Menu of Adaptation Strategies and Approaches

Non-Forested Wetland Conservation and Management (**Draft** – v3.0)

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One of the major challenges of adapting wetlands 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 reports and peer-reviewed publications on climate change adaptation 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 an **Adaptation Workbook**, which provides a structured, adaptive approach for integrating climate change considerations into planning, decision-making, and implementation.

This resource 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 and will be sustainable.

This document includes a preliminary set of adaptation strategies and approaches for non-forested wetlands that can be used by managers working on projects related to supporting hydrologic function, vegetation management, and infrastructure improvements. In Wisconsin, non-forested wetlands have been roughly characterized as having less than 25% overall canopy cover from mature trees (WDNR 2019). Shrub-dominated wetlands (e.g., shrub-carr) support more than 50% cover of shrubs, while truly 'open' wetlands (e.g., southern sedge meadow) have less than 50% cover of shrubs (WDNR 2019).[1] It is intended to complement the adaptation strategies and approaches developed as part of the *Forest Adaptation Resources: Climate change tools and approaches for land managers and Adaptation Workbook, 2nd edition* (www.nrs.fs.fed.us/pubs/52760, (Swanston et al. 2016) and the corresponding online interactive tool (adaptationworkbook.org). A complementary adaptation menu for managing wildlife species is being developed by the WICCI Wildlife Working Group.

[1] These numerical values were developed to support a dichotomous key to wetlands for use by wetland professionals in Wisconsin, and are not entirely based on rigorous vegetative sampling or field tests. They do, however, provide a useful framework for discussion within the context of this menu.

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 land 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 land managers to consider additional actionable tactics appropriate for their projects. Further, not all possible tactics have been vetted through research and so should be employed with caution and followed-up with monitoring and adaptive management.

How to read the 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 enhance 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 form and restore hydrologic function of streams and ditches.

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 enhance wetland structure

Approach 3.2: Enhance and maintain species diversity, floristic quality, and plant trait diversity in wetlands

Approach 3.3: Promote prescribed fire in fire-adapted wetlands

Approach 3.4: Promptly revegetate bare soils with species that are likely to persist under variable and extreme conditions

Approach 3.5: Prevent non-native 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

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

Approach 4.5: Adjust wetland structure 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: Adjust systems to cope with increased water abundance and higher water levels

Approach 5.3: Design enhanced and created wetlands to accommodate changing hydrology

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

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 changing climate. Hydrology is a leading driver of wetland character and function (Cowardin et al. 1979, Mark M. Brinson 1993, Tiner 2011) and so expected changes to hydrologic regimes, hydraulics, 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 and longer drought periods between rain events (USGCRP 2017). Some wetlands will be dryer and others may be wetter. 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 target 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 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 enhance 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 (Marchildon et al. 2016)(Sampath et al. 2015). 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 wetland buffers within at least the first 100 meters (328 feet) surrounding a wetland (Faber-Langendoen et al. 2016). Consider the following buffer characteristics to "slow the flow" and improve infiltration: 1) Maximize natural habitat or other cover types that are effective in slowing the flow (e.g., natural upland habitats and plant communities, vegetated levees, old fields, naturally vegetated rights-of-way); 2) Minimize land covers that offer little to no opportunities for rainwater infiltration and that accelerate water movement across the landscape (e.g., non-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 traditional golf courses); 3) implement proper road and construction maintenance and best management practices for forestry activities to control erosion.
2. In developed areas, install and maintain bioswales, rain gardens, large cisterns, and rain barrels alongside impervious surfaces (e.g., paved roads, parking lots), and install pervious pavers instead of continuous pavement (Jefferson et al. 2017).
3. In agricultural areas adjacent to wetlands, incorporate deep-rooted perennials or cover crops into fields via buffer strips to reduce runoff rates and improve infiltration (Union of Concerned Scientists 2017). Grassy waterways/swales and countour/strip cropping can also slow-the-flow, increasing infiltration rates (NRCS Field Office Technical Guides).
4. 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 (Lane et al. 2018)(Sampath et al. 2015).

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 already 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 and 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 spatially and temporally abandoned 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 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 2016).
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).
    - 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.
    - 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).
3. 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 (Yochum 2017), to reconnect floodplains adjacent to incised river channels.
4. 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).
5. 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).
6. Remove legacy sediment to restore hydrologic processes to aggraded floodplains and depression wetlands (Booth et al. 2009).
7. 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 form and restore hydrologic function of streams and ditches.

