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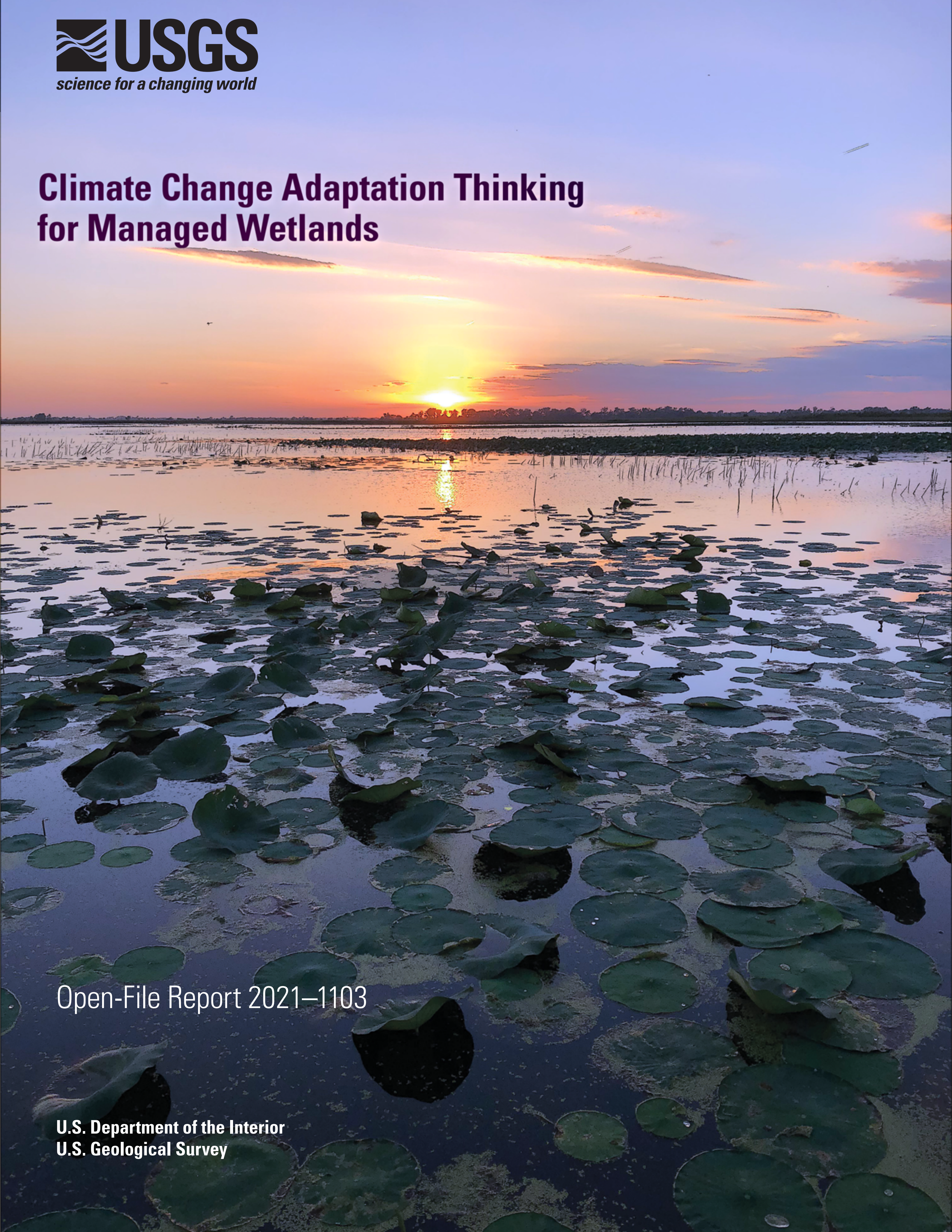
Climate Change Adaptation Thinking for Managed Wetlands



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U.S. Department of the Interior
U.S. Geological Survey

Front cover. Eagle Pool at Loess Bluffs National Wildlife Refuge; photograph by James Stack, U.S. Fish and Wildlife Service.

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Conversion Factors

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
	Mass	
metric ton (t)	1.102	ton, short [2,000 lb]
metric ton (t)	0.9842	ton, long [2,240 lb]
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

HUC Hydrologic Unit Code

IPCC Intergovernmental Panel on Climate Change

RCP Representative Concentration Pathway

Climate Change Adaptation Thinking for Managed Wetlands

John T. Delaney[1], Kristen L. Bouska[1], and Josh D. Eash[2]

Abstract

Climate change presents new and ongoing challenges to natural resource management. To confront these challenges effectively, managers need to develop proactive adaptation strategies to prepare for and deal with the effects of climate change. We engaged managers and biologists from several midwestern U.S. Fish and Wildlife Service field stations to understand recent and future climate change effects, identify adaptation barriers and opportunities, and pilot an approach for integrating adaptation thinking into management planning. To start, three structured discussions informed our understanding of how managers currently deal with climate change effects, the strategies being implemented to cope, and the barriers that limit climate change adaptation efforts. We used these insights to develop a multiday virtual workshop geared toward identifying potential adaptation strategies for managed wetlands. First, we developed a conceptual model to visualize how management actions are used to meet habitat objectives within wetland management systems. Next, we discussed how climate change may affect management actions and objectives; we used this understanding of potential effects to spatially assess vulnerability of managed wetlands to climate change. Using a scenario planning approach, we incorporated multiple potential future conditions and identified effects and adaptation strategies that could be considered for each scenario. As a result, several adaptation strategies for managed wetlands under dry and wet future scenarios were identified that can be applied when developing site-specific adaptation plans. Based on our piloted approach, we determined it would be important to have an adaptation team composed of scientists and managers to facilitate discussions, develop appropriate scenarios, and identify realistic adaptation options. We document the tools, findings, and adaptation thinking process taken to enhance adaptation efforts of managed wetlands. The adaptation thinking process can be applied to advance adaptation efforts in other habitats, ecosystems, and site-specific land management.

Introduction

Since the middle of the 20th century, global temperatures have increased at an unprecedented rate and precipitation patterns have changed, and these trends are likely to continue into the future (Intergovernmental Panel on Climate Change [IPCC], 2014). In the midwestern United States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin), there have been increases in temperature and precipitation over the 20th century (Pathak and others, 2017), with more frequent precipitation events (Zhang and Villarini, 2021) and flooding in recent decades (Mallakpour and Villarini, 2015), and increases in base flow (the proportion of streamflow contributed by groundwater) over the past 50 years (Ayers and others, 2018). Climate change projections for the future indicate increases in temperature, changes in precipitation, and shifts in seasonality such as greater precipitation and base flow earlier in the spring in the Midwest (Byun and others, 2019). Climate change represents a major threat to our natural resources (McCarty, 2001; Dawson and others, 2011) and will require adaptation efforts (West and others, 2009). Although progress has been made in developing resource management approaches for climate change adaptation, more work is needed to prepare resource managers for adaptation at local scales (LeDee and others, 2021).

The IPCC defines climate change adaptation as “the process of adjustment to actual or expected climate and its effects” (IPCC 2014, p. 118). For natural systems, several climate change adaptation planning frameworks have been developed (for examples, see Cross and others, 2012; Stein and others, 2014; Swanston and others, 2016). They generally follow a similar process of understanding effects of climate change, identifying management goals, developing management strategies, implementing management strategies, and monitoring outcomes. The planning process is iterative with opportunities to evaluate and adjust as conditions change in

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the future. Commonly the focus of climate change adaptation strategies is on resisting the effects of climate change, but it also is important to consider directing change toward a future condition or accepting changes that cannot be effectively managed (Thompson and others, 2020).

For resource managers to engage in climate change adaptation, it is important to understand how the climate could change in order to characterize how specific changes could affect natural resources, management actions, and the infrastructure necessary to carry out those actions. Climate models are produced from modeling groups around the world and combined in an ensemble of models that indicate a range of possible future conditions (Meehl and others, 2014), with each model run under several pathways that characterize how greenhouse gas emissions could change over the 21st century based upon possible socioeconomic and policy changes (van Vuuren and others, 2011). There are so many irreducible uncertainties associated with climate change projections that uncertainty is commonly characterized as “deep uncertainty” (Lempert and others, 2003). Planning into the future without being able to understand the probability of an outcome is challenging when actions require a large investment or are of high consequence. Indeed, managers commonly cite uncertainty in climate change projections as a barrier to adaptation planning (Kemp and others, 2015; Dilling and Berggren, 2015; Yocum and Ray, 2019).

Because of the deep uncertainty when projecting into the future, adaptation efforts that are explicit about uncertainty are important (Woodruff, 2016). Scenario planning offers one solution to dealing with uncertainty and has been used in a variety of applications including climate change adaptation (Peterson and others, 2003). During the scenario planning process, possible climate change futures are selected to capture a range of potential outcomes by examining climate change effects and other possible factors (for example, socioeconomic or technological changes) that could affect the focal system (Star and others, 2016).

Fischman and others (2014), in a review of U.S. National Wildlife Refuge plans, determined that, although plans incorporated climate change effects and acknowledged a need for more monitoring, many of them lacked information on how to actively respond to climate change. To address this, we developed a process that incorporated elements of existing tools and methodologies for climate change adaptation to assist U.S. Fish and Wildlife Service resource managers in thinking about how to integrate climate change adaptation into their formal planning efforts. Here we focus on identifying current (2020) and future climate change effects, vulnerabilities, and identify adaptations under different climate change scenarios. We refer to this process as “adaptation thinking,” because it does not go further into the implementation stage. We tailored the process specifically to the needs of U.S. Fish and Wildlife Service resource managers by discussing these needs with managers that work at regional and local scales.

