Alberta Guide to Wetland Construction in Stormwater Management Facilities

December 2018

Title:	Alberta Guide to Wetland Construction in Stormwater Management Facilities
Number:	AEP, Water Conservation, 2018, No. 4
Program Name:	Water Policy Branch
Effective Date:	December 1, 2018
This document was updated on:	
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Purpose

The Alberta Guide to Wetland Construction in Stormwater Management Facilities provides guidance on how to construct wetland habitat within a stormwater management facility.

Policy Context

This guide supports the Alberta Wetland Policy. Where permanent wetland impacts cannot be avoided or minimized, wetland construction is one type of wetland replacement that can maintain wetland area and relative wetland value in Alberta.

Reference Documents

- Directive for Permittee-Responsible Wetland Construction in Alberta
- Alberta Wetland Mitigation Directive
- Alberta Wetland Restoration Directive
- Alberta Wetland Classification System
- Alberta Wetland Identification and Delineation Directive
- Professional Responsibilities in Completion and Assurance of Wetland Science, Design, and Engineering Work in Alberta

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Citation

Government of Alberta. 2018. Alberta Guide to Wetland Construction in Stormwater Management Facilities. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta.

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1. Introduction

The wetland mitigation hierarchy is a key component of the Alberta Wetland Policy's goal to "conserve, restore, protect and manage wetlands to sustain the benefits they provide to the environment, society and the economy." The highest priorities of the wetland policy are to conserve and maintain wetland area and value by avoiding or minimizing impacts to wetlands. However, where permanent wetland impacts cannot be avoided or minimized, wetland construction is one type of wetland replacement that can be used to offset the loss of wetland area and value in Alberta. A constructed wetland can support water storage demands, improve water quality to downstream waterbodies, provide wildlife habitat for a diversity of species, and provide social and cultural values to Albertans.

This document provides guidance on wetland construction practices in stormwater management facilities based on scientific and practical knowledge and experience gained across Canada. By following this guide, a wetland construction project team will be able to create a healthy, functioning, and self-sustaining (or low maintenance) marsh or shallow open water wetland with a seasonal to permanent hydroperiod.

This guide may be used in conjunction with other Alberta Wetland Policy documents, such as the Directive for Permittee-Responsible Wetland Construction in Alberta, which outlines regulatory requirements for meeting permittee-responsible wetland construction.

1.1. Constructed Stormwater Facility Wetland Overview

Wetland construction refers to the creation of new wetland areas through the following actions:

- Re-contouring the topography of land, including placement of materials and soils, to a natural wetland shape with slopes and elevations that will allow wetland soil development and vegetation establishment
- Planning hydrology to establish and maintain appropriate water depths and hydroperiod to promote the growth and establishment of self-sustaining wetland plant communities
- Seeding and planting of suitable native upland and wetland species in appropriate water depths
- Incorporating wildlife habitat structure within or near to the wetland
- Incorporating human use features

1.2. Stages of Wetland Construction in a Stormwater Management Facility

This document will guide a wetland construction project team through the site assessment, design, construction, commissioning, monitoring and maintenance of a constructed stormwater facility wetland (CSFW).

- **Site Assessment** (Section 2): Local site conditions, including the hydrology, existing topography, soil availability and quality, and flora and fauna in the area that will influence the design of a CSFW and reveal site constraints and opportunities.
- **CSFW Design Plans** (Section 3): The design of a CSFW should consider physical topography of the wetland, including quality, quantity and placement of soils, the hydrologic and hydraulic design, plant community structure, diversity and composition, wildlife habitat structure, and human amenities and values. The design considerations should support wetland functions and values related to hydrology, water quality improvement, biodiversity, and human use. The CSFW should be designed to require minimal or no maintenance.

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- **Construction** (Section 4): The physical construction phase follows the design plan. Construction planning and timelines should ensure best practices to minimize impacts to soils, vegetation and wildlife during the active construction period.
- **Commissioning, Monitoring and Maintenance** (Section 5): Commissioning refers to the processes and time required to establish wetland hydrology and plant communities. During this period, the CSFW should be monitored to identify site problems and stressors, and adaptive management actions should be employed as necessary. Monitoring provides data and information to evaluate and track wetland characteristics and performance measures over time. Performance measures are proxies of wetland condition or health and can inform adaptive management and maintenance.

1.3. Team Members

Professionals responsible for authenticating CSFW projects for regulatory purposes ensures their team collectively meets the competencies identified in the Professional Responsibilities in Completion and Assurance of Wetland Science, Design, and Engineering Work in Alberta. A wetland construction team may consist of a multi-disciplinary team from a broad range of professional fields: the roles of two principle team members, engineers and biologists, are described below.

1.3.1. Engineers

Engineers are principally involved with site assessment and design of the CSFW, and may include a storm water engineer, civil engineer and geotechnical engineer. Their key roles include assessing the pre-development hydrology and geotechnical analysis to determine whether the site has a reliable water source to support a self-sustaining or low maintenance wetland, and designing the topography, hydraulics, and hydrology in collaboration with other team members.

1.3.2. Scientists (biologists, soil scientists, agrologists, hydrogeologists)

Scientists are involved throughout the life cycle of a CSFW project from site assessment to monitoring and maintenance, and may include wetland specialists, soil scientists, hydrogeologists, agrologists, botanists, and wildlife biologists. They must have a strong understanding of physical, chemical and biological characteristics of wetlands, including hydrology, soils, and vegetation. They must have expert knowledge of the variability of wetland characteristics in the region, and of the growth characteristics and habitat requirements of regional flora and fauna. They will also be able to apply their knowledge of natural wetlands into the design of a CSFW with minimal to no maintenance.

2. Site Assessment

Not all sites are suited to wetland development and should be evaluated before any design or construction takes place. A thorough review of existing conditions will identify constraints related to topography, hydrology, soils, biology or other factors such as zoning or surrounding land uses. This section is intended to help the wetland construction project team gather information and evaluate factors that may limit or contribute to site suitability, and that will influence the site design. A summary of the site assessment components is provided in Table 1.

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Table 1. Overview of pre-development site assessment components and considerations.

Component	Reporting Requirements
Site location	Determine land ownership, municipal zoning codes, and proximity to existing utilities, roads, infrastructure
	Assess whether there are conflicts associated with existing infrastructure or utilities
Landscape position and site characteristics	Develop a map of the wetland's pre-development catchment area and describe the topographic setting (e.g., headwater)
	Identify constraints or considerations associated with the landscape position and site characteristics (e.g., steep slopes, ridge, isolated low areas)
	Identify and verify surrounding land uses within the catchment area and upland habitat land cover types and any known problems with invasive species
Hydrology	Identify pre-development drainage patterns in the catchment area
	Develop preliminary pre-development site water balance to assess whether there is sufficient water to sustain a CSFW
	Review available data to determine if the site is connected to a groundwater supply (e.g., perched, local groundwater table, regional groundwater fed, groundwater variability)
Soils	Describe available soil materials on site and whether they have potential use in the construction design. Soil pits are recommended to determine texture, soil profile and characteristics. Soil samples and analysis are recommended to evaluate nutrient content, salinity
Water chemistry	If available and relevant, review any available water quality information for source waters (surface and groundwater)
Upland plant communities	Identify existing upland plant communities and habitat connected or adjacent to the wetland site
Wildlife habitat connectivity	Identify existing wildlife habitat connected or adjacent to the wetland site.
Human use	Identify pre-development human use features in or adjacent to the planned wetland.
Risks, conflicts and constraints	Identify potential risks and conflicts associated with wetland development at the site (e.g., downstream landowner concerns, impacts to groundwater supply, regulatory or jurisdictional concerns, flooding, slope stability, water supply, or insufficient data).
	Identify sources of sedimentation and erosion, and potential issues.

2.1. Existing Topography and Catchment Area

The pre-development catchment and local topography will inform the post-development design. Wetland location, size, shape, grades, slopes, depths, location of inlets and outlets, plant communities, physical features, hydraulics, and hydrology will all be influenced by the existing conditions and characteristics of the site. The following questions should be considered in the site assessment:

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- Is the site in a geomorphological position where water will flow by gravity into the proposed CSFW? If not, will grading enable this?
- How will topography influence how water is conveyed from the catchment area to the site?
- Will the potential catchment size sustain a wetland relative to the size, shape and topography (e.g., elevations, slopes) of the existing site?
- Are there any topographical constraints, such as ridges, isolated low areas, or channels?
- What areas within the CSFW will allow wetland development?
- What and where will erosion and sedimentation pose a risk?

2.1.1. Slopes

Existing slopes should be examined to determine if the site can be developed as a wetland. Wetland slopes should be sufficiently gentle (e.g., ≥ 7:1) to support revegetation. Considering the following questions would be beneficial to the site assessment:

- If slopes need to be re-contoured, how will this change the catchment size, CSFW footprint and other needs of the site, such as water storage capacity within a storm water facility?
- If land is not available to regrade the whole perimeter of the wetland, are there opportunities to regrade on one or a few sides?

2.1.2. Water Source, Drainage Patterns and Inlet Constraints

The local topography influences how a catchment area will drain into a CSFW. Generally, the site needs to be within a depressional area after site grading. Precipitation or groundwater alone will not be enough to support a wetland.

Surface water inputs in CSFWs are either conveyed by overland systems such as channels or ditches, or by subsurface systems such as pipes. Pipes require a minimum depth of cover, and unless a pump station is used, surface water runoff will need to flow into the CSFW by gravity. The following questions should be considered in the site assessment:

- What is the gradient and imperviousness of the catchment area?
- Are there portions of the catchment that cannot drain to the site by gravity? Is pumping a viable option?
- Where and how many inlets are anticipated based on the catchment topography? Where would these inlets be located?
- Are there portions of the catchment that will drain to the site via overland conveyance versus piped conveyance? How might this change under higher or lower flows?

2.1.3. Outlet Constraints

A CSFW will typically have an artificial outlet, such as a storm sewer or channel, that eventually discharges to a downstream water body (e.g., river, creek, lake). The site assessment should identify potential outlet(s) and associated constraints. The CSFW will require an appropriate internal gradient to allow for water at the inlet to flow to the outlet, while allowing for adequate retention time within the CSFW. At the site assessment stage, the following questions should be considered:

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- Is there a downstream waterbody within reasonable proximity to the project that the water can be transported to?
- Is there enough capacity at the identified downstream waterbody to receive water from the CSFW?
- Are there regulations in place (e.g., volume control target) which limit or prevent discharge to the identified downstream waterbody?
- Is there an adequate location to construct an outlet?
- Are there elevation constraints that will impede gravity discharge to the identified outlet(s) and downstream water bodies (e.g., outlet elevation is close to or higher than desired normal water level or is higher than the inlet)?

In stormwater facilities, an outlet structure must be able to stabilize the NWL, simplifying the hydrological assessment and enabling designers to predict the range of operating levels. It is preferred that the outlet can drain the wetland an additional 30 - 60 cm below the NWL to facilitate germination of wetland plants.

2.2. Hydrologic Assessment

Sufficient analysis should be completed in the site assessment to confirm there is sufficient inflow and outflow to provide and maintain a hydrologic regime that will sustain a wetland and its processes, habitats, and species diversity.

As shown in the equation below, the change in water storage (ΔS) is based on direct precipitation (P), runoff (R), direct evapotranspiration (ET), groundwater flux (GW), outflows (O) and other inputs (Q_{in}) and outputs (Q_{out}).

$$\Delta S = (P + R + GW_{in} + Q_{in}) - (ET + GW_{out} + O + Q_{out})$$

A hydrologic assessment may include development of a continuous simulation water balance model based on the available period of record. A sensitivity analysis is recommended if there is uncertainty associated with specific model parameters, such as groundwater flux or sublimation. If the site is influenced by groundwater, a hydrogeologist may quantify groundwater flux and provide input on how this may change as a result of development.

2.2.1. Surface Water

Surface water can contribute inflow to the constructed site via runoff (R) and as precipitation falling directly into the wetland (P). A site assessment will quantify anticipated inflow from surface water. In Alberta, snowmelt constitutes the primary source of freshwater to wetlands (Su 1998); however, losses due to snow interception and sublimation should be considered, as this can significantly impact the available water from snowpack.

At the site assessment stage, it is important to consider both existing (pre-development) and potential (post-development) runoff. At sites where a natural wetland is being altered, integrated or replaced with a CSFW, an evaluation of existing runoff is recommended. This will enable the team to design and build a wetland that preserves the natural hydrology to the greatest extent practicable. Physical characteristics that affect runoff include annual precipitation, land use, vegetative cover, catchment area, imperviousness, and conveyance infrastructure.

2.2.2. Groundwater

Groundwater recharge refers to the process of water moving from the ground surface to below ground, contributing to water outputs from the wetland. Groundwater discharge is the process of water moving from below ground to the surface, contributing to water inputs to the wetland. Groundwater may need to be considered in a site water budget if the project is connected to the groundwater table by permeable soils, although the CSFW may be capped

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or lined to prevent groundwater interactions. More information is available at Alberta Environment and Parks' Groundwater Information System website.

2.2.3. Outflow

Outflow (O) includes water that exits the site from either an outlet structure or an emergency overflow.

2.2.4. Evaporative Losses

In sites without a fixed outlet, evaporative losses may represent the primary output from the site. While evapotranspiration rates are often reported as potential evapotranspiration (PET), actual evapotranspiration (ET) can be much less than PET.

2.2.5. Other Inputs and Outputs

Other inputs and outputs (Q_{in} and Q_{out}) include any direct flows either to or from the site which are not included in the above variables. This may include water loss due to soil permeability or human use, such as pumping for irrigation or firefighting.

2.3. Soil Assessment

A soil assessment at the site and at any soil donor sites should consider physical, chemical, and environmental factors that could impact success. The site assessment will include digging a soil pit to determine the soil profile, and soil analysis to determine percent organic matter, nitrogen and phosphorus content, macro- and micro-nutrients, soil texture, salinity and cation exchange capacity (CEC). These tests will inform substrate and soil design plans, including whether organic material needs to be added to the CSFW. Soil texture influences the soil permeability and thus its water holding capacity. Soil structure and chemistry, including salinity and organic and nutrient contents in the soil, will influence the ability of the wetland to support plant growth and affect plant abundance and composition (Ross & Gabruch 2015). Sedimentation rates will influence the development of the plant communities over time.

The soil site assessment should consider the risk of erosion and sedimentation from within the catchment area to the constructed site. Soil trafficability, the ability of the soil structure to support heavy equipment, varies by soil texture and should be considered in construction planning to prevent effects of soil compaction from heavy equipment. The soils at both the existing site and any donor soils should be evaluated for potential weed sources.

If the biologist or engineer does not have the expertise to conduct soil assessments, a soil scientist should be part of the project team. Table 2 provides chemical and physical guidelines for the successful establishment of soils in CSFWs.

2.3.1. Soil Properties

The recommended soil textures for wetland construction by the USDA are sandy loam (SL), fine sandy loam (FSL), silt loam (SiL), or loam (L). Additional guidelines for soil parameters are provided in the Soil Quality Criteria Relative to Disturbance and Reclamation by Alberta Agriculture, Food and Rural Development (2004).

Mineral wetland soils have a lower percentage of pore spaces (e.g., 45-55 % compared to >80%) and a higher bulk density than organic soils. Heavier and more compact particles within a soil (i.e. OM < clay < silt < sand) have a higher bulk density. As a result, the soil type in CSFWs will influence the susceptibility to compaction and erosion. (Ross and Gabruch 2015). Substrate suitability for plant growth can be tested by a penetrometer, an instrument for determining the consistency or hardness of substance, or by measuring bulk density. Penetrometer resistance

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should be between 10 and 15 bars (or kg cm^3), and soil bulk densities should have an organic matter content of > 5% should be below 1.35 g cm^3 for clay soil and 1.6 g cm^3 for sandy soil.

Table 2. Recommended surface soil and subsoil characteristics and placement protocols for CSFWs (Ross & Gabruch 2015).

Rating/Property	Good (G)	Fair (F)	Poor (P)
pH	6.5 to 7.5	5.5 to 6.4 and 7.6 to 8.0	4.5 to 5.4 and 8.1 to 8.5
Salinity (dS/cm)	< 2	2 to 4	5 to 8
Sodicity (SAR)	< 4	4 to 8	9 to 12
Texture[1]	FSL, VFSL, L, SL, SiL	CL, SCL, SiCL	LS, SiC, C, S, HC
Moist consistency	very friable, friable	loose	firm, very firm
Organic Matter (%)	> 12	≥ 5	< 5
Bulk Density	< 1.35 g cm^3	< 1.45 g cm^3 (clay soils) < 1.60 g cm^3 (sandy soils)	> 1.61 g cm^3
Available Rooting Zone (cm) (Surface soil + subsoil)	≥ 70	40 to 70	< 40

2.4. Biological Assessment

A site assessment of the existing flora and fauna will help answer the following questions:

- Are there opportunities to incorporate existing wetland species on-site?
- What are the opportunities for and risks of using locally sourced plant propagules or other donor materials?
- Can the site connect to existing natural habitats and features?
- Are there timing-restrictions for construction activities related to sensitive wildlife species?

