PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP or Program)
2020-2032 DRAFT Extension Science Plan
Conceptual Ecological Models, Prioritized Uncertainties and Potential Hypotheses

EVALUATION AND REFINEMENT OF CONCEPTUAL ECOLOGICAL MODELS (CEMs)

A revised CEM was developed and discussed with the AMWG both in 2019 and again in the fall of 2020. CEMs provide a visual framework or graphical representation for the Program's current or hypothesized understanding of the central and lower Platte River associated habitats relative to the target species. The conceptual models describe general functional relationships among essential components of the Platte River system, present an interpretation of how the Platte River system works, and reflect how Program management actions intend to alter key processes or attributes. CEMs are also used to identify areas of uncertainty relevant to Program decision-making to be evaluated and reduced through the application of adaptive management. During the Extension, the CEMs will be reviewed on a regular basis as new information becomes available and will be modified as warranted based on science learning from implementation of the AMP.

How were these CEMs developed?

The CEMs presented are revised versions of the CEMs included in the original AMP (Program, 2006a) that was negotiated as part of the Final Program Document (Program, 2006b). The revised CEMs were first developed by the Executive Director's Office (EDO) based on a large set of source material:

- Original CEM and priority hypotheses in the AMP.
- Synthesized learning from the First Increment as summarized in six (6) State of the Platte reports (2012, 2013, 2014, 2015, 2016, 2019).
- Peer-reviewed Program synthesis documents – [1]Tern and Plover Habitat Synthesis Chapters (EDO, 2015), Whooping Crane Habitat Synthesis Chapters (EDO, 2017).
- Program manuscripts published in refereed journals.
- CEMs developed for adaptive management programs on the Missouri River (Wildhaber et al., 2007; Buenau et al., 2016).
- Several publications on the subject of CEMs and their use in recovery, restoration, and adaptive management programs, including Ogden et al., 2005; Fischenich, 2008; and Nelitz et al., 2015.
- Review of publications recently provided from the U.S. Fish and Wildlife Service on the use of conceptual models in Structured Decision Making (SDM) numerical modeling exercises, including Martin et al., 2011; Stenton et al., 2011; and Webb et al., 2015.

The CEM was discussed with and is being revised in conjunction with the Adaptive Management Working Group (AMWG) and the Independent Scientific Advisory Committee (ISAC) through a series of workshops and webinars in 2020-2021 as part of the development of this revised content for the Science Plan. The final CEM will be evaluated by the Technical Advisory Committee (TAC) and approved by the Governance Committee (GC) as part of approval of the revised Science Plan. Future updates to the CEM will be completed by the EDO, AMWG, and TAC with input from the ISAC and will be approved by the GC.

[1] The interior least tern was delisted in 2021 but is expected to remain a Program target species throughout the Extension. It has not been removed from the CEM but all hypotheses are specific to the piping plover.

General Structure of CEMs and Uncertainties

- **Drivers** are underlying factors that determine much of the dynamics of the Platte River system, but do not themselves determine physical riverine or target species responses. The drivers include social, political and economic factors in the basin that are the basis for the development and implementation of the Program and climate which is largely determinative of basin runoff.

- **Habitat management actions** represents management actions the Program may undertake during the Extension to improve quality or quantity of target species habitat.

- **Physical factors** include environmental conditions that drive Platte River structure and function and that link drivers to hydrological and geomorphological responses.

- **Habitat responses** describe the expected responses of target species habitat to Program management actions and physical factors.

- **Species management actions** (tern/plover) describe additional Program management actions that, in combination with habitat management, are expected to result in a target species response.

- **Productivity factors** (tern/plover) are a set of factors through which drivers, habitat management, and species management act to directly influence target species behavior and productivity.

- **Species performance indicators** describe and measure target species behavior and productivity in response to physical factors, habitat management, species management, and interactions with other species (predation). Species performance includes the indicators (metrics) used to evaluate the relationships identified in the conceptual ecological model and the responses of the target species to Program management actions.

- **Other factors** are larger-scale influences on species performance that are outside the control of the Program but that may have a large, if not determinative, effect on the species.

The CEMS were developed with enough detail to allow for continued evaluation of the depicted relationships and to identify and explore critical remaining uncertainties that can be related to Program management and decision-making.

Key to CEM Figures

- **High Focus During Extension (solid boxes)** – Based on Program learning, these components and relationships are anticipated to be effective at meeting Program management objectives during the Extension. As such, these will be the primary focus of research, monitoring, and associated data analysis and synthesis during the Extension.

- **Low Focus During Extension (partially transparent boxes)** – Based on Program learning, it is anticipated that these components and relationships will be ineffective at meeting Program management objectives during the Extension. As such, these will not be a focus of research, monitoring, and associated data analysis and synthesis during the Extension.
- **High Control – High Uncertainty (heavy red arrows)** – These relationships are the primary focus of adaptive management during the Extension. These represent areas of critical uncertainty that require reduction through research, monitoring, and associated data analysis and synthesis. Each heavy red arrow is accompanied by a red boxed number to identify the uncertainty. The red boxed numbers carry over to the tables that follow each CEM and provide more detail on the statement of the uncertainty as a Big Question, potential language for underlying

hypotheses and competing hypotheses, potential management actions, key data to be collected, and the source of those data.

- **Low Control – High Uncertainty** (light red arrows) – These relationships indicate uncertainty but the lack of ability on the part of the Program to implement management actions to affect these relationships reduces the level of uncertainty to a second tier that likely will not be the subject of adaptive management focus during the Extension.

- **High Control – Low Uncertainty (heavy black arrows)** – These relationships can be affected by Program management actions but are not uncertain in terms of target species responses due to existing knowledge or the synthesis of Program learning from the First Increment.

- **Low Control – Low Uncertainty** (light black arrows) – These relationships are not uncertain in terms of target species responses but are also not able to be significantly affected by Program management actions.

Black boxes represent the grouping of similar components to minimize the number of connecting lines and reduce model complexity to improve readability and enhance focus on a smaller number of the most relevant uncertainties.

Tern and Plover Conceptual Ecological Model (CEM)

This section contains a brief description of the components of the CEM for least terns and piping plovers (Table 1) and the CEM (Figure 1). A script providing an explanation of the linkages between components and hyperlinked citations to key reference documents is provided in Appendix 1.

Table 1. Description of the components of the CEM for least terns and piping plovers as illustrated in Figure 1.

Component Category	Component	Description
Drivers	Social, Political, Legal, & Economic	Actions that affect the priorities of the Program, how it is implemented, and the bounds of GC decision-making.
	Climate	Basin and regional factors affecting water supply and hydrology, such as annual precipitation, temperature, and resulting weather patterns and their timing and magnitude over multiple years. Climate conditions affect the social, political, legal, and economic factors driving Program management.
Habitat Management Actions	Channel Inundation Release	Flows maintained during the germination season for the purposes of reducing vegetation establishment within the channel and maintaining wide channels for the potential establishment of suitable in-channel nesting islands following natural high-flow events.
	High Flow Release	Flows of 5,000-8,000 cfs for 3-5 days during the fall to remove annual vegetation following the germination season for the potential establishment of suitable in-channel nesting islands following natural high-flow events.
	Sediment Augmentation	Annual augmentation of sediment for the purposes of reducing the sediment deficit in the channel to reduce or prevent the downstream migration of channel degradation.
	Mechanical Channel Maintenance	Channel disking, herbicide application, and mechanical channel-widening activities for future channel inundation releases to reduce vegetation establishment and remove vegetation through high flow releases for the potential establishment of suitable in-channel nesting islands following natural high-flow events.
	MCA Islands	Established vegetated islands cleared and maintained free of vegetation for the purposes of in-channel nesting islands for terns and plovers and eventual channel widening through lateral erosion for whooping cranes.
	Off-Channel Habitat Creation & Maintenance	Creation and maintenance of off-channel sand and water nesting habitat for terns and plovers.
Physical Factors	Hydrology	The movement and quantification of river and ground water through the Associated Habitat Reach (AHR).
	Sandbar Morphology	The creation and evolution of sandbars and the factors that drive these processes. Visible result of braided river processes whereby sediment continuously erodes and deposits in the downstream direction with respect to stage and sandbars are the visible waves in which energy is dissipated.
	Unvegetated Channel Width	Width of open channel area maintained free of vegetation to encourage on-channel tern and plover nesting within the AHR
Habitat Responses	On-Channel Nesting Habitat	Suitable nesting habitat, as defined by the Program's minimum habitat criteria, created and/or maintained for the purposes of on-channel nesting by terns and plovers.
	Off-Channel Nesting Habitat	Suitable off-channel sand and water nesting habitat, as defined by the Program's minimum habitat criteria, maintained for the purposes of off-channel nesting by terns and plovers.
Species Management Actions	Predator Control	Trapping, fencing, and other activities implemented to reduce predation on tern and plover nests, chicks, and adults.
Productivity Factors	Weather	The state of the atmosphere at a place and time including heat, humidity, solar intensity, wind, rain, etc.
	Disturbance	Any human activity that reduces the occurrence of and productivity on suitable nesting and foraging habitat.
	Forage Availability	Availability of tern (small-bodied fish) and plover (invertebrates) forage.
	Site Age	The age of a nesting site since first established as suitable nesting habitat.
	Site Size	The size of a nesting site in acres
	Predation	The act of predators consuming tern and plover nests, chicks, or adults.

Component Category	Component	Description
Species Performance Indicators	Nest Location	The physical location of individual tern and plover nests.
	Nest Density	Number of tern and plover nests per acre of suitable nesting habitat as defined by the Program's minimum habitat criteria.
	Breeding Pairs	An estimate of the number of unique male/female pairs nesting at a specified location during a specified period of time based upon nest and brood counts and taking renesting into account (Baasch *et al*. 2015). The Program typically reports breeding pairs at their peak, when numbers of breeding pairs observed during a single observation period within the entire Program AHR first peaked.
	Eggs Produced	Highest number of eggs observed over the nesting period within a single unique nest.
	Egg, Nest & Chick Survival	The survival of tern and plover eggs, nests and chicks through hatching and fledging, respectively. *Not currently measured.*
	Fledges	Number of plover chicks attributed to a unique nest that survive to 28 days of age. Number of tern chicks attributed to a unique nest that survive to 21 days of age.
	Fledge Ratio	Number of tern and plover fledglings produced per breeding pair within a site or the AHR.
	Adult Survival	Annual probability of a uniquely marked individual adult surviving and being detected from one year to the next. *Not currently measured.*
Other Factors	Non-Program Habitat	Nesting and foraging habitat outside the AHR (i.e., McConaughey, lower Platte River, Missouri River, etc.).
	Overwinter & Migratory Conditions	Other factors that reduce or enhance the survival of tern and plover fledglings and adults and ultimately influence recruitment.
	Dispersal	The process of terns and plovers distributing throughout their breeding range which include immigration and emigration.
	Stochastic Events	Factors such as disease outbreaks, etc. that reduce the overall size or health of the population.

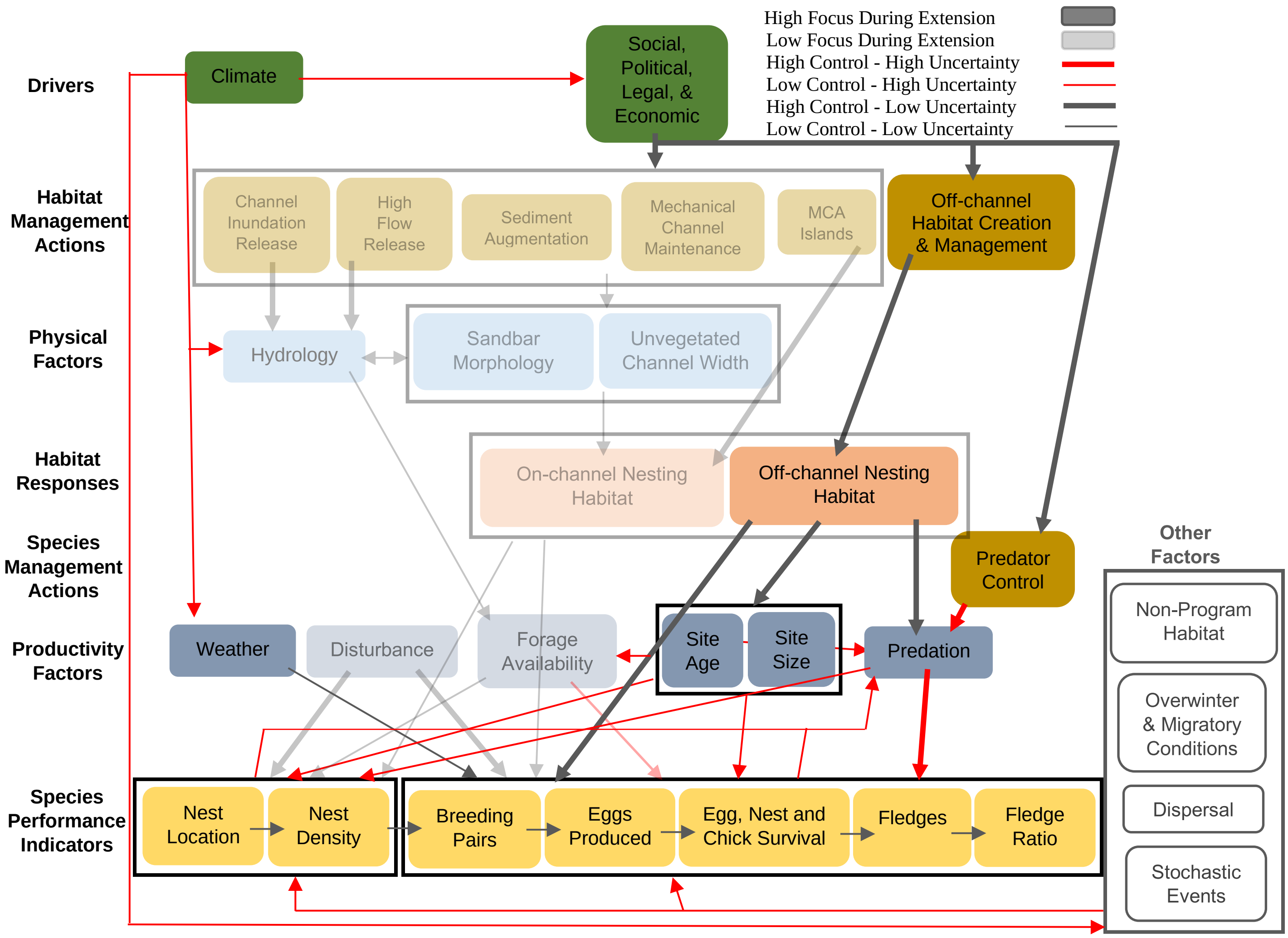


Figure 1. Tern and Plover Conceptual Ecological Model (CEM).

The goal in developing CEMs is to hypothesize relationships among Program management actions, physical factors, habitat response, productivity factors and species performance that reflect our current understanding of the system we are charged with managing. Some of these relationships were the focus of prior Program learning as part of the First Increment AMP which reduced our uncertainty about the relationship. Others were the focus of external science, from which the Program has gained and utilized information. The ability of the Program to control the outcome of these relationships through management actions was also evaluated based upon Program and external management experience over the years. Relationships for which prior learning has reduced our uncertainty about the nature of the relationship or for which prior experience has indicated a low degree of control over outcomes were given low priority for inclusion in the Science Plan going into the Extension.

IDENTIFY UNCERTAINTIES AND DEVELOP PRIORITY HYPOTHESES FOR PIPING PLOVER

The AMWG identified two remaining areas of uncertainty related to PP productivity over time and developed priority hypotheses to obtain information to fill these gaps (Table 2).

1) Why did PP productivity numbers decline from 2017-2019?

Based on the results of annual Program monitoring, PP productivity declined over the three-year period from 2017-2019. Losses attributed to predation vary over time and site, but losses in 2019 were particularly high (PRRIP Tern and Plover Monitoring and Research Reports). Although productivity numbers increased during the 2020 nesting season, Program participants still expressed concern over the previous decrease. The Program is not certain of the cause for this episodic productivity decrease, leading to the exploration of predation as one possible cause. As noted by AMWG members, shorebird breeding literature indicates weather patterns, forage availability, habitat structure, and other factors can be important.

Uncertainty Factor = Predation

The AMWG identified the impacts of predation on plover productivity and the Program's ability to mitigate this impact as an area of remaining uncertainty for which negative impacts on productivity have been documented (PRRIP Tern and Plover Monitoring and Research Reports), and the Program has the ability to manage. There is uncertainty with types of predation (avian, terrestrial or aquatic) and predation intensity (numbers of eggs and chicks lost to a single predator or chronic predation). The AMWG discussed alternative management and monitoring strategies for addressing this uncertainty.

