PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Data Synthesis Compilation

Whooping Crane (*Grus americana*) Habitat Synthesis Chapters

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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 solely on informing the use of Program land, water, and fiscal resources to achieve one of the Program's management objectives: 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 eight years in implementation of an adaptive management program 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). The Program has pursued all three of these approaches, producing multiple lines of evidence across a range of spatial and temporal scales. These lines of evidence indicate implementation of the Program's Flow-Sediment-Mechanical (FSM) management strategy, particularly the flow component, may not achieve the stated management objective and sub-objectives for whooping cranes; contribute to improved whooping crane survival during migration through increasing habitat suitability and use of the AHR.

This document is a compilation of four topical chapters with unique objectives and analyses that generally build on one another. Each of the chapters, which are intended to be useful as independent documents, include background information on the Program and thus may contain redundant content. Chapter 1 was developed to provide background and context to the discussions in the subsequent chapters. It provides a brief overview of whooping crane life history and occurrence within the AHR, a summary of previous investigations of habitat selection by whooping cranes along the Platte River, changes in river morphology that sparked regulatory intervention through the Endangered Species Act, and the competing management strategies the Program is implementing through an adaptive management framework. Chapters 2 and 3 focus specifically on whooping riverine habitat selection and suitability within the AHR and throughout the North-central Great Plains, respectively. Chapter 4 focuses on assumptions of priority hypotheses related to the beneficial effects of the FSM strategy on channel width measures and thus whooping crane habitat suitability, use of the Platte River, and survival during migration. Finally, a brief Summary of Key Findings has been added in order to combine and distill the most important conclusions of each chapter for Program decision makers.

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CHAPTER 1 – History and Context: The Path to Adaptive Management of Whooping Crane Habitat in the Central Platte River

Abstract

Observations of whooping crane use of the central Platte River is reviewed in relation to changes in hydrology and channel morphology over historical timeframes. The first observations of whooping cranes in the Associated Habitat Reach of the central Platte River date to the early 1800s. By the 1930s and 1940s river hydrology was altered by irrigation infrastructure and the channel actively narrowed in response to changing flow, sediment, and disturbance regimes. The loss of roosting habitat and whooping crane resources (forage) along the Platte River are hypothesized to be associated with the ongoing changes in the magnitude of channel forming flows and sediment transport. It is believed whooping crane survival during migration is negatively impacted by reductions in unobstructed channel width and unforested width along the Platte River. Adaptive management at a large scale is being used to test two management strategies to maintain suitable stopover habitat within the Associated Habitat Reach and thus to contribute to the survival of whooping cranes during migration.

Introduction

The Platte River Recovery Implementation Program (Program) is responsible for implementing certain aspects of the endangered whooping crane recovery plan. More specifically, the Program's Adaptive Management Plan (AMP) management objective is to improve survival of whooping cranes during migration through increased use of the Associated Habitat Reach (AHR) of the Platte River in central Nebraska (Program 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 one half miles of the river (Figure 1).

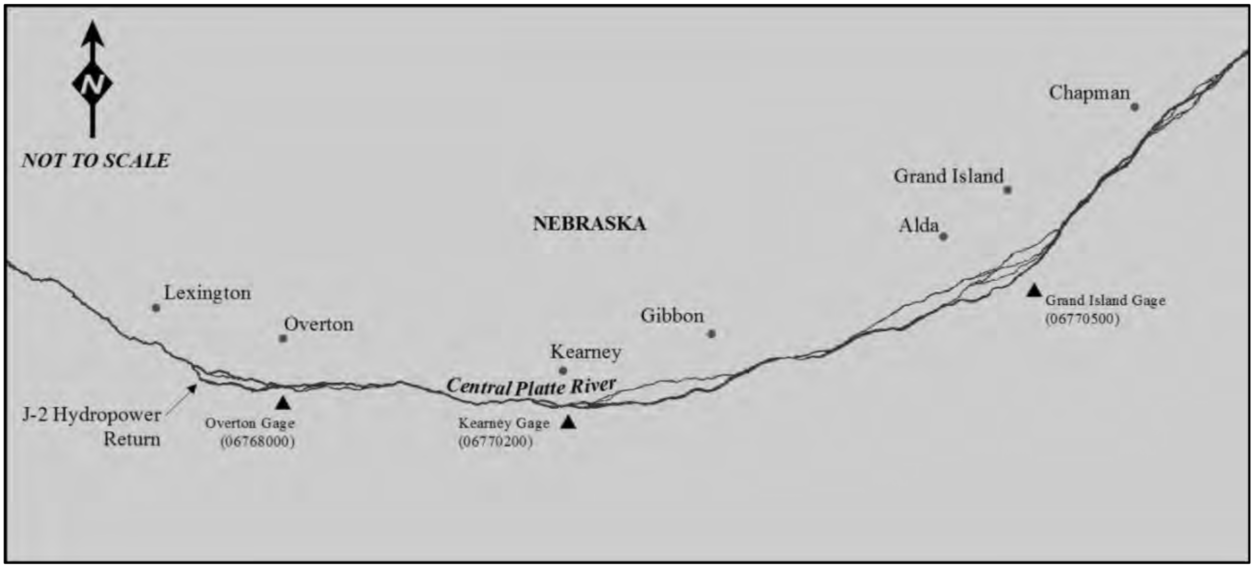

Figure 1. Associated Habitat Reach (AHR) of the central Platte River in Nebraska extending from Lexington downstream to Chapman.

The Program has invested nine years implementing an adaptive management program to test strategies for increasing whooping crane use of the AHR. Subsequent chapters of this document present analysis and interpretation of modeling, research, and monitoring efforts to date. The objective of this introductory chapter is to provide a brief overview of the large body of relevant Platte River literature and outline regulatory actions that led to the formulation of the Program. The chapter begins with a review of whooping crane monitoring and research in the AHR. Changes in hydrology and channel characteristics over historical timeframes are then explored. Finally, the rationale for regulatory intervention on behalf of the species is discussed and related to two management paradigms being evaluated by the Program.

Whooping Crane Life History

Whooping cranes are the tallest of North American birds and stand nearly five-feet tall. Their wingspan measures between seven and eight feet. Males weigh about 16 pounds and females about 14 pounds. Whooping cranes are a long-lived species that have been observed in the wild at an age >25 years. Adults are snowy white except for black primary feathers on the wings and a bare red face and crown. Immature cranes are a reddish cinnamon color that results in a mottled appearance as the white feather bases extend. The juvenile plumage is gradually replaced through the winter months and becomes predominantly white by the following spring as the dark red crown and face appear. Yearlings achieve the typical adult appearance by late in their second summer or fall. Whooping cranes are considered sub-adults and generally do not produce fertile eggs until they are 4 years old.

The whooping crane population, variously estimated at 500 to 1,400 individuals in 1870, declined to only 16 individuals in the migratory population by 1941 as a consequence of hunting and specimen collection, human disturbance, and conversion of the primary nesting habitat to hay, pastureland, and grain production (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005). The whooping crane was listed as endangered on March 11, 1967 (USFWS 1986). The historic range of the whooping crane once extended from the Arctic coast south to central Mexico, and from Utah east to New Jersey, into South Carolina, Georgia, and Florida. The historic breeding range once extended across the north-central United States and in the Canadian provinces, Manitoba, Saskatchewan, and Alberta. Currently the main threat to whooping cranes in the wild is the potential of a hurricane or contaminant spill destroying their wintering habitat on the Texas coast.

The Aransas – Wood Buffalo population of whooping cranes are long-distance migrants that breed in and around Wood Buffalo National Park located in Northwestern Canada and the Northern Territories and winter in and around Aransas National Wildlife Refuge (ANWR) located along the Gulf Coast of Texas. The migration route is well defined and a vast majority of all observations occur within a 200-mile wide corridor through Alberta, Saskatchewan, Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas (Figure 2). Whooping cranes are diurnal migrants, use traditional migration staging areas, and during migration utilize stopover sites to rest and build energy reserves to complete migration (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2007). Although a variety of habitats are used during migration, a wetland is nearly always associated with a stopover site. At stopover sites, whooping cranes roost standing in shallow water associated with palustrine, lacustrine, or riverine wetlands. Whooping cranes are omnivorous feeders that forage on many items including mollusks, crustaceans, minnows, reptiles, amphibians, invertebrates, small mammals, small birds, berries, live oak, agricultural grains, and plant tubers located in wetlands, grasslands, and agricultural fields.

Whooping cranes migrate singly, in pairs, in family groups, or in small flocks and sometimes accompany Sandhill cranes. Spring migration is preceded by mating behaviors such as dancing, unison calling, and frequent flying. Family groups and pairs are the first to leave the ANR in late-March to mid-April. Whooping cranes are monogamous and form life-long pair bonds but will re-mate following the death of a mate (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2007). Whooping cranes return to the same breeding territory in Wood Buffalo National Park in April and nest in the same general area each year (Whooping Crane Tracking Partnership unpublished data). The nesting area in Wood Buffalo National Park is a poorly drained region interspersed with numerous potholes. Bulrush is the dominant emergent in the potholes used for nesting. Adult whooping cranes construct nests of bulrush and lay one to three eggs (usually two) in late April and early May. The incubation period is about 29 to 31 days. Whooping cranes will renest if the first clutch is lost or destroyed before mid-incubation. Both sexes share incubation and brood-rearing duties. Despite the fact that most pairs lay two eggs, sibling rivalry usually results in only one chick reaching fledging age. Only one-fourth of chicks that hatch survive to reach the wintering grounds.

Autumn migration begins in mid-September and most birds arrive on the wintering grounds on the Texas Gulf Coast by mid-November. On the wintering grounds, pairs and family groups occupy and defend territories. Sub-adults and unpaired adult whooping cranes form separate flocks that use the same habitat, but remain outside of occupied territories. Sub-adults tend to winter

Figure 2. Dotted line delineates the migration corridor of whooping cranes, including breeding areas in Wood Buffalo National Park and wintering areas near Aransas National Wildlife Refuge.

in the area where they were raised their first year and paired cranes often locate their first winter territories near their parents' winter territory.

Whooping crane observations on or along the Platte River

Historical records of whooping occurrence on or along the Platte River from 1820–2014 were compiled or recorded by Swenk, Black, Brooking, Allen, USFWS, NGPC, Ross Lock, and Hastings Museum and have been summarized by Tom Pitts (1985), the Biological Work Group (1990), and the Executive Director's Office of the Program (Figure 3). It is important to note detection of whooping cranes along the central Platte River increased substantially beginning in 2001 with the implementation of systematic surveys of the AHR and that survey methodologies at Aransas National Wildlife Refuge were modified in 2011. Population estimates were obtained from the United States Fish and Wildlife Service (USFWS), the Whooping Crane Recovery Team, and the Whooping Crane Studbook and were compiled by Betsy Didrickson of the International Crane Foundation and the USFWS.

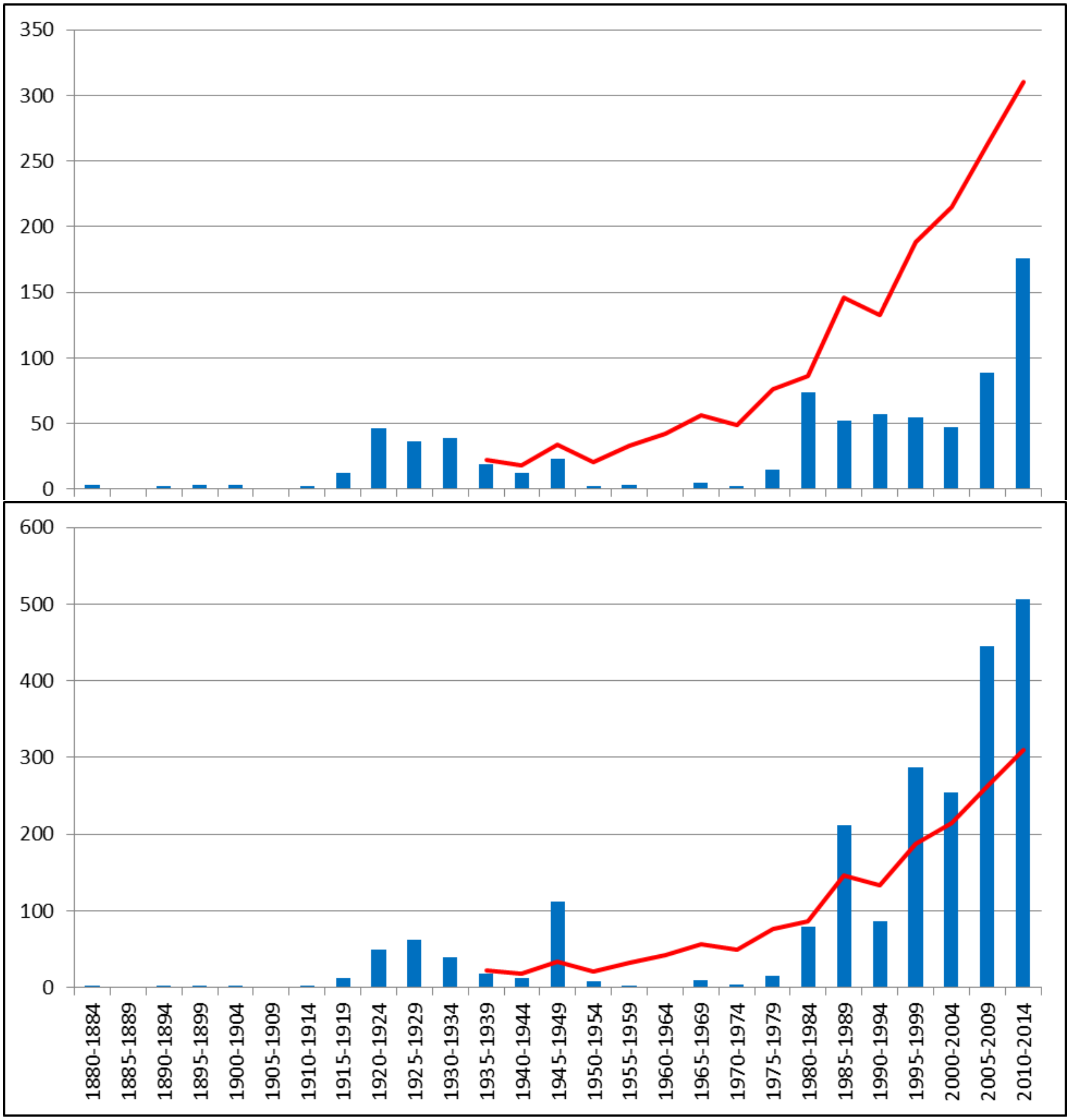

Figure 3. Numbers of whooping cranes (top bar plot) and whooping crane use days (bottom bar plot) reported on or near the Platte River in 5-year blocks of time, 1880-2014. The red line represents the numbers of whooping cranes counted in the Aransas-Wood Buffalo population at the end of each 5-year interval, 1939-2014. Monitoring effort changed substantially beginning in 2001 when systematic surveys of the Program Associated Habitat Area were initiated. It should also be noted that Allen (1952) and Pitts (1985) concluded the increase in observations along the Platte River during the 1920's was likely due to misidentification of whooping cranes.

Platte River habitat selection investigations

Characteristics of whooping crane roost habitat have been examined and described for the central Platte River in Nebraska (Johnson 1981; Lingle et al. 1984; Armbruster 1990; Faanes 1988; Faanes and Bowman 1992; Faanes et al. 1992). Several characteristics common to whooping crane riverine roost sites include shallow, wide, unvegetated channels and open visibility with the absence of tall trees or dense shrubs near the roost (Johnson and Temple 1980; U.S. Fish and Wildlife Service 1981; Johnson 1981; Armbruster 1990; Faanes et al. 1992; Austin and Reichert 2001; National Research Council 2004). Ziewitz (1987) described whooping roosting habitat suitability using several parameters including unobstructed channel width. In this assessment, unobstructed channels ≤500 feet wide were assigned a minimum suitability value while unobstructed channel widths ≥1,150 were assigned a maximum suitability value. Table 1 of the Program's land plan infers whooping crane habitat suitability and use are maximized at 1,150 feet (Program 2006b). Shenk and Armbruster (1986) reported unobstructed channel widths <75 meters (246 feet) were unsuitable roosting habitat for whooping crane and roost habitat was optimized at unobstructed channel widths of 400 meters (1,312 feet). Similarly, the USFWS (1986) reports whooping roosting habitat is optimized at unobstructed channel widths ≥1,158 feet and channels with unobstructed widths <500 feet were deemed unsuitable roosting habitat. Contrary to these reports, Austin and Reichert (2005) found unobstructed channel widths at riverine roost sites averaged 233 meters (764 feet) and Johnson (1981) described optimal riverine roost habitat as being any channel with an unobstructed width ≥155 meters (509 feet). Pitts (1985) even went so far as to report whooping crane selection of stopover habitat occurs at random. To date, however, roost characteristics and criteria have been developed based on a limited amount of quantitative information and most criteria have been derived from circumstantial roost locations that may not be representative of a typical stopover site (Armbruster 1990).

Changes in Associated Habitat Reach hydrology over historical timeframes

Water development in the Platte River basin began in the mid-1800s as settlers migrated to the region in search of gold and to homestead after the federal government opened the basin for settlement. The Platte River is now heavily developed with over seven thousand diversion rights and seven million acre-feet of storage (Figure 4; Simons & Associates Inc. 2000). Platte River discharge records begin in 1895, fifteen years before the completion of Pathfinder Dam, the first major agricultural storage project in the basin. Mean annual discharge and the magnitude of the mean annual peak discharge in the contemporary river are less than 40% of what was observed during the brief period of record prior to reservoir construction (Table 1; Stroup et al. 2006).

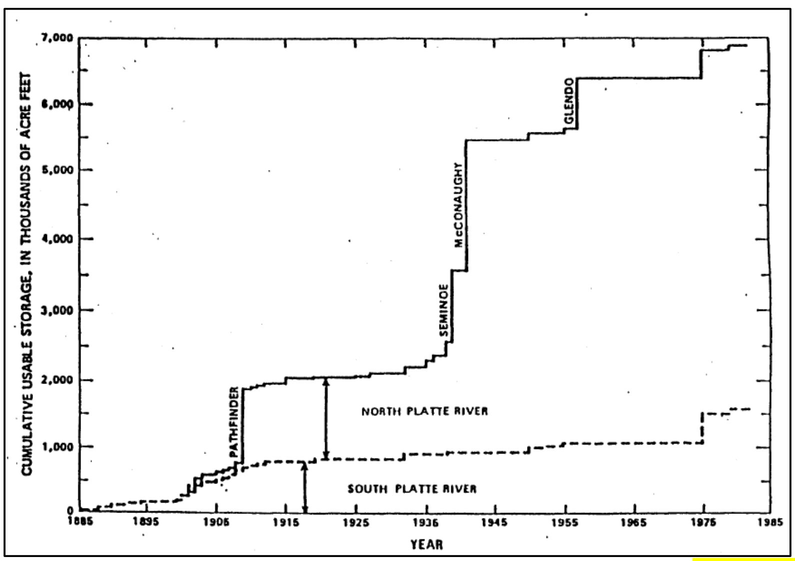

Figure 4. Cumulative usable storage in reservoirs in the Platte River basin (Simons and Associates Inc. 2000).

Table 1. Mean annual discharge and mean annual peak discharge at Overton gage adapted from Stroup et al. (2006).

	1895-1909	**1910-1927**	**1928-1941**	**1942-1958**	**1959-1974**	**1975-1998**	**1999-2013**
Mean Annual Discharge (cfs)	4,584	4,323	1,845	1,223	1,636	1,938	1,232
Mean Annual Peak Discharge (cfs)	20,725	18,218	11,548	6,685	7,301	7,176	5,056

Changes in Associated Habitat Reach sediment transport over historical timeframes

There is little bed material or sediment transport data available for the historical AHR. Simons and Associates Inc. (2000) generated a crude predevelopment sediment transport estimate of approximately 7.8 million tons per year based on a flow/sediment regression analysis and an estimate of sediment trapping in North Platte River reservoirs. Murphy et al. (2004) estimated much lower predevelopment sediment loads on the order of one to two million tons per year using a range of sediment discharge equations and discharge records from the period of 1895-1909. As indicated by the differences in these estimates, there is a high degree of uncertainty related to sediment loads in the historical AHR. Contemporary sediment load estimates are less variable and generally range from 400,000 – 1 million tons per year (Simons and Associates Inc. 2000, Murphy et al. 2004).

One of the most significant changes in sediment dynamics from predevelopment conditions is a sediment deficit in the upper half of the AHR due to clear water hydropower returns at the Johnson 2 (J-2) Return structure on the south channel downstream of Lexington, NE (Figure 5). An average of approximately 73% of Platte River flow is diverted at the Tri-County Diversion Dam downstream of North Platte and returns to the river at the J-2 Return where it constitutes approximately 47% of river flows (Murphy et al. 2004). Once diverted at North Platte, flow travels through several off-line reservoirs where almost all of the sediment is trapped. Accordingly, return flows at the J-2 Return structure are sediment-starved resulting in a sediment deficit (hungry water) below the return.

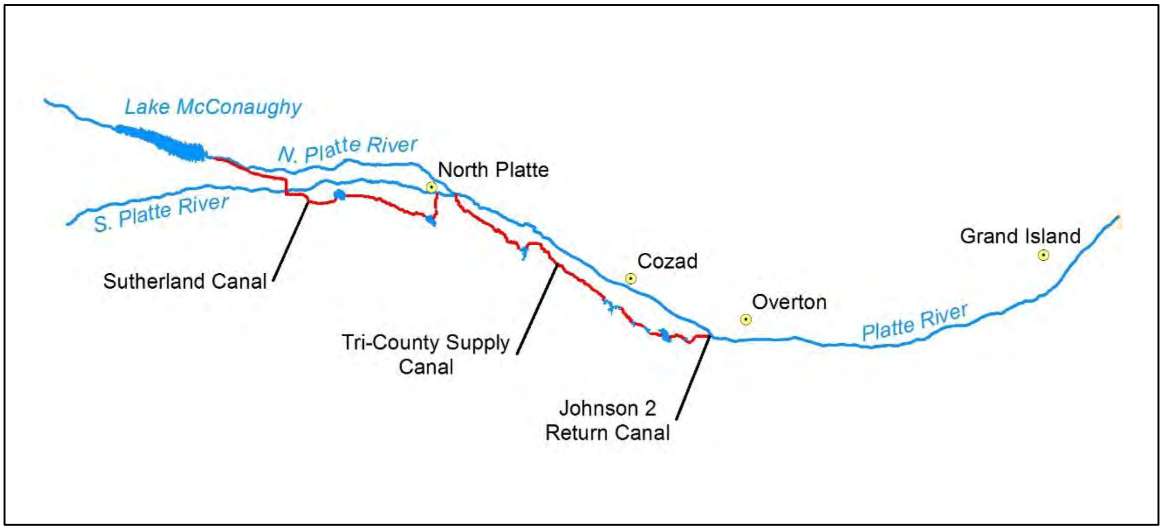

Figure 5. Map of Lake McConaughy, Tri-County Supply Canal and J-2 Return Canal. Figure reproduced from Murphy et al. (2004).

Changes in Associated Habitat Reach channel morphology over historical timeframes

The reduction in AHR active channel width (unvegetated width between permanently vegetated left and right banks) over historical timeframes through expansion of woody vegetation was first quantified by Williams (1978) and has been expanded upon in several subsequent analyses (Eschner et al. 1983, Currier et al. 1985, Peake et al. 1985, O'Brien and Currier 1987, Lyons and Randle 1988, Sidle et al. 1989, Johnson 1994, Simons and Associates 2000, Parsons 2003, Murphy et al. 2004, Schumm 2005, Horn et al. 2012). With the exception of Parsons (2003), which asserted no width change, investigators have generally concluded the AHR experienced a significant width reduction as a result of the expansion of cottonwood forest into the channel. The change is evident in comparisons of aerial photography (Figure 6).

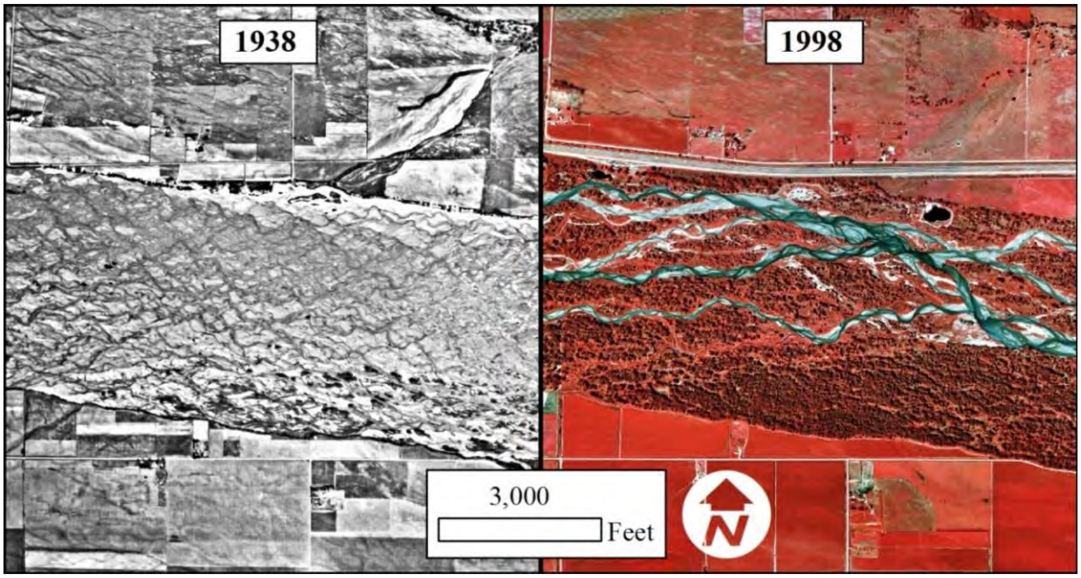

Figure 6. Comparison of 1938 and 1998 aerial photographs of the Associated Habitat Reach at River Mile 218 in the Odessa to Kearney bridge segment. Much of the 1998 channel area is occupied by riparian cottonwood forest.

The surveyed bank-to-bank or total width of the channel in the 1860s excluding large permanent islands was highly variable and averaged 3,800 ft (Figure 7). The proportion of the total width of the historical channel that was unvegetated is not known but has been estimated to be on the order of 90% (Johnson 1994). At the earliest aerial photography collection in 1938, unvegetated channel width averaged 2,600 ft. By 1998, average unvegetated width was 900 ft. Johnson (1994) evaluated the rate of change in active channel width in the AHR from 1938 to 1988 and found the majority of narrowing occurred during the 1940s and 1950s with channel area stabilizing by the 1980s (Figure 8).

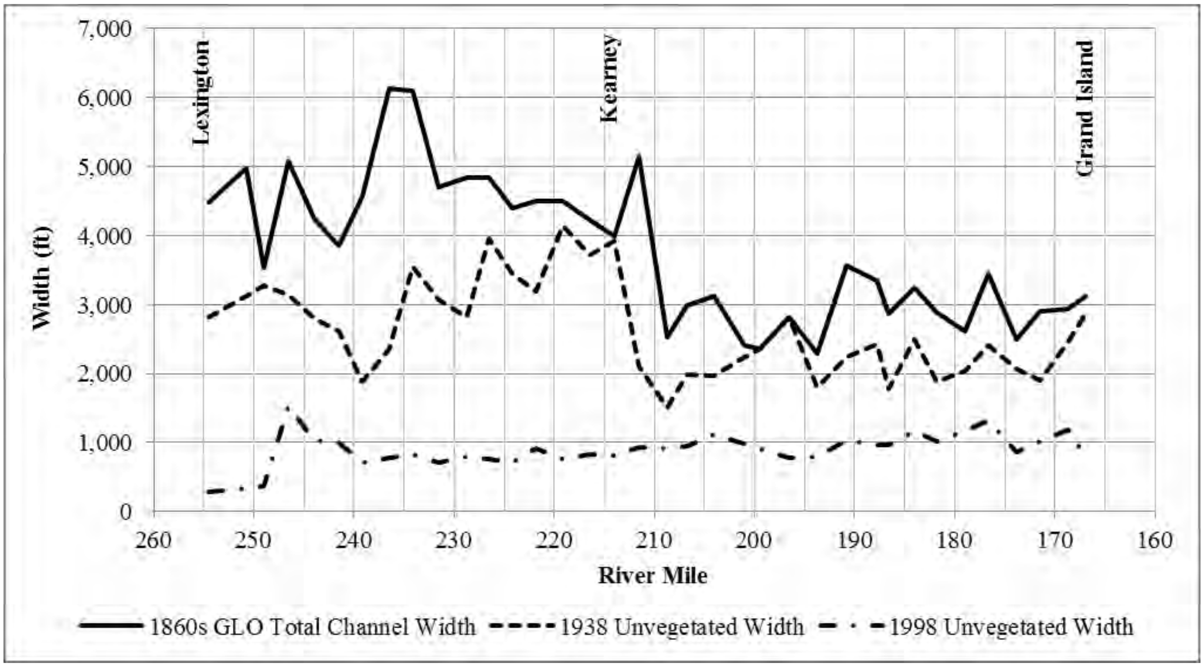

Figure 7. Total channel width in the Associated Habitat Reach from the 1860s General Land Office (GLO) survey, total unvegetated width in 1938 aerial photographs and total unvegetated width in 1998 aerial photographs.

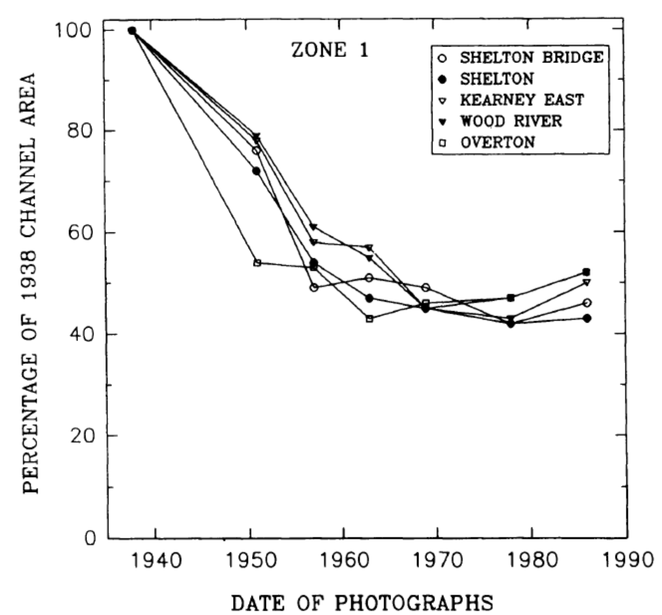

FIG. 8. Changes in active channel area in Zone 1 reaches from 1938 through 1986. Starting channel area in 1938 was set equal to 1.

Figure 8. Change in active channel area in the upper half of the Associated Habitat Reach 1938-1988 from aerial photography (Johnson 1994).

The drivers of woody vegetation expansion were explored in many of the channel width analyses with investigators generally concluding the change was due to alterations in hydrology caused by water development in the basin. Alternative hypotheses of the specific mechanisms of narrowing include:

1) a reduction of peak flow magnitude and associated ability to scour vegetation (Williams 1978, O'Brien and Currier 1987, Murphy et al. 2004),
2) a reduction in flow during the cottonwood germination period leading to increased recruitment (Johnson 1994, Simons and Associates 2000), and
3) a decrease in desiccation mortality of seedlings in summer as the river transitioned from ephemeral to perennial due to irrigation return flows (Schumm 2005).

Although changes in AHR channel width have been widely studied and debated, sandbar characteristics in the historical river are not well documented. Several investigations include brief descriptions of sandbars and islands recorded by travelers in the 19th Century (Eschner et al. 1983, Simons and Associates 2000, Murphy et al. 2004). The most descriptive observation of bedforms was contained in Mattes (1969) who reproduced a quote from a Mr. Evens in 1848 describing the Platte River near Kearney as "running over a vast level bed of sand and mica… continually changing into short offsets like the shingled roof of a house..." Other travelers generally characterized the bed of the river as being comprised of innumerable sandbars continually shifting and moving downstream (James 1823, Mattes 1969).

The first detailed characterization of AHR sandbar morphology was provided by Ore (1964) who classified Platte River bedforms as transverse bars. Further attempts to characterize sandbar morphology identified dominant bedforms as transverse/linguoid bars (Smith 1971, Blodgett and Stanley 1980), macroforms (Crowley 1981 and 1983), or a combination of both types (Horn et al. 2012). The historical accounts of Platte River bedforms appear to agree well with contemporary descriptions of transverse/linguoid bars.

Regulatory intervention in the Platte River Basin through the Endangered Species Act

In 1981, the USFWS deduced the most likely factors resulting in decreased whooping crane use of the Platte River between 1950 and 1980 were decreased unobstructed channel width, growth of woody vegetation along the bank lines, and increased human activity along the Platte River (USFWS 1981). The USFWS concluded additional diversions were likely to cause further habitat degradation and threaten the welfare of whooping cranes. As such, the USFWS determined whooping crane habitat along the central Platte River was threatened by upstream impoundments and diversions that reduce the magnitude of the annual spring runoff credited with historically creating and maintaining open-channel roosting habitat and for sustaining suitable bottomland (wet meadow) habitat deemed to be essential for foraging (USFWS 2006). The following excerpt from the Biological Opinion for the Platte River Recovery Implementation Program (USFWS 2006) provides the rationale for USFWS conclusions about the effects of upstream water development on whooping crane habitat in the AHR.

"<u>Open Channel Roosting Habitat</u>

During the past century, channel habitat in the 170-mile long reach that lies within the whooping crane migration corridor has been transformed from a very wide and braided sandy channel to anabranched channels and heavily forested floodplain. Historical accounts of the Platte River place its width between 0.75- and 3 miles. Actual measurements by Bonneville in 1837 was a 1.25-mile width 25 miles downstream of Fort Kearney, and a 1.0-mile width that was measured, by the explorer Fremont in 1845, downstream from the confluence of the North Platte and South Platte rivers (Currier et al. 1985).

Encroachment of woody vegetation into the former wide expanse of the river bed is described by Williams (1978), Eschner et al. (1983), Peake et al. (1985), Johnson (1990, 1994, and 1996), McDonald and Sidle (1992), Currier et al. (1985), and Currier (1995 and 1996a), Simons and Associates (2001), Murphy et al. (2004), and summarized by Sidle *et al. (1989) and the EIS (2006). Within the Lexington to Chapman reach alone, Sidle et al. estimated that by the early 1980s the channel area had been reduced by 73 percent with the greatest reductions in the critical habitat reach from Lexington to Shelton (RM 196 to 250) (Figure VI-A6).*

Currier et al. (1985) estimated that 70 percent of the open channel and 90 percent of the habitat value had been lost. Habitat loss and the threat of the Platte River whooping crane resources are related to the ongoing deterioration of forming processes (i.e., changes in the magnitude of channel forming flows and sediment transport) as described above. Further information on channel changes and loss of open channel discussed in 'Status of the Platte River Ecosystem' (Chapter VI, Section A) apply to the critical habitat reach.

Downstream of Lexington, the channel degradation described in the Status of the Platte River Ecosystem (Environment Baseline section, part A) of this biological opinion affects both channel roosting habitat and wet meadow foraging habitat. No major tributary inflows or outflows occur between the J-2 Return and river flow patterns at Overton and Grand Island are generally similar, yet channel habitat losses are not uniform within the reach. Sediment-free J-2 Return discharges increase the downstream sediment transport to rates that are about twice the indicated amount supplied in to the habitat reach at Lexington (Randal and Samad 2003). Channel surveys indicate that much of the difference in the amount of sediment transported is from erosion of the channel bed.

