicide (blue) occurred.

and predicted MUOCW for all transects within the study area in each year and found eight of the nine years assessed contained mean prediction errors that were <20% of observed values (Table 8).

3.4. Analysis of short duration high flow performance

Based on simulated releases, short duration high flow volumes ranged from 32.6 m^3 million to 83.6 million m^3. Implementation of a short duration high flow release in a given year was predicted to increase TUCW by 0.0−6.7 m and MUOCW by 0.0−4.6 m depending on baseline river discharge at the time of the release. The greatest increase in TUCW and MUOCW were predicted to occur when baseline river discharge was low.

4. Discussion

We found 40-day mean peak discharge, wetted width of the channel, disking and herbicide application to be the best predictors of TUCW in the study area. The strong influence of peak discharge is consistent with previous investigations which identified peak flows as an important driver of unvegetated width within the study area (Williams, 1978; O'Brien and Currier, 1987; Murphy et al., 2004). Williams

https://doi.org/10.1016/j.heliyon.2018.e00851

Table 8. Comparison of mean observed and predicted maximum unobstructed channel width (MUOCW) in the Associated Habitat Reach (study area) for the period of 2007–2015 using a 0.5 quantile regression. Values in parentheses represent 90% quantile regression prediction intervals.

Year	Observed MUOCW (m)	Predicted MUOCW (m)	Error (m)	Error as % of Observed MUOCW
2007	92	121 (50–292)	29 (−42–200)	32 (−46–217)
2008	135	145 (60–312)	10 (−75–177)	7 (−56–131)
2009	114	106 (45–274)	−8 (−69–160)	−7 (−61–140)
2010	125	135 (61–299)	10 (−64–174)	8 (−51–139)
2011	147	148 (67–304)	1 (−80–157)	1 (−54–107)
2012	138	115 (51–287)	−23 (−87–149)	−17 (−63–108)
2013	147	138 (61–303)	−9 (−86–156)	−6 (−59–106)
2014	131	132 (57–301)	1 (−74–170)	1 (−56–130)
2015	190	187 (85–335)	−3 (−105–145)	−2 (−55–76)

(1978) was the first investigator to assert that declines in study area channel width were likely due to systematic reductions in peak flow magnitude. O'Brien and Currier (1987) expanded upon Williams' work by postulating that peak flow magnitudes of 226–453 m^3/s were necessary to maintain the channel. Murphy et al. (2004) further refined the peak flow hypothesis by narrowing it to the 1.5-year flood and hypothesizing that mechanical channel widening in combination with an average 1.5-year flood magnitude of 170–227 m^3/s would allow for sustained unvegetated channel widths exceeding 300 m. Notably, none of these investigations assessed peak flow event duration and associated flow volume. The short duration high flow (i.e., flow prescription) component of the Program's Flow-Sediment-Mechanical management strategy grew out of the work by Murphy et al. (2004), reflecting both the frequency and magnitude postulated by the authors. The short duration high flow duration of 3–5 days was borne out of necessity, reflecting the volume of water that the Program could reasonably store and release on a near-annual basis.

Our investigation strongly supports the assertion of a positive relationship between peak flow magnitude and both TUCW and MUOCW in the study area. The analyses, however, do not support the assertion that increasing the frequency of peak flow of 227 m^3/s magnitude through short duration high flow releases for 3–5 days in two out of three years will produce substantive increases in the vegetation-free width of the channel. The minimal effect of short duration high flow releases is likely due to the very short duration and low volume in relation to the 40-day peak discharge duration that was the best hydrologic predictor of unvegetated width in the study area. The disparity between short duration high flow and natural peak flow event volume is apparent in Fig. 5.

 https://doi.org/10.1016/j.heliyon.2018.e00851

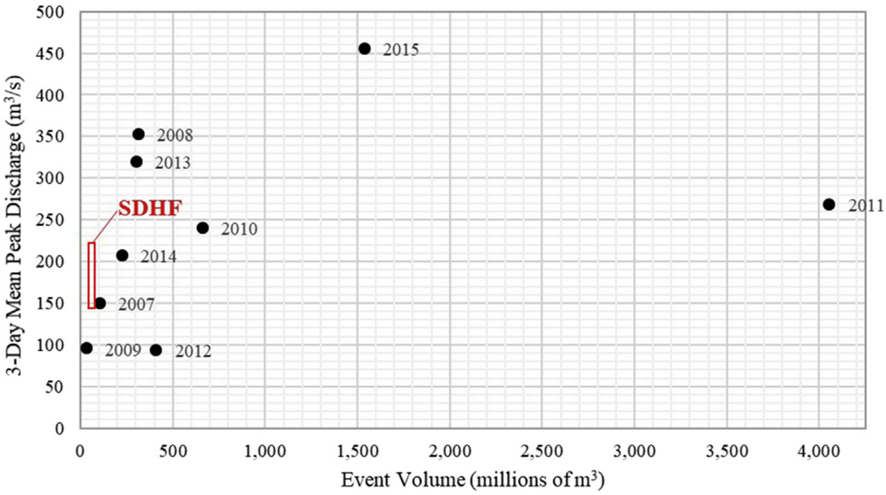

Fig. 5. 2007−2015 three-day mean peak discharge (m^3/s) and total event volume (millions of m^3) at Grand Island (USGS Gage 06770500) in relation to the range of Short-Duration High Flow (SDHF) magnitudes and volumes. Event volumes are cumulative volumes from concurrent days during annual peak flow events when discharge exceeded 57 m^3/s.

Other investigators have identified mean June flows (Johnson, 1994) as a key predictor of channel narrowing as specifically related to the establishment of cottonwood seedlings in the channel. Johnson (1994) suggested that mean June flows ranging from 75−85 m^3/s would prevent seedling establishment during the cottonwood germination period and maintain existing channel widths. We did not find mean June flow to be effective at maintaining or increasing the unvegetated width of channel. This may be due to the broader focus of our analysis, which was not limited to woody vegetation. Other factors such as summer flow (Schumm, 2005), slight differences in channel slope (Schumm, 2005) and differences in bed material grain size (Murphy et al., 2004) have been hypothesized as potentially controlling or at least influencing unvegetated channel width in the study area. Some or all of these metrics might influence unvegetated channel width to some degree but were not were not found to be strong predictors of channel response in our analyses.

Wetted width of the channel and application of management in the form of disking and herbicide application were found to have the strongest influence on in-channel vegetation. We attribute the inclusion of wetted width in the top model to the influence of the vegetation ratchet effect (Tal et al., 2004). The historical proliferation of scour-resistant vegetation such as cottonwood trees and the more recent establishment of phragmites limits the ability of the channel to adjust laterally in response to peak flows. The two remaining metrics, disking and herbicide, reflect the intensive management of in-channel vegetation by the Program and other conservation organizations and the degree to which those activities influence the presence and

https://doi.org/10.1016/j.heliyon.2018.e00851

distribution of in-channel vegetation. The importance of herbicide application is underscored by research indicating that phragmites is resistant to erosion due to drag and local scour associated 100-year recurrence interval discharge in the study area (Bankhead et al., 2016).

4.1. Management implications

Our research indicates that attempts to increase the magnitude of the 1.5-year recurrence interval flow magnitude through implementation of short duration high flow releases would have a minimal effect on TUCW and MUOCW with predicted increases on the order of 5−7 m. Accordingly, short duration high flow releases as presented in the Program's Adaptive Management Plan do not appear to be a viable management action for maintenance of highly-suitable whooping crane roosting habitat. In contrast, disking in combination with herbicide application does appear to be effective in managing unvegetated channel width in the study area. The predicted effect of channel disking and spraying was an increase of well over 30 m in MUOCW across most of its distribution. The major limitation of disking, however, is the lack of a system-scale beneficial effect. In general, disking can be utilized to effectively manage MUOCW at owned habitat complexes but cannot be done elsewhere without landowner agreements. It is also important to note that long duration, natural high-flow events such as those occurring in 2011 and 2015 do substantially increase TUCW. Activities that reduce the magnitude and/or duration of large natural peak flow events would likely necessitate an increase in the frequency and scale of mechanical management.