2.4.1. Locally Sourced Wetland Plant Species for Propagation

Opportunities may exist for vegetating newly CSFWs using locally sourced live plant material, donor soils, and wetland seed.

A detailed species inventory can determine if existing wetland vegetation has potential as a donor site. Excellent donor sites contain a diversity of wetland plants, including species that may be difficult to establish from seed (e.g., some *Carex* species). Weeds and invasive plants in the potential donor site should be assessed, identified and mapped. Soils from these sites should not be used; however, wetland seeds can be collected from a donor site if the collection process can avoid contamination by weedy species.

[1] Clay (C), silt (Si), sand (S), loam (L), clay loam (CL), sandy loam (SL), fine sandy loam (FSL), very fine sandy loam (VFSL), sandy clay loam (SCL), silty loam (SiL), silty clay (SiC), silty clay loam, loamy sand (LS), hard clay (HC).

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An assessment of suitability of donor soils and plant propagules should consider the following questions (Ross et al. 2014):

- Will the plant species present in the donor soils suit the flooding depths of the CSFW?
- Do the donor soils provide enough species diversity?
- Are there invasive or weed species within the donor soil?
- Do the physical and chemical characteristics of the donor soil match the site characteristics for the CSFW?

2.4.2. Incorporating Natural Habitats

Site investigations, combined with a review of current and historical aerial photography, will help identify opportunities to incorporate existing natural habitat into the CSFW design plan. Wildlife use and plant establishment are influenced by the following factors:

- Proximity to the nearest natural habitat or wetland
- The distribution of aquatic, riparian, and terrestrial habitats within an area
- Riparian zones
- Connectivity to other habitats

The distance to the nearest wetland should be recorded and referred to when selecting wetland habitat features for a particular taxa or guild (e.g., invertebrates, amphibians, waterfowl, songbirds, raptors and mammals). In general, the amount of natural habitat within a 2 km radius of a potential CSFW is usually a good measure for genetic exchange and species dispersal for many wetland organisms (TRCA 2007).

Availability and distribution of natural habitats is important for wetland-associated wildlife species who use multiple habitat types for their life stages. For example, Scheffers and Paszkowski (2013) found that native upland habitats within 100 m of CSFWs improved the occurrence of breeding amphibians. Upland or riparian habitats next to a wetland (i.e. buffer or setback) provide important aquatic and terrestrial habitat as well as water storage, flood control and water quality improvement. Stepping Back from The Water (AERSD, 2012) provides guidance on setback distance and minimum corridor widths for conservation of wildlife habitat in Alberta lakes, rivers, streams and wetlands.

Ecological connectivity refers to the connection of two or more areas of functional habitat that facilitate wildlife movement between habitat patches. Site assessments should include surveys of natural existing habitats adjacent to the proposed wetland site. Opportunities to include or introduce these habitats within the wetland design will increase wildlife establishment and use of the area.

2.4.3. Inventory of Weedy and Invasive Species

An invasive species management plan based on the site assessment should be developed. Poor weed control prior to and during construction and commissioning can result in the establishment of weedy species, especially in the first few years following site development. Incorporating upland buffers of native perennial species around a CSFW during the design phase will help reduce weedy and invasive species.

2.5. Water Quality

A well-designed CSFW can retain sediments in the vegetated wetland zones and upland buffer areas by dispersing water and reducing water velocity.

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Due to the environmental and maintenance concerns that high sediment loading in a storm water system can cause, many jurisdictions set guidelines for Total Suspended Solids (TSS) in constructed storm water wetlands. The Canadian Council of Ministers of the Environment (CCME) set guidelines for maximum increases of TSS for regular and high flow events based on background levels (CCME 2002; Table 3). Background levels for TSS should be investigated as part of the site assessment to guide the design parameters that will encourage sediment removal.

CSFWs can contribute to the reduction of phosphorous and nitrogen, heavy metals, pesticides and pathogens when designed to encourage a high rate of biological activity. Setting target levels for nutrients, heavy metals, pesticides and pathogens for CSFWs is not recommended. Unlike wastewater treatment systems that are highly engineered to provide predictable and regulated water quality, the contaminant concentrations in a CSFW should be much lower and more variable, depending on the hydrological design, the amount of hard surface runoff entering a system, and potential local pollution sources.

If the CSFW will discharge into receiving waterbodies, baseline water quality from the receiving waters should be determined to ensure that these values will not change post-construction. Water quality parameters may include the following:

- Total suspended solids
- Total dissolved carbon
- Total carbon (inorganic and organic)
- Kjeldahl nitrogen (dissolved and total)
- Phosphorus (total dissolved and total reactive)
- Conductivity, hardness, pH, total dissolved solids and alkalinity
- Ammonia, bicarbonates, carbonates, chloride, hydroxide, nitrate, nitrite, sulfate, calcium, magnesium, potassium, silicon and sodium.

Table 3. Water quality guidelines for total suspended sediments for the protection of aquatic life (CCME 2002).

Event periods	Guideline value
Background (clear) flow periods – the period when background TSS levels can be determined and are site-specific.	Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 hours and 30 days).
High flow periods – determined on a site-specific basis, during spring freshets and storm events.	Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is > 250mg/L.

3. CSFW Design Plans

Wetland characteristics that are fundamental to the success of a CSFW are physical topography, soil texture, hydrology, and plant community structure and diversity. It is important that the physical topography, and post-development or post-reclamation hydraulics is designed appropriately and accurately to support hydrology that reflects the natural range of variability of marshes and shallow open water wetlands in Alberta. Achieving hydrologic conditions within the natural range of variability will facilitate wetland soil development and wetland plant species establishment.

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The goal of a CSFW is to enhance the ecological functions and values of a post-development or post-reclamation site by creating self-sustaining, diverse and healthy wetland plant communities, and habitat structure and connectivity. Secondary goals are water quality improvement through enhanced retention or removal of sediments, nutrients and contaminants, and social and recreational value to humans.

Table 4 provides a summary of the design objectives, guidelines and performance measures. Table 5 provides a summary of design drawings for constructing a wetland.

Table 4. Wetland design objectives, guidelines and performance measures for constructing a CSFW.

Design Component	Objective	Design Guidelines and Performance Measures
Physical Design and Basin Topography	To create physical conditions that will promote establishment of plant cover and diversity for both water quality improvement and habitat structure for organisms. Design will vary according to the wetland class and type that is being constructed	• No less than a 3:1 length to width ratio; or incorporate other features (e.g., peninsulas) to increase the flow path. • Of the whole site, a minimum of 35% of the area designed at multiple depths between 0 and 60 cm to support growth of hydrophytic plants; +/-5 cm design tolerance • Slope designed to support wet meadow and emergent plants is 7:1 or gentler and is optimally 10:1 or gentler • Slope designed to support upland and riparian vegetation is 5:1 or gentler and optimally 7:1 or gentler • Minimum Shoreline Development Index (SDI) value of 1.2
Hydrologic Design	Design should support a natural-like wetland hydroperiod and water levels that will promote formation of hydric soils, establishment of hydrophytic vegetation, and support of biological processes and organisms adapted to wetlands.	• Reliable water source to support wetland development • Volume supports site water balance • Multiple water depths between 0 and 60 cm at NWL • Inlet and outlet separated by longest distance to increase flow path and detention time • Control structure to manipulate water levels and maintain discharge rate • Water levels lowered after storm surge to NWL to minimize stress or loss of plant species • Allow periodic exposure of soils in wet meadow and emergent zones to promote germination during construction and commissioning
Plants Communities and Habitat Structure	To establish plant cover and diversity for both water quality improvement and habitat structure Design will vary according to the designed hydroperiod, soils, vegetative structure.	• Target at least 20 native wetland vegetation species • Designed to have 35% to 65% ratio of vegetation to open water coverage • Vegetated wetland plant communities have a minimum total cover of 75% • Target a maximum of 10% cover and Class 5 or less density/distribution of invasive species in all vegetated wetland zones • Emergent zone water depth from 10 cm to 60 cm. • Create a minimum average emergent zone width of 5 m for Class V wetlands and 10 m for Class III and IV wetlands • Wet meadow zone water depths ≤ 10cm

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Design Component	Objective	Design Guidelines and Performance Measures
		• Create a minimum average wet meadow zone width of 8 m for all wetland classes
Wildlife Features	Create appropriate habitat for native species, including specific species, guilds, taxa. Specific objectives will depend on local and regional climate, ecology, and species as well as the designed hydroperiod, soils, vegetative structure.	• 43 - 54 plants/m^2 in upland • Minimum 30 m of native upland buffer with plant cover > 10 cm tall • Plant a diversity of native perennial vegetation (a minimum of three species) • Design plant benches and peninsulas • Incorporate at least one of the following: • Sandbars and gravel bars • Install woody debris, rocks and other material at least 10 cm in diameter in water depths > 0.5m • Place downed wood > 2m long, diameter >10cm, not persistently submerged, at least one piece per ha. • Install or maintain snags > 20cm in diameter, within 10m of the wetland edge, > 2 snags per ha
Human Use Features	Create amenity for the public, incorporating educational, recreational, social and environmental values.	• Maintain majority of trails at least 30 m away from the wetland edge • A maximum area of 10% of the wetland has trails constructed within 10 m of the wetland extent • Create vantage points from trails, residential streets and parking lots, trails • Restrict trails to walking and biking • Signs that pets must be kept on a leash • Soil, vegetation and wildlife best management practices • Create interpretive signage, brochures, tours, educational centres and programs (recommendation only)

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Table 5. Figures and drawings associated with a CSFW design.

Figures/Drawings	Requirements and information
Post-development catchment	• Catchment-scale drawings of pre- and post-development catchment area and drainage patterns
Site Plan view	• Wetland dimensions and calculated wetland area between NWL and two metres below NWL
	• Grades of all wetland and upland areas, peninsulas, benches, slopes, and any other habitat design features
	• Wetland Plant Community zones with widths and percent slopes, with species lists for each zone and proposed depths
	• Access and human use infrastructure (e.g., paths, boardwalks, signs)
	• Piped and overland conveyance systems (inlets and outlets) and control structures with information on dimensions, material type, bedding, slope
	• Operating levels (e.g., NWL, HWL), facility area and volumes
Cross-sectional drawings	• Wetland Plant Community zones with widths and percent slopes
	• Piped and overland conveyance systems and control structures with information on dimensions, material type, bedding, slope

3.1. Physical Design and Basin Topography

The physical measurements of a wetland need to be designed with engineered drawings and adjusted in the field based on site observations, as slight changes in topography, slope and water depth may alter the growing conditions enough to limit or eliminate growth of wetland plants.

3.1.1. Catchment Area and Site Grading

For some sites, the catchment area may change dramatically because of site grading. This is an important consideration, especially when there is an opportunity to influence site grading to optimize wetland performance.

3.1.2. General Design and Shape

Natural wetlands vary in size, shape, basin morphology, substrate type, hydrology, vegetation, wildlife communities, depth, and amount of open water (Mitsch & Gosselink 2007). A natural shape will increase the likelihood that the CSFW is self-sustaining, higher functioning, more aesthetically pleasing, and resilient to disturbances (Eaton et al. 2014a). The shape of every constructed storm water wetland may vary according to the land configuration, surrounding land uses, previous site activities and site topography. A minimum width of 40 m is recommended to ensure there is adequate land for vegetation, open water zones, and retention time.

Some design features that can enhance wetland functions include wide benches at appropriate depths for plant development, peninsulas, and gravel or sand bars. Construction of islands, dykes and berms are not recommended because they are difficult to construct with accuracy, present challenges for revegetation, and provide little water quality improvement. The design team must consider the influence of these features on hydraulic design and constraints to flow, particularly for a constructed storm water wetland.

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3.1.3. Length to Width Ratio

A CSFW should be designed to have a length to width ratio (L:W ratio) of at least 3:1 to slow water flow and increase the sediment settling and breakdown and sequestration of contaminants. Length is measured as the linear distance along the wetland's main flow path from the inlet to the outlet, and width is measured as the average distance across the NWL of the wetland.

If achieving this ratio proves challenging, other design features such as vegetated peninsulas and bays can help to lengthen the travel path of water from inlet to outlet. Only peninsulas planted with emergent vegetation will slow the flow and improve water quality. These features also help support wildlife and aquatic diversity within the system. Many storm water facilities have rectangular shorelines; however, this shape is poorer at all other functions and values other than water storage in comparison to CSFWs (Buttleman 1992).

3.1.4. Shoreline Index

Natural wetlands have irregular as opposed to straight or linear shorelines. Increased shoreline complexity increases the surface area of the site available for plant community establishment and thereby increases the amount of available wildlife habitat (Buttleman 1992, ALCRC 1992, Eaton et al. 2014a).

Shoreline development index (SDI) is a ratio of the perimeter of a wetland to the perimeter of a circle of the same area as the wetland (Hutchinson 1957); it can be used as a measure of the irregularity of the shoreline.

$$Shoreline\ development\ index\ (SDI) = \frac{wetland\ perimeter}{2\sqrt{\pi}(wetland\ area)}$$

The SDI of a circle has a value of 1, with higher SDI values having increasing complexity. Based on research by Ducks Unlimited Canada on over 1000 marshes in the prairie pothole region of Alberta, Saskatchewan and Manitoba, SDI values range between 1.1 and 2, with the 50th percentile at 1.2. Figure 1 shows varying shoreline complexity of natural wetlands in Alberta and their accompanying SDI value for reference. Shoreline complexity can be increased with the incorporation of peninsulas, bays, inlets and sand or gravel bars. The design team should consult with the construction specialist on shoreline design, as the level of complexity that can be attained may be limited by equipment and other factors.

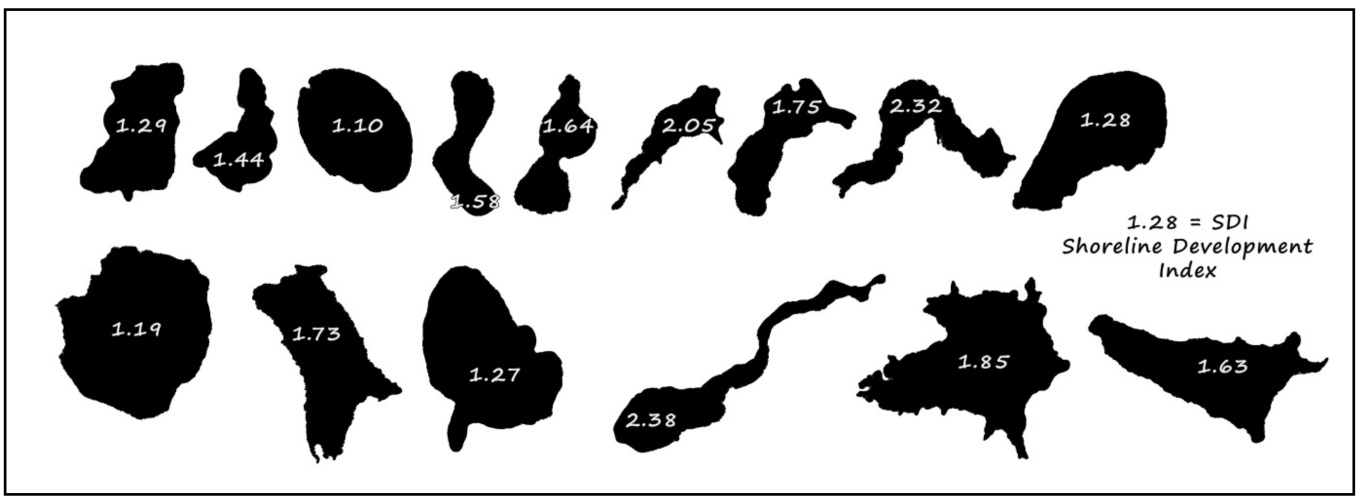

Figure 1. Varying shoreline complexity of natural wetlands in Alberta and their associated SDI values (McKenna et al. 2014a).

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3.1.5. Deeper Pools

Although areas that are > 2 metres deep are not technically part of a CSFW (Government of Alberta 2015d), deep water areas will help with water circulation and the control of nuisance aquatic species. Areas greater than 2 m deep is a requirement for the construction of a storm water facility under the *Environmental Protection and Enhancement Act*.

