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Climate Adaptation Strategies and Approaches
for Conservation and Management of Non-Forested Wetlands

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Climate Adaptation Strategies and Approaches for Conservation and Management of Non-Forested Wetlands

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Summary

In a collaborative effort to advance climate adaptation resources available to wetland practitioners, the Wisconsin Initiative on Climate Change Impacts (WICCI) and the Northern Institute of Applied Climate Science (NIACS) have partnered to create adaptation resources for non-forested wetland management. This effort is also supported by the USDA Northern Forests Climate Hub. This publication provides perspectives, information, resources, and tools to wetland managers and natural resource professionals in the Midwest and Northeast regions of the United States as they endeavor to adapt natural communities and ecosystems to the anticipated effects of climate change.

In this publication, we identify potential strategies and approaches that facilitate climate adaptation while meeting wetland conservation or restoration management goals and objectives. Adaptation strategies and approaches are intended to build upon current management actions that work to sustain ecosystems over the long term and support site goals while also adjusting systems to changing conditions. While it is beyond the scope of this publication to comprehensively address all potential adaptation tactics applicable to the conservation of wetlands, we provide examples to guide thinking, recognizing that individual wetland management projects have unique goals. Wetland professionals, reliant on their expertise and judgement, can use the adaptation strategies and approaches presented in this document to develop custom adaptation tactics based on the local conditions.

We encourage readers to integrate these strategies into the "Adaptation Workbook" (Swanston et al. 2016) decision-support framework found online at www.adaptationworkbook.org, and "Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition" (www.nrs.fs.fed.us/pubs/52760). Strategies and approaches included in this publication are meant to be used within an adaptive management framework to consider not only potential adaptation actions for a site but to deliberately consider climate change in short- and long-term management. The resources described in this publication are tools, not mandates on how, when or what tactics to implement, and serve to support resource managers to develop adaptation actions customized to their own situation. Taken together, these resources do not replace other forms of management planning and decision-making in accordance with wetland protection and permitting laws.

Non-forested wetland: A wetland dominated by herbaceous and shrub species, with less than 25% cover of trees. Note: Some wetland types, such as muskegs, represent transitions between open and forested wetland communities. While many aspects of this menu will apply to these transitional wetlands, managers may also find it useful to pair this non-forested wetland menu with the menus for forests and forested watersheds (Swanston et al. 2016, Shannon et al. 2019).

Adaptation: Adjustments in human and natural systems, in response to actual or expected climate stimuli or their effects, that moderate harm or exploit beneficial opportunities (IPCC 2001). Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

About the adaptation strategies and approaches

One of the major challenges of adapting ecosystems to climate change is translating broad concepts into specific, tangible actions. This menu of adaptation strategies and approaches provides options for adaptation actions to support integrating climate change considerations into management and conservation activities. The strategies and approaches are derived from a wide range of contemporary reports and peer-reviewed publications on climate change adaptation or resource management and serve as intermediate "stepping stones" for translating broad concepts into targeted and prescriptive tactics for implementing adaptation. These are intended to be used with the Adaptation Workbook (see above), which provides a structured, adaptive approach for integrating climate change considerations into planning, decision-making, and implementation.

Non-Forested Wetland Conservation and Management: Climate Adaptation Strategies and Approaches is designed as a flexible approach (rather than specific guidelines or recommendations) to accommodate diverse management goals, geographic settings, local site conditions, and other management considerations. For these reasons, this set of adaptation strategies and approaches serves as a menu of potential adaptation actions. It helps wetland managers identify their adaptation intention and supports them in developing and implementing their own specific adaptation actions. Although menu items can be applied in various combinations to achieve desired outcomes, not all items on the menu will work together. Furthermore, actions that work well in one wetland type may not work in another; it is up to the land manager to select appropriate actions for a specific project and specific goals. Importantly, the adaptation strategies and approaches presented are intended to build upon current management actions that work to sustain and conserve wetlands over the long term. A changing climate may compel some managers to adopt new practices, but it is equally important to review existing management practices through the filter of climate change adaptation to ensure that they remain suitable for meeting management goals and objectives into the future.

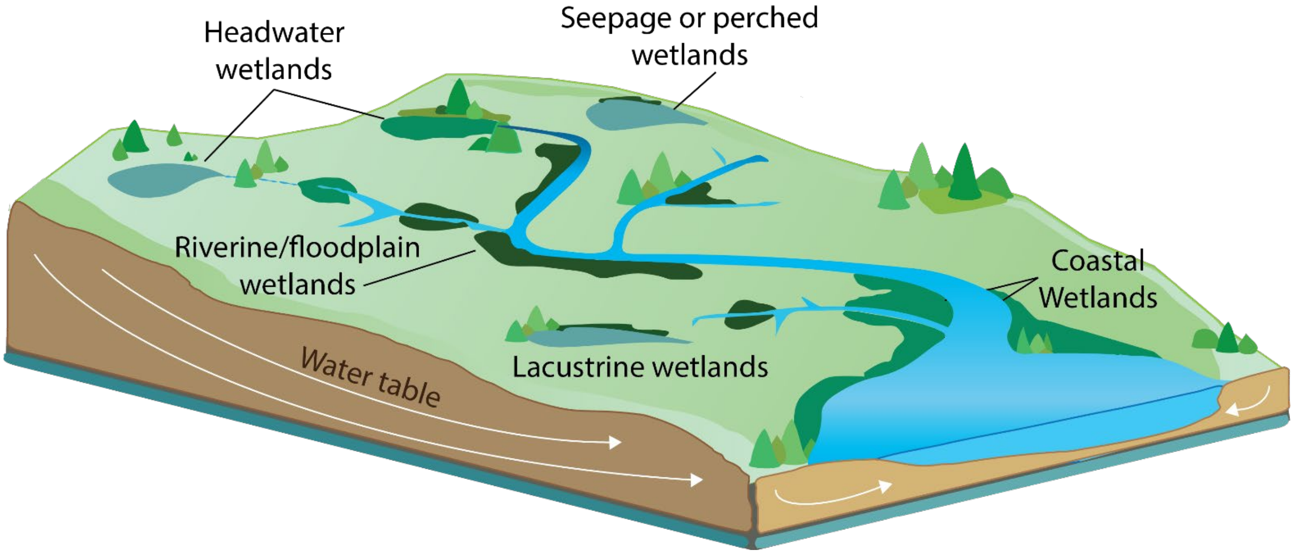

Figure 1. Non-forested wetlands are found throughout the watershed from the headwaters to coastal wetlands.

When used in tandem with the Adaptation Workbook, this adaptation menu helps people link their actions to broader adaptation strategies that align with their values and objectives, generally define success, and explicitly identify intent (Swanston et al. 2016, Shannon et al. 2019). This menu of adaptation strategies, approaches and example tactics is intended to complement existing menus published by NIACS on other themes: Forests (Swanston and Janowiak 2012, Swanston et al. 2016), agriculture (Janowiak et al. 2016), forested watersheds (Shannon et al. 2019), forest carbon management (Ontl et al. in review), culturally relevant tribal perspectives (Tribal Adaptation Menu Team 2019), and others related to recreation, wildlife management and coastal ecosystem management (www.forestadaptation.org). Each menu addresses a different resource area, using relevant and appropriate terms, strategies, approaches, and example tactics.

Adaptation concepts: Resistance, Resilience, Transition

Adaptation strategies and approaches are part of a continuum of adaptation actions ranging from broad, conceptual application to practical implementation. This continuum builds upon the adaptation framework described by Millar and colleagues (2007). The concepts of resistance, resilience, and transition serve as the fundamental options for managers to consider when responding to climate change (*excerpt from Swanston et al. 2016*):

> Resistance actions improve the defenses of an ecosystem against anticipated changes or directly defend the ecosystem against disturbance in order to maintain relatively unchanged conditions. Although this option may be effective in the short term (mid-century or sooner), it is likely that supporting persistence of the existing ecosystem will require greater resources and effort over the long term as the climate shifts further from historical norms. This option may also be most effective in ecosystems with low vulnerability to climate change impacts. As an ecosystem persists into an unfavorable climate, the risk of the ecosystem undergoing irreversible change (such as through a severe disturbance) increases over time.
>
> Resilience actions enhance the ability of the system to bounce back from disturbance and tolerate changing environmental conditions, albeit with sometimes fluctuating populations (Holling 1973). Such actions may be most effective in systems that can already tolerate a wide range of environmental conditions and disturbance. Like the resistance option, this option may be most effective in the short term and may be subject to increasing risk over time. Resilience is effective until the degree of change exceeds the ability of a system to cope, resulting in transition to another state.
>
> Transition actions intentionally anticipate and accommodate change to help ecosystems adapt to changing and new conditions. Whereas resistance and resilience actions foster persistence of the current ecosystem, transition actions intentionally facilitate the transformation of the current ecosystem into a different ecosystem with clearly different characteristics. These actions may be considered appropriate in ecosystems assessed as highly vulnerable across a range of plausible future climates, such that the risk associated with resistance and resilience actions is judged to be too great. Transition actions are typically designed for long-term effectiveness. They are often phased into broader management plans that predominantly have a shorter-term focus on resilience actions.

These options of resistance, resilience, and transition serve as the broadest level in a continuum of adaptation responses to climate change (Janowiak et al. 2011, Swanston and Janowiak 2012, Swanston et al. 2016). Along this continuum, actions for adaptation become increasingly specific. Adaptation strategies are abundant in recent literature and illustrate ways that adaptation options could be employed (Figure 2). Strategies are however, still very broad and can be applied in many ways across a number of landscapes and ecosystems. The six adaptation strategies for non-forested wetland management are generally arranged to start with ideas that focus on the "resistance" adaptation option, progressing to ideas that focus more on "transition," although this arrangement does not indicate preference or priority.