Our investigation also highlights uncertainties that are introduced when exploring the relationship between physical process and species habitat metrics. The quantile regression analysis results indicate a strong relationship between TUCW and hydrologic, geomorphic, and management variables with the top model explaining on the order of 42% of the variability in the data at the 0.5 quantile of the response. However, when evaluating the relationship for MUOCW, which is primarily a habitat suitability metric for whooping cranes, the top model only explained 15% of the variability in the data at the 0.5 quantile of the response. This loss of predictive ability occurs because the random spatial distribution of vegetated bars and/or islands within the channel exerts a strong control on MUOCW. Mechanical interventions like disking and herbicide applications can have a disproportionally large effect on habitat metrics like MUOCW as they allow for targeted application to maximize effectiveness. Specifically, conservation organizations could prioritize treatment of vegetated, mid-channel sandbars and islands that have a substantial effect on unobstructed channel width, which is a primary driver of whooping crane habitat suitability.

https://doi.org/10.1016/j.heliyon.2018.e00851

Declarations

Author contribution statement

Jason Farnsworth, David Baasch, Patrick D. Farrel, Chadwin Smith, Kevin Werbylo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by the Platte River Recovery Implementation Program.

Competing interest statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2018.e00851.

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Attachment 2 - Adaptive Management Modeling Tool Progress (Machine Learning Model Update)

Adaptive Management Modeling Tool Progress

Introduction

Program efforts to contribute to the survival of WC during migration have focused on providing WC roosting and foraging habitat along the central Platte River. Suitable WC on-channel roosting habitat has been defined as river channels with ≥650 ft wide channels unobstructed by vegetation. The flow routing tool and channel width model address two important whooping crane Extension Big Questions (EBQs) regarding Program flow management and whooping crane habitat response.

1) EBQ #1 – How effective is it to use Program water to maintain suitable whooping crane roosting habitat?
2) EBQ #2 – How effective is Program management of *Phragmites* for maintaining suitable whooping crane roosting habitat?

Previous Program investigations of flow and unobstructed channel width relationships are not sufficient to estimate First Increment Extension river channel conditions due to bias prediction outside of the timeframe used to develop the model and lack of parameterization to address channel maintenance of suitable whooping crane roosting habitat. To answer these Extension Big Questions, we developed a more flexible statistical model of flow and channel width relationships to capture a variety of conditions possible experienced during the first increment extension. This scientific report reflects the comments and suggestions received at the February 2021 AMP Reporting Session.

To provide suitable riverine whooping crane habitat, management on the central Platte River employs a variety of tactics including river channel disking during low flow periods, herbicide application of Phragmites, and in-channel woody vegetation removal. These methods mostly have direct, site-level influence on creation of suitable whooping crane habitat where management activities take place (PRRIP 2017). Peak river flows can provide system-level channel widening and increase whooping crane habitat suitability throughout the central Platte River (Farnsworth et al. 2018). In the 2010s, peak flow events widened channels throughout the Associated Habitat Reach (PRRIP 2017). Farnsworth et al. (2018) used flow and channel width conditions from 2007-2015 to model channel width relationships and found both site and system-level variables were important to create suitable in-channel whooping crane habit in the central Platte River. However, the variability in channel width response can hinder the interpretation of results and lead to varying certainty of predictive results (i.e., wide prediction intervals). Additionally, predictive models of maximum unobstructed channel width have performed, on average, well within the time periods for which they were developed but have greatly under predicted channel widths in recent years (Figure 1).

Negative unobstructed channel width predictive bias suggests a fundamental change in the central Platte River system regarding obstructed channel widths where channel widths were increasing with increased high-water events from mid 2000s to 2015. Wide channel widths were then maintained close to those created in 2015 without the high flows predicted as necessary on an annual basis according to Farnsworth et al. 2018. This suggests a predictive model should both account for channel widening flows and channel width maintenance flows in absence of high flow events. Our objectives were to 1) develop an updated predictive model of unobstructed channel width that incorporates variables to address both channel widening and width maintenance and 2) apply Executive Director's Office developed Flow Routing Tool and channel width model to evaluate the benefits of flow releases during for in-channel whooping crane habitat during the Program's First Increment Extension.

Methods

Study Area

Our study area comprised of a 90 mile, or 145 km, stretch of the central Platte River from Overton to Chapman, Nebraska as part of PRRIP's Associated Habitat Area (Figure 1). During the 20th century, the central Platte River underwent a dramatic change due to water development of upstream reservoirs. Prior to major water developments, the central Platte River comprised on a mostly single, braided consolidated channel with wide shallow channel widths. However, by the mid-1900s, reductions in river flows led to substantial narrowing of river channel width as vegetation encroached into the former active channel (Currier 1997, Johnson 1997). The current central Platte River from Overton to Chapman contains three distinct geomorphic reaches defined by differing planform and river channel patterns (Table 1, Fotherby 2009). These reaches are characterized by anastomosed to braided channels with unvegetated and non-vegetated sandbars.

Measurement of Main Channel Total Unobstructed Channel Width

To measure to ability of flow and physical management techniques to create and maintain suitable unobstructed channel widths for whooping cranes, we measured the annual change in two different channel widths from 2004-2020. Instead of modeling channel width directly, change in channel width provides the ability to understand channel narrowing, channel widening, and channel maintenance through various conditions experience along the central Platte River. Assessing change in channel width directly assists the Program in answering the First Increment Extension Big Questions related to use of Program water to maintain unobstructed channel widths for whooping crane roosting habitat. Previous investigations of flow and channel width relationships for whooping cranes have sought to explain variability in maximum unobstructed channel width (hereafter, MUCW) as a direct species-habitat relationship and total unvegetated channel width (hereafter, TUCW). Maximum unobstructed channel width, and its relationship to total unvegetated channel width, is positive but has a somewhat random variability based on the in-channel location of vegetated islands (Farnsworth et al. 2018). For these analyses, we used annual change in Maximum unobstructed channel width (ΔM) as the channel width response variable. Changes in maximum unobstructed channel width were then used to understand how channel width distributions change over time from an initial year.

We used annual fall aerial imagery collected during periods of low flow to photo-interpret unobstructed channel widths throughout the study area from 2004–2020. Unobstructed channel widths were delineated at a scale of 1 ft = 2,400 ft along 436 predefined transects using ESRI ArcMap Geographic Information System (GIS) software. Transects were oriented perpendicular to flow, spaced at 1000 ft intervals along the channel throughout the study area and encompassed all channels in split-flow reaches. Channel widths were delineated by observers who identified the widest contiguous extent for MUCW (Figure 2). We then compared annual unobstructed channel width measurements at individual transect locations to measure the difference between subsequent annual measurements to obtain ΔM (Figure 2).

Model Variables and Statistical Analyses

We selected variables important to explain unobstructed channel width in past studies and included other variables to increase predictability of results outside of timeframe assessed (Table 1). Farnsworth et al. (2018) found several important variables to explain unobstructed and unvegetated channel widths in the central Platte River which included 40-day mean peak discharge, river channel disking, herbicide application, and wetted width of channel at bankfull discharge. During the time assessed in the study (2007-2015), average unobstructed channel width positively increased. Parameter considerations and parameter effect sizes created predictable flow and channel width relationships for a system influenced by annual high flow events (Figure 3). Our modelling effort included some modifications of these variables and further included previous channel conditions, flow conditions and spatially grouping variables.

We incorporated both channel width maintenance and channel widening flow variables to develop a model with application outside a period of channel widening predicated on annual high flow events. Average June discharge was included to represent channel maintenance flows in this investigation. Flows during June are associated with germination suppression of *populus-salix* seedling establishment in the Platte River system and represent the most important period of the growing season to limit their establishment. We hypothesize unobstructed channel widths can be maintained with sufficient June flows in the absence of annual high peak flow events. Change in unobstructed channel width was also likely predicated on past influential peak flows that caused channel widening. Prior four years of 40-day mean peak flows were additionally included as annual variables to predict change in channel width. We did not include peak flows within the current year due to the overlap of peak flow events with average June flows in recent years, leading to high correlation between variables. Current year and past years flow through the main channel were calculated to explain spatial differences in flow and channel width relationships. Transect level flow splits were calculated at each transect with a 1-D hydrology model using 2011 channel information to estimate proportion of total flow contained within the main channel and side channels. Only flow contained within the main channel was used to explain changes in maximum unobstructed channel width measurements.

Incorporating the previous year's MUCW to explain annual changes constitutes an autoregressive, lag-1 relationship to current year channel conditions. Maximum unobstructed

Channel widths experienced the previous year can contribute to predicting the change (narrowing, widening, or stability) of maximum unobstructed channel widths based on relationships to total channel width at a transect. Main channel total channel width (TCW_M) is the wetted width of channel at bankfull discharge in 2011. TCW_M approximates the maximum width possible for unobstructed channel widths and is much less dynamics than unobstructed channel width. If, for example, the previous year's MUCW equals TCW_M, ΔM in the current year will likely be stable or narrowing regardless of other conditions, due to widening requiring extensive lateral erosion of high bank areas on channel edges.