To pilot our adaptation thinking process, we held a 4-day workshop focused on managed wetlands in the Midwest. Managed wetlands are an important component of the National Wildlife Refuge System (Lyons and others, 2008). Managed wetlands are commonly a complex of units where water levels are managed to provide resources and habitat for wetland-dependent wildlife (Kaminski and others, 2006). The primary function of water manipulation is to provide habitat and food production for waterfowl, but it also is utilized to control invasive species, provide fish nurseries, manage water supply, etc. The timing of water level management actions varies seasonally, differs for different management objectives, and is commonly tied to the phenology of waterfowl or vegetation (Fredrickson and Taylor, 1982). Infrastructure is an important component of managed wetland systems, with water level controls dependent upon infrastructure such as levees, pumps, wells, ditches, and culverts. Management of these systems is challenged because of recent weather-related changes (such as flooding and wetter conditions generally), the pervasiveness of managed wetlands across the National Wildlife Refuge System, the complexity of management goals and actions, and reliance on infrastructure. Thus, it is important to identify adaptation strategies that can be used by managers to address current and future challenges of managed wetlands and to develop effective long-term planning and conservation delivery.

Study Area

The field stations (National Wildlife Refuges and Wetland Management Districts) involved in this project are depicted in figure 1. To assess vulnerability, we used 360 Hydrologic Unit Code (HUC)-8 drainage basins in an 8-state region including Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin (fig. 1). HUC-8 is a level (subbasin) of a standard nested categorization of drainage basins in the United States (Seaber and others, 1987). Initially, to assess manager needs, we led structured discussions with personnel from field stations that were in drainage basins with higher vulnerability based upon a recent vulnerability assessment (Delaney and others, 2021) and that collectively represent a variety of known regional natural resource challenges. Model inputs for the vulnerability assessment are available for the data (Delaney and Bouska, 2021a), and the R code used to summarize the raw output is available (Delaney and Bouska, 2021b). We hereafter refer to these initial discussions as adaptation needs discussions. During these discussions we assessed recent weather-related changes the managers have experienced, how they are currently adapting or plan to adapt to climate change, and the barriers to climate change adaptation. The adaptation needs discussion meetings were intended to gain a better understanding of current challenges and barriers to adaptation and to identify a focus for the adaptation

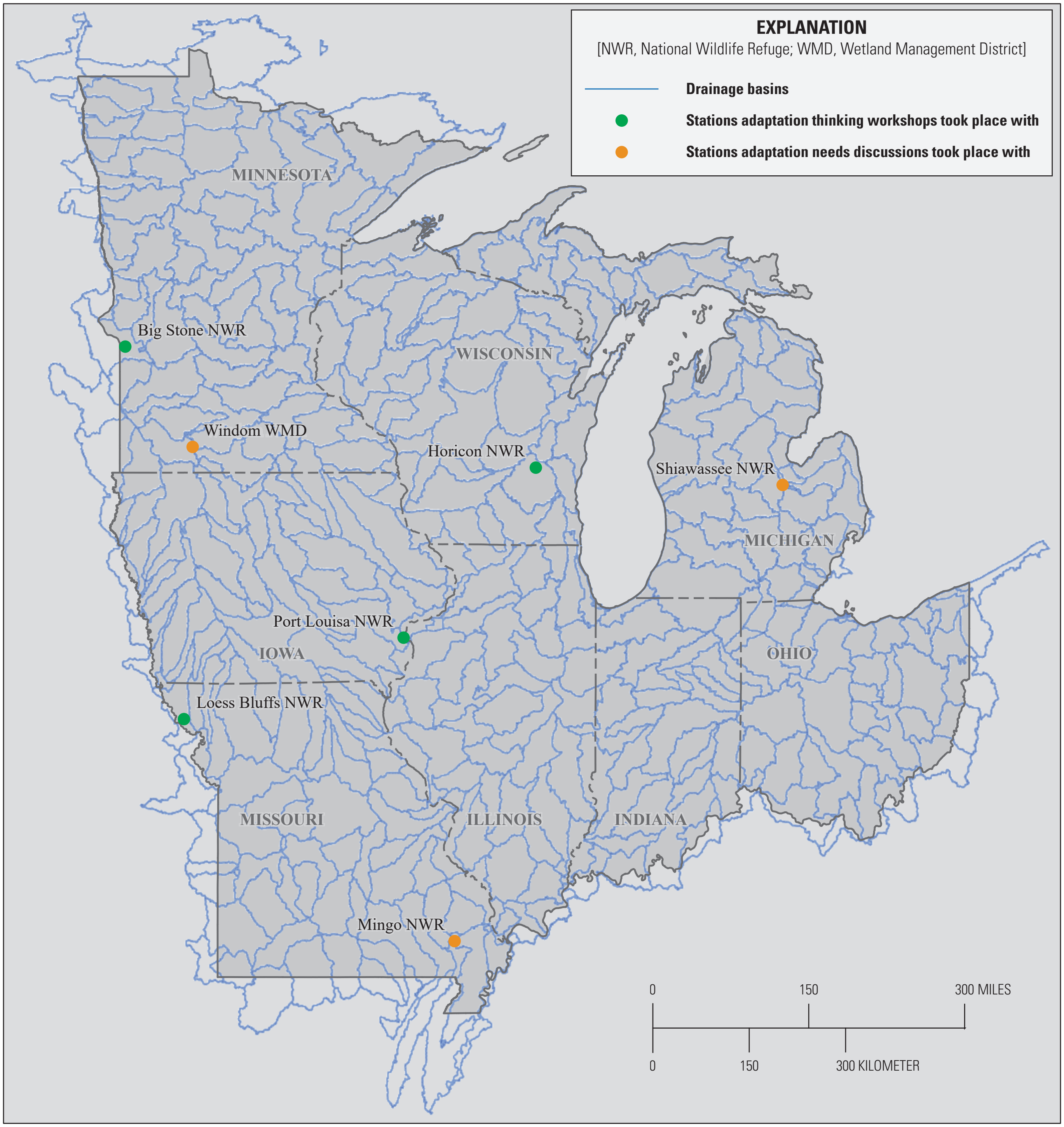

Figure 1. Map depicting study area with field stations. Orange dots depict field stations that were engaged in adaptation needs discussions. Green dots are field stations that participated in the adaptation thinking workshop. Blue polygons represent 360 Hydrologic Unit Code (HUC)-8 drainage basins for which vulnerability to climate change was assessed (Delaney and others, 2021) and used to select stations (National Wildlife Refuges [NWR] and Wetland Management Districts [WMD]) to include in the discussions and workshop.

thinking workshop. Once we identified managed wetlands as a focus for the workshop, we selected different stations to maximize the information gathered during the project. Regional hydrologists and biologists aided in the identification of field stations based upon perceived need, recent effects (for example, flooding issues), and level of interest of field station staff.

Methods

This section of the report describes the methods used to identify climate change adaptation needs and apply adaptation thinking. Virtual meetings and a virtual workshop were critical to pilot guided discussions on these topics.

Adaptation Needs

We held virtual adaptation needs meetings with three field stations to discuss recent weather-related challenges, climate change, and adaptation. Before each meeting, we synthesized available information to provide a summary of historical changes in temperature, precipitation, and hydrology, and future projections in temperature and precipitation for each of the field stations depicted in figure 1. Historical temperature and precipitation data were collected for each field station from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset (https://www.prism.oregonstate.edu) at monthly (1895–2019) and daily (1981–2019) scales. For future climate projections, we used Coupled Model Intercomparison Project phase 5 (CMIP5) climate projections (Taylor and others, 2012) that were statistically downscaled using the Localized Constructed Analogs (LOCA) technique (Pierce and others, 2014). We accessed the datasets from the Center for Integrated Data Analytics threads server (https://cida.usgs.gov/gdp) using the geoknife package (Read and others, 2016) in R (R Core Team, 2020). For our scenarios, we used two emissions pathways, Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 8.5 represents a possible future that lacks mitigation efforts so greenhouse gas emissions continue to increase through the century; RCP 4.5 represents a future where mitigation policies and green energy investments cause greenhouse gas concentrations to increase more slowly and level out after mid-century (van Vuuren and others, 2011). For each field station, a total of 60 climate model outputs (30 models run under each RCP) were downloaded at a daily timestep for the baseline period (1961–1990) and the future period (2036–2065). The historical trends and future projections were provided to each field station in a summary report before each meeting.

The first adaptation needs meeting took place on May 20, 2020, with Windom Wetland Management District in southwest Minnesota, with the district manager, wildlife biologist, and private lands wildlife biologist from the field station, one regional fishery biologist, and one regional hydrologist. The second adaptation needs meeting occurred on June 24, 2020, with Mingo National Wildlife Refuge in southeast Missouri, with the refuge manager, assistant refuge manager, wildlife biologist, and two regional hydrologists. The third adaptation needs meeting took place on August 13, 2020, with Shiawassee National Wildlife Refuge in east-central Michigan, with the wildlife biologist and two regional hydrologists. Each call began with a presentation that provided an overview of a regional drainage basin-based climate change vulnerability assessment we created in an earlier stage of the project (Delaney and others, 2021), a review of climate change adaptation concepts, and an exploration of local historical and projected changes in temperature and precipitation. For each of these meetings, we structured the adaptation needs discussions around the following five questions:

(1). What are some of the recent climate- or weather-related changes that have affected your work?

(2). In what ways have you been dealing with, or adapting to, these changing conditions?

(3). How are projected climate changes likely to affect your work, and how might you adapt?

(4). What do you see as major barriers to expanding climate change adaptation efforts in your work?

(5). What types of information and level of specificity would be useful in preparing for climate change adaptation?

Responses to these questions helped us to better understand the status of adaptation efforts at field stations and current barriers to further climate change adaptation efforts. This feedback (see “Results”) was used to design a workshop targeted at identifying adaptation options for one of the most common types of habitat management units: managed wetland systems.

Adaptation Thinking

We held a 4-day (November 5, 10, 13 & 24, 2020) virtual workshop to work through an adaptation thinking process for managed wetlands. Each meeting ranged between 2 and 3 hours in length and included various objectives along with homework assignments before and following each meeting to help keep virtual face-to-face meeting times at a minimum. There were 12 attendees, with 1–2 managers and (or) biologists from each of 4 refuges (Big Stone, Horicon, Loess Bluffs, and Port Louisa National Wildlife Refuges; fig. 1), along with regional hydrologists and biologists. The overall goal of the workshop was to pilot a streamlined process for incorporating climate change adaptation planning into decision making by presenting information as concisely as possible and incorporating uncertainty in climate change projections.