3.1.6. Water Depths for Wetland Plant Communities

The topography of plant benches (or zones), peninsulas, bays, and other features designed to be planted with wetland vegetation should be planned relative to the NWL, as this will help determine the positioning of plant communities and species within a wetland. Plant communities shift along a gradient corresponding to species' tolerance of water depth and duration of inundation. Wetland plants generally position themselves in water depths ranging from 0 cm at the wetland-upland edge to water depths up to 60 cm depending on the plant species. The key for successful vegetation establishment in a CSFW is to create water depths suited to specific plant zones (i.e. wet meadow, emergent and submergent).

Semi-permanent to permanent natural wetlands typically possess four vegetated zones: wet meadow, shallow marsh, deep marsh, and open water. The wet meadow zone contains grasses and sedges adapted to saturated soils and infrequent inundation. The shallow marsh and deep marsh zones contain emergent plants adapted to growing in surface water (e.g., sedges, hardstem bulrush, cattail). Floating and submersed aquatic vegetation inhabits open water areas up to a depth of approximately 2 m. The physical extent of each vegetation zone will depend on the footprint of the wetland, the slope grades, and the water depths.

3.1.7. Slopes for Wetland and Upland Plant Communities

Slope, measured as a ratio of horizontal and vertical distances, should 7:1 or gentler, and optimally ranges between 10:1 to 40:1. Shallow slopes provide for successful plant establishment in wetlands. Forrest (2010) found that the steeper slopes (i.e. 5:1 to 10:1) in CSFWs led to fewer and narrower vegetation zones. Steeper slopes result in greater water level amplitude, which increases stress to wetland plant species and increases the probability of vegetation die off. Gradual slopes support wider and more numerous vegetation zones (Forrest 2010). However, based on Ducks Unlimited Canada's construction experience, long and gradually sloping zones can be difficult to commission and are prone to invasion by weedy species. In locations where slopes drop down to deeper elevations, such as from the emergent zone at 60 cm to the open water areas 1 - 2 m deep, slope grades of 4:1 to 3:1 will provide slope stability while preventing vegetation from advancing further into the wetland.

Wetland and upland slopes steeper than 5:1 can present challenges for plant establishment using mechanical approaches (e.g., drill seeders), are unsafe for equipment operators, and can result in additional erosion and sedimentation downslope. As recommended by provincial guidelines (Alberta Environment Protection 1999) and municipal design standards (City of Calgary 2011, City of Edmonton 2008), shoreline slopes between NWL and High Water Level (HWL) should between 5:1 to 7:1, with more gentle slopes preferred.

3.1.8. Forebays for Sediment Capture and Removal

Forebays help capture and store sediment at the inlets where sediments can be maintained and cleaned without disturbing the rest of the storm water management facility. There are certain design approaches that can make forebays look like a natural extension of the main wetland. This includes incorporating emergent and wet meadow vegetation in the forebays and on surrounding dikes.

Most jurisdictions in Alberta (City of Calgary 2011, City of Edmonton 2008) require forebays for storm water management facilities to reduce sediment deposition in the main basin.

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3.1.9. Substrate Availability

Substrate such as gravel and rock used to re-create a suitable elevation and topography for wetland construction, will not be able to accommodate the nutrient and structural requirements of plant roots. Therefore, any coarse material used to raise the elevation of the site will need to be covered with an adequate amount soil capable of supporting root growth.

Best management practices in the mineable Oil Sands region (Alberta Environment and Water 2012) provide guidance on conservation of reclamation materials, including salvaging topsoil and subsoil material, stockpiling soils, and soil placement.

3.1.10. Soil Amendments

Mixing organic material into the topsoil of new CSFWs can create an optimal soil bed for plant establishment and promote soil development and plant growth. Adding organic material to the soils can also provide additional nutrients for plants and improve the soil's water holding capacity. Daniels & Whittecar (2004) state that the absence of soil organic matter (SOM) and litter layers, combined with soil compaction from heavy construction, often results in poor plant establishment. 20% SOM content in the final soil mix is a regulatory standard in the United States. Examples of organic material sources include leaf litter, biochar, peat, and donor soils from existing wetlands that will be lost to development (and that have a regulatory approval to be disturbed). It is important that organic material is mixed into the soil rather than placed on top of it, as many organics have a loose, soft texture that may not provide adequate support for plants, and could be easily washed or blown away.

Many native plant species, including wetland plants, have adapted to growing in nutrient poor soils. Too much nitrogen (N) in the soil may result in rapid weed growth, while too much phosphorus (P) could affect water quality and lead to algal blooms. Topsoil often contains approximately 30 lbs of phosphorus per acre and 20 lbs of nitrogen per acre, which is enough for plant establishment and growth without the need for adding fertilizer.

3.1.11. Soil Salinity

Most plant species do not grow well in saline soils. For plant communities in both wetlands and uplands, salinities that fall below 4 Deci Siemens per cm (dS/cm) are recommended. Young plants and seedlings may become stressed if salinities in soil or water are too high (Koropchak 2007). Different planting methods, such as using mature donor plants and establishing plants from seed, may be more desirable in locations where wetland salinity cannot be controlled.

3.1.12. Soil Placement

After overburden and subsoil placement, surface soil that is suitable to create a substrate for the rooting zone of wetland vegetation in CSFWs should be placed on the subsoil (Ross & Gabruch 2015). Recommended surface soil depths for CSFWs are between 20 cm and 45 cm. On saline substrate, this may need to increase to 50 to 70 cm. Use on-site materials where possible. Is off-site material is required, use soils that are as weed-free as possible, especially if they contain *Phalaris arundinacea*, *Phragmites australis*, and *Lythrum salicaria*.

3.1.13. Erosion and Sedimentation Design

Erosion and sedimentation will have negative effects on seed germination and plant establishment in a CSFW. The seeds of most wetland species are unable to germinate when covered with more than 1 cm of soil. Erosion and sedimentation control measures need to be designed to ensure that soil erosion is minimized and will not impact the success of vegetation establishment. Rapid establishment of plants in the first few years of site commissioning will aid in minimizing impacts of erosion and sedimentation.

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3.2. Hydrology

The hydrologic design of a CSFW will determine the site water balance and hydroperiod, the seasonal change in water level in relation to time. The design needs to have multiple water depths to which different species assemblages are adapted.

Key hydrologic design considerations for a CSFW should include the following:

- What is the predicted maximum and minimum water depth?
- What is the frequency, timing and duration of flooding above NWL during a normal flooding event?
- Will the plant communities be able to withstand the proposed hydroperiod, particularly during and after storm events?
- Are anticipated changes in imperviousness and vegetative cover within the surrounding catchment area fully accounted for in the water balance?
- What design parameters can be modified to facilitate a hydrologic regime that achieves the key wetland functions?
- Will groundwater inputs be part of the hydrologic design?

3.2.1. Hydroperiod and Plant Responses

Wetlands are dynamic ecosystems that depend on disturbance by flooding and drying conditions (Murkin et al. 2000); CSFWs that have more stable hydroperiods tend to support fewer plant species, and over time, shift towards larger, more monotypic plant stands. Creating plant benches at a variety of water depths within the wetland will help to promote and support higher plant diversity over the long term. A variable hydroperiod that periodically exposes the seedbed will promote seed germination and help to maintain plant diversity.

The hydroperiod will inform basin slopes and planting design. A CSFW will normally have enough inflow as the volume of facility is designed to provide water storage for the post-development catchment area, and it contains an outlet structure to stabilize water levels. For sites without an outlet, hydroperiod may be larger or may be more variable, which could lead to more uncertainty in planting success.

Plant species have different morphological and physiological adaptations to flood- and drought-induced stress, and they exhibit different degrees of tolerance to water level fluctuation. Based on experience by Ducks Unlimited Canada, plant communities within a CSFW can usually tolerate the following deviations in normal hydroperiod once plants have established themselves in the wetland:

- Up to 60 cm above the normal water level for no longer than 20 consecutive days during any one growing season
- Up to one consecutive growing season without water

If high water levels are maintained for too long after a storm event, it could cause the plant community to die.

3.2.2. Inlets and Outlets

To take advantage of a wetland’s significant treatment capabilities, the inlet and outlet of a CSFW should be located as far as possible from each other to maximize flow path length and detention time. Where this is infeasible due to site constraints, incorporating physical features such as peninsulas can increase retention time.

Both submerged and unsubmerged inlets can be used, but submerged inlets are generally preferred for aesthetic reasons. Hydraulic calculations must demonstrate that the proposed pipe invert elevations will not introduce flood

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risk by generating backwater effects. Where overland conveyance systems require an unsubmerged inlet, appropriate erosion control measures should be designed to create a natural appearance, including a planting plan suited to site hydrology.

It is also preferred that all inlets and outlets be gravity fed; designing a permanent lift station must be carefully weighed against cost, operations and maintenance requirements, and potential liability.

3.2.3. Control Structures

A control or outflow structure maintains the elevation of the CSFW at NWL and controls the discharge rate from the wetland, thereby providing more predictable hydroperiods. Wetland outlet elevation is considered by some experts to be the single most important design choice for a CSFW (McKenna et al. 2014a). Common control structures used in wetlands are culverts**,** weirs, orifices, sluice gates, and stoplogs. Wetlands without an outlet pose a greater risk to the success of a CSFW.

Establishment of plant growth often requires the water level to be manipulated either up or down after planting and during the commissioning stage to encourage and support plant germination. Once vegetation within the CSFW is established, however, the elevation of the CSFW will remain set at NWL in most years.

3.2.4. Overflow Provisions

The design of appropriate emergency overflow provisions will ensure the protection of public property. An emergency outlet, such as a spillway, provides overflow in the case of a clogged outlet or a storm surge. Typically, the spillway is a trapezoidal or V-shaped channel notched into the wetland embankment that acts as a broad-crested weir or channel in overflow conditions. The spillway must be designed to safely direct overflow water to a receiving conveyance system such as a road, ditch or watercourse. To promote a naturalized look, overflow spillways can be stabilized with vegetation, provided that the vegetation cover can support the spillway velocities without eroding. If not, natural infrastructure is preferred to riprap or other hard engineered solutions.

Where an emergency spillway or overflow route is not feasible, the design plan should include an analysis of flood risk considering both impact and probability of occurrence and, if necessary, the incorporation of additional freeboard.

3.3. Plant Communities and Habitat Structure

Wetland plant communities support key wetland functions, including water quality improvement (Lin et al. 2002, Wassen et al. 2002, Smialek et al. 2006, Debing et al. 2009) and habitat for biodiversity (Eaton et al. 2014a). CSFWs that experience water quality problems are often linked to poor establishment of emergent vegetation or an inadequate upland buffer to protect the wetland from sedimentation.

The hydroperiod of the wetland, along with basin topography and corresponding water depths, will inform the location of wetland zones and suitable species to plant within them. Plant species in wetlands are often distributed into spatially distinct concentric zones within wetlands based on their ability to tolerate flooding, their ability to germinate during drought periods, their abundance in the seed bank, and their capacity to compete with other species (Stewart & Kantrud 1971, van der Valk & Welling 1988, van der Valk 2000). Wetland plant zones reflect the species adapted to specific environmental and hydrologic conditions (van der Valk & Welling 1988, van der Valk & Pederson 1989, van der Valk et al. 1999, van der Valk 2000).

3.3.1. Vegetation to Open Water Area Ratio

A CSFW should be designed to have between 35% and 65% aerial cover of emergent and wet meadow vegetation coverage relative to open water. Emergent vegetation provides habitat for aquatic life and wildlife and aids in water

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treatment. The wetland should have a minimum 3:1 slope in between these two zones to minimize slumping. The recommended vegetation to open water ratio creates the required vegetated surface area to support wetland biological activity, water quality improvement, habitat for aquatic and terrestrial invertebrates, songbirds, waterbirds, and mammals.

3.3.2. Species Diversity

In CSFWs, there will not likely be a seedbank in the topsoil to jumpstart wetland plant establishment. Diversity will need to be established by active methods such as seeding, planting or salvaging donor soils. Plant diversity within the system will also be influenced by factors such as species competition, natural disturbances, propagule dispersal by vector species, and connectivity with other aquatic systems. Higher plant diversity can also enhance the functioning and associated services of wetland ecosystems by improving wildlife habitat and increasing the capacity to improve water quality (Engelhardt & Ritchie 2001, 2002).

3.3.3. Species Selection

CSFWs should be planted with native species biologically adapted to that region's climate and soils. Native species are more likely to outcompete ornamental and many non-native species since they are more resilient, won't likely require pesticides, and will support higher quality habitat and water quality improvement. Non-native and invasive species should be avoided. Planting of aggressive species, pioneer species or annual species should be avoided or planted with careful consideration of long-term plant diversity. The Alberta Wetland Classification System (AESRD 2015) and Stewart & Kantrud (1971) provide extensive plant species lists. Utilizing greater variety of planting techniques leads to more diverse wetland communities (Mulhouse & Galatowitsch 2003, Gutrich et al. 2009). Submergent and floating vegetation species tend to establish on their own in CSFWs and do not require additional design or planting.

3.3.4. Emergent Zone

The emergent zone is immediately upslope of the open water zone; its topography should have wetland plant benches with gentle slopes and water depths ranging between 10 cm and 60 cm. Table 6. provides a list of various emergent species and their depth tolerances to flooding.

The emergent zone in a wetland refers to both the deep and shallow wetland plant communities, which are dominated by erect, herbaceous wetland vegetation. The species present in this zone can tolerate flooding by extending their plant growth above the water table. This zone tends to be flooded in most years for most of the summer growing season.

Narrow-stemmed species, such as sedges (*Carex* spp.), bur-reed, and whitetop (*Scolochloa festucacea*), are unable to adjust their shoot length to maintain enough shoot area above the water surface if water depths exceed 20 cm for a prolonged duration. Wide-stemmed species, such as cattails (*Typha* spp.) and bulrushes (*Schoenoplectus* spp.), can adjust their shoot lengths up to water depths of 70 cm. However, both aboveground and belowground biomass will be greatly reduced for these plants to adjust to unfavourable water depths, and prolonged periods under this stress can eliminate the entire plant community in a single growing season.

The emergent zone has the most capacity out of any wetland zone to break down and sequester nutrients and contaminants. The vegetation and associated bacteria, fungi and algal communities aid in the breakdown and uptake of these nutrients. Wider emergent zones result in better water quality treatment.

3.3.5. Wet Meadow Zone

The wet meadow zone is the zone immediately upslope of the emergent zone and downslope of the upland or riparian buffer; it is located slightly above and below the water's edge at NWL in CSFWs. The wet meadow zone

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is created by constructing wetland plant benches and gentle slopes that will have prolonged saturated soils up to a maximum depth of 10 cm above the ground surface.

Table 6. provides a list of some wet meadow species and their depth tolerances to flooding. Appropriate plant species in this area include water-loving sedges, flowers, and grasses. Creating wide plant benches (> 10 m) with a gentle slope beginning slightly below NWL and ending slightly above NWL will enhance the probability of successful plant establishment and resilience to water level changes.

In natural wetlands, the wet meadow zone usually contains the greatest diversity of plant species, and it is important for several bird species (Fairbairn and Dinsmore 2001), including wetland-dependent songbirds. It also helps prevent shoreline erosion, protects the wetland from sedimentation, and improves water quality.

This zone is often the most difficult community to establish within a constructed wetland (Galatowitsch et al. 1999, Mulhouse & Galatowitsch 2003) because of the ephemeral nature of the flooding regime in this zone and the challenges with species establishment (e.g., sedges; see van der Valk et al. 1999). The ability of wet meadow species to withstand prolonged, above normal flooding is extremely limited.

Table 6. Recommended water depth for common marsh species (adapted from Ross et al. 2014). Negative values indicate planting depths above the normal water level.