There may be a relationship between older sites and predation as predators learn to rely upon stable sources of prey. USDA-APHIS trapping and remote cameras at OCSW managed sites have provided information on the abundance and diversity of the predator community (PRRIP Tern and Plover Monitoring and Research Reports), but without comparable trapping and camera effort across sites and years, it is difficult to assess how predation pressure may vary over time and across sites. Though potential predator presence, both avian and terrestrial, have been well documented, remote cameras have on very few occasions captured what can be clearly identified as actual predation events. High numbers of nest/broods continue to be fated as failed UNKNOWN (without diagnostic evidence of predation) (PRRIP Tern and Plover Monitoring and Research Reports). Thus, the actual impact of predation on plover productivity remains uncertain.

Predator management at OCSW sites has targeted terrestrial mammals without evaluating the effectiveness of Program actions in reducing the impacts of predation. Avian predators have also been identified as a major threat to productivity (PRRIP 2020 Tern and Plover Monitoring and Research Report), but no management actions have been consistently applied at Program sites to mitigate avian impacts.

Relative to predation, questions of interest: What is the impact of predation types on PP productivity? Does predation increase as sites age? How can the Program reduce the impact of predation on PP productivity?

Uncertainty Factor = Forage

The AMWG engaged in a discussion about PP forage availability (invertebrates along wetted habitat perimeters, at off-channel nesting sites) as another possible factor in the recent PP productivity decrease. Little is known about the type and abundance of invertebrate forage available to PP on OCSW sites each summer, and how forage availability changes as OCSW sites age. A single study on invertebrate forage availability along wetted shorelines demonstrated comparable invertebrate abundance at OCSW nesting sites to that of riverine sandbars (Sherfy et al. 2012). The Program has no evidence of declining PP body condition that might suggest limited food resources at OCSW nesting sites.

Relative to forage, questions of interest: Are there enough forage resources on off-channel habitat PP nesting sites to maintain PP productivity? What influences forage resource availability on off-channel sites? How can the Program implement management actions to improve forage availability?

Table 2. Hierarchy of potential piping plover uncertainties.

Uncertainty: How much of an effect does predation have on PP productivity?
General Hypothesis **PP1:** Predation is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity within the AHR.
Management Hypothesis: **PPM2:** Predator fencing enclosing nesting sites and/or predator deterrent lights are necessary for sustaining sufficient long-term plover productivity within the AHR.
General Hypothesis **PP3:** Predation increases as sites age.
Management Hypothesis **PPM4**: Allowing OCSW sites to "rest" intermittently is necessary to reduce losses to predation and sustain sufficient long-term plover productivity within the AHR.
Uncertainty: Are there enough forage resources at off-channel nesting sites to maintain PP productivity?
General Hypothesis **PP5:** Additional forage resources are needed along wetted OCSW shorelines to sustain sufficient long-term plover productivity within the AHR.
General Hypothesis **PP6:** Site age reduces forage availability along wetted shorelines at OCSW nesting sites.
Management Hypothesis **PPM7**: Allowing OCSW sites to "rest" intermittently is necessary to allow for replenishment of shoreline forage availability and to sustain sufficient long-term plover productivity within the AHR.

Piping Plover Uncertainties and Hypotheses

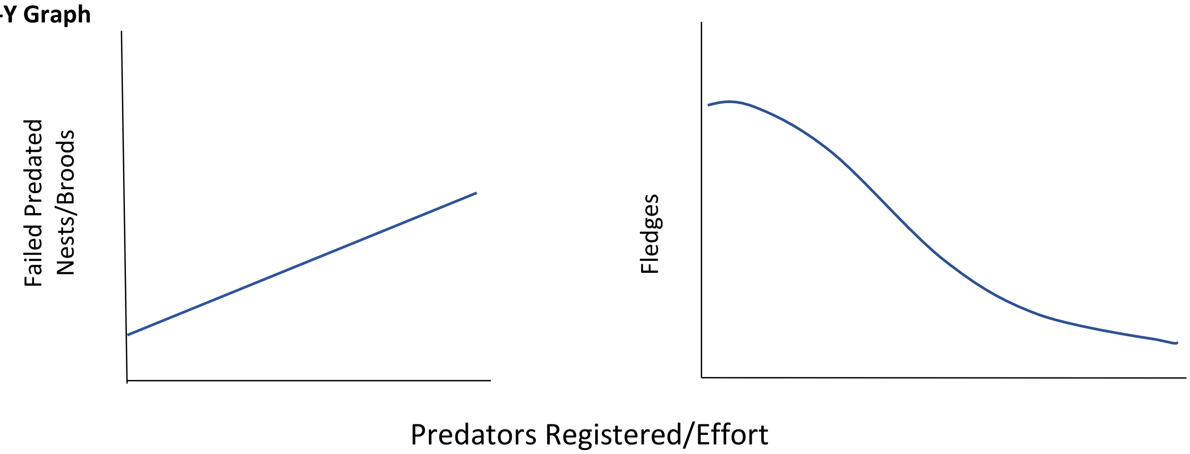
This section contains a list of general and management-related hypotheses proposed to address the hierarchy of potential piping plover uncertainties contained within Table 2 above. Predicted relationships are represented with XY graphs. Alternative hypotheses are also presented for consideration. Learning actions for obtaining and analyzing the data necessary to test hypotheses posed are included.

How much of an effect does predation have on PP productivity?

General Hypothesis PP1: Predation is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity within the AHR.

- Number of failed predated nests and broods is higher at sites with more predators registered.
- Number of failed unknown nests and broods is higher at sites with more predators registered.
- Number of breeding pairs is lower at sights with more predators registered.
- Egg/nest/chick survival is lower at sites with more predators registered.
- Number of fledges and fledge ratios are lower at sites with more predators registered.

X-Y Graph



Alternative Hypotheses:

PP1$_{Alt1}$ – Weather (low temperatures, rain) is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity.

PP1$_{Alt2}$ – Site age is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity within the AHR.

PP1$_{Alt3}$ – Low forage availability along wetted shorelines is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity within the AHR.

PP1$_{Alt4}$ – Abandonment of nests is responsible for significant reductions in plover productivity and poses a significant threat to sustaining sufficient long-term plover productivity.

Learning Action:

Additional monitoring of predator presence and predation on plover nests, chicks, and adults.

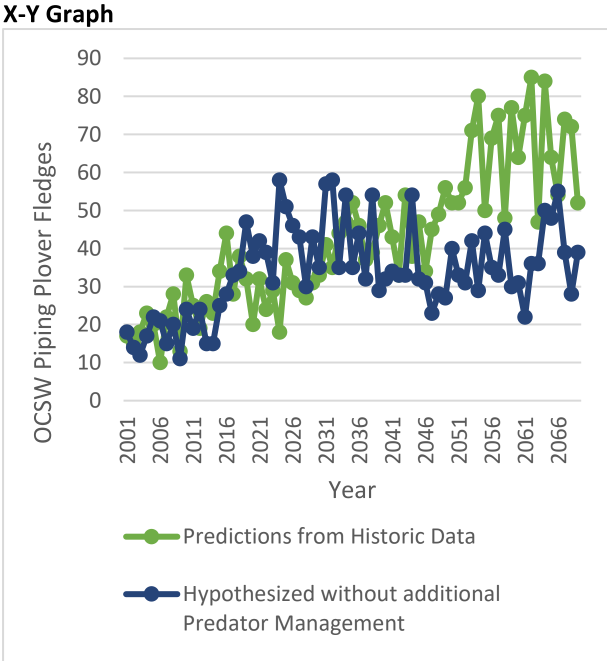
Remote camera/video monitoring at the site and nest level at all off-channel sand and water (OCSW) nesting sites.

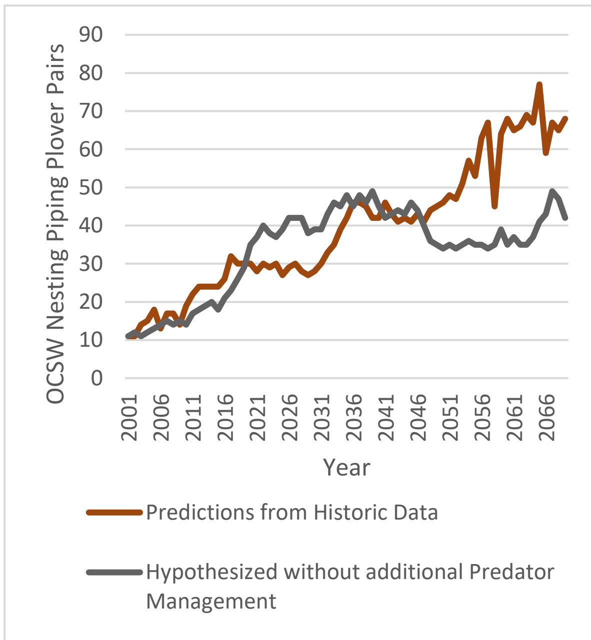
How much of an effect does predation have on PP productivity?

Management Hypothesis PPM2: Predator fencing enclosing nesting sites and/or predator deterrent lights are necessary for sustaining sufficient long-term plover productivity within the AHR.

- As trapping, predator fencing, and/or deterrent lighting is implemented through the breeding season, the number of predators trapped and registered on camera will decrease.
- Number of predators registered on nesting peninsulas at sites with predator fencing and/or deterrent lights will be significantly lower than at sites without predator fencing or deterrent lights.
- Number of predators registered on nesting peninsulas with predator fencing and/or deterrent lights will be significantly lower than before implementation of predator fencing and/or deterrent lights.
- Number of predation events registered at sites with predator fencing and deterrent lights will be significantly lower than at sites without predator fencing and/or deterrent lights.
- Number of predation events registered at sites with predator fencing and/or deterrent lights will be significantly lower than before implementation of predator fencing or deterrent lights.
- Number of breeding pairs, egg/nest/chick survival, fledges and fledge ratios at sites with predator fencing and/or deterrent lights will be significantly higher than at sites without predator fencing and/or deterrent lights.
- Number of breeding pairs, egg/nest/chick survival, fledges and fledge ratios at sites with predator fencing and/or deterrent lights will be significantly higher than before implementation of predator fencing and/or deterrent lights.

X-Y Graph





Alternative Hypotheses:

PPM2$_{Alt1}$ – Increasing moat width is necessary for sustaining sufficient long-term tern and plover productivity within the AHR.
PPM2$_{Alt2}$ – Control of tall peripheral vegetation (increasing distance to predator perch and increasing unobstructed visibility) is necessary for sustaining sufficient long-term tern and plover productivity within the AHR.
PPM2$_{Alt3}$ – Turtle trapping is necessary for sustaining sufficient long-term tern and plover within the AHR.
PPM2$_{Alt4}$ – Preventing nesting and "resting" nesting sites intermittently will reduce predator presence and losses to predation.

Learning Action:

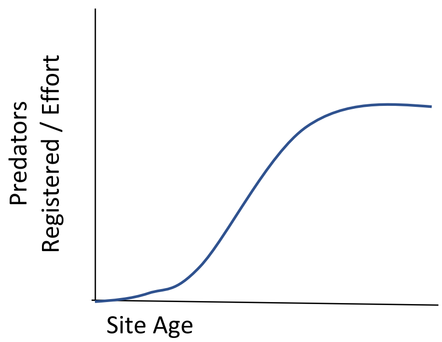
Additional aerial and terrestrial predator control test. Predator fencing and/or deterrent lights around a subset of off-channel sand and water (OCSW) nesting sites in addition to terrestrial mammalian predator trapping that is done at all sites.

How much of an effect does predation have on PP productivity?

General Hypothesis PP3: Predation increases as sites age.

- Predator presence is higher at older sites with more predators registered.
- Number of failed predated nests is higher at older sites with more predators registered.
- Number of failed unknown nests and broods is higher at older sites with more predators registered.
- Number of breeding pairs is lower at older sights with more predators registered.
- Egg/nest/chick survival is lower at older sites with more predators registered with more predators registered.
- Number of fledges and fledge ratios are lower at older sites with more predators registered.

X-Y Graph



Alternative Hypotheses:

$PP3_{Alt1}$ – Sites closer to the river are more prone to losses from predation.
$PP3_{Alt2}$ – Sites with greater proportion of non-developed landcover are more prone to losses from predation.
$PP3_{Alt3}$ – Sites with taller vegetation are more prone to losses from predation.
$PP3_{Alt4}$ – Sites with narrower moats are more prone to losses from predation.
$PP3_{Alt5}$ – Sites with greater turtle presence are more prone to losses from predation.
$PP3_{Alt6}$ – Sites not managed by the Program are more prone to losses from predation.

Learning Action:

Examine long term dataset for relationships between site age and losses attributed to predation.

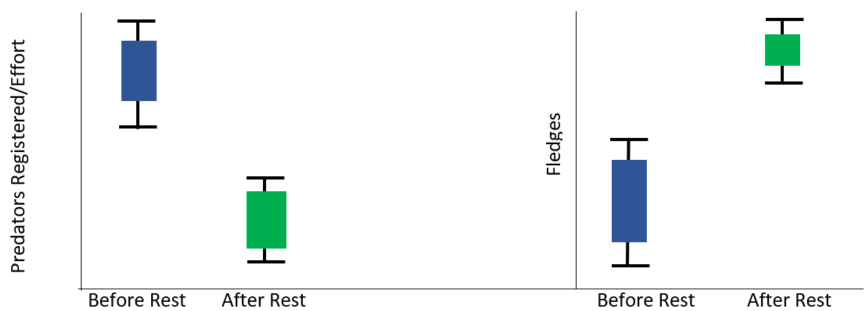
How much of an effect does predation have on PP productivity?

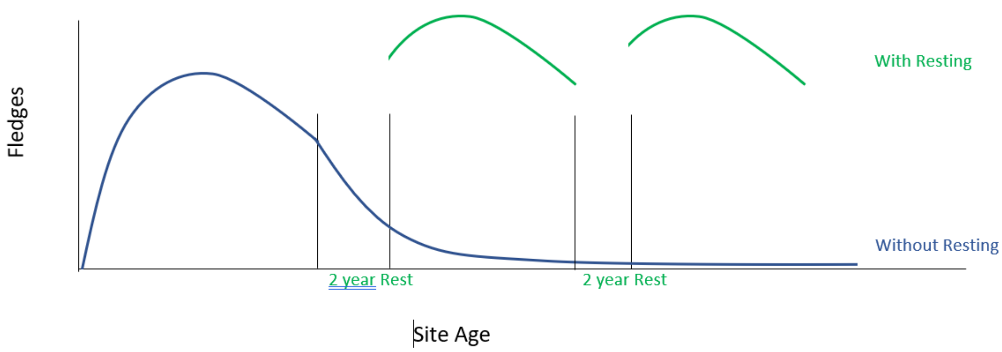
Management Hypothesis PPM4:

Allowing OCSW sites to “rest” intermittently is necessary to reduce losses to predation and sustain sufficient long-term plover productivity within the AHR.

- Predator presence is higher at older sites than rested sites.
- Number of failed predated nests is higher at older sites than rested sites.
- Number of failed unknown nests and broods is higher at older sites than rested sites.
- Number of breeding pairs is lower at older sights than rested sites.
- Egg/nest/chick survival is lower at older sites than rested sites.
- Number of fledges and fledge ratios are lower at older sites than rested sites.

X-Y Graph





Alternative Hypotheses:

$PPM4_{Alt1}$ – Sites closer to the river are more prone to losses from predation.
$PPM4_{Alt2}$ – Sites with greater proportion of non-developed landcover are more prone to losses from predation.
$PPM4_{Alt3}$ – Sites with taller vegetation are more prone to losses from predation.
$PPM4_{Alt4}$ – Sites with narrower moats are more prone to losses from predation.
$PPM4_{Alt5}$ – Sites with greater turtle presence are more prone to losses from predation.
$PPM4_{Alt6}$ – Sites not managed by the Program are more prone to losses from predation.

Learning Action:

Prevent nesting at sites, letting them “rest” intermittently to make OCSW less predictable in terms of prey availability.

