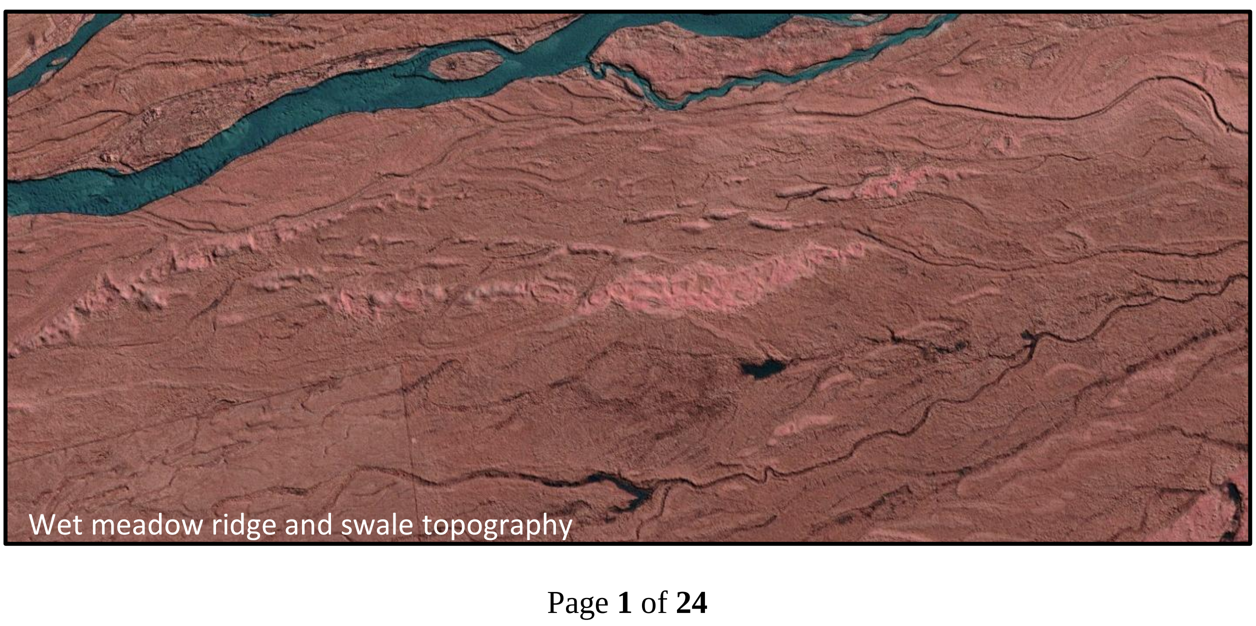
# PLATTE RIVER WET MEADOW GEOHYDROLOGY AND MANAGEMENT THROUGH FLOW RELEASES

## Introduction

Understanding the distribution and movement of groundwater (geohydrology or groundwater hydrology) at Platte River wet meadow sites is a critical issue for the Platte River Recovery Implementation Program (Program or PRRIP) which is tasked with managing land and water resources to benefit threatened and endangered species. Fully one third of the Program's land holdings are to initially be managed as wet meadow habitat and flow releases to benefit wet meadows could easily consume the entire annual water accrual to the United States Fish and Wildlife Service (USFWS) Environmental Account (EA). The Program has applied modeling and management tools in conjunction with previous wet meadow research to better characterize groundwater depth distributions at known wet meadow sites and evaluate the ability to influence groundwater levels through flow releases.

The first part of this paper is informational in nature, explaining the importance of geohydrology in defining and managing wet meadow habitat and summarizing past efforts to characterize the interactions between groundwater and surface water at Platte River wet meadow sites. The paper then expands on those characterizations by providing a process for estimating groundwater response to flow releases at wet meadow sites using existing data and tools. The paper culminates with a case study application of this process at two sites to demonstrate the release volumes necessary to achieve USFWS wet meadow pulse flow targets and the expected magnitude and duration of groundwater response.



Wet meadow ridge and swale topography

## The importance of wet meadow geohydrology

*Shallow groundwater is a key wet meadow attribute*

Central Platte River valley (CPRV) wet meadows have been an area of interest and discussion since at least the mid-1970s. Given the body of literature generated during this time and prominent place that wet meadows hold in Program management (some stakeholders refer to wet meadows as the Program's fifth species), the Governance Committee (GC) commissioned a literature and information review by the Crane Trust in 2010. That review identified and organized PRV wet meadow literature and proposed that the Program adopt the Mitch and Gosselink (1993) description of wet meadows as grasslands with waterlogged soil near the surface but without sanding water most of the year. Specific references to groundwater hydrology from the literature review and other Program documents are presented in Table 1.

**Table 1. Platte River valley wet meadow groundwater hydrology characteristics**

| Characteristics | Source |
|---|---|
| Waterlogged soil near the surface but without standing water most of the year | Mitch and Gosselink 1993 |
| Between February and April, mean monthly groundwater levels are at or above the surface 25% to 75% of the time. | Zuerlin et al. 2001 |
| Mean monthly groundwater depths between February and June are within 0.5 feet of the surface 55% to 80% of the time in wet plant communities, but are never within 0.5 feet of the surface in transitional or dry plant communities. | Zuerlin et al. 2001 |
| Groundwater levels are relatively constant in February through April and are at or above the surface more often than in May and June. | Zuerlin et al. 2001 |
| Swales sub irrigated by ground water seasonally near the soil surface and by precipitation and surface water, with the root zone of the soil continuously saturated for at least 5 - 12.5% of the growing season. Except immediately following precipitation events, higher areas may remain dry throughout the year. | Table 1 of the Land Plan (PRRIP 2006) |
| Continuously saturated soils during the WC migration season 2 out of 3 years if possible. | Program WMWG Gold Standards[1] |
| Between February and April, mean monthly groundwater levels are at or above the ground surface in swales 25% to 75% of the time. | Program WMWG Gold Standards[1] |

[1]These are ideal or "gold standard" wet meadow characteristics developed by the Program's Wet Meadow Work Group (WMWG) in 2012.

The Crane Trust literature review indicates that much of the hydrology-related wet meadow research has focused on the relationship between river stage and groundwater elevations in wet meadows. There appears to be consensus in the literature that river stage exerts a dominant influence on groundwater elevations adjacent to the channel with the degree of influence becoming less clear with increasing distance from the river. Regardless, the Crane Trust identified a belief among many ecologists that wet meadow integrity throughout the CPRV is directly related to river hydrology and wet meadows can only be restored by restoring a natural hydrograph. This restoration strategy is reflected in the USFWS 1994 pulse flow requirements for the central Platte River (Bowman and Carlson 1994) which are commonly referred to as target flows.

*USFWS target flows to benefit wet meadow groundwater hydrology*

The USFWS target flows with wet meadow-related beneficial effects are summarized in Table 2. The objective of these flow targets is generally to increase river stage for the purpose of elevating groundwater levels in wet meadows to or near the ground surface. This, in turn, is expected to drive a variety of biological responses across range of trophic levels.

**Table 2. USFWS target flows with wet meadow-related beneficial effects**

| USFWS Target Flow | USFWS Beneficial Effect | Hydrologic Condition | Target Flow (cfs) | Exceedance |
|---|---|---|---|---|
| February 15 to March 15 Pulse Flow | Maintain and enhance occurrence of soil moisture and pooled water during the growing season for lower tropic levels of the food chain in low grasslands and for biologically diverse communities in the ecosystem over the long term. | Normal and wet | 3,350[1] | Exceeded in 75% of Years |
| | | Dry | 2,250[1] | Exceeded in 100% of Years |
| May 20 to June 20 Pulse Flow | Bring ground water levels in grasslands near to the soil surface in most areas of grassland and above the soil surface in some surface depressions in grasslands. One effect of this is to bring up soil organisms to near or above the soil surface for predation by migratory birds and other animals and provide pooled water for other aquatic food organisms. | Wet | 3,700[1] | Exceeded in 33% of Years |
| | | Normal | 3,400[1] | Exceeded in 75% of Years |

[1] Based on "Fixed Daily Target Flows" from Appendix E of the Program's Water Plan Reference Materials (Program Water Plan, Attachment 5, Section 11).

In order to put the flow management implications of the February 15 to March 15 pulse flow recommendation into perspective, a flow exceedance analysis was performed for the United States Geological Survey (USGS) stream gage at Grand Island (USGS 06770500) for the period of 1942-2011. Flow exceedance was then compared to the Fixed Daily Target Flows in Table 2 to calculate the range of deficits to the flow targets. Results, which are presented in Table 3, indicate that under normal hydrologic conditions, the combined mean annual deficit during the early spring (February-March) and late spring (May-June) periods, exceeds 200,000 acre-ft. In comparison, the First Increment Program water management objective is to reduce annual deficits by 130,000 to 150,000 acre-ft with on the order of 60% of that in a form or location that can be managed through controlled releases. In many years, the entire Program water supply could be used during these periods and still not eliminate the deficit.

**Table 3. Annual deficits to USFWS pulse flow targets by hydrologic condition**

| | **Dry Condition Deficits (Acre-Ft)** | | | **Normal Condition Deficits (Acre-Ft)** | | | **Wet Condition Deficits (Acre-Ft)** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Pulse Flows** | Max | Mean | Min | Max | Mean | Min | Max | Mean | Min |
| February 15 - March 15 Pulse | 99,306 | 71,837 | 50,384 | 111,471 | 85,255 | 59,345 | 56,985 | - | - |
| May 20 - June 20 Pulse | - | - | - | 174,863 | 139,860 | 94,255 | 94,695 | - | - |
| ***Total*** | 99,306 | 71,837 | 50,384 | 286,334 | 225,114 | 153,600 | 151,680 | - | - |

*Management of wet meadow habitat on Program lands*

As mentioned in the introduction, fully one third of the lands (10,000 acres) to be acquired by the Program during the First Increment are to be managed as wet meadow habitat. This equates to approximately 640 acres of wet meadow habitat at each of the five planned First Increment Program habitat complexes. The Program has developed or is currently developing four habitat complexes in bridge segments along a fifty-mile reach of the Associated Habitats extending from Overton downstream to Alda. From a management perspective, this means that the Program will be responsible for restoring and managing multiple large-scale tracts of wet meadow habitat with a variety of geographic, hydrologic, and management constraints.