Management actions of river channel disking and herbicide application were quantified by spatial effort. Annual delineations of river channel disking and herbicide application were used to classify transects in GIS as to whether these management actions were applied. If any portion of a transect was intersected by an annual disking or previous year's herbicide polygon, the length of disking and herbicide along the transect was measured and recorded from the previous year. Disking occurs late summer to early fall and direct influence on unobstructed channel width was observed when imagery is collected later each year in October-November. The effect of spraying to influence unobstructed channel width is better represented by previous year's spraying. A majority of herbicide is applied to stands of invasive reed canary grass (Phragmities spp.), killing the above ground portions of the plants and damaging the root system. Those stands of dead, standing Phragmites are typically obstructions that limit unobstructed channel width until subsequent winter flows and peak flow events can remove previously sprayed obstructive Phragmites stands.

Geomorphic reaches were also included to aid in prediction of spatial differences in flow and channel width relationships. Fotherby (2009) developed central Platte River geomorphic reaches and sub reaches based on river channel composition, flow consolidation, and introduced structures influence flow routes such as bridges. Three major reaches were identified by main channel characteristics and included (3) Overton to Newark, (4) Newark to West of Grand Island, and (5) West of Grand Island to Chapman. Historical reach observations described single to anabranched channel throughout the central Platte River, which provided highly suitable unobstructed channel widths for whooping cranes roosting during migrations. By 1998, dominate channel characteristics were described as anastomosed to braided and greatly decreased in suitability for whooping cranes.

Farnsworth et al. (2018) used quantile regression to predict unobstructed channel widths. This analysis technique was able to account for heterogeneous variances and influences of unmeasured or unaccounted for variables to explain unobstructed channel widths (Koenker 2005). While this technique was helpful to understand channel width relationships to riverine physical management practices and flows, the high variability in channel width response to flows made it difficult to develop specific generalizations of flow and channel width relationships. Additionally, the years of channel widths used in the study were associated with a general increase in channel widths over time (Figure 3). To account for a more diverse period of flow and channel width conditions, we used random forest machine learning techniques to predict change in unobstructed channel widths with physical management practices, geomorphic characteristics, and flow variables.

One of the most important contributions of machine learning techniques are classification and regressions tree-based (CART) methods. These models incorporate tree-based analysis method, where a dataset is split by rules that divide it into increasingly homogenous groups where rules are identified by a search algorithm and often produce increased predictive abilities over traditional statistical techniques (Breiman 2001, Prasad et al. 2006, Thessen 2016). Random forests are bootstrap aggregations incorporating many CARTs that build on a large collection of de-correlated trees and averaging of CART outputs to create the 'forest'. The goal of regression-based random forest models is similar to traditional regression models; to reduce variance of an estimated prediction function (Friedman et al. 2001).

Random forest machine learning modeling has several advantages over traditional regression-based analyses that makes in advantageous to use for flow and channel width modeling. Random forests can account for highly complex relationships between variables, non-linear relationships, and resists model overfitting, which can all be issues in traditional regression analyses (De'ath and Fabricius 2000, Olden et al. 2008, Thessen 2016). To increase predictability and avoid overfitting the model to data available, random forests utilize model validation practices usually conducted after a model is developed during initial development. An out-of-bag (OOB) data sample is taken to test each bootstrap iteration (or tree) against data points left out of the regression tree formulation and operates like an N-fold cross-validation for each tree in the random forest model. These advantages make Random Forests a better analysis technique to predict how flow, and other variables, influence change in unobstructed channel widths.

Independent variables were included in a global random forest models to predict ΔM. The model was run with 3 iterations of a 10-fold cross-validation in Program R (R Core Team 2020) with R package caret to tune number of trees and number of randomly selected predictors variables considered at each decision tree split. We tuned our random forest to optimize the accuracy of predictions by investigating the number of trees generated and number of randomly selected predictors variables considered at each decision tree split. We tested random forests generated with 500, 1000, 1500, and 2,000 trees and then used the number of trees resulting in the lowest average RMSE to optimize model predictive accuracy. We then used the optimum-tree model to test how many predictor variables should be considered at each decision tree split by testing 1-11 considered variables within the optimum-tree model and further increased predictive accuracy by selecting the model with the lowest predictor RMSE generated random forest model runs. The resulting optimized random forest was limited to 500 trees generated and up to 4 randomly selected predictor variables considered at each decision point.

Model independent outputs included variable importance (%IncMSE) for each independent variable and testing dataset model performance evaluations including pseudo-R-squared and mean square error (MSE). Variable importance evaluates the predictive accuracy of each OOB sample compared to accuracy when recalculated with randomly permuted predictor variables. The percent increase in mean squared error (%IncMSE) is then generated for each OOB and the average increase is used to present predictive independent variable importance. The greater the percent increase in mean squared error, the more important a variable is to explain a channel width measurement. Pseudo r-squared was defined as the variation explained by the model where the sum of mean-squared error is divided by the variance and subtracted from 1 and MSE is the average squared difference between the observation value and model predicted value in the testing dataset. Additionally, we used results from this model to understand possible benefits of flow release to maintain MUCW during the First Increment Extension.

First Increment Extension Scenarios

One major flow uncertainty to answer during the remainder of the First Increment Extension (2021-2032) is how flow can maintain high quality channel conditions for whooping cranes through preservation of wide, unobstructed channel widths at are still, on average, present in 2020 throughout the AHR. Future flow scenarios were developed with and without June flow releases to estimate the ability of released water to augment flow during a critical time of year for vegetation germination suppression and avoid reduction in maximum unobstructed channel widths to maintain widespread suitable roosting habitat for whooping cranes.

Base flows for future scenarios were drawn from 2001-2012, a period of drought transitioning to normal/wet conditions. Dry flow conditions were prevalent from 2002 to 2007 and transitioned to normal/wet conditions from 2008-2012. In 2004, dry flow conditions were experienced throughout the year and average June flows were the lowest observed in the sequence of years at less than 100 cfs throughout AHR main channels. This period represents the decadal cycles of wet/dry flow conditions experienced on the central Platte River in recent years. We measured the ability of June flow releases to prevent channel width declines during future flow conditions assuming germination suppression flow releases were the only annual Program flow release considered. Flow releases were simulated using an EDO-developed flow routing tool to evaluate flow release scenarios from the Lake McConaughy Environmental Account (EA) to benefit the Program's target species and their habitat in the Associated Habitat Reach (AHR) from Lexington to Chapman along the Platte River in central Nebraska.

The structure of the flow routing tool distills the complex system of the North Platte River, central Platte River, and several large irrigation canals down to the key components necessary for routing of flow releases through the system for Program purposes. Large portions of the canal/river system were approximated with two simplified model reaches from Lake McConaughy to North Platte and from North Platte to Grand Island. While this approach ignores the complexity of how water may be routed through the system, it assumes the path water takes through the system does not impact its ultimate arrival at the AHR with respect to timing or magnitude. The simplicity of the flow routing tool allows the user to focus on the constraints that drive decision making, including the available volume of EA water and the available flow capacity at the North Platte chokepoint.

The flow routing tool was created using Microsoft Excel and evaluates how EA flow releases and releases with a 1,500 cfs bypass canal are represented in the AHR on a daily time step over a 12-year scenario period. Specifically, we are using the tool to predict average June flows using a base flow, base flow with flow releases, and base flows with flow release with a 1,500 cfs bypass canal, as well as how many days within June we meet the germination suppression minimum flow of 1,500 cfs. The operation of the flow routing tool currently begins by comparing historic baseflows at Grand Island for 2001-2012 streamflow with EA flow releases to satisfy the future scenarios of interest developed to understand how flow/flow releases maintain unobstructed channel widths during drought conditions. For our purposes, a germination suppression flow target during the month of June was 1,500 cfs at Grand Island. Daily deficits were calculated and routed upstream (i.e., increased) to North Platte by accounting for transit losses that would occur in the reach. The amount of flow needed to pass through North Platte to fully eliminate the deficits at Grand Island is compared to and potentially constrained by the available flow capacity at the North Platte chokepoint (currently 1,775 cfs at the minor flood stage of 6.0 ft). The flow that can pass through North Platte is then routed upstream to Lake McConaughy by applying additional transit losses to determine the total flow that needs to be released from the Lake McConaughy EA on a given day (Figure 4A). To test how additional chokepoint flow capacity would benefit channel maintenance, a 1,500 cfs bypass was added into the tool (Figure 4B). The calculations also account for the travel times along the river: water released from the Lake McConaughy EA on Day 1 reaches Grand Island on Day 8. For the present analyses, the flow routing tool was also modified to provide estimates of flow at Overton (110% of GI flows), Kearney (90% of GI flows), and Duncan (120% of GI flows) as a percentage of the calculated Grand Island flow.