This approach targets wetlands connected to, or adjacent to streams, rivers and other flowing surface waters. As hydrologic regimes change, more extreme and variable precipitation is expected to alter the volume and rate of water entering wetlands (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 are shifting 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). Altered hydrology can degrade the structure and function of wetland ecosystems. Particularly vulnerable to degradation include wetlands receiving water from currently unstable or altered hydrologic networks, including channelized streams and ditches. Stream channel alteration often results after land-use changes and related changes in runoff (observed in agricultural and urban areas), but also when flows are regulated, and after the physical re-routing and straightening of channel form by humans. Channelized flow creates wider and straighter stream channels, increases flow velocity, and reduces overbank flooding to riparian wetlands

(Shankman 1996). Restoring and improving connections of networks can prepare wetlands to absorb additional climate-related stresses (Wohl et al. 2015).

Examples of adaptation tactics are:

1. Remeander 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. Resculpt functioning ditches to two-stage designs that mimic a floodplain to better handle large storm events by providing more consistent fluvial form and process, as well as greater channel stability (Powell et al. 2007a, 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, Olson et al. 2017)(SSWG 2008).

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 in dissolved oxygen levels and water chemistry (Whitehead et al. 2009), increases decomposition rates (Brinson et al. 1981), and shifts species composition including invasion by non-native species (Havel et al. 2014). Increased storm events resulting in greater runoff may increase heavy nutrient loading (Whitehead et al. 2009). This adaptation strategy applies to managing all wetland types, especially mesotrophic wetlands (e.g., fens) that are maintained by a delicate balance of inputs of groundwater, surface water, and precipitation; and oligotrophic peatlands (precipitation-dependent), and freshwater coastal estuaries and lagoons abutting oligotrophic lakes (e.g., Lake Superior). 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 continues to be exported 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, such as peatlands. Preserving peatland wetland function can improve long-term sequestration of CO_2 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 which is observed to be warming (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 and 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).

5. 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).
6. Reduce urban development and incorporate nature-based infrastructure and forested buffers near high quality, sensitive wetlands 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 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, particularly influxes of phosphorus (Reddy et al. 1999), reduces the water holding capacity of wetland soils (Gleason and Euliss 1998) and alters the rate of nutrient cycling (Marton et al. 2015)(Marton et al. 2015). Intensive land-use activities can significantly accelerate the rate and magnitude of erosion and sedimentation occurring on-site. As hydrologic regimes intensify, altering land-use zoning to protect wetlands, and implementing best management practices (BMPs) in forestry and agricultural operations will be of utmost importance to sustaining soils and 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). Suggested modifications or expansions of BMPs for climate change adaptation include:
   - 2.1. For forestry operations near wetlands, maintain “filter strips”, but consider expanding well beyond the minimum recommended size (e.g., 15-foot, WDNR 2010b).
   - 2.2. For forestry operations near streams, maintain a forested Riparian Management Zone (RMZ) beyond the minimum recommended size (e.g. 100 feet, WDNR 2010b). This is particularly important for headwater streams and associated riparian wetlands, which largely influence watershed water quality (Kaplan et al. 2008).
   - 2.3. In forested watersheds, maintain a buffer of mature forest in uplands adjacent to high-quality non-forested wetlands.
   - 2.4. 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).
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 Field Office Technical Guides) that holistically considers the effects of planting design, crop selection, discontinuous vegetative cover, tillage practices, nutrient management, pest management, and irrigation on the watershed. Examples:
   - 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.
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 (WWA 2018 - https://wisconsinwetlands.org/wp-content/uploads/2018/06/WetlandsFloodHazards_WWA_web.pdf).
5. Preserve and restore large-scale acreage of vegetation adjacent to wetlands (Houlahan and Finlay 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 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). For an example, see Dane County Wisconsin's initiative to remove legacy phosphorus as part of Yahara Chain of Lakes Clean Up (Dane County Wisconsin 2016).
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 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 P, or where water control structures exist manage water levels to promote aquatic macrophyte 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 (USDA 2014).
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 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 millenia 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 dynamism, resulting in changes in plant community structure and composition (Johnson et al. 2005). In identifying approaches that bolster wetland community structure, managers will need to consider woody species imbalances, altered microtopography, and diminished soil seed banks. Approaches relating to plant community composition emphasize quickly vegetating bare soil and limiting non-native invasive species while enhancing diversity of native species that are best-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 non-native 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 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, microtopography) are arranged both horizontally and vertically. Changing precipitation patterns and evapotranspiration rates are anticipated to decrease water levels in some wetlands, favoring woody species invasion and spread (Weltzin et al. 2003, Wisconsin Initiative on Climate Change Impacts [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 wetland hydrology. Conversely, flooding and elevated water levels can cause mortality of woody species, leading to conversion of shrub-dominated wetlands to open wetlands. Where feasible, maintaining historical 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. Herbaceous plants also play an important role in community structure. For example, microtopographical variation associated with tussock sedge (Carex stricta) plays an important role in supporting plant species diversity and richness in sedge meadow (Peach and Zedler 2006). Increasing sedimentation associated with changing precipitation patterns can reduce or eliminate this microtopography, facilitating invasions of non-native plants such as reed canary grass and lowering native species richness and diversity (Werner and Zedler 2002). 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, poorly timed 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).