The importance of groundwater in making a wet meadow "wet," the significant release volumes necessary to achieve wet meadow-related target flows, and the scale at which the Program will need to manage wet meadow habitat all point to the need for tools that will help the GC make wet meadow management decisions. More specifically, the GC needs to know the "cost" of flow releases for wet meadow management and the resulting response of groundwater elevations in the CPRV. The GC will also need a way to assess the ecological or species-related value of increased groundwater levels, which will be the most challenging part of the management process.

**The hydrogeological characteristics of an archetype wet meadow**

The 2010 Crane Trust information review summarized the various characteristics that researchers believe to be indicative of a quality CPRV wet meadow. Most of these characteristics have one thing in common; they are based on, or meant to describe physical and biological conditions at the Mormon Island wet meadow site in the Alda to Highway 281 bridge segment. The focus on this site arguably makes it the archetype CPRV wet meadow and the yardstick by which CPRV wet meadow habitat will intentionally or unintentionally be measured.

Much effort has been expended during the last three decades to catalog the abundance and distribution of a host of flora and fauna in this wet meadow. To a lesser degree, those biological characteristics have been linked to the range of topographic and associated groundwater variation at the site. Much of this research was conducted by Henszey and Wesche in the late 1980's and early 1990's (Henszey and Wesche 1993 and Wesche, et. at. 1994). These researchers established a groundwater and surface water monitoring network on an approximately 1,200 acre site on Mormon Island (Figure 1) which has been utilized sporadically since that time.

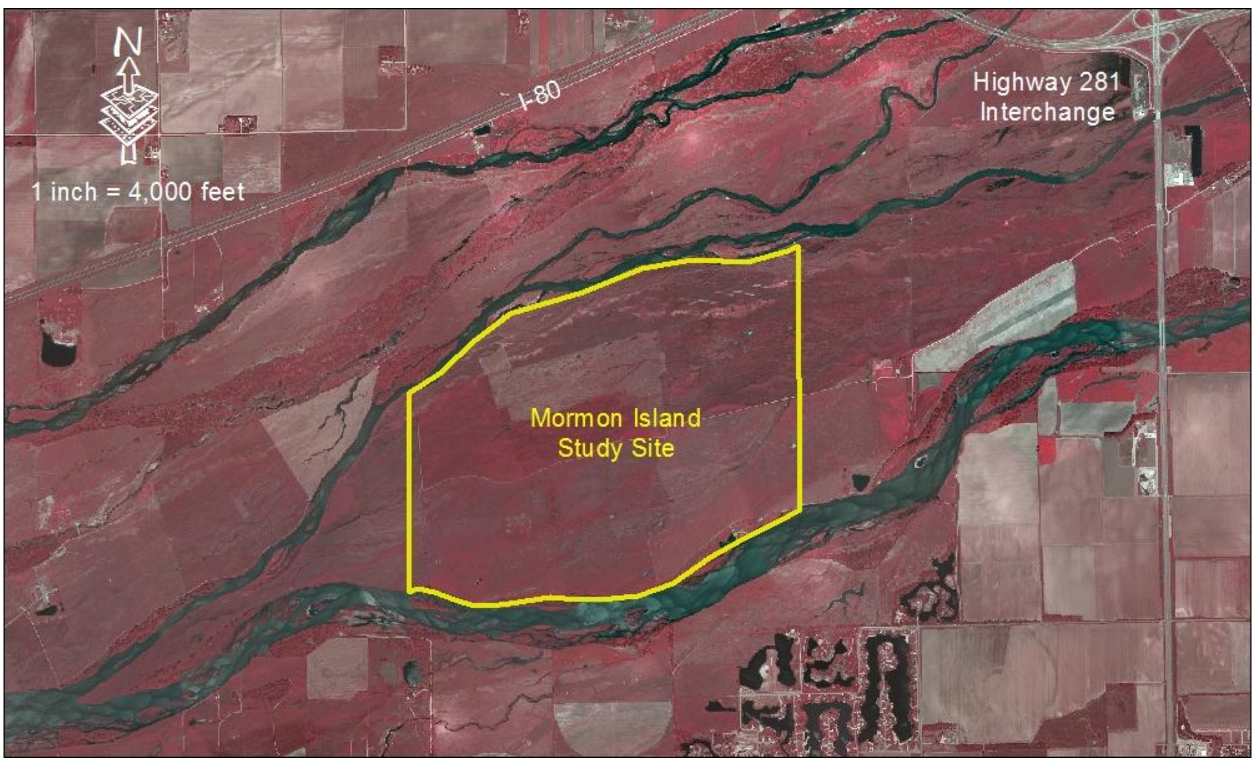



**Figure 1. Henszey and Wesche (1994) Mormon Island wet meadow study site**

*Depth to groundwater at the Mormon Island study site*

Depth to groundwater is a key hydrogeological characteristic of interest to the Program given the requirement that wet meadows have waterlogged soil for at least a portion of the year (see Table 1). Henszey and Wesche (1993) and Wesche, et. al. (1994) reported the following depth to groundwater characteristics for the Mormon Island study site:

1) The median groundwater monitoring well levels at the study site in February through April ranged from 0.2 to 3.2 feet below ground surface in 1989-1992.
2) The median groundwater monitoring well levels at the study site in June through September ranged from 1.8 to 4.2 feet below ground surface in 1989-1992
3) Sixty percent of the time, groundwater depths varied less than 1.5 feet between minimum and maximum depths for each monitoring well.
4) Groundwater levels were relatively constant from February through April.
5) Groundwater levels were about a foot higher in February and March than they were in May and June, but May and June had groundwater levels above the surface more often.

This information was based on groundwater depths at study site monitoring well locations. There was no discussion of whether or not the well locations were descriptive of the full range of topographic variation and associated groundwater depths in the study area, likely because this would have been a very difficult and costly analysis at that time. However, it remains as an important consideration given the potentially significant variability of ground elevations in CPRV wet meadows due to their characteristic ridge and swale topography.

In order to better characterize the groundwater depth distribution at this archetype wet meadow, groundwater contour maps from Wesche, et. al. (1994) were digitized and georeferenced using the geographic coordinates of monitoring wells on the maps. Groundwater contours from the georeferenced maps were then converted to groundwater digital elevation models (DEMs) for the study site. This was done for Figures 38 and 38 of Wesche, et. al. (1994) which approximated median groundwater elevations during the February through April and June through September study periods. Groundwater elevation values were subtracted from 2010 Light Detection And Ranging (LiDAR) bare earth DEM values to produce depth to groundwater DEMs for the study site (Figure 2). These distributions indicate that the range of median groundwater depths reported in Wesche, et. al. (1994) were representative of approximately the shallowest 50% to 70% of groundwater depths at the site. In other words, groundwater depths in 30% to 50% of the study site were deeper than the reported ranges.

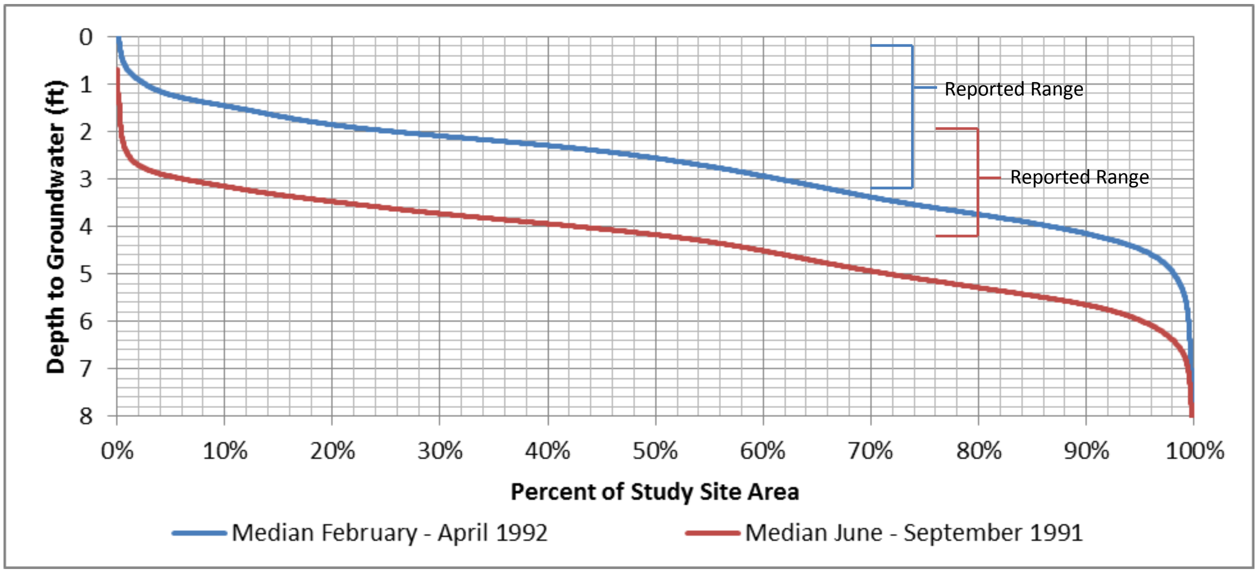



**Figure 2. Depth to groundwater distributions for Henszey and Wesche (1994) Mormon Island study site based on median February-April and June-September groundwater level maps and 2010 LiDAR data.**

<u>*Comparison of the groundwater depth distribution at Mormon Island to other sites*</u>

Given that Mormon Island is the archetype CPRV wet meadow and groundwater depth is a key wet meadow characteristic, comparing the groundwater depth distribution at Mormon Island with other sites is a useful exercise for assessing the potential "quality" of those sites. Due to the annual and even seasonal variability in CPRV groundwater elevations (see Figure 2), temporally consistent site comparisons are probably the most useful. The most recent geographic information system (GIS) groundwater level dataset for the entire CPRV is the University of Nebraska-Lincoln, Conservation and Survey Division (UNL-CSD) spring 1995 water table coverage. Comparison of wet meadow groundwater levels from that dataset to Program LiDAR topography produces a temporally consistent analysis.