We assumed herbicide application was the only other river management activity in our First Increment Scenarios and was applied to all scenarios. Herbicide application was assumed to occur throughout the AHR annually as identified by applicators and land managers in accordance with the First Program Increment herbicide protocol and effort would equal the spatial coverage of application observed along active channels in 2020.

Three future flow scenarios were evaluated to understand our ability to achieve minimum flow targets for germination suppression flows during the First Increment Extension with the chosen annual hydrology. These scenarios included (1) base flows, (2) base flows + flow releases, (3) base flows + flow releases with a 1,500 cfs bypass canal. Annual number of days 1,500 cfs flow were achieved at Grand Island and average June flow were used to evaluate flow response to releases and releases with a bypass canal. Base flows only achieved full (30 day) germination suppression flows in two years (range = 0 – 30 days), compared to 3 with flow releases (range = 0 – 30 days), and 8 years with flow releases with a bypass canal (range = 12 – 30 days, Figure 5). Main channel average June flows were exceptionally flow (<400 cfs) in six of the 12 years and flow releases and flow releases with a bypass canal had the greatest increase in average germination suppression flows in dry years (2021-2027). June flows increased from an average of 388 cfs with base flows only to 771 cfs with flow releases and 939 cfs with flow releases plus a bypass canal from 2021-2027 (Figure 6).

Flow information from each scenario was then used to project possible change in MUCW through the First Increment Extension. We used the MUCW from 2020 as a known starting point for each transect and predicted 2021 MUCW as 2020 MUCW plus predicted 2021 ΔMUCW from the random forest model. After 2021, predicted previous year's MUCW plus annual ΔMUCW calculated annual MUCW. We presented bootstrapped average predicted unobstructed channel width, with bootstrapped 90% confidence intervals, along with the predicted percent of transects ≥650 ft for each scenario annually from 2021-2032.

Results

The ΔM Random Forest model performed well to predict changes in unobstructed channel widths. The ΔM Random Forest model incorporating physical management practices, geomorphic characteristics, and flow variables explained 67.31% of model variation. Test dataset predicted and observed values had adequate agreement and average ΔM random forest model MSE was 122.15 ft, which was 26.6% of the average MUCW in the full dataset. The greatest percent increase in mean square error (%IncMSE) to explain ΔM was previous years' maximum unobstructed channel width measurements (Figures 7). Average June flow was the second most important variable to explain ΔM as indicated by %IncMSE. Total main channel width and past peak flow were the third and fourth most important variables in the model (Figure 7).

First Increment Extension Forecasting

Annual base flows with germination suppression flow releases were predicted to maintain wider maximum unobstructed channel widths than base flows in both dry years and wet/normal water years. Predicted average MUCW during dry years was 51 – 238 ft wider with flow releases and 51 – 267 ft wider with flow release including a bypass canal than with only base flows (Figure 8). Predicted average MUCW during wet/normal years was 80 – 164 ft wider annually with flow releases and -20 – 105 ft wider with flow release including a bypass canal. Predicted percentage of transects ≥ 650 ft during dry years was 0 – 6 % greater with flow releases and 0 - 8 % greater with flow releases including a bypass canal than with only base flows (Figure 8). Predicted percentage of transects ≥ 650 ft during wet/normal years was 0 – 15 % greater with flow releases and -1 – 17 % greater with flow releases including a bypass canal.

Conclusions

Our updated modeling effort proved to perform well within a diverse period of flow and unobstructed channel width conditions experienced within the last two decades. We improved upon previous flow and channel width modeling effort to better forecast channel conditions into the First Increment Extension in several ways including: (1) adopting random forest machine learning techniques, (2) modifying peak flow variables to include legacy effects, (3) adding an annual channel maintenance flow variable, (4) quantifying spatial efforts of disking and herbicide application, and (5) accounting for channel response variability in different geomorphic reaches.

Forecasted estimates of channel widths suggest maximum unobstructed channel width would greatly decrease during dry periods without annual germination suppression flow releases and remain narrower as annual flows return to wet/normal conditions. These decreases would greatly impact the availability of wide, maximum unobstructed river channels for whooping crane use. However, the introduction of germination suppression flow releases may preserve and maintain most of the unobstructed channel width observed in 2020 during periods of drought.

A North Platte chokepoint bypass canal was predicted to greatly benefit flow release conveyance to meet minimum germination suppression flows but did not have a similar positive effect on MUCW compared to flow releases through the North Platte chokepoint. These results suggest less flow than 1,500 cfs was required to wet the active river channel and have a channel width maintenance benefit. Our results parallel recent results of 2-D hydrologic modeling of the AHR (Figure 9). The 2-D model shows average 2020 channel geometry only requires 700 cfs to wet 650 ft of river channel compared to 2,900 cfs with 2011 channel geometry. These channel width and 2020 2-D model results reflect a period of wide, flat channel widths throughout the AHR. However, if dry flow conditions persist for several years, channel geometry could reflect 2011 geometry and require much higher flows to maintain MUCWs. Under these conditions, we predict additional bypass canal flow capacity would be crucial to convey flows through the AHR to maintain suitable MUCW for whooping cranes.

Two additional years (2022-2023) of germination suppression flow releases and subsequent measurements of maximum unobstructed channel width responses will occur to understand if augmented June flows from releases will produce predicted channel width maintenance that higher June baseflows have provided in the recent past. In June 2021, the first germination suppression flow release occurred starting in early June and lasting until early July. In early 2022, the Program will evaluate baseflows occurring before the flow releases occurred, flows throughout the Associated Habitat Reach during flow releases, and flows after release effects have subsided. Measurements of maximum unobstructed channel width, along with associated measurements of all modeled explanatory variables, will occur to further validate model performance with and without the additional of this information.

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Tables and Figures

Table 1. Central Platte River geomorphic reaches and sub reaches according to Fotherby (2009).

Reach	Sub Reach	Location	River Mile	Average proportion Q in main channel
3	3A	Near Overton	240	1
	3B	Kearney Diversion	231	1
	3C	Near Odessa	226	1
	3D	Kearney	215	1
4	4A	Near Newark	211	0.85
	4B	Near Gibbon	200	1
	4C	Wood River	188	0.85
	4D	Alda	180	0.75
5		Grand Island	168	1

Table 2. Hydrologic, geomorphic and management variables included in the Random Forest analyses for annual change in unobstructed channel width measures from 2004–2020. Type, units of measurement and a description of data acquisition are included for each metric.

Metric	Type	Units	Description
Main Channel Total Channel Width	Geomorphic	ft	Total channel width of the main channel at bankfull discharge. Metric included to represent "vegetation ratchet" control on width adjustment potential. Widths were delineated from June 2011 aerial imagery, which was flown at near bankfull discharge. Areas of shallow overbank flow were omitted.
Previous Year Maximum Unobstructed Channel Width	Geomorphic	ft	Previous years' measurement of maximum unobstructed width at a specific transect. Widths were delineated by observers based on annual fall imagery.
Germination Suppression	Hydrologic	ft^3/s	Mean daily discharge during the early growing season (1-June through 30-June) assessed from the Overton, Kearney, Grand Island, and Duncan USGS rivers gages.
Annual Disking	Managemen t	Linear feet	Annual delineations of disking application were used to classify transects in GIS as to whether these management actions were applied. If any portion of a unvegetated/unobstructed channel width along a transect was intersected by the same year disking polygon, the length of disking along the transect was measured and recorded.
Annual Herbicide	Managemen t	Linear feet	Annual delineations of herbicide application were used to classify transects in GIS as to whether these management actions were applied. If any portion of a unvegetated/unobstructed channel width along a transect was intersected by the subsequent years' herbicide polygon, the length of herbicide along the transect was measured and recorded from the previous year.

Peak Legacy Flow 1	Hydrologic	ft^3/s	A 40 day mean peak discharge from previous year assessed from the Overton, Kearney, Grand Island, and Duncan USGS rivers gages.
Peak Legacy Flow 2	Hydrologic	ft^3/s	A 40 day mean peak discharge, from two years prior, assessed from the Overton, Kearney, Grand Island, and Duncan USGS rivers gages.
Peak Legacy Flow 3	Hydrologic	ft^3/s	A 40 day mean peak discharge from, three years prior, assessed from the Overton, Kearney, Grand Island, and Duncan USGS rivers gages.
Peak Legacy Flow 4	Hydrologic	ft^3/s	A 40 day mean peak discharge from, four years prior, assessed from the Overton, Kearney, Grand Island, and Duncan USGS rivers gages.
Geomorphic Reach	Geomorphic	Categorical	Unique contiguous sections of Associated Habitat Reach active channels characterized by geomorphic qualities as described by Fotherby (2009)[a].