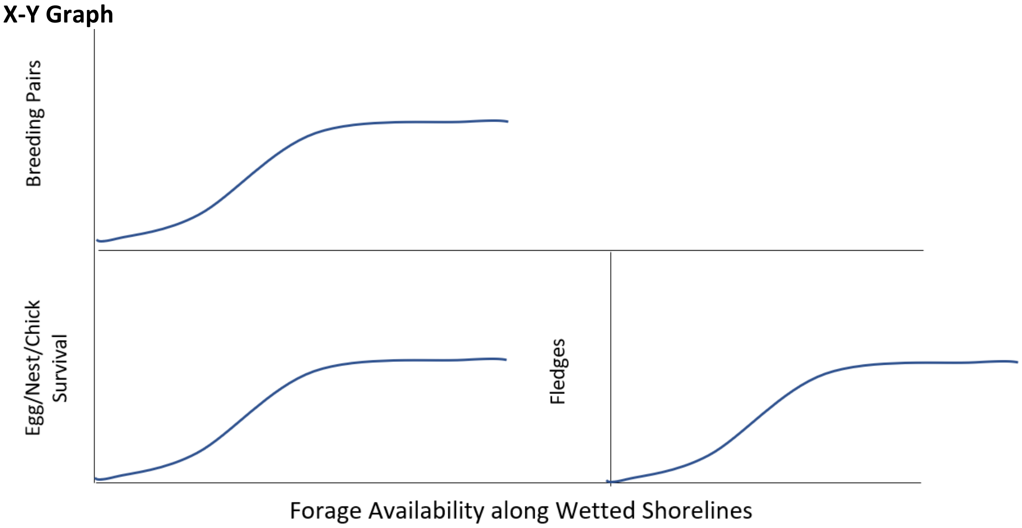
Are there enough forage resources at off-channel nesting sites to maintain PP productivity?

General Hypothesis PP5:

Additional forage resources are needed along wetted OCSW shorelines to sustain sufficient long-term plover productivity within the AHR.

- Number of breeding PP pairs will be significantly higher at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- Body condition of PP adults will be significantly better at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- Body condition of PP chicks will be significantly better at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- Number of PP eggs laid per nest will be significantly higher at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- Number of PP eggs hatched per nest will be significantly higher at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- PP egg/nest/chick survival will be significantly higher at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.
- Number of PP fledges and fledge ratios will be significantly higher at OCSW sites with higher availability of macroinvertebrates along wetted shorelines.

X-Y Graph



Alternative Hypotheses:

PP5$_{Alt1}$ – Additional forage resources along wetted OCSW shorelines are not necessary for sustaining sufficient long-term plover productivity within the AHR.

Learning Action:

Test relationship between forage availability along wetted shorelines and plover productivity at OCSW nesting sites.

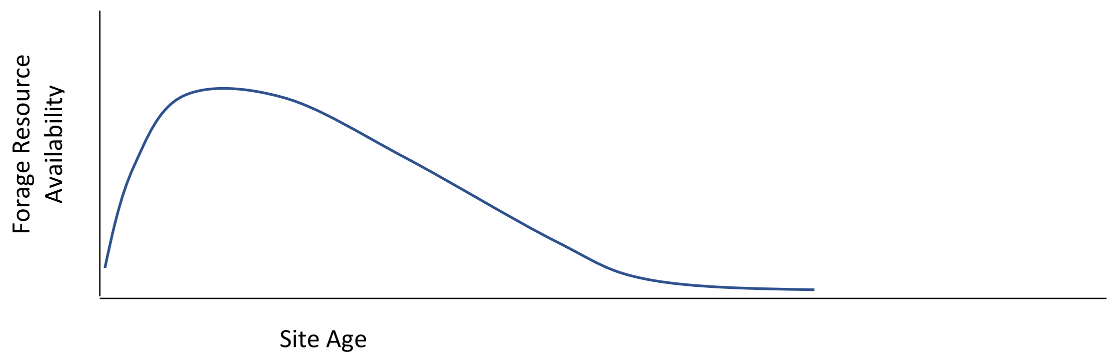
Are there enough forage resources at off-channel nesting sites to maintain PP productivity?

General Hypothesis PP6:

Site age reduces forage availability along wetted shorelines at OCSW nesting sites.

- The quantity of macroinvertebrate forage resources along wetted shorelines decreases as sites age.
- Older OCSW sites have fewer macroinvertebrate forage resources per linear foot of shoreline than newer sites.

X-Y Graph



Alternative Hypotheses:

$PP6_{Alt1}$ – Pre-emergent spraying along shorelines reduces forage availability along wetted shorelines at OCSW nesting sites.
$PP6_{Alt2}$ – Reduced inflow from surrounding water sources reduces forage availability along wetted shorelines at OCSW nesting sites.
$PP6_{Alt3}$ – Weather (lower temperatures, rainfall) reduces forage availability along wetted shorelines at OCSW nesting sites.
$PP6_{Alt4}$ – High tern and plover density reduces forage availability along wetted shorelines at OCSW nesting sites.
$PP6_{Alt5}$ –Competition among other macroinvertebrate consumers (birds, amphibs, fish) reduces forage availability along wetted shorelines at OCSW nesting sites.
$PP6_{Alt6}$ – Steep shorelines reduces forage availability along wetted shorelines at OCSW nesting sites.

Learning Action:

Test relationship between forage availability along wetted shorelines at OCSW nesting sites and various management actions and site-specific conditions.

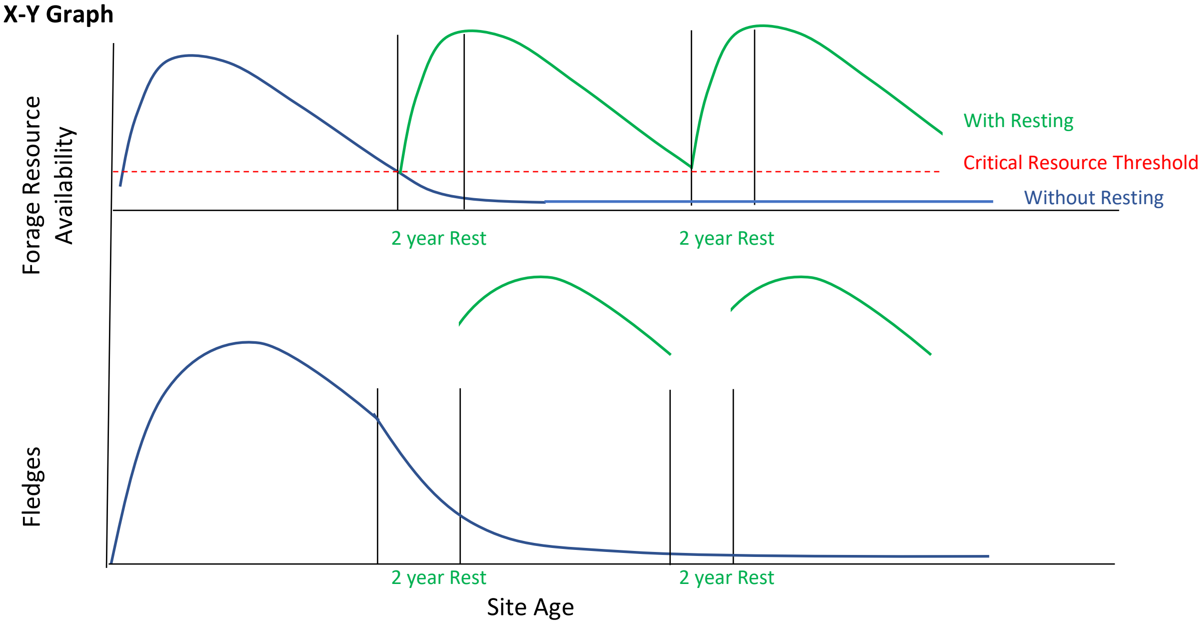
Are there enough forage resources at off-channel nesting sites to maintain PP productivity?

Management Hypothesis PPM7:

Allowing OCSW sites to "rest" intermittently is necessary to allow for replenishment of shoreline forage availability and to sustain sufficient long-term plover productivity within the AHR.

- OCSW sites "rested" for two years will have higher forage resource availability along wetted shores than prior to "resting".
- Number of breeding PP pairs will be significantly higher at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- Body condition of PP adults will be significantly better at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- Body condition of PP chicks will be significantly better at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- Number of PP eggs laid per nest will be significantly higher at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- Number of PP eggs hatched per nest will be significantly higher at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- PP egg/nest/chick survival will be significantly higher at OCSW sites allowed to "rest" to replenish shoreline forage resources.
- Number of PP fledges and fledge ratios will be significantly higher at OCSW sites allowed to "rest" to replenish shoreline forage resources.

X-Y Graph



Alternative Hypotheses:

PPM7$_{Alt1}$ – Supplementing shoreline forage resources is necessary to sustain sufficient long-term plover productivity within the AHR.
PPM7$_{Alt2}$ – Halting pre-emergent spraying along selected shorelines is necessary to allow for replenishment of shoreline forage availability and to sustain sufficient long-term plover productivity within the AHR.
PPM7$_{Alt3}$ – Increasing linear footage of wetted shorelines is necessary to increase forage availability and to sustain sufficient long-term plover productivity within the AHR.
PPM7$_{Alt4}$ – Reshaping unutilized shorelines is necessary to increase forage availability and to sustain sufficient long-term plover productivity within the AHR.
PPM7$_{Alt5}$ – Selective removal of competitors is necessary to increase forage availability and to sustain sufficient long-term plover productivity within the AHR.

Learning Action:

- Prevent nesting and let sites "rest", veg over, then rehab them again to make them "new".
- Supplement shoreline forage resources.
- Halt pre-emergent spraying along selected shorelines
- Increase linear footage of wetted shoreline with pit design.
- Reshaping unsuitable shorelines (reduce depth, steepness).
- Selective removal of competitors for forage resources.

Whooping Crane Conceptual Ecological Model (CEM) and Sub-models

This section contains a brief description of the components of the CEM for whooping cranes (Table 3), the whooping crane CEM (Figure 2). The whooping crane CEM is followed by two sub-models that represent a deeper explanation of the relationships between hydrology, vegetation, and channel width (Figures 3 and 4). A script providing an explanation of the linkages between CEM and sub-model components and hyperlinked citations to key reference documents is provided in Appendices 2 - 4.

Table 3. Description of the components of the CEM for whooping cranes as illustrated in Figure 2.

Component Category	Component	Description
Drivers	Social, Political, Legal, & Economic	Actions that affect the priorities of the Program, how it is implemented, and the bounds of GC decision-making.
	Climate	Basin and regional factors affecting water supply and hydrology, such as annual precipitation, temperature, and resulting weather patterns and their timing and magnitude over multiple years. Climate conditions affect the social, political, legal, and economic factors driving Program management.
Non-Program Habitat Management Actions	Baseflow for fish guilds	USFWS release of water to prevent fish kill, typically in late summer.
	Hydro-stepping	CNPPID operation that incrementally increases flow for more efficient power generation and returns it rapidly to baseflow levels in a repeating pattern during low flow periods typically occurring during Fall WC migration, but also possible depending on natural flows or flow releases during Spring WC migration.
	Migration Flow Release	Flows released during the spring and fall whooping crane migration seasons for the purposes of potentially enhancing roosting/foraging conditions and increasing whooping crane use of the AHR. USFWS EA manager decision with input from Program.
Program Habitat Management Actions	Migration Flow Release	Flows released during the spring and fall whooping crane migration seasons for the purposes of potentially enhancing roosting/foraging conditions and increasing whooping crane use of the AHR. USFWS EA manager decision with input from Program.
	Fall High Flow Release	Late summer or early fall releases of 5,000-8,000 cfs of flow for 3-5 days as measured at Overton for the purposes of removing annual vegetation established within the channel.
	Channel Inundation Flow Releases	Flows maintained during the germination season for the purposes of reducing vegetation establishment within the channel and maintaining wide unobstructed channel widths for whooping cranes.
	Mechanical Channel Maintenance	Disking, herbicide application and mechanical channel-widening activities for creating and maintaining wide unobstructed view widths for whooping cranes and prepping the channel for future summer flow releases to reduce vegetation establishment and for the removal of annual vegetation through peak flow releases.
	Sediment Augmentation	Annual augmentation of sediment for the purposes of reducing the sediment deficit in the channel to reduce or prevent the downstream migration of channel degradation.
	Off-Channel Habitat Creation & Maintenance	The creation and maintenance of suitable off-channel palustrine wetlands and wet meadow habitat for whooping cranes
	Wetland Pumping	Augmentation of water via pumping into palustrine wetlands to increase the acres of suitable off-channel roosting area.
Physical Factors	Hydrology	The movement and quantification of river and ground water through the AHR.
	Channel Width	Width of channel unobstructed by dense vegetation ≥2-feet tall.
	Vegetation	Established, dense vegetation ≥2-feet tall.
	Ice	Establishment of ice within the channel with the potential of scouring vegetation during the winter months.

Component Category	Component	Description
Habitat Responses	Acres of Suitable On-Channel Foraging Habitat	Acres of channel with ≥650-foot-wide unobstructed view widths and ≥1,100-foot-wide unforested corridor widths.
	Acres of Suitable On-Channel Roosting Habitat	Acres of channel with ≥650-foot-wide unobstructed view widths and ≥1,100-foot-wide unforested corridor widths.
	Acres of Off-channel Foraging Habitat	Acres of Program-defined wet meadow habitat within the AHR.
	Acres of Off-Channel Roosting Habitat	Acres of palustrine wetlands within the AHR.
Performance Indicators	Proportionate Use	Proportion of the annual population, as determined at Aransas National Wildlife Refuge, observed using the AHR through Program monitoring efforts.
	Distribution of Use	Distribution of whooping crane use locations within the AHR.
	Length of stay	Number of use days by a unique WC group within the AHR.
	On-Channel Foraging	Abundance of whooping cranes observed in the channel within the AHR during daylight hours.
	On-Channel Roosting	Abundance of whooping cranes observed in the channel within the AHR during twilight, dusk, dawn, and overnight hours.
	Off-Channel Foraging	Abundance of whooping cranes observed off-channel within the AHR during daylight hours.
	Off-Channel Roosting	Abundance of whooping cranes observed off-channel within the AHR during twilight, dusk, dawn, and overnight hours.
Management Objective	Contribute to Survival	Contribution to whooping crane migratory survival which results in population growth.
	Contribute to Reproduction	Contribution to whooping crane reproduction which results in population growth.
Other Factors	Migratory Habitat Conditions	Suitable roosting and foraging habitat within the migration corridor but outside the AHR.
	Natural Flows	Flows within the AHR not including EA released water or Program flow augmentation through groundwater recharge and other projects.
	Spring vs Fall	Migratory patterns vary depending on season.
	Breeding Ground Conditions	Conditions on the breeding ground including nesting habitat availability and suitability, forage, weather, etc.
	Wintering Ground Conditions	Conditions on the wintering ground including forage availability, weather, etc.
	Stochastic Events	Factors such as disease outbreak, hurricane, etc. that influence the overall size or health of the population.