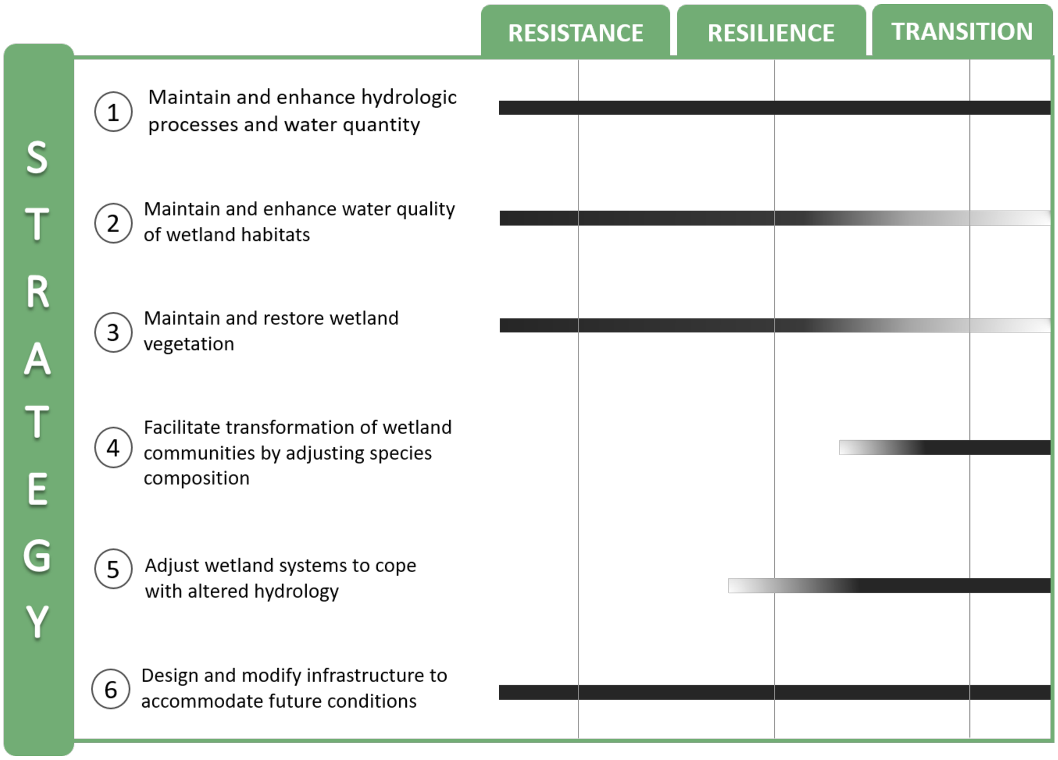

Figure 1. Climate change adaptation strategies work to achieve three broad adaptation options: resistance, resilience, and transition. Strategies may be used to achieve one or more options. A solid line indicates a strong relationship between an option and a strategy, whereas fading indicates that the strategy relates to that option under some circumstances. Although a strategy may work under multiple options, the implementation is likely to be achieved through very different approaches and tactics.

Using the Menu of Adaptation Strategies and Approaches

The menu of adaptation strategies and approaches can provide:

- A broad spectrum of possible adaptation actions that can help sustain healthy ecosystems and achieve management goals in the face of climate change
- A framework of adaptation actions from which managers select actions best suited to their specific management goals and objectives
- A platform for discussing climate change-related topics and adaptation methods
- Examples of tactics that could potentially be used to implement an approach, recognizing that specific tactics will be designed by the land manager.

The menu of adaptation strategies and approaches does not:

- Make recommendations or set guidelines for management decisions. It is up to the manager to decide how this information is used.
- Express preference for any strategies or approaches within an ecosystem type, location, or situation. Location-specific factors and manager expertise are needed to inform the selection of any strategy or approach.
- Provide an exhaustive set of tactics. We encourage managers to consider additional actionable tactics appropriate for their projects. Further, some tactics have not been vetted through research and so should be employed with caution and followed-up with monitoring and adaptive management.

Strategy is defined as a broad adaptation response that is applicable across a variety of resources and sites, hydrologic and ecological conditions, and overarching management goals.

Approach is defined as a more detailed adaptation response specific to a resource issue, site condition, and management objectives. Adaptation approaches describe in greater detail how strategies could be employed.

Tactics are defined as prescriptive actions designed for specific site conditions and management objectives. Tactics are the most specific adaptation response, providing prescriptive direction about what actions can be applied on the ground, and how, where, and when. Tactics can be developed specific to a species, the ecosystem type, site conditions, management objectives, and other factors. We have provided examples of tactics for each approach, but do not intend that they be implemented without due consideration of all relevant factors, including wetland protection and permitting laws. The Adaptation Workbook also provides a method to explicitly consider the benefits and drawbacks of potential adaptation tactics. Additional 'bonus' tactics are also found in the Appendix.

How to read this menu

Strategy: A strategy is a broad adaptation response that is applicable across a variety of resources and sites

Approach: An approach is an adaptation response that is more specific to a resource issue or geography

Tactic: Tactics are the most specific adaptation response, providing prescriptive direction about what actions can be applied on the ground, and how, where, and when.

Menu of strategies and approaches

Strategy 1: Maintain and enhance hydrologic processes and water quantity.

Approach 1.1: Maintain and facilitate infiltration and water storage within wetlands, adjacent uplands, and groundwater recharge areas.

Approach 1.2: Maintain and restore a natural hydrologic regime.

Approach 1.3: Restore stream channel processes and restore hydrologic function of waterways connected to wetlands.

Strategy 2: Maintain and enhance water quality of wetland habitats.

Approach 2.1: Moderate surface water temperature increases.

Approach 2.2: Reduce soil erosion and sediment deposition.

Approach 2.3: Reduce loading and export of nutrients and other pollutants.

Strategy 3: Maintain and restore wetland vegetation.

Approach 3.1: Maintain and restore wetland structure.

Approach 3.2: *Maintain and enhance diversity of plant species and their life histories, ecological niches, morphologies, and phenologies.*

Approach 3.3: Promote prescribed fire in fire-adapted wetlands.

Approach 3.4: Prevent invasive species establishment and limit their impacts where they already occur.

Strategy 4: Facilitate transformation of wetland communities by adjusting species composition.

Approach 4.1: Favor and restore native species and genotypes that are expected to be adapted to future conditions.

Approach 4.2: Increase genetic diversity of seed mixes within appropriate seed transfer zones.

Approach 4.3: Move at-risk species to locations that are expected to provide more suitable habitat.

Approach 4.4: Adjust wetland and composition to meet functional values.

Strategy 5: Adjust wetland systems to cope with altered hydrology.

Approach 5.1: Manage systems to cope with decreased water levels and limited water availability.

Approach 5.2: Manage systems to cope with increased water abundance and higher water levels.

Approach 5.3: Design and manage enhanced and created wetlands to accommodate changes in hydrologic variability.

Strategy 6: Design and modify infrastructure to accommodate future conditions.

Approach 6.1: Reinforce infrastructure to meet expected conditions.

Approach 6.2: Reroute or relocate infrastructure, or use temporary structures.

Approach 6.3: Incorporate natural or low impact development into designs.

Approach 6.4: Remove infrastructure and readjust system.

The Adaptation Workbook is a structured process designed to be used in conjunction with vulnerability assessments and adaptation strategies and approaches to generate site-specific adaptation actions that meet explicit management and conservation objectives under a range of potential future climates. This document is intended to be used with the Adaptation Workbook found in, Forest Adaptation Resources: Climate Change Tools and Approaches for land managers, 2nd edition (www.nrs.fs.fed.us/pubs/52760, Swanston et al. 2016) and the corresponding online interactive tool (adaptationworkbook.org).

Strategy 1: Maintain and enhance hydrologic processes and water quantity.

This strategy outlines resistance and resilience approaches to manage wetlands facing altered water budgets (water inputs, storage capacity, and outputs) due to a changing climate. Hydrology is a leading driver of wetland character and function (Cowardin et al. 1979, Brinson 1993, Tiner 2011) and so expected changes to hydrologic regimes, hydrodynamics, and water levels concern wetland managers (Erwin 2009). Projections in the Upper Midwest indicate that wetlands will be influenced both by extreme precipitation and flooding events and longer drought periods between rain events (USGCRP 2017). Some wetlands will become dryer and others may become wetter than long-term averages. Thus, managers face challenges (i.e., extreme flooding; drought) and opportunities (i.e., restored flood pulses to wetlands disconnected from surface or groundwater flows) in managing wetlands in the context of climate change (Mallakpour and Villarini 2015). Restoring hydrologic connectivity has historically been a primary tactic of management efforts to restore wetlands lost or degraded by filling or draining due to land-use conversion and water extraction (Zedler 2000), and many of those same tactics can be applied or amended by wetland managers to meet climate change adaptation objectives (Middleton et al. 2017). Restoring hydrologic connectivity and ameliorating saturated, anoxic conditions that limit decomposition also supports the capacity of wetlands to actively remove and sequester atmospheric carbon and mitigates future carbon losses (Moomaw et al. 2018).

Approach 1.1: Maintain and facilitate infiltration and water storage within wetlands, adjacent uplands, and groundwater recharge areas.

This approach aims to alleviate drought stress in wetlands prone to increased drying. To meet the goals of this approach, managers should consider tactics they can apply at different scales, including the wetland-scale, adjacent uplands and buffers (Correll 2005), and areas on the landscape physically conducive to groundwater recharge (Sampath et al. 2015, Marchildon et al. 2016). Non-floodplain ("geographically isolated") wetlands are especially effective at meeting water infiltration and storage functions. Tactics here address slowing the rate of flow to and from wetlands (Fritz et al. 2018). By improving the water-holding capacity of wetlands, this approach also contributes to watershed-scale flood management by mitigating the impacts of downstream flooding due to extreme precipitation and runoff (Hey and Philippi 1995).

Examples of adaptation tactics are:

1. Maintain or create buffers within at least the first 100 meters (328 feet) surrounding a wetland (Faber-Langendoen et al. 2016).
2. Implement proper road and construction maintenance and best management practices for forestry activities to control erosion.

3. In developed areas, install and maintain bioswales, rain gardens, large cisterns, and rain barrels (for slow release to adjacent wetlands) alongside impervious surfaces (e.g., paved roads, parking lots), and install pervious pavers instead of continuous pavement (Jefferson et al. 2017).
4. In agricultural areas, incorporate deep-rooted perennials and native perennials or cover crops into fields to reduce runoff rates and improve infiltration (Union of Concerned Scientists 2017). Grassy waterways/swales, contour/strip cropping, and no-till cropping, can also slow-the-flow, increasing infiltration rates (Lucke et al. 2014, Janowiak et al. 2016).
5. Limit water extraction from confined aquifers to maintain groundwater supply and connectivity to non-floodplain wetlands. Minimize disturbance to these small wetlands to improve water storage and groundwater recharge at watershed scales (Sampath et al. 2015, Lane et al. 2018).

Approach 1.2: Maintain and restore a natural hydrologic regime.

This approach targets wetlands that will be impacted by changes in hydrologic regimes due to altered precipitation patterns and extreme precipitation and drought events. Hydrologic regimes within wetlands reflect the frequency, magnitude, and duration of high and low flow events. These fluxes in hydrology are influenced by water inputs, the storage capacity, and output components of the wetland's water balance (Mitsch and Gosselink 2015). Where hydrologic connectivity of wetlands to adjacent streams is diminished due to water control structures or diversions, more frequent prolonged droughts may further degrade wetland function and quality (Souter et al. 2014, Perry et al. 2015). Mismatches between extreme flood timing, phenology, and other biologic processes may also occur and are a concern to managers (Royan et al. 2013, Lynch et al. 2016). Restoring hydrologic connectivity and water storage in wetlands can help mitigate the impacts of altered water budgets and extreme flooding throughout the watershed (Hey and Philippi 1995, Alexander et al. 2018). While land use management alone cannot fully mitigate changes to water balances at broader spatial scales due to the more significant forces of climate change, local-scale land use management that focuses on runoff reduction, improved infiltration rates, and base flow management may reduce the impacts of climate-induced drought (Zipper et al. 2018).