[a] Fotherby, L. M. 2009. Valley confinement as a factor of braided river pattern for the Platte River. Geomorphology 103:562–576.

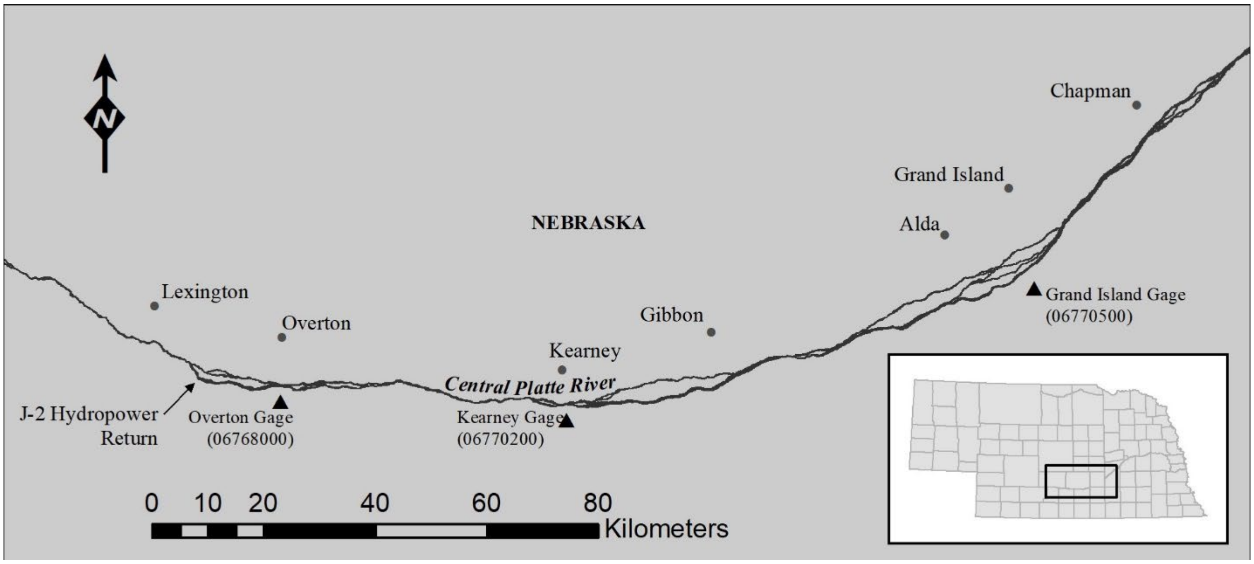

Figure 1. Associated Habitat Reach of the central Platte River extending from Lexington downstream to Chapman, Nebraska. Locations of stream gages (triangles) used in our analyses are included as well.

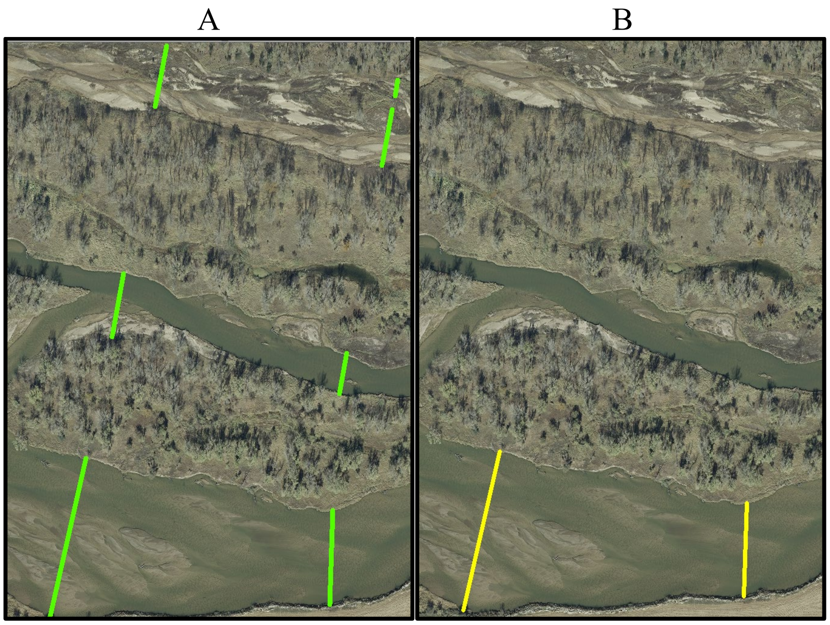

Figure 2. Examples of (A) total unobstructed channel width and (B) maximum unobstructed channel width from 2018 aerial imagery.

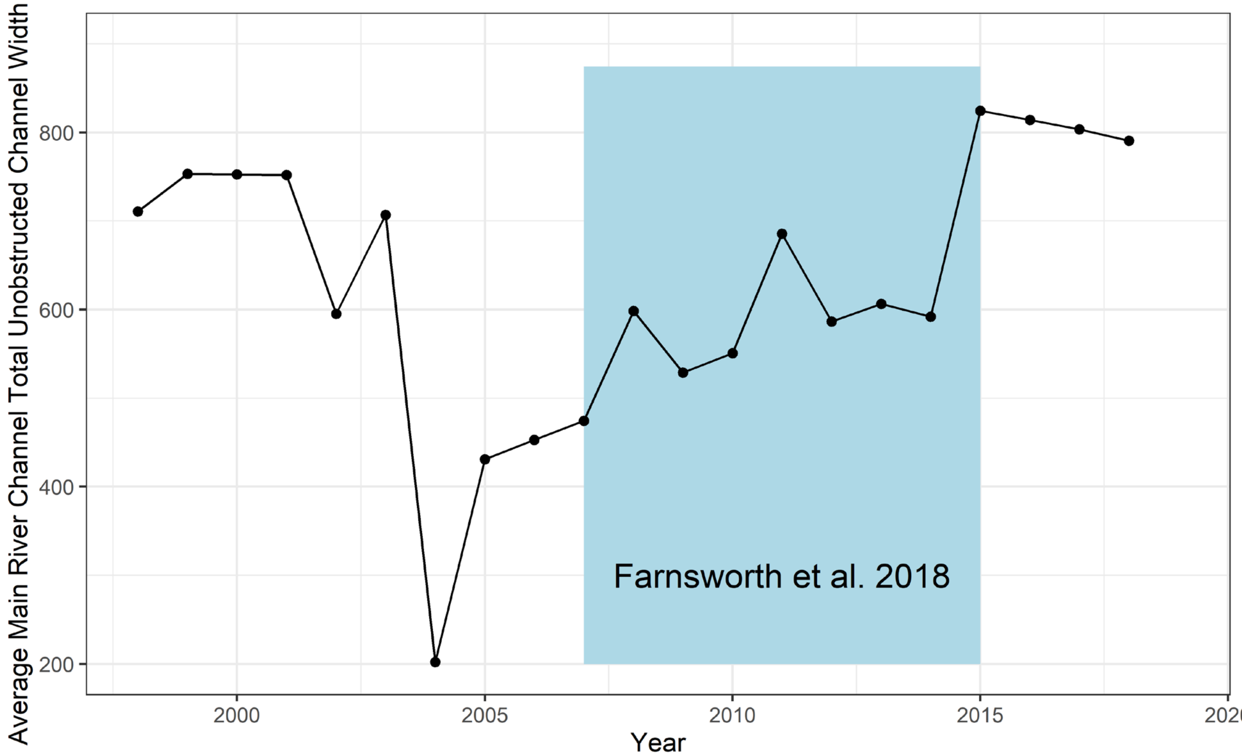

Figure 3. Median unobstructed channel width measurements in the central Platte River from 1998 to 2018. The Blue area indicated the period of data Farnsworth et al. (2018) used to develop flow and other relationships to unobstructed channel width.