Zone	Common Name	Scientific Name	Water Depth (m)
Emergent	Alkali bulrush	*Bolboschoenus maritimus*	0 - 0.3
	Giant bur-reed	*Sparganium eurycarpum*	0.15 - 0.45
	Common cattail	*Typha latifolia*	0.15 - 0.45
	Sweet flag	*Acorus americanus*	0.15 - 0.5
	Hardstem bulrush	*Schoenoplectus acutus*	< 1.5
	Softstem bulrush	*Schoenoplectus tabernaemontani*	< 1.2
	Rush	*Juncus spp.*	< 0.2
	Arum-leaved arrowhead	*Sagittaria cuneata*	0 - 0.3
	Water arum	*Calla palustris*	0 - 0.2
	Spike rush	*Eleocharis spp.*	-0.03 - 0.6
	Water plantain	*Alisma spp.*	0 - 0.15
	Sedge	*Carex spp.*	-0.5 - 0.5
	Hemlock water parsnip	*Sium suave*	-0.5 - 0.15
	Manna Grass	*Glyceria spp.*	-0.5 - 0.15
	Northern wild rice	*Zizania palustris*	0.3 - 0.45
	Horsetail	*Equisetum spp.*	-0.5 - 0.7
	Reed Grass	*Calamagrostis spp.*	-0.5 - 0.15
	Sloughgrass	*Beckmannia syzigachne*	< 0.15
	Wool-grass	*Scirpus atrocinctus*	< 0.30

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Zone	Common Name	Scientific Name	Water Depth (m)
	Small-fruited bulrush	*Scirpus microcarpus*	< 0.30
Wet Meadow	Tickle grass	*Agrostis scabra*	< 0.15
	Prairie cordgrass	*Spartina pectinate*	-0.5 - 0.5
	Reed Grass	*Calamagrostis spp.*	-0.5 - 0.15
	Sedge	*Carex spp.*	-0.5 - 0.5
	Sloughgrass	*Beckmannia syzigachne*	< 0.15
	Tufted hairgrass	*Deschampsia cespitosa*	< 0
	Rush	*Juncus spp.*	< 0.2
	Hemlock water parsnip	*Sium suave*	-0.5 - 0.15
	Spike rush	*Eleocharis spp.*	-0.03 - 0.6
	Manna grass	*Glyceria spp.*	-0.5 - 0.15
	Wool-grass	*Scirpus atrocinctus*	< 0.30
	Small-fruited bulrush	*Scirpus microcarpus*	< 0.30

3.3.6. Upland or Riparian Buffer

The upland buffer zone consists of flood-tolerant native flowers, grasses, shrubs and trees located in the active storage zone between the NWL and the HWL of the wetland. Upland buffers help slow surface flow from upslope areas, stabilize soils surrounding the wetland, contribute to water quality improvement, provide additional wildlife habitat, and link a CSFW to other habitats.

The deposition of excess soil and nutrients into outer wetland margins severely impacts the viability and establishment of native plants in these areas (Ross 2009). Even small amounts of overlying soil (e.g., ≥ 1 cm) will impact wetland seed germination, species richness and diversity (Galinato & van der Valk 1986, Dittmar & Neely 1999, Werner & Zedler 2002), while favoring the establishment of invasive species such as reed canary grass (*Phalaris arundinacea*) or aggressive species such as foxtail barley (*Hordeum jubatum*; Galinato & van der Valk 1986, Werner & Zedler 2002). Although the upland or riparian buffer is not technically part of a CSFW, it is, like the open water areas, essential to a healthy, functioning constructed wetland. In the absence of an adequate and healthy upland or riparian buffer, the success of wetland planting, its ability to reduce sedimentation and erosion, improve water quality and provide habitat connectivity will all be reduced, thereby lowering the overall value of the CSFW.

3.4. Wildlife Habitat Features

From a wildlife perspective, the design goals of a CSFW are to create habitat that will promote plants and animal diversity, add greater connectivity on the landscape, and reduce human wildlife conflicts. In addition, a CSFW can include other habitat features that are suited to the appropriate environmental, physical, and hydrologic characteristics of the designed wetland as well as the regional biodiversity and surrounding landscape features.

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3.4.1. Native Upland Buffer

Adjacent habitat such as native grassland, forests, wetlands, watercourses, cliffs and steep banks can provide habitat for species that also utilize or live in wetlands. Perennial vegetation > 10 cm in height provides cover for nesting waterfowl and habitat for songbirds, raptors, mammals, and pollinators. In addition, natural upland vegetation has been found to be strongly linked to amphibian presence in storm water ponds (Scheffers & Pazkowski 2013). A minimum upland buffer of 10 m is recommended for CSFWs on glacial till, while a minimum upland buffer of 30 m is recommended for CSFWs on coarse textured sand or gravel (adapted from Stepping back from the Water).

3.4.2. Native Wetland or Upland Shrubs

Native shrubs can provide nesting and foraging sites in addition to water quality improvement (Eaton et al. 2014a), and can provide habitat for songbirds, raptors, mammals, and pollinators. Native forbs can also provide important food source for pollinators. Planting a diversity of three or more species is preferable.

3.4.3. Peninsulas

Peninsulas can provide habitat for waterfowl while allowing easy access for vegetation planting and adaptive management. Although one of the most common wildlife features recommended for waterfowl is islands (Government of Alberta 2014 a,b,c, Adams et al. 1986, ALCRC 1992, Buttleman 1992, Berry & Juni 2000), Ducks Unlimited Canada has found that they are prone to slumping, difficult to establish native vegetation on, and are often dominated by weedy species due to overgrazing by geese. Islands may lead to greater effort and cost of weed management and could become a long-term weed source. The use of islands as a wetland habitat feature is discouraged.

3.4.4. Sandbars and Gravel Bars

Sandbars and gravel bars provide habitat for feeding shorebirds and require less management of weedy species than mudflats.

3.4.5. Structure

Placing non-vegetated aquatic cover such as woody debris or waste rock in water depths greater than 0.5 m can provide habitat for invertebrates and amphibians (Government of Alberta 2014a,b,c, Buttleman 1992). Downed wood in the upland area can support invertebrate, amphibian, songbird and native plant habitat: it should be > 2 m long, have a diameter > 10 cm and is placed so that it is not persistently submerged, with about one piece per ha. Snags in the upland area can support waterfowl, songbird, mammal raptor, and native plant habitat: they should be > 20 cm in diameter, within 10 m of the wetland edge, and have a density of > 2 per ha). Materials to create wildlife habitat structure can often be salvaged on-site from development activities within the project area: woody debris and downed wood can be salvaged from forest clearing and brush piling activities.

3.5. Human Use Features

A landscape architect or team will be involved in designing a CSFW that serves as an amenity and asset to humans, responsible for harmonizing the ecological needs and values with the aesthetic, cultural and social uses. They may be responsible for designing accessible pathways, gathering spaces, viewing areas, seating, and interpretive signs that will integrate into the natural wetland and will have minimal impact of the environmental and ecological values and services of the CSFW.

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3.5.1. Educational Values

Interpretive signage, brochures, tours and education centres within the area can encourage human use and appreciation of a CSFW, especially CSFWs in urban areas. Educational materials can allow users to understand and enjoy the many functions that CSFWs can provide as opposed to the singular function of conventional storm water facilities. Interpretive signs could provide information on wetland construction methods, plant identification, wetland functions, or wildlife facts.

3.5.2. Human Access

Access to a CSFW by humans and pets can spread invasive or weedy species, increase erosion and soil compaction, and cause harassment and physiological stress on wildlife. A harmonized approach to human use and wildlife protection can be achieved by placing trails at least 30 m from the edge of a wetland. Although limiting access to most of the wetland is recommended, allowing access to specific areas of the wetland such as viewpoints, boardwalks, or platforms will increase the educational and social value of a wetland.

3.5.3. Best Management Practices

Upland buffers and erosion and sediment controls can protect a CSFW from erosion and sedimentation. Designated trails and boardwalks help reduce human access and disturbance to soils and vegetation within the wetland. Disturbance to wildlife by humans can be minimized by planning trails at least 30 m away from the wetland, protecting important bird habitats from direct human access, restricting access to motorized vehicles, and designating the area as a pet friendly, on-leash zone.

4. Construction

Site preparation, earthworks, infrastructure placement, vegetation establishment and water management all have activities that may be restricted to certain seasons. A construction schedule can prevent seasonal delays and reduce the overall time it takes to construct a wetland by a year or more.

A construction specialist or certified engineering technologist (CET) will often oversee the construction phase of the project, conduct regular inspections and certify the finished wetland grading and infrastructure. They may also provide input on practical modifications to the proposed design, based on site conditions and operational considerations. Key roles include supervision of the earthworks, including on-site grading and excavation, salvage of topsoil and subsoil management and placement, and erosion and sediment controls. They will also identify site constraints and opportunities as they are encountered in the field.

4.1. Construction Timelines for Minimal Impacts

Construction timelines should aim to minimize impacts on vegetation and wildlife, while choosing optimal seasons to conduct each activity.

4.1.1. Physical Grading, Earthworks and Basin Topography

Earthworks includes all activities that execute the physical construction of the wetland, including site grading and contouring, and control structures. Earthworks is most efficient in summer or fall when soils are dry and stable. Winter access allows for easy movement of equipment over frozen areas, but it is not recommended because it is less precise and accurate: soils are frozen and clumped together and final grades will change after soil settling. Achieving grades within +/- 5 cm of the design plan will significantly increase the chance of planting success.

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4.1.2. Timing of Planting

It is recommended that wetland plants are transported from a donor location to a new wetland site when nutrient reserves are in their aboveground growth (e.g., stems and leaves) or roots. Nutrient reserves are highest in plant roots during winter months (e.g., November through March) and in stems and leaves in summer months (e.g., July and August). Winter planting is generally recommended for larger wetland sites, as it is cost effective and plant material such as propagules, roots and donor soils can be moved more efficiently over frozen soils. The following spring, the wetland must have a source of water if plants transplanted under these conditions are to survive. Summer is recommended for hand planting in smaller wetlands or to perform targeted planting of species. Summer transplants must be planted in the CSFW at water depths close to, or slightly less than, the species' optimal water depth.

Timing of wetland seeding will depend on the seed mix and the seeding approach: broadcast or drill seeding. Drill-seeding is the preferred technique for establishing native vegetation and is most effective when performed in dry soil conditions, such as in the fall. Broadcast seeding is effective in late spring or early summer when natural seed germination occurs. Winter broadcasting is best for some species, and the snow and frost helps drive down seed to soil contact.

4.1.3. Construction Phasing

In the first growing season, a CSFW must be filled to NWL, especially if mechanical wetland planting was done the preceding winter or wetland seeding was done the preceding fall. Control structures such as weirs with stop logs can be used to manipulate water levels, or if there is no control structure or it is not yet constructed, water level manipulation can be performed using techniques such as pumping and ballooning.

If there is insufficient runoff to fill the wetland, other storm water ponds within the same hydrologic network may provide an alternative water source if approved by the regulatory body. If no water source is available in the first year, delaying planting is recommended. In this case, a suitable cover crop should be planted below NWL to reduce erosion and weed invasion, while maintaining the soil bed for wetland planting.

4.2. Erosion and Sediment Control

Erosion control includes practices that keep soils stabilized or protected from water or wind erosion; sediment control includes practices that capture soil particles after they have been picked up by wind or water (City of Moncton 2015). Erosion and sedimentation, both upslope and downslope of the wetland plantings, will negatively affect seed germination and plant establishment. Rapid establishment of upland and wetland plants in the first few years after construction will minimize erosion.

Poor management of soils can increase the need for maintenance of structural controls, re-grading and repair of severely eroded areas. Sediment removal may be required if soils are not properly managed at the outset of the project. Excessive erosion and sedimentation may require re-planting large portions of the wetland and upland areas and will prolong the commissioning of the wetland. Erosion and sedimentation also lead to weedy species establishing and outcompeting native species (Ross 2009).

All exposed soils should be stabilized as soon as possible after completing grading activities. Erosion controls should be guided by a combination of five factors: soil erodibility, vegetation cover, topography, climate, and season. Erosion control measures include sediment and earth interceptor barriers and fences, swales, earth dykes, check dams, sediment ponds, temporary cover crops and permanent vegetation cover.

Consider the following erosion and sediment control practices for every CSFW project (adapted from City of Moncton 2015, Ross & Gabruch 2015):

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- Clearly mark construction zone and identify sensitive site areas and their buffer zones
- Stabilize all down slope and side slope perimeters as soon as possible after land disturbance activities have occurred using soil erosion techniques such as blanketing, erosion fencing, and soft berms
- Delay disturbances until it is necessary for construction to proceed
- Cover or stabilize disturbed areas as soon as possible
- Time construction activities to limit the impact from seasonal changes or weather events
- Delay construction of infiltration measures (e.g., connected bioswales, use of sand soils) until the end of the construction project when upstream drainage areas have been stabilized
- Do not remove temporary perimeter and erosion controls until after all soft and hard surfaces are stabilized
- Consider using an annual seed cover crop in all exposed upland areas until the installation and establishment of native vegetation is successful. If an annual seed crop is used, consider managing the crop before it sets seed
- Incorporate erosion control blankets and the construction of temporary soft berms on steeper slopes where possible
- Include sediment forebays on sites where excessive sediments into the wetland may occur
- To minimize soil slumping, maintain gentle slopes on adjacent upslope areas of 5:1 or less and 7:1 or gentler slope in the wet meadow and emergent zones
- Conduct site inspections regularly to assess how protection measures are performing, particularly after rain events and after every site activity
- Clean out sediment trap periodically and redress silt fences when necessary
- Keep all erosion and sediment control measures in place until construction is complete and all areas are stabilized

Both the City of Calgary (2017a,b) and the City of Edmonton (2005a,b) have good erosion and sediment control guidelines.

4.3. Grading, Earthwork, and Soils

Earthworks includes land grading and contouring to reconfigure the topography to support a CSFW. In storm water management facilities, excess material should be reused on site for berms, plant benches or other re-contouring.

A grading and earthworks plan should outline a clear strategy for the salvage, handling, storage and use of topsoil and subsoil throughout the project. This plan, which needs to be effectively communicated to equipment operators prior to commencement of work (Government of Alberta 2013b), should include the following information:

- Estimated quantities of available topsoil and subsoil
- Identified stockpile locations for storing topsoil separately from subsoil in a safe location, such as away from steep slopes, watercourses or waterbodies
- Best practices for handling and storing soils, including separation of topsoil from subsoil
- Best practices to minimize compaction of topsoil and subsoil by heavy equipment
- Erosion and sediment control measures

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4.3.1. Salvage and Storage of Material

Surface soil should be salvaged across the full extent of the disturbed area. Topsoil stripping should not be completed when the ground is frozen as it is difficult to separate it from the underlying subsoil or overburden when surface soils are frozen.

Ensure that salvaged subsoil is not pushed on top of stored topsoil during storage (Government of Alberta 2013b) and that subsoil and topsoil is stored separately. Leave a buffer zone between all storage piles, windrows and the proposed excavation edge, and a minimum of 30 m away from water bodies or valley breaks (Government of Alberta 2013b). If stockpiled material will be stored for long periods (e.g., during operation of aggregate mining), seed with appropriate vegetation to reduce erosion and provide weed control (Alberta Environment 2004).

4.3.2. Soil Handling and Stockpiling

During construction, the following best practices should be employed to avoid compacting the topsoil and subsoil layers (Government of Alberta 2013b):

- Never handle or move topsoil or subsoil when it is wet
- Avoid using large heavy earth scrapers
- Use wide tracked, low ground pressure equipment
- Minimize the number of trips travelling over the site, especially after replacement of salvaged soil
- Consider ripping soils before replacing the subsoil and topsoil to mitigate compaction from construction activities
- Consider discing the surface of replaced subsoil to break larger soil clods prior to topsoil placement

4.3.3. Reconfiguring Topography: Grading, Material Placement and Contouring

Site grading involves reconfiguring the topography by replacing materials and soils according to the physical dimensions in the design plans: inlets, outlets, wetland zones, plant benches, and uplands are contoured according to the precise gradients, slopes, and elevations, and the topsoil is prepared for planting. Final grades and measurements should be within +/- 5 cm of the design plans: anything greater will risk large-scale changes or failure in wetland plant development.

If there is reject material or overburden, it should be placed on the site first. Then, higher quality overburden can be spread evenly across the site and used for grading and contouring. Grading needs to account for the additional depth of subsoil and topsoil that will be placed afterwards. After overburden or other materials are placed and contoured to achieve the grade (not including subsoil and topsoil depths), salvaged subsoil can be spread evenly and used for minor re-contouring. Finally, topsoil can be spread over the site. If topsoil is limited, placement should be prioritized in the emergent zone, wet meadow zone, and upland to a depth of at least 30 cm.

Design grades should be marked in the field for construction crews to follow. After topsoil has been placed, a survey of the final physical measurements and dimensions is recommended.

4.4. Planting Techniques

Selection of native plant species for each plant zone should consider geographical and biophysical parameters, native species lists for the region, as well as individual species attributes. Other criteria will include the plant availability, species establishment requirements and adaptability to site conditions.

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Planting of wetland and upland species involves creating a new, clean seedbed for the new or transplanted material to grow. See Wark et al. (2006), Woosaree & McKenzie (2012) and Government of Alberta (2013b) for additional information on upland reclamation techniques.