Examples of adaptation tactics are:

1. Use ditch plugs, fill ditches, or disable drain tile to increase residence time of water in disturbed wetlands (NRCS 2008, 2011).
2. Where roads cross wetlands and streams, install adequately-sized drainage structures and stream crossings based on the upper-range of anticipated future conditions (Januchowski-Hartley et al. 2013). For examples, see Appendix.
3. Remove or modify restrictions that inhibit longitudinal flow between upstream and downstream habitats, in order to enhance aquatic organism migration to more favorable habitats (e.g. upstream, seasonal habitats, off-channel or cool-water areas).
4. Use appropriate restoration techniques for the site, choosing from a spectrum of options that range from process-based (using natural hydraulics; these are preferred methods) to form-based (using hardened infrastructure) options (Yochum 2017), to reconnect floodplains adjacent to incised river channels.
5. Maintain beaver dams in headwater wetlands and avoid straightening stream channels to maintain a high water table in floodplain wetlands, reduce stream incision rates and encourage stream channel aggradation (Beechie et al. 2010).

6. Remove or modify dams and weirs where possible or manage water flow to mimic a more natural flow regime (i.e., frequency, magnitude, duration and timing of flood pulses) at both high flows and low flows (Yochum 2017).
7. Remove legacy sediment to restore hydrologic processes to aggraded floodplains and depression wetlands (Booth et al. 2009).
8. Amend or remove compacted soils to restore resident time and hydrologic processes in disturbed wetlands (Sax et al. 2017).

Approach 1.3: Restore stream channel processes and restore hydrologic function of waterways connected to wetlands.

This approach targets actions focused on wetlands connected to, or adjacent to streams, rivers and other flowing surface waters. As hydrologic regimes change, driven by more extreme and variable precipitation, it is expected that the volume and rate of water entering wetlands will change (Prein et al. 2017, USGCRP 2017). In Midwestern and Great Lakes watersheds affected by snowmelt, peak flood events are projected to shift to a month earlier, extreme low flows will shift from winter/spring to summer/fall, and soil moisture is expected to be lower during the growing season through the middle of the 21st century (Byun et al. 2019). This alteration in hydrology within waterways can degrade the structure and function of connected wetland ecosystems. Wetland types particularly vulnerable to degradation include those receiving water from currently unstable or altered hydrologic networks, including channelized streams and ditches. Stream channel alteration often results from land-use changes and related changes in runoff (observed in agricultural and urban areas), but also when flows are regulated, for example, after the physical re-routing and straightening of channel form by humans. Channelized flow creates deeper and straighter stream channels that become incised and potentially destabilized and wider, increasing flow velocity and reducing overbank flooding to riparian wetlands (Shankman 1996). Restoring and improving lateral connections of riverine systems can prepare wetlands to absorb excess water associated with extreme precipitation events, reduce peak flows, and reduce downstream flooding, as well as improve stream baseflow during droughts (Wohl et al. 2015).

Examples of adaptation tactics are:

1. Re-meander channelized streams using natural channel design methods (Yochum 2017) to slow the velocity of flow, create more habitat heterogeneity, and improve connectivity to adjacent floodplain wetlands.
2. Re-sculpt functioning ditches to two-stage designs that mimic a floodplain to better handle large storm events by providing more consistent fluvial form and processes, as well as greater channel stability (Powell 2007 a,b; NRCS 2007).
3. Remove or modify levees, dams and other hardened infrastructure to restore a more natural hydrologic regime and to increase channel sinuosity and associated functions (Yochum 2017).
4. Add culverts or alternative low-water crossings to roadways that impede flow and replace undersized culverts with larger culverts to improve natural stream-flow and debris-flow dynamics during large flood events (Clarkin et al. 2006, USFS 2008, Olson et al. 2017).

Strategy 2: Maintain and enhance water quality of wetland habitats.

Approaches outlined by this strategy provide managers with adaptation options aimed to sustain or enhance the quality of wetland habitats susceptible to warming waters and reduced water quality. Warmer water increases the rate of algal growth, changes dissolved oxygen levels and water chemistry (Whitehead et al. 2009), increases decomposition rates (Brinson et al. 1981), and shifts species composition by altering abundance or cover of existing species and encouraging invasion of non-native species (Havel et al. 2015). Increased frequency of large storm events resulting in greater runoff may increase heavy nutrient loading (Whitehead et al. 2009). This adaptation strategy applies to managing the quality of all wetland types, but especially mesotrophic wetlands (e.g., poor coastal fens and inland fens) that are maintained by a delicate balance of hydrologic inputs (groundwater, surface water, and precipitation) and ombrotrophic peatlands (e.g., precipitation-dependent bogs). Wetland managers may already focus on protection of water quality in their management activities, as nutrient enrichment and sedimentation are among the leading causes of current wetland degradation (Junk et al. 2013). The likelihood of more extreme precipitation events further amplifies the risk of harmful chemical-laden runoff from adjacent land-uses, particularly in agricultural or urban areas. This strategy addresses the additional protection and focus necessary to ensure clean water inputs to wetland areas. Further, management of wetland processes, given changes in climate, has local and global implications, particularly for wetlands known to sequester large volumes of carbon in soils (e.g., peatlands). Reducing excess nutrient inputs that speed up decomposition rates in organic-rich wetlands (e.g., peatlands) can improve long-term sequestration of CO2 in wetland soils and mitigate future greenhouse gas emissions (Moomaw et al. 2018).

Approach 2.1: Moderate surface water temperature increases.

This approach outlines tactics that managers can apply to wetland ecosystems most susceptible to impacts from warming waters. Urban wetlands are particularly vulnerable to increased stream temperature (Kaushal et al. 2010). Warming in rural or remote wetlands may also be a concern, especially in bog and fen peatlands at northern latitudes. Cool substrates are a defining trait of these northern peatlands, therefore warming induces compositional shifts (Weltzin et al. 2000) and loss of stored carbon and other ecosystem functions (Moomaw et al. 2018).

Examples of adaptation tactics are:

1. Reconnect floodplains and wetlands to surface waterways to increase groundwater recharge and promote flow of cool groundwater in the system (Tague et al. 2008).
2. Maintain and restore groundwater-fed headwater wetlands to promote cooler, late summer flows to downstream wetlands (Erwin 2009).
3. Modify dams and impoundments from top-draw to bottom-draw structures to release cold water from lakes or reservoirs (Olden and Naiman 2010).

4. Where feasible, leave beaver dams in place in headwater wetlands. Beaver dams add habitat complexity and can increase the extent of wet meadow and groundwater recharge area over long time-spans, moderating warming impacts to downstream wetlands and fisheries habitat (Burchsted et al. 2010, Bouwes et al. 2016, Weber et al. 2017). However, where water temperature is a primary concern to high quality headwater wetlands near groundwater springs, cautiously remove beavers and dams to promote flow of cold groundwater through wetlands and seepage areas (McRae and Edwards 1994).
5. Reduce urban development and incorporate nature-based infrastructure and forested buffers near high quality, sensitive wetlands and riparian areas to limit the "urban heat island effect" and warm storm water runoff (Kaushal et al. 2010, Sutton-Grier et al. 2018).

Approach 2.2: Reduce soil erosion and sediment deposition.

Reducing the rate and magnitude of soil erosion and sedimentation is an important step in both resisting transformative changes and improving the resilience of wetlands and riparian areas to absorb frequent and severe disturbances and extreme rain events. Sedimentation increases nutrient availability in wetlands resulting in deleterious effects on ecosystem function and quality. In particular, reductions in the water holding capacity of wetland soils buried by sediment (Gleason and Euliss Jr 1998) alter the rate of nutrient cycling (Marton et al. 2015). Sediment build-up can also bury native seed banks (Jurik et al. 1994). Intensive land-use activities can significantly accelerate the rate and magnitude of erosion and sedimentation occurring on-site, resulting in Influxes of phosphorus from sediment deposition that can have negative effects (Reddy et al. 1999). As hydrologic regimes intensify, altering land-use zoning to protect wetlands, implementing best management practices (BMPs) in forestry and agricultural operations will be of utmost importance to sustaining soils and wetland ecosystems into the future (Cristan et al. 2016).

Examples of adaptation tactics are:

1. Where roads cross streams and wetlands, create vegetated ditches with waterbars and bioswales uphill of crossing to reduce runoff and sedimentation (Keller and Ketcheson 2015).
2. During forestry operations in sites adjacent to open wetlands, meet or exceed standards for forestry BMPs for water quality (WDNR 2010b). For examples, see Appendix.
3. If agricultural producers work near the wetlands that you manage, encourage them to work with their local NRCS Conservationist to develop a 'Cropland Conservation Management System' (NRCS Conservation Practices webpages) that holistically considers the effects of planting design, crop selection, discontinuous vegetative cover, tillage practices, nutrient management, pest management, and irrigation on the watershed. For examples, see Appendix.
4. In areas of erodible soils, employ proper road construction maintenance, erosion control measures, and increase forested acreage adjacent to open wetlands to "Slow the Flow" of runoff to limit the formation of gullies or ravines (Wisconsin Wetlands Association 2018).
5. Preserve and restore large-scale acreages of perennial vegetation adjacent to wetlands (Houlahan and Findlay 2004).
6. Employ and maintain approved methods for managing sediment transport in dam regulated systems to limit sedimentation impacts to riparian wetlands (Kondolf et al. 2014).

Approach 2.3: Reduce loading and export of nutrients and other pollutants.

This approach is aimed at reducing chemical impacts and degradation of wetlands due to increased extreme precipitation events and warming. Wetlands adjacent to agricultural and urban areas are most susceptible to nutrient inputs from fertilizer runoff, nutrient-rich sedimentation, and municipal-urban pollutants in storm water discharge. Increased drought events can decrease the area of saturated, anoxic substrates in wetlands, reducing denitrification rates and increasing nitrogen exports, especially in watersheds influenced by agricultural runoff and industrial processes (Hansen et al. 2018). Wetland community types vary with substrate fertility and differ in their capacities to accommodate chemical inputs without undergoing significant shifts in biological composition and structure (Larsen and Alp 2015). For example, wetland systems that formed in conditions of low nutrient availability (i.e., bogs, poor fens) are the most vulnerable to compositional shifts and changes in ecosystem function due to increased nutrient loading via runoff or increased decomposition rates due to warming (Keddy 2010). Hydrologic change that increases runoff and chemical loading to wetlands may exacerbate existing challenges associated with a legacy of land-use impacts (Motew et al. 2017). Nutrient deposition via sedimentation processes can also be addressed using Approach 2.2 tactics.