A

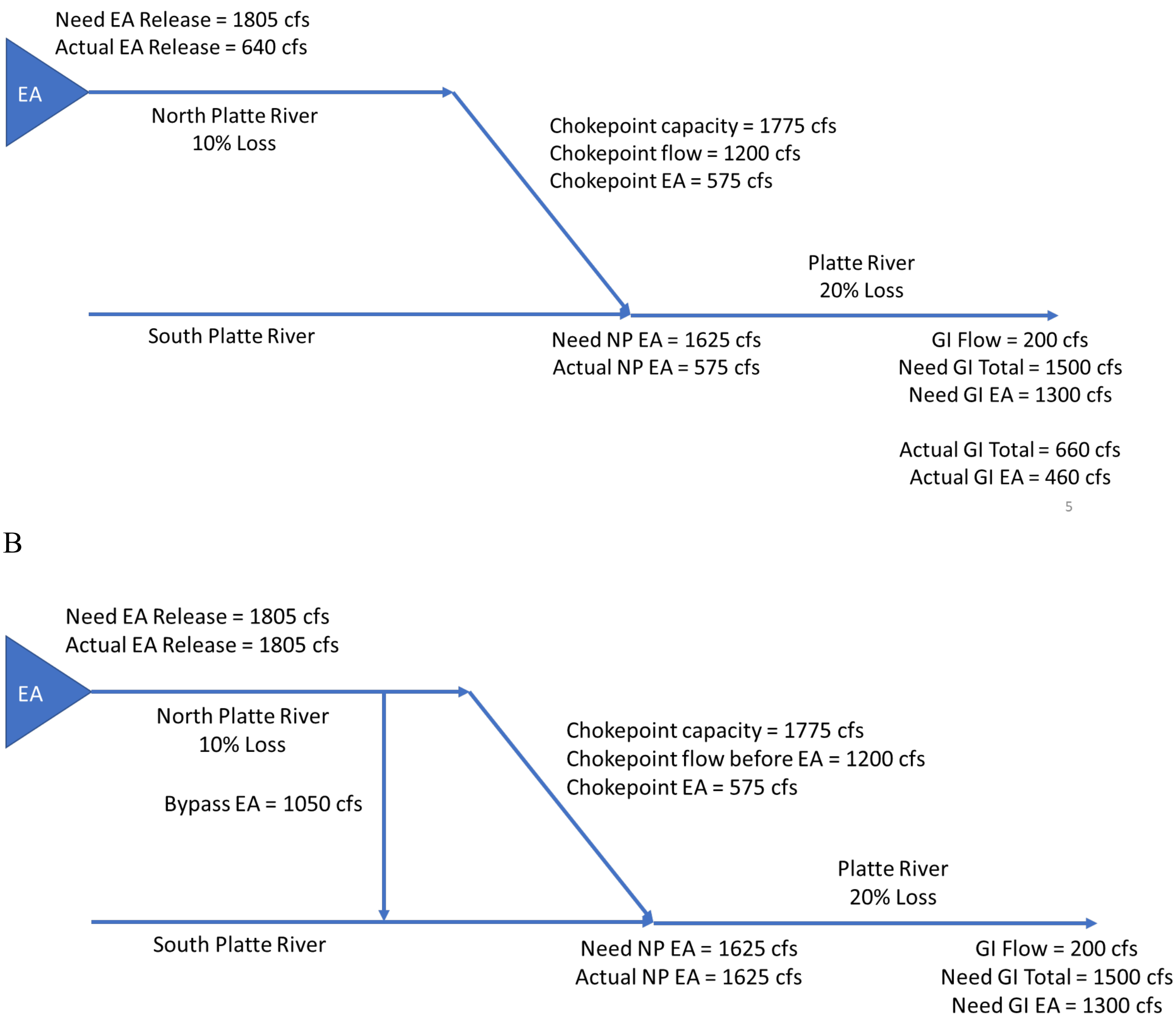

Figure 4. Flow routing tool flow calculation examples with (A) and without (B) a North Platte chokepoint bypass canal (Bypass EA).

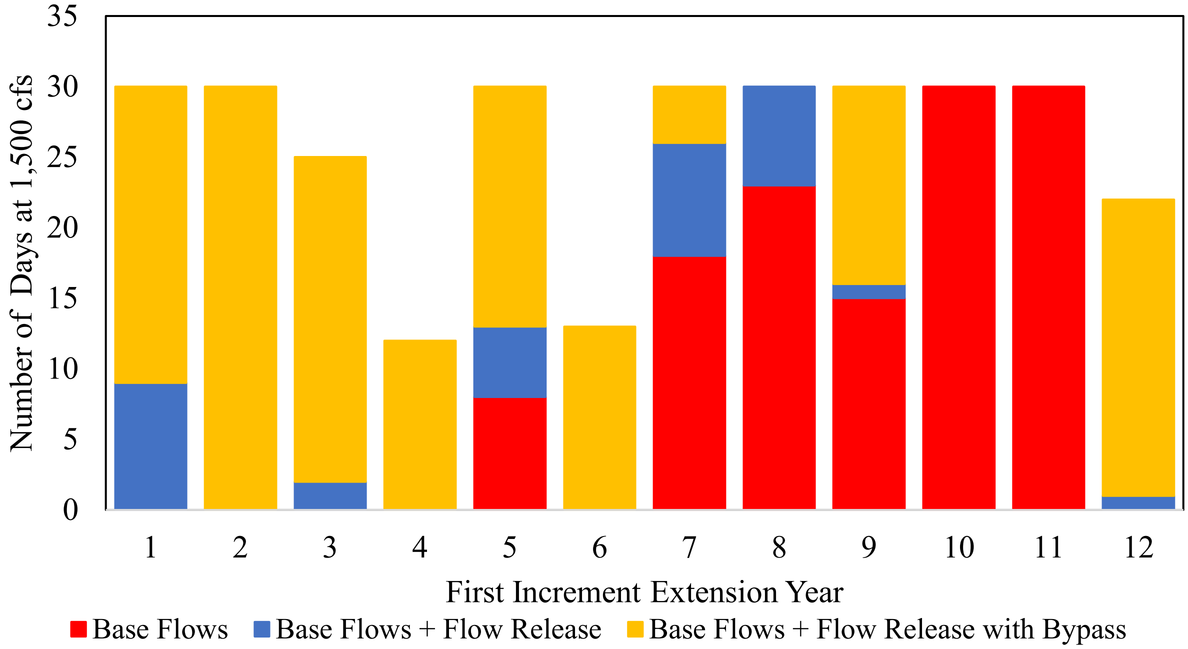

Figure 5. The number of days 1,500 cfs was achieved at Grand Island with only base flows (red) base flows plus flow releases (blue), and base flows plus flow releases with a bypass canal (orange) during the reminder of the First Increment Extension (2021-2032) under a possible flow regime with several years of low flows.

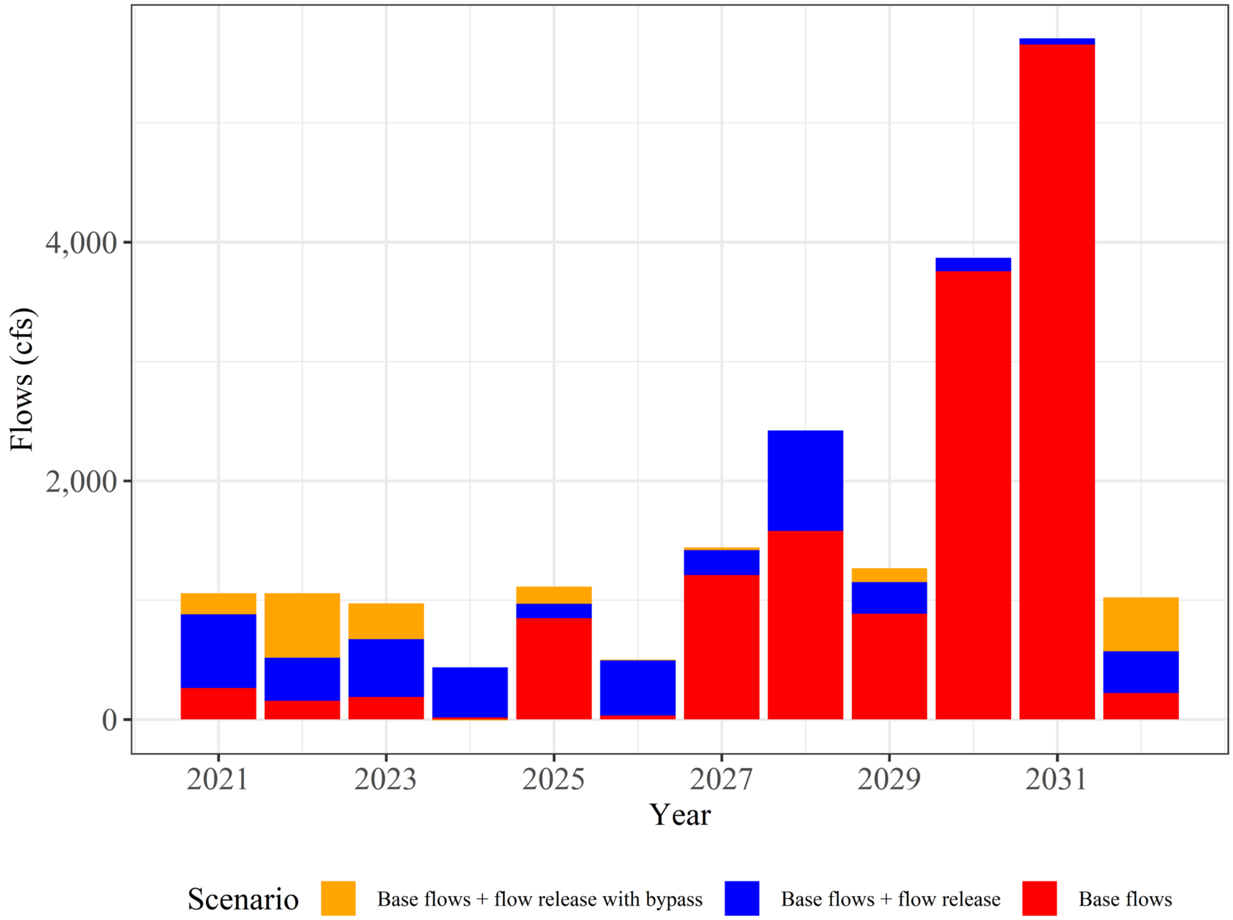

Figure 6. Main channel average June flows with only base flows (red) base flows plus flow releases (blue), and base flows plus flow releases with a bypass canal (orange) during the reminder of the First Increment Extension (2021-2032) under a possible flow regime with several years of low flows throughout the central Platte River.

