Report

Wetland Design Guidelines

Prepared for

City of Saskatoon

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CH2MHILL®

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Executive Summary

This document, the Wetland Design Guidelines (Guidelines), provides a basic set of guidelines to developers and designers, to aid them in understanding, siting, and design requirements for surface flow constructed wetlands (SFCW) and floating wetland island (FWI) systems within proposed developments. Each site should be assessed on its own merits including topography, catchment area, expected water quality, predicted stormwater flows, design storm event return period, and available footprint for a stormwater management constructed wetland (SWMCW) to achieve the best solution possible, taking into consideration the current surrounding natural environment and proposed development. These Guidelines align with and must be used in concert with the current Wetland Policy; as previously stated they are offered for guidance only and should not be used in the place of required detailed site specific engineering drawings and specifications. Furthermore, a design example is included in Appendix A of a project constructed by CH2M HILL and provides some guidance for sizing, structures, and overall design.

Table ES.1 gives an overview of the stormwater treatment wetlands design elements and considerations that have been described in more detail elsewhere in this document. It also provides an index to the section in which the element is discussed.

TABLE ES.1
Summary – Elements of the Stormwater Treatment Wetland Design Guidelines

Design Component	Details	Comments	Index
Source controls	To manage runoff volume and sediment within the generating site	New or retrofitting of existing residential and industrial developments using porous pavement, perforated stormwater piping, vegetated filter strips, rain gardens, vegetated curbs, rain barrels, disconnect roof drains, and sumps	Section 2.1 Figure 2.2
Bypass conveyance	Riprap, paver, or concrete lined channel or a pipe	Needs to be sized for the predicted extreme event flows and in conjunction with modelling of flow routing and water depth control through the stormwater management system	Section 2.4.3 Figure 2.20
Pretreatment	Forebay, vortex separator	Limited available land and health and safety issues drive towards installing a vortex separator rather than a forebay	Section 2.3 Figures 2.13-2-15
Inflow/outflow structures	Three-chamber, reversed flow pipe, perforated riser pipe, orifice, gate valves, trash rack	Two main outlet flow structure design most appropriate for Saskatoon CW are reverse sloped outlet pipe and perforated riser outlet pipe.	Section 2.4.2 and 2.4.3 Figures 2.16-2.20
Water level control	Stepped weirs	Incorporate weirs into inflow structure if there is available footprint at the CW.	Section 2.4.3
Freezing conditions	Weirs, large-diameter pipes	Inlet and outlet structures must be resistant to freezing and to ice build-up. Wetland to be designed to provide increased water depth during winter months to maintain hydraulic retention time	Section 2.4.2-3
Piping	For inflow, outflow (including between cells), and bypass conveyance	Design for pipe sizing and configuration based on expected flows and flow path	Section2.4.2-3 Figures 2.16-2.20
Active storage depth/ freeboard	Minimum of 2 m	Based on design flow capture and determined inflow/discharge rate	Section 2.7
Aspect ratio (L:W)	Minimum 2:1	Based on available footprint and influenced by shape of existing prairie pothole wetland Incorporate deep zones for flow distribution	Section 2.6 Figure 2.24

TABLE ES.1

Summary – Elements of the Stormwater Treatment Wetland Design Guidelines

Design Component	Details	Comments	Index
Berm	Slope 3:1 above base flow level, 5:1 below base flow level Materials of construction – able to compact to 98% Proctor, water tight or water tight core Width – min 1 m for foot traffic and min 3 m for a half-ton pickup truck	Critical to design for expected access requirements (such as, public, maintenance, monitoring)	Section 2.6.3 Figure 2.25
Liner	Options are none, compacted existing soils, imported clay, HDPE	If water quality will not negatively impact groundwater, not installing a liner may be acceptable in CW or allowing use of prairie pothole wetland with only perimeter berm installation. Note CW soils will blind over time and percolation rate will decrease. Where concern regarding potential groundwater contamination, some type of liner will be required	Section 2.7.3
Vegetation	Seeding, planting, volunteer vegetation of re-engineered wetland, transfer of wetland muck	Native wetland vegetation from local seed source should be used. Transplant of wetland muck will provide better substrate for plant growth.	Section 2.5.3
Floating wetland islands	Floating wetland islands	Generally higher cost in construction than SFCW or an ENW.	Section 1.3.2 Figures 1.4-1.6
Excavation	For new or expanded natural wetland	Excavation will depend on if SFCW is incorporated into the bottom of the SWMP or separate from it and the storm event containment required	Section 2.5.3
Topsoil placement	75-150 mm	Topsoil of stockpiled topsoil from initial surface of excavation or wetland muck harvested from a pothole wetland that will be developed	Section2.5.3
Wetland bottom	Flat bottom	Side-to-side and end-to-end to promote sheet flow for improved water quality improvement	Table 2.5
Reducing flow channelization potential	Deep zones	Excavated across the entire width of the wetland at the point of inflow, one or more a portion of the way through the wetland, and at the outflow	Section 2.6.2, 2.8.2 Figure 2.24
Controlled overflow	Riprap dips or concrete weirs in berm	For high flows that may overtop the berm, these reinforced spillways provide a point of overflow that will not erode and cause berm failure	Section 2.3.2 Figure 2.13

TABLE ES.1
Summary – Elements of the Stormwater Treatment Wetland Design Guidelines

Design Component	Details	Comments	Index
Plants for vegetated shelves	Plant diversity dependant on aesthetic and habitat requirements and O&M budget	Cattail, bulrush, and tall reed grass will dominate most stormwater wetlands. Planting for diversity will require regular removal of unwanted plant species. Most cost effective method of plant establishment is to re-purpose an existing wetland as a SWMP and CW since the plants will be established. For new and expanded wetland construction, harvest the wetland muck from other pothole wetlands and transfer to CW site.	Section 2.5.3 Figure 2.22
Habitat improvements	Habitat creation for wildlife	SFCW, FWI, and ENW may attract wildlife and provide a resting area for migratory species and breeding grounds for residents.	Section 2.5.4
Nuisance and wildlife controls	Buffer consideration when incorporation CW into urban settings	CW will contain floatables, odours, and geese. Keeping a 75% undisturbed buffer zone of trees and shrubs will help minimize disturbance to surrounding wildlife. Where muskrats are a concern for their ability for removal of vegetation, muskrat exclusion fencing should be installed to keep them from entering the wetland.	Sections 1.4, 2.6.3, 2.9
Fencing and gates	Public safety	Fencing and gates can act as both safety for humans and a buffer distance for wildlife. It can also act as barrier for debris (e.g. garbage) entering the CW from wind. If they are in the wetland, trapping may be required. Fences and gates to be constructed in accordance with Current City of Saskatoon Design standards for normal construction sites and civic amenity sites	Section 2.9
Viewing platforms	Public interest	Provides a viewing area for people to enjoy the benefits of a CW without disrupting the CW. Viewing platforms to be constructed in accordance with Current City of Saskatoon Design standards for normal construction sites and civic amenity sites.	Section 2.5.5 Figure 2.23
Signage	Public education	Informational signage provides the public with education and knowledge of CW activities and what they are viewing. Signage to be constructed in accordance with Current City of Saskatoon Design standards for normal construction sites and civic amenity sites	Section 2.5.5 Figure 2.23

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Acronyms and Abbreviations

AENV	Alberta Environment
BMP	best management practice
cm	centimetres
CW	constructed wetlands
ENW	enhanced natural wetlands
FWI	floating wetland islands
GHG	greenhouse gas
ha	hectare
HDPE	high density polyethylene
HWL	high water level
km	kilometres
L:W	length-to-width ratio
LID	low impact development
m	metre
mm	millimetre
NWL	normal water level
PF	peaking factor
P-k-C*	Wetland sizing model name that refers to number of tanks-in-series (P), areal rate constant (k), and constituent background concentration (C*)
SFCW	Surface flow constructed wetland
SSFCW	Subsurface flow constructed wetland
SWMCW	Stormwater management constructed wetland
SWMP	Stormwater management ponds
the City	City of Saskatoon
TSS	total suspended solids
WDD&MG	Wetland Development, Design and Management Guidelines
WPP	Wetland Policy Project

Definitions

Best management practice (BMP) – A schedule of activities, prohibitions of practices, maintenance procedures, and other management practices to mitigate changes to stormwater quantity and quality. Steps taken to reduce stormwater volume, peak flows, or nonpoint source pollution would be considered best management practices.

Cells-in-series – The governing rate equation for all treatment processes in a treatment wetland is affected by the number of cells-in-series (also referred to as reactors-in-series- or tanks-in-series). The outlet concentration is inversely proportional to the number of cells-in-series that represents flow through the wetland. A very large number of cells-in-series approaches plug flow conditions.

Constructed Wetland (CW) – Human-made wetland. Can be of a variety of hydrologic modes and purposes (that is, habitat creation, flow attenuation, aesthetics, treatment, stormwater/wastewater)

Enhanced Natural Wetlands (ENW) – Enhanced natural wetlands are natural wetlands that are modified in some way to increase their functional performance in stormwater storage, flood attenuation, and water quality improvement, while maintaining or improving all other wetland functions. These modifications may include installation of water inlet, outlet, or level control structures, as well as re-vegetation, weed removal, wildlife habitat improvement measures, or recreation/education facilities.

Floating Wetland Island (FWI) – Floating wetland island systems are designed to provide wildlife habitat and improved aesthetics in stormwater management ponds and will be tethered such that they will float with changing water levels without being entirely submerged. The root mass that hangs down into the water column as well as the leafy vegetation component provides water quality improvement capabilities that enhance those of an open pond.

High Water Level (HWL) – Maximum water level possible before bypass/overflow within the forebay/wetland during storm events including 100-year storms.

Hydroperiod – The length of time and portion of the year that the wetland soils are saturated or covered by standing water. It also refers to water depth changes as would be experienced through damming or by dam removal.