Examples of adaptation tactics are:

1. Remove legacy phosphorus from degraded streams and headwater lakes (Sharpley et al. 2013).
2. In agricultural areas with drain tiles, create small, precisely positioned "in-line" wetlands along ditches and small streams to intercept and naturally remove nitrogen from drain-tile flows before it enters a higher quality wetland or major stream (The Wetlands Initiative 2016, Hansen et al. 2018).
3. In agricultural areas upstream from wetlands, employ precision agriculture and cover crops to reduce unnecessary nitrogen application (Zedler 2003).
4. Limit algal growth impacts by harvesting algae from surface waters, physically flush and mix waters, apply chemical treatments, apply materials that promote immobilization of phosphorus, or where water control structures exist manage water levels to promote aquatic macrophytes rather than algal growth (Paerl et al. 2016).
5. Design wetland creations and enhancements to increase the area and duration of soil saturation to improve denitrification rates (Zedler 2003).
6. Install sediment basins to capture nutrients before they enter wetlands and waterways.
7. Apply a nutrient management plan that includes limiting manure spreading on frozen surfaces, steep slopes, near streams, or in areas of fractured bedrock/karst and employ manure biodigesters (NRCS "Nutrient and Manure Management" webpages).
8. In phosphorus-rich fields that were previously farmed, eliminate tillage and manure application and transition fields to forage and harvest hay twice a year to reduce soil phosphorus over time (Hille et al. 2018).

Strategy 3: Maintain and restore wetland vegetation.

This strategy addresses the strong influence of plant community structure and composition on wetland ecological integrity and function, and outlines approaches that managers can take to resist climate change influences and build resilience into the sites that they manage through purposeful vegetation management. Wetland plant communities have evolved over millennia as dynamic systems that respond to a range of natural disturbance regimes (van der Valk 1981). Changes in precipitation and temperature regimes may push these plant communities outside of their natural range of variability, resulting in changes in plant community structure and composition (Johnson et al. 2005). For example, changing precipitation patterns and evapotranspiration rates are anticipated to decrease water levels in some wetlands, favoring woody species growth (Weltzin et al. 2003, Wisconsin Initiative on Climate Change Impacts [WICCI] 2010). In fire-dependent wetlands, wetter springs and prolonged droughts may present new challenges and opportunities for conducting prescribed burns (WICCI 2017), which can further influence community composition and structure. Increasingly frequent and intense floods may scour wetland substrates and vegetation, rendering them vulnerable to non-native invasives (WICCI 2010). Early spring warming, poor synchronization between seedling emergence and precipitation, and prolonged inundation may lead to seedling mortality and exhaustion of a wetland's soil seed bank (WDNR 2010a, Walck et al. 2011). Increasing sedimentation associated with increasing precipitation and intense storm events can also bury wetland seed banks to the extent that native species are lost (Gleason et al. 2003, Peterson and Baldwin 2004). In identifying approaches that bolster wetland plant community structure, managers will need to consider tactics that reduce imbalances in species dominance (e.g., woody or invasive species encroachment) and altered microtopography. Approaches relating to plant community composition emphasize limiting invasive species while maintaining and promoting taxonomic and functional diversity of native species and seed banks that are adapted to current and future conditions. Applying fire where appropriate will further support efforts to achieve target community structure and composition. Managing for diverse wetland plant communities with intact structure will promote resistance to invasions (Funk et al. 2008), support vegetative flexibility as environmental conditions change (van der Valk and Pederson 1989), and provide habitat for broad suites of fish and wildlife species (WDNR 2015).

Approach 3.1: Maintain and restore wetland structure.

This approach addresses the importance of maintaining and restoring wetland structure to support ecosystem processes such as soil microclimate, light regime, moisture regime, and fire regime. Wetland 'structure' is characterized by how the various physical elements of a given wetland (e.g., trees, shrubs, herbs, substrate microtopography) are arranged both horizontally and vertically. Changing precipitation patterns and increased evapotranspiration rates are anticipated to decrease water levels in some wetlands, favoring woody species invasion and spread (Weltzin et al. 2003, WICCI 2010). Woody species (both native and non-native) can exert significant influence on the plants that grow beneath them by competing for light, water and nutrients. The cool, moist microclimate that they create can also alter fuel characteristics and fire behavior for prescribed burns (Brooks and Zouhar 2008). Higher evapotranspiration rates associated with woody species invasions can also contribute to altered water budgets. Conversely, flooding and elevated water levels can cause mortality of woody species, leading to conversion of shrub-dominated wetlands to open wetlands (Keddy 2010). Where feasible, maintaining historic proportions of herbaceous to woody species in open wetlands will support a diverse herbaceous flora and associated fauna, and will keep more options open for using prescribed fire as a management tool. In some situations, allowing open wetlands to convert to shrub-dominated or forested wetlands may be the only feasible scenario if management options are limited; in these cases, controlling the trajectory of change will be the priority (see Approach 4.4). Microtopography plays an important role in community structure and resilience to changing environmental conditions. For example, microtopographical variation promotes species richness in sedge meadow (Peach and Zedler 2006) and minerotrophic peatlands (Caners et al. 2019); it also confers resilience to fluctuating moisture levels by expanding available microsites for plants (Doherty and Zedler 2015). Increasing sedimentation associated with changing precipitation patterns can reduce or eliminate this microtopography, facilitating invasions of non-native plants such as reed canary grass (*Phalaris arundinacea*) and lowering native species richness and diversity (Werner and Zedler 2002).

Examples of adaptation tactics are:

1. Control woody species invasions if they: a) change desired cover and diversity of native wetland species; b) alter site hydrology; c) limit use of prescribed fire in fire-dependent wetlands.
2. If using heavy equipment (e.g., forestry mower) to control invading brush, operate only on frozen ground or dry substrate conditions. Low ground pressure vehicles (e.g., with tracks) can help minimize damage to soil and vegetation and can be operated under a wider range of site conditions.
3. Restore microtopographic variation by: 1) using earth-moving equipment to roughen surface soil and create dips and hummock-mimicking mounds (Moser et al. 2007, Doherty and Zedler 2015, Caners et al. 2019); 2) placing logs or stumps to decay on site; 3) installing or seeding tussock-forming species (e.g., Carex stricta, Scirpus cyperinus, C. sartwellii). Also see Tactic 5.3.1.

Approach 3.2: *Maintain and enhance diversity of plant species and their life histories, ecological niches, morphologies, and phenologies.*

Diverse communities may be less vulnerable to climate change impacts because risk is distributed among multiple species (Engelhardt and Kadlec 2001). In a changing climate, conditions may change and some species at the southern extent of their range or with a narrow tolerance to edaphic conditions may be vulnerable or lost (Lawler 2009). One can diversify a site's flora by simply increasing the base number of species, or one can diversify the plant traits represented by various species). These plant traits may reflect diverse life histories, ecological niches, and phenologies. This ‘functional redundancy’ allows fluctuations of favored species and guilds in response to climate variations and other disturbance factors and ensures that all microhabitat niches are occupied at all times, thus maintaining ecosystem services (e.g., securing substrates) and limiting non-native species invasions (Brotherton and Joyce 2015). Recruitment of these diverse species and functional groups may be impacted by climate change as changing precipitation patterns and rising temperatures can affect seed dormancy, germination, and seedling survival (Seabloom et al. 1998, Walck et al. 2011). Wetlands also rely heavily on robust and diverse soil seed banks to ensure consistent vegetative cover as water levels and soil moisture fluctuate, and as plant assemblages shift in response to disturbance such as muskrat herbivory (van der Valk and Davis 1978). Early spring warming, poor synchronization between seedling emergence and precipitation, heavy precipitation and prolonged inundation may lead to seedling mortality and exhaustion of a wetland’s soil seed bank (WDNR 2010a, Walck et al. 2011), while increasing sedimentation can bury wetland seed banks to the extent that native species are lost (Gleason et al. 2003, Peterson and Baldwin 2004). Promoting a soil seed bank with species that have diverse germination strategies will build resiliency into wetlands (Jiménez-Alfaro et al. 2016).

Examples of adaptation tactics are:

1. Increase the number of native species in wetland plant mixes or in established wetlands to increase the odds that a high number of native plants will occupy all microhabitat niches under variable and changing environmental conditions.
2. Adjust species lists for inclusive representation of various life histories (annuals/biennials, short-lived perennials, perennials), wetland rankings (FACW, FAC, OBL; USACE 2016), seed germination strategies and phenologies that enhance plant trait diversity of wetland planting mixes or existing sites.
3. Release existing wetland seed banks, e.g., by restoring historic water levels, or by removing legacy sediment overlying the original substrate (Zedler 2000, Beas et al. 2013). If seed bank is diminished, conduct seed bank germination studies to identify species that are underrepresented (WDNR 2010a), then restore by seeding at higher densities than standard practices (NRCS 2013) to promote a robust soil seed bank.
4. Favor and restore native species local to a given wetland that are most likely to be to be adapted to future conditions, e.g., avoid species that are at the southern edge of their range (see Approach 4.1 for further details).
5. In low-diversity plantings or degraded wetlands, interseed following prescribed burns to boost diversity (Packard 1997). For details, see Appendix.
6. Maintain and enhance microsite complexity and heterogeneity by burning, mowing, or planting in irregular patterns and by establishing rotational management units (Larkin et al. 2016).
7. Promote phenological diversity by conducting prescribed burns in different seasons (Middleton 2002).
8. Restore tussock sedge (*Carex stricta*) in degraded wet meadows. Tussocks provide microsite complexity and thus contribute to floristic diversity (Peach and Zedler 2006).
9. Consider “regional admixture provenancing,” which involves the mixing of seeds from different populations for a given species within a carefully defined region that includes the target planting site. The goal of the seed mixing is to increase genetic diversity at a local scale while maintaining (and maximizing) regional adaptations and avoiding potential maladaptation and outbreeding depression (Bucharova et al. 2019).

Approach 3.3: Promote prescribed fire in fire-adapted wetlands.