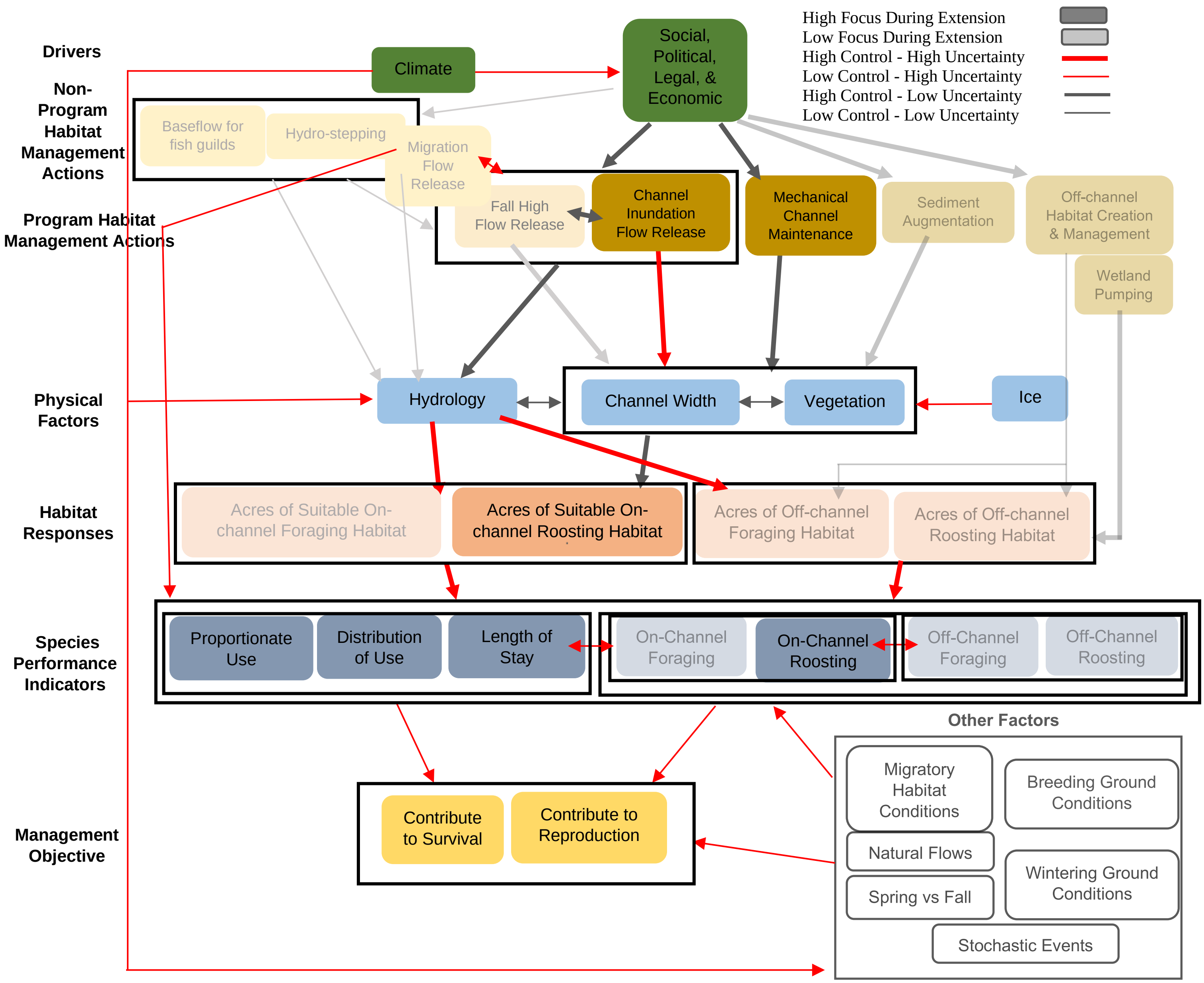


Figure 2. Whooping Crane Conceptual Ecological Model (CEM)

Annual and Perennial Vegetation Establishment Sub-model (Figure 3)
This sub-model relates the potential channel inundation flow release, fall high flow release, herbicide and disking to vegetation suppression and vegetation scour. A script providing an explanation of the linkages between sub-model components and hyperlinked citations to key reference documents is provided in Appendix 3.

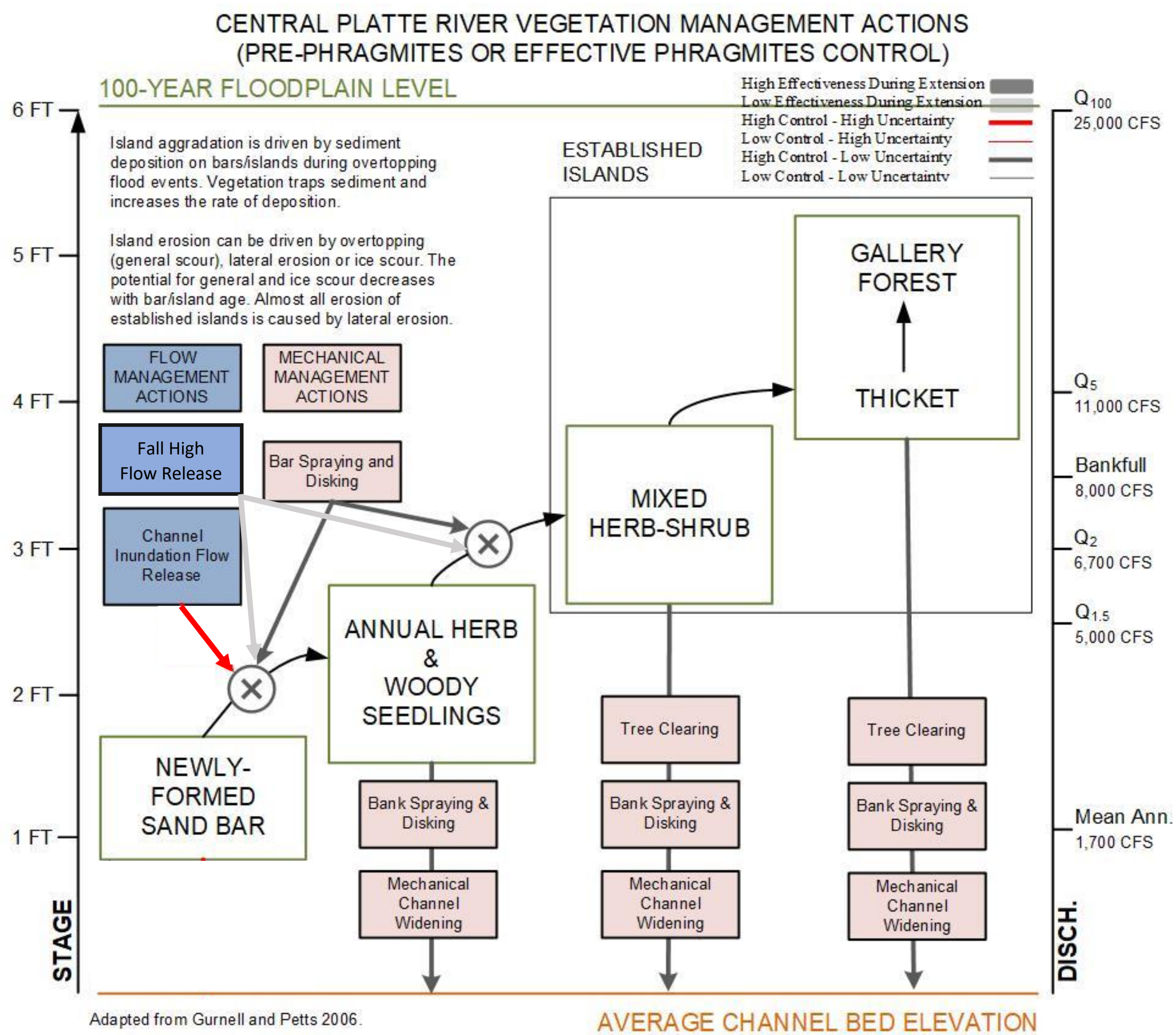


Figure 3. Annual and perennial vegetation establishment sub-model.

***Phragmites* Sub-Model (Figure 4)**

This sub-model relates the potential channel inundation flow release and annual herbicide application to the prevention of *Phragmites* germination and expansion. A script providing an explanation of the linkages between sub-model components and hyperlinked citations to key reference documents is provided in Appendix 4.

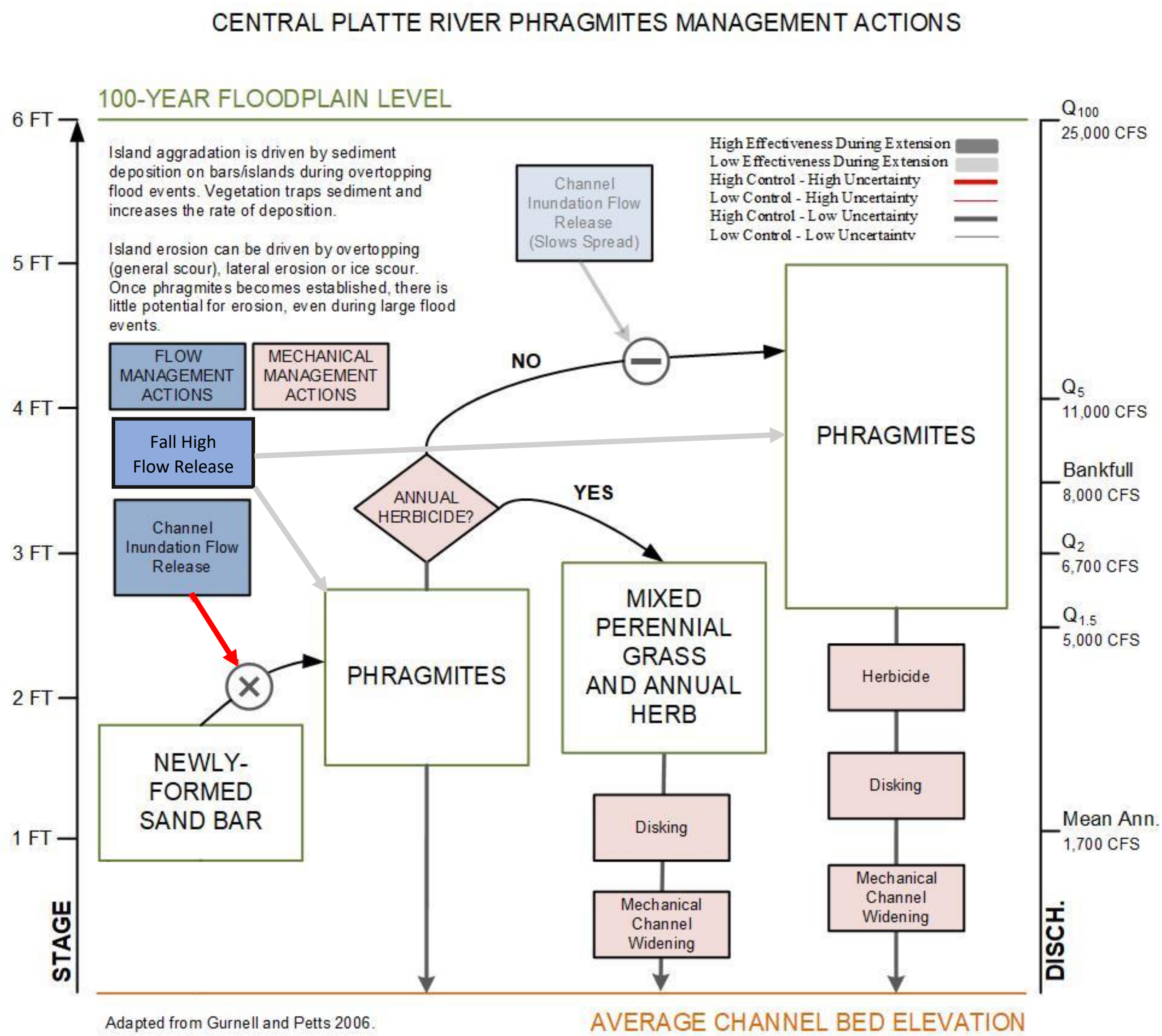


Figure 4. *Phragmites* sub-model.

IDENTIFY UNCERTAINTIES AND DEVELOP PRIORITY HYPOTHESES FOR WHOOPING CRANES

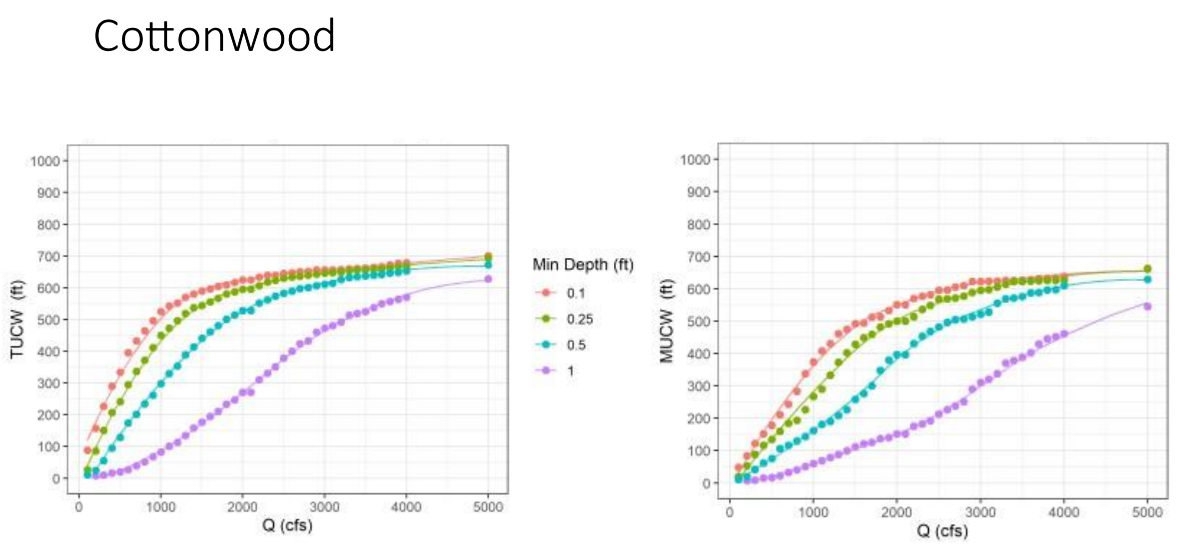
The AMWG identified remaining areas of uncertainty related to WC use of the Associated Habitat Reach (AHR) of the central Platte River and developed priority hypotheses to obtain information to fill these gaps (Table 4).

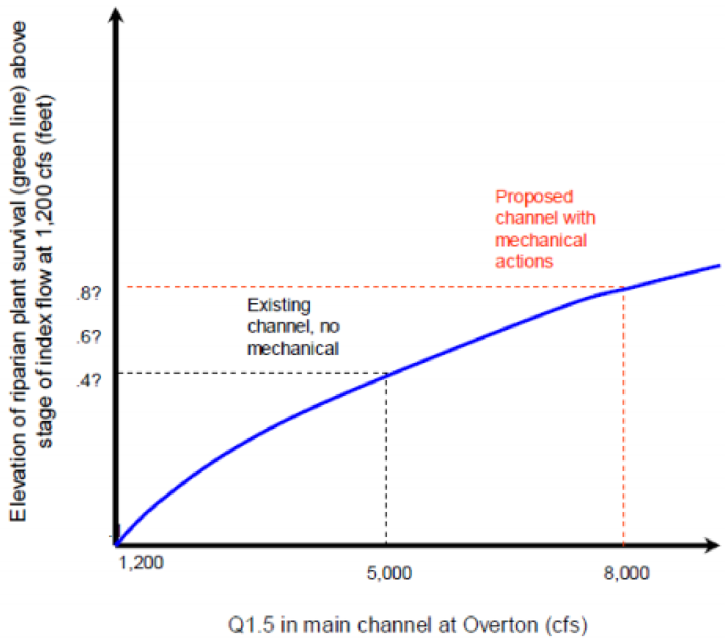
Table 4. Hierarchy of potential whooping crane uncertainties.

Uncertainty: Can we use Program water to maintain suitable WC roosting habitat?
Management Hypothesis: **WCM1:** Low-magnitude, long-duration flow releases of 1,200 – 2,400 cfs during the germination period can be used to maintain suitable unobstructed channel width for WC roosting when large natural peak flows do not occur?
Management Hypothesis **WCM2**: Late summer short-duration high flow releases of 5,000 – 8,000 cfs for 3 days can be used to create and/or maintain suitable unobstructed channel width for WC roosting?
Uncertainty: Management of *Phragmites*.
Management Hypothesis **WCM3**: Annual spraying of *Phragmites* is necessary to create and/or maintain suitable unobstructed channel widths for WC roosting.
Uncertainty: What conditions influence whether a WC will stop or fly over the AHR?
General Hypothesis **WC4**: Time of day is the primary driver of WC stopovers with probability of use increasing with decreasing time until dark.
Management Hypothesis **WCM5**: Probability of WC stopping within the AHR increases with increasing flow until flow reaches 1,800 cfs and declines with increasing flow above 2,000 cfs.
Uncertainty: What conditions influence how long a WC will stop on the AHR?
General Hypothesis **WC6**: Length of stay at previous stopover is primary driver of WC stopover length with length of stay increasing with decreasing length of stay at previous stopover.
Management Hypothesis **WCM7**: Length of WC stopover within the AHR increases with increasing flow until flow reaches 1,800 cfs and declines with increasing flow above 2,000 cfs.
Uncertainty: AHR contributions to WC fitness.
General Hypothesis **WC8**: WC that stop within the AHR are more likely to successfully complete migration (spring and fall), have higher survival rates, and reproduce more successfully than those that fly over the AHR.
General Hypothesis **WC9**: WC with longer stopovers within the AHR are more likely to successfully complete migration (spring and fall), have higher survival rates, and reproduce more successfully than those with shorter stopovers.
Uncertainty: What is the importance of the AHR to WC survival in the fall vs. the spring?
General Hypothesis **WC10**: Survival rates differ between WC that stop over in the fall vs. spring.
Management Hypothesis **WCM11**: Prioritizing flow releases during the fall WC migration will increase survival more than flow releases during the spring migration.
Uncertainty: What is the impact of hydro-stepping on WC use of the AHR?
General Hypothesis **WC12**: WC length of stay and/or roost locations are influenced by daily flow variability.
Management Hypothesis **WCM13:** Reducing or eliminating hydro-stepping by maintaining flows at 1500 cfs during spring and fall WC migration will increase the length of WC stopovers and/or increase use of the western segments of the AHR for WC roosting.
Uncertainty: Program management of river flow to maintain wet meadow hydrology.
General Hypothesis **WC14**: Natural peak flows from March 1 – June 30 have the largest effect on wet meadow hydrology.