Mean Flow – The average flow, typically described over a certain period of time (daily mean flow, or annual mean flow).

Natural Wetlands – Non-engineered wetlands that have formed in the existing landscape without engineering manipulation, including directed surface or subsurface water flow.

Normal Water Level (NWL) – Water level under base flow conditions

Peaking Factor (PF) – Ratio of the peak flow to the mean flow.

Peak Flow – The maximum instantaneous flow from a given storm condition at a specific location.

Stormwater Management Constructed Wetland (SWMCW) – Stormwater management constructed wetland systems are 'storm event-driven' wetlands and, although the same biological, chemical, and physical processes drive water quality improvement capabilities that can be optimized through engineering, differ from wetlands designed to treat municipal/industrial wastewater in that they require greater freeboard along with associated inflow/bypass and discharge/overflow structures. They commonly are incorporated into residential areas or green spaces for their wildlife habitat, recreation, educational, and aesthetic benefits. SWMCW systems also commonly receive a different suite of contaminants than municipal/wastewater treatment wetlands at concentrations that vary through the runoff cycle but are generally lower concentrations than other pollutant sources.

Stormwater – Rainfall and snowmelt that runs off the land and buildings into storm sewers, streams, and nearby lakes or rivers.

Stormwater Management Ponds (SWMP) – Stormwater management ponds are designed to contain and attenuate flow and provide some limited treatment (typically removal of total suspended solids [TSS] and associated contaminants) of stormwater flows. Their objectives are to reduce flooding potential and to protect receiving waters from sediment loads.

Subsurface Flow Constructed Wetland (SSFCW) – Subsurface flow constructed wetland systems are constructed with substrate commonly consisting of gravel or soil beds about 1 metre (m) deep and vegetated with rooted emergent plant species. They receive water flow that remains below the media surface, and may flow vertically (up or down) or horizontally from inflow to outflow location.

Surface Flow Constructed Wetland (SFCW) – Surface flow constructed wetland systems are typically shallow basins, with densely vegetated areas of rooted emergent plant species such as cattail (*Typha* spp.) and bulrush (*Scirpus* spp.). SFCW substrates are comprised of flooded organic or mineral soils, with standing water on the surface.

Total Suspended Solids (TSS) – Total suspended solids is the suspended sediment that is picked up and transported by stormwater flow from roadways, fields, residential neighbourhoods, industrial sites, and roof tops. TSS is a combination of inert materials (such as, clays, sands) but commonly contains other constituents such as metals, organics, phosphorus, and nitrogen that have been sorbed onto or encapsulated in with these particles.

SECTION 1

Introduction

1.1 Background

The City of Saskatoon (City) recognizes the benefits of integrating natural, re-engineered natural, and constructed wetlands into future residential and industrial development stormwater management plans (SWMPs), based on research to date. Preservation of wetlands in Saskatoon helps to improve the quality and reduce the quantity of stormwater run-off that flows to the river, provides some storage for greenhouse gases (GHGs), maintains wildlife habitat and corridors, and improves public access to ecological systems and spaces.

To realize these benefits, the City is working to adopt the Wetland Policy (City of Saskatoon, 2013a, see Appendix B), a framework to guide land use and development decisions. The policy requires establishment of wetland development and management guidelines to sensitively integrate wetlands into urban development and to adopt specific design guidelines for constructed stormwater wetlands, both of which would help to mitigate the risk and severity of flooding. The City's Design & Development Standards Manual (new neighbourhoods) (City of Saskatoon, 2012) also requires that stormwater runoff generated within new developments route through conveyance, storage, and/or treatment systems to regulate the rate of discharge and the quality of the water that is released into the South Saskatchewan River. This Wetland Development and Design Guidelines (the Guidelines) document is an integral implementation tool of and must be used in concert with the Wetland Policy, and the Wetland Policy must be carefully reviewed for compliance before moving forward with a wetland design. It supports the new neighbourhood design and development standards by guiding how development should relate to wetlands and providing general guidelines for the design of wetlands integrated into the stormwater management system. The Guidelines do not provide detailed engineering specifications for re-engineered natural and constructed stormwater wetlands since each application is unique and it is not possible to provide one set of design specifications that cover all eventualities.

The Draft Wetland Policy development included a pilot project in the Holmwood neighbourhood and pilot project results informed the Guidelines. For example, to protect the type, nature, and function of natural wetlands, there was clear evidence that sediment input will need to be managed through the use of sumps, vortex separators, and/or forebays, and stormwater peak flows will need to be attenuated through storage to manage impacts to receiving wetland hydroperiods. These constraints, among others, may be addressed through the use of individual cells or back-to-back wetland cells-in-series, depending on site opportunities, requirements, and constraints. The development of the cells-in-series concepts, how and where natural wetlands best fit into the overall system, and how to minimize land area requirements of stormwater management system components have been key considerations in developing these Guidelines.

1.1.1 Objectives

Following are the objectives of this project, as stated in the Wetland Policy Project (WPP) (City of Saskatoon, 2013b):

- Define wetland development guidelines, as required by the Wetland Policy
- Guide the integration of natural wetlands into future developments while retaining or enhancing hydrological and ecological functions
- Adopt specific design guidelines for constructed wetlands

The City desires to develop design guidelines for constructed and modified stormwater wetlands. The intent is to minimize negative impacts of urban development on wetlands and to balance the ecological integrity of wetlands with the objectives of urban development.

This document provides a set of guidelines to developers and designers, to aid them in understanding siting and design requirements for surface flow constructed wetlands (SFCW) and floating wetland island (FWI) systems within proposed developments. These guidelines are summarized in Table ES.1. Each site should be assessed on its own merits including topography, catchment area, expected water quality, predicted stormwater flows, storm event return period, and available footprint for a stormwater management constructed wetland (SWMCW) to achieve the best solution possible, taking into consideration the current surrounding natural environment. These Guidelines align with the current Wetland Policy; as previously stated they are offered for guidance only and should not be used in the place of required detailed engineering drawings and specifications.

Subsurface flow constructed wetland (SSFCW) design details have not been included in this document since their application to stormwater flows is very limited and specialized because of the following factors:

- The cost of construction and maintenance are much higher because of the requirement of gravel bed media that needs regular replacement throughout the design life of the system
- SSFCW require significant upgradient flow attenuation to provide a more steady flow to the wetland (that is, it has difficulty tolerating and treating the variability of event flows)
- SSFCW design details offer far fewer wildlife benefits

A future task once the Guidelines are completed that the City has discussed would be to develop the accompanying operations, maintenance, and monitoring document that would be used to keep the wetland systems functioning and to track their benefits of stormwater attenuation, habitat creation, improved aesthetics, and water quality improvement.

1.2 Natural Wetlands for Stormwater Management

1.2.1 History of Wetlands and Stormwater Management

The North American development of constructed wetland system technology began with studies of natural wetlands that received wastewater discharges. As early as the 1960s and 1970s, Dr. H.T. Odum led research and advanced the use of natural wetlands for water quality improvement as an aspect of ecological engineering. Natural wetlands began to be monitored and constructed wetlands began to be built for stormwater management in North America in the 1980s (Kadlec and Wallace, 2009).

Wetlands form in landscape locations where sufficient runoff and/or groundwater supply is received to create specific conditions. This hydrology sustains the soils and vegetation communities that are characteristic of wetlands. The City defines wetlands (City of Saskatoon, 2013a) as:

Lands having water at, near, or above the land surface or land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, aquatic vegetation and various kinds of biological activity which are adapted to a wet environment.

Wetlands can hold water temporarily or permanently, with water levels fluctuating over the course of a single year and over many years with climactic cycles.

Whether planned or unplanned, natural wetlands usually receive some stormwater flow from upgradient urban and rural areas. Natural wetland systems in the Saskatoon area are generally mosaics of juxtaposed wetland and upland ecosystems, typical of the aspen parkland biome that is transitional between prairie and boreal forest. Common types of wetlands are shallow open water, marshes (shallow and deep water), and graminoid wet meadows, created in depressions from glacial erosion and fed by snowmelt, precipitation (direct and as stormwater runoff), and groundwater. Larger depressions hold permanent lakes, while smaller isolated depressions may contain wet meadows that are dry by fall and may be quite saline from the accumulation of salts from this drying cycle. Counterpart upland ecosystems are fescue prairie, aspen woodlands, and the South Saskatchewan drainage system (Huel, 2000).

1.2.2 Advantages of Incorporating Natural Wetlands as Features in Urban Planning

Wetlands in landscape settings, whether urban or rural, provide open space, wildlife, aesthetic, recreation, ambient temperature, and educational benefits to local and regional residents in addition the direct stormwater flood management and water quality improvements. Many award-winning urban planning projects highlight wetlands to best advantage (for example, the Spring Creek Greenway Master Plan, Joliet, Illinois, which received the American Planning Association's 2011 National Planning Excellence Award for Implementation). Key advantages of incorporating natural wetlands as features in urban planning include the following:

- Demonstrated ability to provide stormwater attenuation to reduce flooding potential, thus performing services provided by higher capital cost infrastructure(Girts et al., 2012), as well as being a superior land use for floodplain areas than development
- Maintenance or enhancement of wildlife habitat and biodiversity by improving hydrologic connections (primarily surface flows) of functioning and/or degraded wetlands
- Provision of open space, aesthetics, recreation, and community education in sustainable resource management
- Enhancement of the physical and mental health of the community, through recreation, aesthetics, and open space benefits (Watson and Albon, 2011)
- Demonstrated ability to improve water quality within natural wetland and prior to discharge to sensitive down gradient water bodies, thus performing services provided by higher capital cost infrastructure (Girts et al., 2012)
- Increase adjacent property values (Trust for Public Land, 2010)
- Passive nature leads to lower energy use and maintenance requirements than constructed infrastructure, thus providing infrastructure as well as ecosystem services at lower operations and maintenance costs (Girts et al., 2012)

1.2.3 Environmental Implications

As noted, natural wetlands provide valuable ecological benefits such as groundwater recharge and improved water quality, storage and cycling of nutrients and sediments, carbon sequestration, and enhanced wildlife habitat and biodiversity. Therefore, the preservation of wetlands within Saskatoon and within the stormwater management system will improve water quality and quantity, preserve biodiversity, and have a positive effect on the carbon cycle (WPP, 2013).