Prior to comparing UNL-CSD spring 1995 groundwater depth distributions between sites, the EDO compared the UNL-CSD 1995 distribution at the Mormon Island study site to the Wesche et. al (1994) data presented in Figure 2 to evaluate how well the system-scale UNL-CSD dataset agreed with that site-scale analysis. River flow conditions during the three dataset periods (Table 4) indicate that hydrologic conditions were comparable. The UNL-CSD dataset represented a period of greater median river flow than the Wesche, et. al. (1994) June - September period and lower flow than the February - April period.

**Table 4. Median Platte River flow at Grand Island during UNL-CSD and Wesche, et. al. (1994) groundwater level dataset periods used in groundwater depth distribution analysis.**

| Groundwater Level Dataset | Dataset Period | Median Grand Island Flow for Dataset Period (cfs) |
|---|---|---|
| UNL-CSD Spring 1995 | Spring[1] 1995 | 1,330 |
| Mormon Island Study Site per Wesche, et. al. (1994) | February - April 1992 | 1,570 |
| | June - September 1991 | 326 |

[1] Spring was not defined in UNL-CSD dataset so months of February through April used for consistency.

The UNL-CSD groundwater coverage was converted to a DEM and compared to the 2010 LiDAR data using the same process described previously in this document. The resulting groundwater depth distribution is plotted together with the Wesche, et. al. (1994) distributions in Figure 3. The UNL-CSD distribution falls between the two Wesche distributions, which is consistent with the hydrologic conditions presented in Figure 3. The same analysis was also completed at the Wesche, et. al. Rowe Sanctuary study site. At that location, UNL-CSD groundwater depths were on the order of one to two feet shallower than recorded by Wesche during both periods. This discrepancy indicates that although distributions based on the 1995 UNL-CSD water table data should be useful for qualitative comparisons of similarities between sites, they need to be verified at a site-scale through groundwater level monitoring.

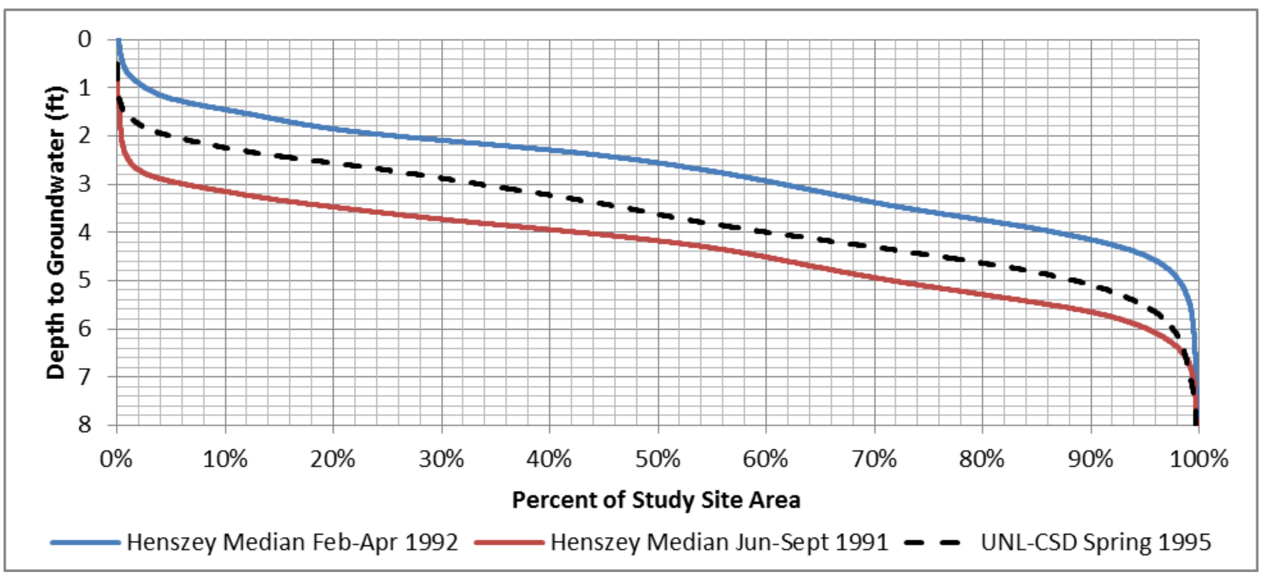



**Figure 3. Depth to groundwater distributions for Henszey and Wesche (1994) Mormon Island study site median February – April and June – September groundwater levels and UNL-CSD spring 1995 groundwater levels.**

In the spring of 2012, the Program's WMWG identified the area at each Program habitat complex that would be managed as wet meadow habitat. Maps of those areas are included as Appendix A. The groundwater depth distribution for each of those areas (based on spring 1995

UNL-CSD data) is presented in Figure 4 along with the Mormon Island study site distribution. All of the distributions appear to be similar to the Mormon Island study site. Interestingly, the site with the shallowest depth to groundwater distribution is the wet meadow management area at the Elm Creek complex. The majority of this area was part of the active channel of the Platte River as recently as the early 1940s. The deepest distribution occurs at the Program's Fox Tract, which is a part of the Fort Kearny complex.

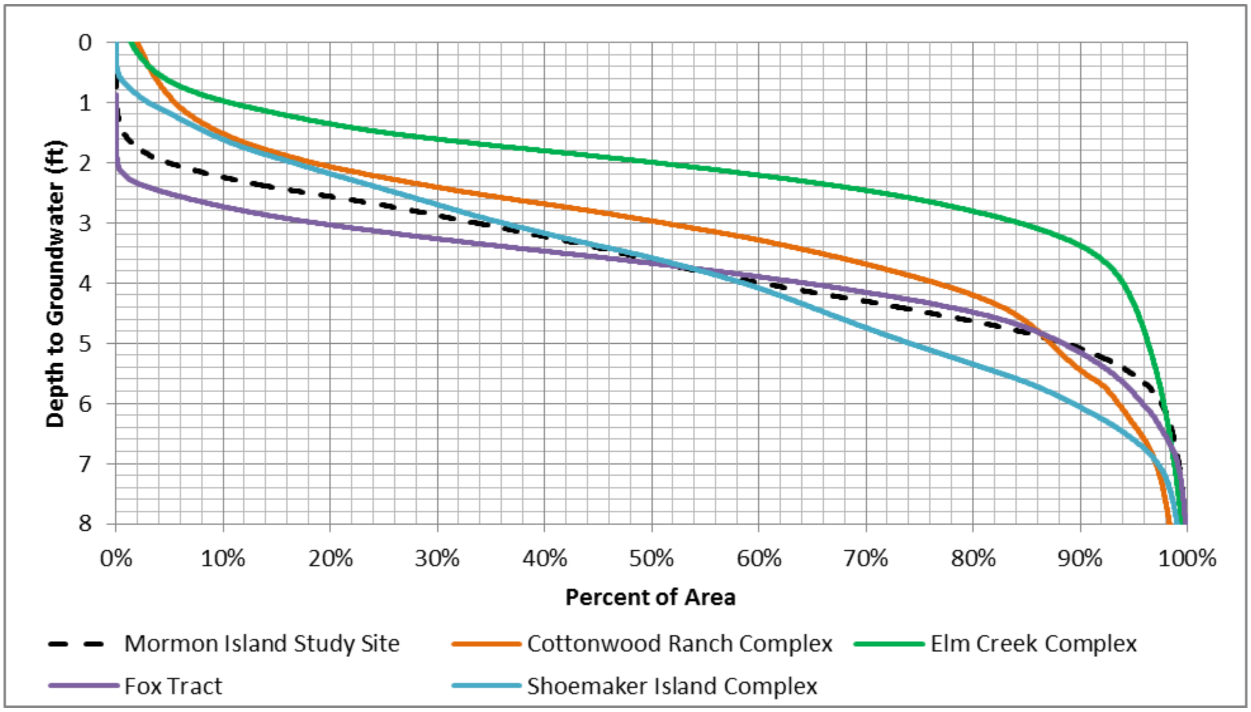



**Figure 4. Comparison of Mormon Island study site and Program wet meadow management area groundwater depth distributions using UNL-CSD spring 1995 groundwater level data.**

In 2011, the Program installed a groundwater well monitoring network on the Fox Tract to help inform wet meadow restoration design efforts. For much of the time that the network has been in place, flows have been significantly higher than in the spring of 1995, when the UNL-CSD groundwater level coverage was developed. However, the last data download included groundwater levels associated with river flows on the order of 1,500 cfs in late March, 2012. The depth to groundwater distribution based on the March groundwater well data is, on average, 0.26 feet shallower than the spring 1995 UNL-CSD data. This indicates that the UNL-CSD dataset is a good baseline for comparison of groundwater depths at the Fox Tract and Mormon Island study sites.