Channel bed degradation extends downstream from the J-2 Return near Lexington. The length of river reach undergoing degradation is not precisely determinable with existing data, but appears to be at least 20 miles and perhaps as much as 40 miles of a recent 15- year interval (Murphy et al. 1998, Holburn et al. 2006).

Channel bed erosion is a factor that adversely affects open channel roosting habitat by entrenching the channel and concentrating flow and increasing water depth and velocity. Channel downcutting has left high islands, banks, and benches at higher elevations and provide a surface for vegetation growth. Though the affects of this process on habitat vary somewhat among river reaches, the confining and down-cutting of the river channel between high banks has contributed to substantial decreases in horizontal visibility, open channel, and wetted channel area, and to changes from braided to anabranched river plan form.

The area of open, wide channels is not entirely eliminated in the critical habitat reach, but it is substantially reduced in amount and quality (Figure VI-B6). Consequently, whooping crane use of the river channel for roosting is substantially limited from Lexington (RM 251) to the vicinity of Fort Kearny State Recreation Area (RM 210) (Fort Kearney lies in bridge segment 8 of Table IV-B2). Portions of the river in bridge segment 7 and 10 are maintained as open channel habitat by private non-government organizations.

Quantitatively, loss of whooping crane roosting habitat due to channel degradation is greatest in the upstream reaches. For example, between 1985 and 2000 near Overton, changes in channel morphology (i.e., channel downcutting and narrowing) virtually eliminated whooping crane roost habitat in a segment of the critical habitat reach near Overton (Figure VI-B7).

Changes in river morphology may have a controlling affect on the hydrologic relationship between the river and subirrigated meadows and wetland components of the adjoining bottomland grasslands. Platte River channel morphology must be improved and maintained in order to provide the wide channels suitable as roosting habitat and to restore and maintain wet meadows where cranes feed and rest.

<u>Hydrocycling</u>

Flows of the Platte River during spring and fall whooping crane migration seasons are composed in part of water diverted into CNPPID's system and returned at the upstream end of the central Platte River habitat area near Lexington. Returns at the J-2 Return and flows remaining in the south river depend in part on the releases from Lake McConaughy and inflows from the South Platte River. Releases depend in turn on available water supplies in the basin.

During low water supply conditions, discharges from the J-2 Return are variable. Based on operational descriptions, Hydrocycling may occur when flows reaching the Johnson No. 2 power station are less than 1.300 to 1.400 cfs, and must occur when flows reaching the Johnson No.2 power station are less than 1,050 cfs because of the risk of cavitation damage (CNPPID 2005). During low flow years, Hydrocycling may occur during whooping crane spring and fall migration periods.

The magnitude of the change in river stage attenuates downstream. Changes in river stage may range from imperceptible to a few inches (at RM 206 and 207) to more than 2 feet (RM 243-244) during Hydrocycling. The potential adverse effects of current Hydrocycling operations on whooping cranes may be occurring in a limited portion of the J-2 to Kearney reach of the river where wide channels occur, and most specifically in the segment of wide channels maintained as crane habitat.

Thought migrating whooping cranes may use the Platte River at various times of day and are observed to retreat from fields to Platte River roosts during severe weather, the primary concern is the potential effects on nocturnal roosts. Whooping cranes stand in shallow (usually <0.7-foot) slow-moving water to roost. The current Hydrocycling operations may affect cranes in several ways, including the potential to flush the birds from their roosts at night, cause restless roosting behavior, and potentially increase exposure to predators (pers. comm., Gary Krapu 2006). Collision with utility lines is a principal *known cause of direct injury and mortality to migrating whooping cranes (USFWS 1994g, Ward and Anderson 1992, Stehn and Wassenich 2006), and of Sandhill crane injury and mortality along the Platte River (USFWS 1984g, Ward and Anderson 1992). Discussions are currently underway with CNPPID to develop and agreement on modified Hydrocycling operations to avoid or minimize effects to listed species and program benefits."*

As indicated in the excerpt, a decline in AHR whooping crane habitat suitability has been inferred from the body of evidence documenting a significant change in Platte River hydrology and a morphological reduction in unvegetated AHR channel width over historical timeframes. Within this context, the USFWS began issuing jeopardy opinions for water projects that could further affect the hydrology of the AHR. These jeopardy opinions prompted the states of Wyoming, Colorado, and Nebraska and the Department of the Interior to enter into a Cooperative Agreement in 1997 for the purpose of negotiating a program to conserve threatened and endangered species habitat in the AHR while accommodating certain ongoing water development activities in the basin. Through the negotiation process, it became apparent that uncertainty and disagreements about species habitat requirements and appropriate management strategies were making it difficult to reach agreement on a program. Resolution was achieved through the development of an Adaptive Management Plan (Program 2006a) that treats these disagreements as uncertainties related to two competing management strategies.

Competing Management Paradigms

The Program's two competing management strategies reflect different paths to achieving the objective of improving survival of whooping cranes during migration. The first strategy is the Mechanical Creation and Maintenance (MCM) approach. This approach focuses on mechanical creation and maintenance of both in- and off-channel habitats for the whooping cranes including channel widening through management activities such as in-channel and bank line vegetation removal, the acquisition and restoration of off-channel wetland habitat, and the construction and preservation of wet meadow habitat. Various entities have created, maintained, and monitored whooping crane stopover habitat use in the AHR since 2001. Accordingly, there is little uncertainty about the ability to mechanically create and maintain wide open channels for whooping cranes. Instead, the uncertainties pertain to characteristics that influence selection of in- and off-channel habitats and the most economical means of creating and maintaining that habitat (Program 2006a).

The second strategy is the Flow-Sediment-Mechanical (FSM) approach. This approach is water-centric with a focus on restoring channel width, improving sediment supply, and increasing annual peak flow magnitudes to increase the braided channel morphology and maintain unobstructed channel width. The FSM strategy is rooted in the view that, prior to the onset of water development and channel narrowing, the historical AHR once provided stopover habitat conditions critical for whooping crane survival and that the contemporary Platte River is insufficient to provide the population this critical resource. As discussed previously, there is a large body of evidence documenting AHR channel narrowing over historical timeframes with the most significant changes occurring during the period of 1940-1970 (Johnson 1994).

Chapters 2 and 3 provide an overview of whooping crane riverine habitat selection along the central Platte River and throughout the North-central Great Plains, respectively. Chapter 4 explores the validity of the assumption the FSM management strategy can create and maintain habitat conditions suitable for whooping crane use as identified in chapters 2 and 3 and preludes into a discussion on the potential implications for the Program's ability to create and maintain whooping crane roosting habitat using short-duration high flows.

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CHAPTER 2 – Whooping Crane Use of Riverine Stopover Sites along the Central Platte River, Nebraska

Abstract

The “Big Bend” reach of the central Platte River has been identified as critical habitat for the survival of the endangered whooping crane (*Grus americana*). Management intervention is now underway to rehabilitate habitat form and function on the central Platte River to increase use and thereby contribute to the survival of whooping cranes. The goal of our analysis was to develop habitat models that could be used to direct management activities along the central Platte River. As such, we focused our analysis on metrics the Platte River Recovery Implementation Program (Program) has the ability influence to some degree. Within several stretches of river, the Program owns land or has management agreements that allow for the ability to alter physical features such as unobstructed channel width, unforested channel width, distance to nearest forest, and total channel width of an area through mechanical intervention. Through the U.S. Fish and Wildlife Service’s Environmental Account, the Program also has access to a limited amount of water that, through timed releases, could be used to influence unit discharge and thus several hydrologic metrics. We used an *a priori* set of models to evaluate the influence of various metrics on the probability of whooping crane use. We were unable to establish a strong relationship between whooping crane use and flow metrics, total channel width or unforested channel width, but found unobstructed channel width and distance to the nearest forest were the best predictors of whooping crane use. Our findings indicate the Program would have the potential to influence whooping crane use of the central Platte River through channel widening along narrow (<500ft) channels and mechanical removal of trees within areas where the distance to nearest forest from the center of the channel is <500ft (i.e., unforested corridor width ≥1,000ft).

Introduction

The Platte River Recovery Implementation Program (Program) is responsible for implementing certain aspects of the endangered whooping crane (*Grus americana*) recovery plan. More specifically, the Program’s management objective is to contribute to the survival of the whooping crane during migration by increasing and maintaining migratory stopover habitat in the Associated Habitat Reach (AHR) of the Platte River in central Nebraska. 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 one half miles of the river (Figure 1).

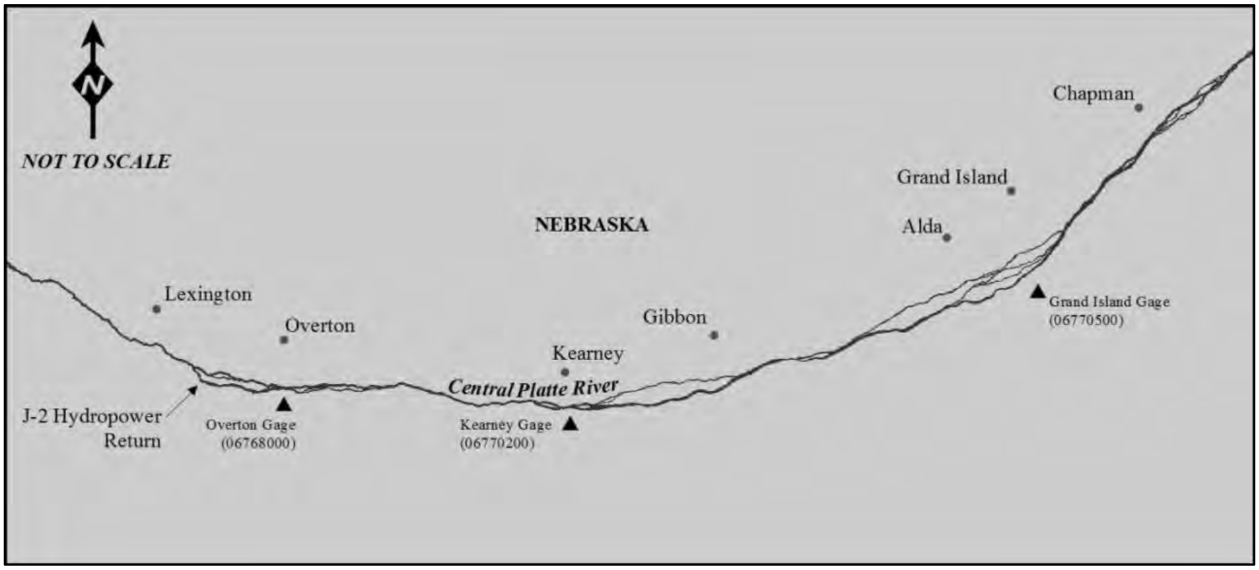

Figure 1. Associated Habitat Reach of the central Platte River extending from Lexington downstream to Chapman, NE.

During the First Increment of the Program (2007-2019), stakeholders committed to working toward this management objective by acquiring and managing 10,000 acres of land and 130,000-150,000 acre-feet of water to benefit target species. However, there has been significant disagreement about species' habitat requirements and the appropriate strategy for managing the Program's land and water resources (Freeman 2010). In order to reach consensus for Program implementation, stakeholders agreed to treat disagreements as uncertainties to be evaluated within an adaptive management framework. The result is an Adaptive Management Plan (AMP) designed to test priority hypotheses including several associated with whooping crane responses to management actions designed to influence river form and habitat (Program 2006).

The whooping crane was listed as a federally endangered species in March 1967, and portions of the central Platte River were designated as critical habitat under the Endangered Species Act in May 1978 (U.S. Fish and Wildlife Service 1978). The National Research Council (2004) supported this critical habitat designation and concluded that current habitat conditions along the central Platte River adversely affect the likelihood of survival and recovery of the whooping crane population. Whooping crane stopovers occur throughout the migration corridor and last from one to several days during migrations that can last several weeks. Possible impacts of water and land development in the migration path has led to concern about the quality and quantity of stopover habitat for roosting and foraging. Along the central Platte River, riverine habitat has by far the highest incidence of stopover use for whooping cranes (Austin and Richert 2001, National Research Council 2004).

This analysis investigates riverine habitat selection by systematically detected unique whooping crane groups during migration stopovers on the central Platte River, fall 2002 – spring 2013. Evaluations of riverine roost site habitat characteristics along the central Platte River have been focused on hydrologic and geomorphic metrics including unobstructed channel widths, distance to obstruction (i.e., nearest forest), view widths, flow, wetted width, suitable depth, etc. (Johnson and Temple 1980; U.S. Fish and Wildlife Service 1981; Johnson 1981; Armbruster 1990; Biology Workgroup 1990; Faanes et al. 1992; Austin and Reichert 2001; National Research Council 2004; Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005, Farmer et al. 2005). We focused the analysis on the description of habitat metrics to facilitate application of Program management activities. The characteristics of in-channel habitat were quantified with three basic sources of information: land cover vector shapefiles, aerial imagery, and the HEC-RAS hydraulic model. Each habitat descriptor was calculated remotely so it will be possible to track and evaluate changes in each measure. The goal of this analysis was to develop habitat models that can inform management using activities the Program is able to implement.

Methods

The study area, the Associated Habitat Reach (AHR), for the Program's monitoring protocol encompasses 3.5 miles on either side of the central Platte River from the junction of US Highway 283 and Interstate 80 (near Lexington, Nebraska to Chapman, Nebraska (Program 2011). Aerial surveys were flown daily during both migration seasons, with the spring time period spanning from March 21 to April 29, and the fall time period spanning from October 9 to November 10. Flights followed the main river channel and took place in the morning intending to locate crane groups before they departed the river to begin foraging at off-channel sites. Return flights were scheduled after the main river channel flight and systematically surveyed upland areas and smaller side channels. A full description of the data collection methods is included in the Program's whooping crane monitoring protocol (Program 2011). In addition to the Program's systematic monitoring data, the U.S. Fish and Wildlife Service (FWS) has maintained a long-term database that includes opportunistic whooping crane sightings throughout the migration corridor.

Whooping Crane Group Observation Data

The basic sample unit for our analyses was a crane group (≥1 whooping crane) location within the study area. The Program's monitoring protocol compiles observations of crane groups in the study area identified with the systematic aerial surveys, follow-up ground monitoring efforts, and opportunistically identified locations from the public and other professional biologists (Program 2011). Analyses presented here only pertain to data collected through systematic aerial surveys and for the first location of a crane group in the area during the migration season (i.e., systematic unique observations). For example, if a crane group is identified multiple times throughout the day or multiple days in a row, only the first detection is included here. The first observation of a crane group was considered "unique", or independent, and subsequent observations were not included to ensure independence of observations. This dataset, and subsequent analysis, was unbiased with respect to reporting of observations by the public.

With the exception of spring 2003, whooping crane migrational habitat use within the AHR has been monitored following the Program's whooping crane monitoring protocol since 2001. There were minor operating procedure changes as a result of evaluations conducted during the early years (e.g., flight height, flight direction), but since the end of 2002 the monitoring protocol has been consistent in the aerial survey methodology. Correspondingly, our analysis excluded crane group observations during 2001 and spring of 2002. Analyses presented here are based on systematically collected unique observations of crane groups observed within the AHR, spring 2001 – spring 2013.

Similar to Program data described above, the FWS database contains information documenting locations of initial sightings of whooping cranes and excludes subsequent locations of use. For this analysis, we only included 'GPS-quality' use sites located within the river channel of the AHR. Many additional entries within the FWS database indicate the whooping crane group was initially spotted within the Platte River, however, the accuracy of the data was not sufficient to identify where the group was located within the channel. It has long been known the FWS database includes observational biases toward areas where birders are most likely to be (FWS unpublished report). Despite this caveat, we evaluated all GPS-quality data within the FWS database that were located in a channel of the Platte River within the AHR.

Parameterization of the A priori Model Set

Characteristics of in-channel habitat were quantified with two basic sources of information: aerial imagery and a HEC-RAS hydraulic model. Aerial photographs were used to determine measures of Unobstructed Channel Width (UOCW), Nearest Forest (NF) and Unforested Channel Width (UFCW; Figure 2).

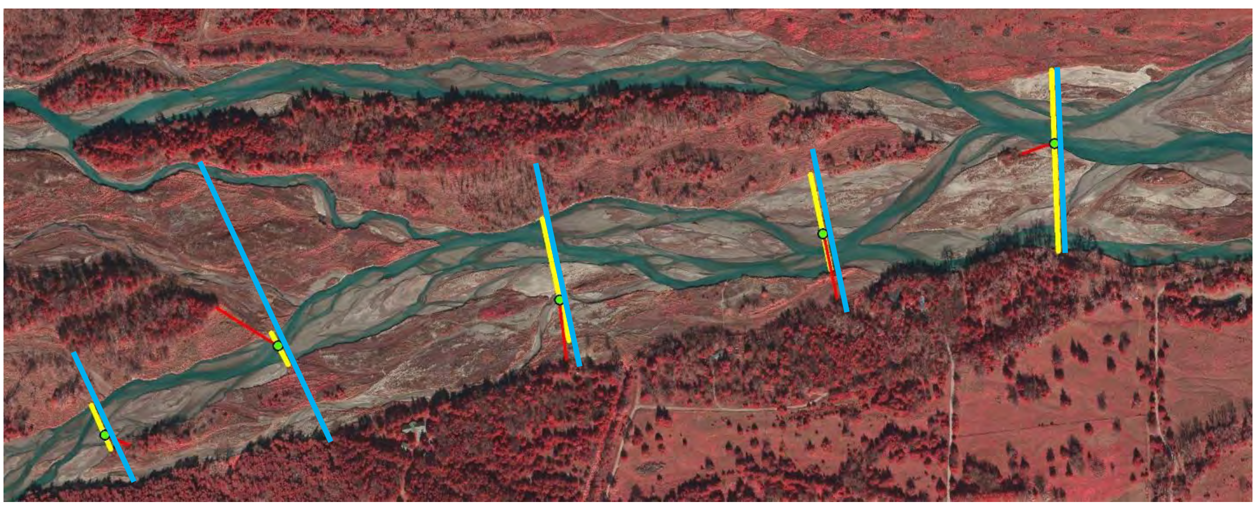

Figure 2. Example of how Unobstructed Channel Width (UOCW; yellow lines), Nearest Forest (NF; red lines) and Unforested Channel Width (UFCW; blue lines) were measured at whooping crane use and available locations.

The Program's HEC-RAS hydraulic model was run to predict Total Channel Width (TCW) and Unit Discharge (UD) metrics for the analysis. The HEC-RAS model was developed primarily using 2009 topography (updated based on 2009 surveyed channel transects and longitudinal profile surveys) and 2005 land use conditions. The model was calibrated based on gaged rating curves, March 2009 inferred water surface elevation from LiDAR data, and 2009 surveyed water surface elevation. Each descriptor of habitat was tested for possible inclusion as a predictor variable in the habitat selection models. The metrics were calculated for the whooping crane use point and the available points in each choice set. Eleven *a priori* candidate models, including a null model, were selected based on variables that could potentially be used by the Program to manage in-channel habitat for whooping cranes (Table 1). Habitat characteristics found to influence use-site selection by whooping cranes within the AHR using the Program's systematic monitoring data were then used to model the FWS data.

Whooping Crane In-channel Habitat Selection

The evaluation of habitat selection by whooping crane groups in the central Platte River was conducted within a resource selection function (RSF) estimation framework. In this model, characteristics of points used by whooping crane groups were contrasted to characteristics of points defined to be available for use by the whooping crane group. The relative difference in the distribution, or density, of these characteristics defines habitat selection. Multiple modelling paradigms were available for this estimation, with recent statistical advances demonstrating spatial point process models are underlying both the use-available approach and the presence-only approach (Johnson et al. 2006, Aarts et al. 2012, McDonald 2013, Warton and Aarts 2013). The use-available approach was chosen for this study because of the presence of existing literature for the handling of an important factor affecting whooping crane selection in AHR: changing availability.

Table 1. In-channel *a priori* model list evaluated for whooping crane habitat use. The interpretation assumes an *a priori* direction (positive or negative) in the relationship between whooping crane habitat use and the covariates, but actual model fit, based on data, could have been in the opposite direction.

Model	*A priori* Models	Interpretation
1	NULL	Habitat selection is random
2	UOCW	Select channels with views unobstructed by dense vegetation or wooded islands.
3	TCW	Select channels with increased distance from right to left bank including vegetated and wooded islands.
4	NF	Select channels with increased 'openness' which includes areas without trees located nearby in any direction.
5	UFCW	Select channels with wide unforested widths.
5	TCW+UOCW	Select channels with views unobstructed by dense vegetation or wooded islands and increased distance from right to left bank that can include vegetated and wooded islands.
6	TCW+UD	Select channels with increased distance from right to left bank including vegetated and wooded islands during times when the amount of flow (cfs) per unit width (ft) of channel provides suitable conditions for use.
7	UOCW+NF	Select channels with views unobstructed by dense vegetation or wooded islands and with increased 'openness' which includes areas without trees located nearby in any direction.
8	TCW+UOCW+UD	Select channels with views unobstructed by dense vegetation or wooded islands and increased distance from right to left bank that can include vegetated and wooded islands during times when the amount of flow (cfs) per unit width of channel (ft) provides suitable conditions for use.
9	TCW+NF+UD	Select channels with increased distance from right to left bank including vegetated and wooded islands with increased 'openness' which includes areas without trees located nearby in any direction.
10	TCW+NF+UOCW	Select channels with increased distance from right to left bank including vegetated and wooded islands, with increased 'openness' which includes areas without trees located nearby in any direction, and with views unobstructed by dense vegetation or wooded islands.
11	TCW+UOCW+NF+UD	Select channels with increased distance from right to left bank including vegetated and wooded islands, with increased 'openness' which includes areas without trees located nearby in any direction, with views unobstructed by dense vegetation or wooded islands and during times when the amount of flow (cfs) per unit width (ft) of channel provides suitable conditions for use.

Analyzing wildlife selection studies with changing availability has been a part of the RSF literature for more than 20 years (Johnson 1980, Arthur et al. 1996, McCracken et al. 1998, Manly et al. 2002, McDonald et al. 2006). Whooping crane use of the Platte River represents a unique situation in that availability of resources change on both spatial and temporal scales. The spatial aspect of changing habitat conditions is chiefly due to the variability in geomorphic channel type throughout the 90 mile AHR and the temporal component is associated with changes in channel form through time. We chose the discrete choice method of RSF estimation to incorporate changing availability at temporal and spatial scales. The discrete choice model accounts for changing habitat conditions in the study area, while modeling the underlying relationships between selection and predictor variables. Non-linear changes in the RSF due to changing availability were handled with penalized regression splines to approximate the functional response (Aarts et al. 2013). With the exception of mixed linear models (Hebblewhite and Merril 2008, Duchesne et al. 2010, Matthiopoulos 2011), other methods of estimating RSF's using the inhomogeneous point process have not incorporated this facet of habitat selection into the statistical underpinnings of the method. It is possible that recent advances in space-time point process models proposed by Johnson *et al.* (2013) may be appropriate for this type of data, but the incorporation of changing availability has not been addressed at this time.

Defining the Available Choice Set

The choice set represents a sample of points from an area the crane group could have selected for use. This distribution is analogous to the background sample in Maxent (Phillips et al. 2006, Phillips and Dudik 2008) and the integration points in point process models (Hefley et al. 2015). In the discrete choice framework, the choice set is unique for each choice, or used location, and is linked to the choice through the likelihood terms in the model. In effect, the model allows the comparison between characteristics of each used location and the characteristics of the choice set. This pairing in the model is accomplished through the use of strata in the gam function (R Core Team, 2013).

As an aerially migrating whooping crane group approaches the river, the options for a stopover location were assumed to be limited by sight to a reduced section of the 90-mile AHR. It is assumed that the entire length of the central Platte is not available to the migrating group, but rather a subsection is evaluated by the whooping crane during the selection process. For our habitat use analysis, the choice set was centered on the use location and extended 10 miles upstream and downstream from that point. It was assumed by Program personnel that cranes could reasonably evaluate this area based on an aerial evaluation of viewsheds from 3,000ft above ground level. There were 20 locations in the choice set for each use location in the model. This description of the choice set had the effect of limiting inference of the in-channel habitat model to areas within 10 miles of selected use locations, but was implemented in order to facilitate the study of habitat selection at the spatial scale of interest.

Functional Response to Resource Selection

We used penalized regression spline methodology to evaluate a functional response in habitat use. Resource selection models evaluate functional responses (i.e., change in selection as a function of spatial or temporal changes in resource availability) and spline smoothers allow for non-linear effects. Smooth spline functions enabled a wide array of functional forms to be incorporated into the RSF, with the implementation of model selection determining the precise shape of the functional response. The smooth term in the habitat model likelihood is represented with a set of basic functions and associated penalties (Hastie and Tibshirani 1990, Wood 2006). The penalty is larger when the smoothing function is very "wiggly" and requires more degrees of freedom. The degrees of freedom for each smooth term is optimized for each iteration when the likelihood is maximized.

Statistical Modeling of Habitat Use/Resource Selection

Resource selection functions were developed to evaluate characteristics of whooping crane habitat selection in the central Platte River. The basic premise of resource selection modeling is that resources (which may be food items, land cover types, or any quantifiable habitat characteristic) that are important to cranes will be "used" disproportionately to the availability of those resources in the environment (Manly et al. 2002). In our analyses, the characteristics at the used locations were contrasted to characteristics at randomly selected "available" locations in the study area.

To model habitat selection, a discrete choice model (Manly et al. 2002) of resource selection was fit to the datasets. This model facilitates modeling habitat selection when the habitat that was available for use changes both temporally and spatially. The model is a multinomial logit model of the form:

$$w(X_{ij}) = \exp(s_1(X_{1ij}) + s_2(X_{2ij}) + \cdots + s_p(X_{pij}))$$

where X_1 to X_p are habitat metrics, j indexes the units in the choice set, and i indexes the unit selected, s_1 to s_p are the smooth functions of X_1 to X_p, respectively. The smooth terms are penalized regression splines, or smooth functions of the predictor variables describing the relationship between selection and the habitat metrics. The incorporation of penalized regression splines (i.e. smooth terms) into the linear predictor of the model is analogous to the parameterization of a generalized additive model (Wood 2006).

The use-availability likelihood was maximized using R statistical software (R Core Team 2013), specifically the gam function of the mgcv package. The mgcv package determines the smoothness of the spline, and associated degrees of freedom, through iteratively re-weighted least squares fitting of the penalized likelihood (Wood 2006). The penalty for the smoothing parameters is determined at each iteration using generalized cross validation (GCV). Final model determination among the set of candidate models was obtained using Akaike's Information Criterion (AIC).

Interpretation of the relationship between covariates in the model and habitat selection was through response functions and the degrees of freedom for the smooth terms. The estimated degrees of freedom indicate the amount of smoothness, with a value of 1 equivalent to a straight line. In cases where the estimated degrees of freedom were 1, we removed the smoothing component for that covariate and fit a parametric straight line. P-values indicating the significance of the smoothed terms were not presented as they are known to reject the null too often when using penalized models (Wood 2006).

Response Functions

After identifying the best fit models, we estimated the predicted relative probability of selection across the range of observed values of the covariates in the models. This analysis provided a graphical display of the modeled relationship between the predictor variables and the response, holding the effects of the other variables in the model constant at the mean. The 95% confidence intervals for the response functions were developed through a bootstrap resampling approach (Manley 1997). The bootstrap approach assumes the variation contained in the dataset is equivalent to the variation contained in the population, and resamples the dataset to get an estimate of this variation. A bootstrap distribution of the predictions was compiled by resampling the input data 1,000 times, fitting the model to get new estimated coefficients and estimating the prediction with each resampled dataset. The confidence interval is obtained by calculating the 2.5 and 97.5 percentiles of the bootstrap distribution of the prediction.

Graphical display of response functions was combined with rug plots to show the underlying data in model fitting. Rug plots display a tick mark for each data point in the model, with used points displayed at the top (use equals 1) and the choice set displayed at the bottom of the figure (use equals 0). The effect resembles that of a shag carpet, or rug. Response functions were scaled to the largest predicted value (maximum equals 1) and only displayed out to the 75th percentile of the use points in order to limit the influence of values from the extreme end of the distribution in the interpretation of the results.

Data Summary

We included the mean and standard deviation of each metric included in the *a priori* model set to provide basic summary statistics for each descriptor of whooping crane habitat. For each predictor variable in the top-ranked in-channel habitat selection model, we developed mirrored histograms to graphically display the Program's systematically collected data. Figures 3 and 4 show the distribution of the values for each variable in order to contrast the distributions of the used set and available set of data. For each probability histogram, the area of the bars sums to one. Although these figures display the relationship between the predictor variables and the outcome (use by whooping cranes), they simplify the assessment by combining data across the many choice sets. Despite this caveat, they are presented to provide a graphical precursor to understanding the statistical models of habitat use.

Results

Program Database - Whooping Crane Habitat Selection

In-channel habitat selection models were developed for the 55 spring and fall systematic and unique whooping crane group observations and the associated 1,060 available points. Mirrored histograms were provided to graphically display the data for each predictor variable in the top- ranked habitat selection model (Figures 3 and 4). These figures show the distribution of the values for each variable in order to contrast this distribution for the used set to the available set. We also provided basic summary statistics for all covariates included in our *a priori* set of models in Table 2.

Statistical modeling of habitat use indicated UOCW and NF were the most important predictors of whooping selection of in-channel habitat (Table 3). In addition, the top model exhibited a lower AIC than the intercept only model, indicating a parsimonious selection of covariates. The smoothing spline functions for each of these variables were positively increasing with larger values of UOCW and NF, indicating a positive relationship between predicted relative probability of use and each variable, as is consistent with expectations. The model results indicate increased UOCW was associated with a higher predicted relative probability of use with the highest values predicted to occur at widths ≥488ft (Figure 5). Increased NF was associated with a higher predicted relative probability of use with the highest values predicted to occur at distances ≥523ft (Figure 6). The estimated degrees of freedom for the smoothed terms were 3.47 for UOCW and 3.69 for NF.

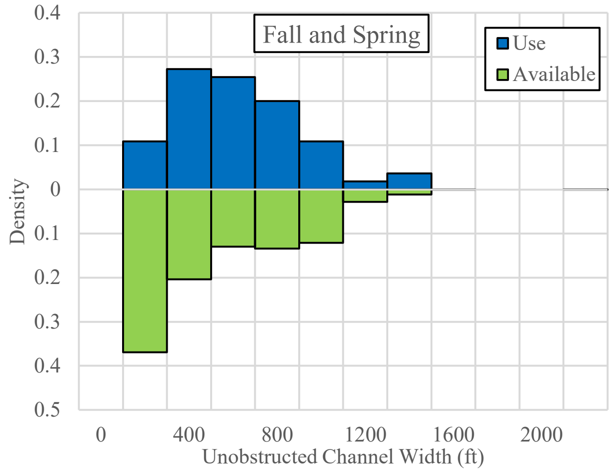

Figure 3. Mirrored histogram to graphically display the distribution of values for unobstructed channel width in order to contrast measurements collected at stopover (blue bars) and choice set or 'available' (green bars) locations. The area of the bars for stopover and available locations each sum to one.

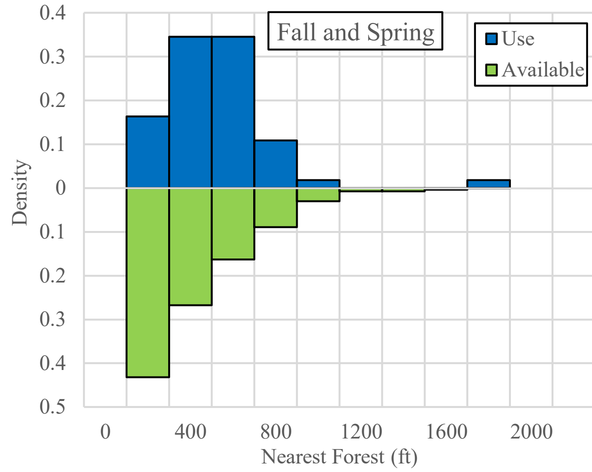

Figure 4. Mirrored histogram to graphically display the distribution of values for distance to nearest forest along a line running perpendicular to the channel in order to contrast measurements collected at stopover (blue bars) and choice set or 'available' (green bars) locations. The area of the bars for stopover and available locations each sum to one.

Table 2. Mean (feet) and standard deviation (in parenthesis) of covariates included in the *a priori* models for whooping crane habitat selection analyses. The mean and standard deviation are provided for spring, fall, and a combination of spring and fall whooping use locations.

Covariate	Abbreviation	Spring Mean (SD)	Fall Mean (SD)	Combined Mean (SD)
Unobstructed Channel Width	UOCW	485 (270)	579 (286)	523 (278)
Unforested Channel Width	UFCW	857 (370)	1,133 (374)	967 (393)
Total Channel Width	TCW	690 (350)	919 (407)	782 (387)
Nearest Forest	NF	386 (308)	470 (175)	419 (265)
Unit Discharge	UD	1.77 (1.39)	1.22 (1.39)	1.55 (1.41)

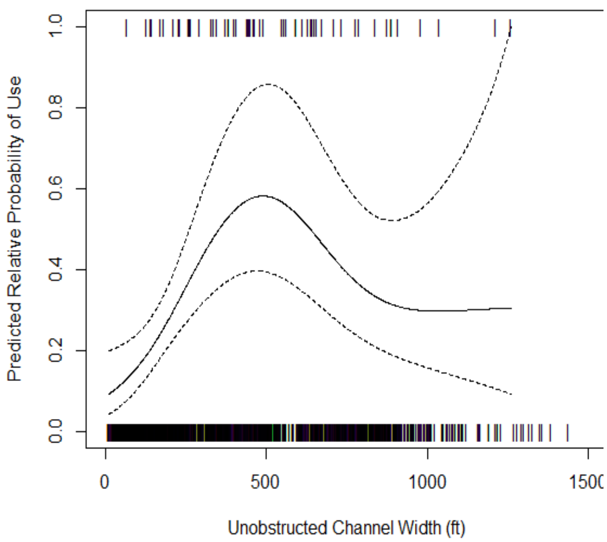

Figure 5. Predicted relative probability of use for the top ranked RSF model, with 90% confidence intervals, of unobstructed channel widths in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1; choice set points are below at y=0). Data is displayed to the 100th percentile of use locations.

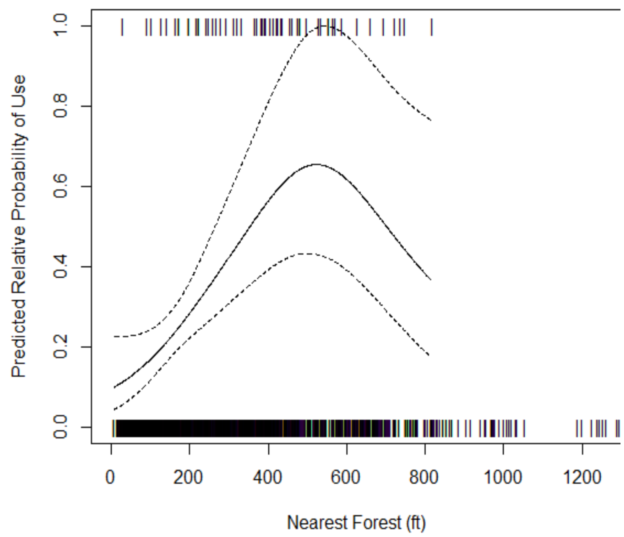

Figure 6. Predicted relative probability of use for the top ranked RSF model, with 90% confidence intervals, of distances to nearest forest in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1; choice set points are below at y=0). Data is displayed to the 98th percentile of use locations to eliminate the influence of a single use location on the extreme right (1,790 ft) of the response function.

Table 3. Top 6 models for in-channel habitat use. The AIC value for the null model was 883.70.