Whooping Crane Uncertainties and Hypotheses

This section contains a list of general and management-related hypotheses proposed to address the hierarchy of potential whooping crane uncertainties contained within Table 4 above. Predicted relationships are represented with XY graphs. Alternative hypotheses are also presented for consideration. Learning actions for obtaining and analyzing the data necessary to test hypotheses posed are included.

Can Program water be used to maintain suitable WC roosting habitat?
Management Hypothesis WCM1: Maintaining average flows of 1,800 cfs during the germination period (June 1 – June 30) will prevent vegetation encroachment into the channel where it exceeds 650 ft, thereby maintaining 650 ft MUCWs for whooping cranes.
X-Y Graph 
Alternative Hypotheses: **WCM1$_{ALT1}$** - Maintaining average flows of 2,400 cfs during the germination period (June 1 – June 30) will prevent vegetation encroachment into the channel where it exceeds 650 ft, thereby maintaining 650 ft MUCWs for whooping cranes. **WCM1$_{ALT2}$** - Maintaining average flows of 1,200 cfs during the germination period (June 1 – June 30) will prevent vegetation encroachment into the channel where it exceeds 650 ft, thereby maintaining 650 ft MUCWs for whooping cranes. **WCM1$_{NULL}$** - Maintaining average flows between 1,200 and 2,400 cfs during the germination period (June 1 – June 30) will have no effect on vegetation encroachment into the channel where it exceeds 650 ft.
Learning Action: Maintain 1,200 – 2,400 cfs during June 1 – June 30 and evaluate change in MUCW annually.

Can Program water be used to maintain suitable WC roosting habitat?
Management Hypothesis WCM2: Flows of 8,000 cfs for three days in September will remove enough ≤1-year-old vegetation in channels with 650-foot wide MUCWs to maintain those widths.
X-Y Graph 
Alternative Hypotheses: **WCM2$_{ALT1}$** - Flows of 5,000 cfs for three days in September will remove enough ≤1-year-old vegetation in channels with 650-foot wide MUCWs to maintain those widths. **WCM2$_{ALT2}$** - Flows of 12,000 cfs for three or more days in September are needed to remove enough ≤1-year-old vegetation in channels with 650-foot wide MUCWs to maintain those widths. **WCM2$_{NULL}$** - Flows of 5,000 – 12,000 cfs for three or more days in September will not remove enough ≤1-year-old vegetation in channels with 650-foot wide MUCWs to maintain those widths.
Learning Action: Implement 5,000 – 8,000 cfs releases for three days during September and evaluate change in MUCW annually.

How can the Program control the expansion of *Phragmites*?

Management Hypothesis WCM3:

Annual application of herbicide will prevent *Phragmites* encroachment into the channel, thereby maintaining 650 ft MUCWs for whooping cranes.

X-Y Graph

Alternative Hypotheses:

$WCM3_{ALT1}$ - Maintaining average flows of 1,200 – 2,4000 cfs during the rhizome/stolon expansion period (June 1 – June 30) will prevent *Phragmites* encroachment into the channel, thereby maintaining 650 ft MUCWs for whooping cranes.

$WCM3_{ALT2}$ - Flows of 5,000 – 12,000 cfs for three days in September will remove enough *Phragmites* in channels with 650-foot wide MUCWs to maintain those widths.

$WCM3_{NULL}$ – Neither Program flow management actions nor annual application of herbicide prevent *Phragmites* encroachment into channels with 650-foot wide MUCWs to maintain those widths.

Learning Action:

Implement annual spraying for *Phragmites* and evaluate change in *Phragmites* cover and MUCW annually.

Implement germinations suppression flow release (1,200 - 2,400 cfs releases from June 1 – June 30) and evaluate change in *Phragmites* cover and MUCW annually.

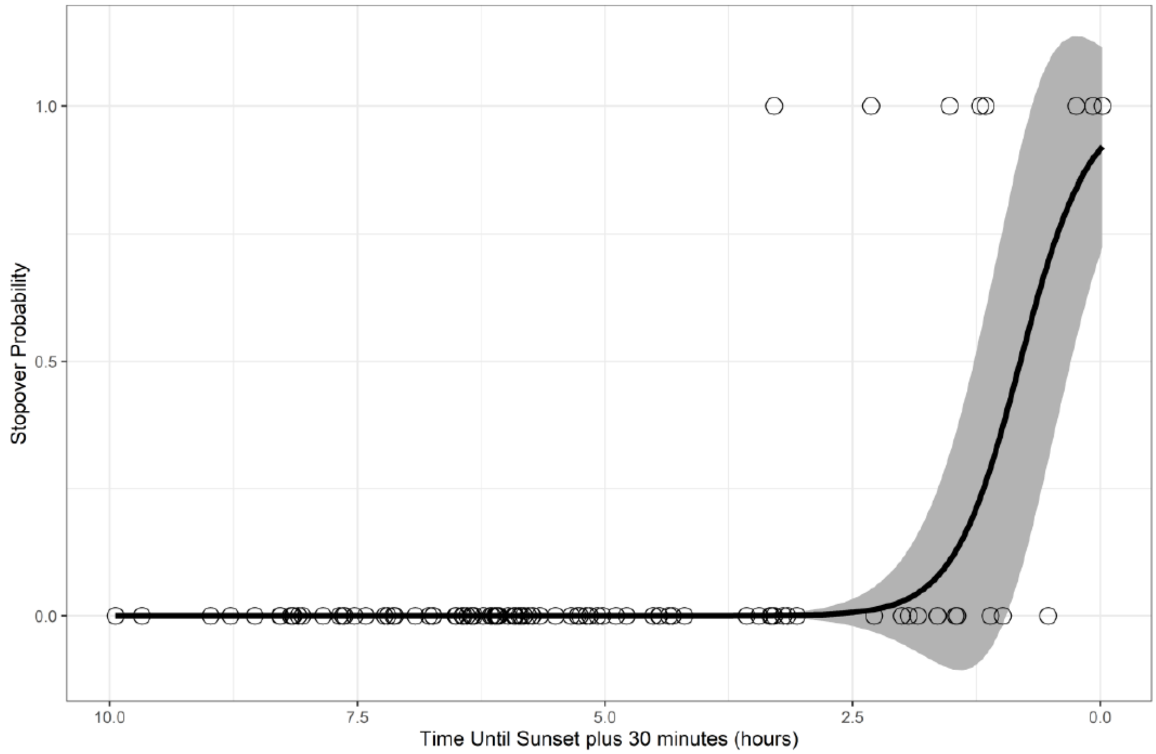
Implement fall short duration high flow release (5,000 – 8,000 cfs releases for three days during September) and evaluate change in *Phragmites* cover and MUCW annually.

Use Program data to analyze the effects of high vs. low flow with and without herbicide in controlling *Phragmites* expansion and maintaining 650 ft MUCWs.

What conditions influence whether a WC will stop or fly over the AHR?

General Hypothesis WC4: Time of day is the primary driver of WC stopovers with probability of use of the AHR increasing with decreasing time until dark.

X-Y Graph



Alternative Hypotheses:

$WC4_{ALT1}$ – Distance from the last stopover is an important predictor of WC stopovers with probability of use of the AHR increasing with distance since last stopover.

$WC4_{ALT2}$ – Number of opportunities for late in the day (after 3 p.m.) stopovers that meet minimum criteria before reaching the AHR is an important predictor of WC stopovers with the probability of use of the AHR increasing with fewer opportunities available prior to the AHR.

$WC4_{ALT3}$ – Weather (wind speed and direction, precipitation, temperature) encountered since the last stopover is an important predictor of WC stopovers with the probability of use of the AHR increasing as weather conditions become less favorable.

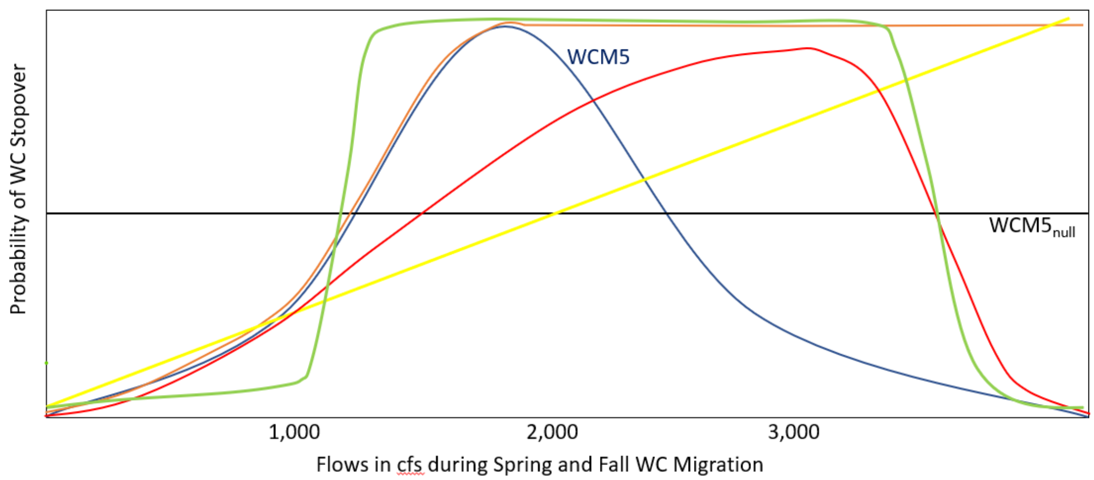
Learning Action:

Analysis of WC telemetry dataset to examine the relative importance of factors outside of Program control on the decision of WC to stopover within the AHR.

What conditions influence whether a WC will stop or fly over the AHR?

Management Hypothesis WCM5: Probability of WC stopping within the AHR increases with increasing flow until flow reaches 1,800 cfs and declines with increasing flow above 2,000 cfs.

X-Y Graph



Alternative Hypotheses:

$WCM5_{Alt1}$ – The probability of a WC stopping within the AHR increases with MUCW to peak at 650 ft, but providing no incremental benefit of increasing MUCW above 650 ft.

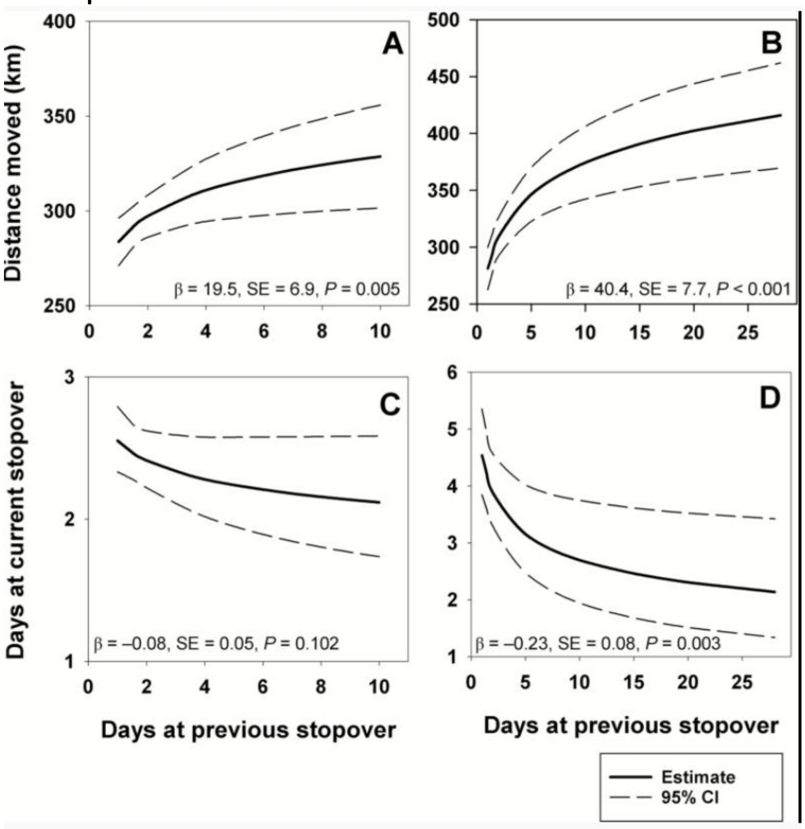
$WCM5_{Alt2}$ – The probability of a WC stopover increases with unforested corridor width to peak at 1,000 ft, but providing no incremental benefit of increasing unforested corridor width above 1000 ft.

$WCM5_{Alt3}$ – The probability of a WC stopping within the AHR increases as the number of acres of suitable on and off-channel habitat increases.

$WCM5_{Alt4}$ – The probability of a WC stopover increases with the proportion of landcover classified as wetlands within a 1-mile radius of first associated AHR location.

Learning Action:

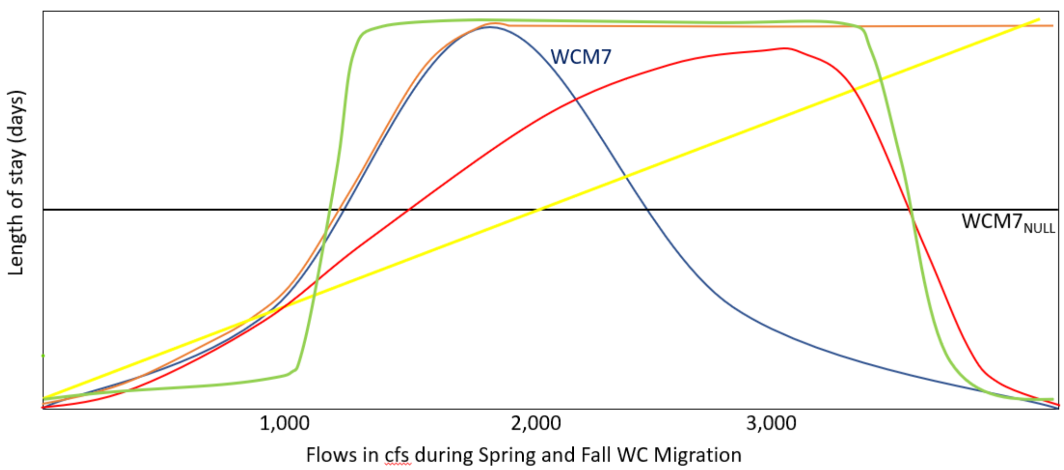
Provide a range of flows during multiple spring and fall migration seasons, evaluating the importance of flow on the probability of a stopover vs. a flyover by individual telemetry-marked WC.

What conditions influence how long a WC will stop on the AHR?
General Hypothesis WC6: Length of stay at previous stopover is primary driver of WC stopover length with length of stay increasing with decreasing length of stay at previous stopover.
X-Y Graph  Pearse et al. 2020
Alternative Hypotheses: **WC6ALT1** – The length of a WC stopover within the AHR increases as distance since the last stopover increases. **WC6ALT2** – The length of a WC stopover within the AHR increases as group size increases. **WC6ALT3** – The length of a WC stopover within the AHR increases when sandhill cranes are present. **WC6ALT4** – The length of a WC stopover within the AHR is longer for juveniles. **WC6ALT5** – The length of a WC stopover within the AHR is longer during the Fall migration. **WC6ALT6** – The length of a WC stopover within the AHR increases when weather conditions are unfavorable for flight.
Learning Action: Analysis of WC telemetry to examine the relative importance of factors outside of Program control on the length of WC stopovers within the AHR.

What conditions influence how long a WC will stop on the AHR?

Management Hypothesis WCM7: Length of WC stopover within the AHR increases with increasing flow until flow reaches 1,800 cfs and declines with increasing flow above 2,000 cfs.

X-Y Graph



Alternative Hypotheses:

$WCM7_{Alt1}$ – Length of a WC stopover within the AHR increases with MUCW to peak at 650 ft, but providing no incremental benefit of increasing MUCW above 650 ft.

$WCM7_{Alt2}$ – The length of a WC stopover within the AHR increases with unforested corridor width to peak at 1,000 ft, but providing no incremental benefit of increasing unforested corridor width above 1000 ft.

$WCM7_{Alt3}$ – The length of a WC stopover within the AHR increases as the number of acres of suitable on and off-channel habitat increases.

$WCM7_{Alt4}$ – The length of a WC stopover within the AHR increases as the proportion of landcover classified at wetlands within a 1-mile radius of stopover location increases.