While the wetlands cover only 6 percent of the world's surface, they are estimated to hold 771 gigatons of GHGs, or 10 to 20 percent of the globe's terrestrial carbon (Mitsch et al., 2012). The emission of N2O and CH4 from constructed wetlands (CWs) is high; however, their global influence is not significant, as Teiter and Mander (2005) established, even if all global domestic wastewater will be treated by wetlands, their share in the trace gas emission budget would be less than 1 percent. Moreover, GHG fluxes are higher in unplanted and non-aerated treatments and, thus, the addition of artificial aeration reduces CH4 fluxes (Maltais-Landry et al., 2009).

Wetland vegetation provides benefits such as green space, wildlife habitats, water and ambient temperature reduction, and recreational and educational opportunities (Sundaravadivel and Vigneswaran, 2001). The prairie pothole wetlands are some of the most productive wetlands in the world, and are especially critical to waterfowl overwintering and reproduction, which represent key organisms (predator and prey) that regulate other processes in these ecosystems.

These benefits can be quantified economically and contribute significantly to quality of human life in urban communities; an increasing number of documentation is available regarding approaches for doing so and results (Watson and Albon, 2011, is a recent example regarding UK ecosystem services and management; Alberta Environment [AENV], 2011, represents a recent Canadian analysis specific to wetlands). Higher quality water avoids downstream treatment costs for human use of water, and supports the human as well as wildlife food chain through fisheries and waterfowl harvest. Human health is positively influenced by exercise and time in green spaces, and property values increase with proximity to green spaces and wetlands. Wetlands provide open air classrooms for students of all ages, building basic observation and communication skills in addition to tools and understanding in the science, technology, engineering, and mathematics (STEM) fields.

1.2.4 Design and Regulatory Constraints of Natural Wetlands

In many jurisdictions in Canada, discharge to natural wetlands must meet specific water quality criteria, and the use of natural wetlands for stormwater is discouraged because of concerns over potential impacts and perceptions of impacts. A major reason for concern is limited knowledge of the impacts of increased loads and flows on different types of wetland habitats, and a need for better tools to assess changes in wetland processes. That said, there is the potential for enhancement of wetland functions for some wetlands through stormwater discharges. Studies have shown that through careful design and best management practices, some natural wetlands can consistently and cost-effectively provide water quality improvement of stormwater (AENV, 2000).

In 2009, Stantec Consulting Ltd. prepared a Wetland Policy Study report for the City including an examination of the regulatory environment at both the federal and provincial levels (Stantec, 2009). Discharges from stormwater retention facilities discharging to the natural environment are regulated by several federal and provincial policies. The Environmental Management and Protection Act prohibits discharges to the environment that may cause and adverse effects (Government of Saskatchewan, 2002), while the Canadian Environmental Assessment Act (Government of Canada, 1995) and the Environmental Assessment Act (Government of Saskatchewan, 1980) requires new developments to conduct an environmental impact assessment. Other legislations exist to cover the protection of wild species and their habitats (such as, the Species at Risk Act, Fisheries Act, and Wildlife Act), many of which would be found in natural wetlands. Although most policies deal with protecting the environment against detrimental or adverse effects caused by anthropogenic activity, many policies also encourage constructed wetlands (including for stormwater management purposes) providing restoration or rehabilitation of degraded wetland ecosystems (such as the Saskatchewan Wetland Policy, 1995).

There are several policies concerning land use surrounding the Saskatoon John G. Diefenbaker International Airport (such as, the Aeronautics Act, Transport Canada publications, Saskatoon Airport Zoning Regulations). Stormwater retention facilities are not recommended for areas 3.2 kilometres (km) or less from the airport, and are restricted within 4 km of the airport, unless bird deterrent mechanisms are in place.

Design and regulatory constraints to the use of natural wetlands for stormwater quality improvement include the following considerations:

- Level of pretreatment

- Ability to achieve adequate distribution of pretreated water across the natural wetland to promote sheet flow, maximize water quality improvement per unit area, and minimize erosion
- Availability of sufficient area for the predicted flow and hydroperiod with identification of potential resulting changes in vegetation community
- Degree of ecological change that can be tolerated within the natural wetland. With any change in hydroperiod, hydraulic loading rate, or constituent loading rates, the ecosystem will change to some degree (slight to significant) in response. Such change may be within the range of tolerated variability, but a shift in ecosystem functions may occur over long periods of time (decades)
- Public response to long-term effects of wetlands on wildlife and on local residents living in close proximity to a wetland site (See Appendix C) (AENV, 2000)
- Potential for adverse environmental/wildlife and vegetation communities impacts and mitigation measures (see Appendix D) (AENV, 2000)

It is also noted that if a natural wetland is to be part of the storage volume, there will be a requirement to modify the natural wetland such that there is opportunity to control the water level. However, for these guidelines it is assumed that the natural wetland is the receiver and that discharge into the natural wetland will be done by a riprapped or otherwise erosion protected spreader swale.

1.2.5 Constructed Wetlands Complement Natural Wetlands in a Stormwater Management System

Upgradient constructed wetlands can protect natural wetlands by acting as buffers and reducing stormwater contaminant loads/concentrations before they enter natural wetlands. Additionally, through land use planning, pretreatment, and natural wetland enhancement, constructed and natural wetland treatment system complexes can augment recreational resources by linking respective nature centres, hiking trails, boardwalks, and other passive recreation public facilities. A prime approach to determine how constructed wetlands and natural wetlands can together provide maximum value within a stormwater management program context is to first identify high-value natural wetlands and the upgradient watersheds that support these wetlands, and then the optimal locations for siting constructed wetlands to manage sufficient flow and provide needed flood attenuation and water quality treatment post-development.

1.3 Constructed Wetlands for Stormwater Management

The benefits of incorporating wetlands into a SWMP for an existing or future development include flow attenuation, water quality improvement, and creation of wildlife habitat. This section deals primarily with the first two benefits.

Wetland systems rely on natural sources of energy to lower aquatic contaminant loads and concentrations through physical, chemical, and biological assimilative processes. Natural and CW systems have been engineered to provide predictable water quality improvement of stormwater and wastewater from a wide range of sources, achieving high levels of water quality improvement with low capital investment and maintenance costs. Dozens of pilot and demonstration projects have proven and refined the CW technology, which is applied in hundreds of full-scale applications throughout much of North America and Europe. Several types of CW technologies exist and differ primarily by water depth, substrate type, and plant species, because of differences in target constituent removal rates, loading, and flow rates.

The major categories of constructed wetland systems that have proven stormwater applications are SFCW and FWI treatment systems. In limited, specialized conditions (such as, high contaminant load requiring winter treatment, public exposure to colifoms, and where infiltration is preferred over surface flow discharge), SSFCW have also been used for stormwater treatment but are sensitive to variable hydraulic loadings and are much more expensive to construct because of the gravel media. SSFCW are thus not included as an application in this guidance document.

In general SFCW or FWI systems are expected to be the most suitable applications in Saskatoon, as standalone systems or as components of constructed and natural wetland complexes. A discussion of each of the three CW system forms follows.

1.3.1 Surface Flow Constructed Wetlands

SFCW systems are typically shallow basins, densely vegetated by a variety of rooted emergent plant species such as cattail (*Typha* sp.) and bulrush (*Scirpus* sp.). SFCW substrates are comprised of flooded organic or mineral soils. Average water depths are typically less than 45 centimetres (cm) (see Figure 1.1). In SFCW, the emergent plants take up nutrients in stormwater flows and provide a substrate for the growth of microbial, algal, and invertebrate populations that assimilate constituents in the stormwater through uptake, transformation, and sedimentation processes. Above the sediment-water interface, aerobic conditions predominate, while below the interface, anaerobic processes occur.

SFCW systems offer the most potential for creating environments for wildlife habitat, public recreational uses such as bird watching and nature study, and surface runoff flow detention. Alternating zones of deep water and shallow emergent marsh, interspersed with habitat islands (see Figure 1.2), can create optimal habitat for waterfowl, wading birds, raptors, reptiles and amphibians, and other species valued for their ecological and recreational value.

When SFCW are incorporated into stormwater management ponds, the freeboard is increased to provide sufficient storage volume for the design storm event.