It would probably be unwise to draw firm conclusions from the groundwater depth comparisons beyond making the observation that all of the sites appear to be qualitatively similar to the Mormon Island study site from a depth to groundwater perspective. However, the comparison may hint that other geohydrological characteristics (beyond the general distribution of groundwater depths) are important in making Mormon Island the archetype wet meadow. One of the characteristics identified as a common theme in the Crane Trust literature review, is the response of wet meadow groundwater levels to changes in Platte River stage.

*The relationship between groundwater levels and river stage*

The following excerpt from Wesche, et. al. (1994) outlines the authors' conclusions regarding the relationship between wet meadow groundwater elevations and Platte River stage. These conclusions were developed based on daily and seasonal correlation analyses to attempt to separate the influence of river stage, precipitation, and evapotranspiration on groundwater levels at each of the monitoring well locations.

> *Wet meadow groundwater elevations along the Platte River in south central Nebraska are influenced by a combination of river stage, precipitation, and evapotranspiration. River stage was most often the dominant factor. The influence of river stage decreases with increasing distance from the river, and decreases when the stage is sufficient to maintain the groundwater water level at or above the surface (e.g., wells CM26CDA and CM35BBB). When the water level is at or above the surface, raising the river stage has little influence because the surface water tends to flow away from the area. Although raising the river stage has little influence once the groundwater reaches the surface, lowering the stage will lower the groundwater once it has dropped below the surface.*
>
> *After river stage, precipitation is usually the next most dominant influence on groundwater levels. An isolated precipitation event can temporarily elevate the water table over three feet, with residual effects lasting up to two weeks. The closer the water table is to the surface before the precipitation, the closer the precipitation will bring the water table to the surface. If the water table reaches the surface, then standing water and overland flow may occur.*

In the late 1990s, the joint United States Bureau of Reclamation (Reclamation) and USFWS Platte River Environmental Impact Statement (EIS) Team recognized that the observed decrease in groundwater level correlation with river stage as distance from the river increased would have important implications for groundwater management through flow releases. In 1999, the EIS Team began an intensive data collection, analysis and modeling effort that was published as an EIS Team Technical Report in 2001 (Reclamation 2001). The following findings regarding the relationship between river stage and groundwater levels and the ability to influence groundwater levels using flow releases have been reproduced from that report:

***River levels***

- *River levels have an influence on ground water levels near the river. At distances more than a few thousand feet from the river, the water table elevation is generally several feet higher than the river and thus does not react to river levels.*

- *Because ground water moves slowly, river rises and adjacent ground water level rises are not simultaneous if the ground water level is responding to a change in the river. Thus, when ground water levels rise at the same time as the river rises, a third factor (e.g., precipitation) must be involved.*

- *Infiltration in the Platte River Valley is high and the storage capacity is about 15 to 20 percent. Once inch of rainfall that reaches the water table raises the water table 5 to 6 inches.*

- *Ground water levels in the Central Platte Valley outside the flood plain are typically higher than the river elevation. Therefore, water movement is toward the river. Currently, the one exception is in the Upper Big Blue and Little Blue River drainage where the natural gradient is away from the Platte River to the southeast.*

- *Within the primary flood plain, the ground surface is typically 1 to 3 feet above the river water level. In such conditions, evaporation and plant usage work to lower the water table to roughly the same elevation as the river. When this condition develops, ground water movement tends to be down the valley parallel to the river.*

***Program Flows***

- ***Pulse flows** of 6,000 to 10,000 cubic feet per second would raise the river level at most 10 to 12 inches (but not above full bank capacity) for 3 days. Under this regime, ground water levels would raise 11/2 inches 500 feet from the river and ½ inch 2,000 feet from the river for a short time. Ground water levels would not be affected more than 3,500 feet from the river.*

- ***Base flow augmentation** would add 500 to 1000 cfs to existing flows. These increases would be provided several times during the average year to meet various species' needs. Flows would raise the river by about 5 inches. If this continued for 30 days, ground water levels would raise by 3 inches 500 feet from the river and 1 inch 2,000 feet from the river. Ground water levels would not be affected more than 3,000 feet from the river.*

The findings presented above capture the relative magnitude of groundwater response to flow releases. But, in the absence of more detailed initial flow conditions and stage-discharge relationships, they are less useful for estimating the rise in groundwater level when flows are increased to a specific discharge at a specific location. However, the Reclamation findings were developed using the Glover Bank Storage method (Glover 1985), which can be applied on a site or reach-scale in conjunction with Program hydraulic model output to provide a more focused estimate of groundwater response.

**A process for predicting groundwater response to flow releases**

The following process is a way to rapidly assess wet meadow groundwater response to flow releases. It is intended to be a relatively simple and quick tool that facilitates identification of costs (in terms of water released) and benefits (in terms of groundwater response) at a given location for a wide range of flow release magnitudes and durations. Because of this, it is not intended to encompass all aspects of the geohydrology of wet meadows, which would require development of a coupled groundwater and surface water numerical simulation model.

The process is currently organized in a way that facilitates evaluation of the cost and benefit of a release to meet a predetermined flow target. It could also be organized in a way that facilitates estimation of the magnitude and duration of flow release needed to produce a desired increase in groundwater levels. The flow target-based process is presented in Figure 5 and includes cost and response components. A discussion of each step of the process the follows.

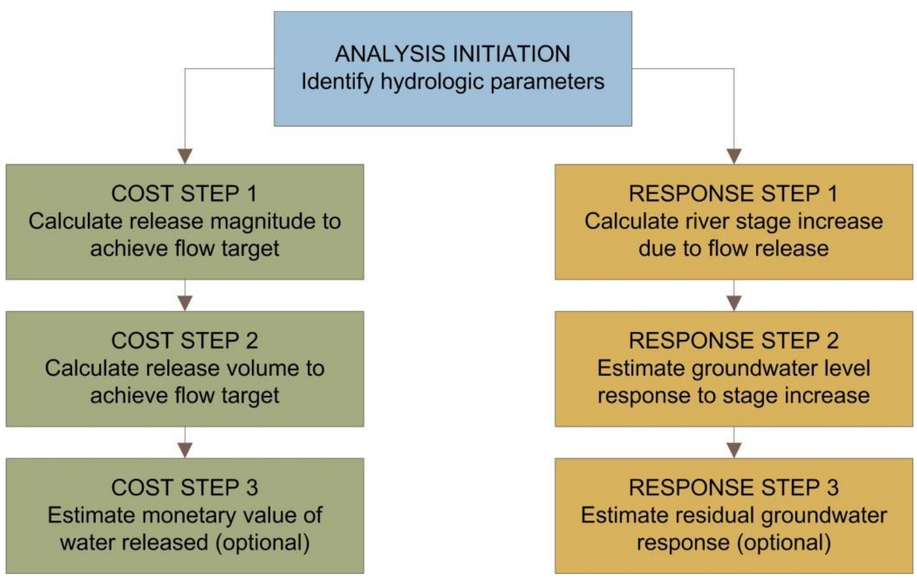



**Figure 5. Process for estimating groundwater level response to flow releases and associated costs**

***ANALYSIS INITIATION** – Identify site hydrologic parameters*

The first step in this process is identification of flow target magnitude and duration, natural flow conditions, and physical characteristics of the analysis location. Existing USFWS pulse flow recommendations include magnitude and duration targets to provide wet meadow benefits. Natural flow conditions can be determined from real-time USGS gage data or estimated through analysis of historic flow records. The physical characteristics of a site can be determined using a GIS application.

***COST STEP 1** – Calculate release magnitude to achieve flow target*

The release magnitude to achieve a flow target can be calculated as the difference between the target flow and natural discharge at the analysis site multiplied by an attenuation factor in Table 5 to account for flow attenuation between Lake McConaughy and the location of interest (Equation 1). Data from the April 2009 flow routing test were used to develop the attenuation factors in Table 5 and assume that none of the release is diverted into the Central Nebraska Public Power and Irrigation District (CNPPID) or Nebraska Public Power District (NPPD) systems. Routing a portion of the release through the district systems would likely reduce attenuation.

**Table 5. Flow attenuation factors by bridge segment based on 2009 flow routing test data**[1,2]

| Location | Release Magnitude as a Percent of Release at Lake McConaughy | Flow Attenuation Factor |
|---|---|---|
| Overton | 64% | 1.56 |
| Elm Creek | 65% | 1.54 |
| Odessa | 66% | 1.52 |
| Kearney | 67% | 1.49 |
| Minden | 68% | 1.47 |
| Gibbon | 69% | 1.45 |
| Shelton | 71% | 1.41 |
| Wood River | 72% | 1.39 |
| Alda | 74% | 1.35 |
| Grand Island | 75% | 1.33 |

[1] Attenuation by bridge segment was approximated through pro-rating the nearest gaged flows by the bridge segment distance (i.e., assumed to be constant between gages).
[2] Attenuation factors assume no flow is diverted into the CNPPID or NPPD systems.