The structure of the workshop built upon the first two steps of the Adaptation for Conservation Targets (or ACT) framework (Cross and others, 2012), which included selecting a conservation feature and assessing climate change effects by building a conceptual model, identifying future scenarios, and assessing responses to scenarios. The process for our workshop (fig. 2) further built upon several methodologies including conceptual model building (Jacobson and Berkley, 2013), vulnerability assessment (Glick and others, 2011), scenario planning (National Park Service, 2013; Star and others, 2016), and adaptation thinking (Thompson and others, 2020), that are explained in their respective sections that follow. One week before the start of the workshop, we shared a 30-minute recorded video presentation that outlined the previous work on the project and the process, goals, and objectives for the upcoming workshop.

The workshop began with a conceptual model exercise to understand how management actions are used to support different habitats and biota in managed wetland systems. To facilitate the process, workshop organizers created a draft conceptual model before the workshop using refuge-specific Habitat Management Plans. The conceptual model built upon established conceptual models used for river restoration and management (Jacobson and Berkley, 2013), where management actions are characterized as propagating through chemical/physical processes from habitats down to biota. Workshop participants collectively refined the model and added components during the meeting. Once participants were satisfied with the layout of the model, we discussed how recent weather patterns and projected climate changes could affect managers' ability to implement management actions, manage for particular habitats, and affect targeted biota. We then added lines to depict which weather and climate changes affect management actions and biota. We discussed the importance of each effect and weighted them appropriately by using different thickness of lines based upon the expert knowledge of the workshop participants. The goal of this conceptual model building exercise was to reach a consensus on how weather and climate affect the system and to ensure that we had identified the main components and priorities of managed wetland systems across the region.

To assess vulnerability, we utilized an interactive tool that was created during an earlier phase of our project for the HUC-8 drainage basins in our study region (Delaney and Bouska, 2021c, Delaney and others, 2021). A data release containing the code used to run the tool is publicly available (Delaney and Bouska, 2021d). The tool follows a vulnerability framework (fig. 3) that involves discerning the potential effects of changes in climate that the resources are exposed to, the sensitivity of the resources to those effects, and the capacity of the resources to adapt to those changes (IPCC, 2007; Glick and others, 2011). The tool allows users to select from 15 climate change exposure indicators and weight the importance of each for a specific species or habitat to create an estimate of potential impact for each drainage basin. The exposure indicators are a collection of indicators calculated from daily climate model outputs and hydrology models that were run using the climate model outputs and split into three categories: hydrology, temperature, and precipitation (see table 2 in the "Results" section and Delaney and others [2021] for complete list of indicators). Adaptive capacity is calculated from the selection and weighting of five indicators related to a drainage basin's potential to buffer against the effects of climate change. To calculate a vulnerability score for each drainage basin, adaptive capacity is subtracted from potential impact. For specific information on the selection of indicators, the hydrology models, and the quantification of vulnerability see the methods in Delaney and others (2021). During the workshop, participants collectively selected the exposure indicators they felt were relevant to managed wetland systems and weighted the importance of each indicator.

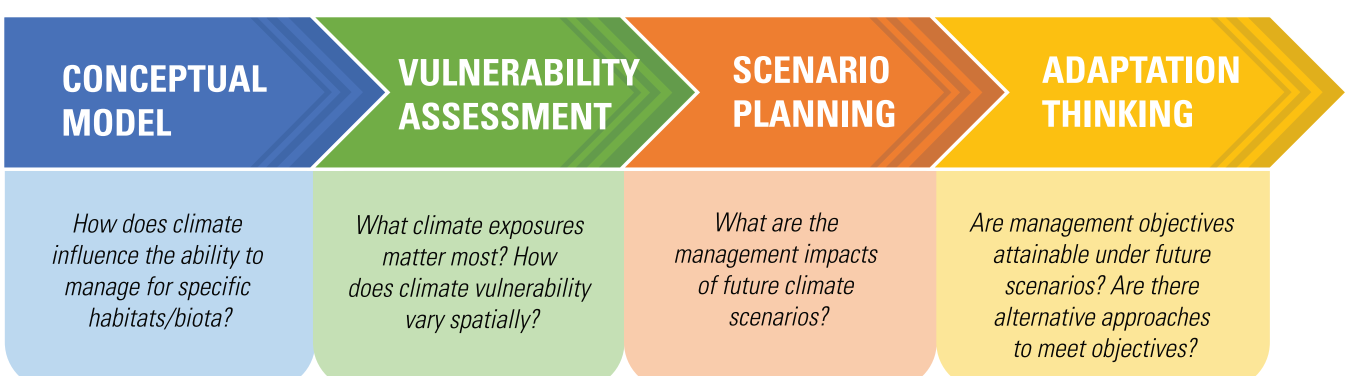

Figure 2. Summary of the adaptation thinking workshop process. We incorporated several methodologies to create a process for our workshop that included conceptual model building, assessing climate change vulnerability, identifying climate change scenarios, and developing adaptation thinking strategies.

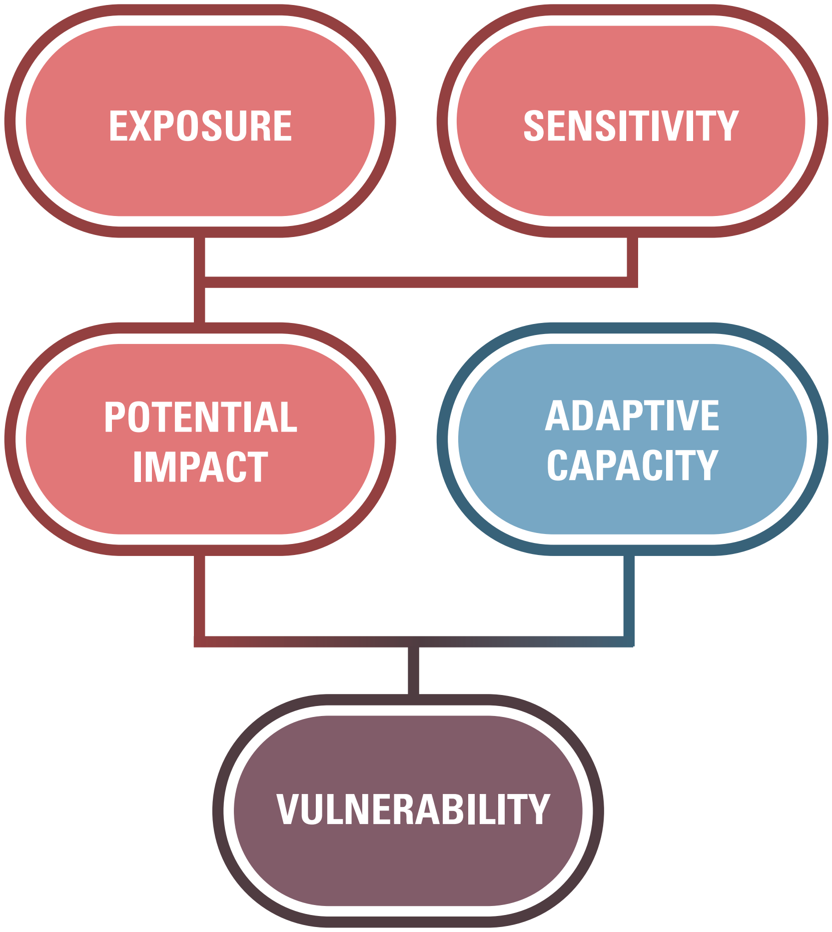

Figure 3. Vulnerability framework used to assess climate change vulnerability of managed wetlands. Climate changes that a resource is exposed to and the resource's sensitivity to those exposures determine the potential impact on the resource, which, together with the resource's ability to adapt to those changes (adaptive capacity), determines the resource's vulnerability. Adapted from Glick and others (2011).

Table 1. Thematic summary of responses to questions from our adaptation needs discussions.

Recent changes	How have/will you adapt	Major barriers to adaptation
• Precipitation events are more frequent and intense • More flooding • Water management more complicated • Field work more complicated • Earlier springs • Warmer winters • More summer droughts • Increase in undesirable/invasive vegetation	• Increasing flexibility • Proactive when planning infrastructure changes/upgrades • Research/monitoring • Increasing partnerships and communication with other groups and peers • Focus on system-wide approaches	• Information overload. • Uncertainty in projections. • Little expertise and staff time • Funding limitations. • Buy-in from the public.

Table 2. Twelve exposure indicators and weights selected by workshop participants.

[Weights are on scales 1-5 with 5 being the most important; m^3/s, cubic meters per second; ≥, greater than or equal to; mm, millimeters; °C, degrees Celsius]

Category	Exposure indicator	Abbreviation	Weight	Description
Hydrology	Spring flow	MSF	5	Mean discharge (m^3/s) over March, April, and May.
	Number of high flow months	NHFM	3	Number of months that discharge (m^3/s) exceeds baseline threshold (mean 90th percentile from baseline period).
	Sediment load	SEDL	4	Annual sediment load in metric tons.
	Total nitrogen load	TNL	2	Annual total nitrogen load in metric tons.
Precipitation	Consecutive wet days	CWD	1	Annual maximum number of days when precipitation is ≥ 1 mm.
	Fall precipitation*	FAP	2	Change in total mm of precipitation in the fall (September, October, and November).
	Maximum 5-day rainfall	Rx5day	4	Annual maximum amount of rainfall (mm) in a 5-day window.
	Spring precipitation	SPP	3	Change in total mm of precipitation in the spring (March, April, and May).
	Summer precipitation	SUP	2	Change in total mm of precipitation in the summer (June, July, and August).
Temperature	Freezing temperature reversals	FTR	2	Count of times sign changes (+,- °C) in January and February.
	Growing season start	GSS	3	Annual day of year of first 6 consecutive days where daily mean temperature > 5 °C.
	Warm days	TX90p	1	Number of days where temperature (°C) > 90th percentile from the baseline period.

*This indicator was not in the original set of 15 from the vulnerability assessment; it was added specifically for this workshop.