Rank	AIC Value	Covariates
1	862.18	UOCW+NF
2	864.01	UOCW+NF+TCW
3	865.41	UOCW+NF+TCW+UD
4	865.58	NF
5	868.47	UOCW
6	868.94	UFCW

FWS Database - Whooping Crane Habitat Selection

A habitat selection model, including UOCW and NF, was analyzed using 75 GPS-quality whooping crane group observations identified within the FWS database (2001 – 2014) as well as the associated 1,500 available points. The 75 GPS-quality use locations included the 55 locations in the Program's systematic monitoring data as well as 20 additional observations that generally occurred outside the Program's monitoring season or when flights were cancelled due to inclement weather. UOCW averaged 513ft (SD = 289ft; median = 469ft) and NF averaged 435ft (SD = 279ft; median = 406ft). Model results indicate UOCW and NF relationships were similar, but slightly higher than results of models derived from the systematic monitoring dataset. We found the highest probability of use occurred when UOCW was ≥522ft and NF was ≥549ft. The estimated degrees of freedom for the smoothed terms were 3.17 and 3.56, respectively.

Discussion

The use of systematic aerial surveys to detect stopovers of whooping cranes over the course of 11 years provided 55 independent stopover locations and allowed access to a set of data to evaluate whooping crane use of riverine habitat throughout the AHR. Evaluations of riverine roost site habitat characteristics along the central Platte River have largely been focused on geomorphic and, more recently, hydrologic metrics including unobstructed channel width, distance to obstruction (e.g., nearest forest), wetted width, area of suitable depth, and flow (Biology Workgroup 1990; Farmer et al. 2005). Of these, wetted width and area of suitable depth are highly dependent on instantaneous flow and change continuously while, without intervention, other metrics generally change over longer periods of time (i.e., years). Given the relative stability of geomorphic features, we were able to obtain good estimates of UOCW, TCW, and NF remotely. However, the variability in hydrologic metrics such as area of suitable depth and wetted width forced us to use a more stable and estimable measure of flow, unit discharge. Where unit discharge is simply the quotient of two readily available and calculable metrics, flow and channel width, we were able to obtain reasonable estimates of unit discharge within the area and during the timeframe each whooping crane group was observed on the central Platte River.

Past research indicates whooping cranes tend to select roost habitat with increased wetted width and area of suitable depth (Farmer et al. 2005). Unit discharge is related to flow, wetted width, and area of suitable depth in that an increase in unit discharge (increase in flow or decrease in channel width) would generally equate to an increase in wetted width and decrease in area of suitable depth. Given the relatedness (correlation) between these metrics, including unit discharge in our analysis was equivalent to testing each of these metrics at once. Contrary to previous studies on the central Platte River (Biology Workgroup 1990; Farmer et al. 2005), we were unable to establish a strong relationship between unit discharge and whooping crane use as unit discharge was not included in the top four models. However, it may not be appropriate to assume flow metrics are not important to selection of habitat by whooping cranes. Instead, it appears area of suitable depth and wetted width surrounding areas selected by whooping cranes were equally available and potentially adequate at flows observed during times of whooping crane use.

Farmer et al. (2005) reported whooping cranes selected channels with wider unobstructed channel widths at both scales they evaluated. Our results corroborated their finding in that unobstructed channel width influenced stopover site selection by whooping cranes (i.e., use is not random with respect to unobstructed channel width). Contrary to several reports (Johnson and Temple 1980; Lingle et al. 1986; Shenk and Armbruster 1986; Biology Workgroup 1990, Program 2006, Chapter 3), we found whooping crane stopover locations occurred in channels with unobstructed channel widths that averaged 523ft (SD = 278ft; median = 465ft) and the probability of use was maximized at widths ≥488ft. Johnson (1981) described optimal riverine roost habitat as being any channel with an unobstructed width ≥155 meters (509ft) which is similar to our findings. Austin and Reichert (2001) found river widths at stopover roost locations distributed throughout the migration corridor ranged from 76 m (249ft) to 457 m (1,499ft) and averaged 233 m (764ft). Though river widths reported by Austin and Reichert (2001) are wider than unobstructed channel widths we observed within the AHR, discrepancies in these measures could simply be an artifact of biases in the observational data or how each metric was measured (i.e., river width may not be comparable to unobstructed channel width).

Horizontal visibility has long been viewed as an important aspect for defining optimum and secure habitat for whooping crane roosts (Shenk and Armbruster 1986; Armbruster 1990; Farmer et al. 2005). Our results support that characterization as unobstructed channel width and distance to nearest forest were found to be important predictors of whooping roost site selection. With regards to distance to nearest forest, using

Program data we found stopover locations were on average 420ft (SD = 265ft; median = 397ft) from the nearest forest and that probability of use was maximized at distances ≥523ft. When placed in the context of a 488-foot channel, this result is equivalent to having 279ft from the bank line to the nearest forest and an unforested corridor width of 1,046ft. Similarly, using FWS data we found UOCW averaged 513ft (SD = 289ft; median = 496ft) and NF averaged 435ft (SD = 279ft; median = 406ft). We also found probability of use was maximized when UOCW was ≥522ft and NF was ≥549ft which represents an unforested corridor width of 1,098ft.

Though increased unobstructed channel width and distance to nearest forest were important predictors of whooping crane roost site selection, we were unable to establish a strong relationship between UFCW or TCW and whooping crane use. Failure to find a strong relationship between UFCW and whooping crane use is unknown given the similarity between UFCW and the combination of UOCW and NF. We suspect this is related to the fact that several large mid-channel islands are heavily vegetated and have not progressed to the succession stage of mature forest, which decreases the similarity of UFCW and the combination of UOCW and NF in the central Platte River. Failure to find a strong relationship between TCW and whooping crane use is likely related to the fact wider, unmanaged channels on the central Platte River are generally split by one or more densely vegetated or wooded islands which reduces distance to forest and unobstructed channel width. As such, we assume if such an effect did exist in the data the relationship would have been the shape of a quadratic term with a negative coefficient (i.e., TCW would increase until probability of use was maximized and then decrease).

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CHAPTER 3 – Whooping Crane Use of Riverine Stopover Sites within the North-central Great Plains

Abstract

Although whooping cranes are known to use riverine roost sites throughout the migration corridor, few studies have attempted to evaluate habitat selection at riverine roost sites across multiple river systems. An important aspect of whooping crane roosts along their migration route is the amount of unobstructed visibility provided by stopover sites. Whooping cranes have been reported to select stopover locations based on the security offered by the site. One such form of security offered by riverine sites is the presence of water surrounding the roost. Another factor that is generally believed to enhance site security is wide open views not obstructed by dense, tall vegetation or wooded areas. We used telemetry data obtained from a sample of 68 birds of all ages over the course of five years to provide an unbiased evaluation of whooping crane use of riverine habitat throughout the migration corridor. We evaluated the influence of unobstructed channel width and distance to nearest forest on whooping crane selection of riverine habitat throughout the North-central Great Plains in the United States. Our results indicate probability of selection was maximized when unobstructed channel widths were ≥739ft and when distance to nearest forest from the edge of the channel along a line running perpendicular to the channel was ≥190ft. Based on results of Chapters 2 and 3, it appears maintaining unobstructed channel widths of 600 – 650ft and unforested widths of 200 – 250ft along the edges of the channel would result in highly favorable whooping crane riverine roosting habitat.

Introduction

The Platte River Recovery Implementation Program (Program) is responsible for implementing certain aspects of the endangered whooping crane (*Grus americana*) recovery plan. More specifically, the Program's management objective is to contribute to the survival of the whooping crane during migration by increasing and maintaining migratory stopover habitat in the Associated Habitat Reach (AHR) of the Platte River in central Nebraska. 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 one half miles of the river (Figure 1).

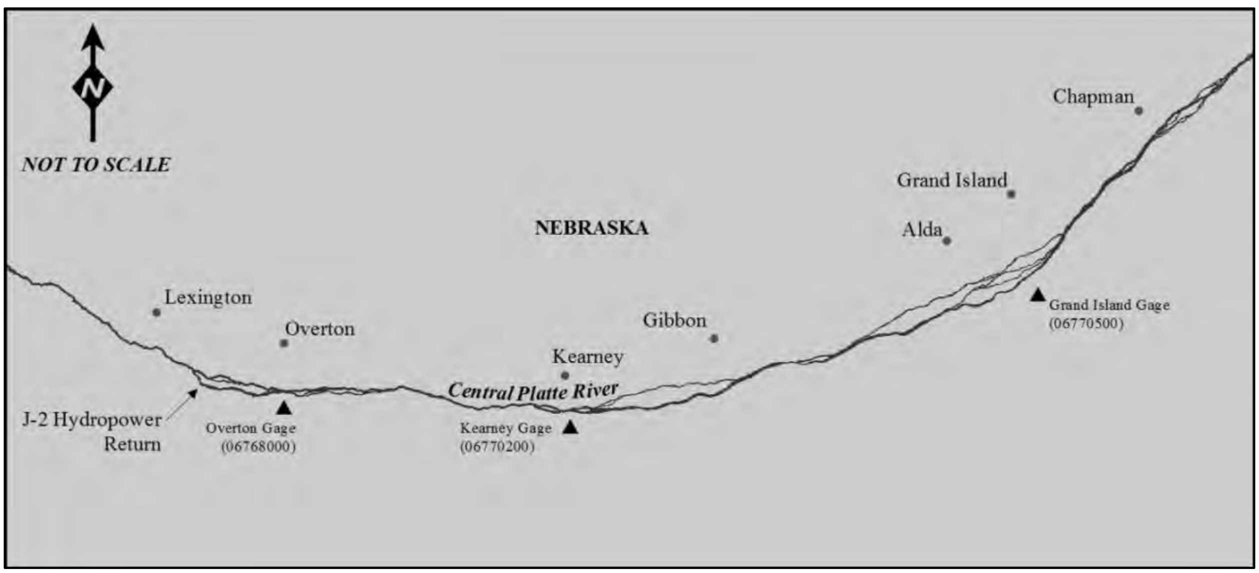

Figure 1. Associated Habitat Reach of the central Platte River extending from Lexington downstream to Chapman, NE.

During the First Increment of the Program (2007-2019), stakeholders committed to working toward this management objective by acquiring and managing 10,000 acres of land and 130,000-150,000 acre-ft of water to benefit target species. However, there has been significant disagreement about species' habitat requirements and the appropriate strategy for managing the Program's land and water resources (Freeman 2010). In order to reach consensus for Program implementation, stakeholders agreed to treat disagreements as uncertainties to be evaluated within an adaptive management framework. The result is an Adaptive

Management Plan (AMP) designed to test priority hypotheses including several associated with whooping crane responses to management actions designed to influence river form and habitat (Program 2006).

Each year, the Aransas–Wood Buffalo (AWB) population of whooping cranes undertakes a 5,000-mile round-trip migration from the breeding area in and near Wood Buffalo National Park in Northern Canada to the wintering area in and around Aransas National Wildlife Area on the gulf coast of Texas. The migration route is well defined and the vast majority of observations occur within a 200-mile wide corridor through Alberta, Saskatchewan, Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. During migration, whooping cranes utilize stopover sites to rest and build energy reserves to complete migration. Although a variety of habitats are used during migration, water is nearly always associated with a stopover site. At stopover sites, whooping cranes typically roost standing in shallow water associated with palustrine or lacustrine wetlands and river channels.

Some stopover sites in the migration corridor are used consistently and receive relatively high annual use. One of these sites, the Big Bend reach of the Platte River central Nebraska, is the only stretch of river designated as critical whooping crane habitat under the Endangered Species Act (Armbruster 1990; Biology Workgroup 1990). Characteristics of central Platte River roost habitat have been examined and described in detail (Johnson 1981; Lingle et al. 1984; Ziewitz 1987; Faanes 1988; Faanes and Bowman 1992; Faanes et al. 1992). Early examinations of roost sites in the central Platte River identified wide, unvegetated channels and open visibility with the absence of tall trees or dense shrubs near the roost as important habitat characteristics (Johnson and Temple 1980; U.S. Fish and Wildlife Service 1981; Johnson 1981; Ziewitz 1987; Armbruster 1990; Faanes et al. 1992; Austin and Reichert 2001; National Research Council 2004). Recent Program analyses of central Platte River whooping crane use locations during the period of 2002-2013 found the width of channel unobstructed by dense vegetation and the distance to nearest forest to be important predictors of whooping crane use (Chapter 2). Ziewitz (1987) described whooping roosting habitat suitability using several parameters including unobstructed channel width. In this assessment, unobstructed channels ≤500ft wide were assigned a minimum suitability value while unobstructed channel widths ≥1,150 were assigned a maximum suitability value. Table 1 of the Program's land plan infers whooping crane habitat suitability and use are maximized at 1,150ft (Program 2006). Contrary to Ziewitz (1987) and Table 1 of the Program's Land Plan (Program 2006), Austin and Reichert (2005) reported unobstructed channel widths at riverine roost sites averaged 233 meters (764ft) and Johnson (1981) described optimal riverine roost habitat as being and any channel with an unobstructed width ≥155 meters (509ft). Pitts (1985) even went so far as to report whooping crane selection of stopover habitat occurs at random.

Although whooping cranes are known to use riverine roost sites throughout the migration corridor, few studies have attempted to evaluate selection of riverine roost sites across multiple river systems (Stahlecker 1997; Austin and Reichert 2005). The objective of this investigation is to assess if and how unobstructed channel width or distance to nearest forest (distance along a line running perpendicular to the channel from the edge of channel to the nearest wooded area) influence whooping crane selection of riverine habitat throughout the North-central Great Plains in the United States. Results of this investigation provide an additional line of evidence regarding the importance of these habitat metrics in whooping crane roost site selection as well as an opportunity to compare habitat use along the central Platte River to riverine use throughout the migration corridor.

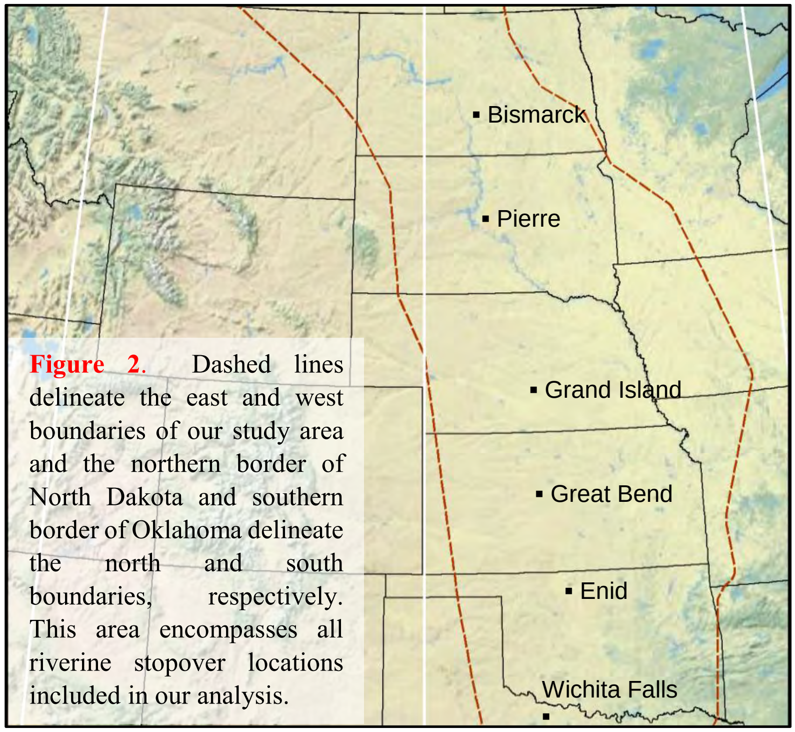

Figure 2. Dashed lines delineate the east and west boundaries of our study area and the northern border of North Dakota and southern border of Oklahoma delineate the north and south boundaries, respectively. This area encompasses all riverine stopover locations included in our analysis.

Methods

Our study area included the migration corridor for the Aransas-Wood Buffalo population within North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma (Figure 2). Locational data (henceforth, telemetry data) generated from 68 GPS-marked whooping cranes (2010-2014) was filtered to only include stopover (use) locations that occurred in riverine habitat within the study area. The data was further filtered to only include a single location per whooping crane per stopover location. When >1 radio-marked whooping crane was present at a stopover at the same time, we included a use location for each bird present at the stopover site. We defined stopover locations as sites used as a roost for ≥1 night.

Defining the Choice Set

A National Operational Hydrologic Remote Sensing Center river segment shapefile was used to identify all river systems within our study area. A 10-mile radius buffer was generated around each stopover location and the buffers were used to clip the river shapefile into individual segments associated with each stopover location. Hawth's Tools (Jenness 2011) was then used to generate 20 available locations per stopover location along each river segment. The points were stratified so each stopover location was paired with 20 available locations in the same river segment as the stopover location. It was assumed the cranes could reasonably evaluate this area based on an aerial evaluation of viewsheds from 3,000ft above ground level by Program personnel.

Parameterization of the A priori Model set

A GIS and Environmental Systems Research Institute's (ESRI) World Imagery was used to delineate the unobstructed width of the channel along a line running perpendicular to the channel and through each stopover and available location. When locations generated along the river system shapefile did not fall within the channel in aerial imagery, they were relocated to the channel along a line running perpendicular to flow. Unobstructed channel width was defined as the width of channel lacking dense vegetation as observed in ESRI World Imagery. When channels were segmented by a densely vegetated island, unobstructed channel width was delineated based on the channel segment nearest the stopover or available location. Nearest forest was defined in Chapter 3 as the distance from the edge of the channel to the nearest forest along a line running perpendicular to the channel. The difference in methodology was required because annual delineations of river-channel bank lines for river systems throughout the migration corridor are not available except for within the Program Associated Habitat (AHR) of the central Platte River. This caveat required us to measure distance to nearest forest from the edge of the channel as we could not generate random locations within the channel banks as was done in Chapter 2. Distance to nearest forest was truncated at 1,320ft (1/4 mile) when no forested area was located within a quarter mile of the edge of channel. Hawth's Tools (Jenness 2011) was used to calculate the length of each unobstructed channel width and perpendicular distance from the edge of channel to the nearest forest delineation.

A list of 3 candidate models was developed, each containing a different combination of covariates. This set of models, with the inclusion of a null model containing no covariates, composed the complete set of *a priori* models evaluated (Table 1). The model selection process determined which *a priori* model was most parsimonious and useful in predicting habitat use with the Akaike Information Criterion statistic (AIC, Burnham and Anderson 2002). The model in the *a priori* list with the lowest AIC value was used to infer conclusions about habitat use.

Statistical Modeling of Habitat Use/Selection

Methods and procedures used to model habitat selection throughout the North-central Great Plains were identical to those presented in Chapter 2 with the exception that nearest forest (NF) was calculated as the perpendicular distance from the edge of channel to the nearest forest along a line running perpendicular to the channel as described above.

Results

The use of telemetry data obtained from a sample of 68 birds of all ages over the course of five years provided 158 independent stopover locations. Measurements at these 158 riverine stopover ('use') locations and 3,160 available locations were obtained and incorporated into the habitat use analysis. Though highly variable, mean unobstructed channel width and distance from edge of channel to nearest forest along a line running perpendicular to the channel were wider at stopover locations than available locations for each metric (Table 2). Median unobstructed channel width was 549ft at stopover locations and 441ft at available locations. Median distance from edge of channel to nearest forest along a line running perpendicular to the channel was 130ft at stopover locations and 79ft at available locations.

Table 1. *A priori* model set tested in the use-availability habitat selection analysis.

Covariate	Definition of Model Terms
Null	No covariate (use is random)
UOCW	Unobstructed channel width
NF	Distance from the edge of channel to nearest forest along a line perpendicular to the channel and maximized at 1,320ft
UOCW+NF	Unobstructed channel width plus distance from the edge of channel to nearest forest along a line perpendicular to the channel and maximized at 1,320ft

Table 2. Mean unobstructed channel widths and distance from edge of channel to nearest forest along a line running perpendicular to the channel. Standard deviations are provided in parentheses. See Table 1 for a description of metrics.

Metric	Mean Width At Stopover Locations (SD)	Mean Width At Available Locations (SD)
UOCW	708 (596)	567 (517)
NF	366 (467)	301 (431)

Mirrored histograms were prepared for each predictor in the top model (Table 3) to graphically display the data (Figures 3 and 4). These figures show the distribution of the values for each variable in order to contrast this distribution for the stopover sites to the available sites. For each probability histogram, the area of the bars sums to one. Although these figures display the relationship between the predictor variables and the outcome (use by whooping cranes), they simplify the assessment by combining data across the many choice sets.

Statistical modeling of habitat use indicated unobstructed channel width (UOCW) and distance from edge of channel to nearest forest along a line perpendicular to the channel (NF) were both important predictor variables (Table 2). The smoothing spline functions for each of these variables were positively increasing with larger values of UOCW and NF, indicating a positive relationship between predicted relative probability of use and each variable. Model results indicate increased UOCW was associated with a higher predicted relative probability of use with the highest value predicted to occur when UOCW was ≥739ft (Figure 5). Increased NF was associated with a higher predicted relative probability of use with the highest value predicted to occur when NF was ≥190ft (Figure 6). The response functions for UOCW and NF were scaled to the largest predicted value (maximum equals 1). Unobstructed channel width and NF were only displayed out to the 75th percentile of the stopover locations in order to limit the influence of values from the extreme end of the distribution (Figures 5 and 6).

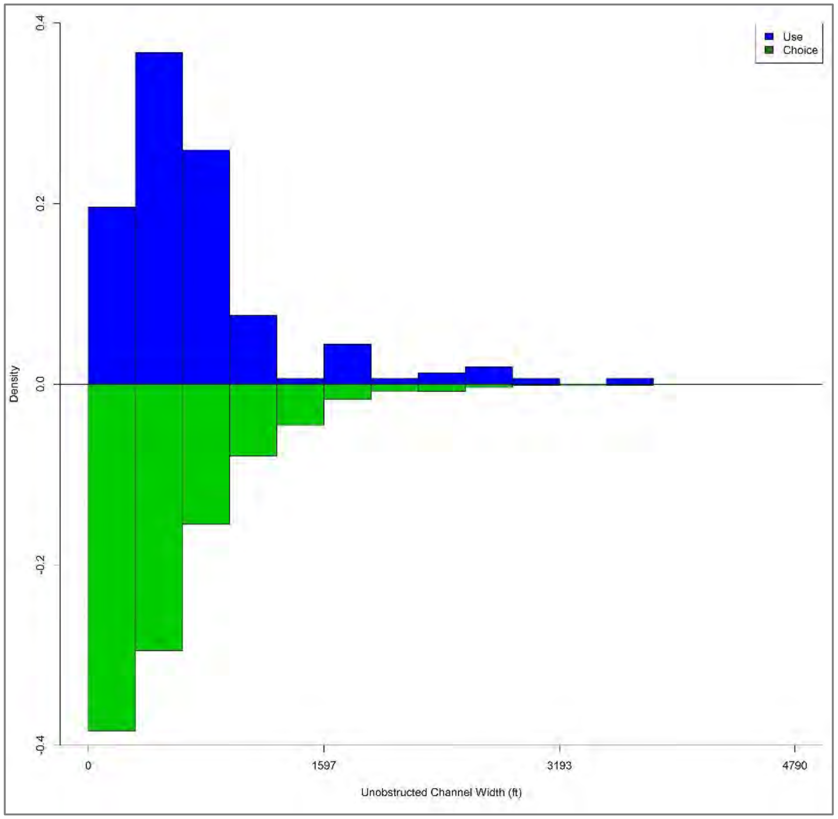

Figure 3. Mirrored histogram to graphically display the distribution of values for unobstructed channel width in order to contrast measurements collected at stopover (blue bars) and available (green bars) locations. The area of the bars for stopover and available locations each sum to one.

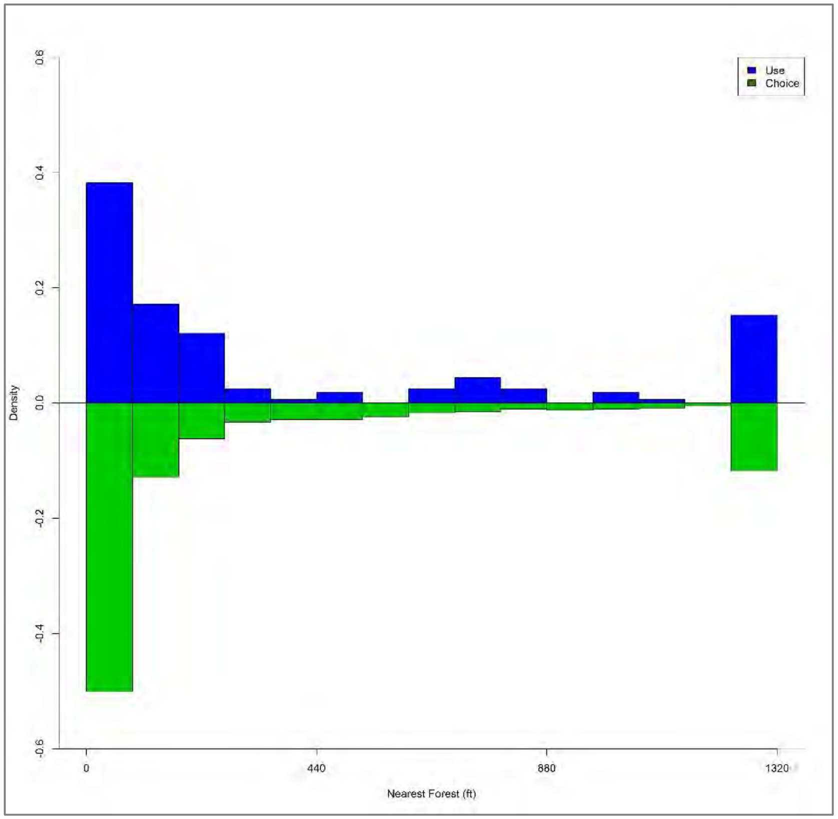

Figure 4. Mirrored histogram to graphically display the distribution of values for distance from the edge of channel to nearest forest, maximized at 1,320ft, along a line running perpendicular to the channel in order to contrast measurements collected at stopover (blue bars) and available (green bars) locations. The area of the bars for stopover and available locations each sum to one.

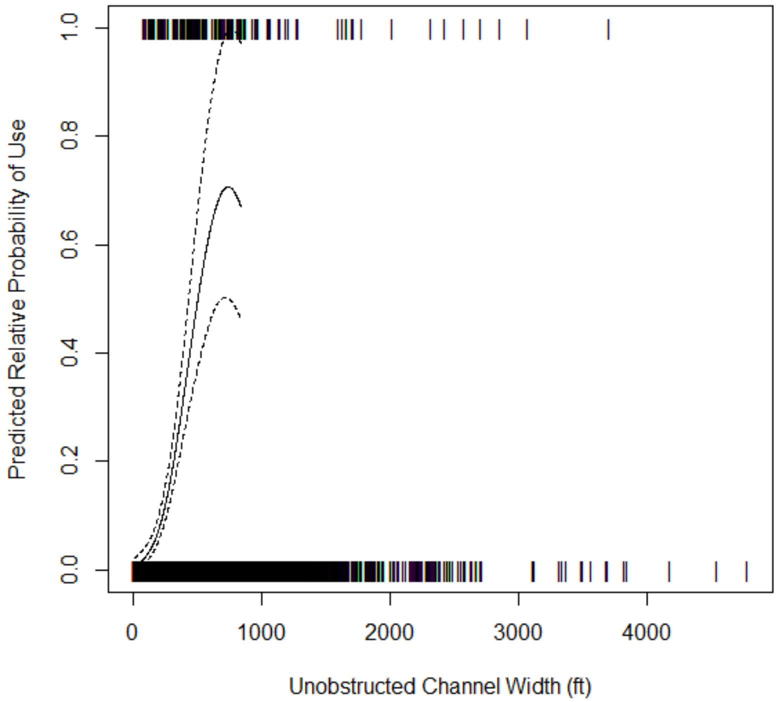

Figure 5. Predicted relative probability of use, with 90% confidence intervals, across the range of unobstructed channel widths. The response function was scaled to the largest predicted value (maximum equals 1) and is only displayed out to the 75th percentile of the stopover locations in order to limit the influence of values from the extreme end of the distribution in the interpretation of the results. The probability of use is maximized when unobstructed channel width is ≥739ft. Tick marks indicate actual data (use locations are at y=1, available locations are at y=0).

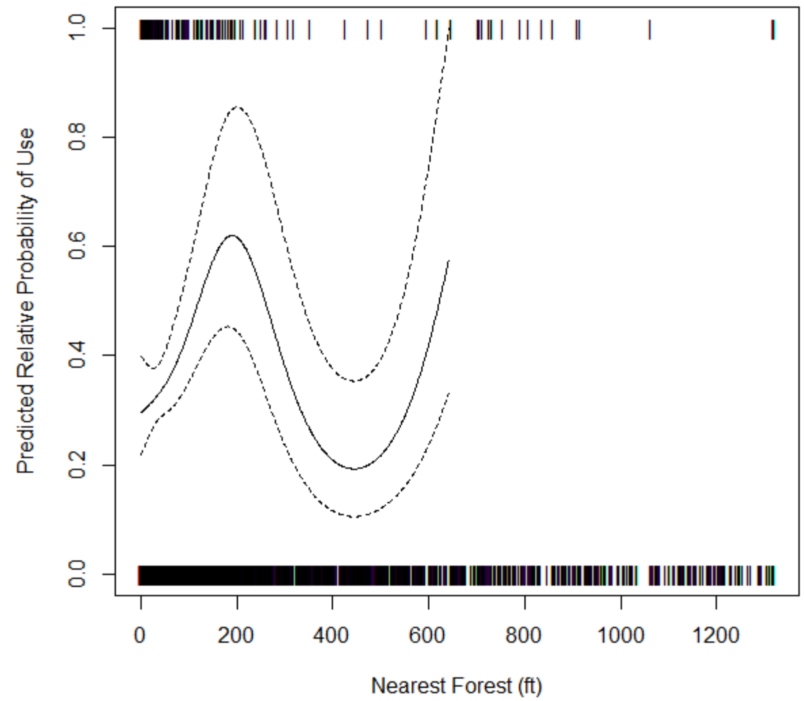

Figure 6. Predicted relative probability of use, with 90% confidence intervals, across the range of distance from the edge of channel to nearest forest along a line running perpendicular to the channel. The response function was scaled to the largest predicted value (maximum equals 1) and is only displayed out to the 75th percentile of the stopover locations in order to limit the influence of values from the extreme end of the distribution in the interpretation of the results. The probability of use is maximized when NF is ≥190ft. Tick marks indicate actual data (use locations are at y=1, available locations are at y=0).

Table 3. Models used in our habitat selection analysis ranked by AIC statistic. See Table 1 for a description of the metrics.

Rank	Covariates	AIC	ΔAIC
1	s(UOCW) + s(NF)	2,798	0
2	s(UOCW)	2,807	9
3	s(NF)	2,857	59
4	NULL	2,876	78

Discussion

Several studies have characterized habitat use by whooping cranes using the U.S. Fish and Wildlife Service's opportunistic sightings database (Austin and Reichert 2005; Faanes et al. 1992; Belaire et al. 2013; Hefley et al. 2015). These characterizations, however, are influenced by sampling bias, detection bias, and location error (Hefley et al. 2015). The use of telemetry data obtained from a sample of 68 birds of all ages over the course of five years provided 158 independent stopover locations and allowed access to a substantial set of unbiased data to evaluate whooping crane use of riverine habitat throughout the migration corridor.

An important aspect of the ecology of whooping cranes using roosts along their migration route is the amount of unobstructed visibility provided by stopover sites. Whooping cranes select stopover locations based on the security offered by the site (Ward and Anderson 1987). One such form of security offered by riverine sites is the presence of water surrounding the roost. Water provides a sense of security and enables whooping cranes to hear potential predators as they approach (Ward and Anderson 1987). Another factor generally believed to enhance site security is wide open views not obstructed by dense, tall vegetation or wooded areas. Riverine habitat provides this security with the presence of wide unobstructed widths.

Whooping crane riverine roost sites and day-use sites tend to consistently lack vegetation (Austin and Reichert 2005). Johnson and Temple (1980) reported that throughout the whooping crane's range, unobstructed bank to bank visibility at riverine roost sites was at least 656ft (200 m). Lingle et al. (1984) reported that a Platte River roost site near Prosser, Nebraska, had an unobstructed bank to bank distance of

1,145ft (349 m). Estimates derived by a Biology Ad Hoc Workgroup suggested habitat selection was optimized at unobstructed channel widths of 1,312ft (400 m; Shenk and Armbruster 1986). Subsequent analyses of unobstructed channel width at whooping crane roosts through the spring 1987 migration period ranged from 699ft (213 m) to 1,207ft (368 m; U.S. Fish & Wildlife Service, unpublished data). Although observed stopovers did occur in unobstructed channels of these widths, >50% of stopovers along the migration route were in channels with unobstructed widths that were <550ft. Lingle et al. (1986) suggested whooping cranes choose the widest available sites, but our results do not support that assessment. Though whooping cranes appear to select moderately wide channels, the widest part of the channel generally was not selected and probability of selection was maximized when unobstructed channel widths were ≥739ft.

Whooping crane stopover locations were located in channels with unobstructed widths ranging from 84 to 3,710ft and averaged 708ft (median = 549ft). Johnson and Temple (1980) proposed a minimum suitability criterion for channel width of 180ft (55 m). The narrowest observed unobstructed channel width at stopover locations within the migration corridor was 84ft (26 m), which is slightly narrower than their recommendation. Similarly, Austin and Reichert (2005) found river widths at stopover roost locations ranged from 249ft (76 m) to 1,499ft (457 m) and averaged 764ft (233 m). Telemetry data results are also similar to the 712 foot (217 m) mean unobstructed channel width observed at roost sites on the Platte River (Faanes et al. 1992) and corroborate findings of Johnson (1982) in that >60% of stopover locations were in channels with an unobstructed width >443ft (135 m).

Whooping cranes roosting in the Platte River have been noted to select sites with broad channels free of woody vegetation and with adequate horizontal and overhead visibility (U.S. Fish and Wildlife Service 1981). However, it has also been reported that banks and vegetation that form a visual obstruction may actually enhance their security, as long as they are not too close to the cranes (Faanes et al. 1992). Austin and Reichert (2005) reported >70% of roost sites were adjacent to woodland habitat. To some degree the results of this study support both of these positions. For use locations, the median distance between the edge of channel and nearest forest along a line perpendicular to the channel was 130ft (range = 0ft – >5,280ft) and the relative probability of use was maximized when the distance to nearest forest was ≥190ft.

Probability of whooping crane use along the central Platte River for systematic, unique observations of whooping cranes was maximized in channels with unobstructed channel widths ≥488ft and distances to nearest forest from the center of the channel ≥523ft (Chapter 2). When considering whooping crane use of riverine habitat between the borders of Canada and Texas, probability of use was maximized when unobstructed channel widths were ≥739ft and at distances ≥190ft from the edge of the channel to the nearest forest along a line perpendicular to the channel. We feel the 200+ foot difference between unobstructed channel widths selected throughout the migration corridor and within the AHR may simply be the result of overall channel widths throughout the Great Plains are simply wider than the AHR. Throughout their migration range, including the AHR, it appears whooping cranes select channels that are moderately wide, but not necessarily the widest stretch of river available within 10 miles of each stopover site.

Initially, optimization of unobstructed channel width and unforested width measures seem disparate, however, when differences in the way distance to nearest forest was calculated on the central Platte River (from the locations to nearest forest) and throughout the migration corridor (from the edge of channel to nearest forest) are accounted for, direct comparisons of the measures reveal the unforested corridor width along channels were nearly identical. When measured from the center (average location of use and available points) of a 509-foot channel on the central Platte River, a distance to nearest forest of 520ft would be equivalent to an unforested corridor width along the channel of 1,040ft as compared to a 1,119 foot unforested corridor width within the North-central Great Plains. Given results of analyses described in Chapters 2 and 3, it appears maintaining unobstructed channel widths ranging from 600 – 650ft and unforested widths along the edge of the channel of 200 – 250ft would result in highly favorable whooping crane riverine roosting habitat.