Fire is an important disturbance regime for certain wetland types. In sedge meadows, fire reduces accumulated leaf litter, resulting in enhancement of floral diversity (Middleton 2002), particularly by allowing recruitment of short-lived forbs (Kost and De Steven 2000). In emergent marsh, accumulation of roots, rhizomes, stems and leaves of cattails (*Typha* spp.) results in reduced water depth; implementing summer fire (particularly if combined with draining) can slow or reverse this trend (Mallik and Wein 1986). Fire can also be a helpful tool in limiting overabundance of woody vegetation (Laubhan 1995), particularly when applied in conjunction with cutting and herbicide application (Bowles et al. 1996, Middleton 2002). While wildfire has been an important disturbance regime in peatlands (Brandt et al. 2013), the response of Sphagnum to fire varies greatly depending on landscape position, fire frequency and intensity, and Sphagnum moisture content (Grau-Andrés et al. 2017, Noble et al. 2018). Drought and lowered water tables associated with climate change can strongly influence Sphagnum moisture content and thus the intensity and duration of fire, with intense and prolonged fires in peatlands that occur under dry conditions potentially resulting in catastrophic losses of peat and major compositional shifts (Kettridge et al. 2015). Climate change may necessitate adjustments in timing, frequency, and seasonality of burns in other wetland types too as suitable windows of opportunity shift or contract. For example, wetter springs and rapid green-up (Kucharik et al. 2010) could require a shift in prescribed burning windows. Execution of burns may change as well, particularly if drought conditions increase the chances for smoke issues and air pollution. Warmer, drier conditions may also increase opportunities for burning in wetlands that may have typically been too wet to burn in the past.

Examples of adaptation tactics are:

1. Consider shifting from traditional burn seasons to other seasonal windows where conditions are more conducive to successful and safe burns.
2. In some cases, where peatlands are transitioning, it may be necessary to consider usage of fire. Reduce the loss of peat by avoiding prescribed burning when Sphagnum moisture content and water tables are low (Kettridge et al. 2015) and keep fire at a low to moderate intensity (Grau-Andres et al. 2017).
3. Include wetlands within upland burn units and establish fire breaks well in advance of burn season to maximize limited burn days.

Approach 3.4: Prevent invasive species establishment and limit their impacts where they already occur.

Invasive species may benefit from altered climatic regimes and related secondary effects (Ryan and Vose 2012). For example, reed canary grass capitalizes on warmer temperatures, longer growing seasons, and higher nutrients (Kercher and Zedler 2004, Zedler 2007) while non-native cattails proliferate in wetlands with a consistently higher water table and high nutrient runoff (Woo and Zedler 2002, Zedler 2007, Boers and Zedler 2008). Early detection and rapid control of new or small infestations is a high priority in any invasive species management strategy (Boos et al. 2010). Climate change may present new or previously uncommon opportunities for invasive species management, particularly in terms of seasonal drying. As a resistance or resilience strategy, this approach may work for a while. Over the long term, limitations in available resources may require managers to triage sites for active versus deferred invasives management.

Examples of adaptation tactics are:

1. Utilize on-the-ground phenological cues rather than calendar dates to identify appropriate treatment windows for invasives.
2. Monitor sites that are vulnerable to invasions (e.g., areas prone to flooding, inundation, and erosion) and control new infestations early (Boos et al. 2010).
3. Promptly revegetate bare soils to prevent establishment of invasives.
4. Follow recommendations on the Wisconsin DNR webpage “Best Management Practices for Preventing the Spread of Invasive Species in Wetlands.”
5. Control and report new invasives or unknown species that are spreading aggressively to the Early Detection and Distribution Mapping System (EDDMapS Midwest) webpage or smartphone/tablet app. Learn what

new species are likely to appear in your wetlands at the Midwest Invasive Plant Network "Midwestern Early Detection Plant Species" webpage.

6. Seek out funding or assistance for rapid response to new invasions by viewing the Midwest Invasive Plant Network website ("Cooperative Weed Management Area Resources" and "Grants" webpages).
7. Provide cleaning stations for heavy equipment that are used in response to large-scale disturbances such as wildfire and flood events.
8. Among multiple sites, prioritize areas ahead of an invasion front, and manage high-quality sites first. Within sites, prioritize management of upstream infestations (Boos et al. 2010).
9. On individual sites, prioritize species for management based on: 1) species regulated by state law (e.g., Wisconsin NR40, Illinois Exotic Weed Act, Minnesota Chapter 84D, and Iowa Chapter 317); 2) other Early Detection-Rapid Response species; and 3) those that have the greatest impact.
10. Limit dominance of invasive/aggressive brush through periodic mowing; use heavy equipment only on frozen ground or dry substrate conditions. While managers may see more drought-related opportunities for growing season mowing, care should be taken to avoid destruction of sedge hummock microtopography, if present.
11. Reduce dominance of invasives by promoting their usage for subsistence lifestyles, e.g., harvesting narrow-leaved or hybrid cat-tail rhizomes and watercress.
12. Immediately secure bare soils after seeding/planting by using erosion control fabric or weed-free mulch certified by Wisconsin Crop Improvement Association *(naturally occurring mudflats associated with seasonally dynamic wetlands are not considered a priority for revegetation here, as they provide important habitat for a variety of organisms).*
13. Avoid legume cover crops to limit nitrogen inputs that encourage invasives and low diversity plantings (Ehrenfeld 2003).

Strategy 4: Facilitate transformation of wetland communities by adjusting species composition.

This strategy seeks to enable transitions of communities to new desirable states through shifts in plant species composition while maintaining or producing desired wetland functions (Harris et al. 2006). Climate change may drive major alterations in wetland plant community composition and net primary productivity, as well as geographic shifts of some wetland types (Johnson et al. 2005). Climate parameters are changing at a rapid and unprecedented pace, setting up conditions where local plants may no longer be ideally suited to local conditions (Breed et al. 2013). Habitat fragmentation and isolation further reduce the fitness and adaptive capacity of plant populations by causing reduced gene flow and inbreeding recession. For native wetland species that are already rare, these threats may render populations vulnerable to extirpation or extinction, forcing consideration of drastic measures such as assisted migration (Loss et al. 2011). Managers may determine that resisting such threats and changes is not feasible at some sites, and that managing for a range of acceptable trajectories is more practicable (Choi 2004, Hilderbrand et al. 2005); monitoring outcomes and periodically re-evaluating restoration targets is essential when uncertainty is high (Choi 2004).

Approach 4.1: Favor and restore native species and genotypes that are expected to be adapted to future conditions.

Introducing species from the local region that are adapted to novel site conditions or stressors associated with climate change such as flooding, drought, and road salt pollution may transform vulnerable wetlands into sustainable and functional systems. Introducing species or genotypes from other geographic regions that theoretically are adapted to future projected conditions in a given state or region has associated risks, particularly in terms of the potential for outbreeding depression, maladaptation, and inadvertent introduction of aggressive genotypes or invasive species; research using common garden, controlled environment, and genomic studies is essential before this tactic can be safely executed (Prober et al. 2015). Confining movement of species within their current or historic range ('facilitated adaptation') or slightly beyond that is considered to be a more conservative approach that minimizes these risks, as does moving only common or widespread species with ample information on their life histories (Havens et al. 2015).

Examples of adaptation tactics are:

1. Plant flood-tolerant species in wetlands that are vulnerable to flooding, but that currently do not support such species. Look to nature for candidates, such as native species associated with emergent and submergent marsh communities (Epstein 2017). Favor 'workhorse species' that hold the substrate well, spread effectively through rhizomes/stolons or seed (but don't form monocultures), and are not particularly prone to overgrazing by muskrats and waterfowl (Goggin 2009). For examples, see Appendix.
2. Plant drought-tolerant species in sites that are expected to experience more frequent dry conditions throughout the growing season (e.g., due to soil or hydrological characteristics). For examples, see Appendix.
3. Plant salt-tolerant plants in wetlands that are likely to receive runoff from paved roads in winter, but that currently do not support such species. For examples, see Appendix.
4. Employ the NatureServe Climate Vulnerability Index web-based tool to assess vulnerability of individual species to climate change. Favor and restore species that have low vulnerability rankings.

A note on moving species and genotypes

Practitioners may choose to consider expanding the provenance (geographic source location) of seeds for plantings, though this requires thoughtful and informed development of provenancing guidelines (Breed et al. 2018). The risks of non-local seed provenancing include outbreeding recession (diminishment or loss of local adaptations when local and non-local genotypes hybridize), maladaptation (failure of a non-local genotype to thrive in a new setting), and introduction of a non-local genotype that behaves aggressively in a new setting. The challenge lies in identifying expanded seed provenances that promote genetic diversity and population fitness while avoiding the risks noted above (Breed et al. 2018). We offer approaches and tactics that may act as a suitable guide, but emphasize the vital need for continued research on climate modeling for individual species, empirically designed seed zones based on common garden studies, and long-term monitoring of sites where expanded seed provenancing is applied. Practitioners are additionally encouraged to filter broad-scale provenancing guidelines with their local knowledge of species populations and microsites when selecting species.

5. Use geographic information system (GIS) software and species distribution modeling (SDM) software to support decision making relating to seed provenancing (Ramalho et al. 2017). A decision support framework for this approach along with suggested software options may also be useful (Ramalho et al. 2017).
6. Employ “climate-adjusted provenancing” by supplementing locally collected seed with seed collected along a linear climate gradient that aligns with climate change projections (Prober et al. 2015).
7. Hand pollinate at-risk species in declining populations affected by pollinator disruption (e.g., decline of specific insect pollinators) to accommodate gene flow and outcrossing of species where it may improve seed set (Bossuyt 2007). Small populations may not be undergoing pollination failure, so careful study should occur before implementing genetic rescue (Wilcock and Neiland 2002).

Approach 4.2: Increase genetic diversity of seed mixes within appropriate seed transfer zones.

Mixing seeds from diverse populations within the same region as the target planting site mimics natural gene flow which is otherwise limited due to habitat fragmentation or loss. This enhances population fitness and adaptive capacity by increasing genetic diversity, while avoiding the risks of outbreeding depression, maladaptation, and aggressive genotypes associated with longer distance introductions (Broadhurst et al. 2008). Delineating seed transfer zones is a vital consideration when applying this approach and may require analysis of individual species and their genetic variability within discrete regions. Species that disperse pollen and propagules at long-distances (e.g., those that are wind-pollinated or -dispersed) will likely support larger seed zones than short-distance dispersers (Bucharova et al. 2019).

Examples of adaptation tactics are:

1. Increase genetic diversity of seed mixes within appropriate seed transfer zones.
2. Employ “regional admixture provenancing” by collecting seed from several wild sources (e.g., five or more) within a defined seed transfer zone (Bucharova et al. 2019). Collecting from large populations rather than small fragmented ones may limit the introduction of undesirable traits associated with inbreeding depression (Breed et al. 2013). These seeds can be mixed and planted at target restoration sites, or they can be propagated at nurseries to provide seed mixes for multiple projects. A modification of this tactic (composite provenancing) involves adding a higher proportion of seeds to a seed mix from sites immediately surrounding the restoration site than from sites further afield (Breed et al. 2013).
3. Refer to provisional seed transfer zones (Bower et al. 2014) as coarse-level boundaries for regional admixture provenancing. Provisional seed transfer zone maps and GIS shapefiles for the United States are available at the Western Wildland Environmental Threat Assessment Center "TRM Seed Zone Applications" webpage. Empirically designed seed transfer zones based on common garden studies as well as local knowledge of species populations and microsites should supersede these provisional seed zones.