*Release magnitude in cfs = (flow target in cfs – natural flow in cfs)*(attenuation factor)* (Equation 1)

***COST STEP 2** – Calculate release volume to achieve flow target*

Once the necessary release magnitude is determined, release volume in acre-feet can either be calculated or estimated using Figure 6. To calculate the release volume, use Equation 2:

*Volume in acre-feet = (Release magnitude in cfs)*(Release duration in days)*(1.98)* (Equation 2)

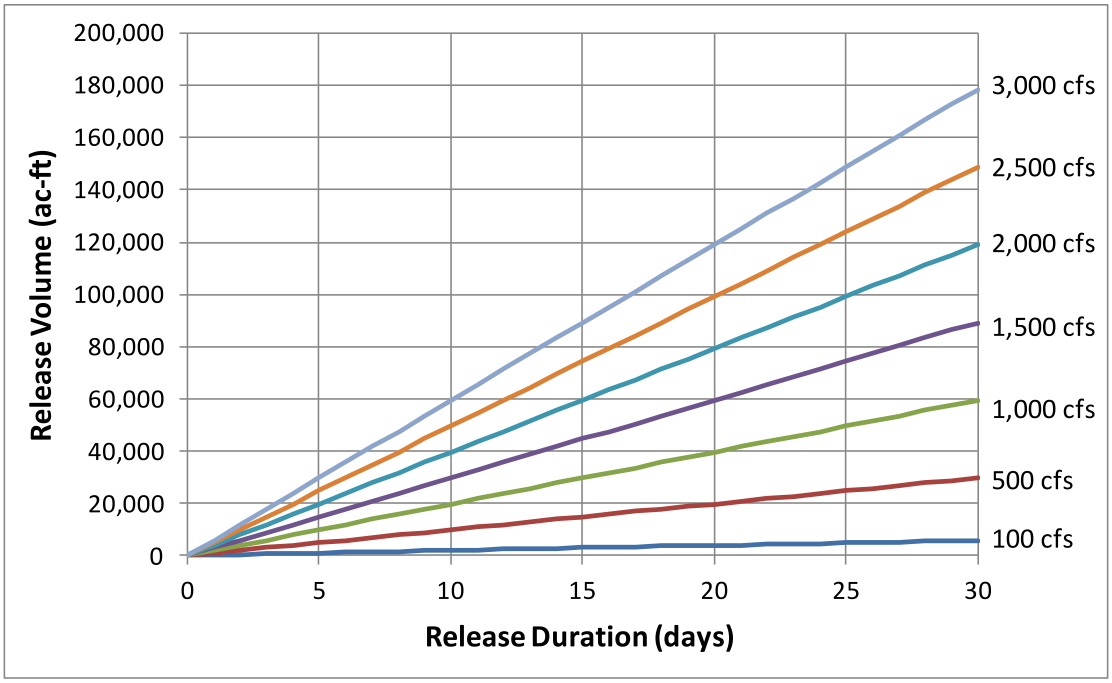



**Figure 6. Release volume as a function of magnitude (cfs) and duration (days)**

***COST STEP 3*** **–** *Estimate monetary value of water released*

This is an optional step that may be useful in providing context to the volume calculation in the previous step. The Program's 2009 Water Action Plan Update (PRRIP 2010) included an analysis of probable Water Action Plan (WAP) project costs and yields. The published annual equivalent water cost (in 2009 dollars) was $186 per acre-foot. To estimate the monetary value of the flow release in 2009 dollars, use the Equation 3:

*Monetary value of water released = (Release magnitude in acre-feet)*($186)* (Equation 3)

***RESPONSE STEP 1*** **–** *Calculate river stage increase due to flow release*

The first step in estimating groundwater response is calculating the increase in river stage in the area of interest. This can be accomplished using output from the Program's one-dimensional hydraulic model for the central Platte River. The model was used to calculate water surface elevations for a range of flows up to 8,000 cfs. Those elevations were then converted to averaged stage-change relationships for each bridge segment. Those relationships, which provide the increase in river stage for any given increase in flow, are presented in Figures 7 and 8. The stage-change relationships were calculated using only main channel cross-sections except for in bridge segments like Alda to Grand Island (Highway 281) where channel splits may have a significant influence on wet meadow groundwater hydrology.

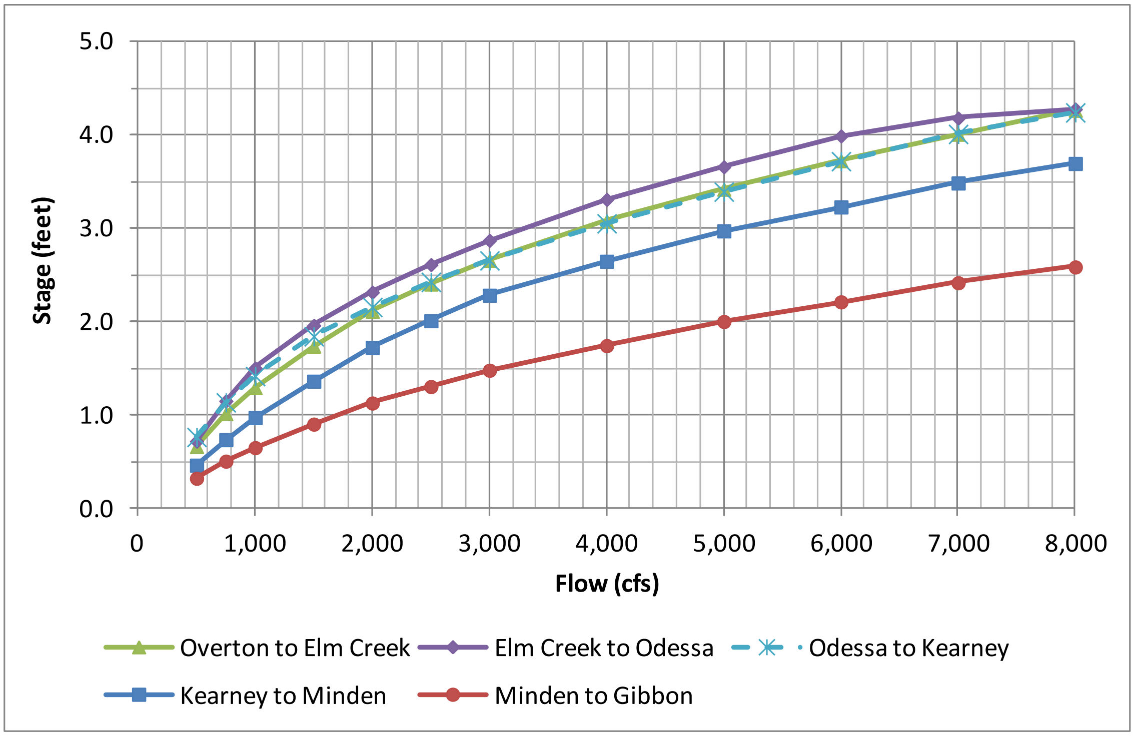



**Figure 7. HEC-RAS stage-change relationships for Overton to Gibbon bridge segments (main channel cross-sections only)**

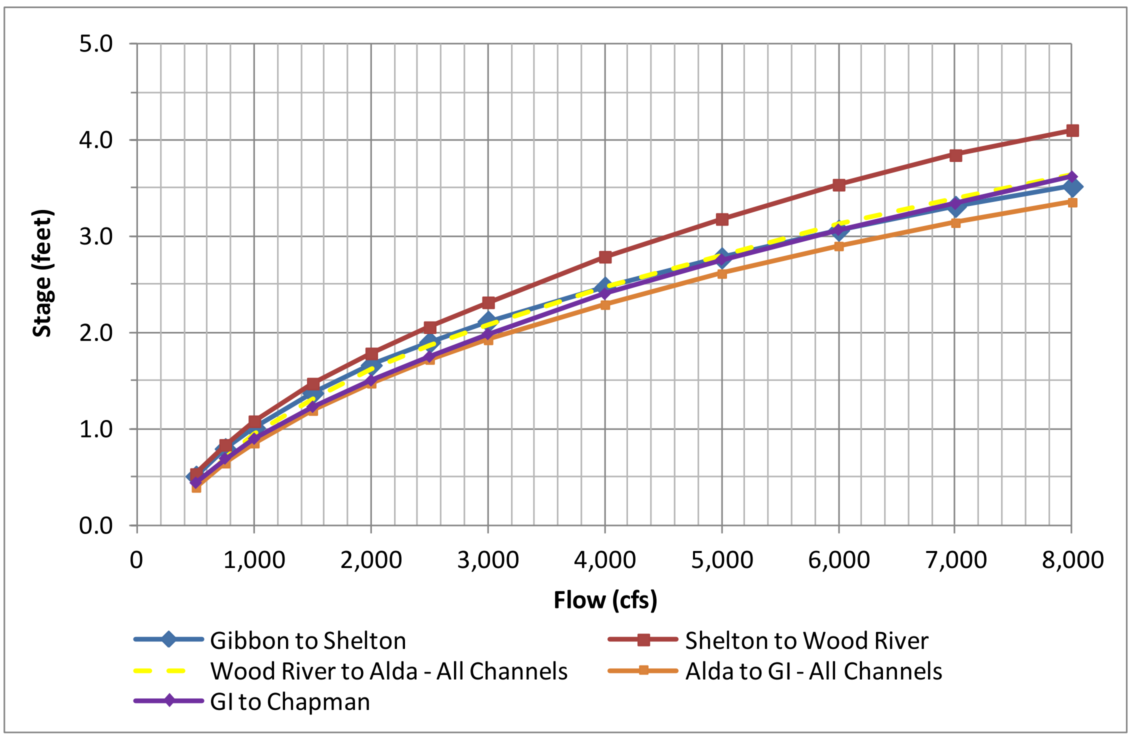



**Figure 8. HEC-RAS stage-change relationships for Gibbon to Chapman bridge segments (main channel cross-sections only except where noted)**

In order to calculate the stage increase due to a flow release, select the bridge segment of interest and subtract the stage associated with natural flow (pre-release) from the stage associated with the targeted flow magnitude.