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CHAPTER 4 – Central Platte River Unvegetated Width Relations to Hydrology, Channel Morphology and Management Actions: Implications for the Flow-Sediment-Mechanical Strategy

Abstract

The Flow-Sediment-Mechanical (FSM) approach is one of two management strategies presented in the Platte River Recovery Implementation Program's (Program) Adaptive Management Plan (AMP) to create and maintain suitable riverine habitat for whooping cranes. The Program's FSM management strategy consists of sediment augmentation, mechanical vegetation clearing and channel widening, and short duration high flow (SDHF) releases of 5,000 to 8,000 cfs for three days in two out of three years to increase the unvegetated width of the main channel and, by extension, maintain suitable habitat for whooping crane use. We examined the influence of a range of hydrologic and physical metrics on UOCW and TUCW during the period of 2007 through 2015 and applied those findings to assess the performance of the FSM management strategy. A strong positive relationship was identified between peak flows and TUCW and UOCW in the AHR. However, peak discharge magnitude and durations that create highly favorable whooping crane roosting habitat are much greater than SDHF releases, as currently envisioned. The analysis also indicates channel disking in combination with herbicide application would be effective in creating and maintaining highly favorable roosting habitat for whooping cranes in all but the very driest years.

Introduction

The Platte River Recovery Implementation Program's (Program) whooping crane management objective is to contribute to improved whooping crane survival during migration. The primary management sub-objective is to increase the availability of whooping crane migration habitat along the Associated Habitat Reach (AHR) of the central Platte River that extends approximately 90 miles from Lexington, NE downstream to Chapman, NE. Performance indicators include area of suitable roosting habitat, area of suitable foraging habitat, proportion of the population using the AHR during each migration season, and the number of days that cranes use the AHR (crane use days) during each migration season (Program 2006).

Whooping Crane Habitat Suitability and Use

The Program's whooping crane management objectives and indicators focus on habitat and use metrics (as opposed to population) due to the small proportion of the whooping crane population that uses the AHR in any given year (~5-10%) and the limited amount of time individual birds spend in the area (~two to three days on average). Investigations of whooping habitat use along the central Platte River have been ongoing since the late 1970s and have focused on a range of hydrologic and geomorphic metrics including unobstructed channel widths, distance to obstruction (i.e., nearest forest), view widths, flow, wetted width, suitable depth, etc. (Johnson and Temple 1980; U.S. Fish and Wildlife Service 1981; Johnson 1981; Armbruster 1990; Biology Workgroup 1990; Faanes et al. 1992; Austin and Reichert 2001; National Research Council 2004; Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005, Farmer et al. 2005).

In 2015, Program monitoring and satellite telemetry data was used to perform whooping crane habitat selection analyses in the AHR (Chapter 2) and at riverine stopover sites throughout the migration corridor (Chapter 3). Those investigations, which included a variety of hydrologic and geomorphic habitat metrics, suggest riverine habitat use by whooping cranes increases with increased width of channel unobstructed by dense vegetation (UOCW) and increased unforested width. Systematic AHR monitoring indicates the probability of whooping crane use of the central Platte River is maximized when UOCW reaches 488 ft and unforested corridor width reaches 1,011 ft (Chapter 2). Migration corridor-wide telemetry data indicates the probability of selection of riverine habitat is maximized when UOCW reaches 739 ft and unforested corridor width reaches 1,119 ft.

It is important to note that many definitions for channel width have been used in past reports. For example, channel width has been defined as the width of channel from outer bank to outer bank (Faanes et al. 1992; Shenk and Armbruster 1986), water edge to water edge (Shenk and Armbruster 1986), unforested channel width (USFWS 1987; Ziewitz 1992), unobstructed channel width in 4 cardinal directions (Faanes 1992), unobstructed width of channel (Lingle et al. 1984 and 1986; Shenk and Armbruster 1986; Biology Workgroup 1990; Johnson and Temple 1980), and generically as river width (Austin and Reichert 2005). The Program habitat selection analysis in Chapter 2 included metrics that described total bank-to-bank width, wetted width, unobstructed width, and unforested width of the channel. However, only unobstructed and unforested widths were found to be important predictors of whooping crane use.

Program Management Actions to Improve Whooping Crane Habitat Suitability

The Flow-Sediment-Mechanical (FSM) approach is one of two management strategies presented in the Program's Adaptive Management Plan (AMP) to create and maintain suitable riverine habitat for whooping cranes. The FSM strategy focuses on flow, sediment, and mechanical management actions. Proposed actions include:

1) vegetation clearing and channel widening (Mechanical),
2) offsetting the average annual sediment deficit of approximately 150,000 tons in the west half of the AHR through augmentation of sand (Sediment), and
3) implementation of short-duration high flows (SDHF) of 5,000 – 8,000 cfs for three days (Flow) in two out of three years to scour vegetation and maintain wide unobstructed channels.

These management actions are hypothesized to be sufficient to increase the unvegetated width of the main channel (Figure 1) and, by extension, increase channel suitability for whooping crane use. The mechanical component of the FSM management strategy has been employed in the AHR by various conservation organizations since the 1980s. Sand augmentation (sediment component) has been ongoing at varying levels since 2006. Implementation of SDHF releases has been limited by flow conveyance issues upstream of the AHR but natural high flow events during the period of 2007-2014 have provided natural peak flows in excess of what the Program could produce at full FSM implementation. Each component of the FSM is discussed in greater detail in the following sections.

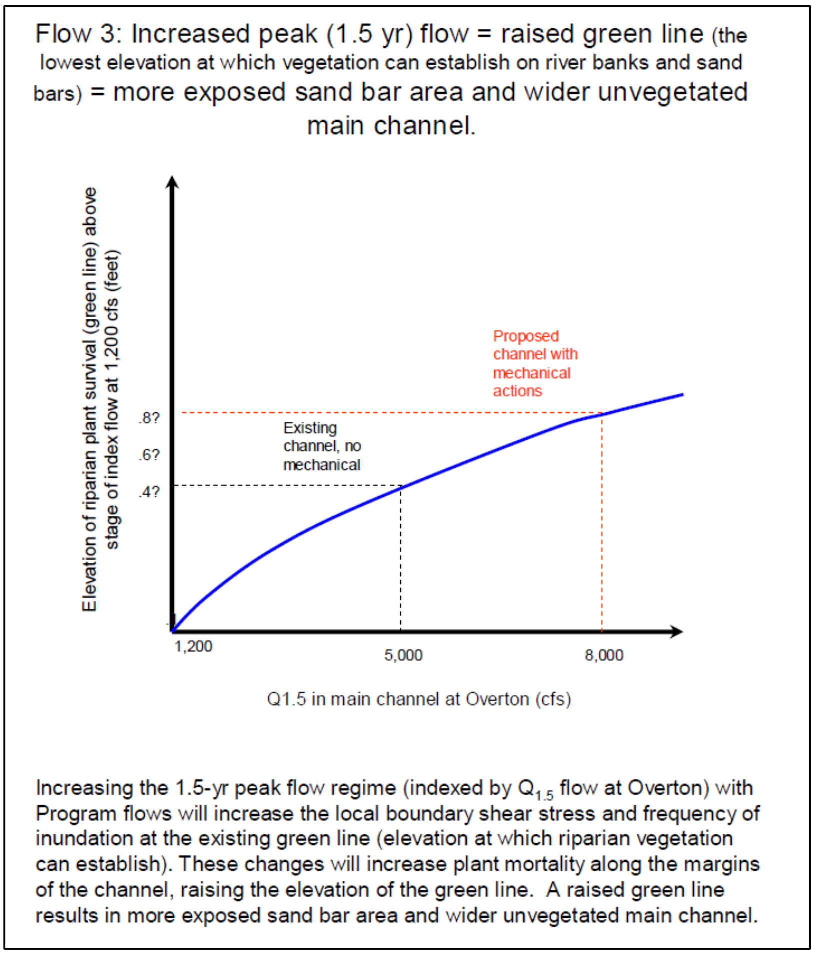

Figure 1. Program priority hypothesis Flow 3 which hypothesizes flows of 5,000 to 8,000 cfs will increase the elevation at which riparian vegetation can establish and will increase the unvegetated width of the main channel.

Mechanical

Overall, conservation organizations own over 30,000 acres in the AHR and have at least partial management control of the channel in approximately 47% of the reach. These organizations have been clearing in-channel vegetation and widening channels since the 1980s in an effort to increase channel width and prevent woody vegetation from establishing in the channel. Since Program inception in 2007, mechanical in-channel vegetation control efforts have included disking to clear islands, bank line disking and other mechanical actions to widen channels. These actions have been implemented by the USFWS Partners for Fish and Wildlife, The Crane Trust, The Nature Conservancy, Audubon Society, Nebraska Public Power District (NPPD), Central Nebraska Public Power and Irrigation District (CNPPID), and the Program. Mechanical channel maintenance activities are ongoing in nine out of 12 bridge segments in the AHR (Table 1).

Table 1. Mechanical management actions undertaken by various entities since Program inception in 2007.

Bridge Segment	Length Managed (mi)	Mechanical Management Actions
Lexington to Overton	9.0	Vegetation removal from banks and islands, channel disking
Overton to Elm Creek	4.0	Vegetation removal from banks and islands, island leveling, channel widening, channel disking
Elm Creek to Odessa	4.0	Vegetation removal from banks and islands, island leveling, channel disking
Odessa to Kearney	0.0	
Kearney to Minden	4.7	Vegetation removal from banks and islands, channel disking
Minden to Gibbon	5.5	Vegetation removal from banks and islands, island leveling, channel disking
Gibbon to Shelton	1.7	Vegetation removal from banks and islands, channel disking
Shelton to Wood River	2.5	Vegetation removal from banks and islands, channel disking
Wood River to Alda	4.0	Vegetation removal from islands, island leveling, channel disking
Alda to Hwy 281	6.5	Vegetation removal from banks and islands, channel disking
Hwy 281 to Hwy 34	0.0	
Hwy 34 to Chapman	0.0	
TOTAL	41.9	

Though not originally included in the FSM management strategy, reach-wide herbicide application has also become an important tool to eradicate and/or control the spread of common reed (*phragmites australis)* during the period of 2008-2014. The spraying program has included aerial and ground application of herbicide to all common reed infestations detected in the channel (Craig 2011). In excess of 15,000 acres have been sprayed in the AHR since the initiation of control efforts.

Sediment

The sediment component of the FSM strategy involves mechanical sand augmentation at the upstream end of the AHR to offset a sediment deficit from clear water hydropower returns at the J-2 return facility near Lexington, NE (Figure 2). The average annual sediment deficit is greatest in the south channel of the river immediately downstream of the J-2 Return. The deficit decreases in the downstream direction. There are no major tributary inputs of sediment in the AHR. Accordingly, the deficit is made up primarily through erosion of channel bed and bank materials in the south channel downstream of the return (Holburn et al. 2006; Murphy et al. 2006; HDR Engineering Inc. 2011).

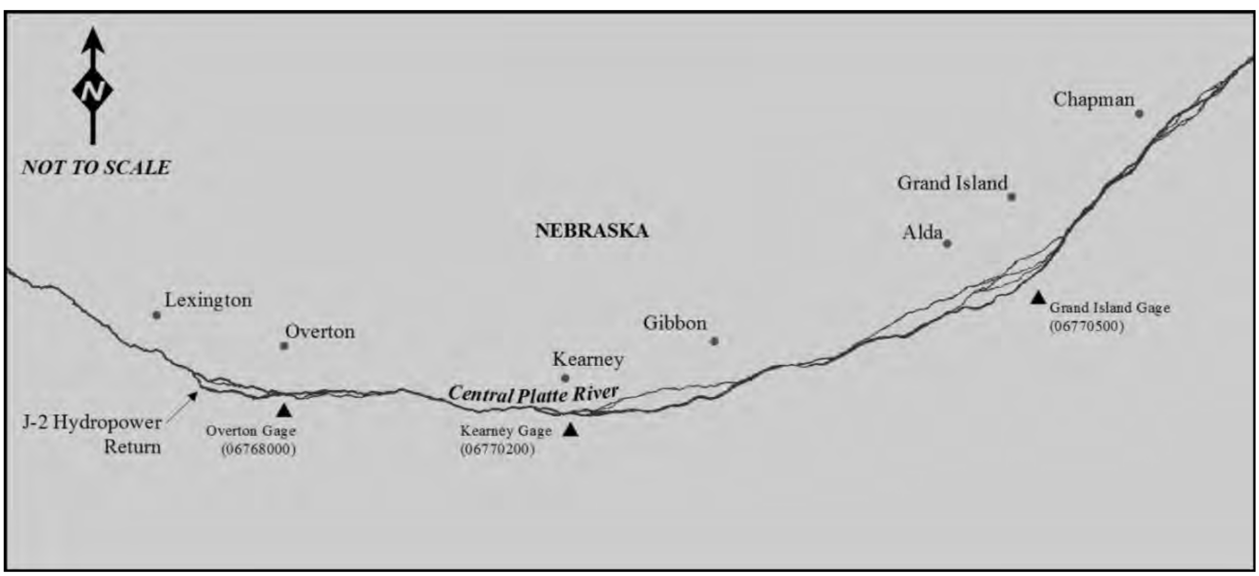

Figure 2. Associated Habitat Reach of the central Platte River extending from Lexington downstream to Chapman, NE. Locations of stream gages used in the analyses are included as well.

Sediment augmentation efforts began in 2006 as part of channel widening activities by NPPD at the Cottonwood Ranch property in the Overton to Elm Creek bridge segment. The Program has since expanded those efforts to include the addition of a second augmentation site upstream of the Overton Bridge (Table 2).

Table 2. Total annual discharge, sediment load, and sediment augmentation by water year. Sediment loads from Program system-scale geomorphology monitoring.

Water Year*	Total Annual Discharge at Overton (Acre-ft)	Sediment Augmented (tons)	Total Sediment Load at Overton (tons)	Total Sediment Load at Kearney (tons)	Total Sediment Load at Shelton (tons)	Total Sediment Load at Grand Island (tons)
2006	272,032	15,570	--	--	--	--
2007	569,912	21,875	--	--	--	--
2008	525,025	42,500	--	--	--	--
2009	585,994	50,000	200,000	207,300	214,900	281,500
2010	1,377,665	50,000	613,000	730,000	719,000	877,000
2011	2,691,194	50,000	1,424,000	1,728,000	1,467,000	2,011,000
2012	1,247,736	0	567,000	641,000	495,000	713,000
2013	638,733	182,000	255,200	268,700	165,700	209,700

* 2014 and 2015 data not available

The Program began conducting annual system-scale geomorphology and vegetation monitoring in 2009. Analysis of transect survey and sediment transport measurement data for the period of 2009-2013 strongly indicates the portion of the reach upstream from Kearney was degradational during that period, with an average annual sand deficit in the range of 100,000 tons (Tetra Tech Inc. 2014). Tetra Tech Inc. (2014) considered both survey and model results and concluded the portion of the reach downstream from Kearney was most likely aggradational. However, given potentially contradictory lines of evidence, Tetra Tech Inc. (2014) indicated this conclusion was only weakly supported by the data.

Flow

The primary physical process driver of the FSM management strategy is the implementation of short-duration high flows (SDHF) of 5,000 – 8,000 cfs for three days on a near annual basis. Implementation of SDHF is intended to increase the magnitude of peak flows (indexed by the $Q_{1.5}$ flow; the peak flow exceeded in two out of three years) from approximately 4,000 cfs to 5,000 – 8,000 cfs. Total release volumes on the order of 50,000 – 75,000 acre-ft are necessary to achieve full SDHF magnitude and duration due to reservoir release ramping constraints and flow attenuation.

Persistent channel conveyance constraints upstream of the AHR limit the Program's ability to generate flow release magnitudes in the 5,000 – 8,000 cfs range. As such, the Program has not had the ability to fully implement an SDHF magnitude release through the AHR. However, the easing of basin drought and subsequent river discharge recovery coincident with Program implementation since 2007 provided natural high flows of similar magnitude and greater duration than contemplated in the AMP. During the first nine years of Program implementation (2007-2015), mean annual discharge more than doubled and the three-day mean annual peak discharge at Grand Island exceeded 5,000 cfs in seven out of nine years and 8,000 cfs in five out of nine years (Table 3; Figure 3). Overall, the shift in basin hydrology resulted in a nine-year period (2007-2015) with peak flow frequency, magnitude, and duration that substantially exceeded what could have been achieved under full FSM implementation during 2000-2006.

Table 3. 2007-2015 median discharge during the growing season (cfs) and annual peak flow event magnitudes (cfs), durations and volumes (acre-ft) at Grand Island (USGS Gage 06770500) in relation to the Short-Duration High Flow management action performance criteria.

Year	Median Discharge during Growing Season (cfs)	Average Daily Peak Discharge (cfs)	3-Day Mean Peak Discharge (cfs)	Days >5,000 cfs	Days >8,000 cfs	Total Event Volume (acre-feet)*
SDHF	NA	NA	5,000 – 8,000	3	0	50,000 – 75,000
2007	1,045	5,312	5,543	3	0	84,813
2008	903	12,472	10,900	13	5	253,012
2009	479	3,379	3,180	0	0	24,258
2010	2,243	8,498	8,540	17	6	535,319
2011	5,468	9,474	9,883	81	16	3,287,603
2012	238	3,300	3,183	0	0	332,310
2013	218	11,313	9,167	9	6	245,871
2014	943	7,342	7,263	6	0	181,269
2015	3,030	16,100	15,666	50	42	1,245,818

*Cumulative flow volume for consecutive days of discharge greater than 2,000 cfs.

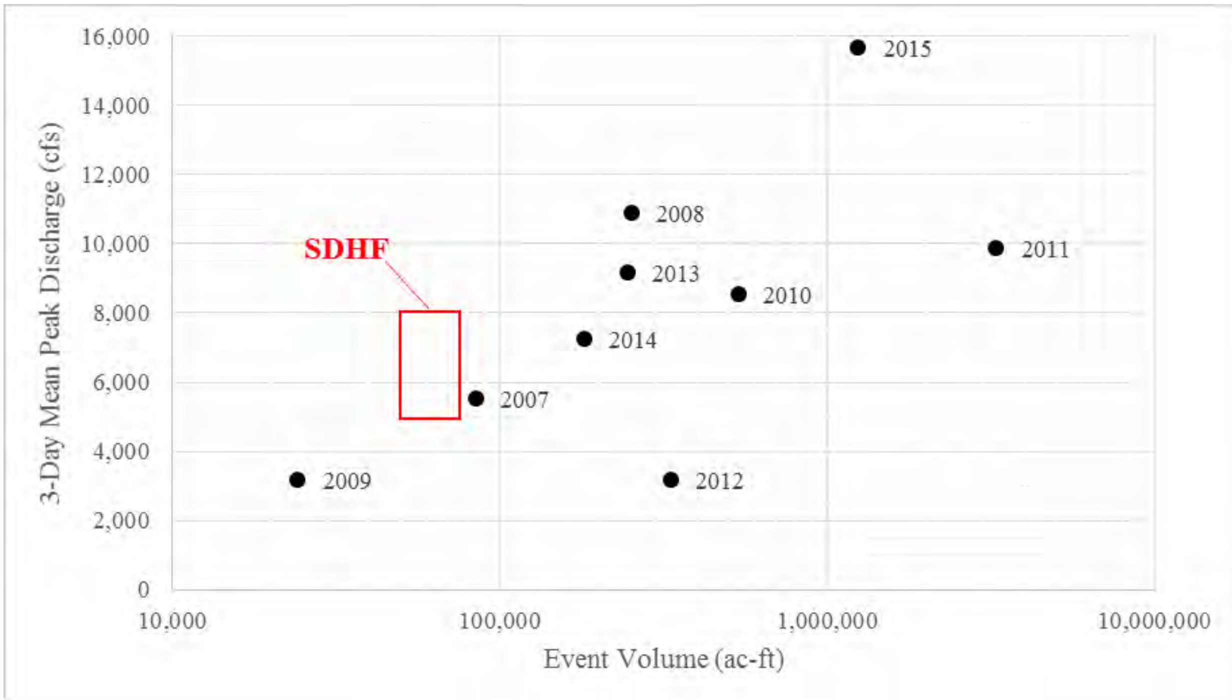

Figure 3. 2007-2015 three-day mean peak discharge (cfs) and event volume (acre-ft) at Grand Island (USGS Gage 06770500) in relation to the range of Short-Duration High Flow magnitudes and volumes. Event volumes are cumulative volumes from concurrent days during annual peak flow event when discharge exceeded 2,000 cfs.

Analysis Objectives

Overall, the scale of flow, sediment, and mechanical management actions and natural analogs during 2007-2015 have been sufficient to allow the Program to effectively explore channel response, specifically change in both TUCW and maximum width of channel unobstructed by vegetation (UOCW), to both natural events and Program management actions. Multiple unvegetated width metrics, including TUCW and UOCW, were included in the analysis for two reasons. First, vegetation response relationships will likely be most easily identified when evaluating TUCW, which encompasses all unvegetated segments across all channels, because it eliminates the randomness associated with the emergence of vegetated islands. Including TUCW, in addition to UOCW, provides the best opportunity to identify the metrics which most influence in-channel vegetation. Second, the inclusion of both metrics also allows for analysis of the relationship between TUCW, which is primarily a geomorphic metric, and UOCW, which is primarily a whooping crane habitat metric.

Accordingly, the objectives of this analysis include 1) quantification of annual AHR TUCW and UOCW through the First Increment of the Program, 2) evaluation of the relationship between TUCW and UOCW in the AHR, 3) identification and quantification of management actions, hydrologic (flow) conditions, and physical conditions that influence annual TUCW and UOCW in the AHR, 4) development of probability estimates for maintenance of 400 – 800 UOCWs given the metrics that appear to most influence UOCW, and 5) application of analysis results to predict the ability of the FSM management strategy to create and maintain highly suitable riverine whooping crane habitat.

Methods

Study Area

The AHR is a ninety-mile reach extending from Lexington, NE downstream to Chapman, NE and encompasses the Platte River channel and off-channel habitats within three and one half miles of the river (Figure 1). The study reach for this analysis focuses solely on the 84-miles of channel extending downstream from the Overton bridge to Chapman. The short reach between Lexington, NE and the Overton, NE was excluded due to the presence of the J-2 hydropower return. Natural river flows are largely confined to the north channel and hydropower return flows are confined to the south channel in this reach making it difficult to interpret relationships between hydrology and physical process relationships in this portion of the AHR.

Measurement of Total Unvegetated Width and Unobstructed Channel Width

We used summer or fall aerial imagery collected annually during periods of low flow to photo-interpret TUCW and UOCW throughout the AHR during the period of 2007-2015. Unvegetated width metrics were delineated at a scale of 1” = 200’ along 436 pre-defined transects using ESRI ArcMAP Geographic Information System (GIS) software. Photo-interpretation of unvegetated width metrics was determined to provide acceptable measurement accuracy based on previous comparisons of field-measured and photo interpreted unvegetated width measurements in the AHR (Program unpublished data). Transects were oriented perpendicular to flow and spaced at 1,000 ft intervals along the channel throughout the study area and encompassed all channels in split flow reaches. Figure 4 provides examples of TUCW and UOCW width delineations.

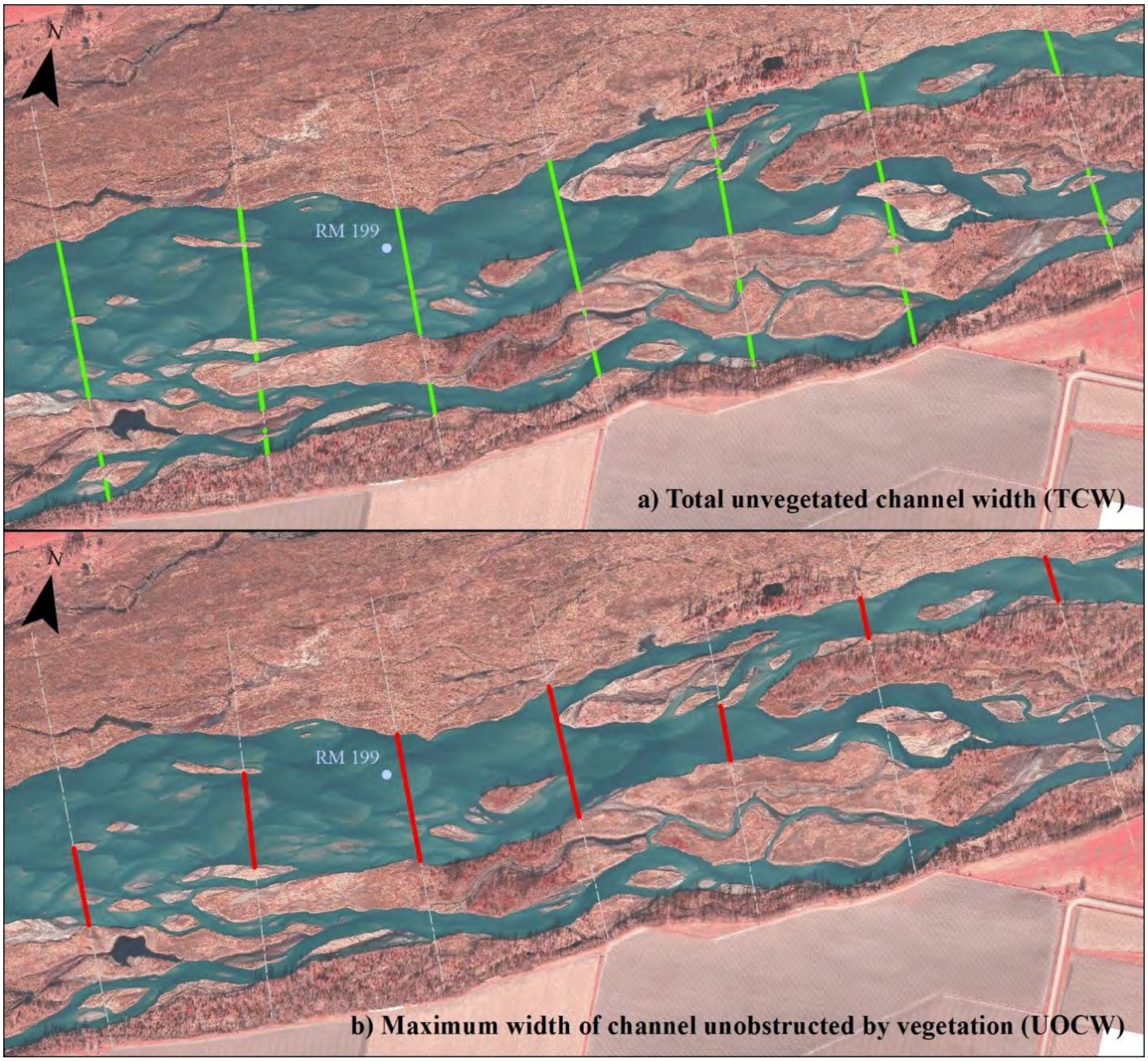

Figure 4. Examples of 2011 a) total unvegetated channel width (TUCW) and b) maximum width of channel unobstructed by vegetation (UOCW) delineations near River Mile 199.

Model Metrics and Statistical Analyses

A number of investigators have attempted to identify the management, hydrologic, and geomorphic factors that influence channel width in the AHR. Most investigations evaluate those factors within the context of changes in unvegetated channel width during the period following water resources development in the basin (Williams 1978; O'Brien and Currier 1987; Johnson 1994; Simons and Associates Inc. 2000; Murphy et al. 2001; Schumm 2005). Several of the investigators identified peak flows as the controlling factor in channel width (Williams 1978; O'Brien and Currier 1987; Murphy et al. 2004) although peak flow metrics of interest had varying return intervals and durations identified by different investigators, these differences were generally not discussed. Investigators also typically cited a secondary effect of reduction in sediment supply/transport. Others have identified mean June flows (Johnson 1994; Simons and Associates Inc. 2000), summer flows (Schumm 2005), slight differences in channel slope (Schumm 2005) and differences in bed material grain size (Murphy et al. 2004) as potentially controlling or at least influencing unvegetated channel width in the AHR.

In addition, investigators have discussed the role of woody and/or scour resistant vegetation in limiting the ability of the AHR to widen in response to changes in hydrology (Tal et al. 2004). This phenomenon has been described as the vegetation ratchet effect because the channel is free to narrow through vegetation encroachment but has limited ability to re-widen once bars and banks are stabilized by woody or other scour-resistant vegetation.

A total of 11 primary hydrologic, geomorphic, and management variables were identified based on our review of the literature, proposed FSM management actions, and our knowledge of ongoing activities in the AHR (Table 4). We performed 2 robust multivariate linear regression analyses to identify and quantify effect sizes of these variables on TUCW and UOCW in the AHR during the period of 2007 to 2015 (Marazzi 1993, Venables and Ripley 2000). Additionally, we performed 5 logistic regression analyses to identify variables that influence whether or not UOCW exceeded 400, 500, 600, 700 or 800 ft.

Table 4. Hydrologic, geomorphic and management variables included in the robust regression analyses for total unvegetated channel width (TUCW) and unobstructed channel width (UOCW) for the period of 2007 to 2015. Units of measurement (Units) and description of data acquisition (Description) are included for each metric.

Metric	Type	Units	Description
Peak Discharge	Hydrologic	Cubic feet per second (cfs)	Mean daily discharge records were obtained from www.water.usgs.gov for the three United States Geological Survey (USGS) stream gages located in the AHR (Figure 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	Cubic feet per second (cfs)	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	Cubic feet per second (cfs)	Mean annual minimum discharge events were identified for 10, 20, 30, and 40 day durations.
Mean June Discharge	Hydrologic	Cubic feet per second (cfs)	Mean daily discharge during the month of June.
Mean Growing Season Discharge	Hydrologic	Cubic feet per second (cfs)	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	Feet (ft)	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.
Median Grain Size	Geomorphic	Millimeter (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.
Channel Slope	Geomorphic	Dimensionless	Mean channel slope for 1-mile reach centered on each transect. Slopes calculated from 2009 longitudinal profile of the AHR.
River Mile	Geomorphic	Mile (mi)	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 or not 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 a herbicide polygon, the transect was considered to be treated with herbicide.
Annual Herbicide	Management	Categorical	

Transects were subset spatially to utilize every fifth transect location to eliminate autocorrelation bias. We used robust regression analysis because the dataset contained influential observations on the extremes of the response distribution, which makes it inappropriate for traditional linear modeling (Marazzi 1993). Robust regression uses iterative re-weighted least squares methods for each observation based on its response (TUCW or UOCW) value compared to the trend of independent covariates. Observations with larger residuals have lower weights than those with smaller residuals. Such observational weighting results in linear models influenced less by outliers, especially extreme outliers, contained in the dataset.

Due to the high number of possible covariate combinations, especially due to uncertainty of best peak and minimum flow durations to predict TUCW and UOCW, we utilized Akaike's Information Criterion (AIC) in a five step model selection process. Similar multi-step model selection efforts have been observed in ecological modeling efforts (McGowan et al. 2011, Catlin et al. 2015). A full description for the TUCW model selection process and tables for the UOCW robust linear regression and logistic regression processes are included in Appendices I to III. We utilized this multi-step selection process to: 1) identify the most important hydrologic variables, 2) identify the duration of hydrologic variables that best explain each response, 3) identify the most important non-hydrologic variables, and 4) produce final models with both hydrologic and non-hydrologic variables that best explain TUCW and UOCW and accurately predict TUCW and UOCW at transect locations in the AHR.

Application of the Final UOCW Model to Evaluate the FSM Management Strategy

The final UOCW model was used to assess the potential performance of the FSM management strategy at a hypothetical habitat complex location given observed hydrology during the period of 1998 – 2015. The habitat complex was assumed to have a main channel bankfull width of 1,000 ft and a median bed material grain size of 0.9 mm. Annual UOCW 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 SDHF events of 8,000 cfs for three days in approximately two out of three years. UOCWs predicted under full SDHF implementation were compared to those predicted given observed hydrology to assess the ability of SDHF releases to increase UOCW and maintain UOCWs that are highly suitable for whooping crane use.

Results

Total Unvegetated Channel Widths (TUCW) and Unobstructed Channel Widths (UOCW)

TUCW and UOCW followed similar trend patterns from 2007 to 2015. The lowest average values for each width measurement were observed in 2007 and the highest was in 2015 (Table 5). From 2008 to 2014, UOCW mean and median values were observed to have little variation, with the greatest yearly difference of 110 ft for mean and 89 ft for median observations. Likewise, from 2008 to 2014, TUCW mean and median values were observed to have little variation, with the greatest yearly difference of 219 ft for mean and 222 ft for median observations (Table 5).

Table 5. Observed total unvegetated channel widths (TUCW) and unobstructed channel widths (UOCW) by river mile for analysis years 2007 to 2015.

Year	TUCW(mean)	TUCW(median)	UOCW(mean)	UOCW(median)
2007	572	558	300	260
2008	720	729	443	383
2009	650	642	373	341
2010	661	653	409	347
2011	869	864	481	430
2012	695	692	454	394
2013	722	720	483	421
2014	716	710	431	373
2015	1054	1027	625	575

Spatially, both TUCW and UOCW were highly variable but generally increased with decreasing river mile (i.e., in a downstream direction). Both width metrics also increased from 2007 to 2015 at almost all locations within the AHR (Figure 6). However, the magnitude of width increases varied based on river segment. For example, the UOCW increase from river mile 170 to 180 was far less than was observed from river mile 160 to 170 (Figure 6).

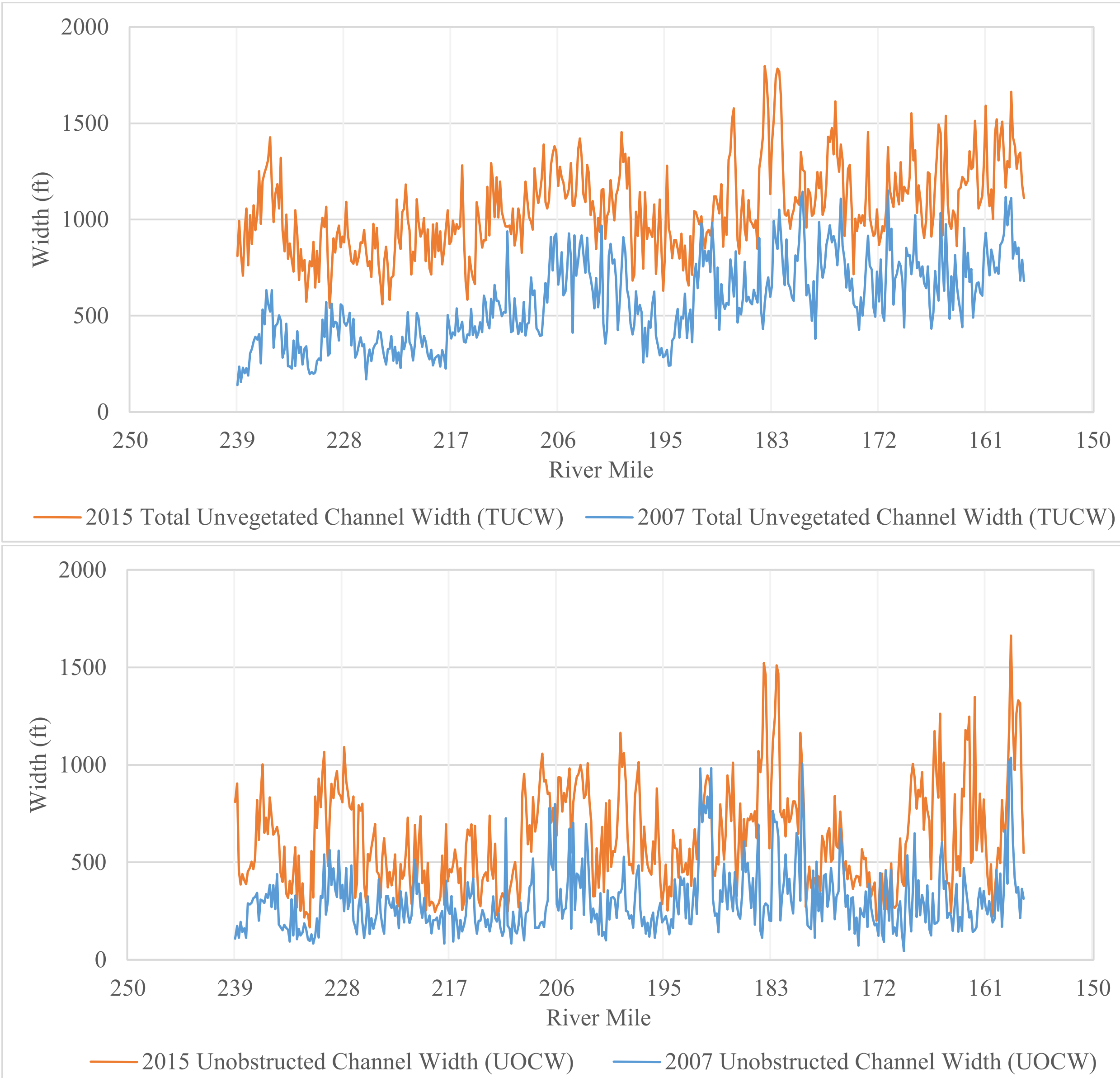

Figure 6. Observed total unvegetated channel widths (TUCW) and unobstructed channel widths (UOCW) by river mile for analysis years 2007 and 2015.