For the scenario planning component of the workshop, we adapted an approach outlined in a climate scenario planning handbook developed by the National Park Service (National Park Service, 2013). We identified critical climate change forces and potential impacts to managed wetland systems based upon the prioritized exposures in the vulnerability assessment and their effect on the components of the conceptual model. We then discussed the importance and uncertainty of the various indicators. Matrix plots (not pictured) were constructed by plotting the projected change (baseline to future period) of multiple indicator combinations with each point representing a climate model. The plots were visually inspected to better understand the range in climate model projections. For instance, plots were used to assess how models depicted a wetter versus drier future. These discussions led to identification of our scenarios and selection of representative climate models used to investigate changes in influential indicators under each scenario.

The adaptation thinking part of the workshop focused on brainstorming potential adaptation approaches that could be applicable to managed wetland systems throughout the Midwest. We refer to this process as “adaptation thinking” where we focus on understanding effects of climate change, identifying management goals, and identifying potential management strategies, but do not go further in the planning process where we would implement management strategies and monitor outcomes. From the list of adaptation thinking approaches, managers could utilize them, or refine them, in their own planning efforts, similar to the “Adaptation Menu” utilized by the Adaptation Workbook (Swanston and others, 2016; Northern Institute of Applied Climate Science, 2021). During the adaptation thinking process we utilized the Resist, Accept, or Direct framework (Thompson and others, 2020), to consider different ways to respond to change. We also identified robust approaches that could be beneficial under multiple scenarios. The brainstorming session lasted 2 hours, where we worked through each of 5 common management goals: implementing water level drawdowns, implementing flood-ups, maintaining targeted water levels, maintaining infrastructure, and ensuring long-term habitat maintenance (for example, use of fire, invasive species management). Participants first identified specific impacts each scenario could have on each management action. Potential adaptation approaches were suggested for each management action under each scenario.

After that day's activities, we shared the list of impacts and adaptation approaches with the participants so they could individually refine and add to the list as their homework assignment for that day.

The final day of the workshop focused on reflection upon our adaptation thinking process. This was an opportunity to get input on how the process could be improved. Time was built in to discuss ways this process could be incorporated into formal planning processes. A full schedule for the entire 4-day workshop can be found in appendix 1.

Results

This section of the report describes the results of the piloted meetings and workshops to identify climate change adaptation needs and apply adaptation thinking.

Adaptation Needs

Our adaptation needs discussions with three field stations detailed how managers across the region are responding to recent climate challenges and changes, how they have or are planning to adapt, and what barriers they may experience to climate change adaptation in the near and distant futures. A summary of themes that emerged from the discussions is provided in table 1. Participants from all the field stations felt that weather and hydrologic patterns have changed in the last 10 or more years. Flooding and its effects on infrastructure, habitat restoration/maintenance, and monitoring and research were primary concerns across the region. Flooding issues were largely attributed to changes in precipitation intensity and timing. Invasive and undesirable species were also a commonly cited issue attributed to earlier springs, both wetter and drier conditions, and (or) increased connectivity because of flooding.

All field stations are responding to recent changes by increasing flexibility in their planning efforts, upsizing infrastructure (when or if opportunities arise) to handle more water, and expanding their monitoring efforts to better understand the system and how it is changing; however, field stations were hesitant about planning into the more distant future (about five or more years out). The overwhelming amount of information and uncertainty in climate change projections, lack of process or guidance, and little staff time were among the major barriers to further planning for climate change adaptation. We used the insights from these adaptation needs discussions on recent changes, current adaptation efforts, and major barriers to design the adaptation thinking workshop. We focused on overcoming barriers to climate change adaptation by outlining a process to reduce complexity of climate change information and deal with the deep uncertainty in climate change projections. These discussions also helped us to identify managed wetland systems as a focus for the pilot workshop.

Adaptation Thinking

During the first day of the adaptation thinking workshop, participants constructed a conceptual model depicting how climate change effects propagate through and among different components of the system (fig. 4). The main components are exposure indicators included in the vulnerability assessment, management actions, habitat types, and biota. We included elements that affect the system but were outside the scope of this conceptual model (diamonds in fig. 4). The thickness of each of the solid lines depicts the perceived importance of each exposure's effect on the associated component. Hydrology and precipitation indicators were among the most influential weather effects. Particularly, mean springtime flow, sediment load, heavy precipitation, wetter springs, and drier summers were perceived to have the greatest effect. Seasonal drawdown and fall pool recharge were the management actions that were most affected by weather. Several indicators directly elicit biotic responses, such as from invasive/undesirable species and dabbling ducks. The conceptual model depicts weather and hydrology exposure effects under current (2020) conditions.

To understand the importance of potential future climate change effects, participants collectively selected and weighted each of the climate change exposure indicators most relevant to managed wetland systems (table 2) and weighted the importance of five adaptive capacity indicators that are included in the vulnerability assessment tool (table 3). Hydrology indicators included the number of high flow months to represent increased potential for flooding; spring flow because of challenges associated with managing water in the spring; sediment load because of issues with sedimentation within units and infrastructure, and total nitrogen load because increased nutrients could promote invasive species and algal blooms. Precipitation indicators included consecutive wet days as an indicator of increasing wet conditions, maximum 5-day rainfall to represent increasing precipitation intensity, spring precipitation as increasing wet conditions in the spring, and summer precipitation to represent possibility for increasing seasonal drought. An additional precipitation indicator was added (fall precipitation) specifically for this workshop because during the first day of the workshop, fall precipitation was determined to be an important effect because large precipitation and flooding events appear to be happening more frequently and create challenges for management activities in the fall. Temperature indicators included freezing temperature reversals (number of times the temperature moves above or below 0 degree Celsius [°C] in January and February) as an

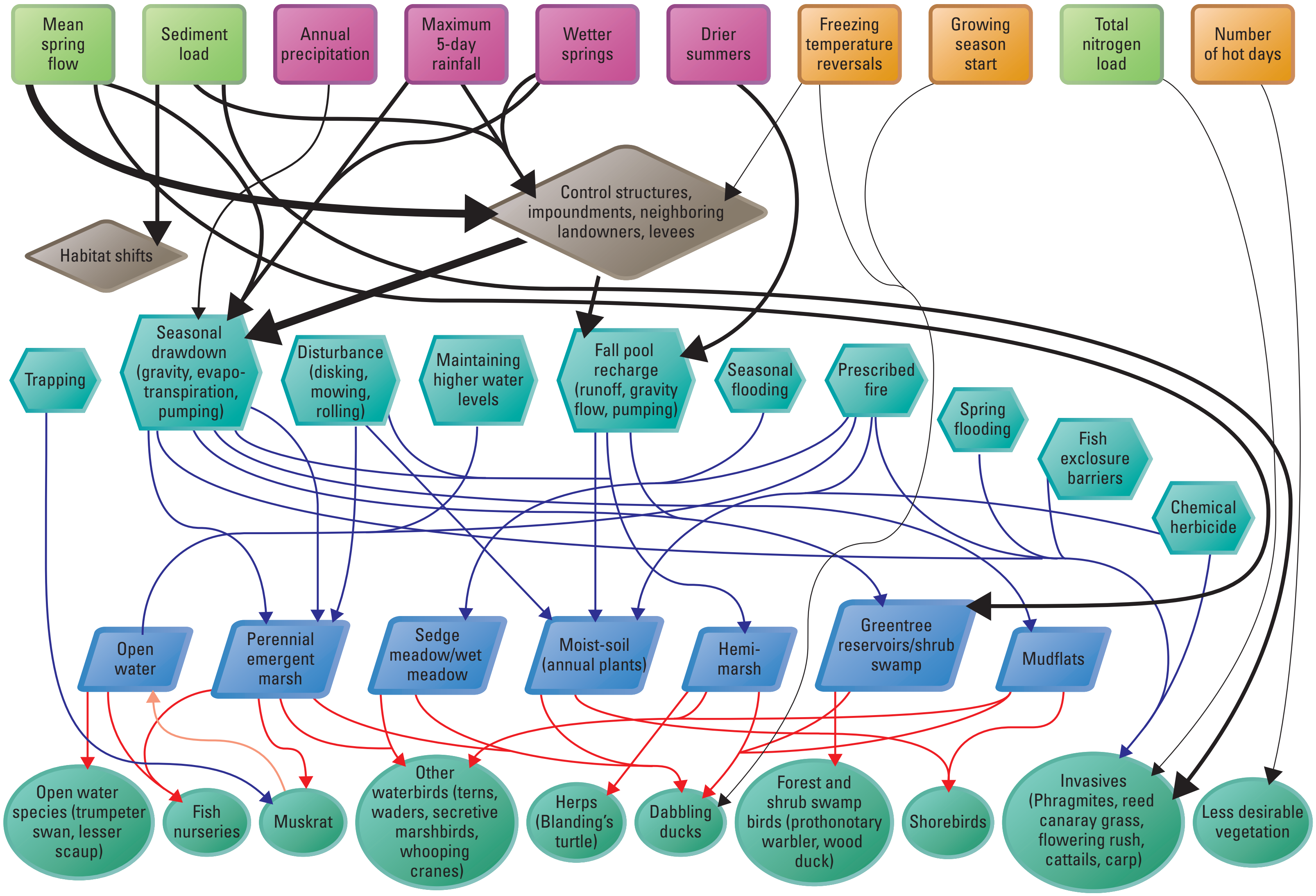

Figure 4. Conceptual model for managed wetland systems constructed during the workshop. Components include current (2020) weather and hydrology indicators that affect the system (squares with rounded corners), management actions (irregular hexagons), habitat types (parallelograms), biota (ovals), and other effects (diamonds). Blue, orange and red lines represent the base model we created to show the effects among management actions, habitat types, and biota, whereas the black arrows depict the current weather and hydrology effects. The weights of the black arrows depict the perceived importance of that effect to the system with thicker lines depicting greater effect. The indicator boxes are color coded with hydrology in green, precipitation in pink, and temperature in orange. Latin names of organisms listed at the species level in the figure are as follows: Blanding's turtle (*Emydoidea blandingii*), cattails (*Typha* spp.), flowering rush (*Butomus umbellatus*), lesser scaup (*Aythya affinis*), muskrat (*Ondatra zibethicus*), Phragmites (*Phragmites australis*), prothonotary warbler (*Protonotaria citrea*), reed canary grass (*Phalaris arundinacea*), trumpeter swan (*Cygnus buccinator*), whooping crane (*Grus americana*), and wood duck (*Aix sponsa*).