***RESPONSE STEP 2** – Estimate groundwater level response to river stage increase based on release duration and distance from the channel*

Once the increase in river stage is known, the groundwater level response can be estimated using the Glover Bank Storage method previously employed by Reclamation. This method is based on a solution of the linear partial differential equation for 1-dimensional unsteady flow, which yields the following equation for aquifer drawdown or buildup:

$$s_{(x,t)} = s_0 * erfc\left(\frac{x}{\sqrt{4\propto t}}\right) \quad \text{(Equation 4)}$$

Where: $s$ is drawdown or buildup
$x$ is distance from the river
$t$ is time
$\alpha$ is hydraulic diffusivity (aquifer transmissivity divided by storativity)
*erfc* is the complimentary error function

The following assumptions were made when calculating effects on groundwater levels using the Glover Bank Storage method:

- Increased river stage is instantaneous at time = 0, and is held constant for entire duration of the release. This is a conservative assumption that would maximize the estimated groundwater response.
- Values for aquifer transmissivity (15,000 $ft^2$/day) and specific yield (0.15) were retained from the Reclamation analysis. The transmissivity value appears to be near the high end of typical values for the CPRV based on COHYST model values which range from about 9,000 to 15,000 $ft^2$/day. Using the Reclamation value is conservative as the lower end of transmissivity values (9,000 $ft^2$/day) would reduce groundwater level response by 5% to 10%.
- Initial groundwater levels are at the same elevation as river stage. If groundwater levels are higher than river stage at the beginning of a release, groundwater response would be over-predicted.
- Groundwater drains or other groundwater control structures are absent from the site of interest.

Figure 9 presents an application of the Glover Bank Storage method to estimate groundwater level response to river stage increase for a variety of release durations and distances from the channel. In order to estimate response at any given point location, calculate the site distance of that point from the channel and find the groundwater effect percentage using that distance along with the appropriate release duration curve. The river stage increase calculated in RESPONSE STEP 1 can then be multiplied by the groundwater effect percentage to estimate the groundwater level response at that location. The groundwater effect calculations in Figure 9 can also be used to estimate an average groundwater response of an entire site based on the proximity of the centroid of the site to the channel.

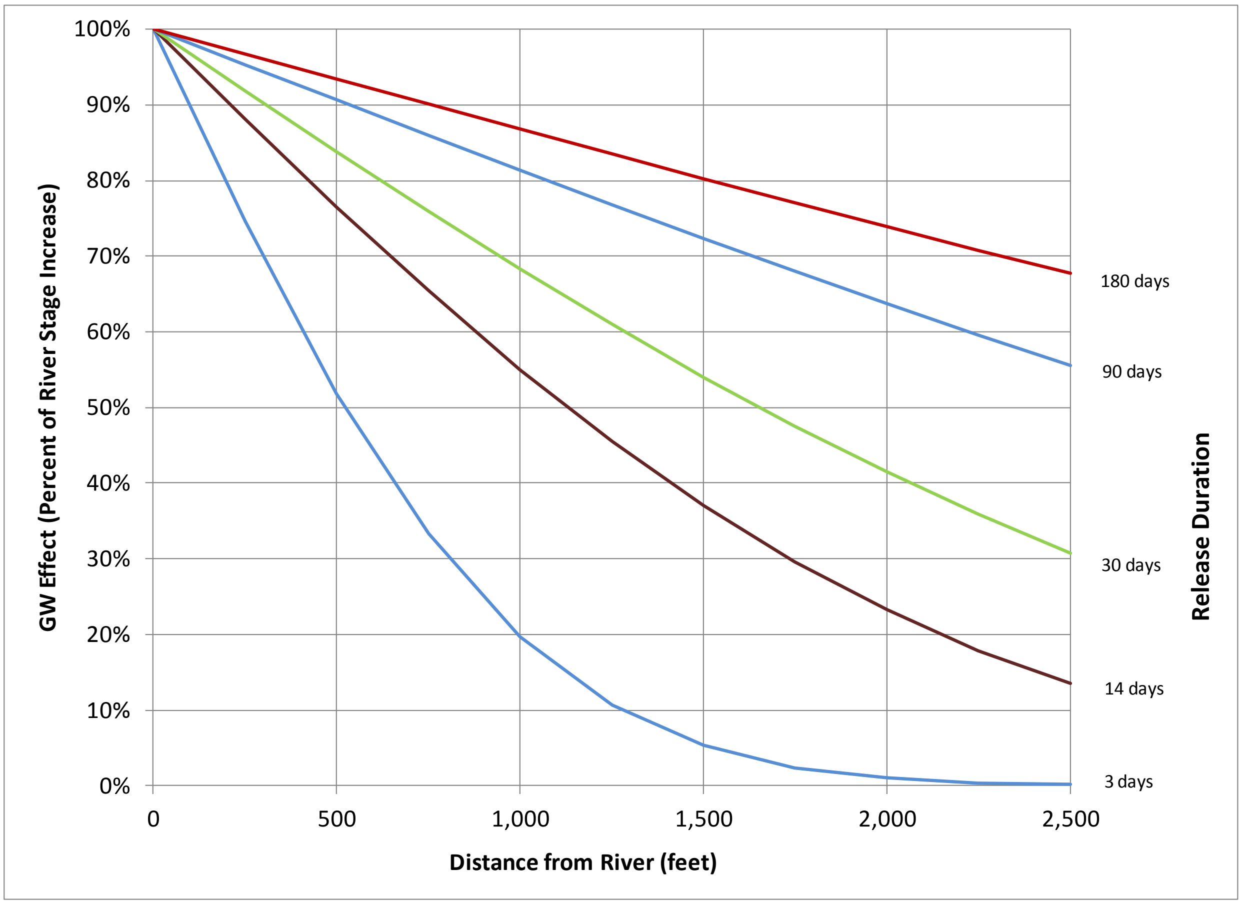



**Figure 9. Estimated increase in groundwater level as a percentage of stage increase based on release duration and distance from the channel**

***RESPONSE STEP 3*** *– Estimate residual groundwater response following release*

As a release ends, groundwater levels begin to adjust to the falling river stage with response varying by time and distance from the channel. The residual effects of the release on groundwater levels are dependent on the duration of the release, time elapsed since the end of the release, and distance from the channel. The residual groundwater effects for a three-day and thirty-day release were calculated using the Glover Bank Storage method and are presented in Table 6 and Table 7. The residual groundwater level increase at any given location and time since release termination can be calculated by multiplying the stage increase from RESPONSE STEP 1 by the groundwater effect percentage in appropriate table.

**Table 6. 3-day release residual groundwater level effect as percentage of river stage change during release. Percentage based on distance from the river and time elapsed since release termination.**

| Distance from River (ft) | Time since Release Termination (days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 2 | 3 | 7 | 14 | 21 |
| 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 250 | 75% | 34% | 20% | 11% | 7% | 3% | 1% | 1% |
| 500 | 52% | 44% | 31% | 19% | 13% | 5% | 2% | 1% |
| 750 | 33% | 35% | 31% | 22% | 16% | 7% | 3% | 2% |
| 1,000 | 20% | 23% | 24% | 20% | 16% | 8% | 4% | 2% |
| 1,250 | 11% | 14% | 16% | 16% | 15% | 9% | 4% | 3% |
| 1,500 | 5% | 7% | 9% | 12% | 12% | 8% | 5% | 3% |
| 1,750 | 2% | 4% | 5% | 7% | 9% | 8% | 5% | 3% |
| 2,000 | 1% | 2% | 3% | 4% | 6% | 7% | 5% | 3% |
| 2,500 | 0% | 0% | 1% | 1% | 2% | 4% | 4% | 3% |

**Table 7. 30-day release residual groundwater level effect as percentage of river stage change during release. Percentage based on distance from the river and time elapsed since release termination.**

| Distance from River (ft) | Time since Release Termination (days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 2 | 3 | 7 | 14 | 21 |
| 1 | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 250 | 92% | 49% | 34% | 23% | 18% | 9% | 5% | 3% |
| 500 | 84% | 73% | 58% | 41% | 33% | 18% | 10% | 7% |
| 750 | 76% | 74% | 67% | 53% | 44% | 26% | 15% | 10% |
| 1,000 | 68% | 68% | 66% | 58% | 50% | 32% | 19% | 13% |
| 1,250 | 61% | 61% | 61% | 57% | 52% | 36% | 22% | 15% |
| 1,500 | 54% | 54% | 55% | 54% | 51% | 38% | 24% | 17% |
| 1,750 | 47% | 48% | 48% | 48% | 47% | 38% | 26% | 19% |
| 2,000 | 41% | 42% | 42% | 43% | 43% | 37% | 27% | 20% |
| 2,500 | 31% | 31% | 32% | 32% | 33% | 32% | 26% | 21% |

## Case study application of groundwater response estimation process

This section provides a case study application of the wet meadow groundwater response estimation process at the Program's Fox Tract and the Mormon Island wet meadow study site. The USFWS February 15 – March 15 pulse flow recommendations are used as the flow target for the case study because of the beneficial effect linkages to wet meadow habitat. The remainder of this section steps through the process presented in the previous section at each site. Release cost calculations are shown in Table 8. When applicable, the table references the process equations or charts used in the calculations.