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. In fire-dependent wetlands that are highly degraded by woody invasion, conduct mechanical or chemical brush removal prior to reintroducing fire.
3. 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.

4. Remove sediment 'overburden' to release existing wetland seed banks and restore sedge tussock microtopography (Zedler 2000, Beas et al. 2013).
5. In wetland restorations where hummocks would be an expected feature, roughen surface soil and construct hummocks before planting to mimick hummock microtopography, thereby facilitating wetland plant and bryophyte establishment (Peach and Zedler 2006, Caners et al. 2018) and increasing plant vigor during periods of low moisture (Doherty and Zedler 2015).
6. At wetland restoration sites, seed at higher densities than standard practices (NRCS 2013) to promote a robust soil seed bank. Conduct seed bank germination studies to identify species that are underrepresented (WDNR 2010a).

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

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 of the site may change and some species may be vulnerable or lost because they are at the southern extent of their range (Lawler 2009). Other species may be more vulnerable due to their dependence on a narrow range of site conditions. 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 (e.g., life history, growth form, nitrogen-fixing). 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). Promoting a soil seed bank with species that have diverse germination strategies will also 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. This can mean exceeding unofficial standard practices that practitioners follow or official performance standards such as those described by the Minnesota Board of Water and Soil Resources (MBWSR, 2017, page 7) or in the U.S. Army Core of Engineers National Wetland Plant List (USACE, Appendix B).
2. Adjust species lists for inclusive representation of various life forms (annuals/biennials, short-lived perennials, perennials), wetland rankings (FACW, FAC, OBL; USACE 2016), seed germination strategies, and phenologies to enhance plant trait diversity of wetland planting mixes or existing sites.
3. 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 nondegraded habitat.
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). 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.
6. Immediately secure bare soils[2] after seeding/planting by using erosion control fabric or weed-free mulch certified by Wisconsin Crop Improvement Association. Seed fast-growing cover crops to further secure substrates (e.g., wild rye [*Elymus* spp.]) and to protect slower-growing native planted species from the

[2] *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.*

elements and competition. Avoid legume cover crops to limit nitrogen inputs that encourage non-native invasives and low diversity plantings.

7. 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*).
8. 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.]).
9. 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).
10. Promote phenological diversity by conducting prescribed burns in different seasons (Middleton 2002).
11. Restore tussock sedge (*Carex stricta*) in degraded wet meadows. Tussocks provide microsite complexity and thus contribute to floristic diversity (Peach and Zedler 2006).
12. In Alder Thicket and Shrub-carr, maximize diversity of native wetland shrub species by planting whips of under-represented species (NRCS 2003, MBWSR 2012).
13. Encourage research on "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. 2018).

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 (Beth 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 cat-tails (Typha spp.) results in reduced water depth; 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, Beth 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 non-native invasive species establishment and limit their impacts where they already occur

Non-native 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 cat-tails 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 invasives 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 prioritize which species to eradicate and which species to allow to occupy a site

Examples of adaptation tactics are:

1. Careful observation of on-the-ground phenological cues to identify appropriate treatment windows for invasives (rather than following calendar dates) is essential as phenologies shift with climate change. For example, 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).
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 non-native invasives.
4. Follow recommendations on the WDNR webpage “Wetland Invasives Best Management Practices,” particularly the following:
    - 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.
5. Control and report new invasives or unknown species that are spreading aggressively to the Early Detection and Distribution Mapping System (EDDMapS Midwest [https://www.eddmaps.org/midwest/]). Learn what species are likely to appear in your wetlands at the Midwest Invasive Plant Network website (https://www.mipn.org/).
6. Seek out funding or assistance for rapid response to new invasions by viewing the Midwest Invasive Plant Network website (https://www.mipn.org/; “Grants” and “CWMA Resources” menus).
7. Provide cleaning stations for heavy equipment that are used in response to large-scale disturbances such as wildfire and flood events.

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.

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, priorities for management include: 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. Manipulate water levels to manage invasives when feasible.
12. Reduce dominance of non-native invasives by promoting their usage for subsistence lifestyles, e.g., harvesting narrow-leaved or hybrid cattail rhizomes and watercress.