Approach 4.3: Move at-risk species to locations that are expected to provide more suitable habitat.

The relocation of a species or population to a location outside of its current or historic range that will offer suitable habitat based on future climate projections is referred to as assisted migration, assisted colonization, or managed relocation (Loss et al. 2011). Considerable uncertainty surrounds the likelihood for success in such relocations, and a high failure rate for establishment is common (Godefroid et al. 2011). Risks include potentially invasive behavior of a translocated species, alteration of ecological processes (e.g., nutrient cycling), transport of diseases and parasites, and hybridization with closely related species (Ste-Marie et al. 2011, Maschinski and Albrecht 2017). Given the high degree of uncertainty and potential risks, this approach is best reserved for situations where assisted migration will forestall extinction of an at-risk species (Vitt et al. 2010, Maschinski and Albrecht 2017).

Examples of adaptation tactics are:

1. Employ resources such as the NatureServe Climate Vulnerability Index or U.S. Fish and Wildlife Service's RAMP program to identify species that are vulnerable to climate change as well as areas where habitat is projected to be suitable for them (see Tactics 4.2.5 and 4.2.6 above).
2. Utilize tools and resources devised for developing seed transfer zones to identify appropriate geographic ranges for assisted migration (see Tactics 4.2.1 and 4.2.2).
3. Develop an assisted migration proposal that clearly identifies all factors that influence a species' or population's vulnerability (including climate change), potential risks if no action is taken, a quantitative model showing predicted outcomes of assisted migration, proposed actions for moving species (and restrictions therein), long-term monitoring approaches, and adaptive management strategies (McLachlan et al. 2007).

Approach 4.4: Adjust wetland and composition to meet functional values.

This approach acknowledges that traditional ecological restoration of wetlands may not be feasible or practical in light of overwhelming impacts from climate change and other threats. However, certain actions can be taken to control the trajectory of change in wetlands that enable them to retain vital wetland functions. The core tenets are to identify the wetland values to be maintained (particularly soil stabilization, storm and floodwater storage, water quality protection, and groundwater recharge [see 'Functional Value Assessment' in WDNR 2014]), and advocate for the protection of all wetlands, even those that support few native species.

Examples of adaptation tactics are:

1. Maintain and establish wetland species that secure soils from erosion, even under high streamflow rates and flooding. Favor 'workhorse species' that hold the substrate well (see Tactic 4.1.1 above).
2. Limit the dominance of species that are maladapted to projected future conditions to ensure long-term vegetative cover (see Tactics 4.2.4 and 4.2.5 above).
3. Maximize cover and diversity of native wetland species in sites that are undergoing conversion. For example, in hardwood swamps where ash trees are anticipated to die due to emerald ash borer, facilitate

conversion to shrub-carr by planting native wetland shrubs and hardy native herbs that can compete with reed canary grass once the canopy opens up.

Strategy 5: Adjust wetland systems to cope with altered hydrology.

This strategy outlines approaches to facilitate ecosystem adjustments to cope with altered hydrology, water budget components (inputs, outputs, and storage of water) and water quality. Managers face both challenges and opportunities from a periodic lack of water (e.g., from drought and higher evaporation) as well as excess water (e.g., from larger precipitation events) that go beyond the historical range of variation in both magnitude and duration (Gotkowitz et al. 2014). Wetland managers will therefore need to adjust systems to maximize desirable ecosystem functions despite altered hydrology (Perry et al. 2015). This adjustment includes all components of wetland systems such as flood storage capacity, site nutrient cycling, as well as the habitat suitability of plants, wildlife, and aquatic species. Adjusting wetland ecosystems to climate changes applies equally to natural areas, as it does to wetland creations and enhancements, and existing hydrologically managed systems (e.g., lakes, impoundments, and rivers regulated by dams and other hard infrastructure) (Great Lakes Commission and National Wildlife Federation 2014). Proactive consideration of hydrologic change can help managers reduce future risks and take advantage of opportunities to sustain hydrologic functions into the future (Erwin 2009).

Approach 5.1: Manage systems to cope with decreased water levels and limited water availability.

This approach addresses scenarios of wetlands becoming drier during the growing season. Less predictable depth, duration and seasonality of saturation and flooding can alter the germination and establishment of wetland plants (Warwick and Brock 2003) and cause shifts in vegetation composition such as the encroachment of shrubs into herbaceous wetlands or the establishment of invasive species on exposed shorelines. Periodic lower water levels may also provide new opportunities to control undesirable vegetation or establish habitat for a different suite of species (Dziegielewska 2012), while recognizing that habitats such as open mudflats are a natural phenomenon and can be very beneficial for annual plants and wildlife such as shorebirds. Techniques utilized in more engineered settings such as the development of unique seed mixes for wetland enhancement may also be useful in natural systems experiencing novel hydrologic changes. To a degree, managers can prepare for these changes and strive to maintain desired habitat and ecosystem functions and services (Galatowitsch et al. 2009).

Examples of adaptation tactics are:

1. Manage the transition of open wetlands to shrub-dominated wetlands by selectively controlling invasive shrubs (National Park Service 2016).
2. Plan for and take advantage of lower water levels by controlling invasive species and/or establishing desirable native species on newly exposed soil (Dziegielewska 2012).
3. In sites with open wetlands that are drying, inter-seed with wet meadow species tolerant of lower water levels (e.g., with wetland ratings of FACW and FAC) suitable for the region (Galatowitsch et al. 2009).

4. In wetlands with distinct vegetative zones along a moisture gradient, plant species from the short-term saturation zone into the long-term saturation zone (Hoag et al. 2007).
5. Install small structures (e.g., one rock dams less than one foot in height) along headwater streams to increase soil saturation depth, extent and infiltration (The Nature Conservancy and Gunnison Climate Working Group 2017).
6. Remove post-settlement alluvium from small incised floodplains and restore sedge meadow and wet prairie vegetation. Removing alluvium reduces depth to water table, increases residual soil moisture, improves water quality by reducing bank erosion sediment sources, and increases flood storage by lowering the floodplain elevation (Booth et al. 2009).

Approach 5.2: Manage systems to cope with increased water abundance and higher water levels.

This approach addresses scenarios in which wetlands may experience larger footprints of saturation and higher water levels for longer periods of time due to increased precipitation (Andresen et al. 2012, USGCRP 2017). Wetlands may also experience inundation outside the normal wet season, such as in late summer due to extreme precipitation events. Water levels may remain high for a prolonged length of time following extreme precipitation in small isolated wetlands (Johnson et al. 2004), in wetlands downstream of managed lakes and rivers due to continued upstream water release, and in groundwater wetlands in areas underlain by shallow unconfined aquifers (Gotkowitz et al. 2014). In riparian systems, higher flows may also lead to greater scouring and spread invasive species propagules; and yet more frequent higher water levels can interfere with the normal low-water cycle of germination and establishment of new seedlings (Perry et al. 2015). These hydrologic shifts will drive changes in the plant community and other wetland ecosystem parameters linked with desirable functions (e.g., biodiversity, nutrient retention and cycling; Perry et al. 2015, Didiano et al. 2018). Managers can help systems adapt by working to maintain desirable functions, such as planting species that are tolerant of anticipated hydrologic changes (Bejarano et al. 2018). Systems with impoundments may necessitate special attention to reduce the adverse impacts of prolonged higher water levels while continuing to provide ecosystem services.

Examples of adaptation tactics are:

1. Control the encroachment of undesirable species that respond to higher water levels (e.g., pickerel weed (*Pontederia cordata*) in wild rice beds, non-native cat-tails (e.g., *Typha angustifolia*, *T. x glauca*), *Phragmites australis* var. *australis*.
2. Encourage seeding or planting of wetland plant species adapted to high water levels (e.g., with a wetland rating of OBL).
3. Install carp barriers to anticipate increased invasion with flooding and higher water levels (Johnson and Havranek 2013)
4. Promote non-invasive plant species in riparian wetlands with adaptations to tolerate alternating heavy flooding (increased soil saturation, submergence, and increased mechanical force due to higher velocity flows) with lower baseflows (drier soils in adjacent floodplains). FACW and FAC wetland plant species are adapted to a broader range of hydrologic conditions than OBL wetland species. Consider including shorter-statured plants with wide root systems and species that can resprout or propagate

vegetatively by rhizomes or fragments in wetlands exposed to increased mechanical stress from floods and ice shearing (Bejarano et al. 2018).

5. In riparian systems influenced by an upstream hydroelectric dam, manage dam releases to mimic natural flow regimes to improve germination and establishment of plant species. Limit dam releases that cause extreme high flows followed by very low flows (i.e., hydropeaking), which prevent plant establishment through repeated water level fluctuations, inundation, and scouring (Bejarano et al. 2018).
6. In impoundments and lakeshores with a steep side slope, supplement wave-reducing measures by installing substrate support agents such as biodegradable geotextiles (Abrahams 2008).
7. Maintain a lower summer water level in impoundments and lakes managed by a dam to increase storage capacity of extreme precipitation events and reduce downstream flooding impacts or consider other operational rule changes for dams and reservoirs in response to a changing climate (Watts et al. 2011).
8. Where concentrated flow enters a wetland, such as at a culvert or a storm sewer outfall, install energy dissipation features to limit negative impacts of extreme runoff events on wetlands (Minnesota Stormwater Manual contributors 2018).

Approach 5.3: Design and manage enhanced and created wetlands to accommodate changes in hydrologic variability.

This approach addresses the need to consider future climate conditions in the design and management of wetland restoration (Harris et al. 2006, Erwin 2009). Modeling efforts show a high degree of uncertainty in parameters such as groundwater recharge and discharge, with the possibility of both increases (Murdoch, unpublished data) and decreases (Hunt et al. 2016). Like natural wetlands, designed wetlands will also be influenced by extreme precipitation and flooding as well as longer drought periods between rain events (USGCRP 2017). Increased uncertainty in the hydrologic regime (especially the amount and timing of precipitation) and outputs (such as evapotranspiration, longer growing seasons, and anthropogenic withdrawal) will affect water levels and soil saturation in unpredictable ways that may vary from site to site and from year to year within a site (Erwin 2009, Zhang et al. 2011, Hunt et al. 2016). In addition, there is a need to augment traditional hydraulic design analysis of system responses to individual, conceptual extreme events, such as a "100-year flood", which are occurring more frequently, with more detailed system response to long simulation periods, which give a more detailed and accurate assessment of wetland conditions and performance over time (Konyha et al. 1995). Consideration of future hydrologic regimes in the up-front design of wetland restoration will increase the likelihood of their success in meeting performance criteria and providing desired ecosystem services (Erwin 2009).