**Table 8. Case study release cost calculations**

| | Process Equation, Table or Chart | Fox Tract | Mormon Island Study Site |
|---|---|---|---|
| ***ANALYSIS INITIATION*** | | | |
| Flow Target Magnitude | - | 3,350 cfs | 3,350 cfs |
| Flow Target Duration | - | 30 days | 30 days |
| Natural Flow Magnitude During Release[1] | - | 1,750 cfs | 1,750 cfs |
| Management Site Bridge Segment | - | Kear – Min | Alda – Hwy 281 |
| ***COST STEP 1*** | | | |
| Difference between Target and Natural Flow | - | 1,600 cfs | 1,600 cfs |
| Flow Attenuation Factor | Table 4 | 1.47 | 1.35 |
| **Magnitude of Release** | Equation 1 | **2,352 cfs** | **2,160 cfs** |
| ***COST STEP 2*** | | | |
| **Volume of Release** | Equation 2 | **139,709 ac-ft** | **128,304 ac-ft** |
| ***COST STEP 3*** | | | |
| Annual Equivalent Water Value per ac-ft | - | $186 | $186 |
| **Estimated Value of Flow Release** | Equation 3 | **$25,985,874** | **$23,864,544** |

[1]1942-2011 median flow for the period of February 15 – March 15

The groundwater response calculations are presented in Table 9. As mentioned in the previous section, groundwater response estimates derived from Figure 9 can be used in a variety of ways. The case study analysis in Table 9 includes groundwater response for a range of distances from the channel as well as an average response for each site based on the average distance of the site from the channel. If a baseline groundwater level DEM is available, a more detailed analysis of groundwater effects can be developed by dividing the site into response zones based on distance from the channel and modifying DEM elevation values in those zones to account for groundwater response estimates.

**Table 9. Case study groundwater response calculations**

| | Process Equation or Chart | Fox Tract | Mormon Island Study Site |
|---|---|---|---|
| ***ANALYSIS INITIATION*** | | | |
| Flow Target Magnitude | - | 3,350 cfs | 3,350 cfs |
| Flow Target Duration | - | 30 days | 30 days |
| Natural Flow Magnitude During Release | - | 1,750 cfs | 1,750 cfs |
| Management Site Bridge Segment | - | Kear – Min | Alda – Hwy 281 |
| Management Site Area | - | 178 acres | 1,162 acres |
| Average Site Distance from Channel | - | 1,750 ft | 1,500 ft |
| ***RESPONSE STEP 1*** | | | |
| Natural Flow Stage | Figures 7 & 8 | 1.6 ft | 1.4 ft |
| Flow Target Stage | Figures 7 & 8 | 2.4 ft | 2.1 ft |
| **Flow Release Stage Increase** | - | **0.8 ft** | **0.7 ft** |
| ***RESPONSE STEP 2*** | | | |
| Response 1 Foot from Channel | Figure 9 | 0.8 ft | 0.7 ft |
| Response 500 Feet from Channel | Figure 9 | 0.7 ft | 0.6 ft |
| Response 1,000 Feet from Channel | Figure 9 | 0.5 ft | 0.5 ft |
| Response 1,500 Feet from Channel | Figure 9 | 0.4 ft | 0.4 ft |
| Response 2,000 Feet from Channel | Figure 9 | 0.3 ft | 0.3 ft |
| Response 2,500 Feet from Channel | Figure 9 | 0.2 ft | 0.2 ft |
| **Average Response for Management Site** | Figure 9 | **0.4 ft** | **0.4 ft** |
| ***RESPONSE STEP 3*** | | | |
| Average Response 3-Days After Release | Table 7 | 0.4 ft | 0.4 ft |
| Average Response 7-Days After Release | Table 7 | 0.3 ft | 0.3 ft |
| Average Response 14-Days After Release | Table 7 | 0.2 ft | 0.2 ft |
| Average Response 21-Days After Release | Table 7 | 0.2 ft | 0.1 ft |

The groundwater response in this case study is primarily constrained by the increase in river stage associated with the flow release and proximity of the sites to the channel. Increasing discharge from 1,750 cfs to 3,350 cfs increases river stage at the case study sites by 8 – 10 inches. This increase in stage establishes the maximum potential rise in groundwater elevation in at the sites, which would occur in areas adjacent to the channel. As distance from the channel increases, the expected response would decrease. The average response for the sites is on the order of five inches and response in portions of the sites furthest from the channel would be two inches. Based on the groundwater depth distributions in Figure 4, this range of response magnitudes would not have an appreciable effect on the area of the sites which have groundwater very near or at the ground surface.

## Final Observations

The process of developing this white paper provided an opportunity to investigate and link several aspects of wet meadow geohydrology and management using a variety of datasets and analysis tools. The following observations provide EDO reflections on new understandings gained during this effort and identify areas where future investigation may be useful.

1. The UNL-CSD spring 1995 groundwater level coverage for the State of Nebraska provides a surprisingly good baseline for comparison of depth to groundwater distributions at various wet meadow management sites under moderate flow conditions.
2. Under moderate flow conditions, the groundwater depth distributions at all Program wet meadow management sites appear to be very similar to the Mormon Island study site. In fact, groundwater depths at several sites may actually be shallower than Mormon Island.
3. Wet meadow groundwater elevations are closely correlated to river stage near the channel but that relationship declines with distance. As such, wet meadow sites directly adjacent to a consolidated channel or located on islands separated by major flow splits have the greatest potential for management through flow releases.
4. Use of the Glover Bank Storage method in combination with Program hydraulic model output appears to provide a good tool for rapidly assessing order of magnitude groundwater response to flow releases.
5. Modeled wet meadow groundwater response to the case study flow release was less than anticipated given the assertion in the literature that wet meadows can only be restored by restoring the natural hydrograph. The USFWS February 15 – March 15 pulse flow targets are intended to provide the early spring hydrograph restoration target but the average groundwater response at the Mormon Island site was only 0.4 feet when compared to the long-term median flow.
6. Assigning a monetary value to the water in the EA using Program WAP cost estimates was a useful way to provide context to "cost" of flow releases. When compared to long-term median flow conditions, the volume of water necessary to achieve the USFWS February 15 – April 15 pulse flow target would have a value of over $20,000,000. This is a good indicator of how limited water has become as a Platte basin resource.
7. Wet meadow performance metrics and benchmarks would help the GC determine if this level of response provides a benefit to the target species that is commiserate with costs.
8. Wet meadows are generally characterized as having highly fluctuating water levels that provide a range of ecological benefits. Given the groundwater depth distributions at wet meadow sites and moderate magnitude of groundwater response to river stage increase, it does not appear that changes in river flow can be the driver of all of this variability. On the other hand, the literature is replete with observations of significant groundwater response to precipitation events. Perhaps the role of precipitation (or other surface water inputs) in wet meadow geohydrology is worthy of closer examination.