Relationship between TUCW and UOCW

The relationship between TUCW and UOCW for all transects in all analysis years is presented in Figure 7. In general, UOCW increased with increasing TUCW but there were few cases when the entire unvegetated width of the channel was consolidated into a single segment (UOCW = TUCW). This indicates that under existing hydrologic, geomorphic, and management conditions, the channels of the AHR tend to contain either densely vegetated sandbars or be split by permanent islands. Accordingly, it is not appropriate to interpret UOCW as being equivalent to TUCW or other metrics intended to describe the total width of AHR channels.

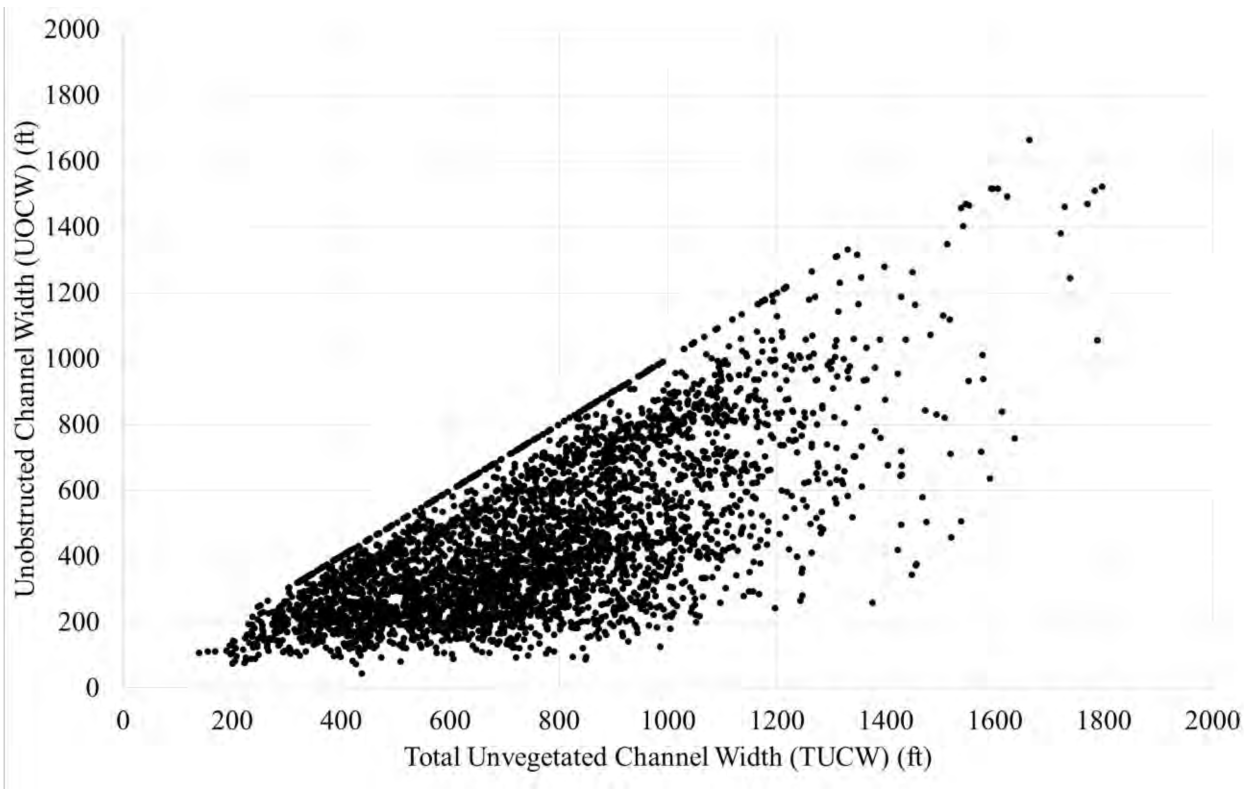

Figure 7. Relationship between total unvegetated channel width (TUCW) and unobstructed channel width (UOCW) for all transects in analysis years 2007-2015.

Robust Regression Analysis – Metrics Found to Influence Total Unvegetated Channel Width

A summary of important annual flow, geomorphic and management variable values in relation to mean AHR TUCW and UOCW are presented in Table 6. 40-day peak discharge ranged from 2,010 cfs to 12,486 cfs and generally occurred between early May and early July (Figure 8). Wetted width ranged from 603 ft to 1,717 ft. Disking was somewhat variable during the analysis period, ranging from a low of 0% of transects in 2011 to a high of 41% of transects in 2007 in the AHR. The proportion of transects sprayed was low in 2007 and 2008, prior to the commencement of large-scale phragmites spraying efforts. At full-scale implementation, up to 83% of transects were sprayed in a single year.

Table 6. Summary of important AHR flow, geomorphic and management metric values from 2007 to 2015 in relation to mean total unvegetated channel width (TUCW) and unobstructed channel width (UOCW) from 2007 to 2015.

Year	40 Day Peak Discharge (cfs)	Bankfull Wetted Width (ft)[1]	Median Grain Size (mm)[2]	% of Transects Disked	% of Transects Sprayed	TUCW (ft)	UOCW (ft)
2007	2,010			33%	0%	558	300
2008	3,825			41%	5%	729	443
2009	2,112			10%	13%	642	373
2010	5,171			5%	77%	653	409
2011	8,171	1,044	0.93	0%	44%	864	481
2012	2,922			9%	81%	692	454
2013	3,661			11%	71%	720	483
2014	2,943			18%	74%	710	431
2015	12,486			0%	83%	1,027	625

[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 to 2015.

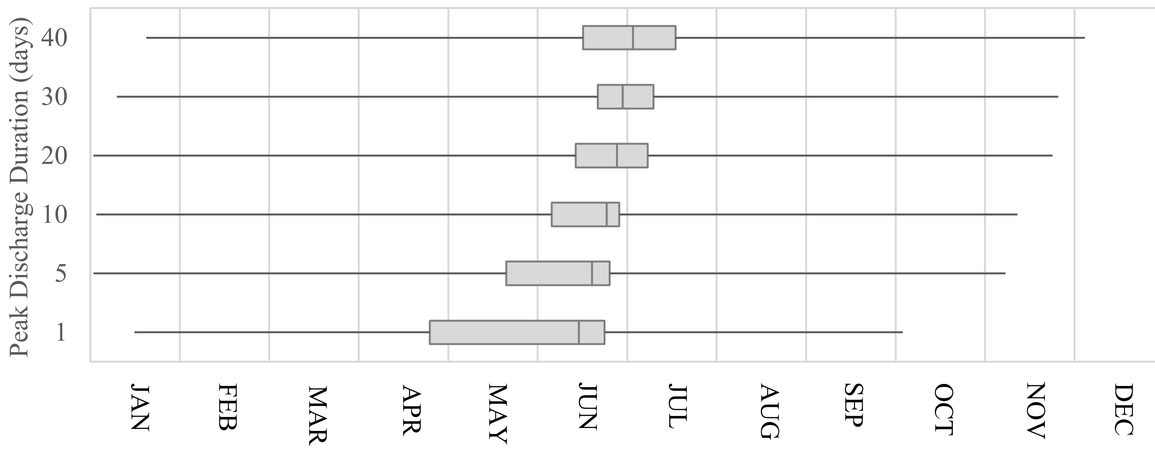

Figure 8. Distribution of peak discharge dates from the Overton, Kearney, Grand Island and Duncan gauges from 2007 to 2015. Median values are presented, along with the lower and upper quartiles. Minimum and maximum values are presented as bars.

We found TUCW was best explained by 40-day duration peak discharge, wetted width of the channel at bankfull discharge, disking, herbicide application, and median grain size (Appendix I Table I-5); all of which were incorporated in the only model that carried a substantial model weight (w = 0.95). AIC values indicated our top model was ~56 AIC units lower than a model only including 40-day peak discharge and wetted width and ~811 AIC unit lower than the null model. The y-intercept of our top model was 201.37 ft. All variables had a positive effect on TUCW from 2007 to 2015 except median grain size, which exhibited a negative relationship. Without accounting for robust regression weighting of individual observations, the top model accounted for about 65% of the variability in the data (P<0.001; traditional linear model R^2=0.65). The formula of the top model to explain TUCW was noted as:

$$TUCW = 201.37 + 0.033 * 40\ Day\ Peak + 0.48 * WettedWidth + 24.63 * Herbicide + 92.87 * Disked - 195.00 * Median\ Grain\ Size$$

where "40 Day Peak" refers to mean 40-day duration peak discharge, "Wetted Width" was a measurement of the wetted width of the channel at bankfull discharge, "Herbicide" and "Disked" were categorical variables based on whether or not herbicide or disking were applied within the last year and "Median Grain Size" refers to the median bed and bar material grain size in the transect reach.

Based on the results of our top robust regression model, for each 1,000 cfs increase in 40-day peak discharge, on average, we would expect a 33 ft (95% CI = 30 – 36 ft) increase in annual TUCW (P<0.001), when no disking or herbicide treatment was applied and wetted width at bankfull discharge and median bed material grain size were held at their median values (Figure 9). For each 100 ft increase in wetted width at bankfull discharge, on average, we would expect a 47 ft (95% CI = 43 – 53 ft) increase in TUCW (P<0.001, Figure 10). When transects were disked, on average, TUCW was 93 ft (95% CI = 60 – 125 ft) wider than at transects where no disking occurred within the last year (P<0.001). When transects were disked and herbicide was applied (P = 0.036), on average, TUCW was 118 ft (95% CI = 62 – 172 ft) wider than transects where no management actions occurred in the last year. Decreases in median grain size were also found to increase TUCW (P<0.001, Figure 11). For each 0.1 mm decrease in median grain size, on average, TUCW increased by 20 ft (95% CI = 10 – 30 ft).

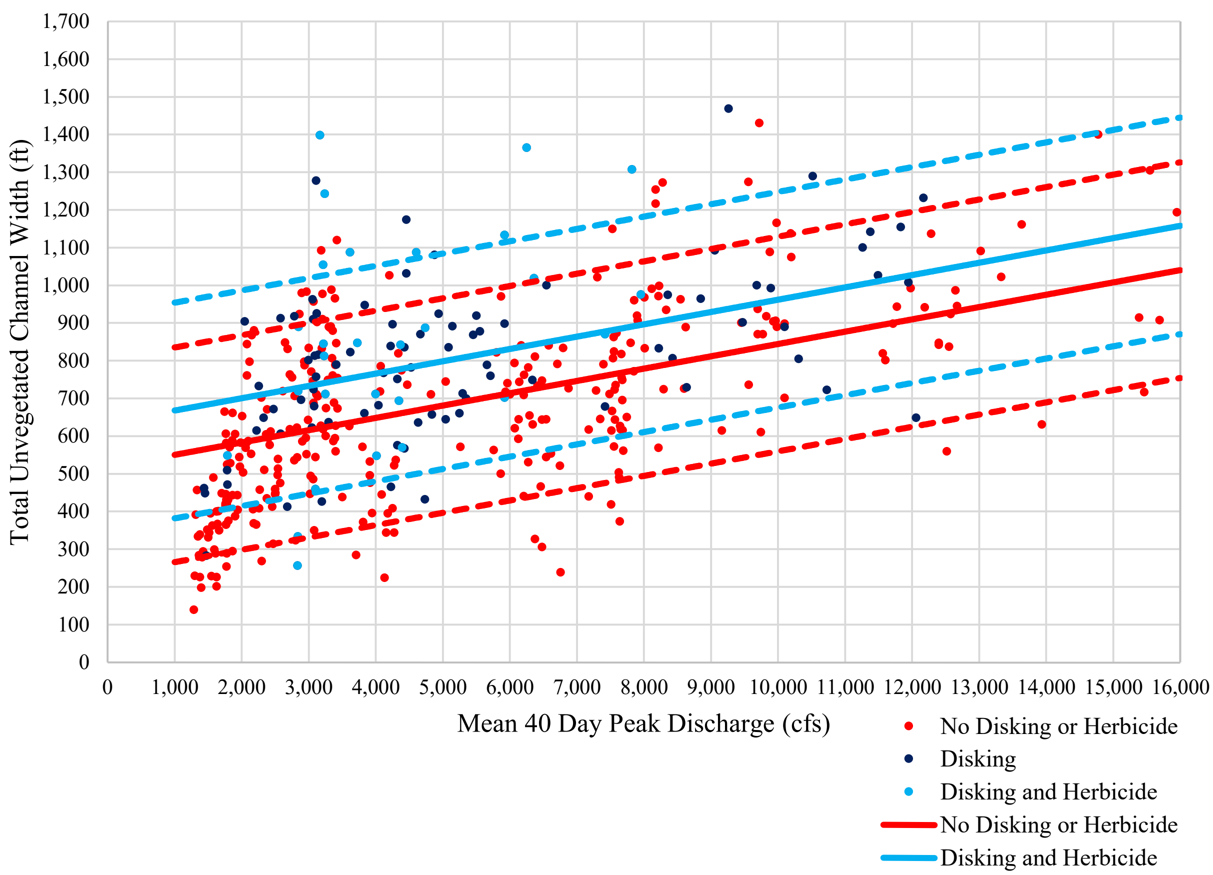

Figure 9. Predicted relationships of total unvegetated channel width (TUCW) to 40-day peak discharge at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals and points display the subset of measured TUCWs at transects used in robust regression analyses. Points represent transects where: no management actions (red), disking only (dark blue), or disking and herbicide (blue) occurred.

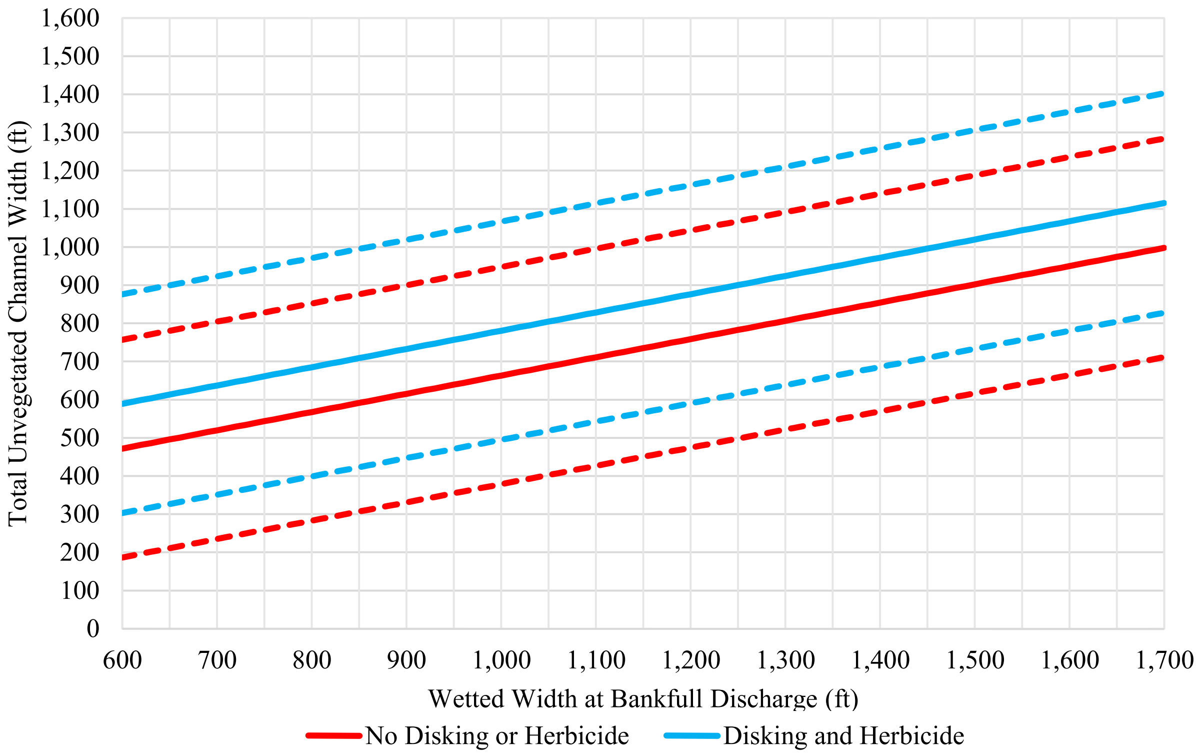

Figure 10. Predicted relationships of total unvegetated channel width to wetted width at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals.

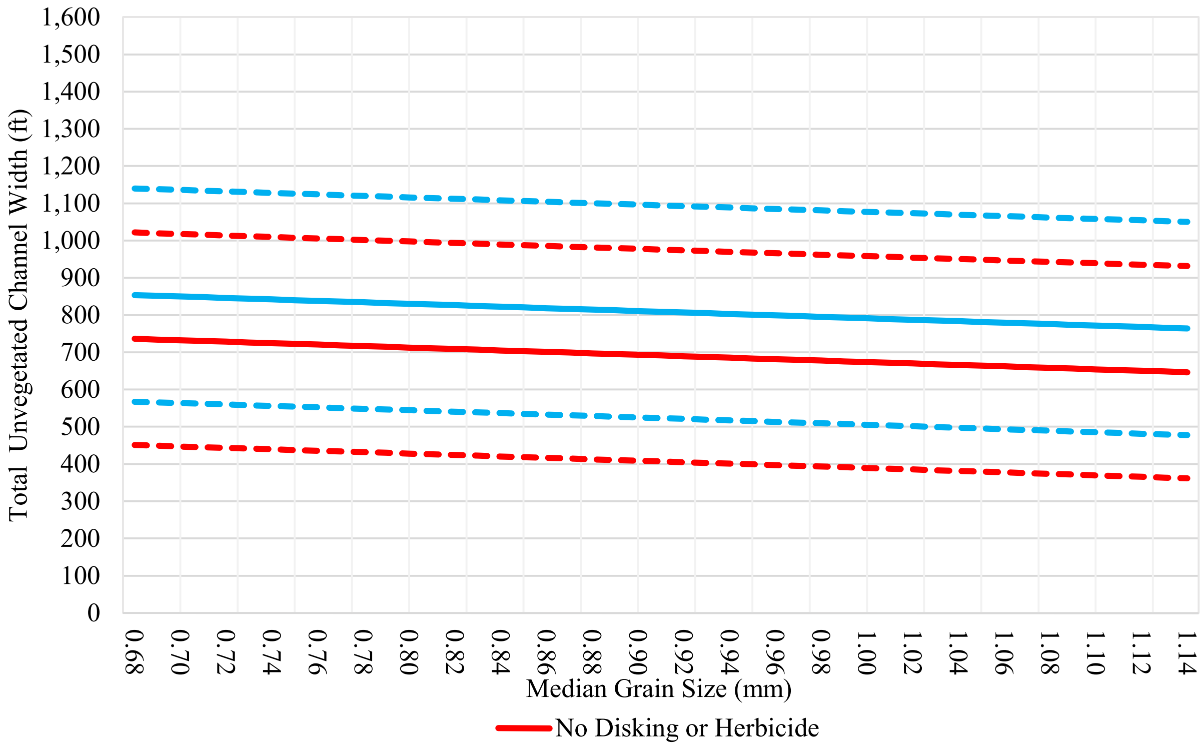

Figure 11. Predicted relationships of total unvegetated channel width to median grain size at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals.

We used several methods to assess the accuracy of the top model we identified through AIC model selection. First, we compared observed and predicted TUCW at each transect for each year. Utilizing the linear model and betas previously stated, 47% of TUCW predictions were within 100 ft and 78% of predictions were within 200 ft of actual values observed from 2007 to 2015. Overestimating TUCW was of special concern since narrower than predicted TUCW potentially have more negative consequences for whooping crane habitat suitability than underestimations. Twenty-eight percent of TUCW predictions were overestimated by more than 100 ft and only 10% were overestimated by more than 200 ft.

We also compared mean observed and predicted TUCW for all transects in each year (Table 7) and compared observed and predicted widths for each AHR bridge segment across all years (Table 8). Only two years, 2007 and 2010, were found to contain mean errors >10% of actual values. When observing errors by bridge segment, only the Minden-Gibbon and Shelton-Wood River segments were found to contain mean errors >10% of actual values.

Table 7. Comparison of mean observed and predicted total unvegetated channel width (TUCW) in AHR for the period of 2007-2015.

Year	Observed TUCW (ft)	Predicted TUCW (ft)	Error (ft)	Absolute Error (ft)	Error as % of Observed
2007	572	666	95	95	17%
2008	720	769	49	49	7%
2009	650	612	-38	38	6%
2010	661	746	85	85	13%
2011	869	815	-54	54	6%
2012	695	648	-47	47	7%
2013	722	755	33	33	5%
2014	716	719	3	3	0%
2015	1054	994	-60	60	6%
MEAN	740	747	7	52	7%

Table 8. Comparison of mean observed and predicted total unvegetated channel width (TUCW) by bridge segment for the period of 2007-2015.

Bridge Segment	Observed TUCW (ft)	Predicted TUCW (ft)	Error (ft)	Absolute Error (ft)	Error as % of Observed
Overton - Elm Creek	553	536	-17	17	3%
Elm Creek - Odessa	592	570	-21	21	4%
Odessa - Kearney	508	518	11	11	2%
Kearney - Minden	718	657	-61	61	8%
Minden - Gibbon	955	778	-177	177	19%
Gibbon - Shelton	738	736	-2	2	0%
Shelton – Wood River	666	754	88	88	13%
Wood River – Alda	944	931	-13	13	1%
Alda – Hwy 281	917	951	35	35	4%
Hwy 281 – Hwy 34	854	910	56	56	7%
Hwy 34 - Chapman	871	960	88	88	10%

Robust Regression Analysis – Metrics Found to Influence Unobstructed Channel Width

We found UOCW was best explained by 40-day duration peak discharge and wetted width of the main channel (Appendix II Table II-4) and were incorporated in the only model with a model weight >0.10 (w = 0.83). Disking, herbicide application, and median grain size were also included in the top model explaining UOCW. AIC values indicated our top model which included disking, herbicide application and median grain size was ~38 AIC units lower than a model that only included 40-day peak discharge and wetted width and ~219 AIC unit lower than the null model. The y-intercept of our top model was 247.82 ft. All variables had a positive effect on UOCW from 2007 to 2015 except median grain size, which exhibited a negative relationship. Without accounting for robust regression weighting of individual observations, the top model accounted for about 25% of the variability in the data (P<0.001; traditional linear model R^2=0.25). The formula of the top model used to explain UOCW was noted as:

$$UOCW = 247.82 + 0.02 * 40\,Day\,Peak + 0.19 * Wetted\,Width + 38.64 * Herbicide + 125.50 * Disked - 130.32 * Median\,Grain\,Size$$

where descriptions correspond to those described for the TUCW robust linear regression equations except "Wetted Width" refers only to the main channel and not the total wetted width of all channels at bankfull discharge.

Based on the results of our top robust regression model, for each 1,000 cfs increase in 40-day peak discharge, on average, we would expect an 18 ft (95% CI = 14 – 22 ft) increase in annual UOCW (P<0.001), when no disking or herbicide treatment was applied and wetted width and median discharge were held at their median values (Figure 12). For each 100 ft increase in bankfull wetted width of the main channel, on average, we would expect an 18 ft (95% CI = 13 – 24 ft) increase in UOCW (P<0.001, Figure 13). When transects were disked, on average, UOCW was 126 ft (95% CI = 82 – 168 ft) wider than transects where no disking occurred within the last year (P<0.001). When both disking and herbicide were applied, on average, we found transects were 164 ft (95% CI = 74 – 238 ft) wider than transects where no management actions occurred in the last year. We also found as median grain size decreased, UOCW increased (P<0.02,

Figure 14). For each 0.1 mm decrease in median grain size, on average, UOCW increased by 13 ft (95% CI = 2 – 24 ft).

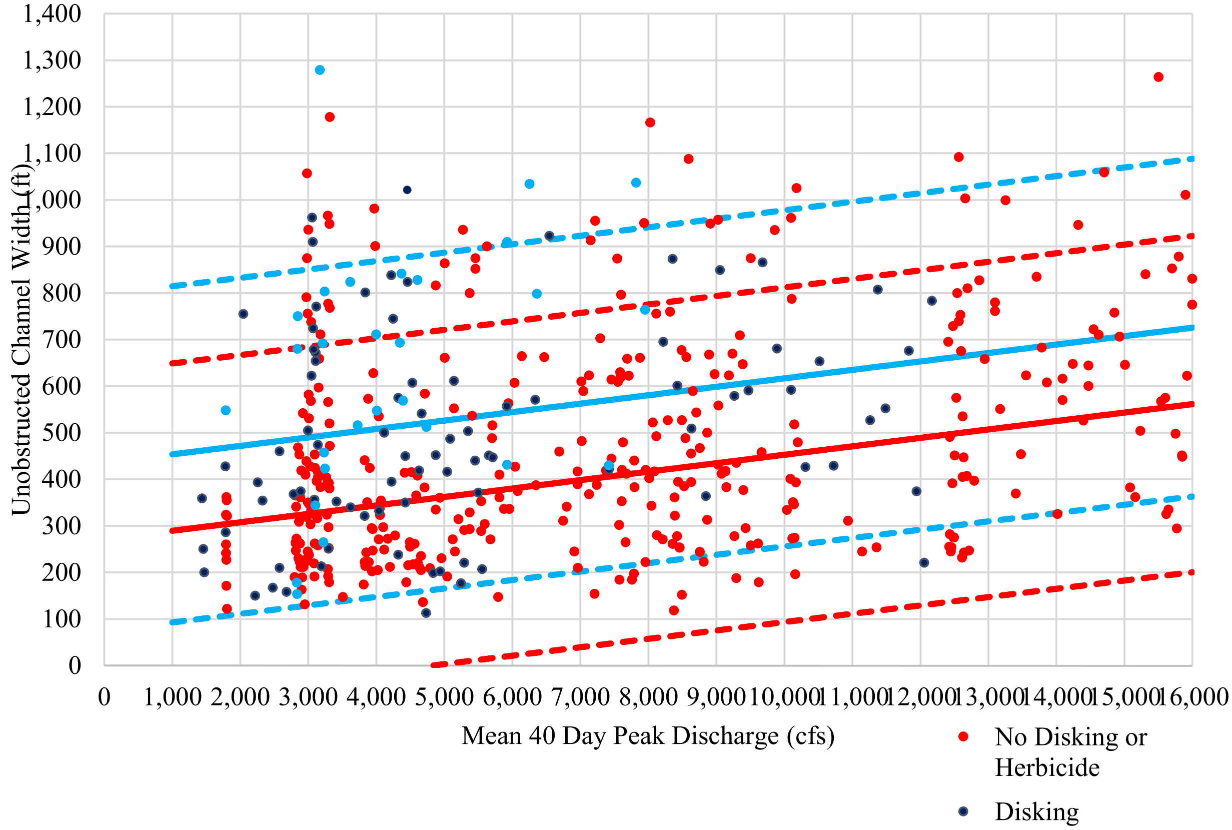

Figure 12. Predicted relationships of unobstructed channel width (UOCW) to 40-day peak discharge at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals and points display the subset of measured UOCWs at transects used in robust regression analyses. Points represent transects where: no management actions (red), disking only (dark blue), or disking and herbicide (blue) occurred.

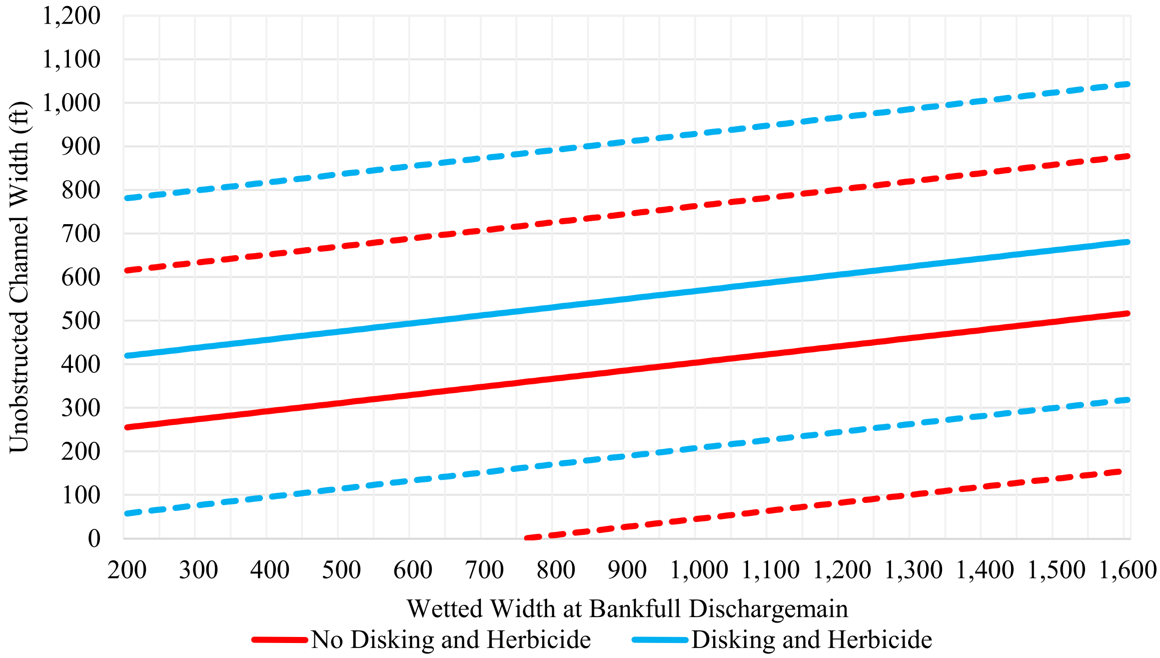

Figure 13. Predicted relationships of unobstructed channel width to main channel wetted width at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals.

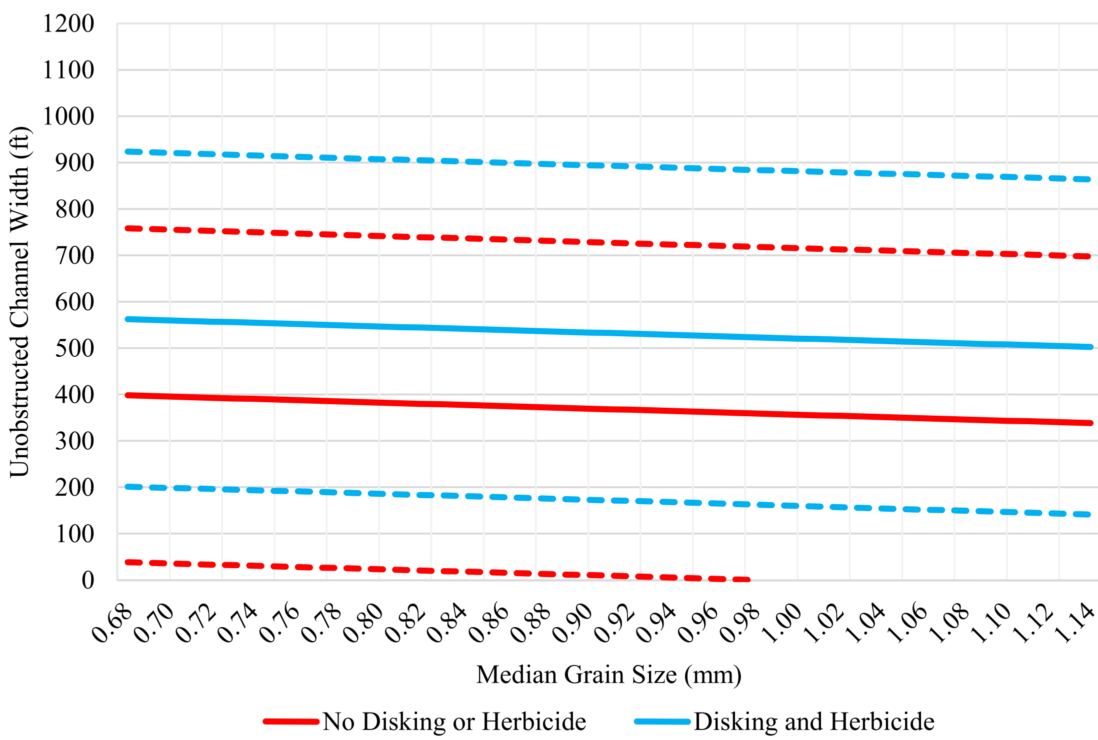

Figure 14. Predicted relationships of unobstructed channel width to median grain size at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals.

We incorporated several measurements to validate the accuracy of the top UOCW model we identified through the AIC model selection process. Utilizing the UOCW linear model and betas previously stated, 38% of UOCW predictions were within 100 ft and 68% were within 200 ft of actual values observed from 2007 to 2015. Once again, overestimating UOCW was of special concern since narrower than predicted UOCW potentially have more negative consequences for whooping crane habitat suitability than underestimations. Only 32% percent of UOCW predictions were overestimated by more than 100 ft and 13% were overestimated by more than 200 ft.

We also compared mean observed and predicted UOCW for all transects in each year (Table 9) and compared observed and predicted widths for each AHR bridge segment across all years (Table 10). Only the years of 2007 and 2012 were found to contain mean prediction errors >10% of actual values (Table 9). Six bridge segments in the AHR were found to contain mean prediction errors >10% of actual values (Table 10).

In addition, we performed a Monte Carlo analysis using Oracle Crystal Ball software to assess the sensitivity of predicted UOCW to the observed distributions of the variables contained in the top model. Simulation results are located in Appendix IV. Overall, disking contributed 36.6% of the variance in predicted UOCWs, 40-day mean peak contributed 33.4%, bankfull wetted width contributed 24.5%, median bed material grain size contributed 2.8% and herbicide contributed 2.7%.

Table 9. Comparison of mean observed and predicted unobstructed channel width (UOCW) in the AHR for the period of 2007-2015.

Year	Observed UOCW (ft)	Predicted UOCW (ft)	Error (ft)	Absolute Error (ft)	Error as % of Observed
2007	300	386	86	86	29%
2008	443	450	7	7	2%
2009	373	342	-31	31	8%
2010	409	429	20	20	5%
2011	481	455	-26	26	5%
2012	454	378	-76	76	17%
2013	483	437	-47	47	10%
2014	431	423	-9	9	2%
2015	625	564	-60	60	10%
MEAN	444	429	-15	40	10%

Table 10. Comparison of mean observed and predicted unobstructed channel width (UOCW) by bridge segment for the period of 2007-2015.