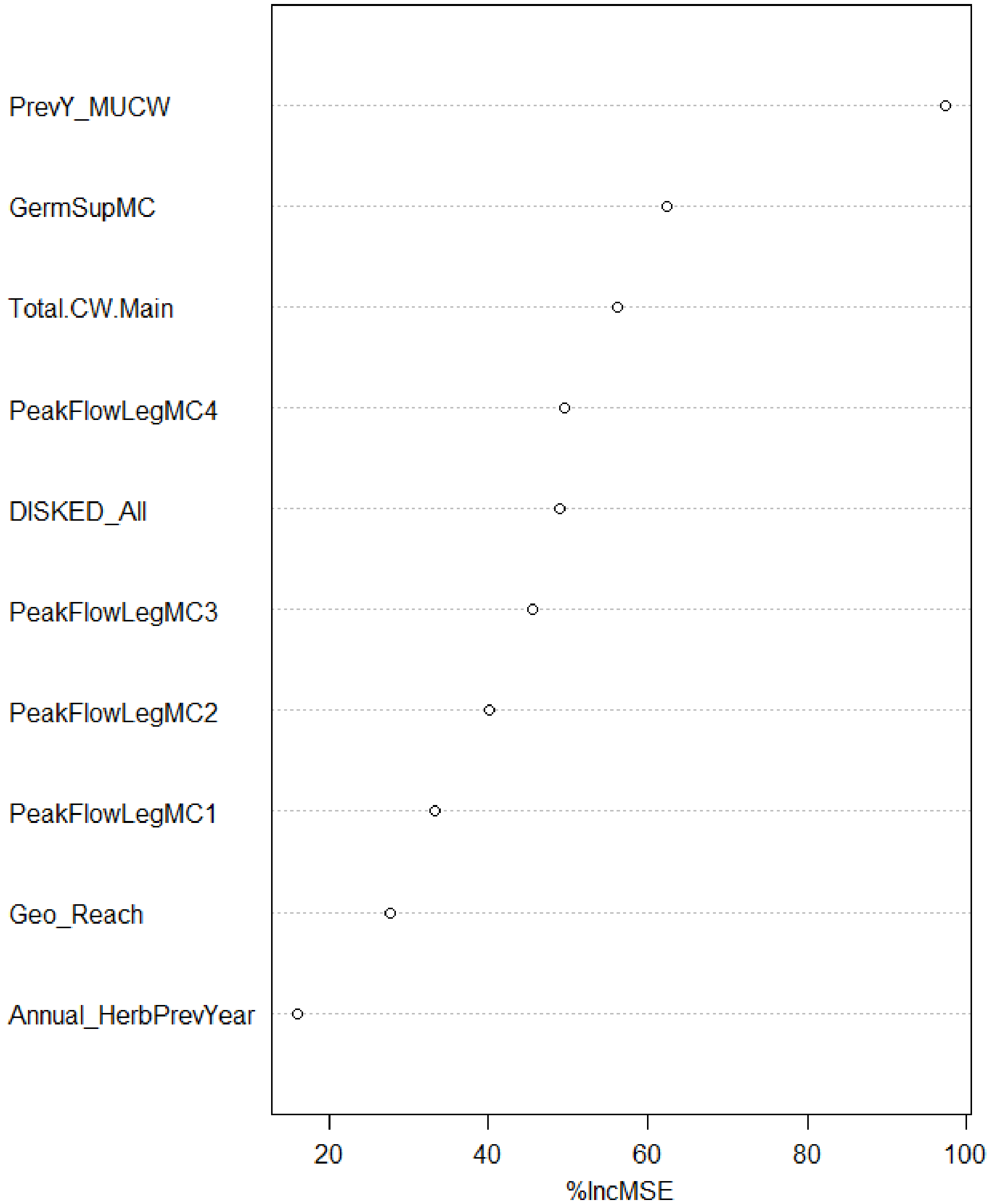

Figure 7. Change in maximum unobstructed channel width (ΔM) Random Forest variable importance measurements of independent variables. Greater percent increase in mean squared error (%IncMSE) indicates a variable of greater importance.

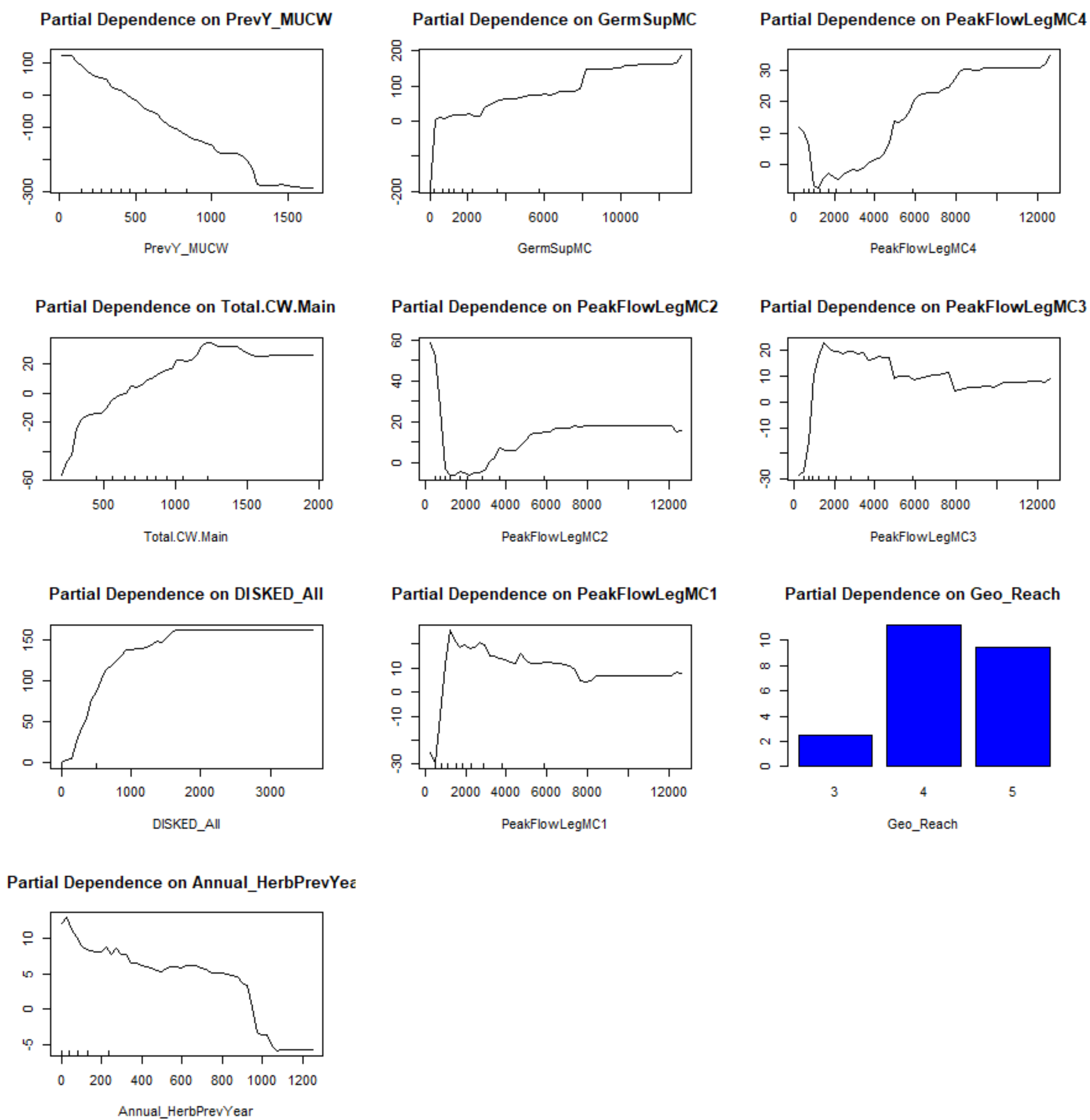

****Figure X.**** Random forest partial dependence plots for predictors variables of change in maximum unobstructed channel width model and include (A) Previous years' maximum obstructed channel width (PrevY_MUCW), (B) Average June flow (GermSupMC) (C) Main channel total channel width (Total.CW.Main), (D) Peak flow including the last 4 years (PeakFlowLegMC), (C) River channel disking (DISKED_All), (D) Geomorphic Reach within the Associated Habitat Reach (Geo_Reach), and (E) Previous years' herbicide application (Annual_HerbPrevYear). ***Included but not yet referenced in text***