FIGURE 1.1
Cross Section of a Surface Flow Constructed Wetland

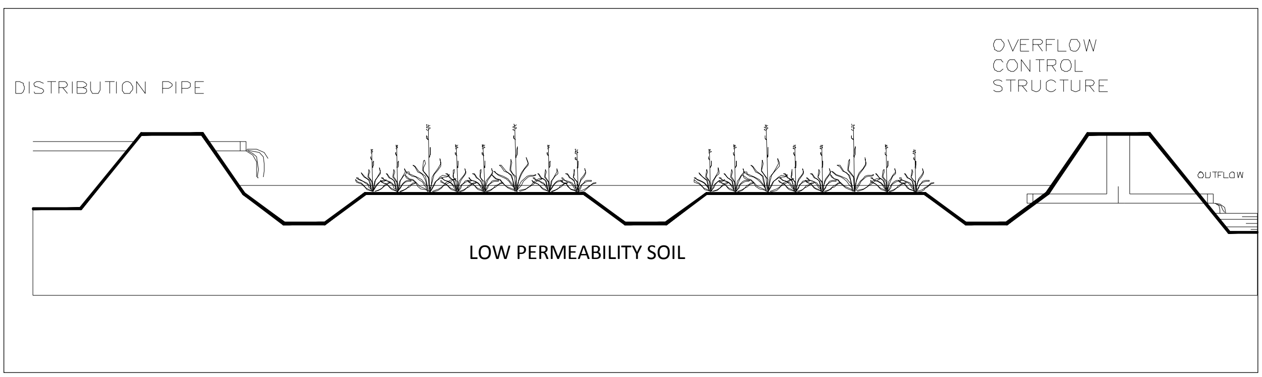


FIGURE 1.2
Surface Flow Constructed Wetland Showing Various Features Including Inflow/Outflow Structures, Deep Zones, and Shallow Vegetated Shelves

1.3.2 Floating Wetland Islands

FWI systems provide a floating mat of vegetation that floats up and down with the changing level of a pond water surface. These floating mats provide wildlife habitat and improve the aesthetics of the pond. The water quality improvement aspect is similar in principal to the SFCW in that water flow runs through the plant material. However, rather than running through the standing plants, the FWI system promotes the flow of water through a submerged root system that hangs down from the floating mat of plants. When designed with the floating mats extended across and perpendicular to the flow of water, the water must pass through the roots and water quality improves. Microbial growth on the plant roots and in the organic litter at the pond bottom take up and transform the carbon, nitrogen, and phosphorus in the stormwater. Nutrients are also taken up by plants but a portion of this uptake is released as organic litter and incorporated into the pond bottom sediment during die-back in the fall. During the winter season in cold climates, there should be no negative impact from ice on the floating wetland islands assuming they are installed to meet the specifications of the supplier/manufacturer and the anchoring mechanism is designed for the expected stresses. (see Figures 1.3 to 1.6).

FIGURE 1.3
Floating Wetland Islands as a Habitat and Aesthetic Feature within a Stormwater Management Pond

FIGURE 1.4
Cross Section of a Floating Wetland Island Showing Water Quality Improvement Mechanisms (source: Floating Islands International)

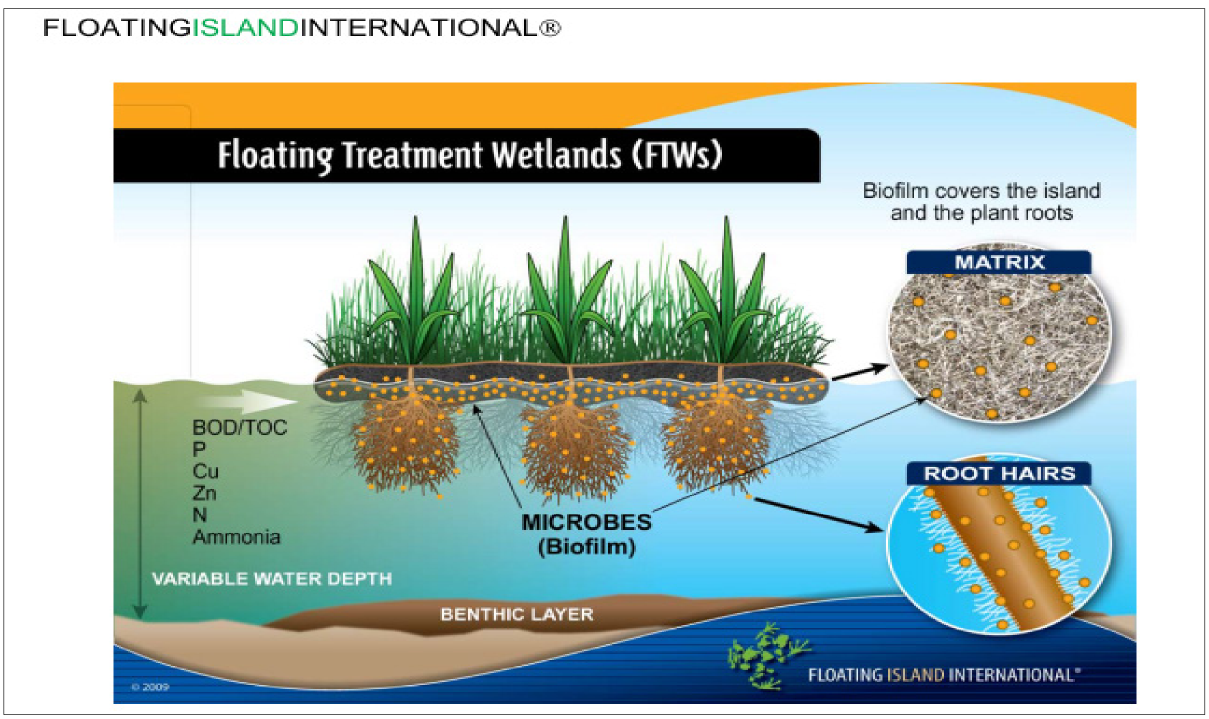


FIGURE 1.5
Raised floating wetland showing the extensive root development beneath the floating mat. System pictured uses the AquaGreen floating mat produced by Bestmann Green Systems in Germany

FIGURE 1.6
Pilot Stormwater System Planted in Summer 2013 in Syracuse, NY Incorporating FWI (Lower Left), SSFCW (Centre), and SFCW (Upper Right) (Source: Aerial Scenes)

1.3.3 Overview of Design Considerations for Constructed Stormwater Wetlands

Stormwater wetlands are event-driven wetlands, with the following special considerations for design:

- Concentrations of most contaminants vary considerably with time, as does the rate of inflow
- The first flush typically has the highest concentrations of pollutants washed out of the contributing watershed and generally is the target storm flow component for treatment in stormwater CW systems. The first flush generally occurs before the hydrograph peak flows.
- Stormwater wetlands typically receive event flows to a peak flow when the inflow is diverted or the system overflows, followed by a period of batch operation in which the inflow is detained within the SFCW for a period of time and then released to make room for more inflow.
- The hydraulics of stormwater wetlands are quite complex, and modelling behaviour is much more difficult than wetlands receiving continuous inflow. They do not behave as a plug flow system.
- Simplistic correlations of conditions with performance are not reliable for final design sizing decisions. For example, the effect of the ratio of wetland area to watershed area on performance is not well quantified or predictable, but can provide a high level understanding of an approximate size of wetland required based on hydraulic loading alone.

1.3.4 Wetland Complexes

The stormwater constructed wetland types can be designed and sited to mimic the typical natural wetland complexes found in the Saskatoon area (see Section 1.2.1), which have adapted over millennia to extremes of hydrologic conditions. Enhancing existing wetlands by providing up-gradient wetland areas with designs maximized for water detention and water quality improvement, complemented by design and siting of purely engineered constructed systems, can provide protection for high quality existing wetlands while maximizing water quality improvement efficiency and benefits from available water in the look-alike constructed systems. Mosaics of SFCW and detention ponds can replicate some of the wetland plant community differences between the marshes/wet meadows and the wet ponds. Complementary upland landscape design standards for cover on upland developed sites will also increase water detention and groundwater recharge so critical to the natural systems, and minimize sediment and contaminant movement (source control).

1.4 Naturalistic Designs

When designing stormwater wetlands that will be located within residential neighbourhoods, it is important to not only provide opportunities for wildlife habitat, recreation, and education, but also to enhance community aesthetics. This can be done by featuring naturalistic wetland designs that mimic the features of prairie pothole wetlands including curving boundaries and natural organic shapes, complemented with islands, strategically placed trees for shading, and boardwalks for human access.

Maintenance and management of such systems are critical for sustaining optimal wetland aesthetics and values. Surface water wetlands are tolerant of a wide range of conditions, but constructed wetlands and trains of system components for stormwater quality improvement require management, starting with periodic observation and measurement of conditions. Water inflow/outflow and depth management, nuisance wildlife and insect management (such as, geese, muskrat, and mosquito), vegetation planting, and weed removal are all components of an operations and maintenance plan for most constructed systems, as well as maintenance of access pathways and recreational facilities (as appropriate).

Appropriately situated natural and enhanced wetlands that might receive stormwater can be planned to be free from maintenance and monitoring after an initial observation period, provided that functions and values have been optimized.

The following project examples demonstrate how aesthetics and wildlife habitat potential of a CW might be maximized in the design of the system. All of these examples are actively managed systems.

1.4.1 Shepard Wetland

The largest constructed wetland for stormwater quality improvement in Canada was constructed in Alberta by The City of Calgary (Calgary) to help solve a stormwater management problem that had slowed industrial development on Calgary's east side for more than 20 years.

The CW that resulted was part of a comprehensive conveyance, storage, and water quality improvement project. The CW, immediately south of an existing hamlet community, occupies about 150 of the 200-hectare stormwater management facility (see Figure 1.7). It manages and provides water quality improvement to stormwater runoff from a catchment area of nearly 6,000 hectares (ha) of existing and future development land as well as a portion of the flow from the Western Headworks Canal, which conveys water from the Bow River and supplies the Western Irrigation District's irrigation system, before discharging back into the Bow River. The Western Headworks Canal receives urban stormwater from Calgary and its diverted flow will provide a baseflow to the wetland during dry periods.

In designing the wetland, the team identified two key functional objectives—to provide short-term stormwater storage facility and to improve the quality of stormwater before it is discharged, at a controlled rate, into the Shepard Ditch for conveyance to the Bow River. For optimum performance, cells were terraced to minimize excavation and earthworks. The wetland is adjacent to, and integrated with, the Ralph E. Klein Legacy Park (see Figure 1.8) thus meeting a third aesthetic objective.

FIGURE 1.7
Shepard SFCW, Calgary, AB

FIGURE 1.8
Ralph E. Klein Legacy Park as Seen Across Shepard Wetland Cell 5 Showing Art Objects and Office/Conference Centre Building

1.4.2 Sawmill Creek

CH2M HILL was retained by the City of Ottawa to complete the environmental assessment and detailed design for the Sawmill Creek Constructed Wetland (see Appendix E). Design included sewers, control structures, and ponds to receive stormwater diverted from two urban creeks and large storm sewers. Approximately 1,000 m in length, with a peak volume of 189,000 m^3, the facility serves a catchment area of 1,420 ha, with peak inflows of 13 metres cubed per second (m^3/s) (see Figures 1.9 and 1.10).