Bridge Segment	Observed UOCW (ft)	Predicted UOCW (ft)	Error (ft)	Absolute Error (ft)	Error as % of Observed
Overton - Elm Creek	348	314	-34	34	10%
Elm Creek - Odessa	484	398	-86	86	18%
Odessa - Kearney	333	301	-32	32	10%
Kearney - Minden	355	395	40	40	11%
Minden - Gibbon	660	439	-221	221	33%
Gibbon - Shelton	416	446	31	31	7%
Shelton – Wood River	440	428	-12	12	3%
Wood River – Alda	647	518	-130	130	20%
Alda – Hwy 281	488	488	0	0	0%
Hwy 281 – Hwy 34	411	484	73	73	18%
Hwy 34 - Chapman	473	563	90	90	19%

Logistic Regression Analysis – Metrics Found to Influence Desired Unobstructed Channel Widths for whooping cranes in the AHR

We performed a logistic regression analysis to understand what variables influence whether or not transects exceed a range of UOCWs from 400 to 800 ft. The regression analysis indicates the creation and maintenance of unobstructed channel widths ≥600 ft (for example) was also best explained by 40-day peak discharge, disking and other management and geomorphic variables (Appendix III Table III-5). Besides river mile, all important logistic regression variables correspond to those important for robust linear regression analysis of UOCW and TUCW. Two models were found to have significant explanatory power and only differed due to one model containing "Median Grain Size" (P = 0.03) and one containing "River Mile" (P = 0.03) among its variables. Top models for UOCW ≥600 ft predict transects with UOCW ≥600 ft were more likely as 40-day peak discharge and wetted width increase and less likely as river mile and median grain size increased (Figure 15). Herbicide application (P = 0.01) and disking (P <0.001) also increased the probability a UOCW was ≥600 ft. Disked transects were 3.24 (95% CI = 1.96 – 5.36) times more likely than non-disked transects to have UOCW ≥600 ft. We also utilized the model equation containing "Median Grain Size" to predict UOCWs of 400 to 800 ft in 100 ft increments because of its similarity to robust linear regression variables (Figures 15 and 16). The logit-link used to calculate these predictions was noted as:

$$Probability\ UOCW\ is\ \geq 600\ ft$$
$$= \frac{EXP(0.12 + 0.00016 * 40\ Day\ Peak + 0.0012 * Wetted\ Width + 1.29 * Disking - 2.83 * Median\ Grain\ Size + 0.38 * Herbicide)}{1 + EXP(0.12 + 0.00016 * 40\ Day\ Peak\ + 0.0012 * Wetted\ Width + 1.29 * Disking - 2.83 * Median\ Grain\ Size + 0.38 * Herbicide)}$$

where descriptions correspond to those described for robust linear regression equations except "Wetted Width" refers to only the main channel and not the wetted width of all channels at bankfull discharge.

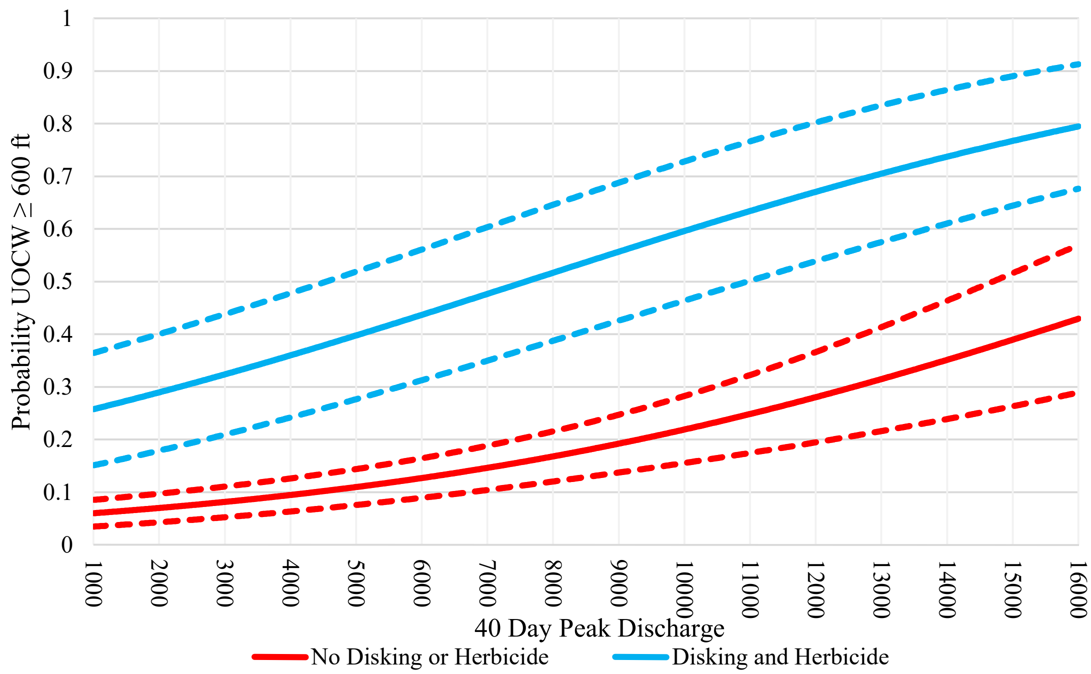

Figure 15. Predicted probability of a transect measuring ≥600 ft in unobstructed channel width compared to 40-day peak discharge at transects with (blue) or without (red) management actions in the AHR from 2007 to 2015. Dashed lines indicated 95% confidence intervals.

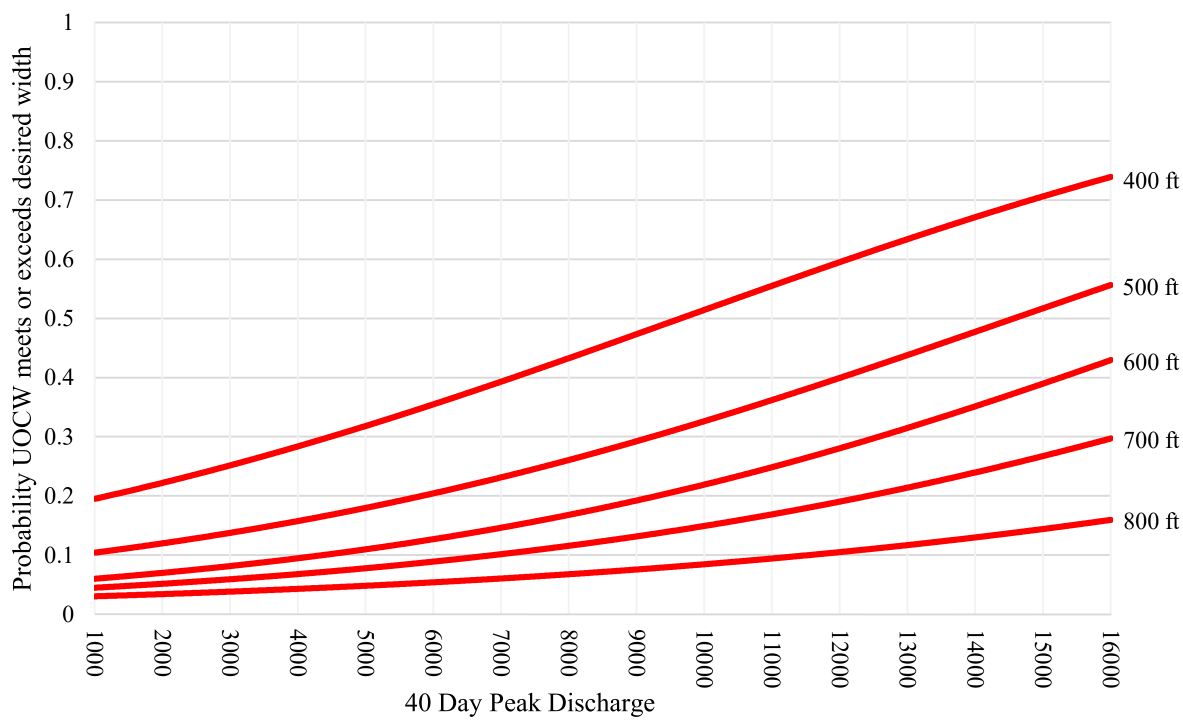

Figure 16. Predicted probability a transect measuring ≥400, 500, 600, 700 and 800 ft (highest probability to lowest probability curve, respectively) in unobstructed channel width (UOCW) compared to 40-day peak discharge at transects without management actions in the AHR from 2007 to 2015.

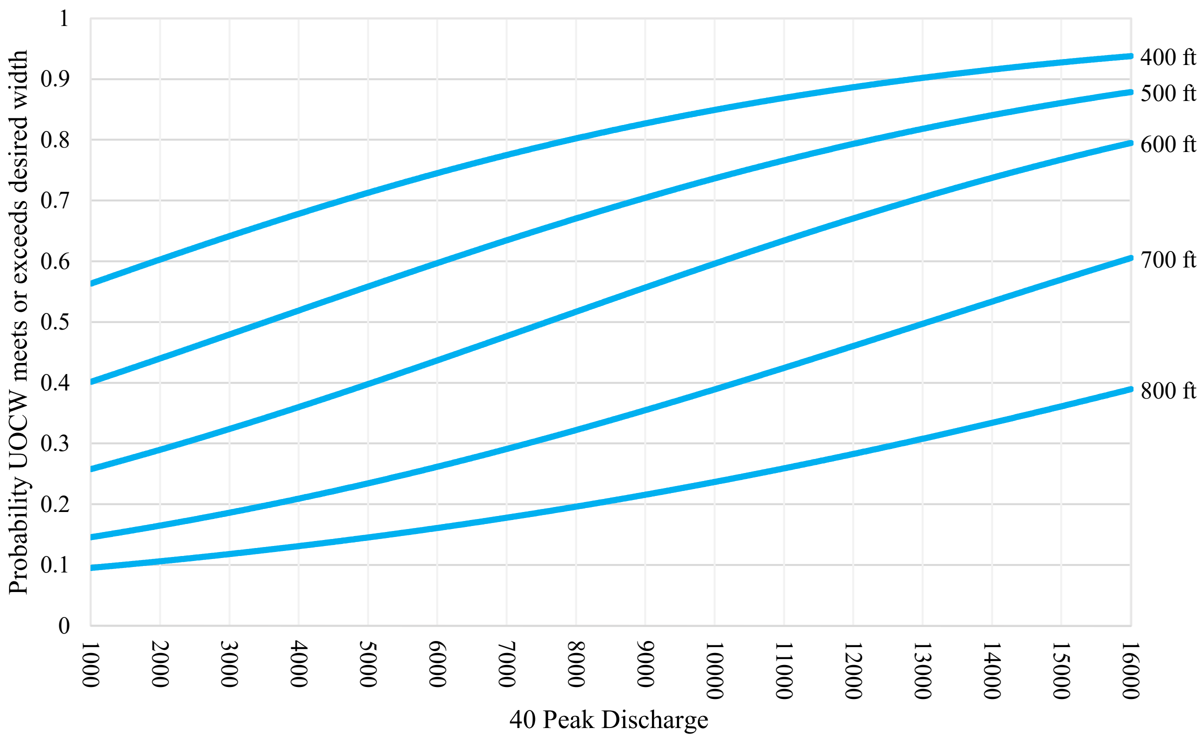

Figure 17. Predicted probability a transect measuring ≥400, 500, 600, 700 and 800 ft (highest probability to lowest probability curve, respectively) in unobstructed channel width (UOCW) compared to 40-day peak discharge at transects with disking and herbicide application management actions in the AHR from 2007 to 2015.

Analysis of SDHF Performance

Simulated SDHF releases were added to observed mean daily flows for the period of 1998-2015 (Figure 18) to evaluate the predicted increase in channel width under full SDHF implementation. The modified flow series included ten SDHF releases. Simulated SDHF releases were added to the flow record during the month of April in two out of three years during dry periods. SDHF releases were not added in wet years or the years immediately following the two highest discharge years (1999 and 2011). The SDHF hydrograph in all cases included two to three days of up-ramping flows, three days at a discharge of 8,000 cfs 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. SDHF volumes ranged from 26,000 to 68,000 ac-ft. Predicted TUCW and UOCW values with and without SDHF releases (assuming a main channel bankfull wetted width of 1,000 ft, median bed material grain size of 0.9mm, herbicide treatment, and no disking) are presented in Table 11. Implementation of an SDHF release in a given year is predicted to increase TUCW by 0 – 22 feet and UOCW by 0 – 12 feet depending on baseline river discharge at the time of the release. The greatest increases in TUCW and UOCW are predicted to occur when baseline river discharge is low.

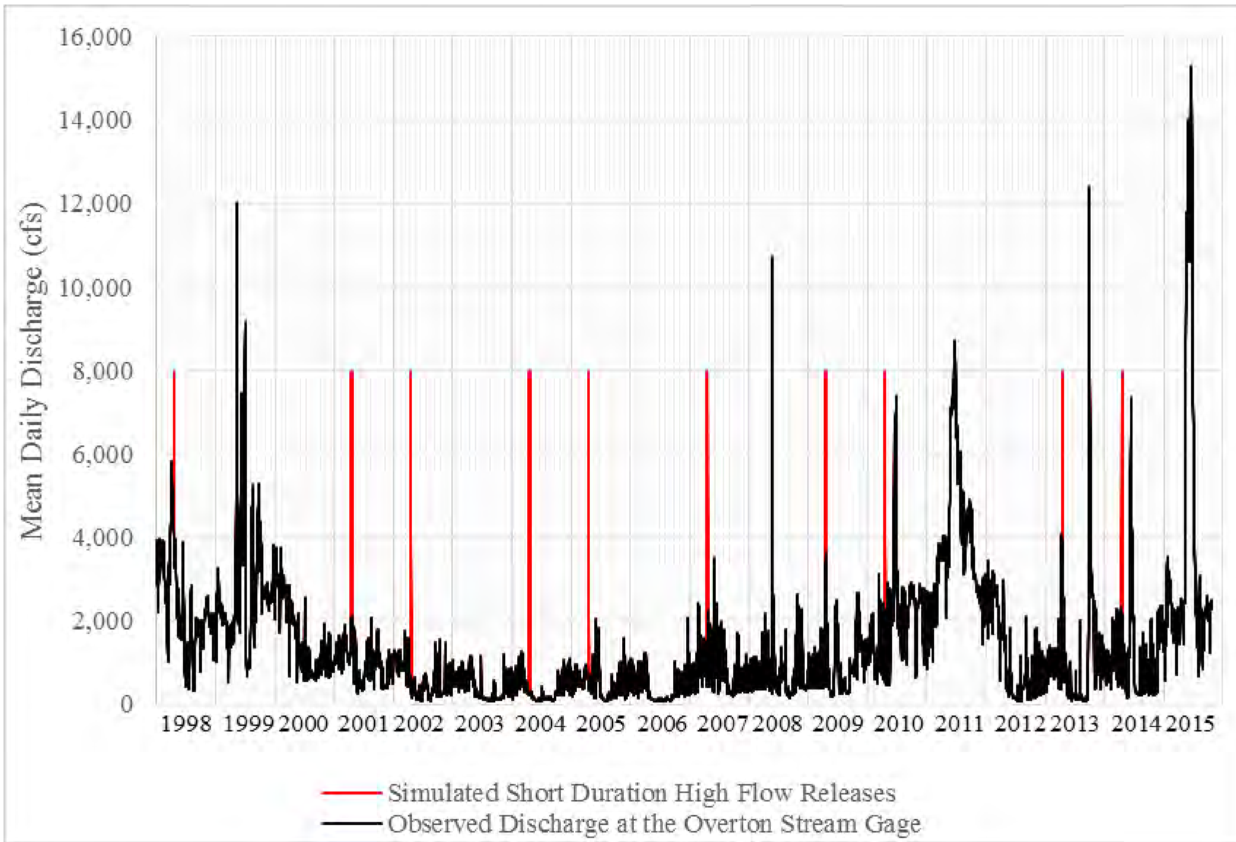

Figure 18. Observed hydrology at the USGS Overton Stream Gage (06768000) and simulated short duration high flow events of 8,000 cfs for three days in approximately two out of three years.

Discussion

The Program's FSM management strategy consists of sediment augmentation to offset the sediment deficit due to clear water hydropower returns, mechanical vegetation clearing and channel widening, and SDHF releases in approximately two out of three years to increase and maintain the width of channel free from vegetation. This investigation provides insights about the beneficial effects of each of these management actions in maintaining TUCW and more specifically, UOCWs that are highly suitable for whooping crane roosting habitat.

This investigation included an indirect evaluation of sediment through inclusion of median grain size. Differences in median grain size through the AHR may be an indicator of sediment balance with coarser grain sizes in deficit reaches due to winnowing of bed material. However, differences in grain size may also be attributable to differences in local sediment transport capacity as a result of width variability. Overall, median grain size was found to be correlated with unvegetated channel width, with a predicted 13-foot increase in UOCW for every 0.1 mm decrease in median bed material grain size. However, it is difficult to assess whether sediment supply is influencing width or width is influencing grain size. Overall, uncertainty in causation versus correlation may not be that important as UOCW appears to be somewhat insensitive to median grain size which only accounted for 2.8% of the variance in predicted UOCWs (Appendix IV).

Program priority hypothesis Flow 3 postulates peak flow magnitude is a major driver in unvegetated channel width. Specifically, increasing peak flow magnitude (metric is $Q_{1.5}$) will increase the vegetation-free width of the main channel in the AHR (Figure 13). The robust and logistic regression analyses in this investigation strongly support the assertion of a positive relationship between peak flow magnitude and TUCW and UOCW in the AHR. Overall, 40-day mean peak discharge accounted for 33.4% of the variance in predicted UOCWs.

The analyses, however, do not support the assertion that increasing peak flow magnitude through SDHF releases of 5,000 – 8,000 cfs for three days in two out of three years will produce substantive increases in the vegetation-free width of the channel. Maximum increases in TUCW of 22 feet and UOCW of 12 feet are predicted. This is due to the very short duration and low volume of SDHF releases in relation to the 40-day peak discharge duration that is the best hydrologic predictor of TUCW and UOCW in the AHR. The difference in peak-volume relationships between observed natural peak flow events and SDHF is apparent in Figure 3.

Overall, these analyses strongly indicate peak flows significantly influence TUCW and UOCW in the AHR, but SDHF releases, as currently envisioned, would not be effective in managing UOCW to create and/or maintain suitable whooping crane habitat. SDHF is predicted to produce maximum increases in UOCW of approximately 12 feet, which is a minimal effect during very dry periods when mean UOCW is on the order of 100 feet narrower than the low end of the 500 – 700 ft range of highly-favorable UOCWs for whooping crane use (Chapters 2 and 3). During wetter years when baseline UOCW is closer to the lower end of the suitable range, the much greater duration of the natural peak flow events appears to eclipse the limited effect of an SDHF.

Although an SDHF release does not appear to be a viable UOCW management tool, disking in combination with herbicide application does. The predicted mean effect of channel disking and spraying is a 126-foot increase in UOCW. Accordingly, these actions would be predicted to increase UOCW past the lower end of the 500 – 800-foot suitability range in all but the very driest years. The major limitation of disking is the lack of a system-scale beneficial effect. The Program can utilize disking to effectively manage UOCW at Program habitat complexes, but cannot utilize disking to manage UOCW on other conservation or private lands without landowner agreements.

This investigation also highlights the uncertainties that are introduced when exploring the relationship between physical process and species habitat metrics. The robust regression analysis results indicated a strong relationship between TUCW and hydrologic, geomorphic, and management variables with the top model explaining on the order of 65% of the variability in the data. However, when evaluating the relationship for UOCW, which is primarily a habitat suitability metric, the top model only explained

25% of the variability in the data. Uncertainty around predicted unobstructed channel widths is evident in the 95% confidence intervals displayed in Figures 11 to 13. This loss of predictive ability occurs because the spatial distribution of vegetated bars and/or islands within the channel exerts a strong control on UOCW. This is evident in Figure 4, where TUCW is somewhat consistent across all transects but UOCW is highly variable depending on the location of vegetated bars within the channel.

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Appendix I. Total Unvegetated Channel Width (TUCW) robust linear regression model selection results from a 5 step process, including a full description of procedures, which were also utilized for both UOCW modeling efforts.

In the first step, we determined the duration of peak discharge that best explained total unvegetated channel width by comparing AIC values of univariate robust regression models of 1, 3, 5, 10, 20, 30, 40, 50, and 60-day mean peak discharge durations. Three and 5 day durations coincide with SDHF flow duration management strategies. Duration covariates in models with a ΔAIC value ≤2.0 were passed along to the second modeling step. Based on AIC values, 40-day peak discharge duration was passed along to the second modeling step (Table I-1).

Table I-1. Akaike's Information Criterion (AIC), robust linear regression model selection of peak discharge duration influence on total unvegetated channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to model selection step 1.

Peak Discharge Duration	AIC	ΔAIC	Likelihood	Weight
40 Days	10566.42	0	1	1
30 Days	10711.63	145.21	2.933E-32	2.933E-32
20 Days	10712.11	145.70	2.304E-32	2.304E-32
50 Days	10718.45	152.04	9.676E-34	9.676E-34
60 Days	10719.81	153.39	4.924E-34	4.924E-34
10 Days	10729.72	163.31	3.456E-36	3.456E-36
5 Days	10750.46	184.0419	1.09E-40	1.09E-40
3 Days	10761.93	195.5165	3.5E-43	3.5E-43
1 Day	10789.89	223.47	2.981E-49	2.981E-49
Null	10937.86	371.44	2.204E-81	2.204E-81

Second, we combined the best annual duration model covariates and mean peak flows from the previous year over the same duration. Forty-day duration peak discharge was combined previous the previous year's peak discharge. Combinations were made with 0 to 100% of peak flow from the previous year at intervals of 20%. We hypothesized a lag effect of peak flows would carry over to the current year and this step would help us determine how important previous year peak flow was to total unvegetated channel width. Important combined previous and current year duration variables, in models with a ΔAIC value ≤2.0, were passed along to the fourth modeling step, which, in part, compared all hydrologic variables for ability to explain total unvegetated channel width (Tables I-2, I-4a). Based on AIC values, 40 Day peak discharge with 0% discharge from the previous year was passed along to the fourth modeling step.

Table I-2. Akaike's Information Criterion (AIC), robust linear regression model selection of current and previous year 40-day peak discharge influence on total unvegetated channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to model selection step 2.

Current and Previous Year Peak Discharge	AIC	ΔAIC	Likelihood	Weight
40 Day with 0% Last Year	10566.42	0	1	1
40 days with 40% Last Year	10698.72	132.31	1.86E-29	1.86E-29
40 days with 60% Last Year	10701.4	134.98	4.89E-30	4.89E-30
40 days with 20% Last Year	10702.75	136.33	2.49E-30	2.49E-30
40 days with 80% Last Year	10709.18	142.77	9.97E-32	9.97E-32
40 days with 100% Last Year	10720.28	153.86	3.88E-34	3.88E-34
Null	10937.86	371.44	2.20E-81	2.20E-81

Third, we performed the same procedure from step 2 for mean minimum discharge for 10, 20, 30, and 40 day durations. A step to add a lag effect of minimum discharge was not included due to little influence of low flows from previous year compared to high flows on total unvegetated channel width. Important minimum duration variables, in models with a ΔAIC value ≤2.0, were passed along to the fourth modeling step (Table I-3).

Table I-3. Akaike's Information Criterion (AIC), robust linear regression model selection of mean minimum discharge 40-day peak discharge influence on total unvegetated channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to model selection step 3.

Mean Minimum Discharge Duration	AIC	ΔAIC	Likelihood	Weight
30 Days	10866.91	0.00	1.00	0.92
20 Days	10871.94	5.03	0.08	0.07
10 Days	10876.65	9.74	0.01	0.01
40 Days	10903.87	36.96	0.00	0.00
Null	10937.86	70.94	0.00	0.00

In our fourth model selection step, we tried to identify to best hydrological and non-hydrological variables. All hydrological variables, including those from the best peak and minimum flow models, were compared by modeling total unvegetated channel width in univariate models (Table I-4a). We then performed the same procedure for all non-hydrological variables (Table I-4b). Covariates in important univariate models (ΔAIC≤2.0) were then passed to the final modeling step. We also included several other non-hydrological variables which have been hypothesized to have an importance in explaining total unvegetated channel width when utilized as an additive effect with 40-day duration peak discharge. For example, we hypothesize disked transects would have wider total unvegetated channel widths than non-disked transects given the same peak discharge duration and flow.

Table I-4a: Akaike's Information Criterion (AIC), robust linear regression model selection of hydrologic variables on total unvegetated channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to model selection step 4.

Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
40 Day Peak Discharge	10566.42	0	1	1
Mean June Discharge	10758.65	192.23	1.81E-42	1.81E-42
Mean Growing Season Discharge	10771.77	205.35	2.57E-45	2.57E-45
30 Day Minimum Discharge	10866.91	300.50	5.60E-66	5.60E-66
Null	10937.86	371.44	2.20E-81	2.20E-81

Table I-4b: Akaike's Information Criterion (AIC), robust linear regression model selection of non-hydrologic variables on total unvegetated channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to model selection step 4.

Non-Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
Wetted Width	10533.96	0.00	1	1
MILE	10717.44	183.48	1.44E-40	1.44E-40
Median Grain Size	10723.45	189.49	7.14E-42	7.14E-42
Herbicide	10910.09	376.13	2.11E-82	2.11E-82
Disking	10927.82	393.86	2.98E-86	2.98E-86
Channel Slope	10934.24	400.27	1.21E-87	1.21E-87
Null	10937.86	403.89	1.98E-88	1.98E-88

Finally, we used the best identified hydrologic and non-hydrologic variables, 40-day peak discharge with 0% of last year's flow and wetted width, along with other geomorphic and management variables to develop a suite of models to explain total unvegetated channel width observed from 2007 to 2015 (Table I-5). We included variables in final models with seemingly little explanatory power based on AIC values reported in step four. These included variables that were hypothesized to explain trends in total unvegetated channel width not captured by wetted width and 40-day peak discharge. For example, disking was included in the final modeling step due to the hypothesis disked transects generally had wider total unvegetated channel width than non-disked channels regardless of wetted width or 40-day peak discharge value.

Table I-5. Akaike's Information Criterion (AIC), robust linear regression model selection results of annual total vegetated channel width in the Associated Habitat Reach (AHR), 2007-2015.

Combined Models	AIC	ΔAIC	Likelihood	Weight
40 Day Peak + Wetted Width + Disking + Herbicide + Median Grain Size	10126.78	0.00	1	0.952
40 Day Peak + Wetted Width + Disking + Median Grain Size	10132.79	6.02	0.049	0.047
40 Day Peak + Wetted Width + Disking + River Mile + Herbicide	10143.94	17.16	0.00019	0.00018
40 Day Peak + Wetted Width + Disking	10149.2	22.42	1.35E-05	1.29E-05
40 Day Peak + Wetted Width + Disking + River Mile	10149.22	22.44	1.34E-05	1.28E-05
40 Day Peak + Wetted Width	10183	56.22	6.19E-13	5.90E-13
Null[1]	10937.86	811.08	7.53E-177	7.17E-177

[1]Null model tests the hypothesis that unobstructed channel width remained constant from 2007 to 2015.

Appendix II. Unobstructed Channel Width (UOCW) robust linear regression model selection results from multi-step process.

Table II-1. Akaike's Information Criterion (AIC), robust linear regression model selection of peak discharge duration influence on unobstructed channel width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to unobstructed channel width model selection step 1.

Peak Discharge Duration	AIC	ΔAIC	Likelihood	Weight
Day40	10695.70	0.00	1.00	1.00
Day20	10714.01	18.31	0.00	0.00
Day10	10715.64	19.94	0.00	0.00
Day30	10716.12	20.42	0.00	0.00
Day5	10722.40	26.70	0.00	0.00
Day50	10723.88	28.18	0.00	0.00
Day60	10725.44	29.74	0.00	0.00
Day3	10729.45	33.75	0.00	0.00
Day1	10742.26	46.56	0.00	0.00
Null	10799.37	103.67	0.00	0.00

Table II-2. Akaike's Information Criterion (AIC), robust linear regression model selection of current and previous year 40-day peak discharge influence on unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW model selection step 2.

Current and Previous Year Peak Discharge	AIC	ΔAIC	Likelihood	Weight
40 Day Peak with 0% Last Year	10695.70	0.00	1.00	0.91
40-day Peak with 80% Last Year	10702.08	6.38	0.04	0.04
40-day Peak with 100% Last Year	10702.67	6.97	0.03	0.03
40-day Peak with 60% Last Year	10703.02	7.32	0.03	0.02
40-day Peak with 40% Last Year	10706.22	10.52	0.01	0.00
40-day Peak with 20% Last Year	10712.08	16.38	0.00	0.00
Null	10799.37	103.67	0.00	0.00

Table II-3. Akaike's Information Criterion (AIC), robust linear regression model selection of mean minimum discharge 40-day peak discharge influence on unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW model selection step 3.

Mean Minimum Discharge Duration	AIC	ΔAIC	Likelihood	Weight
30 Day Mean Minimum	10784.35	0.00	1.00	0.42
20 Day Mean Minimum	10785.06	0.71	0.70	0.30
10 Day Mean Minimum	10785.44	1.09	0.58	0.25
40 Day Mean Minimum	10789.33	4.97	0.08	0.04
Null	10799.37	15.02	0.00	0.00

Table II-4a: Akaike's Information Criterion (AIC), robust linear regression model selection of hydrologic variables on unobstructed channel width (UOCW) width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW model selection step 4a.

Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
40 Day Peak Discharge	10695.70	0.00	1.00	1.00
Mean June Discharge	10748.83	53.13	0.00	0.00
Mean Growing Season Discharge	10759.10	63.40	0.00	0.00
30 Day Minimum Discharge	10784.35	88.65	0.00	0.00
Null	10799.37	103.67	0.00	0.00

Table II-4b: Akaike's Information Criterion (AIC), robust linear regression model selection of non-hydrologic variables on unobstructed channel width (UOCW) width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW model selection step 4b.

Non-Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
Main Channel Wetted Width	10698.6	0.00	1	1
Grain Size	10750.2	51.61	6.2E-12	6.2E-12
MILE	10765.7	67.02	2.79E-15	2.79E-15
DISKED	10783.9	85.23	3.11E-19	3.11E-19
Herb	10786.4	87.76	8.76E-20	8.76E-20
Null	10799.4	100.73	1.34E-22	1.34E-22
Channel Slope	10799.7	101.10	1.11E-22	1.11E-22
Channel Consolidation	10801	102.42	5.76E-23	5.76E-23

Table II-5. Akaike's Information Criterion (AIC), robust linear regression model selection results of annual unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW model selection step 5.

Combined Models	AIC	ΔAIC	Likelihood	Weight
40 Day Peak + Wetted Width + Disking + Herbicide + Median Grain Size	10579.55	0.00	1.00	0.83
40 Day Peak + Wetted Width + Disking + Median Grain Size	10584.06	4.51	0.10	0.09
40 Day Peak + Wetted Width + Disking + River Mile + Herbicide	10584.44	4.89	0.09	0.07
40 Day Peak + Wetted Width + Disking	10588.48	8.93	0.01	0.01
40 Day Peak + Wetted Width + Disking + River Mile	10590.79	11.24	0.00	0.00
40 Day Peak + Wetted Width	10617.95	38.40	0.00	0.00
Null[1]	10799.37	219.82	0.00	0.00

Appendix III. Unobstructed Channel Width (UOCW) logistic regression model selection results from multi-step process.

Table III-1. Akaike's Information Criterion (AIC), logistic regression model selection of peak discharge duration influence on unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 1.

Peak Discharge Duration	AIC	ΔAIC	Likelihood	Weight
40 Days	794.50	0.00	1.00	0.98
10 Days	803.95	9.44	0.01	0.01
20 Days	804.08	9.58	0.01	0.01
5 Days	806.58	12.08	0.00	0.00
30 Days	806.97	12.47	0.00	0.00
3 Days	811.26	16.76	0.00	0.00
50 Days	812.45	17.95	0.00	0.00
60 Days	813.69	19.18	0.00	0.00
1 Day	820.59	26.09	0.00	0.00
Null	862.86	68.36	0.00	0.00

Table III-2. Akaike's Information Criterion (AIC), logistic regression model selection of current and previous year 40-day peak discharge influence on unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 2.

Current and Previous Year Peak Discharge	AIC	ΔAIC	Likelihood	Weight
40 Day Peak with 0% Last Year	794.50	0.00	1.00	0.94
40 Day Peak with 80% Last Year	802.18	7.67	0.02	0.02
40 Day Peak with 60% Last Year	802.39	7.88	0.02	0.02
40 Day Peak with 100% Last Year	803.08	8.58	0.01	0.01
40 Day Peak with 40% Last Year	803.68	9.18	0.01	0.01
40 Day Peak with 20% Last Year	806.31	11.81	0.00	0.00
Null	862.86	68.36	0.00	0.00

Table III-3. Akaike's Information Criterion (AIC), logistic regression model selection of minimum discharge influence on unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 3. Due to the uncertainty of which minimum flow duration is the most important, coupled with the related nature of each duration variables, we passed along only 30-day mean discharge for two reasons. One, a 30-day duration was also found important for TUCW. Two, top duration models had similar explanatory power and using a single metric would decrease final model uncertainty.

Mean Minimum Discharge Duration	AIC	ΔAIC	Likelihood	Weight
30 Days	852.83	0.00	1.00	0.31
20 Days	852.87	0.04	0.98	0.30
10 Days	853.04	0.21	0.90	0.28
40 Days	855.03	2.20	0.33	0.10
Null	862.86	10.03	0.01	0.00

Table III-4a. Akaike's Information Criterion (AIC), logistic regression model selection of hydrologic variables on unobstructed channel width (UOCW) width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 4a.

Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
40 Day Peak Discharge	794.50	0.00	1.00	1.00
Mean June Discharge	825.42	30.92	0.00	0.00
Mean Growing Season Discharge	834.84	40.33	0.00	0.00
30 Day Minimum Discharge	852.83	58.33	0.00	0.00
Null	862.86	68.36	0.00	0.00

Table III-4b. Akaike's Information Criterion (AIC), logistic regression model selection of non-hydrologic variables on unobstructed channel width (UOCW) width in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 4b.

Non-Hydrological AIC table	AIC	ΔAIC	Likelihood	Weight
Main Channel Wetted Width	809.17	0.00	1.00	1.00
Grain Size	836.49	27.31	0.00	0.00
MILE	847.92	38.75	0.00	0.00
Herbicide	853.45	44.28	0.00	0.00
Disking	853.49	44.32	0.00	0.00
Channel Slope	862.80	53.63	0.00	0.00
Null	862.86	53.69	0.00	0.00
Consolidation	863.90	54.73	0.00	0.00

Table III-5. Akaike's Information Criterion (AIC), logistic regression model selection of annual unobstructed channel width (UOCW) in the Associated Habitat Reach (AHR), 2007-2015. Results correspond to UOCW (logistic regression) model selection step 5.

Combined Models	AIC	ΔAIC	Likelihood	Weight
40 Day Peak + Main Wetted Width + Disking + MILE + Herbicide	731.29	0.00	1.00	0.46
40 Day Peak + Main Wetted Width + Disking + Median Grain Size + Herbicide	731.46	0.17	0.92	0.42
40 Day Peak + Main Wetted Width + Disking + MILE	735.07	3.78	0.15	0.07
40 Day Peak + Main Wetted Width + Disking + Median Grain Size	735.99	4.70	0.10	0.04
40 Day Peak + Main Wetted Width + Disking	738.81	7.52	0.02	0.01
40 Day Peak + Main Wetted Width	756.98	25.69	0.00	0.00
Null	862.86	131.58	0.00	0.00

725 **Appendix IV.** Oracle Crystal Ball Monte Carlo simulation results for top UOCW regression model.