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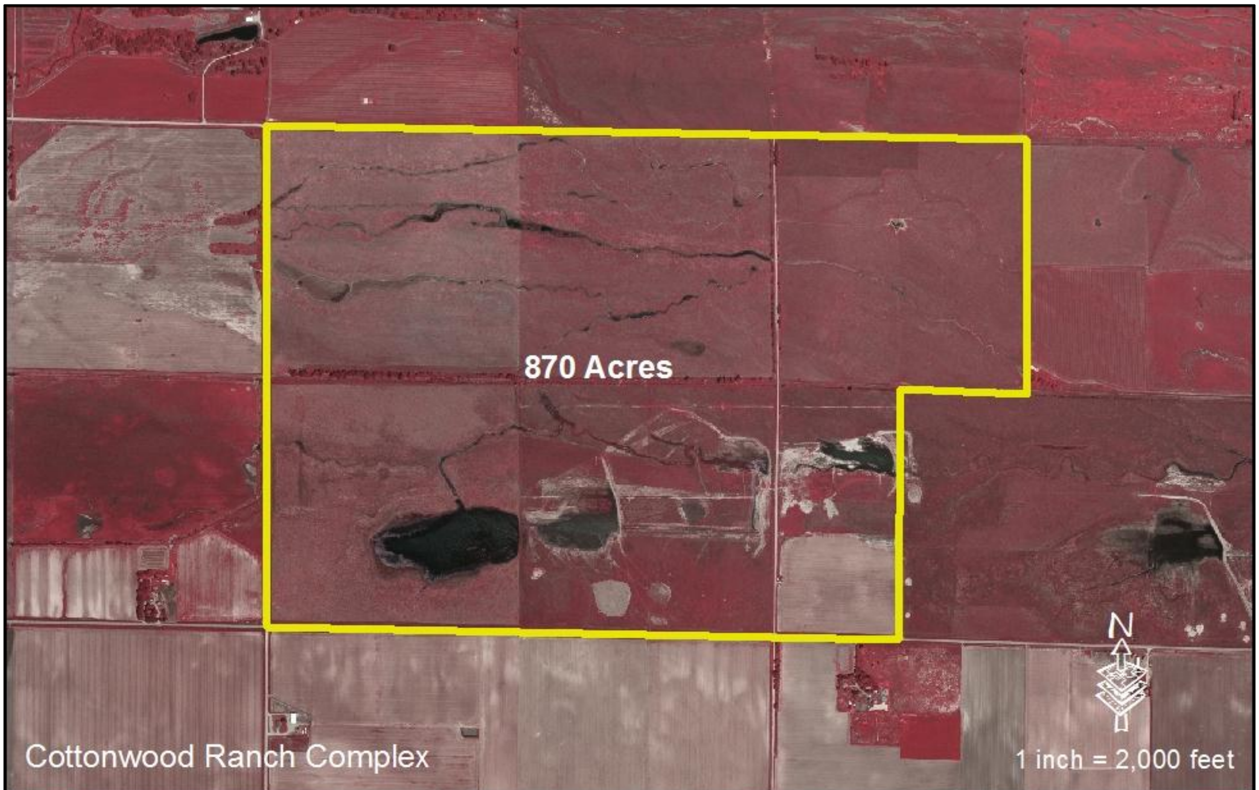
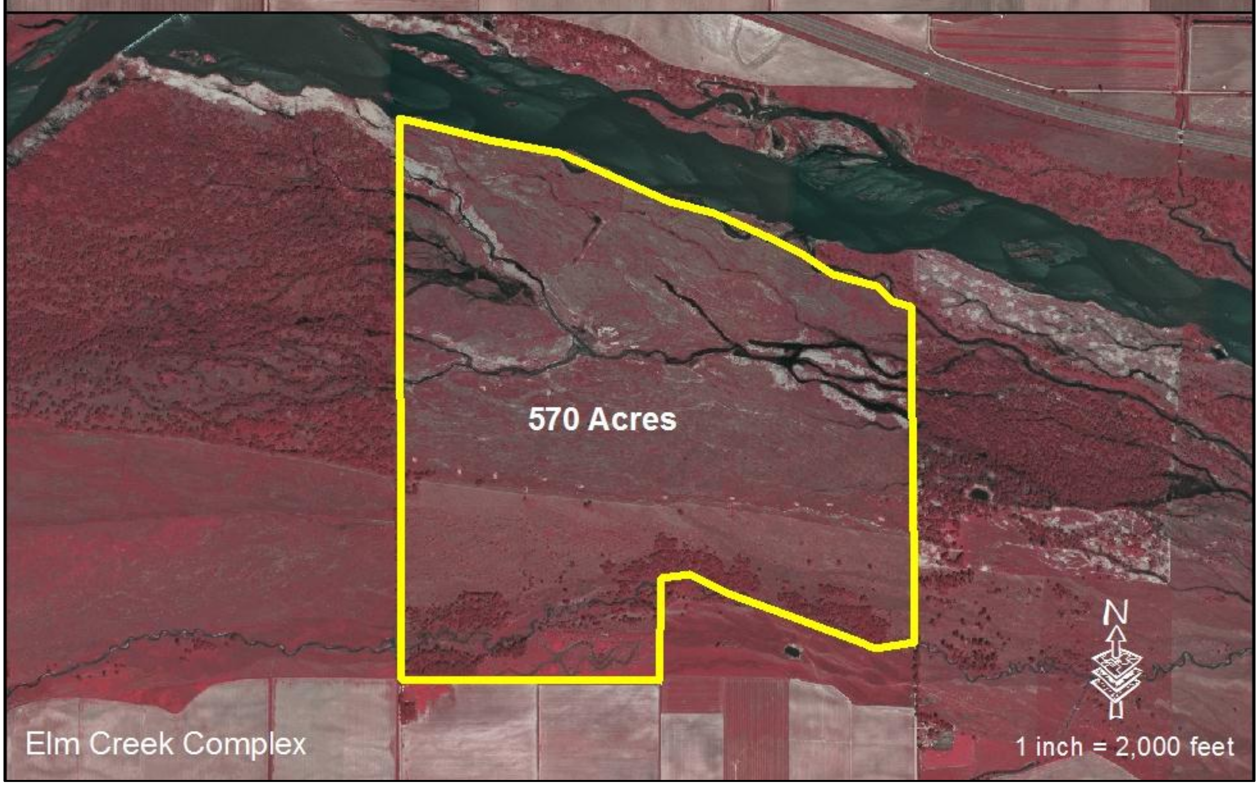
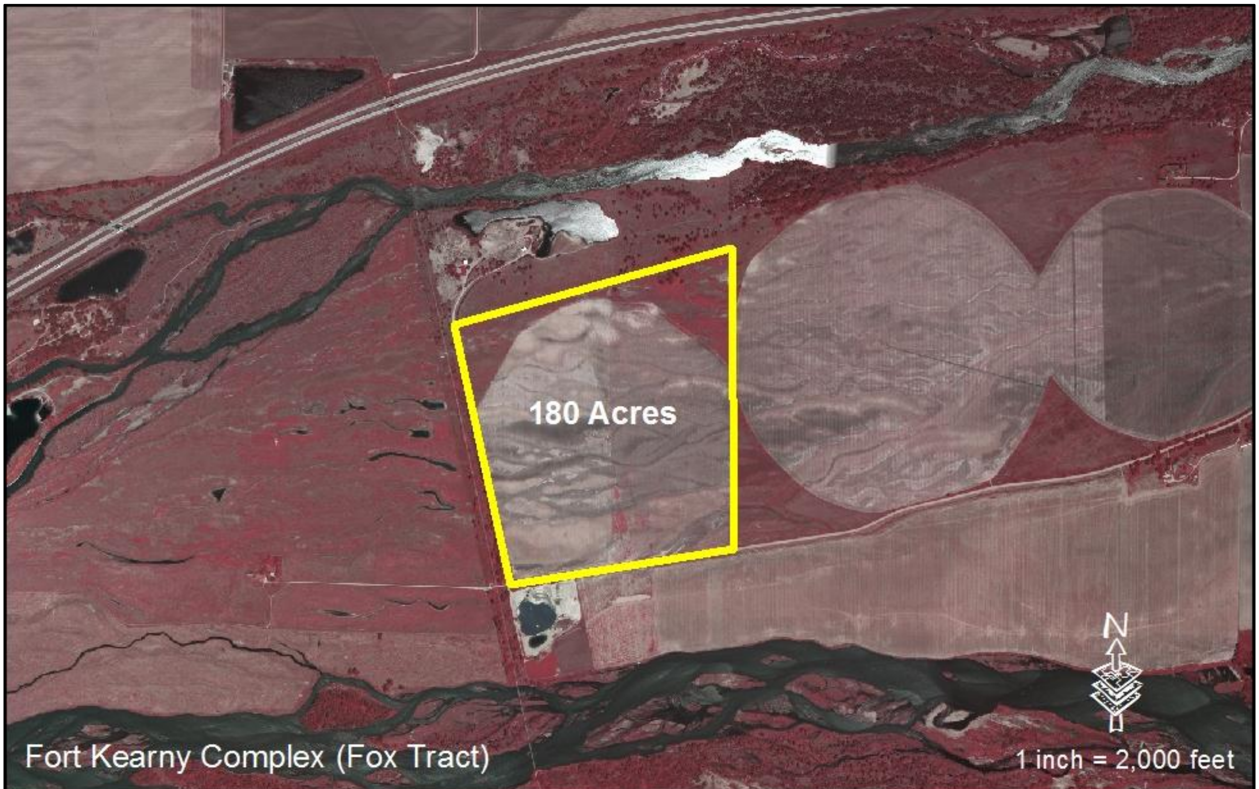
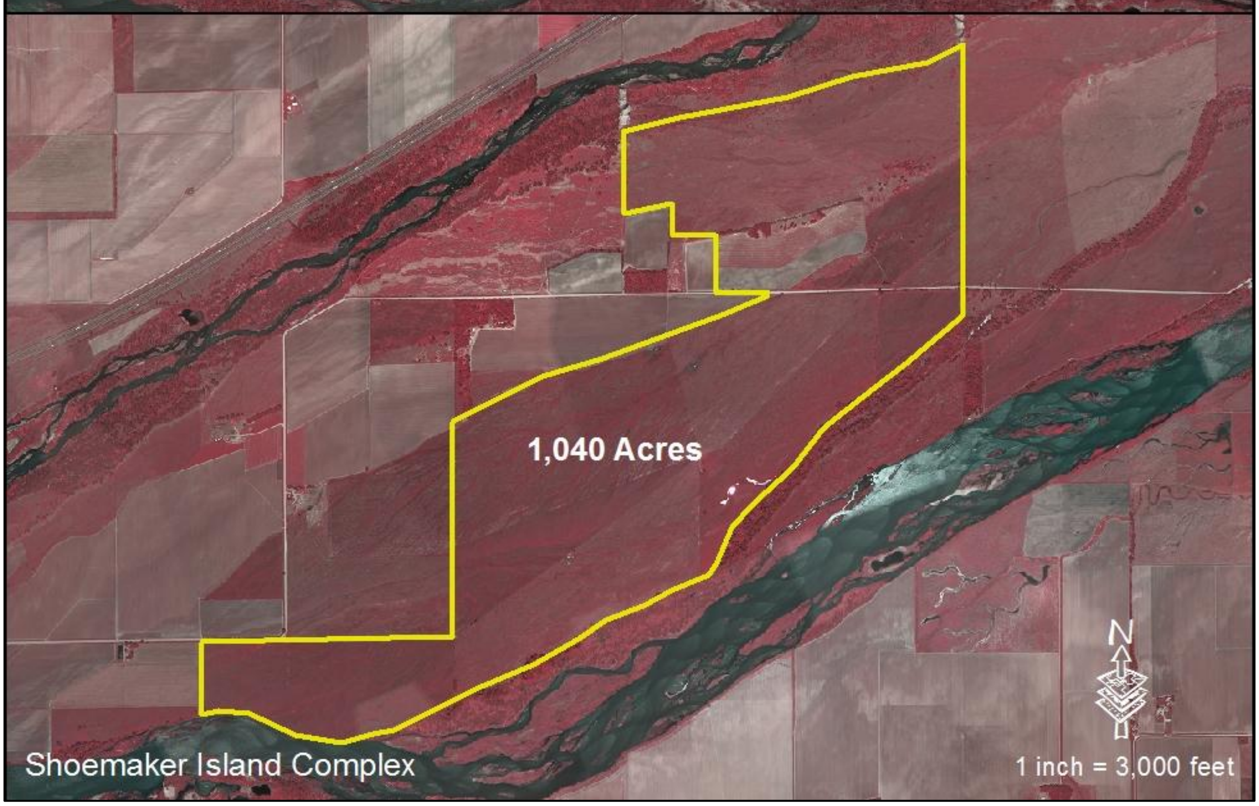
APPENDIX A – PRRIP Wet Meadow Management Areas by Habitat Complex




180 Acres
N
Fort Kearny Complex (Fox Tract)
1 inch = 2,000 feet


1,040 Acres
N
Shoemaker Island Complex
1 inch = 3,000 feet