There are four approaches to planting wetland species:

1) Seeding
2) Manual transplanting of whole plants or live-plant propagules
3) Live-staking using stem-cuttings
4) Mechanical planting using donor soils

Multiple planting techniques should be used to achieve higher species diversity while some species may require specific planting techniques.

Most wetland species are not commercially available, so species will need to be obtained by using local seed sources, collecting seed by hand, transplanting donor soils, living roots and shoots or by purchasing them from local greenhouses.

Table 7 provides a list of planting techniques, and Table 8 provides a list of species to avoid planting in CSFWs.

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Table 7. Planting techniques for common marsh species. An asterisk indicates a preferred or best propagation method (modified from Ross et al. 2014); checkmark indicates potential propagation method.

	Scientific Name	Common Name	Whole Plants	Root/Rhizome	Seed	Cuttings
Emergents	*Acorus americanus*	Sweet flag	*	*	√	
	Alisma triviale	Water plantain	*	*	*	
	Beckmania syzigachne	Slough grass			*	
	Bolboschoenus maritimus	Alkali bulrush	*	√	*	
	Calamagrostis spp.	Reed grass	*	*	√	
	Calla palustris	Water arum	*	*	*	*
	Caltha palustris	Yellow marsh-marigold	√	√	√	
	Carex spp.	Sedge	*	*	√	
	Comarum palustre	Marsh cinquefoil			√	*
	Eleocharis spp.	Spike rush	*	*	√	
	Equisetum spp.	Horsetail	*	*		√
	Juncus spp.	Rush	*	*	√	
	Sagittaria cuneata	Arum-leaved arrowhead	*	*	√	
	Schoenoplectus acutus	Hardstem bulrush	*	*	*	
	Schoenoplectus tabernaemontani	Softstem bulrush	*	*	*	
	Scirpus cyperinus	Wool-grass	*	*	√	
	Scirpus microcarpus	Small-fruited bulrush	*	*	√	
	Sium suave	Common waterparsnip		√	√	
	Sparganium eurycarpum	Giant bur-reed	*	*	√	
	Sparganium natans	Small bur-reed	*	*	√	
	Triglochin maritima	Seaside arrowgrass	√	√	*	
	Typha latifolia	Common cattail	*	*	*	
	Veronica americana	American brookline	*	√	√	√
	Zizania palustris	Northern wild rice	√		*	
Wet Meadow	*Beckmania syzigachne*	Slough grass			*	
	Calamagrostis spp.	Reed grass	*	*	√	
	Carex spp.	Sedge	*	*	√	
	Deschampsia cespitosa	Tufted hairgrass			*	
	Equisetum spp.	Horsetail	*	*		√
	Glyceria spp.	Manna grass	√		*	
	Juncus spp.	Rush	*	*	√	
	Mentha arvensis	Wild mint	*	√	√	*
	Scirpus cyperinus	Wool-grass	*	*	√	
	Scirpus microcarpus	Small-fruited bulrush	*	*	√	
	Spartina pectinata	Prairie cordgrass	*	*	√	
	Symphyotrichum spp.	Aster	√		*	
	Triglochin maritima	Seaside arrowgrass	√	√	*	
	Veronica americana	American brookline	*	√	√	√

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Table 8. List of common invasive or aggressive plant species to avoid introducing in CSFWs (USDA 2017).

Scientific Name	Common Name	Origin	Life History	Invasive	Weed
Agrostis gigantea	Redtop	introduced	perennial	Y	Y
Amaranthus retroflexus	Redroot pigweed	introduced	annual	Y	Y
Artemisia absinthium	Absinthe	introduced	perennial	Y	Y
Artemisia biennis	Biennial wormwood	introduced	annual/biennial/perennial	Y	Y
Avena fatua	Wild oat	introduced	annual	Y	Y
Bromus inermis	Smooth brome	introduced	perennial	Y	Y
Butomus umbellatus	Flowering rush	introduced	perennial	Y	Y
Capsella bursa-pastoris	Shepherd's purse	introduced	annual	Y	Y
Carduus nutans	Nodding plumeless thistle	introduced	biennial	Y	Y
Chenopodium album	Lamb's quarters	introduced	annual	Y	Y
Cirsium arvense	Canada thistle	introduced	perennial	Y	Y
Elymus repens	Quackgrass	introduced	perennial	Y	Y
Equisetum arvense	Field horsetail	native	perennial	Y	Y
Galeopsis tetrahit	Hemp nettle	introduced	annual	Y	Y
Grindelia squarrosa	Curlycup gumweed	native	perennial	Y	N
Hordeum jubatum	Foxtail barley	native	perennial	Y	Y
Impatiens glandulifera	Himalayan balsam	introduced	annual	Y	Y
Iris pseudacorus	Yellow flag-iris	introduced	perennial	Y	Y
Kochia scoparia	Kochia	introduced	annual	Y	Y
Lactuca serriola	Prickly lettuce	introduced	annual	N	Y
Lythrum salicaria	Purple loosestrife	introduced	perennial	Y	Y
Malva pusilla	Roundleaf mallow	introduced	annual	Y	Y
Medicago lupulina	Black medic	introduced	annual	N	Y
Melilotus alba	White sweet clover	introduced	annual/ biennial	Y	Y
Melilotus officinalis	Yellow sweetclover	introduced	annual/ perennial/ biennial	Y	Y
Phalaris arundinacea	Reed canary grass	native or introduced	perennial	Y	Y
Phleum pratense	Timothy grass	introduced	perennial	Y	Y
Phragmites australis ssp. australis	Invasive phragmites	introduced	perennial	Y	Y
Plantago major	Common plantain	introduced	annual/biennial/perennial	N	Y
Poa annua	Annual bluegrass	introduced	annual	Y	Y
Poa compressa	Canada bluegrass	introduced	perennial	Y	Y
Poa pratensis	Kentucky bluegrass	introduced	perennial	Y	N
Polygonum aviculare	Prostrate knotweed		annual/ perennial	Y	Y
Polygonum convolvulus	Wild buckwheat	introduced	annual	Y	Y
Polygonum lapathifolium	Curlytop knotweed	native	annual	Y	Y

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Scientific Name	Common Name	Origin	Life History	Invasive	Weed
Polygonum persicaria	Ladysthumb	native or introduced	annual/ perennial	Y	Y
Portulaca oleracea	Purslane	introduced	annual	Y	Y
Potamogeton crispus	Curly leaf pondweed	introduced	perennial	Y	Y
Ranunculus sceleratus	Celery-leaved buttercup	native or introduced	annual/ perennial	N	N
Raphanus raphanistrum	Wild radish	introduced	annual/ biennial	Y	Y
Rumex crispus	Curly dock	introduced	perennial	Y	Y
Rumex maritimus var. fueginus	Golden dock	native	annual /biennial	N	Y
Rumex pseudonatronatus	Field Dock	introduced	perennial	N	Y
Salix pentandra	Laurel leaf willow	introduced	perennial	N	N
Setaria glauca	Yellow foxtail	introduced	annual	Y	Y
Setaria viridis	Green foxtail	introduced	annual	Y	Y
Sinapis arvensis	Wild mustard	introduced	annual	Y	Y
Sonchus arvensis	Perennial sow thistle	introduced	perennial	Y	Y
Sonchus asper	Annual sowthistle	introduced	annual	Y	Y
Taraxacum officinale	Dandelion	introduced	perennial	Y	Y
Thinopyrum intermedium	Intermediate wheatgrass	introduced	perennial	N	N
Trifolium pratense	Red clover	introduced	biennial/ perennial	Y	Y
Trifolium repens	White clover	introduced	perennial	Y	Y
Typha angustifolia	Narrow-leaved cattail	introduced	perennial	Y	Y
Typha x glauca	Hybrid cattail	native or introduced	perennial	Y	Y

4.4.1. Seeding

When purchasing native seed, ensure a seed analysis report is provided for each seed lot. The report should be examined to ensure quality control and to provide information including percent levels for seed germination, seed purity, percent inert matter, percent dormant seed, and percent of each weedy species present.

A native seed purchase should include:

1. Information on the genetic origin of the species. Specified varieties and sources should be adhered to; however, if the seed specified is not available, substitutions of alternative seed lots should be considered, utilizing regionally acceptable native seed varieties.
2. A current Certificate of Seed Analysis for each seed lot from the supplier. Review germination and dormancy tests reported on the certificate to determine Pure Live Seed content. Each lot needs to meet or exceed Canadian Certified seed standards.
3. Zero tolerance for undesirable, highly invasive or noxious weed species, particularly for any weeds or invasive species. Any weed content should be reported to .01 percent accuracy on the seed certificate.

Hand collection of locally appropriate seed should be considered, as many species will not be available in commercial seed mixes. Wetland species' seeds possess a wide range of dormancy states (i.e. non-dormant,

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dormant, physiological dormancy, morphophysiological dormancy) and may require specific techniques, conditions or long durations in order to break dormancy and germinate.

Seeding is often used in combination with transplanting live-plant propagules. It can be less labour-intensive and more cost-effective than moving live donor soil (Ross et al. 2014). Each seed mix should consider the following criteria: site range capability and seed germination properties, seedling characteristics, and growth habit of individual native species, such as water depth requirements and species competition.

Three seeding techniques used for native plant establishment include drill-seeding, broadcast seeding and hydroseeding. Drill-seeding places seed directly in the soil and is the preferred approach for planting native species. When using a drill-seeder, the depth should be suited to the species' requirements (almost always < 1 cm) and then packed to ensure solid contact of soil around the seed. Incorrect seed depth placement and poor seed to soil contact results in significantly reduced planting success.

Broadcast seeding is a technique where the seed is spread on the surface of the soil instead of being placed directly in the soil (Government of Alberta 2013b). Seed needs good soil contact, and it needs to be covered by less than 1 cm of soil to germinate. The site should be harrowed prior to broadcast seeding, then harrowed again and firmly packed after seeding.

Hydroseeding disperses seeds in a liquid under pressure (Government of Alberta 2013b). Based on Ducks Unlimited Canada's experience, hydroseeding resulted in poor vegetation establishment dominated by invasive and weedy species.

Soils need to be moist or slightly saturated to induce seed germination. Too much water that floods the ground could dislodge seeds or inhibit germination. This is why installing a control structure that can manipulate water levels is imperative to planting success in CSFWs (Baskin & Baskin 2014).

4.4.2. Manual Transplanting

Whole plants and plant propagules, such as the root or rhizome mass, can be manually transplanted from a donor site to a CSFW. This technique can target desirable species from a donor site. The optimal time for manual transplanting is in summer from early July to mid-August (Ross & Vitt 2014), although it can also be done in fall and winter. Live plant material should not be stockpiled for more than 24 hours, as it will rapidly decompose even under frozen conditions. Potential donor sites include wetlands that will be impacted by the same development as where the wetland is being constructed (regulatory approval is required). Common emergent plants such as *Carex aqualtilis*, *Carex utriculata*, *Carex atheroides*, and *Schoenoplectus tabernaemontani* can be transplanted from roadside ditches, dugouts, or other constructed wetlands.

4.4.3. Live Staking

Live-staking refers to the method of planting dormant woody stem-cuttings, which can grow into new individuals once planted. It is most effectively used to establish pioneering species such as willow (*Salix* spp.), wetland-associated poplar species (*Populus* spp.), and dogwood (*Cornus stolonifera*). The minimum diameter of stem-cuttings should be at least 2.5 cm and the length of cuttings should be at least 40 cm long (Polster 2013). Live-staking can be done in either late fall (Polster 2013) or in the early spring (Agroforestry & Woodlot Extension Society).

4.4.4. Mechanical Planting Using Donor Soils

Wetland plants and soils can be transplanted from donor sites into CSFW sites using heavy excavation and hauling equipment. Donor soil contains seeds and other plant propagules in addition to a host of microorganisms (bacteria)

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and invertebrates (Ross et al. 2014). It is imperative that donor soil is free of invasive and weedy plants and their seeds.

Frozen soils are the best conditions to perform mechanical planting because it supports heavy machinery. Plant material handling, including extraction, hauling and placement should be completed within the same day. Final grades need to account for donor soil material placement. Hauling distances should be minimized (e.g., < 50 km) to protect plants from freezing temperatures. Live plant material should not be stockpiled for more than 24 hours, as it will rapidly decompose even under frozen conditions. Mechanical transplanting requires clay in the soil texture to ensure material does not break apart during planting. Donor soil is spread onto the substrate and then is moistened, but not permanently flooded, to induce seed germination. Johnson et al. (2009) found mediocre success using donor soils, suspecting that imprecise extraction depth of donor surface soils affected seed viability. Experience by Ducks Unlimited Canada has found that use of donor soils can also lead to monotypic stands of vegetation.

4.4.5. Upland Planting

The same techniques for wetland planting can be used for upland planting. Broadcast seeding is not generally recommended on uplands, although it may be required if equipment access is restricted by high soil moisture or steep slopes. In these cases, doubling the seeding rate relative to drill-seeding will improve results. Hydroseeding in uplands is not recommended.

Hand planting of container grown seedlings or mechanical planting for large trees or shrubs can be performed to vegetate the upland. Commercially available and locally appropriate nursery grown stock that is free of diseases should be selected for planting.

4.4.6. Invasive Species and Weed Management

Invasive plant species are one of the biggest threats to establishing native plant communities on new CSFW sites. Early, effective control of invasive plants will encourage the growth and expansion of emerging seedlings, especially in the first few years of development (Ross et al. 2014). Lacking natural controls, invasive plants can be extremely difficult to eradicate once an area is infested.

All soils and plant propagules should be assessed during the growing season for the presence of weedy species prior to being used in any component of the CSFW project. Commercially available seed mixes should also be thoroughly screened for site-appropriate species. Although often recommended as options for soil amendment in upland areas (Government of Alberta 2013b), animal manure and straw/hay mulch can both be sources for weed seeds.

Weed control of the soil must be done before seeding or planting, as weeds will prevent seeds from establishing and outcompete planted seedings that are expending most of their energy on belowground growth in their first year. CSFWs require at least two years of weed management and control after seeding or plant establishment, using integrated weed management strategies that combine different mechanical and chemical practices to manage weeds and invasive plants for both the upland and wetland zones. Planting of cover crops in uplands prior to seeding or planting will reduce invasion of weedy species. Inadequate weed management can lead to failure in native plant establishment and increase weed management effort and cost during the first few years of commissioning.

Invasive species of concern include species such as quackgrass (*Elmus repens*), smooth bromegrass (*Bromus inermis*), foxtail barley (*Hordeum jubatum*), and Canada thistle (*Cirsium arvense*) in the upland buffer zone and wetland transitional zone of new CSFWs. In the wet meadow and emergent wetland zones, invasive perennials include reed canarygrass (*Phalaris arundinacea*), common reed (*Phragmites australis*), dock (*Rumex* sp.), narrow-leaved cattail (*Typha angustifolia*), hybrid cattail (*Typha* x *glauca*) and purple loosestrife (*Lythrum salicaria*). Action should be taken to avoid the introduction and prevent the establishment of all invasive species before they take a foothold. Table 8 provides an extensive list of invasive and weedy species of concern.

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4.4.7. Wildlife Management during Construction

If nuisance wildlife species exist within the area (e.g., Canada geese and muskrats), temporary wildlife control fencing can be used to prevent animals from overgrazing or destroying vegetation. Wildlife corridors linking the upland areas to the open water zones of the CSFW will allow wildlife to move unfettered between these two locations while the fencing remains in place.

4.5. Inspection of Construction and Vegetation Planting

It is important to monitor and confirm that the CSFW was built according to the design specs after each wetland construction activity. Changes to the design elevations of wetland planting zones by even +/- 5 cm can affect planting success and may result in poor vegetation establishment, low cover or density, invasion of weedy species or lack of diversity. If a CSFW is not performing as intended, comparing as-built drawings to the design plan drawings may reveal the reason why (Ross et al. 2014). Table 9 provides a list of components to inspect after construction.

Table 9. Wetland inspection components that take place after construction.