Examples of adaptation tactics are:

1. For new wetland creations and enhancements, increase habitat heterogeneity by 1) increasing amount of edge through creation of irregularly-shaped shorelines (i.e., higher perimeter-to-area ratio), and 2) increasing topographic/elevational heterogeneity within the basin through creation of mounds ranging in size from small hummocks to nesting islands to promote a wider range of microsites for species establishment during both high and low water levels (NRCS 2003). Engineered heterogeneity can be

facilitated by technological advances in design and construction such as the widespread availability of LIDAR topographic mapping and highly detailed survey data for design input, analysis and design with Geographic Information System (GIS) and Computer Assisted Drafting and Design (CADD) software, and precision construction methods such as GPS and laser guided earthmoving equipment (Moser et al. 2007, Millard et al. 2013).

2. Incorporate long-term dynamic simulations into hydrologic and hydraulic analysis to simulate wetland response to a changing climate, e.g., changing 100-year floods and five-year storms (Steward et al. 2011, Carlson Mazur et al. 2014).
3. Design, construct and manage engineered wetlands in low-lying former agricultural areas to perform desired ecosystem services (e.g., flood control, sediment retention, nutrient removal, and fish and wildlife habitat) (Rozema et al. 2016) through techniques (IISD 2017) such as:
    - constructing sub-impoundments with different elevations,
    - building capacity for 100-year (or greater) runoff events,
    - managing early summer water releases to prepare for potential summer storms, and
    - providing ability for drawdown below the water table to allow soils to dry enough to allow mechanical biomass harvesting to control cat-tail, remove nutrients stored in plant material, and improve habitat.
4. Adjust the location and size of wetland areas to new or changing water levels, such as moving riparian areas up or downslope to match current or future conditions and/or increasing the sinuosity of stream channels (Perry et al. 2015).
5. Reduce excessive wave disturbance in impoundments by planting shelterbelts, artificially lowering water levels, creating artificial reefs (breakwaters) at a distance from the shoreline in about 1 m of water, or deploying floating timber booms (Abrahams 2006, 2008)
6. Install artificial floating wetland islands (floating treatment wetlands) in storm water ponds and reservoirs to improve water quality of effluent, enhance fish and wildlife habitat, and reduce shoreline erosion (Nakamura and Mueller 2008).

Strategy 6: Design and modify infrastructure to accommodate future conditions.

This strategy addresses adapting infrastructure designs and maintenance to support wetland ecosystems under changing environmental conditions, including infrastructure found within or near wetland watersheds such as bridges, culverts, stream crossings, roads, trails, parking lots, utilities, coastal structures, docks, and piers (Shannon et al. 2019). Roads, stream crossings, recreational trails, facilities, and other infrastructure are known to affect local landforms and hydrology, particularly where impervious surfaces concentrate water into flow pathways, generating high-velocity runoff and erosion (Wemple et al. 2017). For this reason, critical evaluation of past design concepts and criteria with additional consideration for a changing climate and altered hydrology may be necessary to minimize risks and safety concerns over the designed lifespan of the unit (Milly et al. 2015, Kilgore et al. 2016, Douglas et al. 2017, Wilhere et al. 2017, Shannon et al. 2019). A changing climate challenges traditional perceptions of “low maintenance” infrastructure that can be built and left unattended, and heightens the necessity of increased infrastructure monitoring, inspection and routine maintenance. Contemporary philosophies for wetland management, enhancement and restoration have shifted toward the minimization of traditional infrastructure in the watershed (Langridge et al. 2014), and incorporating natural or low impact development to dissipate excess water can both reduce negative downstream impacts and reduce the need for hard infrastructure. However, changing environmental conditions also merit renewed consideration of infrastructure designs that recognize changing conditions to support wetland function and watershed management.

Approach 6.1: Reinforce infrastructure to meet expected conditions.

Engineers often apply standards for sizing and placement of infrastructure with reference to historical hydrological datasets (Maher et al. 2015), yet climate change is shifting watershed hydrology outside of historical norms (Milly et al. 2008), in some cases increasing external stresses and loads on infrastructure and decreasing design life (Wilhere et al. 2017). Any upgrades or reinforcement of infrastructure to accommodate these increasing environmental stresses could be informed by projected changes in hydrology, extremely high temperatures on surfaces, and increased winter soil moisture timing and extent (Strauch et al. 2015, Daniel et al. 2017). Such reinforcement approaches may be especially relevant when seeking to defend infrastructure in order to maintain access and safety.

Examples of adaptation tactics are:

1. Replace undersized culverts with bottomless culverts using bankfull width to guide design, using USFS stream simulation design that allows for sediment and debris to safely pass during higher flows or floods (USFS 2008, Barnard et al. 2015).
2. Install emergency or auxiliary flow routes and overflow paths (e.g., for bridges, culverts and other road crossings) to prevent road blowouts and associated erosion, scour and sedimentation to protect adjacent or downstream wetlands (U.S. Department of Transportation 2018).
3. Where hydraulic structures such as dams, spillways or water control structures are used, install auxiliary or emergency overflow routes to mitigate high water conditions, or at least conduct a cost-benefit analysis to consider whether risks from more extreme hydrologic events warrant an investment in additional reinforcement (Collet et al. 2018).
4. If water level or flow control structures are necessary, consider control structures that provide operational flexibility and adaptability (Shoo et al. 2011). For example, rather than a fixed weir, consider a water control structure with adjustable stoplogs. At culverts, rather than providing a simple culvert pipe with fixed invert elevations, consider the benefits of combining an adjustable water level control structure with the culvert pipe.
5. On low-volume roads or trails, convert culverts to, or supplement culverts with a low-water crossing structure (ford or low-water bridge) designed to be overtopped or impacted by woody debris or ice during floods (Clarkin et al. 2006).

Approach 6.2: Reroute or relocate infrastructure, or use temporary structures.

Locating infrastructure involves an interactive process that considers the advantages, disadvantages, costs, benefits and constraints of numerous location or route alternatives. While climate change projections and impacts were likely not considered in infrastructure design processes historically or in recent times, such considerations are vital now, particularly for infrastructure located in areas prone to flooding or with highly erodible soils, and for high-traffic areas such as roads, bridges and trails (Strauch et al. 2015, Peterson and Halofsky 2018). While initially costly, the relocation or rerouting of vulnerable infrastructure to less vulnerable areas may reduce long-term maintenance costs overall and limit structural losses (Keller and Ketcheson 2015, Strauch et al. 2015).

Examples of adaptation tactics are:

1. Relocate field roads to improve degraded quality of wetland and riparian areas (Daigle 2010).
2. Reroute infrastructure to less vulnerable sites, particularly infrastructure that may affect adjacent wetland hydrology such as heavily trafficked, high-risk trails or roads or those with past issues related to saturated soils, particularly those that lie within a floodplain (Bren 1993).
3. Adjust site access (e.g., for inspection, maintenance, emergency vehicles, recreational use) to accommodate frequent extreme events and the possibility of long-term wetter conditions (Kilgore et al. 2016).
4. Consider adjusting setback standards, such as separation between infrastructure elements and wetland boundaries, floodplain boundaries, steep slope limits, to account for possible changes in hazard areas and hydrologic influence areas from climate change.
5. Avoid construction of infrastructure (e.g., roads, paved trails, etc.) that completely surrounds wetlands, and/or include appropriate setback distances for infrastructure or developments that will alter or impede the flow of groundwater or surface water into or out of the wetland.
6. Use temporary structures for wetland or stream crossings, particularly where vehicle access is needed only seasonally or for a short period of time, e.g., for timber management, powerline installation, etc. (WDNR 2010b).

Approach 6.3: Incorporate natural or low impact development into designs.

Areas downstream from infrastructure that concentrate or divert water flow are vulnerable to flooding, erosion, and impaired water quality as more frequent and intense precipitation events occur (Pyke et al. 2011, Ahiablame et al. 2012, Augustyn and Chou 2013). Therefore, design approaches that use natural materials (e.g., soils and plants) and that enable the landscape to distribute water rather than concentrate it may minimize impacts on vulnerable downstream sites and enhance groundwater recharge (Dietz 2007, Pyke et al. 2011, Ahiablame et al. 2012, Kirshen et al. 2015).

Examples of adaptation tactics are:

1. Use an ecological approach when designing built environments in urban or rural systems, using green infrastructure and low impact development techniques in watershed activities to keep water onsite and protect water quality using natural features (Ahiablame et al. 2012). Examples include reducing and disconnecting impervious surfaces from storm water systems by replacing curbs and gutters with swales or filter strips, and by installing bioretention systems to capture runoff in depressional areas (Ahiablame et al. 2012).
2. In coastal and riparian settings, evaluate the use of vegetation and soil-based systems to provide shoreline stabilization and erosion protection, rather than hard armoring such as concrete or riprap. In river and stream settings, soil bioengineering is a system that may be appropriate (Gray and Sotir 1996). In Great Lakes coastal settings, evaluate the application of the "living shoreline" concept that is currently employed in marine settings (Bilkovic et al. 2016).
3. Where an engineering analysis indicates that some level of armoring or structural protection is necessary to protect structures, utilize ecologically-friendly materials and surfaces. For example, in coastal erosion protection, the "buried revetment" concept has been developed, where a rock revetment designed to withstand occasional extreme wave energy is buried with a softer dune or beach system (Allan et al. 2005, Allan and Gabel 2016). Similar concepts have been developed in stream restoration, where a relatively immobile rock channel is used to try to place outer limits on stream channel migration and cutting, but more mobile material is placed at the surface with the understanding that some stream channel adjustment will occur.
4. For wetland restoration project design, consider grading concepts that spread out water and lower hydraulic energy, rather than concentrate it (Vivian-Smith 1997, Wei et al. 2012). For example, one common design consideration in wetland restoration is how to disconnect artificial or manmade drainage pathways. One option is to construct a berm or plug that blocks concentrated flows and stores water upstream of the element. An alternative to blocking a concentrated flow path would be a larger regrading or topographic alteration that spreads out water even further on the land surface. Although either option may have similar downstream hydrologic effects, the berm or plug may be more vulnerable to "blowouts," scouring or other damage caused by extreme flows.
5. Improve drainage, stabilize slopes, and restore vegetation ground cover adjacent to impervious surfaces to slow runoff, deposit sediments, and reduce erosion potential (Strauch et al. 2015).

Approach 6.4: Remove infrastructure and readjust system.

Roads, trails, levees and other forms of infrastructure may become increasingly difficult to maintain as climate change impacts such as more severe storms and higher flow events exert greater and more frequent stress upon them. In some situations (e.g., if human safety is jeopardized), removing or decommissioning infrastructure may represent the most practical and cost-effective approach. Such actions may also be leveraged to improve quality and functionality of aquatic and wetland resources. For example, by ripping a roadbed as part of the decommissioning process, one can restore soil structure and promote groundwater infiltration (Switalski et al. 2004). Infrastructure removal initiatives that reduce impervious surfaces may result in decreased overland flow and stormwater velocity, thus reducing runoff and erosion and improving water quality. Lastly, infrastructure removal may present opportunities to reconnect floodplains and wetlands to surface waterways, which could result in increased groundwater recharge and flow of cool groundwater in the system (Tague et al. 2008).