FIGURE 1.9
Aerial View of the Sawmill Creek SFCW

FIGURE 1.10
View from the South Bank of the Sawmill Creek SFCW

Notable design features included the following:

- A combination of open wet pond and SFCW cells
- An offline wetland facility
- A specially designed fish-friendly creek diversion structure that diverts storm flows from the creek to the facility while maintaining baseflow downstream
- Extensive landscaping and re-vegetation using native species
- Pathways and bridge crossings to create recreational opportunities
- Good use of vacant land surrounded by major transportation corridors

1.4.3 Confidential Client

Scope of Work

A former phosphate production site is located in southwestern Ontario. As part of the long-term site restoration plan, this decommissioned industrial site, with funding from the Ontario Great Lakes Renewal Foundation, wished to create within a former seepage and stormwater aging pond a pond littoral/marsh wetland/upland wildlife habitat. While providing tertiary water quality improvement, the system also benefits local species of birds and mammals through use of wood duck nesting boxes, osprey nesting platform, and islands. Historically, the site has supported a wide range of flora and fauna that are now further enhanced by this restoration that involved planting and seeding of wetland shelves and upland areas to provide sufficient variety of indigenous of tree, shrub, herbaceous, and emergent species to hinder the potential germination of weedy species.

With project completion, selected areas adjacent to the pond/wetland are now open to the public for wildlife viewing and for educational and research purposes, in keeping with their vision of sustainability and environmental stewardship at this site.

FIGURE 1.11
Aerial Photo of the Wetland (Centre of Photo) and Surrounding Seepage and Stormwater Aging Ponds

FIGURE 1.12
Gray Tree Frog that Resided Within One of the SFCW Level Control Structures

1.5 Constructed Wetlands in Saskatchewan

CWs are found in Saskatchewan. Seven such projects designed for water quality improvement were identified by CH2M HILL in *Wastewater and Stormwater Applications of Wetlands in Canada* (Pries, 1994), and are listed in the Table 1.1. Of those wetlands, six were implemented at full scale, including two urban stormwater treatment wetlands. More than half of these projects appear to be functioning 20 years later (Kells et al., 2002; Ducks Unlimited, pers. comm.). More constructed wetlands have been incorporated into stormwater applications in Saskatchewan since this publication including a demonstration project in the Holmwood community. Reports and conference proceedings have been prepared in the past for several of these facilities. Some are featured in the wetland conference proceedings titled *Treatment Wetlands for Water Quality Improvement: Quebec 2000 Proceedings* (Pries, 2000).

TABLE 1.1
Location and Application of Treatment Wetlands in Saskatchewan (Pries, 1994)

Municipality	Application	Full Scale or Pilot
Meadow Lake	Municipal, Lagoon	Full Scale
Saskatoon	Stormwater, Urban	Full Scale
Aberdeen	Municipal, Lagoon	Full Scale
Humboldt	Municipal, Lagoon	Pilot
Shaunavon	Municipal, Lagoon	Full Scale
Regina	Stormwater, Urban	Full Scale
Estevan	Municipal, Lagoon	Full Scale

1.5.1 Saskatoon Projects

Holmwood Demonstration Project

A wetland assessment as part of a pilot project for the City's Wetland Policy was completed by Stantec Consulting Ltd, along with Holmwood Sector *Stormwater Master Plan* (Dundee Developments, 2013). The retention and incorporation of existing wetlands into new developments was identified as a goal by the City to provide the following benefits:

- Overland runoff mitigation
- Soil stabilization and reduction of soil erosion
- Groundwater recharge and discharge
- Water quality control
- Wildlife habitat

The demonstration project highlights how wetlands and natural low areas can be integrated into an urban context, and how constructed wetlands can be sustainable within an urban stormwater system including incorporation into natural drainage patterns, maintained water levels and functions, creation of recreational space, and long-term function of vegetation zones and wildlife habitat.

The project makes several recommendations for the construction of such wetlands, mainly the following:

- Construction of wetlands required at a lower elevation than natural occurrence to accommodate piped stormwater draining into the wetlands
- Construction of discharge outlets required at a significantly lower elevation than the existing wetlands
- Wherever possible, normal water depths and side slopes should be designed within the wetlands to encourage the establishment of wetland plant species and associated wildlife habitat
- Mitigation measures should be taken during construction
- Maintenance techniques should be noted

Lakewood Pond and Wetland

This pond and wetland system was constructed between 1996 and 1999 and is located in Lakewood Park north of the Recreation Centre and adjacent to the Wildwood Golf Course and Tait Crescent. Prior to the development of Wildwood there was a large natural slough located in this vicinity roughly centered around the current soccer pitch. The slough extended north into Tait Crescent, south to the indoor tennis court, west across McKercher Drive and east to the toboggan hill. When Wildwood was developed in the late 1970s about 50% of the slough was filled to allow developments on McKercher Drive and Tait Crescent and another 25% was filled through what was reported by the City as unauthorized dumping of construction and demolition rubble including asphalt, reinforced and unreinforced concrete, lumber, soil, yard and garden waste, and furniture and appliances. During the storm event of June 24, 1983 several homes along McKercher Drive flooded and the slough was seen as a potential location for a storm water pond. Previously it had been planned to fill this area and develop lots. As an interim measure an emergency outfall pipe was constructed from the Wildwood Storm Trunk to the slough.

In the early 1990s the area where the pond now sits was designated as a Park and storm water management area. In 1995 it was decided to include wetlands in the pond design. The basic design called for diverting about 60% of the flow from the Wildwood Storm Trunk to the wetland. The flow first enters a 0.5 ha 3.0 m deep inlet basin which is intended to remove sediments from the runoff. The flow leaves the inlet basin through six 600 mm culverts and enters the marsh area. The marsh averages 0.45 m deep and has 1.0 ha surface area. The base of the marsh is 0.45 m of pit run gravel. Portions of the marsh were planted with water sedge, bulrushes, reed grass, whitetop grass, horsetail and arrowhead. Cattails have also established themselves in the marsh. The flow leaves the marsh over a weir and enters the outlet basin which is about 2.5 m deep and 1.0 ha in area. The flow finally leaves the outlet basin via a submerged pipe and re-enters the Wildwood Storm Trunk. Some of the outflow from the outlet basin is pumped to the head of an artificial creek east of the wetland. This creek, like the marsh, has a bed of pit run gravel and was planted with the same species. The creek forms the boundary between the park and the golf course and eventually re-enters the marsh. There is a storm sewer outfall that also discharges to the creek. An aeration system was set up in the outlet basin and consists of slotted pipes lying on the floor of the pond, it is not known if the aeration system still operates.

The Lakewood Wetland has been in operation for about 15 years. By all accounts it appears to be functioning well. Further information can be obtained from the Public Works office.

Trounce Ponds and Hyde Wetlands

This Hyde-Trounce System was originally a series of poorly connected sloughs lying in a land-locked drainage basin that includes the Lakewood Wetland as well. The system now consists of five interconnected ponds that eventually drain to the Boychuk Storm Trunk south of Taylor Street.

Pond 1 (the Trounce Pond) is located adjacent to Boychuk Drive north of Slimmon Road. This pond is 2.5 m deep at normal water levels and up to 5.0 m deep at high water level. The Trounce Pond was built as a traditional storm water pond and drains directly to the Boychuk Storm Trunk.

Pond 2 is south of Slimmon Road immediately upstream of Pond 1. Large culverts connect ponds 1 and 2 so that they work together as one.

Pond 3 (the Hyde Wetlands) is east of pond 2. This wetland was not excavated and native plants have been established on the surrounding uplands. The normal water level is 1.8 m above the water levels in ponds 1 and 2 and the rise during a 1 in 100 year storm is 0.7 m. The Hyde Wetland is connected to pond 2 by a large weir. Some storm sewers from Rosewood enter the Hyde Wetland via forebays.

Pond 4 is a natural slough north of the Hyde Wetlands near the intersection of Slimmon Road and Taylor Street and can be considered an extension of the Hyde Wetland. Originally it was planned to excavate this pond, but later it was decided to leave it unexcavated. It is connected to the Hyde Wetland forebay by an open channel.

Pond 5 (Briarwood Swale) is across Taylor Street from pond 4 and is connected to pond 4 by culverts. The Briarwood Swale contains several connected naturalized ponds. The storm drainage from southeast Briarwood drains to these ponds, either directly or via open channels.

Design of the Hyde-Trounce system began in 1999 and initial construction took place in 2001. The construction work was in the final stages in late Fall 2013.