Table 3. Adaptive capacity indicators and weights selected by workshop participants. Each of the adaptive capacity indicators list the dataset and citation of the Geographic Information System (GIS) layer used to estimate adaptive capacity. Weights represent perceived contributions to adaptive capacity and are on a scale from 1 (low) to 5 (high). Percent cultivated land cover, density of dams, and projected increase in developed land cover were multiplied by –1 before including in the composite because they were considered negatively correlated with adaptive capacity.

Indicator name	Weight	Title	Citation
Percent cultivated land cover	4	National Agricultural Statistics Service 2018 Cultivated Layer	(National Agricultural Statistics Service 2019).
Density of dams	4	National Inventory of Dams	(National Inventory of Dams—U.S. Army Corps of Engineers 2019).
Projected increase in Developed land cover	3	Conterminous United States Landcover Projections–1992 to 2100	(Sohl and others 2014).
Landscape diversity	3	The Nature Conservancy Resilient Lands Mapping Project	(Anderson and others 2018).
Local connectedness	3	The Nature Conservancy Resilient Lands Mapping Project	(Anderson and others 2018).

indicator for ice cover and potential for liquid precipitation falling when ground is still frozen; growing season start to capture changes in spring onset; and the number of hot days for warmer summer temperatures. The weights that participants assigned to each indicator can be found in tables 2 and 3.

Once the indicators and their weights were combined into composite scores of potential impact, adaptive capacity, and vulnerability, we produced maps for each component (see methods in Delaney and others, 2021). The resulting maps of potential impact (fig. 5), adaptive capacity (fig. 6), and vulnerability (fig. 7) showed regional differences and differences among emissions pathways for potential impact and vulnerability. Potential impact was greater under the higher emissions scenario, with the greatest difference between scenarios in Minnesota and Wisconsin. Regionally, potential impact was greatest in northern Michigan, central Minnesota and along the Missouri River in Iowa and Missouri. Adaptive capacity was greatest along the northern and southern parts of the region and lower in Iowa, Illinois, Indiana, and northwest Ohio. All four field stations engaged in the workshop were in areas of medium-high vulnerability.

Given the focus on precipitation and water quantity in managed wetland systems, we chose to characterize a wet scenario and a dry scenario for thinking about climate change adaptation. Using annual precipitation and annual mean temperature, we selected the 6 wettest and the 6 driest (3 from each RCP) from the suite of 60 climate models (30 per RCP) from the average across the 4 field stations (fig. 8). We then calculated seasonal changes in select climate change indicators, with one precipitation and one temperature indicator in each season (table 4). We focused on seasonal changes because of the seasonal nature of several wetland management decisions. For winter, participants selected change in precipitation, because more precipitation could create more flooding concerns in winter or spring as snow melts, and freezing temperature reversals, because increases in temperature fluctuations above and below 0 °C could be indicative of greater potential for rain falling on frozen ground, which creates flooding concerns. For spring, participants selected spring precipitation, because of concerns about increased flooding during the spring, and growing season start, which could affect seasonal timing of management actions and affect arrival of waterfowl in the spring. For summer, participants selected summer precipitation, because of the potential for seasonal droughts in the summertime, and number of warm days, which could further stress systems under drought and affect evapotranspiration, algal blooms, and disease outbreaks. For fall, participants selected fall precipitation, because excess precipitation and flooding can cause challenges with fall management activities, and fall mean temperature, as this could indicate an extension of the growing season and lead to further phenological mismatch. Note, we did not use growing season length to keep the metrics within seasonal timeframes or to maintain consistency with the metrics available in the vulnerability assessment tool.

Next, intentionally nontechnical narratives (to facilitate interpretation) were constructed for each scenario. Under the dry scenario, winters have normal precipitation with more possibilities for rain on frozen ground; springs are slightly wetter with much earlier springs; summers are very dry with many more hot days; and falls have normal precipitation but much warmer temperatures. Under the wet scenario, winters have normal precipitation with more possibilities for rain on frozen ground; springs are wetter with earlier springs; summers are slightly wetter with more hot days; and falls are wetter and warmer. Winters are similar between the two scenarios in terms of precipitation and changes in number of freezing temperature reversals. Springs begin earlier under both scenarios but more so under the dry scenario, and precipitation increases under both scenarios in the spring but to a greater degree under the wet scenario. Summers are warmer under both scenarios, indicated by the number of hot days, with

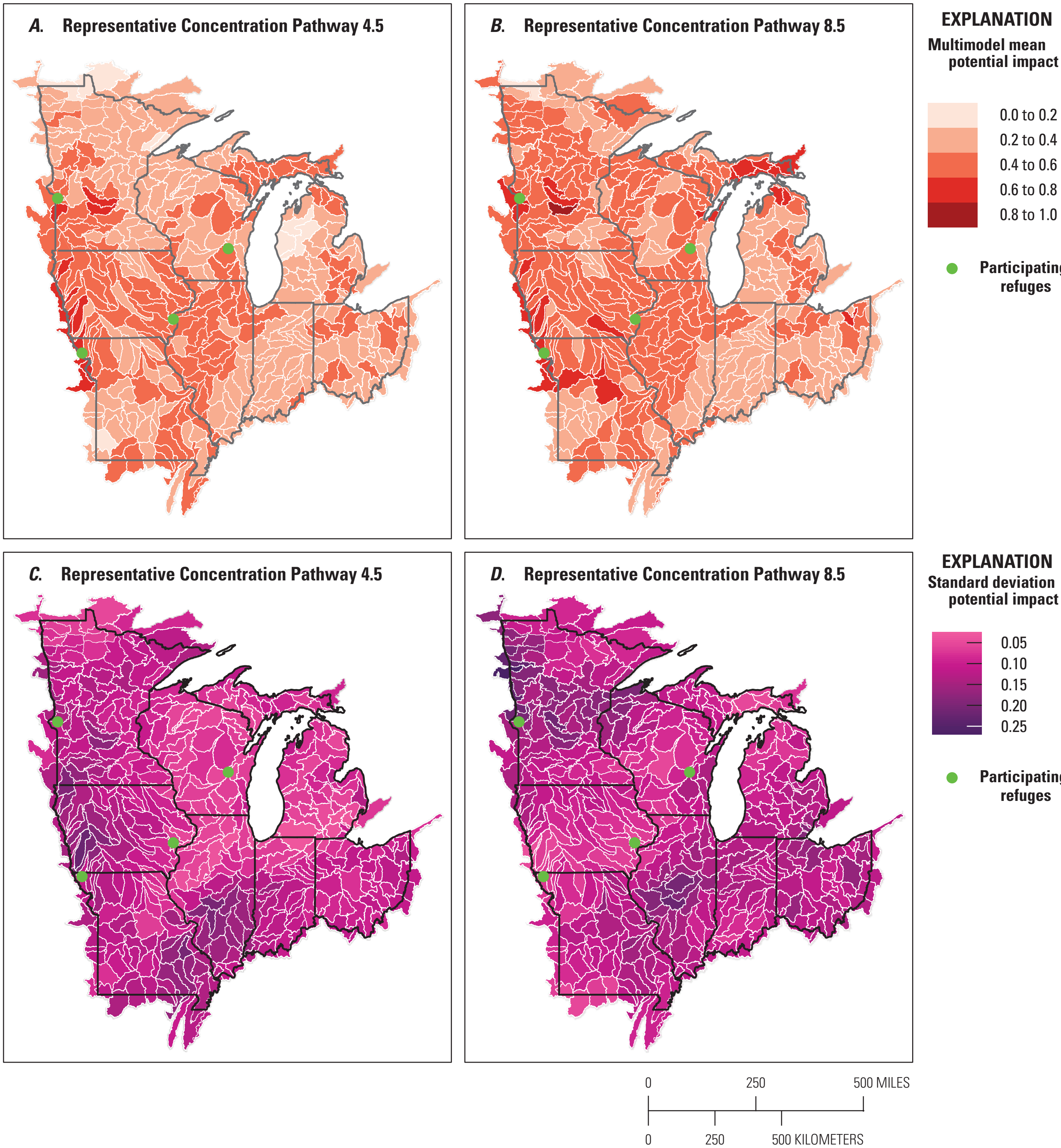

Figure 5. Maps depicting potential impact for managed wetlands across the study area. Top row of panels depicts the multimodel mean of five climate models, and the bottom row of panels show the standard deviation among the models. The 0–1 scale is the minimum-maximum normalized composite of the combined and weighted exposure indicators (from table 2). See Delaney and others (2021) for methodology and the five climate models used in the vulnerability assessment. The left column of panels shows the medium emissions scenario (Representative Concentration Pathway [RCP] 4.5) and the right column of panels are the high emissions scenario (RCP 8.5). Green dots depict the location of the four refuges that participated in the workshop.