Crystal Ball Report - Full

Simulation started on 11/19/2015 at 1:49 PM
Simulation stopped on 11/19/2015 at 1:51 PM

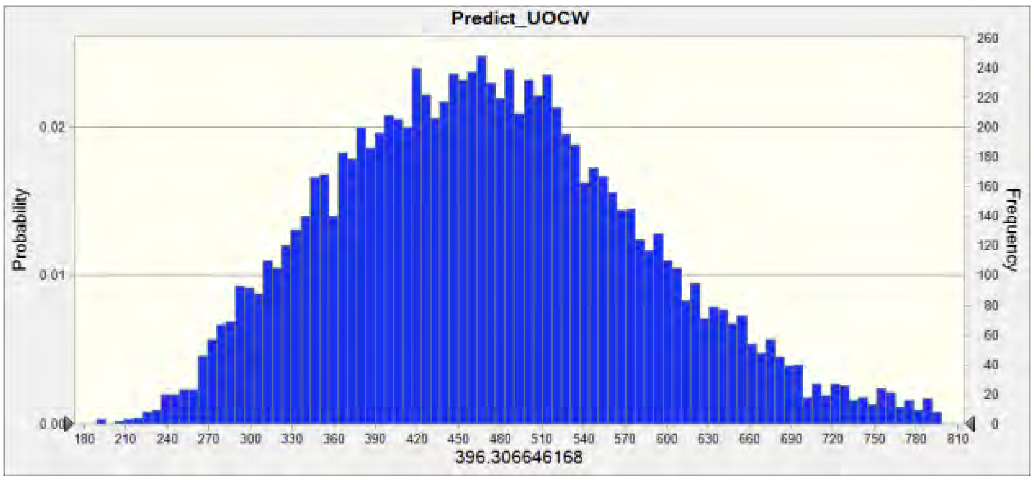
Run preferences:	
Number of trials run	10,000
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	69.77
Trials/second (average)	143
Random numbers per sec	717
Crystal Ball data:	
Assumptions	5
Correlations	0
Correlation matrices	0
Decision variables	0
Forecasts	1

Forecasts

Worksheet: [Copy of Correct Predictions.xlsx]UOCW_MONTECARLO

Forecast: Predict_UOCW **Cell: O2**

Summary:
Entire range is from 189 to 1056
Base case is 396
After 10,000 trials, the std. error of the mean is 1



Statistics:	Forecast values
Trials	10,000
Base Case	396
Mean	475
Median	468
Mode	---
Standard Deviation	116
Variance	13378
Skewness	0.5441
Kurtosis	3.58
Coeff. of Variation	0.2436
Minimum	189
Maximum	1056
Range Width	867
Mean Std. Error	1

Forecast: Predict_UOCW (cont'd) **Cell: O2**

Percentiles:	Forecast values
0%	189
10%	332
20%	374
30%	408
40%	439
50%	468
60%	497
70%	527
80%	567
90%	625
100%	1056

End of Forecasts

Assumptions

Worksheet: [Copy of Correct Predictions.xlsx]UOCW_MONTECARLO

Assumption: 40-DAY MEAN PEAK DISCH **Cell: J2**

Gamma distribution with parameters:

Location	1275
Scale	3548
Shape	1.387575088

Assumption: DISKED **Cell: K2**

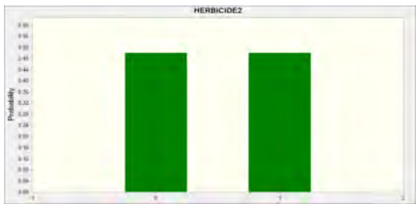
Discrete Uniform distribution with parameters:

Minimum	0.00
Maximum	1.00

Assumption: HERBICIDE2 **Cell: N2**

Discrete Uniform distribution with parameters:

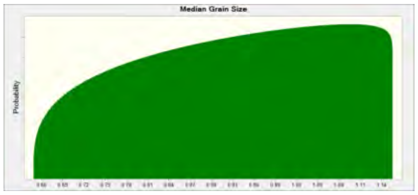
Minimum	0.00
Maximum	1.00



Assumption: Median Grain Size **Cell: M2**

Beta distribution with parameters:

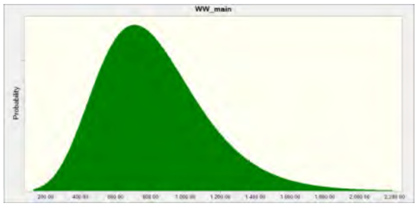
Minimum	0.65
Maximum	1.16
Alpha	1.296602692
Beta	1.039814681



Assumption: WW_main **Cell: L2**

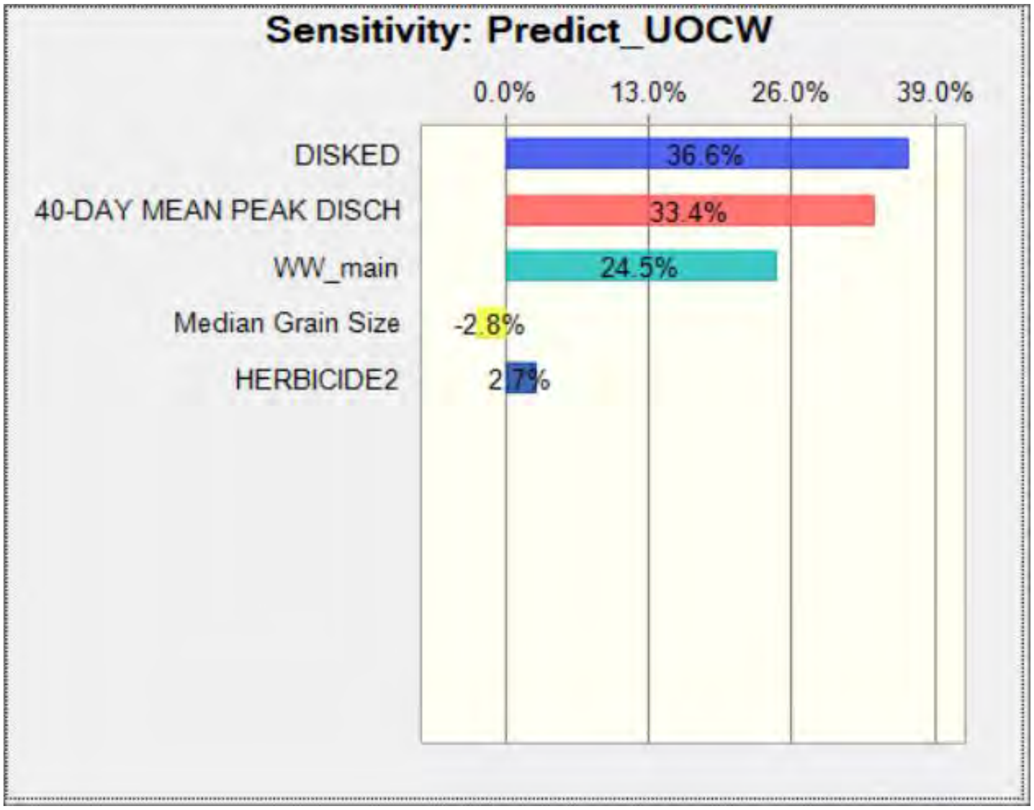
Lognormal distribution with parameters:

Location	-352.59
Mean	822.74
Std. Dev.	311.28



End of Assumptions

Sensitivity Charts



End of Sensitivity Charts

SUMMARY OF KEY FINDINGS

To date, the Platte River Recovery Implementation Program (Program) has invested nine years implementing an Adaptive Management Plan (AMP) to evaluate, in part, the Program's ability to contribute to the survival of whooping cranes during migration through increased habitat suitability and use of the Associated Habitat Reach (AHR). During this time, enough progress has been made to allow us to address critical uncertainties and assess the performance of the Flow-Sediment-Mechanical (FSM) management strategy. In short, given the results of our weight of evidence approach outlined in Chapters 1-4, the Executive Director's Office (EDO) of the Program concludes implementation of the FSM strategy will not create or maintain suitable in-channel roosting habitat for whooping cranes. A narrative of key findings follows.

We used data collected systematically along the central Platte River during 2001-2013 to evaluate riverine habitat selection within the AHR. The goal of our analysis was to develop habitat models to be used to inform and direct management activities the Program is able to implement. We were unable to establish a relationship between whooping crane use and flow metrics or total channel width, but rather found unobstructed channel width and distance to the nearest forest were good predictors of whooping crane use. Our findings indicate the Program would have the potential to influence whooping crane use of the central Platte River through increasing unobstructed channel widths that are <500ft and mechanically removing trees within areas where the unforested corridor width is <1,000ft.

We also used telemetry data obtained over the course of five years, 2010-2014, to provide an unbiased evaluation of whooping crane use of riverine habitat throughout the migration corridor. Based on findings in Chapter 2, we evaluated the influence of unobstructed channel width and distance to nearest forest on whooping crane selection of riverine habitat throughout the North-central Great Plains in the United States. Our results indicate probability of selection for unobstructed channel width was maximized around 750ft and unforested corridor width was maximized around 1,100ft. Based on results of Chapters 2 and 3, the Program informally accepted unobstructed channel widths of at least 600ft and unforested corridor widths of at least 1,000ft as highly favorable whooping crane riverine roosting habitat and as management objectives for whooping crane habitat at the Program's Pawnee complex between Odessa and Kearney, Nebraska.

As a final step, we used annual delineations of total channel width and maximum unobstructed channel width throughout the AHR to evaluate several flow and mechanical management alternatives hypothesized to create and maintain whooping crane roosting habitat. Results of our robust regression analyses indicate a positive relationship between unobstructed channel width and disking and peak discharge. Our results also indicate disking and flows substantially exceeding the magnitude and duration of a Short-Duration High Flow (SDHF) release are the only management activities able to create and maintain 600ft unobstructed channel widths believed to be favorable for whooping crane roosting habitat.

Implementation of SDHF releases, the physical process driver of the FSM management strategy, is hypothesized to produce suitable riverine roosting habitat for whooping cranes within the AHR. However, natural high flow events in 2007, 2008, 2010, 2011, 2013, and 2014 all exceeded minimum SDHF magnitude and duration and only with extreme high flow events occurring in 2015 did average unobstructed channel width exceed 600ft. As such, our weight of evidence approach leads us to conclude implementation of the FSM management strategy will not create or maintain favorable whooping crane riverine roosting habitat. Mechanical creation and maintenance of in-channel roosting habitat in the AHR, however, is ongoing and evaluations of use of these habitats are forthcoming.

TO: TECHNICAL ADVISORY COMMITTEE (TAC)
FROM: EXECUTIVE DIRECTOR'S OFFICE (EDO)
SUBJECT: PLATTE RIVER WHOOPING CRANE UNOBSTRUCTED CHANNEL WIDTH (UOCW) MEASURES
DATE: FEBRUARY 23, 2016

This memorandum presents:

1. A brief summary of Crane Trust thoughts on the EDO's approach to measuring unobstructed channel width (UOCW) used in the analysis for Chapter 2 of the Whooping Crane Synthesis Document,
2. EDO and Crane Trust investigations and comparisons of field measurements versus GIS measurements of UOCW, and
3. a discussion of Crane Trust recommendations, EDO responses, and possible reasons why there seems to be discrepancies in channel measures developed by Crane Trust personnel and the EDO.

Background

Chapter 2 of the Program Executive Directors Office (EDO) staff's Whooping Crane Data Synthesis Chapters (2015) utilizes GIS measured metrics and statistical analyses to model whooping crane habitat selection within the AHR. The EDO utilized a data set of 53 systematically collected unique river roosting locations gathered during systematic flight surveys conducted between 2003 and spring 2013. EDO analyses indicate stopover locations had an average unobstructed channel width (UOCW) of 508ft and that the probability of use was maximized at UOCWs ≥509ft. These results surprised Crane Trust (Trust) personnel which triggered an ad hoc evaluation of the Whooping Crane Tracking Partnership data.

Investigations Conducted by the Crane Trust

The Trust, and subsequently the EDO, utilized Whooping Crane Tracking Partnership data to further investigate UOCW at whooping crane stopover roosting sites. The Trust performed an investigation into the UOCW at whooping crane stopover sites identified by GPS tracked whooping cranes that stopped along the central Platte River. They determined 21 GPS tracked whooping cranes utilized 23 sites on the Platte River across the 10 migrations between fall 2010 and spring 2015. 18 of the 23 locations used in their analyses contained on the ground estimates of UOCW. The study was generally limited to stopover locations between Chapman and Overton, but four sites outside this area were included in the evaluation as well. To estimate UOCW, the Trust used a GIS to measure from bank to bank, occasionally including submerged and sparsely vegetated sandbars just above the water line, and bank to obstruction when an obstruction was present. Obstructions included islands with woody vegetation. This was done in part to evaluate the effectiveness of measuring UOCW utilizing GIS. The Trust utilized this data to produce and compare mean UOCWs measured by the Trust via GIS and field measurements collected by technicians of the Stopover Study. They found average UOCW, as measured in GIS by the Trust, at 23 stopover locations was 967ft (*SD*=478ft). On the ground measurements collected at 18 locations by Stopover Study crews averaged 814ft (*SD*=472ft).

Investigations Conducted by the EDO

In response to findings in the Trust's evaluation, the EDO made several investigations to determine why there was such disparity in average UOCW measures reported in Chapter 2 using 53 systematic unique observations and those reported by the Trust using 23 stopover sites recorded via telemetry. The first evaluation the EDO conducted was an analysis between data collected during drought years (2001-2006) and wet years (2007-2013). We conducted this assessment to evaluate the hypothesis that UOCWs, and thus whooping crane roost locations, were narrower during drought years than during wet years. We used the 53 systematic unique roost locations that were included in analyses reported in Chapter 2. We found UOCW at roost locations identified during the drought years (2001-2006) averaged 485ft (*SD*=310; median=411) and roost locations identified during wet years (2007-2013) averaged 521ft (*SD*=297; median=490).

The next evaluation the EDO made was to compare on the ground field measurements collected by the Program's whooping crane monitoring contractor to measurements collected via a GIS. This assessment was conducted to test the assumption measures collected remotely via a GIS by the EDO were substantially shorter than UOCW measures collected in the field by ground crews. The dataset included 86 measurements to use in the evaluation that were collected between fall 2009 and fall 2013. The EDO found GIS measures were, on average, 14ft (*SD*=37ft; median=13ft) longer than data collected in the field by the Program's Whooping Crane Monitoring contractor. We also found average UOCW, as measured via GIS, for the 86 locations was 693ft (*SD*=271) versus the 508ft (*SD*=299) reported in Chapter 2 for the 53 systematic, unique observations. The EDO suspects the substantial difference between UOCW reported in Chapter 2 (508ft) and measures obtained using the 86 locations from 2009-2013 (693ft) is related to individual whooping cranes that spent numerous days in managed areas (e.g., Trust, Rowe Sanctuary, Shoemaker Island) several years in a row. During these extended stays, the whooping crane(s) used several roost sites and thus the Whooping Crane Monitoring contractor collected a disproportionate number of transects for these individuals which skewed the UOCW measures higher.

The EDO previously conducted a similar analysis that compared 3 independent evaluations of GIS measures of UOCW collected by 3 EDO staff members to measurements collected in the field by the Program's Geomorphology and Vegetation Monitoring contractor. Results of these 3 evaluations were similar to what we found in this study in that there were no significant differences between field measurements and GIS delineations of UOCW.

The EDO then performed an independent evaluation of telemetry data mostly contained in the Trust's dataset. For this evaluation, however, the EDO removed 4 locations that were outside of the AHR (no annual imagery) and 1 location that was on Jeffery Island from the Trust's dataset. The EDO also added 3 locations to the dataset that were identified via telemetry data, but not included in the Trust's dataset. These revisions resulted in a dataset containing 23 stopover locations of which 15 had UOCW measures collected on the ground by Stopover Study crews. This dataset also contained 16 unique and independent roost locations as well as 7 locations that were multi-bird stopover roosts, consecutive day stopover roosts, multiple roost locations for a single night, or day-use sites; however, all 23 locations were included in EDO evaluations. We found measurements of UOCW collected by Stopover Study crews averaged 770ft (*SD*=377ft), measures of UOCW collected via GIS by the EDO averaged 639ft (*SD*=269ft), and measures of Unforested Channel Width (UFCW; Trust's modified version of UOCW) averaged 971ft (*SD*=455ft), respectively. The average difference (mean=388ft; SD=471) in paired measures between UFCW measures obtained via GIS by the Trust and UOCW measures obtained by the EDO were significantly (P<0.01) different from zero. Average differences (mean=214ft; SD=432) in paired measures of UFCW obtained via GIS by the Trust and UOCW measures obtained on the ground by Stopover Study crews were also significantly (P=0.0381) different from zero. However, the average difference (mean=-158ft; SD=298) in measures of UOCW produced by the EDO via GIS and those collected on the ground by Stopover Study crews were not found to be significantly (P=0.9701) different than zero (i.e., the 2 methods of collecting UOCW resulted in similar measures).

Summary of Findings and Considerations

After Trust evaluations were completed, they submitted a report to the EDO stating their findings and provided a few recommendations for the EDO to consider (Attachment 1; FYI, this memo was largely the EDO's response to the Trust report). One such recommendation was for the EDO to consider analyzing only data collected during the wet years (2007-2015) in the habitat selection analysis and using results of this analysis to inform management decisions. Given results of our first assessment (i.e., no difference between dry and wet year UOCW measurements), the EDO does not believe reducing the dataset to 31 observations is warranted or advisable.

UOCWs measured in a GIS by the EDO for 53 systematically collected, unique locations identified via the Program's whooping crane monitoring protocol averaged 508ft (*SD*=299ft; Chapter 2). Using similar methodology to evaluate 23 stopover locations identified via telemetry the EDO found the average UOCW was 639ft (*SD*=269ft). These datasets overlap spatially and temporally, but the Program's data spanned from 2003 to 2013 whereas the Stopover Study data only spanned from 2010 to 2015. Given the insignificant difference between the 2 measures and the fact the EDO recommendation for a minimum UOCW target of 600ft, we do not feel it is appropriate to only use 23 data points collected via telemetry and disregard 53 unique locations collected systematically by the Program's Whooping Crane Monitoring contractor from the analyses.

The EDO found a substantial and significant difference between measures collected remotely via a GIS by the Trust and the EDO. Most if not all of this difference can likely be attributed to the way obstructions were defined. The Trust defined obstructions as islands with woody vegetation or channel bank lines while the EDO considered heavily vegetated islands and bank lines to be obstructions. Given results of EDO comparisons of GIS measurements of UOCW to those measured in the field via the Geomorphology and Vegetation Monitoring study and the Whooping Crane Monitoring study, we feel delineations made by the EDO best represent UOCW. We also believe delineations made by the Trust better represent a slightly modified measure of unforested or total channel width (bank to wooded island or bank to bank) evaluated in chapter 2 which were not included in the top models as ranked by Akaike information criterion **(**AIC**)**.

Ideally the habitat selection analyses conducted for Chapters 2 and 3 would have included measurements collected in the field at use and random locations; however, such data does not exist at random locations. As such, the EDO was restricted to using annual imagery to assess and delineate UOCW at use and available locations. Given previous investigations, the EDO believes heavily vegetated islands identified as obstructions in GIS delineations of UOCW would generally be identified in the field as obstructions as well. The EDO found fairly substantial, but not significant differences between measures collected remotely via GIS and those collected in the field by Stopover Study crews. We are unsure why these discrepancies exist when comparisons to data collected by the Program's Whooping Crane Monitoring crew and Geomorphology and Vegetation Monitoring crews were nearly identical to measures collected remotely by the EDO. A potential reason for these discrepancies may be the Stopover Study crews might be being less stringent on what is considered an obstruction than Program contractors are, but that is simply speculation.

Additional Review Comments/Recommendations

The Trust recommended the EDO consider using model averaging to obtain a 'best' model for Chapter 2. The EDO and WEST do not feel this is appropriate given, among other things, the sparsity of the data and the uncertainty that is not accounted for in the final model. The EDO responded by saying: "As for model-averaging, I'll look into it with other statisticians again, but I don't like it because it only adds uncertainty that can't be accounted for in the final model. As you are probably well aware, AICc penalize overly complex models as one could add any number of nonsensical variables and still end up with a lower log likelihood regardless of no increase in predictive power. The goal of using AIC is to find a balance between predictive ability and parsimony...and that's what I suggest our results show. Here's why I don't like it. Say we model average across the top 5 models by AIC weight. Let's also say the top 5 models all carry 20% of the weight of evidence equally (i.e., 20% * 5 = 100%). Given UD only shows up in the fifth model and given the model weights, the coefficient for UD would be 20% of what it shows up to be in the model (coefficient / 5) since the coefficient in the top 4 models is 0.0. Given this minuscule contribution to the model averaged result and an uncertainty that I don't believe Burnham and Anderson have yet to describe how to calculate (what's the error around the 4 zeros for the top 4 models that don't include UD???), I dislike model averaging even though others may disagree." Despite the concerns mentioned above, the EDO and WEST proceeded to investigate model averaging to assess if the resulting model has greater predictive ability than the current best model as ranked by AIC. However, results of our investigations indicate model averaging is not possible when using penalized regression splines.

The Trust (and ISAC) suggested the EDO consider evaluating the US Fish and Wildlife Service's (FWS) whooping crane data. Among other issues, it is well known the FWS database contains a detection bias toward conservation properties where whooping cranes are more likely to be detected and large locational errors associated with most locations. Despite these inherent limitations, the EDO is in the process of analyzing as much of the FWS data as possible using similar methodology used to measure UOCW in Chapters 2 and 3. These evaluations are forthcoming as we are in the process of gleaning as much information as possible from the FWS data.

The Trust also suggested the EDO examine the accuracy of several UOCW measures contained in the shapefile that was submitted to the Trust. The EDO reviewed several UOCW measures and confirmed there were a few errors in the original file and thus every use and available location necessary was re-delineated. The re-delineation of UOCW measures and inclusion of 2 additional locations resulted in a slight increase in the average UOCW for the systematic unique locations. The final UOCW averaged 523ft (SD=279) versus 508ft (SD=299ft) as originally reported. Though there was not much change in the average UOCW, we proceeded to re-analyze all of the data. The results of the updated analysis indicated probability of use was maximized when UOCW was ≥488ft versus ≥509ft as originally reported. We also found probability of use was maximized when distance to nearest forest (NF) was ≥523ft versus ≥520ft as originally reported. Results of these 2 metrics combined indicate probability of whooping crane use is maximized in channels with UOCWs ≥488ft and unforested corridor widths ≥1,046ft which is indistinguishable from what was originally reported.

<u>Conclusions</u>

Given results of several evaluations including:

- comparisons between the Program's Geomorphology and Vegetation Monitoring data and 3 independent GIS delineations of UOCW,
- comparisons between the Program's Whooping Crane Monitoring data and GIS delineations of UOCW,
- insignificant difference between the Stopover Study and EDO GIS delineations of UOCW,
- the nominal (<10ft) change in average UOCW when fine-scale adjustments were made to GIS delineations of UOCW, and
- the inconsequential change in modeling results after fine scale adjustments were made to GIS delineations of UOCW

the EDO contends that though there were differences in interpretations of what is deemed 'heavily vegetated' (i.e., obstruction) between Trust and EDO personnel, there is no need to further evaluate UOCW measures as delineated by the EDO. However, we also contend care must be taken when using GIS delineations of channel-width metrics and such metrics must be clearly defined.

ATTACHMENT 1:

CRANE TRUST REPORT SUBMITTED TO THE EDO

Comparing Estimated Unobstructed Channel Widths using ArcGIS and On-The-Ground Assessments for Whooping Crane Stopovers sites along the Central Platte River, NE

Crane Trust Internal Report
Shared with the PRRIP

Andrew J. Caven and Ross McLean
Crane Trust
2015

Introduction

Chapter 2 of the Platte River Recovery and Implementation Program's Data Synthesis Compilation of Whooping Crane (*Grus americana*) Habitat Synthesis Chapters (2015) utilizes GIS and sophisticated statistical analyses to model Whooping Crane habitat selection along the Big Bend Region of the Platte River. The Program utilizes a data set of 55 unique river roosting locations garnered from systematic flight surveys conducted between 2003 and 2015. The program (2015) found that stopover locations had an average of 508ft of unobstructed channel width (UCW) and that the "probability of use was optimized at 509ft." The "…USFWS (1986) reports that Whooping Crane roosting habitat is optimized at unobstructed channel widths ≥1,158ft and channels with unobstructed widths <500ft were deemed unsuitable roosting habitat" (PRRIP 2015). Though the US Fish and Wildlife Service's Whooping Crane data contains a known detection bias toward conservation properties, where Whooping Cranes are more likely to be detected, the large differences between the findings of these respective studies warrants further investigation via additional data.

We utilize the Whooping Crane Tracking Partnerships (2015) data to further investigate channel width at Whooping Crane stopover roosting sites along the Big Bend of the Platte River. This data contains exact on the ground estimates of unobstructed channel widths at Whooping Crane stopover sites, and we utilize this data to produce a simple mean unobstructed channel width. However, to experiment with the methodology used by the PRRIP to investigate unobstructed channel width, we generally try to repeat their methodology using ArcGIS to measure unobstructed channel width starting perpendicularly to the river bank. We compare "on-the-ground" measurements to those made in Arc GIS. We also compare stopover data PRRIP's data. These datasets have both significant overlap spatially and in years as well as large differences. The PRRIP's data covers a longer timespan from 2003 to 2015, whereas the Stopover Data simply covers from 2010- 2015. The PRRIP's database goes back much further and includes more dry years which might explain some or most of the variation in the data. However, we may want to consider omitting the driest years in the analysis for setting management objectives.

Methods

We performed an initial investigation into the unobstructed channel width of Whooping Crane (WHCR) (*Grus americana*) stopover sites along the Big Bend Region of the Platte River in Central Nebraska. We utilized Whooping Crane stopover data from GPS tracked Whooping Cranes that stopped along the Platte River during their migration through Nebraska. We determined that 21 GPS tracked Whooping Cranes utilized 24 sites along the Big Bend Region of the Platte River across the 10 migrations between fall 2010 and spring 2015. The study is demarcated by the respective bridge segments at Chapman, NE to the East and Overton, NE to the West. To estimate unobstructed width, we measured from bank to bank including occasionally submerged and sparsely vegetated sandbars just above the water line, and bank to obstruction, when an obstruction was present. Obstructed channels included islands with woody vegetation for example. This was done in part to evaluate the effectiveness of measuring unobstructed width bank to bank utilizing GIS. To evaluate our accuracy in doing this process we compared measurements made using ArcGIS to "on-the-ground" measurements made by technicians using rangefinders working in conjunction with USGS, the Crane Trust, and PRRIP on the Whooping Crane Tracking Partnership's "Stopover Project."

Results

We found that the mean unobstructed channel width recorded via the WHCR GPS tracking partnership's stopover study and the PRRIP's Aerial Monitoring Surveys are significantly different using a 2-tailed t-test for independent samples. This is true regarding both the GIS UCW measurements ($t= 5.62$, $p < 0.01$) and the "on-the-ground" data recorded by technicians ($t= 3.61$, $p < 0.01$) made for WHCR stopover locations, which both reported significantly larger UCW measurements than the PRRIP (2015) study. The two different measurements (on ground and GIS) of "unobstructed channel width" made while analyzing the stopover study data are not statistically different using a standard p value ($p>0.05$) ($t = 1.02$, $p= 0.3149$). As the PRRIP (2015) states in their report "discrepancies in these measurements could simply be an artifact of biases in the observational data…." as unobstructed channel width is difficult to define and measure in an ever changing braided river system. A standard deviation for PRRIP's mean unobstructed channel width was not reported in their synthesis chapters. Thus, we utilized the range reported therein and used the equation SD= Range/C, to estimate the standard deviation of their mean. Determining "C" can be difficult; however, most data on a standard normal curve are contained within 3 standard deviations of the mean, so we assumed "C", our constant, to be a value of 6. This may have underestimated the standard deviation of PRRIP's average unobstructed channel width. However, this was the best assumption we could make not having basic summary statistics for their measurements.

We advocate that given the difference between our respective measurements, the PRRIP should display more basic summary statistics in their work to help us better scrutinize their data. We also advocate that PRRIP uses all available data sets, including the GPS tracking data (USGS 2015), the US FWS database (2015), as well as their WHCR aerial monitoring surveys to increase the "N" (total number of sites) in their database when conducting analysis of unobstructed channel widths. Where points of data overlap, GPS tracking and stopover data (USGS 2015) should provide very valuable information in calibrating measurements of unobstructed channel width, as this data was collected on the ground by qualified technicians.

However, we found similarly to the PRRIP (2015) that GIS and on the ground measurements were congruent, analogous, and not statistically different. Please see Table 1 and Table 2 for summary statistics and Appendix 1 for an explanation of unobstructed channel width measurements for all stopover sites along the Big Bend Region of the Platte River, NE from 2010 to 2015. We think the major reason for a difference in mean unobstructed channel width is likely the high number of dry years in the PRRIP's database. Thus incorporating a larger "N" may help alleviate some this problem, but not the entire problem if the scope of the study is increased only in number of points but not span of years, which would help describe more temporal variation in the data. It may also be pertinent to eliminate observations from drought years from the analysis because in this situation the WHCRs are using what habitat is available and preferred within a denuded sample, and management objectives should not be set based on worst case scenario flows. We would hope that in setting reasonable goals for management we can offset those low water years with supplemental water when possible and necessary. Finally, looking carefully at the data for each one of these stopover locations, it is apparent that trees can play a dynamic role depending on weather and disturbance. One a calm day away from development a WHCR would likely choose a wide open braided channel with clear banks and giant vistas. However, given development's encroachment, high winds, and inclement weather, it may occasionally be beneficial for WHCRs to have access to some partially wooded areas. This may explain some selections of narrower channel sizes. It would be very hard for a model to account for all this variation; however, it may be worthwhile in the long rung to investigate the climatic contexts under which Whooping Cranes choose more open and more narrow channels.

Concluding Remarks

We greatly appreciate you entertaining our opinions and data here. Whooping Crane Habitat along the river is our mission and we work to stay as informed as possible on matters of habitat conservation regarding this species. We hope this simply analysis of the WHCR tracking partnership's stopover data, for the purposes of assessing the average unobstructed channel width of Platte River WHCR roosting sites is helpful in going forward with the PRRIP's analysis. Please let us know if we can be helpful in any way going forward. Thank you again for considering our comments, feedback, and analyses in your work.

Table 1. Summary Statistics of Current Sites Stopover via On-Ground and GIS Measurements

	Whooping Crane GPS Tracking Stopover Locations Data	
	On-The-Ground Data	**Estimates Using GIS**
N	**18**	**23**
Mean	**248.17m**	**294.60m**
	814.20ft	**966.56ft**
Std. Dev	**144.99m**	**145.69m**
	472.42ft	**477.97ft**
Median	**229.50m**	**282m**
	752.95ft	**925.20ft**
Max	**515m**	**524m**
	1,689.63ft	**1719.16ft**
Min	**53m**	**80m**
	173.88ft	**262.47ft**

Table 2. Statistical Comparison of Mean Channel Width Estimated via GIS for Two Data Sets

Comparison of Unobstructed Channel Widths			
	PRRIP 2015	**Stopover (On-the Ground)**	**Stopover GIS**
N	53	18	23
Mean	508ft	814.20ft	966.56ft
Range	48-1,459ft	173.88ft-1689.63ft	262.47-1,719.16ft
SD	235.17ft (est.)	472.42ft	477.97ft
(2-way t-test for independent samples)			
PRRIP	XXX	t= 3.61* p= 0.0006 df=69	t= 5.62* p=0.0001 df=74
SO-OG	XXX	XXX	t = 1.02 p= 0.3149 df = 39
SO-GIS	XXX	XXX	XXX

APPENDIX 1. Stopover Locations by Migration Season

Season	Bird ID	Stopover ID	UCW (OG)	UCW (GIS)	Roost GPS	Cranes	Notes
Spring 2015	F53	2015_04_11_F53_R1	308 m	305m	40.7498, -98.5773	4 adults	Pig operation visible to north. Site is just west of B04 in Spring 2013.
Spring 2015	D21	2015_04_12_D21_R1	149 m	149m	40.7883, -98.4414	4 adults	Crane Trust property (Mormon Island). Really good wetland habitat to south given waterfowl hunting management, and wet meadows to north used by whooping cranes.
Fall 2014	D33	2015_11_10_D33_R1	107 m	103m	40.9028, -98.2496	unknown	This is an unusual site in that it is in a very wide part of the river, but there are vegetated islands breaking up that large channel giving a rather low unobstructed channel width. With management this area could be far wider. However, the train tracks to the southeast and housing community to the south do not make this a prime whooping crane stopover location regardless.
Spring 2014	A02	2014_04_04_A02_R1	142 m	185m	40.6604, -98.9985	unknown	On the ground measurement is exactly same as GIS when the 2013 CIR filter is used. However, this does not take into account that the sandbar to the north is a part of the river channel when looking at the site from a satellite image.
Spring 2014	F48	2014_04_04_F48_R1	264 m	264m	40.6667, -98.9139	unknown	Roost is west of Rowe Sanctuary and just east of where B04 and BO5 roosted in the Spring of 2011. A02 roosted ~7 km west of F48 on the same night but A02 had a day use point in the field just north of roost site of F48 on the same day F48 was still in the area.
Spring 2014	B04	2014_04_05_B04_R1	442 m	444m	40.759, -98.5206	unknown	131 meters west of roost site for D41 and D28 in Fall 2013
Fall 2013	D28 and D41	2013_11_11_D28_D41_R1	444 m	403m	40.7597, -98.5193	2 tracked cranes	The cranes roosted 131 meters east of the roost site for B04 in Spring 2014.

Spring 2013	C02	2013_04_10_ C02_R1	82m	140m	40.7477, -99.8017	unknown	Crane spent three days on river. Far west site surrounded by trees.
Spring 2013	D31	2013_04_11_ D31_R1	150 m	145m	40.6642, -99.2504	unknown	Potential channel estimates would require a great deal of management including a large amount of tree clearing.
Spring 2013	B07	2013_03_28_ B07_DU1	n/a	508m	40.7364, -98.6213	2 adults	The field data was taken on land upstream from the roost site at the day use location instead of in the river at the roost site. This means that the ground data is missing the exact roost site measurements. The reason is not entirely clear given that the land on the north side of the channel belongs to the state and is a wildlife management area.
Spring 2013	D30	2013_03_06_ D30_R1	210 m	220m	40.6624, -98.9345	5 whooping cranes	Site is west of Rowe Sanctuary and near a roost site from B04 and B05 in Spring 2011 as well as F48 in Spring 2014
Spring 2013	D30	2013_03_07_ D30_R1	259 m	354m	40.708, -98.7718	5 whooping cranes	
Spring 2013	B04	2013_04_06_ B04_R1	n/a	205m	40.7513, -98.564	unknown	No field data recoded for this stopover site. Crane Trust spotted untracked family of whooping cranes (2adults, 1juvenile) just east of this location on the Platte during an aerial survey 13 April 2015.
Fall 2012	C07	2012_11_08_ C07_R1	n/a	n/a	40.6962, -99.6622	5 adults and 1 juvenile	Site is considered a non-wetland roost because it was on a narrow island that lies between the dry and very narrow channels running north and south. The island looks like a wet meadow. This outlier roost selection behavior should be factored into the selection made by the same bird (C07) in the spring of 2012. Day use site was on the south channel.