SECTION 2

Constructed/Modified Stormwater Wetlands Design Guidelines

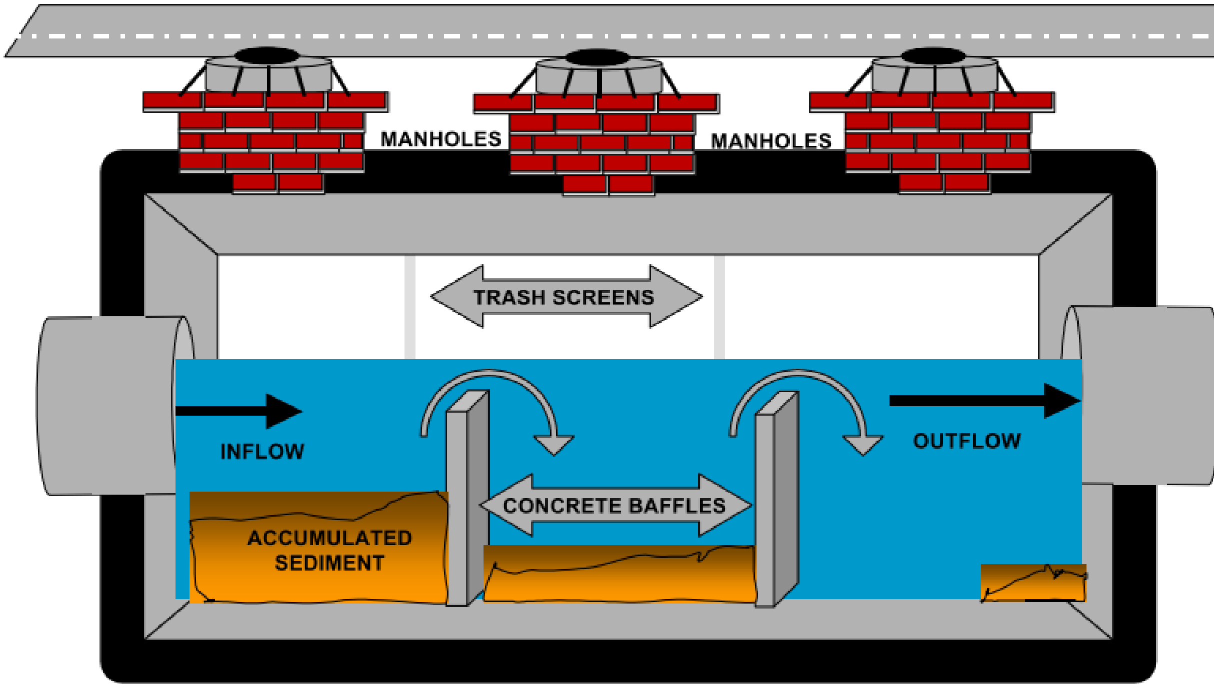
2.1 Upstream Stormwater Source Control Best Management Practices

Source control represents an increasingly important aspect of the larger picture related to stormwater management on a watershed or catchment basis. As is noted in the following subsections, putting in place onsite stormwater best management practices (BMPs) will provide a range of benefits, including the following:

- Flow attenuation – Peak flows are lower and total volume is less, translating to less flow to the SWMP system
- Improved water quality – diminishes the contaminant loading to the SWMP and the CW
- Smaller SWMP/CW system size requirement with the following advantages:
  - Allows space for more homes (benefit to the developer)
  - More homes means more available housing (benefit to home buyers) and larger tax base (benefit to the City)
- As urban landscapes develop, the ratio of hard, impervious surfaces to natural, absorbent landscape increases. This shift from absorbent to impervious landscapes reduces the infiltration rates of stormwater and increases the frequency and intensity of floods. High energy floodwater causes erosion and transports contaminants to receiving water bodies. Low impact development (LID), otherwise known as green infrastructure, is a design philosophy that decreases stormwater runoff and flooding by capturing and storing rain water at its source and allowing natural infiltration and evapotranspiration processes to occur again (EPA, 2013). These principals can be incorporated into a wide range of landscapes and at different scales. Examples include CWs, rain gardens, bioswales, green roofs, and rain barrels. Some benefits of adopting green infrastructure include the following:
  - Absorbent landscapes are more resilient to drought
  - Healthier watersheds and riparian areas
  - Reduced burden on stormwater and sewer infrastructure
  - Reduced burden on water supply infrastructure to irrigate lawns
- As an example, since 2011, the City of Syracuse, NY, has adopted a green infrastructure, stormwater management plan called Save the Rain (see http://www.ongov.net/sustainability/water/str.html) to reduce pollution entering Onondaga Lake and its tributaries caused by heavy flow periods overloading the sewer system during large storm events. This program was initiated when Syracuse committed to constructing over 50 green infrastructure projects such as such as bio-swales, tree plantings, green roofs, and porous parking lots in 2012. In 2013, the program's success earned Onondaga County the United States Water Prize for the Save the Rain program (Onondaga County, 2013).

At a minimum, prior to discharge into any wetland, stormwater needs to have pretreatment to collect floatables (such as, hydrocarbons and paint) and debris prior to entering the receiving wetland. If the pretreatment of the stormwater flow through a forebay, vortex separator, or approved equivalent is not possible, a skimming-type manhole or approved equivalent must be constructed on the first manhole upstream of the inlet(s). Skimming manholes, also referred to as baffle boxes, are concrete or fiberglass structures containing a series of sediment settling chambers separated by baffles. These structures are intended to remove sediment, suspended particles and associated pollutants from inflow and can also contain trash screens or skimmers to capture larger material and floatables. See figure 2.1 for details.

FIGURE 2.1
Schematic of a Baffle Box (From EPA, 2001)



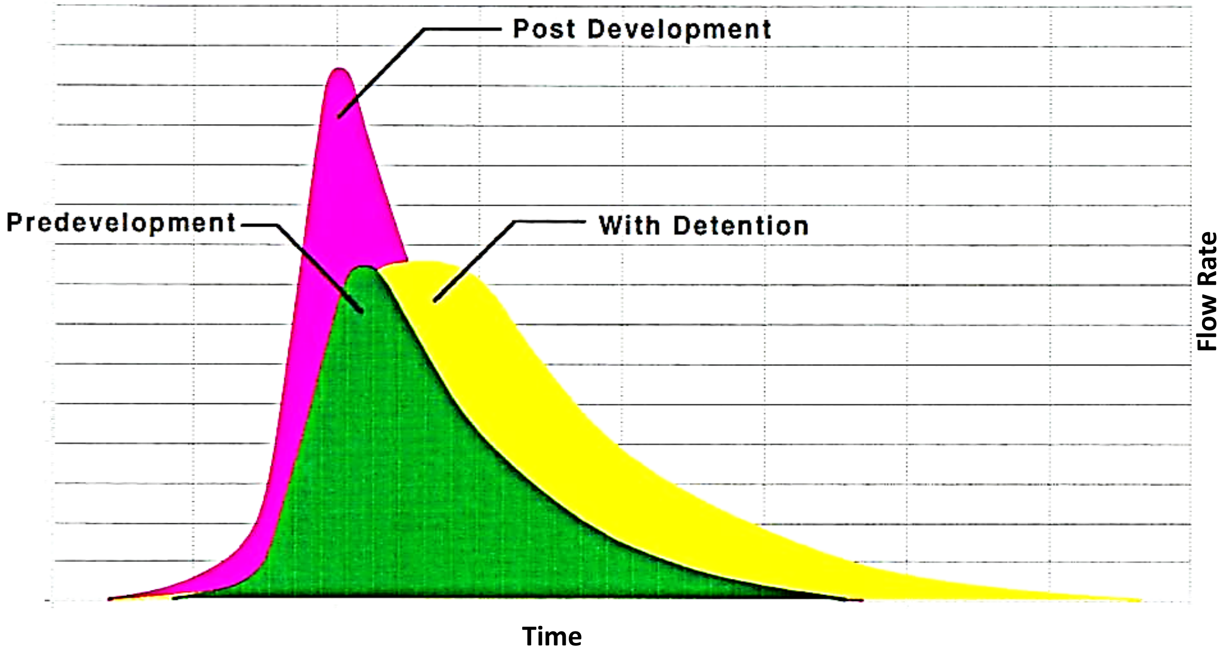
2.1.1 Conventional Stormwater Management Controls

Conventional stormwater infrastructure, known as “grey” infrastructure, is designed to effectively and efficiently convey water to a receiving stream environment. It has several potential post-development effects on the characteristics of runoff events that may include the following:

- Increased frequency of flooding events
- Increased runoff volume
- Decreased evapotranspiration and groundwater recharge
- Increased frequency of minor runoff events
- Faster conveyance of stormwater
- Erosion and stream channel changes
- Decreased stream baseflow and groundwater supply for other downgradient aquatic ecosystems such as wetlands and lakes
- Deterioration in aquatic habitat
- Increased pollutant loads and temperature increases

If conventional grey infrastructure end-of-pipe stormwater controls, such as stormwater detention ponds, are put in place, the post-development peak flow events, as illustrated in Figure 2.2, can be reduced to limit the impact of stormwater runoff on the receiving stream environment. Conventional stormwater end-of-pipe and conveyance infrastructure does not, however, control runoff volume, duration, temperature, or limit pollutant loadings to the receiving stream environment.

FIGURE 2.2
Impact of Conventional End-of-Pipe Detention Facilities



2.1.2 Stormwater Management Low Impact Development

LID stormwater BMPs, commonly referred to as green infrastructure, which are put in place within stormwater source areas such as residential properties, commercial properties, or institutional properties and in place of conventional stormwater conveyance infrastructure can provide many advantages, including the following:

- Reduce volume of urban runoff and combined sewer overflow discharges
- Reduce flooding and erosion
- Improve water quality and ecosystem health
- Rebuild cities and improve quality of urban life
- Improve urban aesthetics and walkability
- Enhance urban landscape and promotes healthier, longer-lived trees
- Enhance traffic calming and pedestrian safety
- Reduce urban heat island effect
- Improve air quality
- Improve energy efficiency
- Reduce gray infrastructure operation and maintenance costs

Green stormwater source and conveyance LID BMPs can also enhance the performance of end-of-pipe stormwater wetlands through a reduction in the volume of runoff and the improvement of runoff water quality reaching the wetlands.

2.1.3 Green Infrastructure

Green infrastructure, sometimes also referred to as green/sustainable site or conservation design, sustainable stormwater management, or sustainable sites (in LEED-NC) consists of stormwater BMPs that mimic predevelopment conditions; infiltrate, filter, evaporate, detain, and store runoff close to its source; and address stormwater management through a variety of small, cost-effective landscape features.

Green infrastructure solutions can be integrated into urban development designs. Table 2.1 lists the more common types of Green infrastructure, with associated figures.