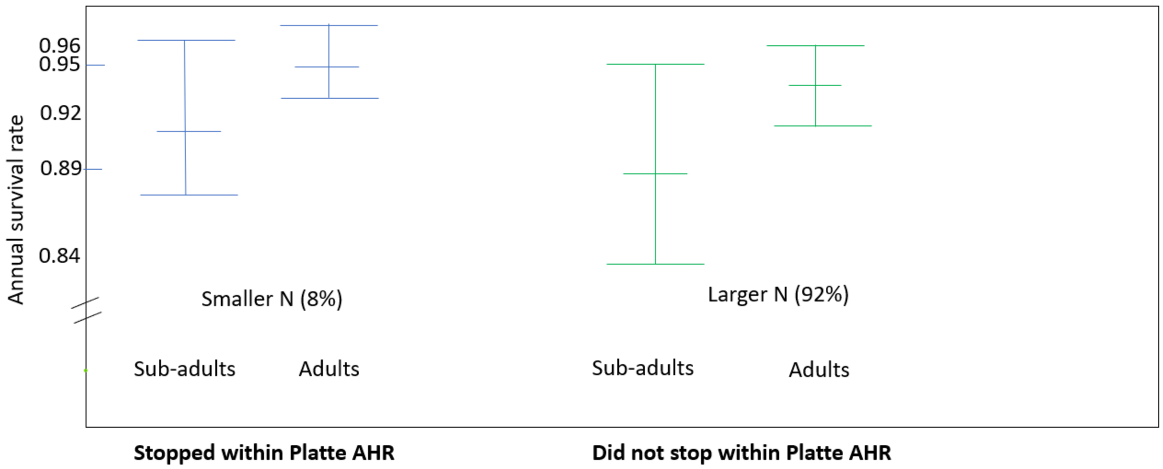
Learning Action:

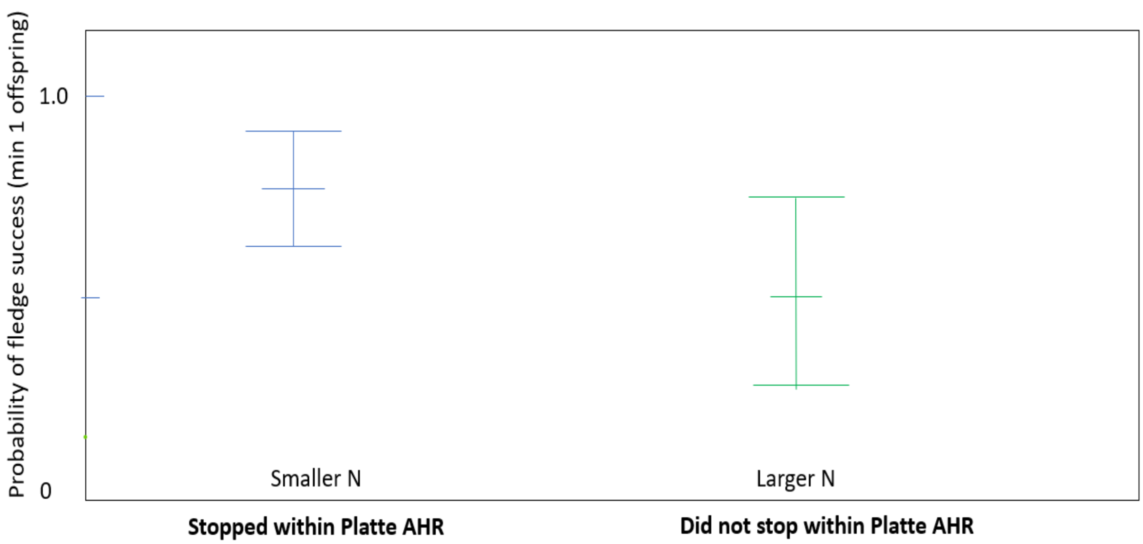
Provide a range of flows during multiple spring and fall migration seasons, evaluating the importance of flow on the length of WC stopovers.

Does the AHR contribute to WC fitness?

General Hypothesis WC8: WC that stop within the AHR are more likely to successfully complete migration (spring and fall), have higher survival rates, and reproduce more successfully than those that fly over the AHR.

X-Y Graph





Alternative Hypotheses:

$WC8_{ALT1}$ – Wider distribution of WC habitat across the AHR increases migratory success, survival rates, and reproduction of WC that stop within the AHR when compared to their counterparts that flyover the AHR.

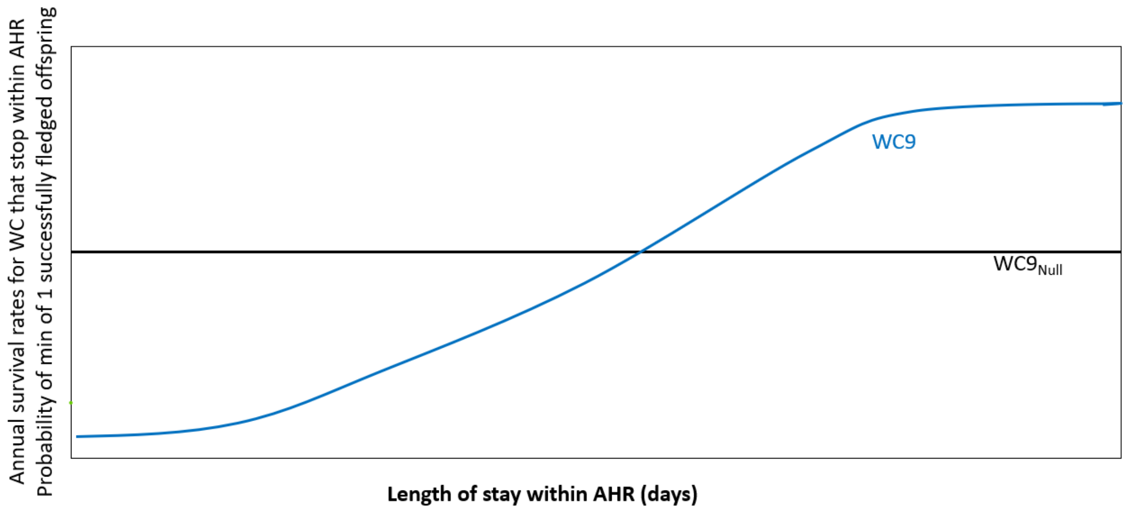
Learning Action:

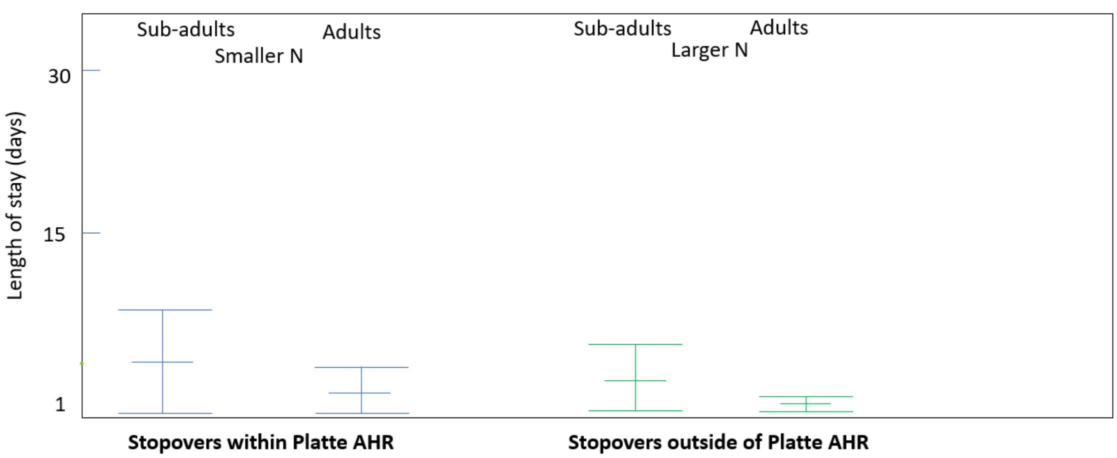
Establish collaborative research partnership to test for difference in successful migration, survival, and reproduction between WC that stop within the AHR and their counterparts that flyover.

Does the AHR contribute to WC fitness?

General Hypothesis WC9: WC with longer stopovers within the AHR are more likely to successfully complete migration (spring and fall), have higher survival rates, and reproduce more successfully than those with shorter stopovers.

X-Y Graph





Alternative Hypotheses:

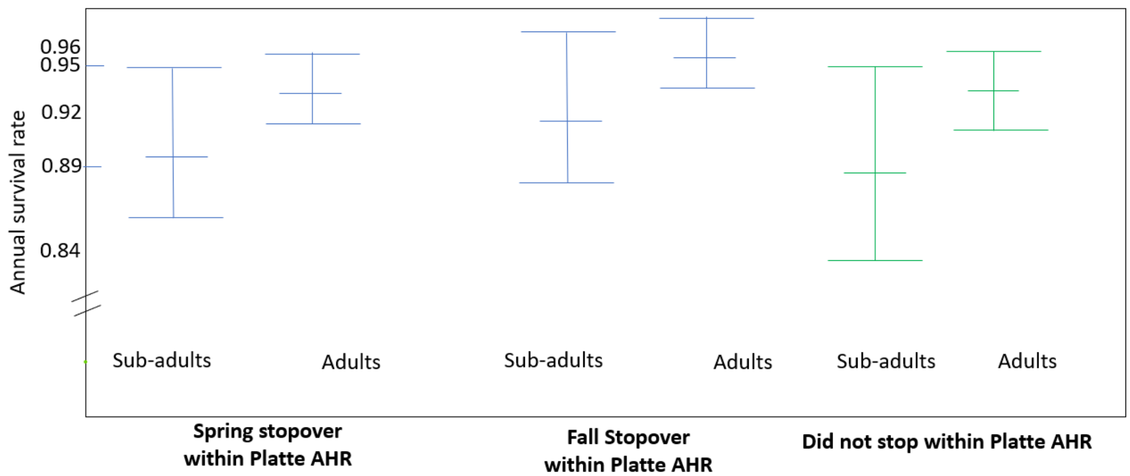
$WC9_{ALT1}$ – WC stopovers within the AHR are longer on average than WC stopovers at other locations.

Learning Action:

Establish collaborative research partnership to examine the potential benefits of longer stays within the AHR in terms of successful migration, survival, and reproduction.

What is the importance of the AHR to WC survival in the fall vs. the spring?
General Hypothesis WC10: Survival rates differ between WC that stop over in the fall vs. spring.

X-Y Graph



Alternative Hypotheses:

WC10$_{ALT1}$ – WC that stopover within the AHR in the Spring have greater survival rates than their counterparts that stop in the AHR in the Fall.

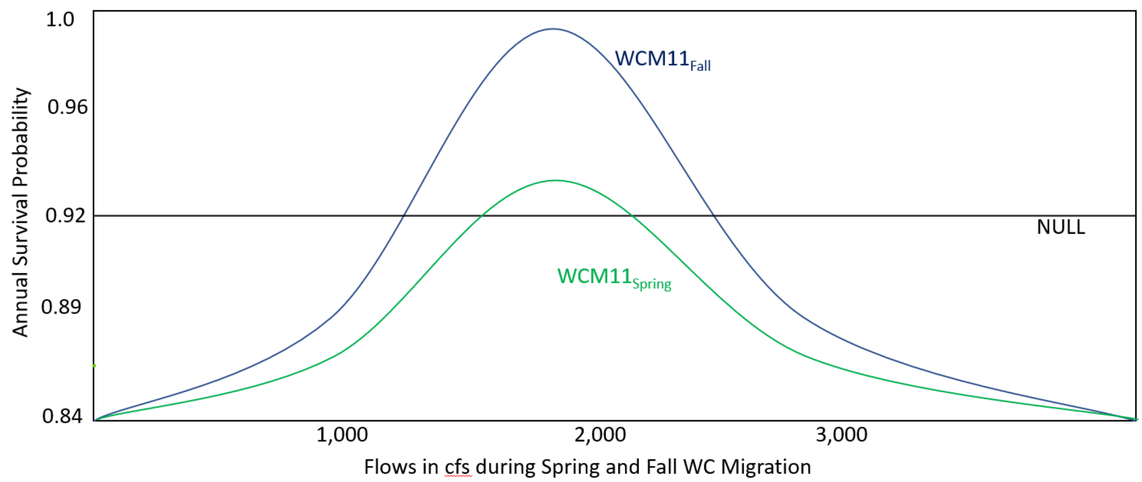
WC10$_{ALT2}$ – The average length of WC stopover in the Spring is longer when compared to the Fall.

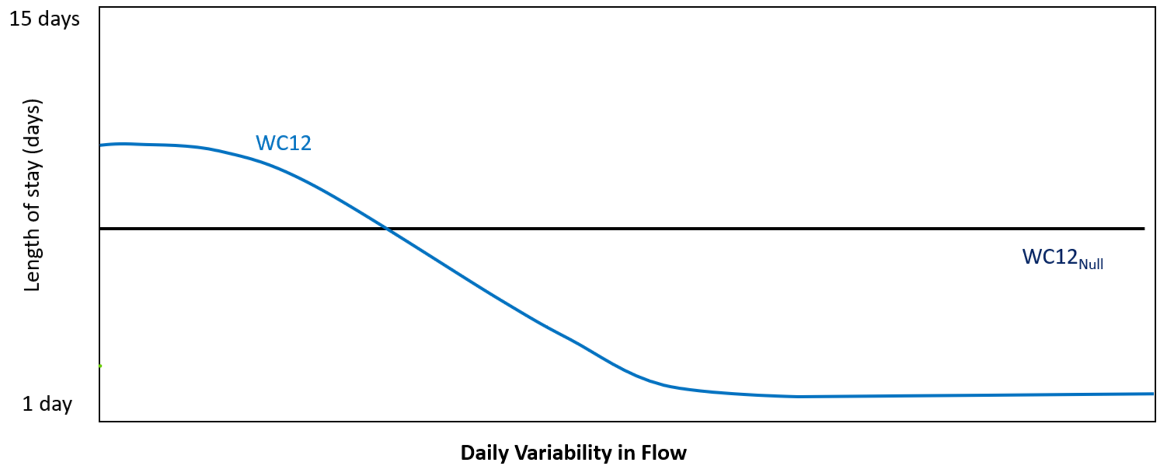
WC10$_{ALT3}$ – Larger groups including adults and juveniles utilize the AHR in the Spring when compared to the Fall.

Learning Action:

Establish collaborative research partnership to examine the potential benefits to WC stopovers within the AHR in the spring vs. fall migratory seasons in terms of survival.

Examine how WC use of the AHR differs during the spring vs. fall migratory seasons.

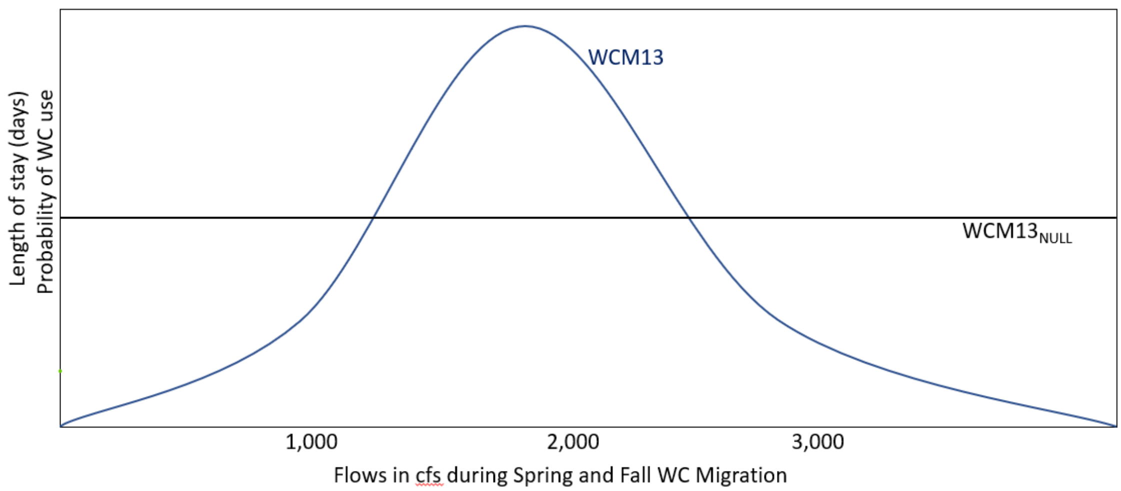
What is the importance of the AHR to WC survival in the fall vs. the spring?
Management Hypothesis WCM11: Prioritizing flow releases during the fall WC migration when natural flows and WC use of the AHR are typically lower will increase survival more than flow releases during the spring migration.
X-Y Graph 
Alternative Hypotheses: **$WCM11_{Alt1}$ –** Program release of water during fall WC migration will increase the proportion of the AWB population that uses the AHR during the fall migration season. **$WCM11_{Alt2}$ –** Program release of water during fall WC migration will increase the average WC stopover length within the AHR during the fall migration season.
Learning Action: Prioritize Program water releases to attain flows between 1,800 -2,000 cfs along the AHR during WC fall migration. Establish collaborative research partnership to examine the potential benefits to WC stopovers while conducting fall flow releases in terms of survival. Compare results to similar analyses of survival benefits to spring stopovers within the AHR.