Examples of adaptation tactics are:

1. Decommission and revegetate unnecessary roads or trails with high risk and low access. For example, many wetland enhancement or restoration sites have old farm lanes and waterway crossings (such as culverts or fords) that may not be needed, once active farming on the property ends or is downscaled (NRCS 2008, Januchowski-Hartley et al. 2013).
2. Remove levees that increase flood stage and flow velocity to restore the riparian ecosystem, reconnecting the channel and floodplains (Acreman et al. 2003).
3. Evaluate removal of unused or obsolete dams. Although there are situations where dams may provide some water management benefits to nearby wetlands, dams also disrupt natural streamflow and sediment transport patterns and negatively impact aquatic organism passage and water temperature (Grant 2001, Gangloff 2013).
4. Decommission infrastructure to allow stream channel to migrate within floodplain. Remove hard stream surfaces such as concrete lining if no longer needed for conveyance or drainage purposes (Acreman et al. 2003, Mohrlok 2003).

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Appendix – Additional Tactics

Supplementary information and "bonus" tactics, organized by approach number first, then tactic number if applicable (e.g., "1.2.2" refers to Approach 1.2, Tactic #2). See bibliography at end of Adaptation Menu for cited references.

Approach 1.1: Maintain and enhance infiltration and water storage within wetlands, adjacent uplands, and groundwater recharge areas.

Additional tactics:

- Maximize natural habitat or other cover types that are effective in slowing the flow to improve infiltration (e.g., natural upland habitats and plant communities, vegetated levees, old fields, naturally vegetated rights-of-way).
- Minimize land covers that offer little to no opportunities for rainwater infiltration and that accelerate water movement across the landscape (e.g., impervious surfaces such as roads, parking lots, intensive agriculture, plantations, railroads, heavily grazed pastures where vegetation is minimal and soil is disturbed and compacted, lawns, and conventional golf courses).

Approach 1.2: Maintain and restore a natural hydrologic regime.

Additional tactics relating to drainage structures and stream crossings:

- Design road-stream crossings to accommodate higher peak flows and minimize obstructions to low flows.
- Install culverts through old roads running through wetlands.
- Remove perched culverts.

Approach 2.2: Reduce soil erosion and sediment deposition.

Additional tactics:

- For forestry operations near wetlands, maintain "filter strips", but consider expanding well beyond the minimum recommended size (e.g., 15-foot, WDNR 2010).
- For forestry operations near streams, maintain a forested Riparian Management Zone (RMZ) beyond the minimum recommended size (e.g. 100 feet, WDNR 2010). This is particularly important for headwater streams and associated riparian wetlands, which largely influence watershed water quality (Kaplan et al. 2008).
- In forested watersheds, maintain a buffer of mature forest in uplands adjacent to high-quality non-forested wetlands.
- Develop pre-logging BMP plans and work closely with loggers to develop appropriate erosion and sediment control structures and materials (i.e., retention of slash and mulch), limits to logging road and trail access during and after operations, increase flotation of harvest equipment to reduce surface

disturbance, and implement appropriate stream and wetland crossings such as temporary bridges and culverts (Cristan et al. 2016, Morris et al. 2016).

Additional tactics related to Cropland Conservation Management Systems:

- Plant winter cover crops and leave crop residues on fields to maintain permanent soil cover.
- Apply no-till practices to minimize mechanical disturbance of soil.
- Employ contour farming and strip cropping in hilly terrain to slow runoff and enhance infiltration.
- Create perennial buffers adjacent to streams and wetlands and grassed drainageways to slow runoff and capture sediment.

Approach 3.2: Enhance and maintain species diversity and plant trait diversity.

Additional tactics:

- Evaluate the biological integrity of wetlands in terms of their ability to support conservative plant species by using Floristic Quality Assessment (FQA; Swink and Wilhelm 1994, Bernthal 2003). Conservatism relates to how a species tolerates disturbance and how strongly it is associated with minimally degraded habitat.
- In situations where managers cannot plan and implement a formal planting on newly exposed soils, secure the soils quickly with native (but non-aggressive) annuals, biennials and short-lived perennials. Ideal selections are those that are easily procured and that will not inhibit establishment of perennials in the future when time and resources allow. These may include 'weedy' natives that are already growing in the area. Examples: fleabanes (*Erigeron* spp.), tall blue lettuce (*Lactuca biennis*), blue vervain (*Verbena hastata*), and Pennsylvania bitter-cress (*Cardamine pensylvanica*).
- Install clusters of multiple plant plugs in wetlands where individual plants may get swamped out and isolated. This is particularly important for species that are difficult to establish from seed (e.g., prairie cordgrass [*Spartina pectinata*], bur-reeds (*Sparganium* spp.), tussock sedge (*Carex stricta*), and arrowheads [*Sagittaria* spp.]).
- In Alder Thicket and Shrub-carr, maximize diversity of native wetland shrub species by planting whips of under-represented species (NRCS 2003, MBWSR 2012).

Additional tactics related to species diversity guidance for wetland plantings:

- Minnesota Board of Water and Soil Resources (MBWSR, 2017, page 7)
- U.S. Army Core of Engineers National Wetland Plant List webpage, Appendix B.

Additional information on interseeding:

- Seed with desired species at higher rates relative to rates used for bare-soil planting. This may be required over multiple years, since conditions that promote germination and survival may not be sufficient in a single year. Optimize seed-to-soil contact and germination by hand-raking, harrowing, or drilling to 0.25-0.5 inch. If possible, employ summer mowing for the first 1-3 years after seeding to set back competition from existing plants to increase the odds of successful germination and survival.

Approach 3.4: Prevent invasive species establishment and limit their impacts where they already occur.

Additional tactics:

- Use field observations to identify optimal time for burning reed canary grass in late spring when it is actively growing but before native plants have broken dormancy (Wisconsin Reed Canary Grass Management Working Group 2009).
- Seek out funding or assistance for rapid response to new invasions by viewing the Midwest Invasive Plant Network website ("Cooperative Weed Management Area Resources" and "Grants" webpages).
- Provide cleaning stations for heavy equipment that are used in response to large-scale disturbances such as wildfire and flood events.
- Among multiple sites, prioritize areas ahead of an invasion front, and manage high-quality sites first. Within sites, prioritize management of upstream infestations (Boos et al. 2010).
- On individual sites, prioritize species for management based on: 1) species regulated by state law (e.g., Wisconsin NR40, Illinois Exotic Weed Act, Minnesota Chapter 84D, and Iowa Chapter 317); 2) other Early Detection-Rapid Response species; and 3) those that have the greatest impact.
- Manipulate water levels to manage invasives when feasible.

Example tactics related to BMPs for wetland invasives that are particularly important:

- Treat infestations prior to any on-site soil-disturbing work.
- Carry out activities only in conditions where soil disturbance is minimal (e.g., frozen or dry ground).
- Avoid moving equipment (e.g., mowers) from infested areas to uninfested areas.

Approach 4.1: Favor and restore native species and genotypes that are expected to be adapted to future conditions.

Additional tactics:

- Refer to climate change vulnerability assessments to identify species that are most likely to persist into the future at a restoration site. To date for the Great Lakes Region, this includes assessments for 60 Ceded Territory species conducted by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC 2018). In the absence of species-specific vulnerability assessments, utilize geographic range as a rough tool for estimating the potential impacts of climate change on plant species. Species with a wide geographic range and broad tolerance of edaphic conditions are generally anticipated to be less vulnerable to changing environmental conditions (Thuiller et al. 2005). Species at the northern edge of their range will likely fare better than those at the southern edge of their range. Refer to the Biota of North America website for species geographic ranges (Kartesz 2013).

Examples of flood-tolerant wetland species identified for Wisconsin:

- dark green bulrush (*Scirpus atrovirens*)
- great bur-reed (*Sparganium eurycarpum*)
- American bur-reed (*Sparganium americanum*)

- river bulrush (*Bolboschoenus fluviatilis*)
- sweet-flag (*Acorus americanus*)
- southern blue-flag; northern blue-flag (*Iris virginica; I. versicolor*)

Examples of drought-tolerant wetland species identified for Wisconsin:

- Perennial species that spread by runners (Hoag et al. 2007), such as:
    - Baltic rush (*Juncus balticus*), little green sedge (*Carex viridula*)
    - tufted hairgrass (*Deschampsia caespitosa*)
    - bottomland aster (*Symphyotrichum ontarionis*)
    - grass-leaved goldenrod (*Euthamia graminifolia*)
    - silver-weed (*Argentina anserina*)
- Wetland plants with deep tap roots:
    - cup-plant (*Silphium perfoliatum*)
- Drought-tolerant woody species:
    - Bebb's willow (*Salix bebbiana*)
    - sandbar willow (*Salix exigua*)

Look to nature for candidate salt-tolerant wetland species ('halophytes'), such as native species associated with Michigan's Inland Salt Marsh natural community (Albert 2001). Examples identified for Wisconsin and Michigan:

- Strong halophytes:
    - prairie cord grass (Warren et al. 1985)
    - water plantain (*Alisma subcordatum*)
    - dwarf spike-rush (*Eleocharis parvula*)
    - bald spike-rush (*Eleocharis erythropoda*)
    - water-pimpernel (*Samolus parviflorus*)
    - water-parsnip (*Sium suave*)
- Moderate halophytes:
    - panicled aster (*Symphyotrichum lanceolatum*)
    - boneset (*Eupatorium perfoliatum*)
    - wild mint (*Mentha arvensis*)
    - three-square (*Schoenoplectus pungens*)

While no specific guidelines for 'climate-adjusted provenancing' are available, circumstances where this may be appropriate include: 1) a target plant species spans a climatic gradient; 2) climate projections for a target plant species indicate a range contraction or shift; 3) the restoration site lies within both the historical and climate-projected range for target plant species; and 4) genetic adaptation is likely across the climate gradient (Ramalho et al. 2017).

Approach 4.3: Move at-risk species to locations that are expected to provide more suitable habitat.

Additional tactics:

- Use the Wisconsin Initiative on Climate Change Impacts (WICCI) Climate Interactive Mapping Tool webpage to project how a specific geography's climate will resemble that of another region (known as a climate analogue) under various climate scenarios.

Approach 4.4: Adjust wetland structure and composition to meet functional values.

Additional tactics:

- Allow patches of native shrubs to invade wetlands to promote microsite and species diversity.
- Plant important native or non-invasive non-native plants to maintain food sources for wildlife.
- Where eradication is not feasible, periodically burn and mow invasives to limit their impact.