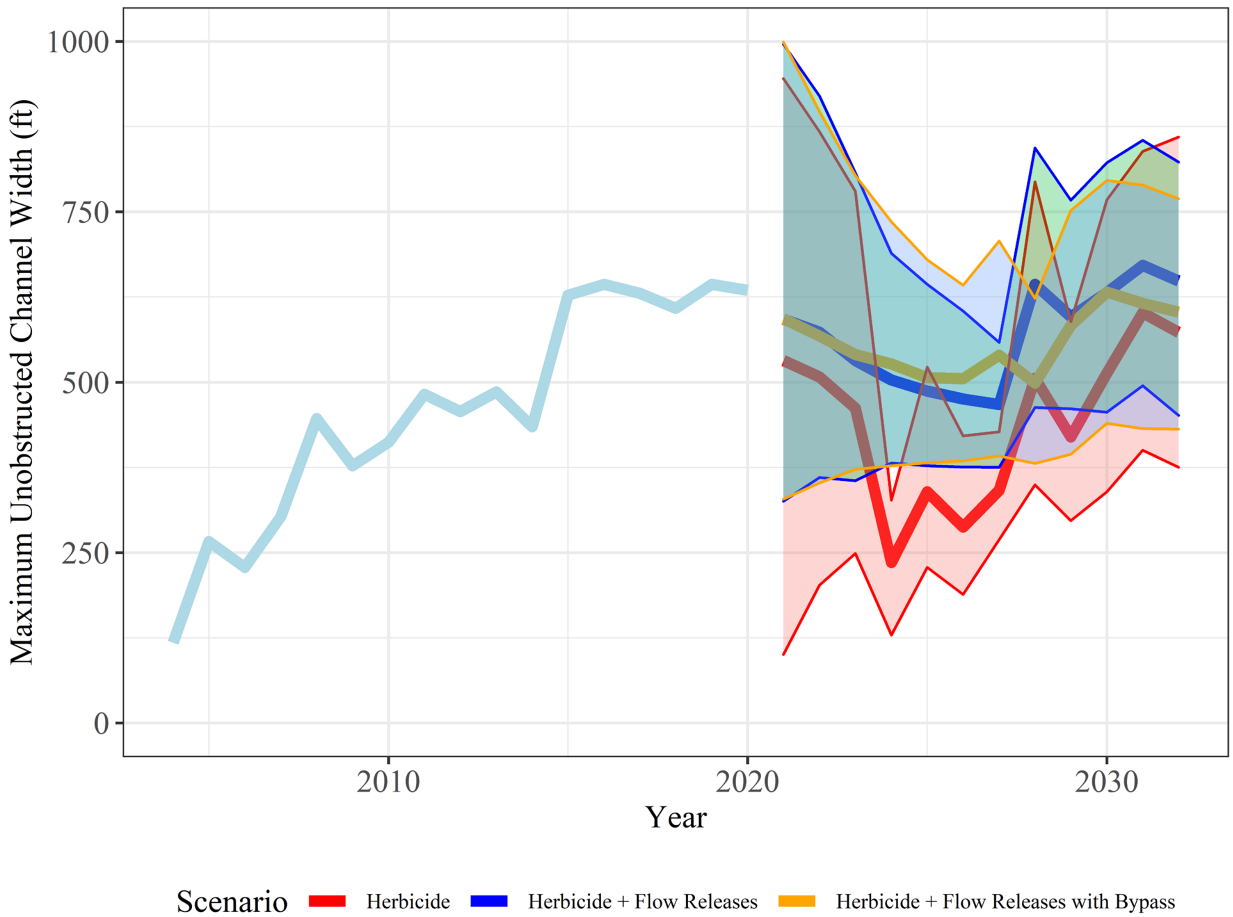

Figure 8. Mean annual maximum unobstructed channel width (MUCW) in the central Platte River from 2004 to 2020 (light blue line) and predicted mean MUCW for 2021-2032 based on drought conditions in early years transitioning to wet/normal hydrology later years with only herbicide application and base flows (red), the addition of flow releases (blue) and flow releases with a 1,500 cfs North Plate chokepoint bypass canal (orange). Channel widths from 2020 were used as a known starting point and predicted 2021 MUCWs were derived from 2020 channel widths plus predicted 2021 ΔMUCW. After 2021, predicted previous year's MUCW plus annual ΔMUCW calculated annual MUCW. Shaded regions represent 90% bootstrapped confidence intervals.

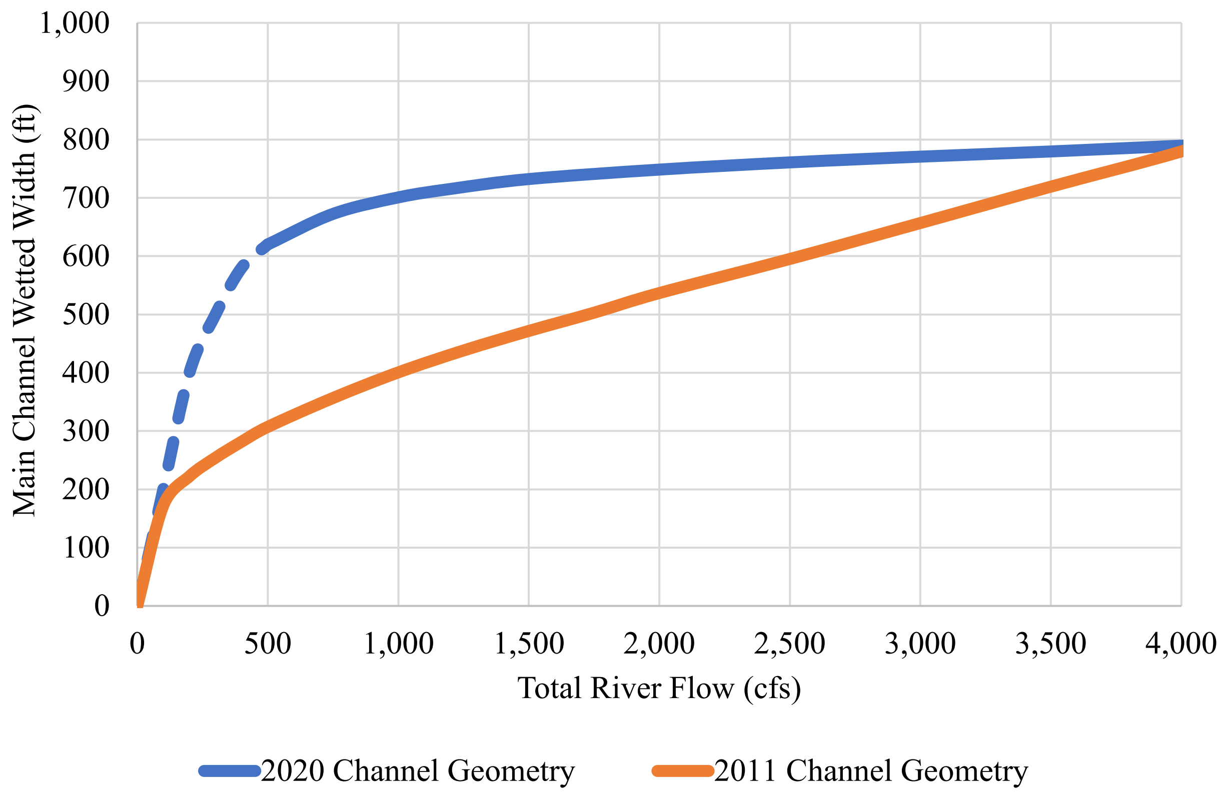

Figure 9. Main channel wetted width compared to total river flow throughout the Associated Habitat Reach using 2-D hydraulic modeling from river channel information in 2011 and 2020.