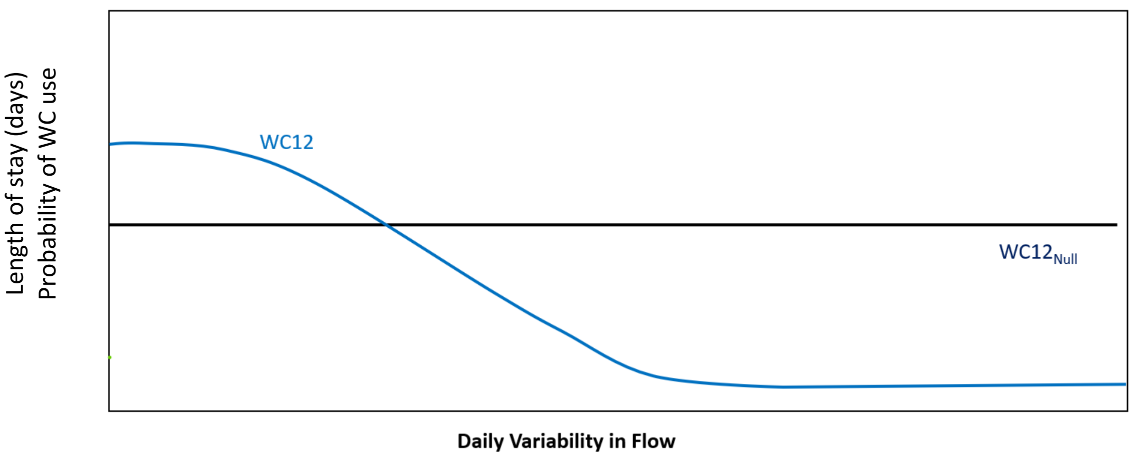
What is the impact of hydro-stepping on WC use of the AHR?
General Hypothesis WC12: WC length of stay and/or stopover locations are influenced by daily flow variability.
X-Y Graph 
Alternative Hypotheses: **$WC12_{ALT1}$ –** The length of a WC stopover within the AHR decreases as variability in daily flow increases. **$WC12_{ALT2}$ –** WC on-channel stopover locations are associated with low daily variability in flow. **$WC12_{ALT3}$ –** The distribution of WC stopovers along the AHR shifts to the eastern portion of the AHR during periods of hydro-stepping.
Learning Action: Utilize Program data on flow and WC use to examine the effects of hydro-stepping (high flow variability) on patterns of WC use of the AHR.

What is the impact of hydro-stepping on WC use of the AHR?

Management Hypothesis WCM13: Reducing or eliminating hydro-stepping by maintaining flows at 1,800 cfs during spring and fall WC migration will increase the length of WC stopovers within the AHR and increase use of the western segments of the AHR for WC roosting.

X-Y Graph





Alternative Hypotheses:

$WCM13_{Alt2}$ – Limiting peak flows due to hydro-stepping at the western end of the AHR during spring and fall WC migration to 9 a.m. to 2 p.m. when WC are typically not on the river roosting will increase length of WC stopovers and increase use of the western segments of the AHR for WC roosting.

Learning Action:

Program management to eliminate the need for hydro-stepping through maintaining flow at 1500 cfs during spring and fall WC migration.

Program management to limit hydro-stepping peaks on the western end of the AHR to hours of the day when WC are typically not on the river roosting.

What are the effects of Program management of river flow on wet meadow hydrology?
General Hypothesis WC14: Natural peak flows from March 1 – June 30 have the largest effect on wet meadow hydrology.
X-Y Graph
Alternative Hypotheses: **$WC14_{ALT1}$ –** Precipitation has the largest effect on wet meadow hydrology. **$WC14_{ALT2}$ –** Program management of river flow has no significant effect on wet meadow hydrology.
Learning Action: Use Program data to analyze the effects river flow on wet meadow hydrology.

IDENTIFY UNCERTAINTIES AND DEVELOP PRIORITY HYPOTHESES FOR NON-TARGET LISTED AND NON-LISTED SPECIES OF CONCERN

The AMWG discussed the possibility of addressing uncertainties related to potential effects of Program land and water management on non-target listed and non-listed species of concern (Table 5). US Fish and Wildlife Service priorities were identified for grassland birds, pollinators (monarch and regal butterflies), and fish species that are currently on the Nebraska state list and being considered for federal listing (sturgeon chub). A technical working group may be an option to identify priority non-target listed and non-listed species of concern to be included in Program land and water management planning. Further guidance from the Governance Committee is necessary to determine where priorities lie and how the Program would like to move forward with this question during the Extension.

Table 5. Hierarchy of potential non-target listed and non-listed species of concern uncertainties.

Uncertainty: How do Program management actions affect non-target listed and non-listed species of concern (species to be identified by USFWS and NGPC)?
General Hypothesis NT/NL1: Program water and land management actions provide benefits to non-target listed and non-listed species of concern.

Non-Target Listed and Non-Listed Species of Concern Uncertainties and Hypotheses

This section contains a list of general hypotheses proposed to address the hierarchy of potential uncertainties contained within Table 5 above. Predicted relationships are represented with XY graphs. Alternative hypotheses are also presented for consideration. Learning actions for obtaining and analyzing the data necessary to test hypotheses posed are included.

How do Program management actions affect non-target listed and non-listed species of concern (species to be identified by USFWS and NGPC)?
General Hypothesis NT/NL1: Program water and/or land management actions provide benefits to non-target listed and/or non-listed species of concern.
X-Y Graph
Alternative Hypotheses: **NT/NL1$_{Alt1}$** - Program water and/or land management actions negatively impact non-target listed and/or non-listed species of concern. **NT/NL1$_{Null}$** - Program water and/or land management actions have no detectable effect on non-target listed and/or non-listed species of concern.
Learning Action: Monitoring of USFWS and NGPC indicated non-target and/or non-listed species of concern in response to Program water and/or land management actions.

Appendix 1. Descriptions of hypothesized relationships between components in the least tern and plover CEM (Figure 1) depicting level of uncertainty about and control over this relationship (arrow color & weight) with accompanying literature in support of these designations.

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Social, Legal, Political, & Economic		Climate	Social, legal, political, & economic factors form the basis of the Program but the ability to implement the Program is influenced by climate, particularly related to water availability. Goals and objectives of the Program influence management decisions and their responses to climate.	Final Program Document; Extension Document; climate change input as part of operational model.
Climate		Hydrology	Large amount of uncertainty relative to future impacts of climate on hydrology and the ability of the Program to model potential impacts and use those modeling results in Program planning and implementation. But the Program has no control over the effects of climate on water availability.	Using historic hydrologic conditions to inform water operations modeling to make predictions under varying climate change scenarios.
Climate		Weather	Uncertainty about the impacts of climate change on local weather patterns and events which can have a significant impact on tern/plover productivity, but again the Program can do little to account for this impact other than to provide nesting dispersal opportunities as a backstop against the effects of localized weather events (heavy rain, hailstorms, etc.).	Climate change input as part of operational model; maybe some expected productivity loss due to more frequent/intense weather events included in operational model and/or models used by the GC in SDM as part of decision-making.
Climate		Non-Program Habitat/Overwinter & Migratory Conditions/Dispersal/Stochastic Events	Uncertainty about the impacts of climate change on weather patterns and events which can have a significant impact on tern/plover survival and recruitment.	
Social, Legal, Political, & Economic		Channel Inundation Release/High Flow Release/Sediment Augmentation/Mechanical Channel Maintenance/MCA Islands	Little uncertainty about the bounds of the Program, resources, water law, etc. that effect the amount of water and land available for management actions and in turn the ability of the Program to manage and control water, augment sand, and apply mechanical actions in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Social, Legal, Political, & Economic		Off-channel Habitat Creation and Maintenance	Little uncertainty about the bounds of the Program, resources, water law, etc. that effect the amount of water and land available for management actions and in turn the ability of the Program to create and maintain off-channel habitat in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Social, Legal, Political, & Economic		Predator Control	Little uncertainty about the bounds of the Program to manage and control predators in the AHR other than the Services' willingness to allow avian trapping at off-channel nesting sites.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Channel Inundation Release		Hydrology	Little uncertainty about the relationship between Program flow management in the summer and river hydrology but the Program cannot control other important factors such as irrigation return flows, hydrocycling, USFWS target flow releases, drought, and runoff events.	Gaging station data

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
High Flow Release		Hydrology	Little uncertainty about the relationship between peak flows and river hydrology but peak flows are currently driven by natural events over which the Program has no control. Program peak flow management is limited by the Good Neighbor Policy and conveyance constraints at the North Platte choke point.	Farnsworth et al. 2017; Farnsworth et al. 2018a; Gauging station data
Channel Inundation Release/High Flow Release/Sediment Augmentation/Mechanical Channel Maintenance/MCA Islands		Sandbar Morphology/Unvegetated Channel Width	The mix of these Program management activities does have an impact on channel morphology and width, but the largest factor now is peak flows driven by natural events outside the control of the Program, except to inform GC and determine if the peak flows may be protected.	Farnsworth et al. 2015; Farnsworth et al. 2017; Farnsworth et al. 2018a
MCA Islands		On-Channel Nesting Habitat	The Program can build and manage this habitat to specification, but on-channel habitat is dynamic, changing in size and location over time	Tern and Plover Final SDM Report
Off-Channel Habitat Creation & Maintenance		Off-Channel Nesting Habitat	The Program can build and manage this habitat to specification.	Baasch et al. 2017a; Farrell et al. 2018; PRRIP Tern and Plover Monitoring and Research Reports
Hydrology		Sandbar Morphology/Unvegetated Channel Width	High correlation but low ability on the part of the Program to control natural peak flow events.	Farnsworth et al. 2015; Farnsworth et al. 2017; Farnsworth et al. 2018a
Hydrology		Forage Availability	Primarily an issue of forage fish for terns. Data from First Increment do not link flow to forage availability or productivity.	Baasch et al. 2017; Sherfy et al. 2012
Sandbar Morphology/Unvegetated Channel Width		On-Channel Nesting Habitat	Creation of on-channel nesting habitat is driven more by natural peak flow events over which the Program has no control. Tern and plover nesting occurs prior to late spring floods within the AHR, reducing the potential for successful nesting.	Farnsworth et al. 2015; Farnsworth et al. 2017; Farnsworth et al. 2018a; Farnsworth et al. 2018b
On-Channel Nesting Habitat		Nest Location/Nest Density	Though external science from the Missouri River and the Atlantic Coast demonstrates large increases in nesting incidence by plovers in response to the creation of on-channel and shoreline habitat, few nests resulted from the creation of in-channel nesting islands by the Program from 2013 – 2016. Nesting prior to cessation of spring flooding further reduced successful nesting. The paucity of on-channel nesting has precluded attempts to characterize preferred on-channel nesting locations or examine nest density limitations for terns and plovers.	Robinson et al. 2019; Catlin 2009; PRRIP Tern and Plover Monitoring and Research Reports; Farnsworth et al. 2015; Farnsworth et al. 2017; Farnsworth et al. 2018a; Farnsworth et al. 2018b

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Off-Channel Nesting Habitat		Nest Location/Nest Density	Alternatively, tern and plover nest counts have increased significantly in response to the creation of off-channel nesting habitat. Nest site selection characteristics have been described for both terns and plovers for off-channel nesting within the AHR.	PRRIP Tern and Plover Monitoring and Research Reports; Baasch et al. 2017a
On-Channel Nesting Habitat		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Few nests resulted from the creation of in-channel nesting islands by the Program from 2013 – 2016. Nesting prior to spring flooding reduced nest and chick survival and provided little opportunity for renesting. Without on-channel habitat creation, no on-channel nesting has been documented since 2016 for either terns or plovers.	PRRIP Tern and Plover Monitoring and Research Reports; Farnsworth et al. 2015; Farnsworth et al. 2017; Farnsworth et al. 2018a; Farnsworth et al. 2018b
Off-Channel Nesting Habitat		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Program can directly impact through habitat creation and management. Significant positive relationship between acres of off-channel nesting habitat and breeding pairs, leading to increased productivity.	PRRIP Tern and Plover Monitoring and Research Reports
Off-Channel Nesting Habitat		Site Age/Site Size	Program can directly impact through habitat creation. Site age is determined at time of habitat creation, and may be linked to predation, forage availability for plovers, and productivity.	
Off-Channel Nesting Habitat		Predation	As predictable sources of tern and plover nesting, predators may learn to target off-channel sites as stable food sources. Important relationship with productivity.	PRRIP Tern and Plover Monitoring and Research Reports
Predator Control		Predation	Important area for Program research directly linked to tern and plover productivity. Need to develop a toolbox for predator control options with information on effectiveness over time.	PRRIP Tern and Plover Monitoring and Research Reports
Weather		Nest Location/Nest Density	Nest site selection based on elevation and distance to water may be in response to potential for inundation during spring rains. Program cannot control weather, but can manage habitat to make less of it subject to flooding.	Baasch et al. 2017a
Weather		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Weather is significant impact but cannot control weather events.	Farrell et al. 2018
Disturbance		Nest Location/Nest Density	Negative impact on nesting, but Program can control at managed sites.	Nest maps in relation to active mining and high traffic areas.

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Disturbance		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Literature on colonial nesting birds demonstrates a negative impact of disturbance on productivity. Program can control disturbance at managed sites. Program research, similar to that on the Missouri River demonstrates no apparent reduction in productivity associated with inside monitoring	Carney and Sydeman 1999; Blackmer et al. 2004; Carey 2009; Roche et al. 2014; Farrell et al. 2020 PRRIP Tern and Plover Monitoring and Research Reports
Forage Availability		Nest Location/Nest Density	Nest site forage availability may be important for plovers that rely more heavily on site-specific resources, whereas this link has not been supported for terns.	Baasch et al. 2017; Sherfy et al. 2012
Forage Availability		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Limited invertebrate forage resources along wetted shorelines may reduce plover productivity. Single study on invertebrate forage availability at off-channel sites demonstrated comparable invertebrate abundance to that of riverine sandbars. No evidence of declining body condition for plovers. Data from First Increment does not indicate limits on forage fish availability to support tern productivity.	Baasch et al. 2017; Sherfy et al. 2012
Site Age/Site Size		Forage Availability	As off-channel nesting sites age, invertebrate forage resources may decline, reducing plover productivity. Single study on invertebrate forage availability at off-channel sites demonstrated comparable invertebrate abundance to that of riverine sandbars. No evidence of declining body condition for plovers.	Sherfy et al. 2012
Site Age/Site Size		Predation	Possibly some relationship between older sites and predation. Predators may learn to rely on predictable off-channel sites as stable sources of prey, but there is only so much habitat that can be purchased and/or developed/managed in the AHR. Predator presence/predation has not been systematically quantified using comparable methods over multiple years. Annual losses to predation show high variability across sites and across years.	
Site Age/Site Size		Nest Location/Nest Density	Identified area of uncertainty with regard to nest site selection based upon site age and site size. Appears to be at least a year lag in site creation and site use by terns and plovers.	
Site Age/Site Size		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	May be relationship between site age/site size and productivity over time but there are only so many sites the Program can acquire and/or develop/manage due to limitations in acres, budget, etc.	