Fall 2012	D28	2012_10_29_D28_R1	249 m	262m	40.6662, -98.917	2 adults and 1 juvenile	Cranes spent a week on Platte River. Area also used by 2 tracked Whooping Cranes (B04 & B05) in the spring of 2011 and by F48 in spring of 2014.
Fall 2012	D28	2012_10_29_D28_R2	122 m	282m	40.6631, -98.9755	2 adults and 1 juvenile	Sand bar to south could potentially be partially submerged by higher flows. The exact bank also seems unclear due to this and thus may be the reason why ground measurements for channel width are half what is expected when using ArcGIS.
Fall 2012	D29	2012_11_16_D29_R1	149 m	490m	40.7569, -98.5277	1 juvenile	Spent a week on the Platte River. West of Alda Farms
Fall 2012	D29	2012_11_16_D29_R2	362 m	490m	40.7510, -98.5347	1 juvenile	Wider channel area with the most activity surrounding it according to Argos data. In fact, there is no data on the GIS map that matches up with the area evaluated for the R1 site. May have been based on flight or ground observations for roosting site?
Fall 2012	B07	2012_11_22_B07_R1	515 m	524m	41.3984, -97.0863	unknown	Site farther east than most. Three miles south of Schuyler, NE and HWY 30. River bank to north is heavily forested, creating a strong buffer between river and disturbance.
Spring 2012	C07	2012_04_11_C07_R1	53m	80m	41.1778, -101.4203	1 adult	C07 chose narrow channels along the Platte on multiple occasions. Roost site measurements taken from sand bar north of channel. This would make measurements highly variable on any given day due to the potential for hydrological change in that channel. Roost site is also very far west for the normal Nebraska flight corridor. Potential width given management is dependent on how much vegetation (trees) are cleared from island that separates channel.
Spring 2012	C09	2012_04_14_C09_R1	460 m	316m	40.7933, -98.3971	unknown	South of Mormon Island/ Crane Trust. Just east of the Bunker Blind.

Fall 2011	C16	2011_11_15_C16_R1	n/a	505m	41.384, -97.245	unknown	Site is far to the east for normal whooping crane range but river channel is in great condition. Each side is covered in trees but this blocks any surrounding disturbances. Most importantly though the channel is braided and wide with a lot of sandbar surface area to choose from in the middle of the river channel. Major Powerlines to the west run across river channel though which is a significant hazard.
Spring 2011	B04 and B05	2011_04_02_B04_B05_R1	n/a	286m	40.6665, -98.9204	2 tracked cranes	B04 and B05 traveling together. Site is heavily used by Whooping Cranes. Rowe Sanctuary is east of site and river channel in this area is close to ideal, with braided sand bars and wetland habitat to the south and parts of the north. Many of the disturbances are blocked by tree lines.
Fall 2010	A02	2010_11_23_A02_R1	n/a	116m	40.663, -99.199	unknown	Heavily forested area south of Kearney. Large buffer of between I-80 and site given forest and braided river channels. If trees in the middle of the channel were managed, the habitat would be considerably wider and more open. Near roost site of D31 in Spring 2013.
Season	Bird ID	Stopover ID	Unobstructed Channel Width (on ground)	Unobstructed Channel (using GIS)	Roost GPS	Number of Cranes	Notes
Spring 2015	F53	2015_04_11_F53_R1	308 m	305m	40.7498, -98.5773	4 adults	Pig operation visible to north. Site is just west of B04 in Spring 2013.
Spring 2015	D21	2015_04_12_D21_R1	149 m	149m	40.7883, -98.4414	4 adults	Crane Trust property (Mormon Island). Really good wetland habitat to south given waterfowl

							hunting management, and wet meadows to north used by whooping cranes.
Fall 2014	D33	2015_11_10_ D33_R1	107 m	103m	40.9028, -98.2496	unknown	This is an unusual site in that it is in a very wide part of the river, but there are vegetated islands breaking up that large channel giving a rather low unobstructed channel width. With management this area could be far wider. However, the train tracks to the southeast and housing community to the south do not make this a prime whooping crane stopover location regardless.
Spring 2014	A02	2014_04_04_ A02_R1	142 m	185m	40.6604, -98.9985	unknown	On the ground measurement is exactly same as GIS when the 2013 CIR filter is used. However, this does not take into account that the sandbar to the north is a part of the river channel when looking at the site from a satellite image.
Spring 2014	F48	2014_04_04_ F48_R1	264 m	264m	40.6667, -98.9139	unknown	Roost is west of Rowe Sanctuary and just east of where B04 and BO5 roosted in the Spring of 2011. A02 roosted ~7 km west of F48 on the same night but A02 had a day use point in the field just north of roost site of F48 on the same day F48 was still in the area.
Spring 2014	B04	2014_04_05_ B04_R1	442 m	444m	40.759, -98.5206	unknown	131 meters west of roost site for D41 and D28 in Fall 2013
Fall 2013	D28 and D41	2013_11_11_ D28_D41_R1	444 m	403m	40.7597, -98.5193	2 tracked cranes	The cranes roosted 131 meters east of the roost site for B04 in Spring 2014.
Spring 2013	C02	2013_04_10_ C02_R1	82m	140m	40.7477, -99.8017	unknown	Crane spent three days on river. Far west site surrounded by trees.

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ATTACHMENT 2:

CRANE TRUST EMAIL RESPONSE TO EDO MEMO

From: Andrew Caven [mailto:acaven@cranetrust.org]
Sent: Wednesday, December 09, 2015 12:00 PM
To: David Baasch <baaschd@headwaterscorp.com>; Ross McLean <rpmclean1777@gmail.com>; Brice Krohn <BKrohn@cranetrust.org>
Cc: Jerry Kenny <kennyj@headwaterscorp.com>; Chad Smith <smithc@headwaterscorp.com>; Jason Farnsworth <farnsworthj@headwaterscorp.com>
Subject: Unobstructed Channel Width Measurements

Hey Folks,

I appreciate this write up. As a small staff I will not have time to dedicate to any further report/comments revision. I have a couple collaborative manuscripts underway, several end of year reports related to grants and permitting, and long-term planning amongst other things. However, I have just a couple comments on the discussion draft you just sent out. I think it is important to address the differences between your N of 86 and N of 53 databases for UOCW formally. As that was part of our conversation, I would like it reflected in this document. Page 2 paragraph 2 of the "PLATTE RIVER WHOOPING CRANE UOCW MEASURES" discussion summary address the differences between AIM's on the ground and the EDO's GIS data, but does not actually formally state the UOCW measurements from those surveys. This dataset (on the ground) has a mean UOCW of 707ft (SD=270FT). I would suggest- 1 you address formally why you suspect there is almost 200ft difference between your 2 datasets and 2- include the basic summary statistics of both measurements in said paragraph (pasted below). We would like this email also formally submitted as comment. You also did not let me know what you found regarding the handful of measurements in your N of 53 databases that I highlighted because I found discrepancy with them? Please let me know what you find with that. After addressing that, my comments will be totally complete. My efforts are only meant to helpful. Thank you for trying to address my concerns; I look forward to continued cooperation in the future.

Page 2 Paragraph 2- PLATTE RIVER WHOOPING CRANE UOCW MEASURES- PRRIP

"The next evaluation the EDO made was to compare on the ground field measurements collected by the Program's whooping crane monitoring contractor to measurements collected via a GIS. This assessment was conducted to test the assumption measures collected remotely via a GIS were substantially shorter than UOCW measures collected in the field by ground crews. The dataset included 86 measurements to use in the evaluation that were collected between fall 2009 and fall 2013. The EDO found GIS measures were, on average, 14ft (median=13ft) longer than data collected in the field by the Program's whooping crane monitoring contractor. The EDO previously conducted a similar analysis that compared 3 independent evaluations of GIS measures of UOCW collected by 3 EDO staff members to measurements collected in the field by the Program's Geomorphology and Vegetation Monitoring contractor. Results of these 3 evaluations were similar to what we found in this study in that there were no significant differences between field measurements and GIS delineations of UOCW.

SUM GIS vs FIELD PRRIP

N=86	**GR**	**GIS**
AVE M.	216	211
AVE ft.	**707**	**693**
ST DEV M.	82	96
ST DEV ft.	**270**	**316**

Thanks again for addressing my concerns.

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP or Program)
U.S. Fish and Wildlife Service TAC Comments on Whooping Crane Synthesis Documents and Responses from the Executive Director's Office (EDO)

Comment 1. Discussion of Bias

While Program information reported in Chapter 2 and 3 was collected systematically, it is difficult to conclude, given existing information, that Program collected data is unbiased. The FWS database is populated using public opportunistic observations, and thus, the non-systematic collection of data implies bias. However, the Program data (systematic aerial and GPS) has limitations in data collection, such as observation or location bias (aerial- observers may be more likely to detect a crane in one channel configuration vs. another), capture bias (GPS), and limited reporting of GPS data that could all introduce statistical bias. Further complicating the data is that the GPS data is populated from a very small subset of the total population. However, we anticipate that the GPS data contains the least influence from human induced bias. It is appropriate to make comparisons according to systematic and non-systematic data collection, but the Service cautions the discussion of relative bias between datasets because they can be compared to the actual statistical population (i.e., total actual Platte River use sites). Because the relative bias between datasets cannot be determined, neither can be discounted and discussions related to them should appropriately portray this.

Bias is also unavoidable within the calculated width measurements for use locations. We recommend appending the calculated measurements (shapefiles, images, etc.) to the chapters for transparency and to assist in making the analyses reproducible.

<u>EDO Response:</u>

<u>Monitoring Bias</u>

The discussion of bias in the chapters was intended to specifically address detection bias associated with opportunistic observations. Aerial and GPS telemetry observations are collected systematically to minimize biases due to unequal observer effort. This is important because all locations having an equal probability of inclusion in the dataset (systematic data collection) is a fundamental assumption of resource selection analyses (Manly et al. 2007). The chapter text will be revised to clarify this point.

The Service's comment indicates larger concerns about other sources of bias associated with systematic aerial and GPS telemetry monitoring data. These concerns are addressed below:

1. *Aerial monitoring observation or location bias – The systematic aerial observation data was analyzed to evaluate the influence of final model covariates (unobstructed channel width and nearest forest) on the probability of whooping crane detection. Detection was found to be independent of these covariates.*
2. *GPS capture bias – The GPS telemetry study design included measures to address various aspects of capture bias. Juvenile, sub-adult, and adult birds were tagged to address the issue of potential biases associated with differential habitat selection by various age classes. Birds were telemetry-*

marked throughout the summer and winter range using various capture methods to address the potential for biases associated capture location or method.

3. *GPS reporting bias – The GPS telemetry units are designed to address the issue of GPS reporting bias. The units record four GPS locations daily and store that data for periodic uploading. The data is stored on the unit until a successful upload is achieved. This prevents underreporting bias due to environmental conditions at the time and place the GPS location is recorded.*
4. *Small subset of the population in GPS telemetry study – The GPS telemetry study involved the tagging of approximately 10% of the wild migratory flock. This is an extremely high proportion of the total population and is almost unheard of in telemetry studies. If marking of 10% of a population is inadequate, no past telemetry analyses should be considered valid.*

The analyses presented in Chapters 2 and 3 assess the relative probability of whooping crane selection of in-channel habitat based on a range of habitat covariates. Program analyses of aerial monitoring data found the covariates in the top AHR riverine selection model did not influence the probability of detection. In order for biases in GPS monitoring data to influence the flyway selection analysis, one would have to assume that 1) certain river channel conditions prohibited telemetry equipment from functioning properly, or 2) the trapping team captured and marked cranes that select riverine habitat differently than the population as a whole. Neither of these concerns has been voiced by telemetry project team members that include representatives of the U.S. Fish and Wildlife Service, U.S. Geological Survey, Canadian Wildlife Service, Crane Trust, International Crane Foundation, Gulf Coast Bird Observatory, and Parks Canada.

The EDO is not aware of a method to quantify and assess the differences in bias between the USFWS database, aerial monitoring, and GPS telemetry datasets. However, it is possible to qualitatively assess the differences in bias as they are relevant to the Program's resource selection analyses. Specifically, the opportunistic location data in the USFWS database is known to include detection bias due to unequal observer effort which is highly skewed toward reaches of the AHR managed by conservation organizations. This bias violates the fundamental assumptions of resource selection analyses. In contrast, the systematic aerial and GPS telemetry monitoring efforts were designed to minimize the potential for biases associated with detection or the marked population so as to not violate the fundamental assumptions of resource selection analyses. Accordingly, it is appropriate to give more weight to the results of analyses performed using the systematic aerial and GPS telemetry data.

At the request of the USFWS, the Program developed a habitat selection model that included 20 opportunistic 'GPS-quality' whooping crane group observations located in a Platte River channel (2001-2014) from the USFWS database that were not part of the Program's systematically collected dataset. The result is a mixed analysis that includes both systematic aerial observations and opportunistic observations from the USFWS database. The methods and results are presented in Chapter 2. As expected, the inclusion of opportunistic observations increased the UOCW and NF at which probability of use was maximized.

Bias in Width Measurements

The EDO will package and make available all GIS and R (statistical analysis code) files associated with the analyses that were conducted in Chapters 2, 3 and 4. In order to minimize the potential for biases to be introduced into the width measurements, all use and available points were plotted the same in the GIS (i.e., same size, shape, color, etc.) so the technician conducting the work would not know whether they were delineating a measurement for a use or available point. As such, any error associated with delineations of measurements was random with respect to differences between use and available locations.

Comment 2. Limited Dataset Analyzed

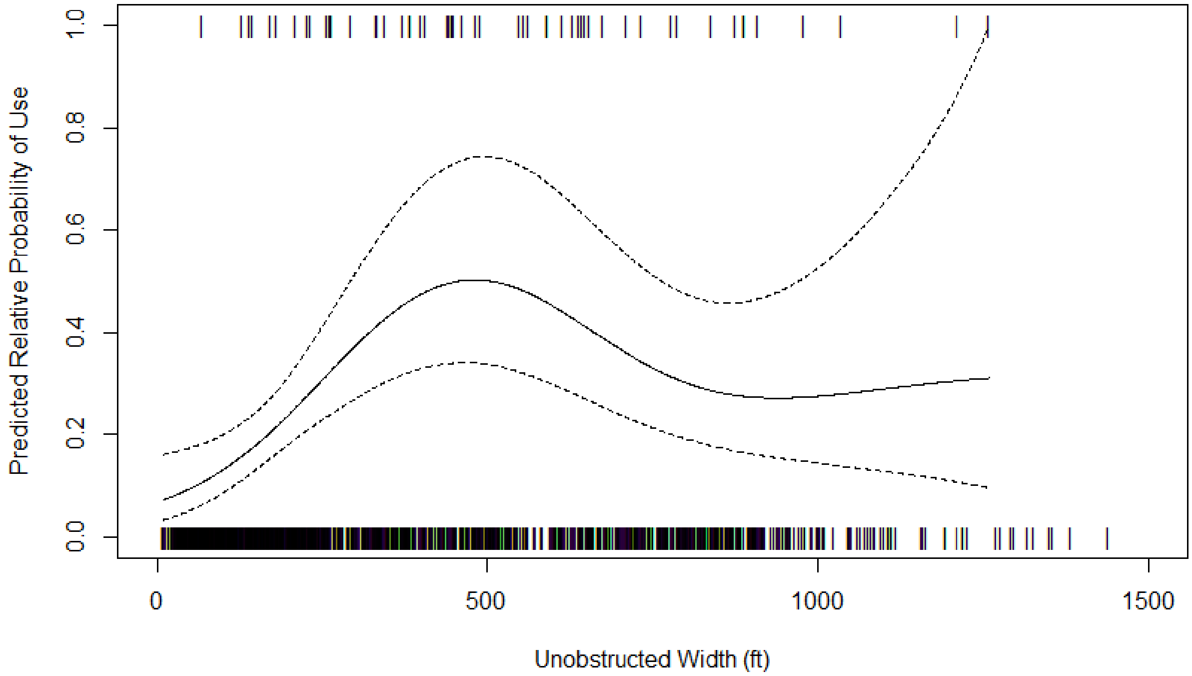
The Service would like to see the response functions include all use points in addition to the current graphs which depict only the 75th percentile of user points. There are differences in whooping crane selection of unobstructed channel widths up to 1,150 feet, and these differences warrant the inclusion of data up to1,150 feet (and beyond). The Service suggests that the Program include a second analysis that includes the full dataset and which could be compared to those using 75 percent of the data points. An explanation could be provided as to the differences in the two and why the response functions using the 75th percentile are expected to better portray WC use.

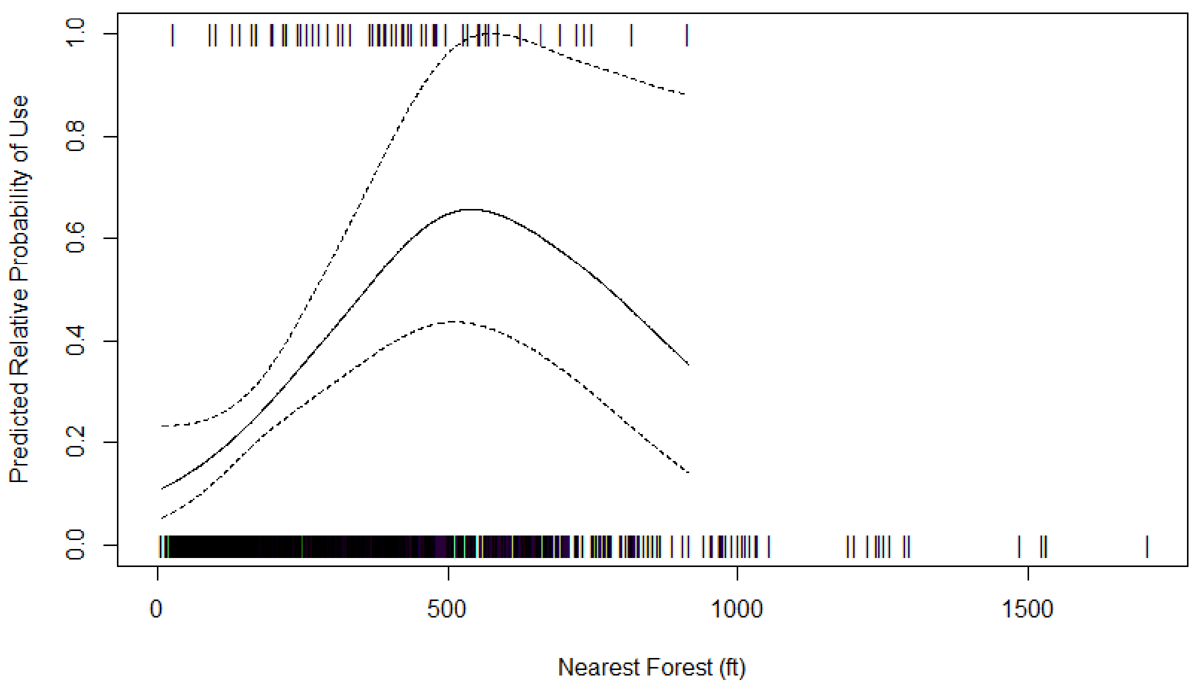
EDO Response:

In all cases, 100% of the data was analyzed in the habitat selection models. However, the response functions were only plotted to the 75th percentile of the data in the figures. The text will be amended to clarify this point. The response functions were only plotted to the 75th percentile to eliminate the influence of the disproportionate ratio between use and random locations (ratio ≠ 1 use per 20 random locations) at the extreme right side of the distribution which results in highly-uncertain and potentially unrealistic response relationships at high widths.

For example, the complete top systematic unique model (UOCW & NF) response functions have been plotted below. The response functions indicate that relative probability of use peaks at an UOCW slightly less than 500 feet and then decreases with increasing UOCW until UOCW approaches 900 feet. At widths exceeding 900 feet, probability of selection increases slightly but is still well below selection probability at 500 feet. The resource selection function for NF is similar except that probability of selection does not increase again after peaking at approximately 500 feet.

From a crane ecology perspective, it does not seem reasonable that whooping cranes select for increasing UOCW up to 500 feet and then comparatively avoid UOCWs between 500 and 900 feet. Accordingly, the EDO chose to cut off response function plots at the 75th percentile in order to reduce the potential for misinterpretation. If the TAC determines that it is appropriate to plot and interpret 100% of the response function relationships, the report figures will be amended.


Predicted Relative Probability of Use
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500
Unobstructed Width (ft)


Predicted Relative Probability of Use
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500
Nearest Forest (ft)

Comment 3. Unit Discharge

The Service cautions the conclusion: "As such, it seems safe to assume flow, and thus area of suitable depth and wetted width had little to no influence on whooping crane habitat selection on the central Platte River during the timeframe of our study". It is not entirely clear how Unit Discharge was applied in the analyses. There is no operational definition for Unit Discharge, but Table 1 implies it is associated with "moderate flow volume". It would be helpful to further expand upon linkage between unit discharge and wetted width/suitable depths. Further explanation of the operational definitions and methods would improve our understanding of the relationship between unit discharge, flow width, suitable depth, and whooping crane use.

In the Farmer et al. report, the relationship between wetted width, suitable depth, and discharge is quite variable from one site to another and is quite variable across multiple years at a single site. The high variability in wetted width/depth per unit discharge observed in Farmer et al. does not reflect the "relative stability of geomorphic features" described in the discussion section.

EDO Response:

Unit discharge (UD) is calculated as flow volume (cfs) / total channel width (ft) with total channel width defined as the distance between left and right bank. The Program's system-scale HEC-RAS model was used to calculate UD at use and random locations based on total channel width at the cross sections nearest to each use and random location and mean daily discharge on the use day. The UD covariate provides a measure of the general depth of flow across the channel. Given that discharge is relatively constant throughout the 20-mile reach of river determined to be available when a crane group selects a roost location, selection for UD would indicate cranes select for a channel with specific depth characteristics. Selection for a high UD would indicate selection for channels with proportionally deeper flow depths than are available at random locations and selection for low UD would indicate selection for channels with proportionally shallower flow depths than are available at random locations. The UD definition will be clarified in the text.

The Service comment indicates the Farmer et al. report does not support the assertion of "relative stability of geomorphic features" in the AHR. The quote, from Chapter 2, was taken from a sentence specific to the relative within-year stability of unobstructed channel width, total channel width, and nearest forest. We agree with the Service's concerns about the spatial and temporal variability associated with width and depth metrics due to the dynamic nature of the central Platte River channel. This concern is the primary reason the TAC chose to use UD as a covariate as opposed to a metric like proportion of channel less than 0.8 feet deep. The UD covariate is based on total channel width, which remains relatively constant at a location through time. Covariates based on specific flow depth distributions and/or wetted widths require measurement of channel bed topography at the time of use. A habitat selection analysis comparing specific depth and/or wetted width covariates at use and random locations would require (in the case of this Program analysis) concurrent collection of topographic data at 21 locations (1 use and 20 random); this is not feasible in the AHR. Past analyses have dealt with this issue by comparing transect-based width and depth covariates at use locations to "available" transects collected across multiple years for other purposes including use of geomorphic transects from hydraulic models. The EDO and TAC determined it *was not appropriate to utilize precise depth/width covariates based on detailed topography that was not collected at the time of use.*

The EDO's conclusions regarding the relationship between flow and habitat selection will be clarified in the text of the Chapters. The primary flow-related covariate (UD) did not appear in the top models. Accordingly, we could not conclude that flow exerted a strong influence on crane habitat selection in the AHR during the study period. This could be interpreted as 1) flow and associated depth/width characteristics are not important for crane habitat selection or 2) an adequate area of suitable depth and wetted width was equally available at whooping crane use sites and available sites given the range of flows observed during the study period; interpretation 2 is more likely. A crane group comprised of four to six individual birds will roost in an area that is generally less than a 50 ft by 50 ft area (see image below). Under most flow and channel configuration combinations, there is much more shallow water (<0.8 ft) roosting habitat than is required to accommodate the crane group sizes observed in the AHR.

Comment 4. Appendix I

An expanded discussion of the methods related to the relationship between the previous year's peak flows and percentages (Lines 663 to 666) would be beneficial.

The Service would also benefit from further clarification on the relationship between minimum and peak discharges discussed on lines 728 and 729 (Table II-3).

EDO Response:

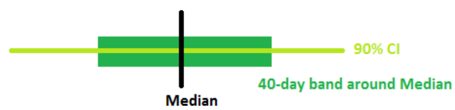
*The current and previous year peak discharge covariates were calculated as current year peak discharge plus the percent of the previous year peak discharge. For example the 40-day mean peak discharge in 2011 was 8,171 cfs and in 2012 was 2,922 cfs. Current year peak discharge plus 50% of previous year would be calculated as: 2,922 cfs + (8,171 cfs * 0.5) = 7,008 cfs.*

There was an error in Table II-3 title. The words "40-day peak discharge" will be removed from the title which should provide the necessary clarification.

Comment 5. Peak Flow Graphs/Tables

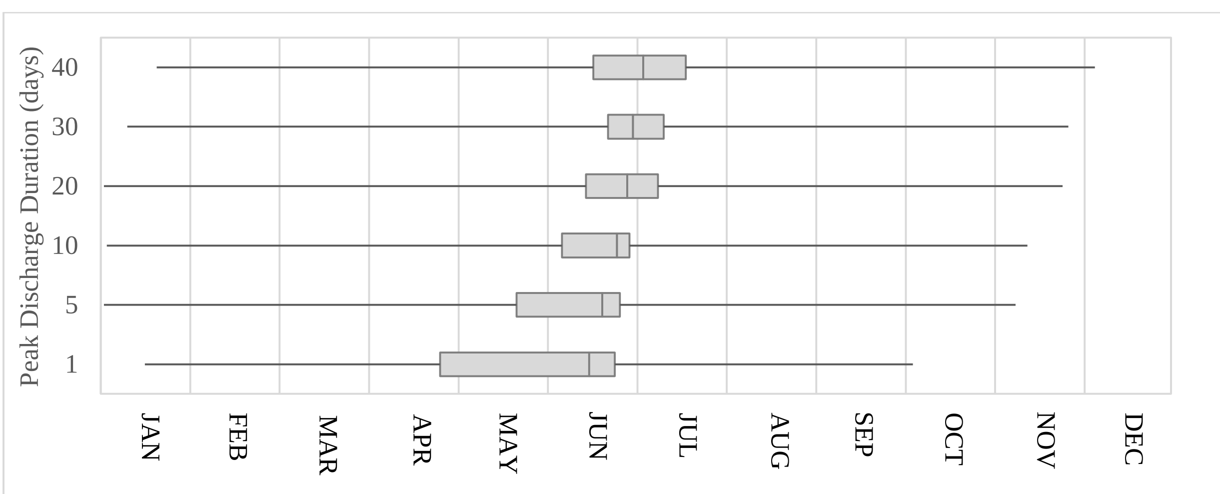
It may be beneficial to include a graph depicting the medians and measure of dispersion (e.g., 90% confidence interval) for flow metrics described in Chapter 4. This could be included in an appendix.

The Service requests that a graph be added that shows when peak flows were observed within the calendar year. For example, the graph could show the median date for the 40 day peak flow ± 20 days. Additional band could be added to represent the 90 percent confidence intervals. This would be helpful for some of the top models (i.e., 10, 20, and 40 day peak) to determine if time frames overlap. This would assist in determining if Program actions could potentially benefit multiple peak flows.



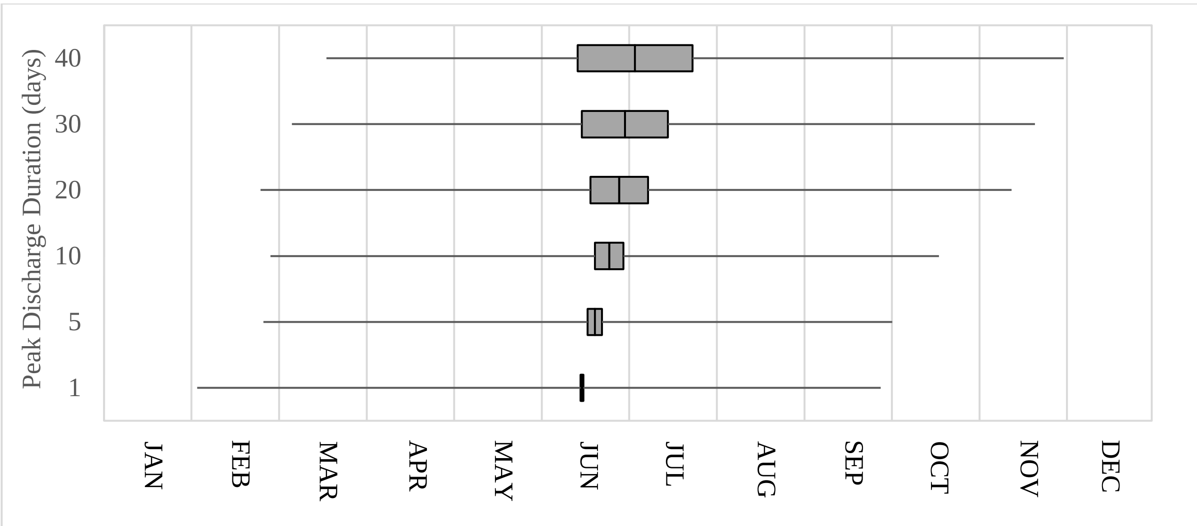
EDO Response:

The figure below presents a box and whisker plot with median values, quartiles (25 % and 75 %) and minimum and maximum values of peak discharge dates for each peak discharge duration.



Distribution of peak discharge dates from the Overton, Kearney, Grand Island and Duncan gauges from 2007 to 2015. Median values are presented, along with the lower and upper quartiles. Minimum and maximum values are presented as bars.

The figure below provides a plot of median peak discharge values, covariate duration (1, 5, 10, 20, 30 or 40 days) and 10% and 90% percentiles for each peak discharge duration.



Central tendencies of peak discharge dates from the Overton, Kearney, Grand Island and Duncan river gauges from 2007 to 2015. Median values are presented along with representation of encompassed daily peak discharge duration. Percentiles (10% and 90%) are presented as bars.

The peak flow figures can be added to Chapter 4 if the USFWS determines they are useful. Distributions have not been developed for flow metrics that exhibited poor predictive value.

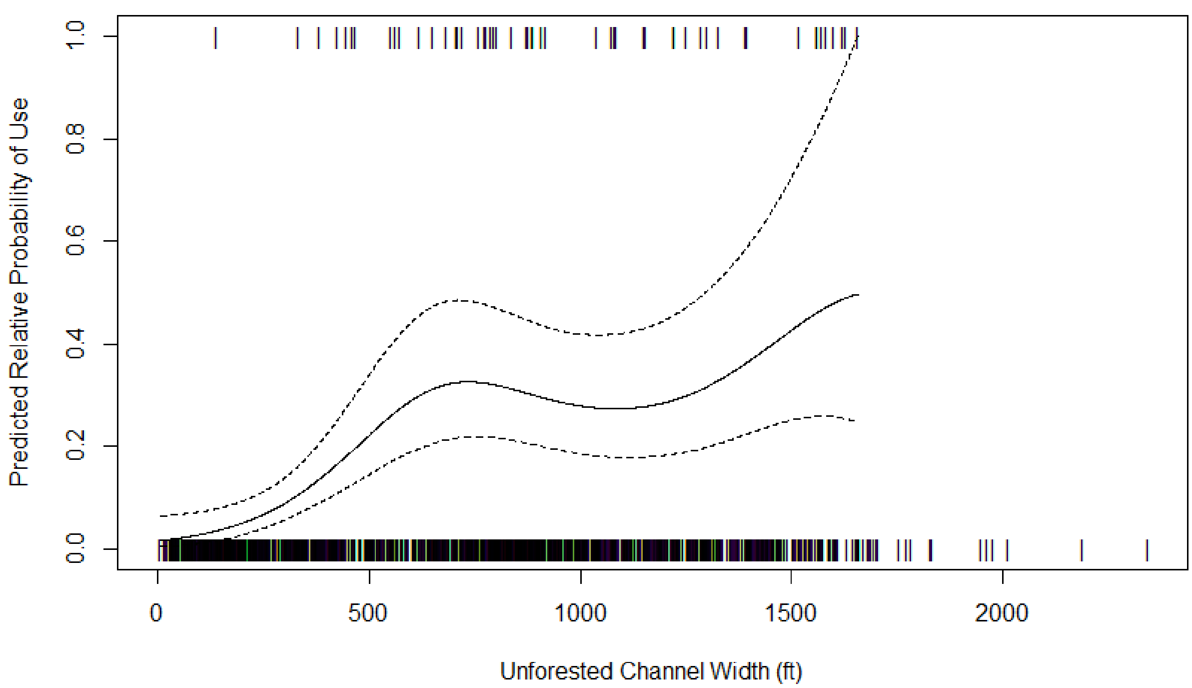
Comment 5. UOCW methods and measurements

Based on a review of the WCT assessment of UOCW and EDO assessments (see EDO memo), the Service believes there is one assessment that has not been conducted which could evaluate the width of the active channel (or individual flow split if island contains trees) for a use location, ending only at the nearest bank or mature woody vegetation. In locations where channel splits around forested islands, the measurement would only include the unforested width of the channel from one bank/forest across the channel containing the use location and ending at the next bank or island with woody vegetation. We consider this the "maximum unforested active channel width". This differs from the EDO "total channel width" which we believe includes the combined width of both wetted portions of the active channel if forested islands occur but excludes the width of the forested island itself. It would include islands with vegetation that may or may not be an obstruction, so long as they do not contain woody vegetation. The EDO's "nearest forest" measurement does not measure any components of the active channel width. The Service wishes to use the diagrams provided within the TAC package as well as any other needed sketches to graphically portray what we perceive has and has not been included in the EDO analyses. Further discussion and examination of this topic is needed by the TAC and EDO during the February 9, 2016 meeting.

EDO Response:

The Service is correct, the width metric described in Comment 5 has never been assessed by the Program or, to our knowledge, included in any previous whooping crane habitat selection analysis. This unforested active channel width (UFCW) covariate differs from UOCW in that UFCW width delineations include all vegetated macroforms and islands that are free from mature woody vegetation whereas UOCW delineations end at dense vegetation regardless of vegetation type. It differs from Program forest covariates in that the width delineation ends at the channel bank instead of extending to forest edge when the forest is outside of the active channel.

The EDO delineated UFCW for systematic unique use and random locations and performed a habitat selection analysis per the methodology presented in Chapter 2. The response function is presented below and indicates an increase in relative probability of selection up to an UFCW of 700 feet, a reduction in relative probability of selection to a UFCW of 1,200 feet, and an increase above 1,200 feet with widths of 1,400 feet having a similar probability of selection to that of 700 feet. If interpreted similarly to other response functions, we would indicate relative probability of selection is maximized when UFCW reaches 700 ft.



The EDO also compared the predictive performance of the UFCW model to the top ranked management models. The UFCW model has an AIC value of 868.94 which is lower than the null model (883.70) and indicates the model performs better than an intercept-only model. However, UFCW does not explain the use-available trends better than the top five management models (see table). Accordingly, it would be appropriate to conclude the UFCW covariate has some predictive value, but much less than the top model (UOCW + NF).

Top models for in-channel habitat use, ranked by AIC statistic. The AIC value for the null model was 883.70.

Rank	***AIC Value***	***Covariates***
1	*862.18*	*UOCW+NF*
2	*864.01*	*UOCW+NF+TCW*
3	*865.41*	*UOCW+NF+TCW+UD*
4	*865.58*	*NF*
5	*868.47*	*UOCW*
6	*868.94*	*UFCW*

** UFCW is unforested channel width*

Reference

Manly B.F.J, L.L. McDonald, D.L Thomas, T.L. McDonald, and W.P. Erickson. 2007. Resource selection by animals: statistical design and analysis for field studies. Second Edition.