TABLE 2.1
Common Green Infrastructure Types with Examples of Each

Common Green Infrastructure Types	Examples	Figure Reference
Runoff Volume/Infiltration-Oriented Vegetative and Soil-based	Rain/recharge gardens/bioretention	Figure 2.10
	Vegetated filter strips	Figure 2.8
	Vegetated Swales (bio-infiltration, dry, wet)	Figure 2.3
	Porous pavement with infiltration beds	Figure 2.5
	Infiltration basins	Figure 2.3
	Subsurface infiltration beds	Figure 2.3
	Infiltration trenches	Figure 2.11
	French drains/dry wells	http://en.wikipedia.org/wiki/French_drain
	Outlet control (such as level spreaders)	http://portal.ncdenr.org/web/wq/ws/su/bmp-ch8
	Retentive grading techniques, berms	Figure 2.14
Runoff Volume/Non-infiltration-Oriented	Vegetated roofs	http://www.wbdg.org/resources/greenroofs.php
	Cisterns/rain barrels/capture reuse	http://www.uri.edu/ce/healthylandscapes/rainbsources.html
	Special storage (such as, parking lot, rooftop)	http://www.invisiblestructures.com/rainstore3.html
Restoration BMPs	Riparian corridor restoration	http://www.epa.gov/reg3hscd/risk/eco/restoration/cs/JacksCreek.htm
	Revegetation/reforestation	http://www.nativerevegetation.org/visualize/
	Soils amendment	No Figure
Green Streets Options	Porous pavements	Figure 2.6
	Infiltration trenches	Figure 2.11
	Vegetated curb extensions and swales	Figure 2.11
	Inlet filter inserts and water quality inlets	http://www.swimsclean.com/stormwater-products/curb-inlet-filter.aspx
	Tree infiltration trenches and enhanced street trees	Figure 2.5
	Planters and bioretention	2.1.3
	Pavement removal	No Figure

Figures 2.3 through 2.11 are associated with common green infrastructure types.

FIGURE 2.3
Streetscape Green Infrastructure

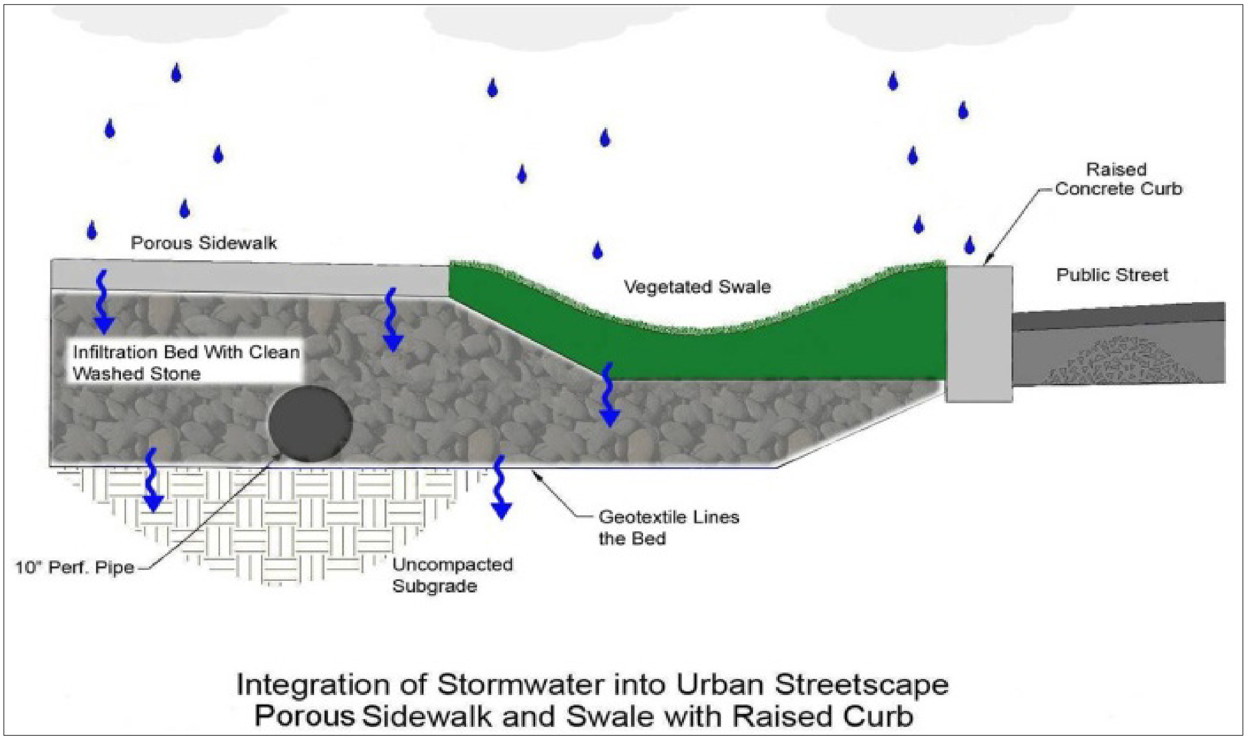


FIGURE 2.4

Typical Green Stormwater Infrastructure Design Components

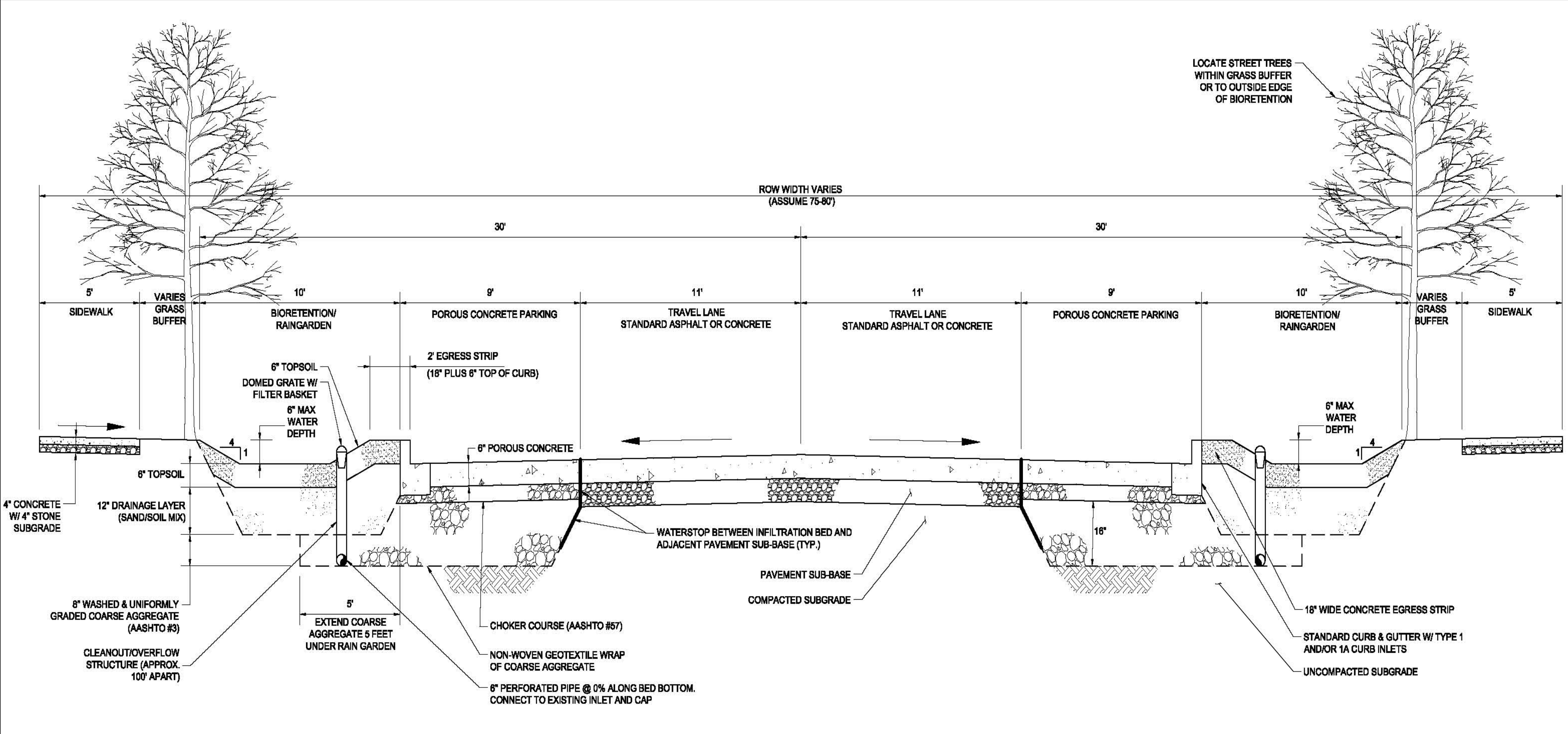


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FIGURE 2.5
Infiltration and Tree Planting