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Predation		Nest Location/Nest Density	Distance from predator perch important criteria for nest site selection. Predation reduces current and potential future nesting densities (reduces renesting probability).	Baasch et al. 2017a; Swift et al. 2020.
Predation		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Documented losses to predation were high in 2018 – 2019. Important area for Program research: determine the impact of predation, types of predators responsible, possible control methods, and the effectiveness of control methods.	PRRIP Tern and Plover Monitoring and Research Reports
Nest Location		Nest Density	Direct relationship. Plover territoriality makes density more important for plover productivity. Program may be able to increase plover densities by modifying site shape (lobular designs separate nesting territories and add linear feet of shoreline for foraging).	Baasch et al. 2017a; PRRIP Tern and Plover Monitoring and Research Reports
Nest Location/Nest Density		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	Direct relationship. Plover territoriality makes density more important for plover nesting. Program may be able to increase plover densities by modifying site shape (lobular designs separate nesting territories and add linear feet of shoreline for foraging). No significant relationship between nest density and nest success.	Baasch et al. 2017a; Farrell et al. 2018; PRRIP Tern and Plover Monitoring and Research Reports; PRRIP Tern and Plover Final SDM Report
Breeding Pairs		Eggs Produced	Direct relationship. Higher forage availability may lead to larger clutches. May be outside of Program control.	
Breeding Pairs		Egg, Nest, and Chick Survival/Fledges/Fledge Ratio	Direct relationship. Program can manage for improved reproductive success through habitat management and predator control.	Baasch et al. 2015; PRRIP Tern and Plover Monitoring and Research Reports
Egg, Nest, and Chick Survival		Fledges/Fledge Ratio	Direct relationship, outside the control of the Program.	PRRIP Tern and Plover Monitoring and Research Reports
Nest Location/Nest Density		Predation	Predators may be attracted to the presence of active nests, with higher densities attracting more predators. Nests at the periphery of nesting sites, closer to predator perches, may be subject to higher predation rates.	Baasch et al. 2017a; Farrell et al. 2018
Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio		Predation	Predators may be attracted to the presence of breeding adults, nests, mobile chicks and fledglings	
Non-Program Habitat/Overwinter & Migratory Conditions/Dispersal		Nest Location/Nest Density	These factors likely have significant impacts on tern/plover use and occurrence in the AHR but are outside the control of the Program.	Swift et al. 2021
Non-Program Habitat/Overwinter & Migratory Conditions/Dispersal		Breeding pairs/Eggs Produced/Egg, Nest and Chick Survival/Fledges/Fledge Ratio	These factors likely have significant impacts on tern/plover productivity in the AHR but are outside the control of the Program.	Swift et al. 2021

Appendix 2. Descriptions of hypothesized relationships between components in the whooping crane CEM (Figure 2) depicting level of uncertainty about and control over this relationship (arrow color & weight) with accompanying literature in support of these designations.

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Climate		Social, Legal, Political, & Economic	Social, legal, political, & economic factors form the basis of the Program but the ability to implement the Program is influenced by climate, particularly related to water availability. The goals and objectives of the Program influence management decisions and their responses to climate.	Final Program Document; Extension Document; climate change input as part of operational model
Climate		Hydrology	Large amount of uncertainty relative to future impacts of climate on hydrology and the ability of the Program to model potential impacts and use those modeling results in Program planning and implementation. But the Program has no control over the effects of climate on water availability.	Water operations model using historic hydrology for wet and dry years
Climate		Migratory Habitat Conditions/Breeding Ground Conditions/Wintering Ground Conditions/Natural Flows/Spring vs. Fall/Stochastic Events	Large amount of uncertainty relative to future impacts of climate on habitat and other conditions outside the AHR. 2019 PVA Report for Species Metapopulation of Whooping cranes listed lower potential recruitment related to climate as one important factor that may reduce growth rates of the Aransas-Wood Buffalo population.	Gil-Weir et al. 2012; Traylor-Holzer 2019
Social, Legal, Political, & Economic		Baseflow for Fish Guilds/Hydro-stepping/ Migration Flow Release	Program has limited control over these water uses that effect the amount of water available for management actions and in turn the ability of the Program to manage and control water actions in the AHR.	USFWS Target Flow Releases; Is there a CNPPID doc with hydro-stepping process/regulations?
Social, Legal, Political, & Economic		Fall High Flow Release /Channel Inundation Flows	Little uncertainty about the bounds of the Program, resources, water law, etc. that effect the amount of water available for management actions and in turn the ability of the Program to manage and control water actions in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Social, Legal, Political, & Economic		Mechanical Channel Maintenance	Little uncertainty about the bounds of the Program, resources that effect the amount of land available for management actions and in turn the ability of the Program to apply mechanical actions in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Social, Legal, Political, & Economic		Sediment Augmentation	Little uncertainty about the bounds of the Program, resources that effect the amount sediment augmentation activities and in turn the ability of the Program to augment sand in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Social, Legal, Political, & Economic		Off-Channel Habitat Creation & Maintenance	Little uncertainty about the bounds of the Program, resources that effect the amount of land available for management actions and in turn the ability of the Program to apply mechanical actions in the AHR.	Final Program Document; Extension Document; AMP Versions 1.0 and 2.0
Baseflow for Fish Guilds/Hydro-stepping/ Migration Flow Release		Fall High Flow Release/Channel Inundation Flow Release	Trade-offs between water usage within and outside Program control. Little uncertainty about how these water uses reduce water availability for Program water management, but largely out of Program control.	Water operations modeling
Baseflow for Fish Guilds/Hydro-stepping/ Migration Flow Release		Hydrology	Little uncertainty about how these water management activities impact river hydrology, but these water uses are largely outside Program control. Program may have a higher degree of control over migration flow releases.	Gaging station data
Migration Flow Release/Hydro-stepping		Proportionate Use/Distribution of Use/Length of Stay/On- and Off-Channel Foraging or Roosting	High uncertainty about the relationship between flow management during migration and whooping crane use. Learning to date on a use site scale suggests the link between flow and WC use may be tentative. Program does not have unilateral control over these flow releases.	Baasch et al. 2017; Farnsworth et al. 2018; Gaging station data
Fall High Flow Release/Channel Inundation Flows		Hydrology	Little uncertainty about the relationship between Program flow management and river hydrology but the Program cannot control other important factors such as natural peak flow events.	Tetra Tech 2014; EDO 2017; Water operations modeling and gaging station data
Fall High Flow Release		Channel Width/Vegetation	Program learning that indicates a spring SDHF as envisioned in AMP Version 1.0 will not result in intended effects on whooping crane habitat. Fall high flow release given lower priority for learning in favor of spring channel inundation flow releases to suppress germination.	Tetra Tech 2014; EDO 2017; Geomorphology and In-channel Vegetation Monitoring data
Channel Inundation Flows		Channel Width/Vegetation	Important uncertainty to explore - ability of Program to manage available water to impede vegetation germination and *Phragmites* expansion and thus maintain or expand unvegetated channel width.	Hosner 1958; Karlinger et al. 1981; Currier 1982; Carter-Johnson 1994; Currier 1997; Knezevic et al. 2008; Rapp 2012; PRRIP 2019; Marks & Atia 2020; Geomorphology and In-channel Vegetation Monitoring modeling; Water operations modeling; Gaging station data;
Mechanical Channel Maintenance		Channel Width/Vegetation	Strong relationship between mechanical channel maintenance and channel width and vegetation. Effectiveness of herbicide on controlling *Phragmites* has not been quantified, but important for building a long-term strategy for maintaining and expanding unvegetated channel width.	Tetra Tech 2014; Farnsworth et al. 2018; Geomorphology and In-channel Vegetation Monitoring data. Annual Aerial Herbicide application (*Phragmites* spraying) data

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Sediment Augmentation		Channel Width/Vegetation	Sediment augmentation together with natural peak flows can help create new sandbars, scour vegetation, and widen channels, but effectiveness is limited by lack of Program control over natural peak flows.	Tetra Tech 2014; Geomorphology and In-channel Vegetation Monitoring data
Off-Channel Habitat Creation & Maintenance		Acres of Suitable Off-Channel Roosting Habitat	WC do use off-channel wetland areas for roosting but there is only so much of that habitat that can be acquired/developed/managed by the Program and use has been low within the AHR..	Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019a
Off-Channel Habitat Creation & Maintenance		Acres of Suitable Off-Channel Foraging Habitat	WC do use off-channel wet meadow areas for foraging but there is only so much of that habitat that can be acquired/developed/managed by the Program and use has been low within the AHR..	Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019a
Wetland Pumping		Acres of Suitable Off-Channel Roosting Habitat	Wetland pumping can be used to fill wetlands created for WC use, but WC use of these palustrine wetlands has been low within the AHR.	Baasch et al. 2017
Hydrology		Channel Width/Vegetation	Interactive effects of hydrology, channel width, and vegetation. Influence of vegetation ratchet effect.	Farnsworth et al. 2018; Baasch et al. 2017; Pollen-Bankhead et al. 2014
Channel Width		Vegetation	Interactive effects of hydrology, channel width, and vegetation. Influence of vegetation ratchet effect.	Pollen-Bankhead et al. 2014; Baasch et al. 2017; Farnsworth et al. 2018
Hydrology		Acres of Suitable On-Channel Habitat	Important uncertainty. Connection between Program flow management activities, acres of suitable on-channel habitat, and whooping crane use.	Baasch et al. 2017; Farnsworth et al. 2018; Baasch et al. 2019b
Hydrology		Acres of Suitable Off-Channel Habitat	Important uncertainty. Connection between Program flow management activities and wet meadow hydrology sufficient enough to improve foraging conditions for whooping cranes.	Wet meadow ground water monitoring data
Channel Width/Vegetation		Acres of Suitable On-Channel Roosting Habitat	Program mechanical management and extreme natural high flow events can have a large impact on this.	Pearse et al. 2017; Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019b
Ice		Channel Width/Vegetation	Likely an important relationship to explore and understand but very difficult for the Program to control, experiment, or monitor to learn.	PRRIP 2019
Acres of Suitable On-Channel Habitat		Proportionate Use/Distribution of Use/Length of Stay/On-Channel Foraging or Roosting	Important uncertainty to explore during the Extension.	Pearse et al. 2017; Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019b
Acres of Suitable Off-Channel Habitat		Proportionate Use/Distribution of Use/Length of Stay/Off-Channel Foraging or Roosting	Important uncertainty to explore during the Extension.	Pearse et al. 2017; Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019a

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
On-Channel Roosting		Off-Channel Foraging	Likely an important behavioral relationship. Diurnal use sites both on and off-channel are selected in closer proximity to the previous night's roosting site.	Howlin and Nasman 2017
Proportionate Use/Distribution of Use/Length of Stay		On- and Off-Channel Foraging or Roosting	Important relationship to explore. WC behavioral patterns likely important for proportionate use, distribution of use, and length of stay. Performance indicators highly interdependent.	Pearse et al. 2017; Baasch et al. 2017; Howlin and Nasman 2017; Baasch et al. 2019a; Baasch et al. 2019b
Proportionate Use/Distribution of Use/Length of Stay		Contribute to Survival/Reproduction	Stopovers along migratory corridor provide essential roosting habitat and energetic resources for successful migration. However, the migratory nature of WC, brief stopover use of AHR along, low numbers and bias with telemetry birds, and natural low variability in adult survival and reproduction parameters make determining this relationship difficult. Collaboration with research partners may help us obtain data for survival and reproduction.	Gil-Weir et al. 2012; Wilson et al. 2016; Pearse et al. 2019; Pearse et al. 2020
On and Off-Channel Foraging		Contribute to Survival/Reproduction	Stopovers along migratory corridor provide essential energetic resources for successful migration. However, the migratory nature of WC, brief stopover use of AHR, low numbers and bias with telemetry birds, and natural low variability in adult survival and reproduction parameters make determining this relationship difficult. Collaboration with research partners may help us obtain data for survival and reproduction.	Gil-Weir et al. 2012; Wilson et al. 2016; Pearse et al. 2019; Pearse et al. 2020
On and Off-Channel Roosting		Contribute to Survival/Reproduction	Stopovers along migratory corridor provide essential roosting habitat for successful migration. However, the migratory nature of WC, brief stopover use of AHR, low numbers and bias with telemetry birds, and natural low variability in adult survival and reproduction parameters make determining this relationship difficult. Collaboration with research partners may help us obtain data for survival and reproduction.	Gil-Weir et al. 2012; Wilson et al. 2016; Pearse et al. 2019; Pearse et al. 2020
Non-Program Habitat/ Natural Flows/Breeding Ground Conditions/ Wintering Ground Conditions/Natural Flows/ Natural Spring vs Fall Use Patterns/Stochastic Events		Proportionate Use/Distribution of Use/Length of Stay/On-Channel Foraging or Roosting	These factors likely have significant impacts on whooping crane use of the AHR but are outside the control of the Program.	Moore et al. 2005, Pearse et al. 2018, Pearse et al. 2020
Non-Program Habitat/Natural Flows/Breeding Ground Conditions/ Wintering Ground Conditions/Natural Flows/ Natural Spring vs Fall Use Patterns/Stochastic Events		Contribute to Survival/Reproduction	These factors likely have significant impacts on the whooping crane population but are outside the control of the Program.	Gil-Weir et al. 2012; Wilson et al. 2016; Pearse et al. 2019; Traylor-Holzer 2019; Pearse et al. 2020

Appendix 3. Descriptions of hypothesized relationships between components in the annual and perennial vegetation sub-model (Figure 3) depicting level of uncertainty about and control over this relationship (arrow color & weight) with accompanying literature in support of these designations.

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Channel Inundation Flow Releases		Newly Formed Sandbars	Important uncertainty to explore - ability of Program to manage available water to impede vegetation germination, thus maintain or expand unvegetated channel width.	Hosner 1958; Karlinger et al. 1981; Currier 1982; Carter-Johnson 1994; Currier 1997; PRRIP 2019; Marks & Atia 2020; Geomorphology and In-channel Vegetation Monitoring modeling; Water operations modeling; Gaging station data;
Fall High Flow Release		Newly Formed Sandbars/Annual Herb and Woody Seedlings	Important uncertainty to explore related to GC policy decision to implement a release 5,000 – 8,000 cfs for three days in September during the Extension and Program learning that indicates a spring SDHF as envisioned in AMP Version 1.0 will not result in intended effects on whooping crane habitat. Fall high flow release given lower priority for learning in favor of spring channel inundation flow releases to suppress germination.	Tetra Tech 2014; Geomorphology and In-channel Vegetation Monitoring data
Bar Spraying/Disking		Newly Formed Sandbars/Annual Herb and Woody Seedlings	Strong relationship between mechanical channel maintenance and channel width and vegetation. These management activities take the channel back to a stage-zero riverbed.	Farnsworth et al. 2018
Mixed Herb-Shrub		Tree Clearing/Bank Spraying and Disking/Mechanical Channel Widening	Strong relationship between mechanical channel maintenance and channel width and vegetation. These management activities take the channel back to a stage-zero riverbed.	Farnsworth et al. 2018
Gallery Forest/Thicket		Tree Clearing/Bank Spraying and Disking/Mechanical Channel Widening	Strong relationship between mechanical maintenance and channel width and vegetation. These management activities take the channel back to a stage-zero riverbed.	Farnsworth et al. 2018

Appendix 4. Descriptions of hypothesized relationships between components in the *Phragmites* sub-model (Figure 4) depicting level of uncertainty about and control over this relationship (arrow color & weight) with accompanying literature in support of these designations.

Starting Component(s)	Arrow Color & Weight	Ending Component(s)	Description	Data Sources & Citations
Channel Inundation Flow Releases		Newly Formed Sandbars	Important uncertainty to explore - ability of Program to manage available water to impede *Phragmites* germination and/or expansion and thus maintain or expand unvegetated channel width and improve flow conveyance.	Hosner 1958; Karlinger et al. 1981; Currier 1982; Carter-Johnson 1994; Currier 1997; Knezevic et al. 2008; Rapp 2012; PRRIP 2019; Marks & Atia 2020; Geomorphology and In-channel Vegetation Monitoring modeling; Water operations modeling; Gaging station data
Annual Herbicide		Mixed Perennial Grass and Annual Herbs	Herbicide has been shown to be effective for controlling *Phragmites*, though effect size has not been quantified at the scale of the AHR. Herbicide is important for building a long-term strategy for maintaining and expanding unvegetated channel width and flow conveyance.	Knezevic et al. 2008; Rapp 2012; Pollen-Bankhead et al. 2014; Farnsworth et al. 2018
No Annual Herbicide		*Phragmites*	Herbicide has been shown to be effective for controlling *Phragmites*, though effect size has not been quantified at the scale of the AHR. Herbicide is important for building a long-term strategy for maintaining and expanding unvegetated channel width and flow conveyance.	Knezevic et al. 2008; Rapp 2012;
Mixed Perennial Grass and Annual Herbs		Disking/Mechanical Channel Widening	Strong relationship between mechanical channel maintenance and channel width and vegetation. These management activities take the channel back to a stage-zero riverbed.	Farnsworth et al. 2018
Phragmites		Herbicide/ Disking/Mechanical Channel Widening	Strong relationship between herbicide, disking, mechanical maintenance and channel width and vegetation. These management activities take the channel back to a stage-zero riverbed.	Knezevic et al. 2008; Rapp 2012; Farnsworth et al. 2018