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

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 or end points 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). This strategy seeks to enable transitions of species and communities to new desirable states while maintaining overall wetland functions (Harris et al. 2006).

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 is fraught with risk, 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). Moving species within their current or historic range 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.

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). Examples include:
    - 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*)

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). These may include:

   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*)
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. Look to nature for candidates, such as native species associated with Michigan's Inland Salt Marsh natural community (Albert 2001):

   Strong halophytes:
   - prairie cord grass (*Spartina pectinata*; 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*)

4. 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).
5. Employ the NatureServe Climate Vulnerability Index to assess vulnerability of individual species to climate change (http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index). Favor and restore species that have low vulnerability rankings.
6. Utilize the U.S. Fish and Wildlife Service’s Risk Assessment Mapping Program (RAMP; Sanders et al. 2014) in ArcGIS to map species-specific suitability to climate scenarios (this program was developed to identify future suitable habitats for non-native invasive species, but could also be applied to natives).
7. 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).

Approach 4.2: Increase genetic diversity of seed mixes

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. 2018).

Examples of adaptation tactics are:

1. Employ 'regional admixture provenancing' by collecting seed from several wild sources (e.g., five or more) within a defined seed zone (Bucharova et al. 2018). 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).
2. Refer to provisional seed zones (Bower et al. 2014) as coarse-level boundaries for regional admixture provenancing. Provisional seed zone maps and GIS shapefiles for the United States are available at https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMapper.php. Empirically designed seed 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). Tremendous uncertainty surrounds the likelihood for success in such relocations, and a high failure rate 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 dire situations where assisted migration will forestall eminent 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 3.2.5 and 3.2.6).
2. Use the Wisconsin Initiative on Climate Change Impacts (WICCI) Climate Interactive Mapping Tool to project how a specific geography's climate will resemble that of another region (known as a climate analogue) under various climate scenarios (http://www.wicci.wisc.edu/climate-map.php).
3. Utilize tools and resources devised for developing seed zones to identify appropriate geographic ranges for assisted migration (see Tactics 4.2.1 and 4.2.2).
4. 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 structure 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. Certain actions, however, 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, 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 4.2.1 above).
2. Limit the dominance of species that are maladapted to projected future conditions to ensure long-term vegetative cover.
3. Allow patches of native shrubs to invade wetlands to promote microsite and species diversity.
4. 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.
5. Plant important native or non-invasive non-native plants to maintain food sources for wildlife.
6. Where eradication is not feasible, periodically burn and mow non-native invasives to limit their impact.

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 non-native 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: Adjust 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 cattails (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 (Bejerano 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 (Bejerano 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.

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. 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 (Natural Resources Conservation Service [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.
2. Work with a water resource engineer to 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).
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 (International Institute for Sustained Development [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 (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 actions for adapting infrastructure that influences wetland ecosystems such as road-stream crossings, bridges, culverts, and dams. Some infrastructure features may affect hydrology by concentrating water into flow pathways that generate high-velocity runoff and erosion. A changing climate and altered hydrology may necessitate critical evaluation of past design concepts and criteria to minimize long-term risks over the designed lifespan of installations.

Approach 6.1: Reinforce infrastructure to meet expected conditions

Examples of adaptation tactics are:

1. Replace undersized culvert with a bottomless culvert following the stream simulation design, to allow for sediment and debris to safely pass during a higher flows or floods (USFS 2008, Barnard et al. 2015).
2. 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).
3. On low-volume roads or trails convert culvert to 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

Examples of adaptation tactics are:

1. Relocate field roads to improve degraded quality of wetland and riparian areas (Daigle 2010).
2. Reroute field roads out of floodplains.
3. Reroute heavily trafficked and high-risk trails or field roads or those with past issues related to saturated soils.

Approach 6.3: Incorporate natural or low impact development into designs

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).
2. Reduce and disconnect impervious surfaces from storm water system (such as eliminating curbs, gutters), replacing with swales or filter strips (Ahiablame et al. 2012).
3. Attenuate and treat stormflows in depressional areas, using bioretention systems to capture runoff, recharge groundwater, plant evapotranspiration of water, and reduce pollutant loads (Ahiablame et al. 2012).

Approach 6.4: Remove infrastructure and readjust system

Examples of adaptation tactics are:

1. Decommission and revegetate unnecessary roads or trails with high risk and low access.
2. Remove levees that increase flood stage and flow velocity to restore riparian ecosystem reconnecting the channel and floodplains.
3. Decommission infrastructure to allow stream channel to migrate within floodplain.

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