Component	Parameter
Basin topography	All basin topography measurements.
Hydrology	Installation and operation of conveyance systems, control structures and other infrastructure. Water supply to NWL guaranteed in the first growing season at appropriate frequency and timing.
Plant communities	Progress or completion of vegetation planting and weed management activities.
Soils	Execution of soil plans and inspection of sedimentation and erosion control measures.
Habitat features	Creation of habitat features such as peninsulas, sandbars and gravel bars, non-vegetated aquatic cover, and upland buffer.
Human use features	Installation of education signs, boardwalks and human use features.
Wetland area and class	Confirmation of the area (ha) and class of the CSFW.
Deviations	Where changes to the original design in the wetland construction plan have occurred, updated drawings and figures (see Table 5) must be provided as well as an explanation for these changes. The Wetland Construction Team must describe the potential effect the design changes may have to the overall objectives and success of the CSFW.
Validation conclusion	Confirmation that the CSFW was developed in accordance with 1) the wetland construction plan; and 2) this guide

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5. Commissioning, Monitoring and Adaptive Management

The main purpose of the Commissioning, Monitoring and Maintenance (CMM) stage is to track and ensure that the CSFW continues on a trajectory to success. Documentation of activities undertaken during the CMM stage of a CSFW project will inform regulatory reporting, when required, such as wetland replacement verification or reclamation certification.

Commissioning activities are generally targeted to aid in wetland vegetation establishment, including manipulation of the CSFW's hydrology to allow for seed germination and seedling growth, and vegetation enhancement activities to improve species diversity. Commissioning begins by filling the CSFW to NWL in preparation for the first growing season and ceases once wetland vegetation can withstand the designed long-term hydrology of the CSFW. Although more effort is required during the commissioning stage, it ensures the wetland develops into a low-maintenance or self-sustaining system over time.

The timing and sequencing of commissioning activities of the wetland can vary from site to site. A wetland needs a minimum of two years of commissioning before wetland vegetation becomes established, while upland native grasses, shrubs, and trees require a minimum of three years. Drought and flooding events during the first years can extend the establishment period. Planting timing will depend on the species and planting approach. Table 10 provides a list of commissioning activities.

Frequent monitoring is required during commissioning, until wetland plants become established and resilient to short-term flooding or to wildlife grazing disturbance events. Regular maintenance checks can decrease as the CSFW vegetation becomes established and hydrology is operated at its long-term design.

Monitoring provides early warning that a CSFW may not be functioning as intended and enables the use of adaptive management strategies to keep a CSFW on a trajectory to success (McKenna et al. 2014b). Adaptive management involves taking opportunities to perform maintenance and management in response to events or stressors that arise over time (McKenna et al. 2014b). A properly designed and CSFW will require minimal management interventions over the lifetime of the project. However, in the first few years more frequent management may be necessary. Tables 11 and 12 contains a summary of the potential problems that may be encountered during the commissioning, monitoring and maintenance stage and the adaptive management strategies that may be employed.

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Table 10. Example of commissioning activities in a CSFW during the first two years post-construction (modified from McKenna et al. 2014b).

Commissioning Activity	Winter (Nov to Mar)	Spring (Apr to May)	Summer (Jun to Aug)	Fall (Sep to Oct)
YEAR 1				
Grading, Infrastructure and Engineering		Annual inspection of control structures		
Hydrology	Dry until April	Fill to normal water level (NWL) in spring	Reset below NWL in June to encourage new plant growth	Reset to NWL if conditions allow
Wetland vegetation	Mechanical planting, as part of construction stage (i.e. prior to commissioning)	Broadcast seeding	Assess and enhance with transplanting using hand planting	Inspect and assess
Upland vegetation		Site inspection and application of integrated weed management strategy (i.e. chemical, cultural or mechanical practices and timing)		
Wildlife	Fence all newly vegetated wetland areas (Canada Goose control)	Inspect	Inspect	
YEAR 2				
Grading, Infrastructure and Engineering		Annual inspection of control structures		
Hydrology	Water level set at NWL	Assess level to determine performance	Manipulate water levels (i.e. raising or lowering) to encourage plant establishment if required	Reset to NWL if conditions allow
Wetland vegetation	Mechanical planting, if required for enhancement	Seeding	Assess and enhance with transplanting using hand planting	Inspect and assess
Upland vegetation		Site inspection and application of integrated weed management strategy (i.e. chemical, cultural or mechanical practices and timing)		
Wildlife		Inspect	Inspect	Remove fencing only if wetland plants are mature

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Table 11. Potential problems that may be encountered with CSFWs and the associated adaptive management strategies to correct them (modified from McKenna et al. 2014b).

Observation	Habitat Indicators	Adaptive Management Strategies
Water loss/drying	• Exposed soil areas • Salts present at soil surface • Invasive plant coverage expanding	• Assess control structure for performance, settling • Assess and reduce outflows (control structure) • Conduct as-built assessment to evaluate wetland surface elevations • Convert drier areas from wetland habitat to upland habitat and report adjusted area to the regulatory body • Reduce Active Evapotranspiration (AET) (windbreaks, shading, shift in vegetation) • Seed or transplant plant species that possess species which tolerate both drier and wetter conditions, such as FAC or FACW species • Reduce recharge (incorporate fine-grained substrate) • Change water management schedules to take advantage of when water is available and when it is not
Abnormal increase of water levels for prolonged period (flooding)	• Water above NWL • Expansion of open water areas • Decrease in plant coverage or species flooded above top of shoots • Vegetation die-off • Littered biomass floating on the surface of the pond	• Manage a drawdown • Assess the cause of the flooding (e.g., pipe and/or outfall blockage, system backed-up, control structure failure) • Re-seed and re-plant as necessary
High rate of infilling with sediments	• Increased turbidity • Decrease in vegetative and biological diversity • Increase in invasive plant species • Blocking of pipes and outfalls	• Dredge and reclaim • Stabilize upland soils with fast-growing vegetation using appropriate species • Add sediment traps upland / upstream • Use vegetative buffer throughout watershed • Slow flows to help sediments settle out
Subsidence/compression of wetland bottom	• Wetland water depths deeper than designed • Expansion of open water areas	• Source additional sediment and add to the sediment cap (infill back to original depth) • Allow to stabilize and adapt target functions • If approved by the regulator, manage water levels at lower elevations than planned

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Observation	Habitat Indicators	Adaptive Management Strategies
	• Thinning in coverage of deeper emergent plant species over time	
Elevated salinity	• Evidence of salt on soil surface • Change in species composition from freshwater plant species to saline species • Decrease in plant diversity over time • Establishment of saline ring around outer wetland edge	• Increase flushing / dilution • Control / increase surface input sources • Increase / change cap on bottom substrates to seal in salts • Establish saline-tolerant communities
Toxicity	• Fish and wildlife die-offs • Vegetation die-off	• Investigate for increase microbial community (e.g., botulism, blue-green algal species) • Change organic content, investigate for excess nutrients/chemicals (e.g., fertilizers, peat)
Lack of vegetation	• Decrease in abundance of wetland vegetation	• Manage water levels to mimic summer drawdown • Increase frequency of drawdowns • Fertilize • If a consequence of herbivory (muskrats), then trap and remove muskrats • Re-seed and re-plant as necessary
Low wetland plant diversity	• Monotypic stands of vegetation present	• Control invasive species • Change water quality or adapt vegetation plantings to suit water quality (e.g., plant wetland species with high nutrient uptake potential for nutrient-rich waters) • Plant species which have low rates of natural dispersal • Manipulate water levels to encourage improved plant growth and wetland coverage
Presence of harmful algae communities	• Toxic blue-green algae becomes dominant algal community	• No management required if dominant algal communities are epiphyton, metaphyton and/or epipelon • Seek out second opinion if phytoplankton is dominant community to determine if community is harmful and whether it is a sporadic occurrence or the result of a permanent shift in wetland conditions

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Table 12. Potential problems that may be encountered with upland areas and associated adaptive management strategies to correct them (modified from McKenna et al. 2014b).

Observation	Habitat Indicators	Adaptive Management Strategies
Thatch/Litter (dead plant material) accumulation on the soil surface	• Lack of vegetation cover (i.e.<40 plants per square metre) • Low plant diversity (i.e. monotypic stands of vegetation present, particularly weeds)	• Assess land management history • Conduct a burn or mow management
Low plant diversity	• Monotypic stands of vegetation present • High abundance of invasive species	• Assess land management history • Conduct a burn or mow management • Control invasive species using one or more of the following methods: herbicide application, mowing or weed-whacking before weed goes to seed, manually pulling weeds • Re-vegetate stand
Lack of vegetation cover	• Exposed soil surface is dominant (>40% of site)	• Re-vegetate stand
Elevated salinity	• Evidence of salt on soil surface (e.g., white crust from elevated salinity) • Change in species composition from native upland to introduced species with salt tolerances • Decrease in plant diversity over time • Poor vegetation cover	• Control salinity at the source (i.e. runoff water) • Increase flushing/dilution with clean source • Assess soil health • Establish appropriate salt tolerant plant communities
Rill Erosion (Active runoff channels cause depressions on exposed soil surface)	• Soil and site stability compromised: wind and water erosion, poor plant cover	• Assess current status and strategize restoration methods (i.e. Installation of erosion control materials, re-vegetate stand)

5.1. Grading, Infrastructure and Engineering

5.1.1. Inspection and Monitoring Activities

Infrastructure requires, at a minimum, annual inspection (and operation) of control structures, particularly to inspect or adjust gates or stoplogs. Erosion and sediment control measures installed during construction should also be inspected to ensure they are operating as intended.

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5.1.2. Adaptive Management Strategies

If grading, infrastructure and engineering are functioning as designed post-construction, no adaptive management strategies are foreseen. In most cases, hydrology or vegetation monitoring will indicate if management of grading, infrastructure or engineering are required.

5.2. Hydrology

5.2.1. Commissioning Activities

Initial operation of the hydrology in a CSFW is one of the most important commissioning activities for wetland development. Water-level control structures may be present to allow for water level manipulation in many constructed storm water wetlands. CSFWs without control structures may require pumping to adjust water levels.

Manipulation of wetland hydrology for commissioning purposes should be suited to a CSFW's intended permanence type. General guidelines for flooding and drawdown are provided below. Whether completing flooding or drawdown, water levels should be changed at a rate of 2.5 cm per day or less.

- **Flooding:** A spring flood-up to a CSFW's normal water level (NWL) is recommended in the first year of commissioning. This provides the moisture conditions required to allow seed germination and seedling development. Flooding to NWL in the fall of the first few growing seasons may also be appropriate, depending on the type of wetland designed and the height of new wetland seedlings, as this ensures a CSFW will have the appropriate hydrological conditions the following spring.

  Water levels should never submerge new wetland seedlings for more than 1 – 2 weeks during the commissioning phase. Consequences of an improperly managed flooding regime can lead to partial or complete die-off of new wetland seedlings. Once wetland vegetation is established, typically following two complete growing seasons, flooding can be used to manage weedy upland species that may have invaded wetland zones in a drawdown cycle during the commissioning process.

- **Drawdown:** Summer drawdown is recommended during the first two years of commissioning, or until wetland plants become established within the various wetland zones. Drawdown promotes seed germination and vegetative growth of new wetland plants. The optimal water depths for commissioning during drawdown include: dry to saturated (i.e. within the wicking zone) conditions for the wet meadow zone; dry to standing water (i.e. 0 – 10 cm) conditions for the shallow marsh zone; and dry to standing water (i.e. 0 – 25 cm) conditions for the deep marsh zone. These depths provide appropriate moisture conditions for each zone without submerging new wetland seedlings. It is better for a wetland zone to remain dry during the commissioning phase, rather than commissioning hydrology at a deeper water level that puts new wetland plant growth at risk.

CSFW commissioning is site-specific; the first few years of site establishment require careful attention to plant growth and interpretation of plant responses to varying water levels. Wetland zones may need to be commissioned in phases. In the first year, water levels may be manipulated to encourage growth of robust emergent species. Once the deep marsh zone is sufficiently established to withstand deeper water levels, water levels can be raised in the second year to encourage wet meadow species and narrow-stemmed emergent species. Note that species planting will need to be timed (i.e., planting wet meadow and narrow-stemmed species after the first year) if this technique is employed.

When commissioning multiple CSFWs simultaneously, or where water level control is not possible, pumping can be used as a temporary method for adjusting water levels to the preferred water depth. For constructed storm

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water wetlands within a storm water network, this may require temporary ballooning or blocking of connecting pipes between storm water ponds in order to isolate ponds from each other.

5.2.2. Monitoring Activities

For CSFWs that are dependent on groundwater to maintain wetland hydrology, ongoing monitoring of groundwater as conducted during site assessment and design should be continued to confirm post-construction hydrology. It is recommended that water levels within the wetland are closely monitored to ensure the hydroperiod of the CSFW matches what was projected in the design plan.

Monitoring of water levels during the first two years after construction requires weekly to biweekly visits during the open water season, and after major precipitation events. Water levels should not remain above NWL, or the operating water level for commissioning activities, for periods longer than 30 days, as this will cause extensive damage to the establishment of wetland vegetation. These frequent water level checks are critical to ensure adaptive management strategies are undertaken in a timely manner, to prevent serious damage to the establishing wetland plant community. Following the first two years after construction, if the wetland appears to be performing as designed and is operating at its designed long-term hydrology, less frequent site inspections can occur.

5.2.3. Adaptive Management Strategies

If water levels remain high following a large precipitation event, water levels may need to be lowered back to NWL or below to prevent damage to young wetland vegetation; this can be done by adjusting the control structure or pumping water out of the CSFW. Investigate and rectify any unexplained cause for extended duration of flooding, such as control structure failure, sedimentation, a blocked channel, or changes to upstream sources or downstream outlets.

Adaptive management may also be required if there is significant water loss within a CSFW. Although drying is an important regenerative process in wetlands, condition that are too dry may enable the establishment of invasive and weedy species. Several adaptive management strategies may be taken, once the cause of lower water levels is identified, ranging from low maintenance solutions such as water level manipulation to intensive techniques, including redesign of basin topography and re-vegetation.

5.3. Wetland Vegetation

5.3.1. Commissioning Activities

Commissioning activities related to plant establishment may include additional seeding activities, or hand planting of propagules in targeted areas and with targeted species. Additional planting and weed management may also be required to support the desired species diversity and abundance and plant community health.

5.3.2. Monitoring Activities

Monitoring of wetland vegetation should be performed on an annual basis, starting the first year after construction and continuing for four years. Indicators that should be measured include:

- The vegetated to open water coverage areas (35 to 65%)
- Percent cover and density within the emergent and wet meadow zone (minimum of 75% cover of emergent and wet meadow species, and less than 10% and Class 5 or less of density/distribution of invasive species in all wetland zones)

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- Species richness (20 native wetland species) or plant health index (e.g., FQI or IBI)
- Water depths
- Zone widths associated with the wet meadow and emergent vegetation zones (see Section 3 for design characteristics)

Wetland vegetation monitoring is best conducted in late July or August when aboveground plant growth is at its peak and plants are easily identified. McKenna et al. (2014b) outline a number of wetland vegetation survey techniques that can be used to evaluate performance measures. Belt transects are recommended because they sample richness and composition across the wetland zones (see Ross 2009 for further detail on the belt transect methodology in wetlands).

If the plant health of a community is being evaluated, the Floristic Quality Index (FQI) or Index of Biological Integrity (IBI) for wet meadow communities in the Aspen Parkland and Boreal ecoregions is recommended. If these are not available in the region where the CSFW is located, species richness, diversity and abundance metrics for native versus weedy and invasive species can be used as a performance indicator. For calculation of FQI or IBI, sampling occurs by identified species cover within two 1 m^2 quadrats placed at the midpoint of the wet meadow zone (for further detail on the methodology, see Forrest 2010 and Wilson and Bayley 2012).

Weekly to monthly visual inspections of the wetland vegetation should be conducted to guide adaptive management strategies. Areas of poor coverage or low diversity that may require additional wetland vegetation planting or management should not be left unmanaged, as it may lead to further degradation and increased effort for adaptive management in the long-term. If wetland vegetation appears to be establishing as designed following the first two years after construction, then less frequent site visits can be made.

5.3.3. Adaptive Management Strategies

Adaptive management strategies may be required to address poor wetland plant coverage, low wetland plant diversity and increased weedy species. Water level manipulation, additional planting efforts, adjusting erosion and sediment controls, or weed management can address these issues.

5.4. Upland Vegetation

5.4.1. Commissioning Activities

Native upland buffer around a CSFW may require up to four years to become established. The upland or riparian buffer may be particularly vulnerable to dominance by weedy or invasive species during the commissioning period; most will have some weedy species in the first year. Spot treatment using herbicide, hand pulling, or mowing can reduce weedy species, depending on the species of concern and timing of management. An integrated weed management strategy during commissioning may include a spring site inspection, application of herbicide or mowing during the summer, and fall application of herbicide.

5.4.2. Monitoring Activities

Monitoring of the upland or riparian buffer should be performed on an annual basis, starting the first year after construction and continuing for four years. Monitoring is best conducted in late July or August when aboveground plant growth is at its peak and plants are easily identified; monitoring metrics include plant density, invasive species coverage, and evidence of erosion.