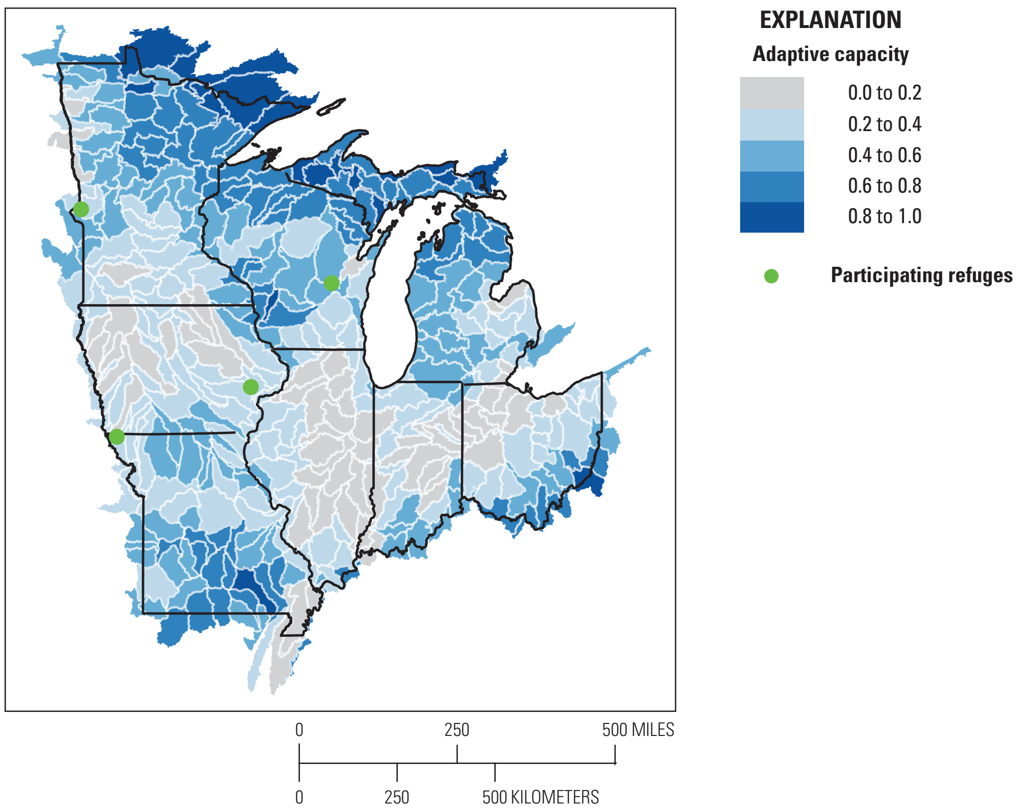

Figure 6. Map depicting adaptive capacity of managed wetlands across the study region. Green dots depict the location of the four refuges that participated in the workshop. The 0–1 scale is the minimum-maximum normalized composite of the combined and weighted adaptive capacity indicators (see table 3 and methods in Delaney and others [2021]).

more hot days under the dry scenario. Precipitation decreases under the dry scenario in summer but increases under the wet scenario. Falls are warmer under both scenarios with a greater increase in fall mean temperature under the dry scenario, and precipitation in the fall under the dry scenario is similar to the baseline period but increases under the wet scenario. Changes are also summarized in a nontechnical graphical table with arrows depicting the approximate change in each metric in each season for each scenario (table 5). Actual change values are presented in table 4.

The impacts that were identified by participants as potentially affecting each of the five management goals under each scenario are presented in table 6. The impacts were not limited only to those having negative implications but also included those that could be beneficial. Examples of beneficial impacts under the wet scenario included the ability to maintain targeted water levels, especially in units at higher elevation, and, in some cases, to control undesirable species. Also, the longer growing season and higher evapotranspiration could offset negative impacts by allowing more flexibility under the wet scenario. Under the dry scenario, examples of benefits included less damage to infrastructure from flooding, greater accessibility, opportunities for infrastructure maintenance, and increased plant diversity by making the soil more favorable for plant establishment and rooting. Some examples of negative impacts under the wet scenario included inability to perform drawdowns or maintain target water levels, disruption of nesting birds and other wildlife, damage to infrastructure, and increased spread of invasive/undesirable species. Under the dry scenario, some negative impacts included difficulty in maintaining water levels or a diversity of a wetland types, inability to perform flood-ups, inability to access water with current infrastructure, decline in muskrats, and increases in invasive/undesirable species and disease outbreaks.

The adaptations identified by participants for each management action under each scenario are presented in table 6. General themes from the adaptation options identified were diversifying management units, altering infrastructure (for example, upsizing or downsizing), adjusting timing of management actions, utilizing seasonal/long-range forecasts (for example, drought forecasts or seasonal weather outlooks), enhancing collaborations and partnerships, and completing more monitoring and research to better understand the systems and identify when changes are occurring. Participants felt that

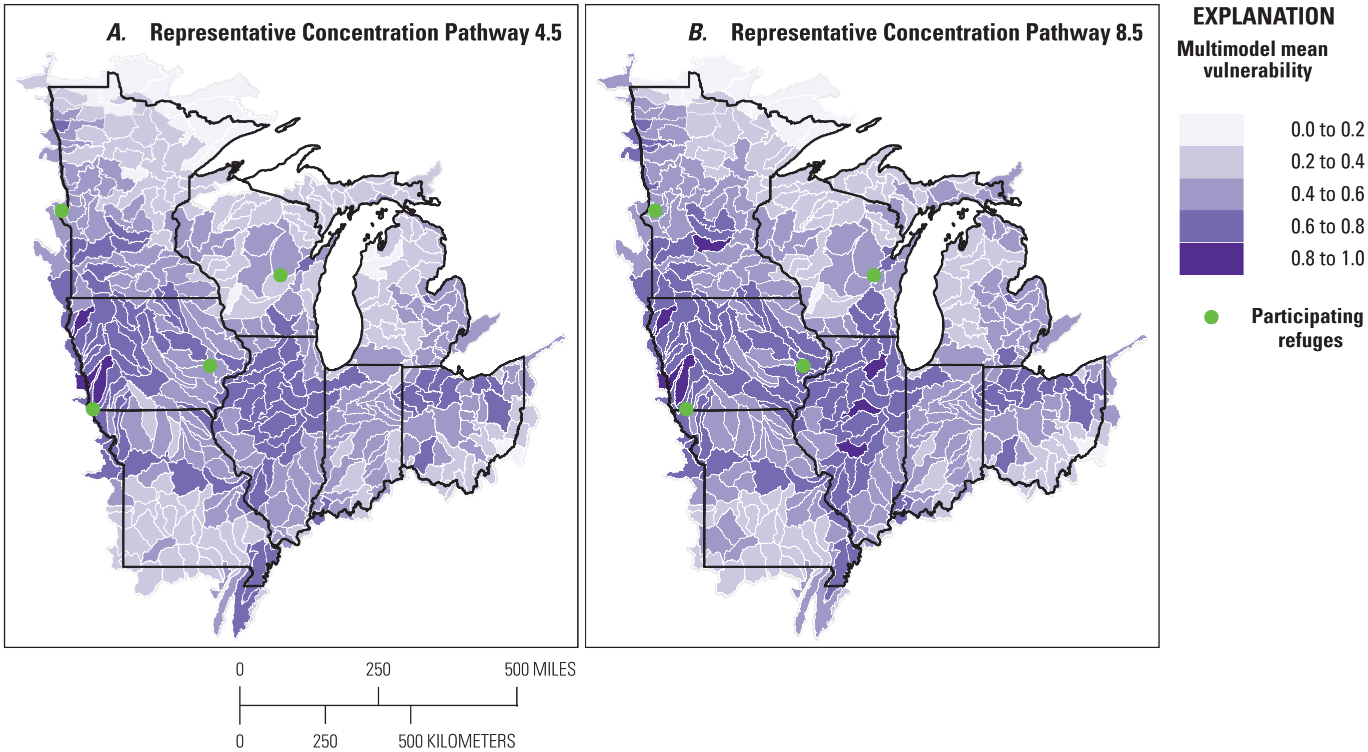

Figure 7. Maps depicting climate change vulnerability of managed wetlands across the study region. Values represent the multimodel mean of five climate models. The left panel shows the medium emissions scenario (Representative Concentration Pathway [RCP] 4.5) and the right panel depicts the high emissions scenario (RCP 8.5). Green dots depict the location of the four refuges that participated in the workshop. The 0–1 scale is the minimum-maximum normalized composite of the combined potential impact and adaptive capacity scores (see methods in Delaney and others [2021]).

adapting to the impacts of the dry scenario would be easier than adapting to a wet future because many of the managed wetland systems were designed decades ago under somewhat drier conditions and dealing with less water would be less difficult than being overwhelmed with water. Examples of resisting change included increasing the size of infrastructure, isolating units from sources of flooding, and investing in invasive/undesirable species control. Strategies that accept changes included adjusting management strategies and timing and designing systems and infrastructure for more passive management. Strategies geared toward directing changes included converting habitat types to different moisture regimes and planning for changes in bird migration. Robust strategies that could be beneficial under either scenario included those that involved enhancing partnerships and collaborations, research and monitoring, seasonal forecasts, and understanding changes in bird migration/behavioral patterns. Because of the wide range of management objectives for managed wetlands across the stations participating in the workshop (see fig. 4), these robust strategies focused more on improving understanding of the system rather than on specific management approaches. Future efforts could focus on identifying on-the-ground actions that could work under multiple scenarios and implement and evaluate them through monitoring and research.

In reviewing the piloted adaptation thinking approach, participants of the workshop felt that the process was helpful and produced information that would be useful in future planning efforts. Overall, the process helped solidify the importance of strong collaboration between managers and scientists when working on climate change adaptation issues. Frequent interactions and structured discussions were key to identifying (1) barriers to climate change adaptation, (2) aspects of climate change most relevant to manager's decision making, and (3) appropriate scenarios to structure adaptation discussions around.

One opportunity for improvement of the process included creating a subgroup of participants to pull out relevant climate information and develop scenarios outside of the main workshop, because this would further reduce the complexity of information needed to review at the workshop. By creating

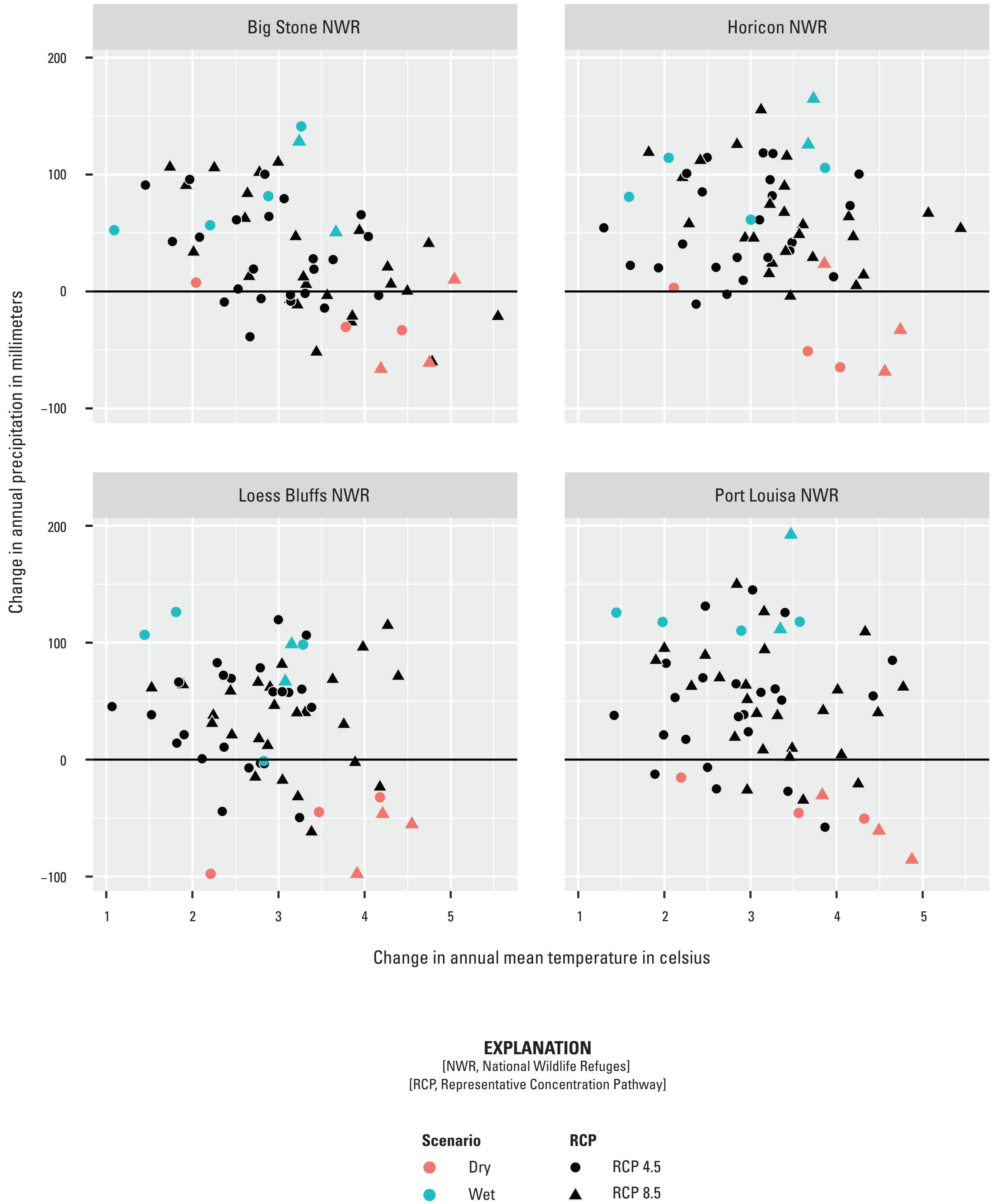

Figure 8. Climate change matrix plots depicting the change in annual precipitation and annual mean temperature from the baseline (1961–1990) to the future period (2036–2065) for four National Wildlife Refuges (NWR). The horizontal line represents zero change between periods. Dots are models run under Representative Concentration Pathway (RCP) 4.5 and triangles are models run under RCP 8.5. Symbols shaded blue are the six models used to create the wet scenario and red are the six models used to create the dry scenario.

Table 4. Climate model outputs for the driest and wettest climate change models. Values are the change from the baseline (1961–1990) to the future period (2036–2065) for each climate model averaged across the four stations (Big Stone, Horicon, Loess Bluffs, and Port Louisa National Wildlife Refuges). Each scenario consisted of six climate models identified as the wettest and driest models after averaging across the four stations with an even split from each Representative Concentration Pathways 4.5 and 8.5. Each of the four seasons (winter, spring, summer, and fall) has one temperature-related indicator and one precipitation-related indicator. WIP stands for winter precipitation (December, January, February) and was added after the vulnerability assessment discussions because of the importance to contribute to winter and spring flooding.

[RCP, representative concentration pathway; ANP, annual precipitation; AMT, annual mean temperature; WIP, winter precipitation; FTR, freezing temperature reversals; SPP, spring precipitation; GSS, growing season start; SUP, summer precipitation; TX90p, number of warm days; FAP, fall precipitation; FMT, fall mean temperature; Min, minimum; Max, maximum.]

Scenario	Model	Annual			Winter		Spring		Summer		Fall	
		RCP	ANP	AMT	WIP	FTR	SPP	GSS	SUP	TX90p	FAP	FMT
Dry	MIROC5	4.5	-44.48	3.50	1.63	9.04	5.89	-23.14	-45.42	48.91	-7.15	3.01
	HadGEM2-AO	4.5	-42.82	4.19	8.50	12.34	16.92	-27.07	-78.54	63.46	-2.64	4.11
	bcc-csm1-1-m	4.5	-25.26	2.16	-5.00	8.23	12.71	-7.85	-42.10	37.27	13.23	1.98
	IPSL-CM5A-MR	8.5	-68.82	3.84	-4.66	6.64	0.23	-10.75	-69.88	55.19	17.68	4.20
	HadGEM2-ES	8.5	-49.49	4.77	13.14	17.53	24.41	-18.94	-111.83	65.00	8.65	4.87
	ACCESS1-0	8.5	-44.00	4.40	10.05	10.07	35.42	-14.86	-92.02	69.37	-10.64	4.23
		Mean	-45.81	3.81	3.94	10.64	15.93	-17.10	-73.30	56.53	3.19	3.73
		Min	-68.82	2.16	-5.00	6.64	0.23	-27.07	-111.83	37.27	-10.64	1.98
		Max	-25.26	4.77	13.14	17.53	35.42	-7.85	-42.10	69.37	17.68	4.87
Wet	GFDL-ESM2M	4.5	91.18	1.42	3.60	5.63	31.38	-10.04	11.23	11.46	39.04	1.73
	CNRM-CM5	4.5	108.67	2.03	3.61	3.37	27.16	-16.52	17.33	21.69	50.08	1.99
	GISS-E2-H	4.5	143.74	3.51	5.35	17.84	74.39	-11.12	-2.90	38.85	40.16	3.57
	CESM1-CAM5	8.5	117.75	3.49	12.23	13.26	44.00	-6.86	28.64	47.87	14.69	3.52
	CMCC-CM	8.5	125.17	2.92	11.06	6.15	38.80	-10.60	48.34	34.20	10.83	3.04
	GFDL-CM3	8.5	158.06	3.40	7.10	5.08	74.24	-8.45	33.08	57.05	30.72	3.58
		Mean	124.09	2.80	7.16	8.55	48.33	-10.60	22.62	35.19	30.92	2.90
		Min	91.18	1.42	3.60	3.37	27.16	-16.52	-2.90	11.46	10.83	1.73
		Max	158.06	3.51	12.23	17.84	74.39	-6.86	48.34	57.05	50.08	3.58

Table 5. Summary of changes in indicators for the wet and dry scenarios. Triangles depict the approximate change from the baseline (1961–1990) to the future period (2036–2065) after averaging among the four stations (Big Stone, Horicon, Loess Bluffs, and Port Louisa National Wildlife Refuges). Tildes indicate little difference between baseline and future periods. Triangles facing up indicate an increase and trigangles facing down indicate a decrease. Larger triangles indicate a greater change.

[mm, millimeters; ºC, degrees Celsius]

	Season	Winter	Spring	Summer	Fall
Variables	Precipitation	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)
	Temperature	Freezing Temperature Reversals	Growing Season Start (number of days earlier)	Number of Hot Days (number of days)	Fall Mean Temperature (°C)
Dry	Precipitation	~	▲	▼ (large)	~
	Temperature	▲	▲ (large)	▲ (large)	▲ (large)
Wet	Precipitation	~	▲ (large)	▲	▲ (large)
	Temperature	▲	▲	▲	▲

two possible futures to plan for, participants got an appreciation for the range in climate change projections but felt it was still challenging to make decisions if they did not know what the ultimate outcome would be. Future efforts could focus on identifying ways to assist managers in making difficult decisions where the outcomes of climate change are uncertain.

Participants noted that they felt that including multiple field stations from across the region was helpful because each field station has unique challenges and methods for dealing with them and those multiple perspectives could enhance the suite of adaptation strategies. Finally, participants discussed potential avenues to adopt adaptation thinking processes more widely, such as integrating the process into internal management planning processes at the region and station level. Although we focused on regional adaptation strategies during the workshop, application of a similar process at individual field stations would be essential to identify and implement adaptation plans that incorporate site-specific vulnerabilities, objectives, and alternatives. The process outlined here, with the integration of the interactive vulnerability assessment, can aid in those efforts.

Table 6. Impacts and adaptation for wet and dry scenarios. Participants focused on the identification of impacts and adaptations for five management goals: implementing drawdowns, implementing flood-ups, maintaining target water levels, maintaining infrastructure, and maintaining long-term habitat.

Management actions	Wet scenario		Dry scenario	
	Impacts	Adaptation	Impacts	Adaptation
Drawdown	The combination of longer growing season and delayed drawdown (late summer) may be beneficial; extra evapotranspiration from hot days may facilitate drawdown; an increase in summer precipitation could affect success of drawdown; inability to drawdown in some years could affect ability to manage units effectively; warmer temperatures may favor cattails rather than annuals	Planning ahead to consider drawdown for following year; increase capacity of water control infrastructure to drain wetland units; isolating units more from sources of unwanted flooding, or, conversely, increasing connectivity to allow flood waters to more rapidly drain; may have to develop other strategies/infrastructure for drawdowns or not expect drawdowns on an annual basis for certain areas	Enhanced capacity to have drawdowns; danger of dry conditions for too long; dry conditions could be more favorable for disease outbreaks (for example, botulism); passive drawdowns could contribute to flourishing invasive plants; hesitation to drawdown; longer drawdowns; ecological implications for declining muskrat populations as result of large-scale drawdowns on entire wetland complex	Retain some water for longer periods (not complete drawdown to maintain moist-soil plants); utilize alternative water sources if conditions get too dry (for example, gravity flow, tractor pumps); utilizing outside information to understand drought conditions and react accordingly (for example, U.S. Drought Monitor); if water shortage was an issue–may consider reducing flooded areas; better utilization of climate/weather projection models annually to inform annual water management plans, being proactive for anticipated conditions.
Flood-up	Potentially beneficial to maintain higher water levels (for example, flood-out/stress cattail); wetter falls could provide source for fall flood-up	Minimizing water storage in late summer in areas without perennial sources; delay reflooding in some units in the fall to take advantage of extended growing season	Could have little access to water; meeting timing of flood-up could be challenged; cattail germination if unable to flood-up; source water supply may be strained; could take more water to flood-up because of dry soil versus normally saturated soil	Flood earlier if possible; install wells; river restoration as water source; portable pumps; water storage; increase water monitoring efforts to (1) assess availability of water and (2) document historical water usage if any legal disputes arise