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5.4.3. Adaptive Management Strategies

The control of invasive and weedy species will likely be the most important adaptive management activity for upland vegetation. If upland plant cover remains low, revegetation activities may be required. In addition, prior to upland plant establishment, buffer areas may be vulnerable to erosion, particularly following large precipitation events. If monitoring activities identify exposed soils, installation of additional erosion control measures should be considered.

Over the long-term, intermittent management may be required within the upland buffer. Although the dead litter (e.g., duff) that builds up over time in a stand of upland native grasses can provide cover and nesting material to birds, occasional management can increase plant diversity and resilience to weedy and invasive species. Management activities may include periodic burning or mowing, depending on site-specific conditions and feasibility. Improper timing and frequency of upland management activities after the plant community has established may damage upland vegetation.

5.5. Water Quality

5.5.1. Commissioning Activities

No specific commissioning activities are required that target water quality for CSFWs.

5.5.2. Monitoring Activities

Alberta Transportation (Government of Alberta 2014a, 2014b, 2014c) recommends monitoring electrical conductivity, pH and dissolved oxygen on an annual basis. For CSFW established in the oil sands, the Cumulative Environmental Management Association (CEMA) recommends testing for salinity (anions and cations), pH, and electrical conductivity at a minimum, with potential additional analyses including temperature, turbidity, dissolved oxygen, nutrients, chlorophyll a, coliforms, dissolved organic carbon, color, TDS, alkalinity, and both major and minor metals of interest (McKenna et al. 2014b). Jurisdictional regulations may require water quality monitoring of constructed storm water wetlands, particularly with respect to total suspended solids (TSS).

Incidental observation of water quality related issues such as turbidity, odor, harmful algal blooms, excessive submergent plant growth in open water areas, or fish kills should be addressed with adaptive management.

5.5.3. Adaptive Management Strategies

There are few know adaptive strategies for water quality parameters that remain outside of targeted ranges (McKenna et al. 2014b). Water quality may improve over time as a CSFW's biogeochemical processes and vegetative communities become established. However, the improvement may take decades. Over the short-term commissioning period, a CSFW's water can be pumped out or displaced with water of better quality. Over the long-term, re-designing vegetation communities for wetland water quality improvement function may be necessary.

5.6. Wildlife

5.6.1. Commissioning Activities

The main objective related to wildlife during the commissioning stage is to deter nuisance wildlife from grazing new vegetation growth. While established CSFWs can withstand the impact of nuisance grazing, the new shoots

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of establishing wetland plants are vulnerable to grazing by species such as Canada Geese and muskrats. Fencing around the newly planted wetland vegetation zones (open water and upland edges) is recommended during the first three years, regardless of whether these wildlife species have been observed within the area during site assessment.

5.6.2. Monitoring Activities

Incidental wildlife observations should be recorded in CSFWs that were designed to promote specific wildlife habitat functions. In addition, the status and evidence of use of wetland habitat features such as gravel bars or woody debris should be monitored.

5.6.3. Adaptive Management Strategies

Repairs to temporary fencing may be required to manage overgrazing of new vegetation growth in a CSFW. Muskrats damage earthworks like constructed dikes or berms, while beavers dam inlets and outlets and alter hydrology (McKenna et al. 2014b) and destroy upland vegetation. Although there are no preventative measures to exclude muskrats and beavers from CSFWs, they can be trapped and relocated if they are damaging vegetation or earthworks.

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6. Glossary

Active Storage – Stormwater that is temporarily stored in a CSFW during and following a storm event. The active storage generally constitutes the volume between NWL and HWL.

Adaptive Management – The process of taking opportunities to perform timely maintenance. In the context of constructed replacement wetlands in Alberta, adaptive management uses monitoring results to inform activities to keep a CSFW on a trajectory to success. The adaptive management stage occurs during the wetland construction process in conjunction with commissioning and monitoring, as a minimum four year process, commencing following the approval of the Wetland Construction Validation Report, prior to the submission of a Wetland Construction Verification Report.

Algae – A simple nonflowering plant of a large group that includes the seaweeds and many single-celled forms. Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue. In wetlands algae exists as metaphyton (floating), epiphytic (attached to substrates), epipelon (in/on soils) and phytoplankton (within the water column).

Basin Topography – The shape, slopes and depths of a CSFW. It influences the types of vegetation and wildlife habitat and can buffer disturbance to native wetland species while promoting their establishment. Basin topography is one of the three wetland design principles.

Best Management Practices (BMPs) – Includes schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent, eliminate, or reduce the pollution of waters of the receiving waters as well as to preserve and protect soils.

Broadcast Seeding – A method of wetland and upland seeding that involves scattering seed, by hand or mechanically.

Buffer – A strip of permanent vegetation between a wetland (in this case, constructed) and receiving waters that helps improve water and soil quality by slowing runoff, filtering pollutants and stabilizing soil.

Catchment Area – The area of land which collects precipitation and contributes runoff to an outlet or body of water. For the purposes of this document, catchment area refers to the land area from which a CSFW receives runoff.

Commissioning – In the context of constructed replacement wetlands in Alberta, commissioning is a process with planned activities, including water level manipulation to assist wetland vegetation in establishing, infrastructure operation and nuisance wildlife control. The commissioning stage occurs during the wetland construction process in conjunction with monitoring and adaptive management, as a minimum four year process, commencing following the approval of the Validation Report, prior to the submission of a Verification Report.

Constructed Stormwater Facility Wetland (CSFW) – A newly created wetland on land that is designed into a portion of an artificial system such as a stormwater pond and that receives treated stormwater. They contain wetland design principles and wetland habitat features, such as native plant species and landscape features, in order to support wetland functions while meeting stormwater requirements. CSFWs are designed to mimic the appearance and function of a natural wetland.

Conventional Stormwater Pond – A stormwater management facility that is partially inundated on a permanent basis, as dead storage, and is built to attenuate peak flows downstream, as active storage. While a conventional stormwater pond may provide some sediment reduction, it has limited ability to improve water quality. The pond edge may be lined with riprap, and the active storage zone is usually top soiled and seeded with kentucky bluegrass.

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Cover Crop – A temporary crop that is planted primarily to reduce soil erosion by wind and water, and manage nutrient levels until the site is ready for permanent native cover.

Culvert – A structure used to convey water from one area to another, often under roads or bridges. May be constructed from pipe, concrete, or other materials. May be used to control water release from CSFW sites.

Deci siemens (dS) – A measure used to determine electric conductance (or electrical conductivity) of the soil. A unit of salinity, when measured as dS/cm.

Discharge Rate – The rate of stormwater flow coming out of a pipe, pond or drainage area, usually measured in L/s or m^3/s.

Donor Site – An area of healthy natural vegetation containing desired plant species which may be harvested and transplanted to other areas to aid in restoration projects. No naturally occurring sites should be degraded or destroyed in order to provide donor material to a CSFW.

Drill-seeding – The use of a seed drill to seed native plants at a consistent rate and uniform depth, as well as provide good seed to soil contact. This practice results in optimal seedling germination and emergence.

Duff – Decomposing organic material, decomposed to the point at which there is no identifiable organic materials. Sometimes referred to as litter. The duff layer is found above the A-horizon (uppermost soil mineral horizon). In grassland ecosystems the duff layer is removed every 5 to 7 years through natural disturbances such as fire or grazing, allowing establishment of new grasses.

Earth Dykes – Used as an erosion control measure, earth dykes are temporary compacted berms used to direct upslope runoff into a stabilized channel.

Emergency Overflow – A channel or notch in the berm of a pond that provides a safe mode of water release if an outlet is clogged or if a storm event higher than the maximum design storm event occurs.

Emergent Zone – The area of shallow standing water dominated by wetland vegetation that is rooted, with leaves and stems that grow above (emerge from) the water surface, with water depths ranging between 10 cm and 60 cm. Includes genera such as *Schoenoplectus* (bulrushes), *Typha* (cattails) and *Carex* (sedges). Includes both shallow wetland and deep wetland zones in terms of the Alberta Wetland Classification System.

Erosion – The wearing away of soils by the natural forces of water, wind and land practices such as construction, tillage.

Erosion Control – The practice of working to keep soil particles in place by protecting them from being eroded by water or wind.

Erosion Control Products – Measures used to intercept sediment or earth. Includes sediment and earth interceptor barriers, swales, earth dykes, temporary cover crops and permanent vegetation cover.

Evapotranspiration (ET) – The loss of water to the atmosphere through the combined processes of evaporation and transpiration, the process by which plants release water they have absorbed into the atmosphere.

Fetch – The distance for wind or wave action to travel across open water.

Flooding – Water-level manipulation either as naturally occurring or human-induced for wetland management. Wetland plants position themselves within a basin based on their ability to survive certain water depths.

Floristic Quality Index (FQI) – Plant based performance indicator that evaluates wetland condition. For FQI application in Alberta, see Bayley et al. (2014).

Freeboard – The volume between the HWL and the bottom of the emergency overflow spillway. Freeboard is usually measured in terms of elevation differential.

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Groundwater – Water under the surface of the ground, originating from rainfall or snowmelt that penetrates the layer of soil just below the surface. For groundwater to be a recoverable resource, it must exist in an aquifer, whose depths, yields and water quality vary.

Groundwater Recharge – Groundwater recharge, deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer.

Groundwater Discharge – Groundwater discharge is a hydrologic process where water moves from the subsurface to the surface.

Habitat − the specific area or environment in which a particular type of plant or animal lives.

Herbicide – A substance that is used to inhibit or destroy unwanted vegetation.

High Water Level (HWL) – The theoretical elevation of the top of water in a CSFW during the maximum design storm event.

Hydric Soil – Formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions (lacking oxygen) in the upper part of the soil profile. It is characteristic of wetlands and is often organic in composition. Specialized wetland vegetation is adapted to these conditions.

Hydrology – The most important variable in wetland design and the main variable that leads to the failure of CSFWs. Hydrology includes the movement and distribution of water on a site: the inflow and outflow, both surface and subsurface; the flood/drought cycle; the water cycle; and environmental watershed sustainability. Hydrologic conditions ultimately determine the type of wetland created. Hydrology is one of the three wetland design principles.

Hydroperiod – The depth, length of time, and the portion of the year a basin holds ponded water. It defines the rise and fall of a wetland's surface and subsurface water and the speed, timing and duration with which these processes occur.

Hydrophytic Vegetation – Plant-life that thrives in wet conditions.

Hydroseeding – A planting process where a slurry of water, seed and mulch is sprayed onto the planting surface for quick seeding and establishment of large areas.

Index of Biological Integrity (IBI) – Plant based performance indicator that evaluates wetland condition. For IBI application in Alberta, see Bayley et al. (2014).

Infiltration – The process by which surface runoff enters the soil and percolates down.

Inlet – A pipe or channel that carries water into a CSFW. There can easily be confusion here since stormwater flows out of the inlet and not into the inlet. For the purposes of this document, the term inlet/outlet is relative to the pond and not to the direction of flow in or out of the pipe or channel.

Length to Width Ratio (L:W) – The L:W ratio is the quotient between the length of a CSFW, forebay or swale and its width between normal water level (NWL).

Litter – Undecomposed dead plant materials such as leaves, twigs and bark that fall and accumulate on the soil surface. Sometimes referred to as duff. This litter layer eventually decomposes and is added to the top layer of soil. In grassland ecosystems the litter layer is removed every 5 to 7 years through natural disturbances such as fire and grazing, allowing establishment of new grasses.

Marsh – A mineral-based wetland having shallow water, with levels that usually fluctuate daily, seasonally or annually due to tides, flooding, evapotranspiration, groundwater recharge, or seepage losses. The water table

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usually remains at or below the soil surface. Portions of a marsh may dry up and have exposed sediment under drought conditions. Marsh vegetation is predominantly comprised of emergent graminoids (reeds, rushes, sedges, grasses); shrubs; emergent, floating or submergent herbaceous plants; and nonvascular plants such as mosses and algae.

Mitigation – Management activities taken to avoid and minimize negative impacts on wetlands, and to replace lost wetlands, where necessary (Government of Alberta 2013a). The mitigation hierarchy for the Alberta Wetland Policy is avoid, minimize, replace.

Monitoring – In the context of wetland construction for restorative replacement in Alberta, monitoring:

1. Acquires the necessary information to demonstrate to the regulatory body that a CSFW is meeting performance measures, as part of the Verification Report for constructed replacement wetland offset approval
2. Provides an early warning that a CSFW may not be functioning as intended, to inform adaptive management.

The monitoring stage occurs during the wetland construction process in conjunction with commissioning and adaptive management, as a minimum four year process, commencing following the approval of the Validation Report, prior to the submission of a Verification Report.

Native Plant Species – A plant species that is indigenous to a given region as a result of natural processes, is adapted to the local environment and has evolved relationships with other organisms in the region.

Natural Wetland – Any area that holds water either temporarily or permanently. Often a naturally occurring transition zone between terrestrial and aquatic systems where the water table is near, at, or just above the surface of the land. Wetland boundaries are delineated using three basic parameters:

1. Presence of plant species adapted to life in moist or saturated soil
2. Presence of soils displaying characteristics that develop due to lack of oxygen
3. Evidence of hydrologic input from surface water and/or groundwater creating conditions favourable to water loving and water tolerant plants and to the development of wetland soils.

Nitrogen (N) – A chemical element with symbol N. Nitrogen is a naturally occurring mineral, essential to plant growth; however, when in excess in aquatic environments it can lead to water quality issues (i.e. eutrophication) and algal blooms. Depending on the ratio of nitrogen to phosphorus when in excess, this may favour blue-green (cyanobacteria) algal growth.

Normal Water Level (NWL) – The elevation of the top of the permanent pool of water in a CSFW.

Permanent Vegetation Cover – Used as an erosion control measure to stabilize disturbed or exposed areas, dense cover and vast root networks can protect soils from the eroding effects of wind and water. Established for the long-term.

Phosphorus – A naturally occurring mineral, this nutrient is essential to plant growth; however, in excess in aquatic environments can lead to water quality issues (i.e. eutrophication) and algal blooms. Depending on the ratio of nitrogen to phosphorus when in excess, this may favour blue-green algal growth.

Propagules – Live wetland plants, including roots and shoots transplanted for the purposes of establishing vegetation in a wetland plant zone.

Reclamation – The practice of returning altered lands to a state that resembles an unaltered natural environment characteristic to an area.

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Runoff - The water that moves over the surface of the ground. Runoff collects sediments and contaminants as it moves from higher elevations to lower elevations.

Seasonal Marsh – Flooded for extended periods in the growing season, but usually no surface water by the end of the growing season. Dry by August each year except in wet years.

Sediment Control – Practices to capture soil particles after they have been picked up by wind or water.

Seed Bank – Critical in the establishment, development and resilience of a wetland, the seed bank is ungerminated seeds that are stored in the sediments of wetland long-term, until conditions are favourable for germination.

Semi-permanent Marsh – Flooded in the growing season in most years. Dry one year in every 5 to 8 years.

Shoreline Development Index (SDI) – A ratio of the perimeter of a wetland to the perimeter of a circle of the same area as the wetland, used as a measure of irregularity.

Site Assessment – In the context of wetland construction for restorative replacement in Alberta, site assessment is the process of acquiring information related to topography, hydrology, soils, and existing biodiversity to inform the feasibility of wetland construction at a selected site. Site assessment informs the design process for wetland construction.

Soil Compaction – The compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water, and affects soil structure. Soil compaction can impair water infiltration into soil, plant emergence, root penetration and nutrient and water uptake.

Soil Organic Matter (SOM) – The organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms.

Soil Permeability – The ability of the soil to transmit water and air. Permeability is affected by factors such as soil particle size, texture, structure, the degree of saturation and adsorbed water.

Sluice gate – A portal which may be opened or closed to allow or prevent the passage of water through a channel.

Spillway – A channel for an overflow of water, as from a reservoir.

Orifice – An orifice is an opening commonly used in control structure to measure flow rate, for reduce pressure or restrict flow.

Stoplog – One of a set of usually square pieces (as of wood or metal) that serve to form a dam or to check the flow of water.

Sublimation – A loss of snow pack and/or snow moisture through evaporation to the atmosphere.

Submergent Vegetation – Plants that have most of their structures below water. Common examples include coontail, milfoils, and pondweeds.

Surface Water – Water on the Earth's surface found in rivers, streams, ponds, lakes, marshes, wetlands, as ice and snow, and transitional, coastal and marine waters. Although separate from groundwater, surface water is interrelated to groundwater.