Table 6. Impacts and adaptation for wet and dry scenarios. Participants focused on the identification of impacts and adaptations for five management goals: implementing drawdowns, implementing flood-ups, maintaining target water levels, maintaining infrastructure, and maintaining long-term habitat.—Continued

Management actions	Wet scenario		Dry scenario	
	Impacts	Adaptation	Impacts	Adaptation
Maintain target water levels	Heavy precipitation/flashy flows are difficult to maintain/meet water level objectives; consistently wet conditions reduce ability to fluctuate water levels; flooding nesting of marsh birds; at the whim of other dams managed by other entities (up or downstream); easier to fill impoundments that are at higher elevations; reduced habitat for shorebirds requiring mudflats; sudden rise in water levels in spring drown out muskrat litters	Drainage basin best management practices/partnerships; enhance partnerships with others managing water up and downstream; better communication tools; changing water control structures to more rapidly pass floodwater or using infrastructure to isolate units from unwanted flooding; this is already a challenge that affects staff time and infrastructure capacity–may have to change infrastructure and (or) water level targets for certain areas/seasons; creation of additional "sacrificial" flood reservoir, intended to be flashier and less suitable for wildlife, to give refuge more control of water levels and prevent flooding of nests, etc. in main impoundments; adapt and account for shifting bird migration patterns/behavior changes; alter drawdown/flood times; installing and monitoring real-time flow gages in system; water budget modeling	More evapotranspiration; difficult to maintain diversity of wetland types; difficult to manage wetland succession; pump intakes may not be able to access water sources; altered spring hydrograph because of frequent winter snowmelt and earlier growing season start; hesitation in implementing partial drawdowns	Slowly adjust management as conditions change; timing/scheduling changes because of longer growing season; additional intakes; keep more water in the system/planning ahead (bathymetric data/modeling to compute overall water storage capacity and distribution of water); more detailed water management plan/development of water budget; connect impoundments to larger water systems and manage passively; plan accordingly for shifts in bird migration patterns
Infrastructure	Silting in of infrastructure (for example ditches, water control structures, weir structures); infrastructure no longer effective; lose capacity to use infrastructure if one structure is not effective; lack of access (roads washing out/becoming damaged); if we can't move water effectively, infrastructure becomes compromised (for example levee breaches, road damage); more frequent/higher cost of maintaining infrastructure (for example, dredging, levee repairs, road repair); water control structures have shorter lifespan because of increased/frequent high magnitude flows/events; flooding uproots large cattail mats that can interfere with infrastructure	Replace/update to fit modern/future conditions; substantial changes to water routing; pulling infrastructure out that is ineffective/inaccessible; more passive approach; levee repairs; dredge/sediment management; avoid bandaid approaches (for example, repairing a levee that will likely fail in the future); increase connectivity to allow flood flows to enter and exit with minimal resistance (for example, building spillways into levees that are prone to overtopping or providing greater outflow capacity for flood prone areas); only 'manage' water that is necessary for habitat management; longer closure of roads when water is high or road flooded to help reduce pressure on weakened roads (for example, change public driving routes to hiking paths)	Pump intakes may not be able to access water; cost of pumping; stress from running pumps for long durations; water may be below intakes of nonpump (gravity flow structures); less road and dike damage; less water could reduce stress on water control structures (decrease maintenance/repair costs) and other infrastructure (roads); better accessibility to allow for infrastructure maintenance	Moving intakes of pumps or other structures to lower elevation; connect impoundments to larger water systems and manage passively

Table 6. Impacts and adaptation for wet and dry scenarios. Participants focused on the identification of impacts and adaptations for five management goals: implementing drawdowns, implementing flood-ups, maintaining target water levels, maintaining infrastructure, and maintaining long-term habitat.—Continued

Management actions	Wet scenario		Dry scenario	
	Impacts	Adaptation	Impacts	Adaptation
Long-term habitat maintenance	Limit prescribed burn conditions; little ability for manual disturbance in wetlands such as disking or spraying; flood conditions could flood out invasive trees; increased flooding increases risk of transport of invasive species (for example, carp, cattail, or other submerged aquatic plants); more potential for erosion with increased flooding, nutrient contamination, contaminants entering system; increased algal blooms; legacy sedimentation have potential to alter vegetation composition and ecosystem processes	Shift seasonality of burning (for example, less snow cover in the winter could provide opportunities); consider ability to manage invasive species in highly dynamic floodplain areas–may have to separate from areas that can be effectively managed; targeted invasive species management where most effective, consider alternative water management strategies and (or) water control structures, hydrologic modifications (removing installing ditch plugs/diversions/dredging) to reduce effects of sedimentation	Provides suitable conditions to allow for ditch cleanout, disturbance activities (for example, cattail mowing), infrastructure maintenance (for example, improve dikes, replace water control structures); increase frequency/duration of burn bans; could lengthen fall burning window and efficacy; sedimentation may exacerbate long-term drought, facilitating cattail expansion or woody encroachment; more suitable habitat for invasive species like *Phragmites australis* (Phragmites), *Phalaris arundinacea* (reed canary grass), and *Butomus umbellatus* (flowering rush); increased risk of wildfire (peat fires); allow for increased mechanical management options to control invasive cattail (mowing, grazing, harvesting); drier conditions could create favorable conditions for plants to root and increase plant diversity	Convert shallow emergent marsh to wet prairie habitat, wet prairie to wet-mesic prairie, etc.; use frequent mechanical disturbance as replacement for fire and flooding; invest heavily in biocontrol options for invasive plants; shifting fall burns later in the year; sediment budget combined with elevation would allow for better understanding of wetland dynamics to help anticipate changes; allow succession to occur (shrub, forested wetlands); reevaluate refuge purpose, adapt and identify priority resources of concern accordingly; mechanical biomass harvesting for biofuel (for example, cattail)

Summary

We developed a process to engage U.S. Fish and Wildlife Service resource managers in climate change adaption thinking that was designed to overcome barriers that were identified by managers working at local and regional scales. Participants of the workshop developed a conceptual model, a vulnerability assessment, and climate change scenarios and evaluated impacts and identified adaptation strategies for managed wetlands in the Midwest. These products from the workshop could help managers develop adaptation plans for local wetland management in preparation for future climate change. The process we used was built upon several published methodologies and could be adapted to other systems.

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Appendix 1. Workshop Agenda

Adaptation Thinking for Managed Wetlands Workshop Agenda

Virtual

Overall Objectives:

(1) Create a conceptual model for managed wetlands.

(2) Create climate change vulnerability assessment.

(3) Identify potential future scenario storylines.

(4) Identify impacts and adaptation strategies for each scenario.

(5) Evaluate process and consider potential to integrate into formal planning processes.

Pre-workshop – Introduction Video (~30 minutes, Scheduled for October 26, 2020, recording and release)

- Objectives:
  - Introduce project and the workshop schedule/objectives/outcomes
  - Provide background for climate change and vulnerability assessment
  - Provide explanation and justification for each indicator
  - Introduce vulnerability assessment tool
  - Introduce draft conceptual model of managed wetland systems
  - Review homework assignment
- Outcomes:
  - Participants will have a better understanding of the scope of the project and objectives for the workshop
- Homework (~0.5 hour):
  - Review draft conceptual model and provide suggested revisions

Day 1 – Refine Conceptual Model – November 5, 2020 (11:00am – 1:30pm central time)

- Materials:
  - A draft version of conceptual model, revised following homework assignment
- Objectives:
  - Review results from virtual discussions with three stations about adaptation efforts
  - Facilitate discussion regarding recent weather and hydrologic impacts
  - Refine conceptual model of managed wetland systems
- Outcomes:
  - An agreed upon conceptual model that incorporates weather and hydrologic effects
- Homework (~30 minutes):
  - Final review of conceptual model for managed wetland systems
  - Review local climate summary reports for field stations

Day 2 – Vulnerability and Scenarios – November 10, 2020 (8:00am – 11:00am central time)

- Materials:
  - Climate projections for each field station attending, with focus on change in temperature, precipitations, at annual and seasonal scales to aid in selecting scenarios
- Objectives:
  - Discuss climate change impacts on conceptual model based upon indicators from the vulnerability assessment
  - Apply weight to each indicator and create custom vulnerability assessment map for managed wetlands
  - Identify potential scenarios based upon a summary of climate change impacts for the region

- Outcomes:
  - Participants will have a better understanding of recent and future climate impacts
  - A custom vulnerability map for managed wetland systems
  - Identification of scenarios that will be used to develop potential adaptation strategies among/across scenarios
- Homework (~1 hour):
  - Review adaptation materials in preparation for Day 3

Day 3 – Adaptation Thinking – November 13, 2020 (9:00am – 12:00pm central time)

- Materials:
  - Review examples of adaptation approaches in other systems
  - Each refuge provides an overview of recent impacts and adaptation efforts
- Objective:
  - Collectively develop a list of impacts of future scenarios on five specific management goals
  - Collectively identify potential adaptation strategies for each scenario
- Outcomes:
  - A list of impacts and adaptation for each of the five management goals
- Homework (~30 minutes):
  - Review updated scenario impacts and adaptation tables

Day 4 – Review and Next Steps – November 24, 2020 (8:00am – 10:00am central time)

- Materials:
  - Presentation summarizing workshop findings
- Objectives:
  - Fill in any missing components on the table of scenario impacts and adaptations
  - Discuss and reflect on the adaptation thinking process
  - Identify additional information needs
  - Identify other resources that may be helpful in working through a similar process
  - Identify how climate science and adaptation could be integrated into formal planning efforts
- Outcomes:
  - A complete table that summarizes resources of interest, scenarios, and adaptation opportunities for managed wetlands
  - An example adaptation thinking process that can be adapted to other habitat types

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