Swales – An erosion control measure used to capture, direct and slow the flow of water, preventing erosion by water.

Trafficability – The ability to support heavy equipment.

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Validation – In the context of wetland construction for restorative replacement in Alberta, the validation stage assesses if construction was completed according to the Wetland Construction Plan. Validation requires the submission of a Validation Report to the regulatory body within 30 working days of completing wetland construction.

Verification – In the context of wetland construction for restorative replacement in Alberta, the validation stage is the final step a proponent takes in the wetland construction process, in order to apply for a constructed replacement wetland offset to the regulatory body. It occurs a minimum of four years after the approval of the Validation Report, following the commissioning, monitoring and maintenance stage.

Weir - A dam placed across a channel to raise or divert the water, or to regulate or measure the flow.

Wetland Construction Plan – A Wetland Construction Plan, submitted to the regulatory body following the site assessment and design stages of wetland construction, is used to ensure that the proponent is on the trajectory to build an effective and functioning wetland. It is referred to throughout the wetland construction project, including the validation, monitoring and verification stages.

Wetland Functions – The Alberta Wetland Policy (Government of Alberta 2013a) identifies four key functional groups that provide wetland value: hydrologic, water quality, ecological (habitat) and human use. It is therefore a requirement that a CSFW supports all of the four key wetland functions, via the wetland design principles and wetland habitat features. Key Wetland Functions will be assessed in the Wetland Construction Plan, as well as when validating, monitoring and verifying that a wetland construction project is on a trajectory to success.

Wetland Plant Communities – One of the three required wetland design principles, the wetland plant communities of CSFWs (including the emergent zone and wet meadow zone) is determined by both the hydrology and basin topography design of a system, and supports many key wetland functions, including water quality and ecological (habitat) functions.

Wetland Restoration – The re-establishment of hydrology, vegetation and wetland processes within a previously drained wetland.

Wet Meadow Zone – The transitional zone between wetlands and uplands where soils are saturated with water just below the surface. Positioned between the emergent marsh zone and upland areas, it often contains the most diversity of all wetland zones. Together with the emergent zone, wetland plant communities is one of the three wetland design principles.

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7. References

Adams L. W., T. M. Franklin, L. E. Dove, and J. M. Duffield. 1986. Design considerations for wildlife in urban stormwater management. Transactions North American Wildlife and Natural Resources Conference 51:249-259.

Agroforestry and Woodlot Extension Society (AWES). N.D. Planting Stem Cuttings in Riparian Sites. http://nebula.wsimg.com/6dae4983cf0b79122d6468f050379735?AccessKeyId=BE98AB9B4735B9BD02B1&disposition=0&alloworigin=1

Alberta Agriculture, Food and Rural Development. 2004. Soil quality criteria relative to disturbance and reclamation. Alberta Soils Advisory Committee, Conservation and Development Branch. Edmonton, AB.

Alberta Environment. 2004. A Guide to the code of practice for pits. Edmonton, AB.

Alberta Environment and Sustainable Resource Development. 2012. Stepping back from the water: a beneficial management practices guide for new development near water bodies in Alberta's settled region. Edmonton, AB.

Alberta Environment and Sustainable Resource Development (AESRD). 2015. Alberta wetland classification system. Water Policy Branch, Policy and Planning Division, Edmonton, AB.

Alberta Environment and Water. 2012. Best management practices for conservation of reclamation materials in the mineable Oil Sands region of Alberta. Prepared by MacKenzie, D. for the Terrestrial Subgroup, Best Management Practices Task Group of the Reclamation Working Group of the Cumulative Environmental Management Association, Fort McMurray, AB.

Alberta Environment Protection. 1999. Stormwater management guidelines for the Province of Alberta. Municipal Program Development Branch, Environmental Sciences Division, Environmental Service. Edmonton, AB.

Alberta Land Conservation and Reclamation Council (ALCRC). 1992. A user guide to pit and quarry reclamation in Alberta. Calgary, AB.

Baskin, C. and J. Baskin. 2014. Chapter 11: Germination ecology of plants with specialized life cycles and/or habitats. Pages 929 to 952 in Seeds: Ecology, biogeography, and evolution of dormancy and germination, 2nd edition. Elsevier.

Bedard-Haughn, A.K. and D.J, Pennock. 2002. Terrain controls on depressional soil distribution in a humocky morainal landscape. Geoderma 110: 169-190.

Berry, C. R. and S. C. Juni. 2000. Guidelines for restoring and creating wetlands associated with highway projects in South Dakota. Bulletins. Paper 737.

Berthold, S., L.R. Bentley, and M. Hayashi. 2004. Integrated hydrogeological and geophysical study of depression-focused groundwater recharge in the Canadian prairies. Water Resources Research 40: 1-14.

Brown, S., D. Shafer, and S. Anderson. 2001. Control of beaver flooding at restoration projects. WRAP Technical Notes Collection (ERDC TN-WRAP-01-01), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Buttleman, C. 1992. A handbook for reclaiming sand and gravel pits in Minnesota. Minnesota Department of Natural Resources. St. Paul, MN.

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Canadian Council of Ministers of the Environment (CCME). 2002. Canadian water quality guidelines for the protection of aquatic life: Total particulate matter. http://ceqg-rcqe.ccme.ca/download/en/217

City of Calgary. 2011. Stormwater management and design manual. Water resources. Calgary, AB.

City of Calgary. 2017a. Erosion and sediment control guidelines. Water resources. Calgary, AB.

City of Calgary. 2017b. Erosion and sediment control field manual. Water resources. Calgary, AB.

City of Edmonton. 2005a. Erosion and sediment control guidelines. Drainage services. Edmonton, AB.

City of Edmonton. 2005b. Erosion and sediment control field manual. Drainage services. Edmonton, AB.

City of Edmonton. 2008. Design and construction standards. Volume 3: Drainage. City of Edmonton. Edmonton, AB.

City of Edmonton. 2010. Wildlife passage engineering design guidelines. Stantec Consulting Ltd., June 2010.

City of Edmonton. 2012. Design and construction standards, Volume 3: drainage. Edmonton, AB.

City of Moncton. 2015. Naturalized stormwater management guidelines. Draft number 2. March 2015.

City of Saskatoon. 2014. Wetland design guidelines. Saskatoon, SK.

Daniels, W. L. and G. R. Whittecar. 2004. Assessing soil and hydrologic properties for the successful creation of non-tidal wetlands. Pages 114-129 in Vasilas, L. M. and B. L Vasilas, editors. A guide to hydric soils in the Mid-Atlantic region. Version 1.0. USDA-NRCS, Morgantown, WV.

Debing, J., Z. Lianbi, Y. Xiaosong, H. Jianming, Z. Mengbin, and W. Yuzhong. 2009. COD, TN and TP removal of *Typha* wetland vegetation of different structures. Polish Journal of Environmental Studies 18:183-190.

Dittmar, L. A. and R. K. Neely. 1999. Wetland seed bank response to sedimentation varying in loading rate and texture. Wetlands 19:341-351.

Eaton, B., J. Fisher, L. Ross, L. Dupuis, D. Vitt, M. Wilson, and T. Charette. 2014. Chapter 3: Natural wetlands in the region. Pages 71-119 in Cumulative Environmental Management Association (CEMA). Guidelines for wetland establishment on reclaimed oil sands leases. Fort McMurray, AB.

Engelhardt, K. A. and M. E. Ritchie. 2001. Effects of plant diversity on wetland ecosystem function and services. Nature 410:687-689.

Engelhardt, K. A. and M. E. Ritchie. 2002. The effect of aquatic plant species richness on wetland ecosystem processes. Ecology 83:2911–2924.

Fairbairn, S.E. and J.J. Dinsmore. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21: 41-47.

Forrest, A.S.M. 2010. Created stormwater wetlands as wetland compensation and a floristic quality approach to wetland condition assessment in central Alberta. Master’s Thesis, University of Alberta, Edmonton, AB.

Gabor, T.S, A. Kiers North, L.C.M. Ross, H.R. Murkin, J.S. Anderson, and M.A. Turner. 2001. Beyond the pipe - the importance of wetlands and upland conservation practices in watershed management: functions and values for water quality and quantity. Report to the Ontario Walkerton Inquiry Commission, Ottawa, ON.

© 2018 Government of Alberta

Galatowitsch, S., R. Budelsky, and L. Yetka. 1999. Revegetation strategies for northern temperate glacial marshes and meadows. Pages 225-241 in W. Streever, editor. An international perspective in wetland rehabilitation. Kluwer Academic Publishers, Dordrecht, Netherlands.

Galinato, M. I. and A. G. van der Valk. 1986. Seed germination traits of annuals and emergents recruited during drawdowns in the Delta Marsh, Manitoba, Canada. Aquatic Botany 26:89-102.

Government of Alberta. 1999. Stormwater management guidelines for the Province of Alberta. Edmonton, AB.

Government of Alberta. 2013a. Alberta wetland policy. Water Policy Branch, Alberta Environment and Parks. Edmonton, AB.

Government of Alberta. 2013b. Alberta transportation guide to reclaiming borrow excavations. Alberta Transportation. Edmonton, AB.

Government of Alberta. 2014a. General design guidelines for a constructed 'habitat' wetland – Grasslands natural region of Alberta. Alberta Transportation. Edmonton, AB.

Government of Alberta. 2014b. General design guidelines for a constructed 'habitat' wetland – Boreal forest natural region of Alberta. Alberta Transportation. Edmonton, AB.

Government of Alberta. 2014c. General design guidelines for a constructed 'habitat' wetland – Parkland natural region of Alberta. Alberta Transportation. Edmonton, AB.

Government of Alberta. 2015. Alberta wetland identification and delineation directive. Water Policy Branch, Alberta Environment and Parks. Edmonton, AB.

Government of Alberta. 2018. Directive for Permittee-Responsible Wetland Construction in Alberta. Water Policy Branch, Alberta Environment and Parks. Edmonton, AB.

Government of Alberta. 2017. Professional responsibilities in completion and assurance of wetland science, design and engineering work in Alberta. Water Policy Branch, Alberta Environment and Parks. Edmonton, AB.

Gutrich, J. J., K. J. Taylor, and M. S. Fennessy. 2009. Restoration of vegetation communities of created depressional marshes in Ohio and Colorado (USA): the importance of initial effort for mitigation success. Ecological Engineering 35:351-368.

Hayashi, M., G. van der Kamp, and D.L. Rudolph. 1998. Water and solute transfer between a prairie wetland and adjacent uplands, 1. water balance. Journal of Hydrology 207: 42-55.

Hutchinson, G. E. 1957. A treatise on limnology v.1. Geography, Physics and Chemistry. Wiley.

Johnson, K., G. Walton, and A. Johnson. 2009. Wetland mitigation in abandoned gravel pits: Creating fresh meadow and shrub swamp. International Conference on Ecology & Transportation (ICOT). 419-440 pp.

Koropchak, S. C. 2007. *Carex Aquatilis* as a pioneer species for boreal wetland reclamation in Northern Alberta. Master's Thesis, Southern Illinois University Carbondale, Ann Arbor, MI.

Lin, Y. F., S. R. Jing, T. W. Wang, and D. Y. Lee. 2002. Effects of macrophytes and external carbon sources on nitrate removal from groundwater in CSFWs. Environmental Pollution 119:413-420.

© 2018 Government of Alberta

McKenna, G., V. Mann, and L. C. M. Ross. 2014a. Chapter 6: Wetland design at the landform scale. Pages 193 to 248 in Guidelines for wetland establishment on reclaimed oil sands Leases, 3rd edition. Cumulative Management Environmental Association.

McKenna, G., V. Mann, and L. Ross. 2014b. Chapter 8: Wetland operation, maintenance and monitoring. Pages 299 to 335 in Guidelines for wetland establishment on reclaimed oil sands leases, 3rd edition. Cumulative Management Environmental Association.

Mitsch, W. J. and J. G. Gosselink. 2007. Wetlands. John Wiley & Sons, New York, NY.

Mulhouse, J. M. and S. M. Galatowitsch. 2003. Revegetation of prairie pothole wetlands in the mid-continental US: twelve years post-reflooding. Plant Ecology 169:143-159.

Murkin, H. R., A. G. van der Valk, and W. R. Clark. 2000. Prairie wetland ecology. Iowa State University Press, Ames, IA.

Polster, D. F. 2013. Soil Bioengineering for Site Restoration. Boreal Research Institute. http://www.nait.ca/docs/Soil_Bioengineering_for_Site_Restoration.pdf

Ross, L. C. M. 2009. Vegetation and soil properties as indicators of the hydrology and ecological health of northern prairie wetlands in native and agricultural landscapes. Master's Thesis, University of Manitoba, Winnipeg, MB.

Ross, L. and D. Vitt. 2014. Appendix B: Functional and Structural Attributes of Wetlands. Pages 356 to 357 in Guidelines for wetland establishment on reclaimed oil sands leases, 3rd edition. Cumulative Management Environmental Association.

Ross, L., D. Vitt, G. McKenna, and V. Mann. 2014. Chapter 7: Wetland construction. Pages 253 to 281 in Guidelines for wetland establishment on reclaimed oil sands leases, 3rd edition. Cumulative Management Environmental Association.

Ross, L. C. M. and L. Gabruch. 2015. Reclamation guidance for soil and substrate material use in mineral based wetlands in the Boreal Forest of Alberta. Cumulative Management Effects Association, Alberta, CEMA #2014-0015.

Scheffers B. R. and C. A. Paszkowski. 2013. Amphibian use of urban stormwater wetlands: The role of natural habitat features. Landscape and Urban Planning 113:139-149.

Smialek, J., V. Bouchard, B. Lippmann, M. Quigley, T. Granata, J. Martin, and L. Brown. 2006. Effect of a woody (*Salix nigra*) and an herbaceous (*Juncus effusus*) macrophyte species on methane dynamics and denitrification. Wetlands 26:509-517.

Stewart, R. E. and H. A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. Resource Publication 92. US Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.

Su, M. 1998. Modeling the water balance of a small prairie wetland. Master's Thesis. University of Saskatchewan, Saskatoon, SK.

United States Department of Agriculture (USDA). 2017. Natural Resources Conservation Service. Plants Database. Accessed March 29, 2017 from http://plants.usda.gov/java/.

© 2018 Government of Alberta

van der Valk, A. G. 2000. Vegetation dynamics and models. Pages 125-162 in H. R. Murkin, A. G. van der Valk, and W. R. Clark, editors. Prairie wetland ecology: The contribution of the marsh ecology research program. Iowa State University Press, Ames, IA.

van der Valk, A. G. and C. H. Welling. 1988. The development of zonation in freshwater wetlands. Pages 145-158 in H. J. During, M. J. A. Werger, and J. H. Willems, editors. Diversity and pattern in plant communities. SPB Academic Publishing, The Hague, Netherlands.

van der Valk, A. G. and R. L. Pederson. 1989. Seed banks and the management and restoration of natural vegetation. Pages 329-346 in M. A. Leck, V. T. Parkers, and R. L. Simpson, editors. Ecology of soil seed banks. Academic Press, Inc., Toronto, ON.

van der Valk, A. G., T. L. Bremholm, and E. Gordon. 1999. The restoration of sedge meadows: seed viability, seed germination requirements, and seedling growth of *Carex* species. Wetlands 19:756-764.

Wark, D. B., L. K. Gabruch, C. Penner, R. J. Hamilton, and T. G. Koblun. 2006. Revegetating with native grasses in the northern Great Plains. Ducks Unlimited Canada, Stonewall, MB.

Wassen, M. J., W. H. Peeters, and H. O. Venterink. 2003. Patterns in vegetation, hydrology, and nutrient availability in an undisturbed river floodplain in Poland. Plant Ecology 165:27-43.

Werner, K. J. and J. B. Zedler. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands 22:451-466.

Wilson, M. J. and S. E. Bayley. 2012. Use of single versus multiple biotic communities as indicators of biological integrity in northern prairie wetlands. Ecological Indicators 20:187-195.

Wilson, M. J., A. S. Forrest, and S. E. Bayley. 2013. Floristic quality assessment for marshes in Alberta's northern prairie and boreal regions. Aquatic Ecosystem Health and Management 16:288-299.

Wilson, M. J., S. E. Bayley, and R. C. Rooney. 2013. A plant-based index of biological integrity in permanent marsh wetlands yields consistent scores in dry and wet years. Aquatic Conservation: Marine and Freshwater Ecosystems 23:698-709.

Woosaree, J. and M. Mckenzie. 2012. When is reclamation success achieved, using the 2010 reclamation criteria as a guide? Petroleum Technology Alliance of Canada. Alberta Innovates - Technology Futures.

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