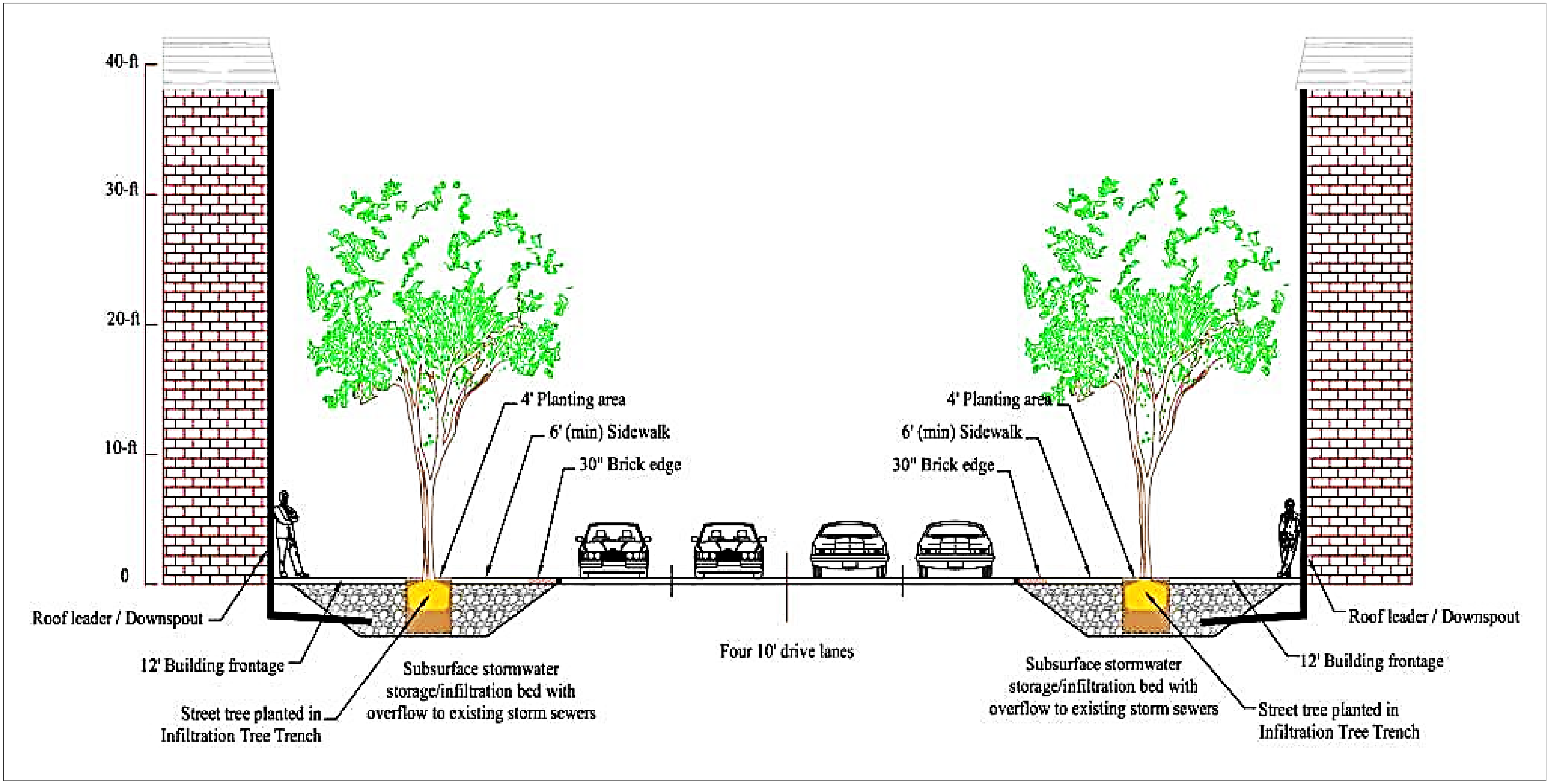


FIGURE 2.6
Porous Pavement

FIGURE 2.7
Porous Pavers

FIGURE 2.8
Porous Concrete

FIGURE 2.9
Infiltration Swale

FIGURE 2.10
Rain Garden

FIGURE 2.11
Vegetated Curb Extension with Infiltration Trench

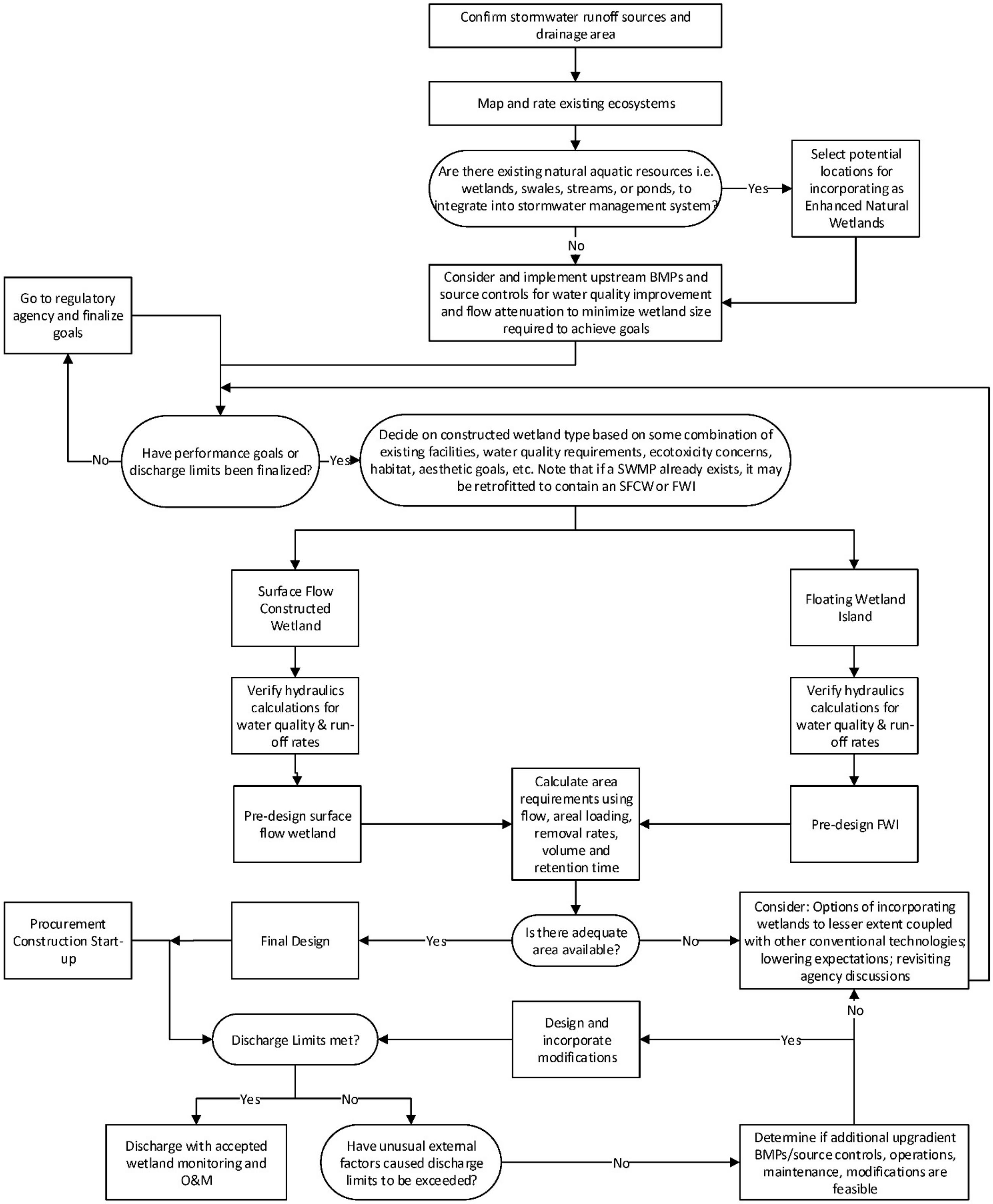
2.2 Site Analysis and Design Selection of CW Alternative

Early in the planning and design process, a review of the hydrology and natural resources of the subject drainage area – this is, the land area from which stormwater runoff is to be treated – needs to be conducted. Water bodies including wetlands, lakes and ponds, and streams of all sizes, with adjacent riparian zones, and key wildlife habitat need to be located and rated as to their overall condition and provision of ecosystem services. This rating provides a quick assessment of which aquatic resources and cover types are best protected, and which might be considered for integration into the stormwater management system or converted by development. Those existing aquatic resources that might become a part of the stormwater management system would then be examined as to their greatest system value, with a goal to increase their overall ecosystem service functionality in concert with meeting the needs for flow assimilation and water quality improvement.

After these steps, the drainage areas are associated with the possible use of enhanced natural wetland (ENW) sites, or SFCW or FWI, and the selection of an online or an offline system is made based on the portion of the storm to be treated within the wetland system. Ecotoxicity issues may suggest a FWI type wetland; however, once the type is selected, the subsequent significant question is whether there is sufficient area to install the predesigned system based on type, flows and loadings, and regulatory discharge requirements.

A decision tree is presented in Figure 2.12 to illustrate the pathway to final design, construction, and start-up.

FIGURE 2.12
Decision Tree for Stormwater Water Quality Improvement



After: The Interstate Technology & Regulatory Council Wetlands Team (ITRCW). 2003. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands. USA

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2.3 Pretreatment Upstream of Stormwater Wetland

2.3.1 General Considerations and Guidance Summary Table

At a minimum, prior to discharge into any wetland, stormwater needs to have pretreatment to collect floatables (such as, hydrocarbons and paint) and debris prior to entering the receiving wetland. If the pretreatment of the stormwater flow through a forebay, vortex separator, or approved equivalent is not possible, a skimming type manhole or approved equivalent must be constructed on the first manhole upstream of the inlet(s).

Pretreatment is used to settle out coarse sediment particles, and remove floatables and debris prior to entering the main wetland cell. By removing these stormwater pollutants before they reach the wetland, the potential for clogging of the system is minimized. Maintenance requirements for a CW are reduced, and potential impacts to ENW are avoided. Pretreatment for wetland systems can be achieved using two different structural solutions, as described in the following sections.

2.3.2 Sediment Forebay

A sediment forebay is a small pool, typically about 10 to 20 percent of the volume of the permanent pool or at least 10 percent of the wetland volume, that decreases water flow velocity and sediment loading to the receiving wetland through temporary flow storage. Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool on a regular basis, avoiding the need to clean out sediment accumulation from the entire wetland. The forebays provide the additional benefits of creating sheet flow across a SFCW or similar type ENW, extending the flow path, reducing the potential for short circuiting, and minimizing the potential for sediment re-suspension. Sediment forebay depth design will depend on hydraulic and sediment loading and is site specific. The recommended depth of a forebay is a minimum of 1 m; the deeper the forebay, the less frequent the required cleaning. Consideration needs to be given to increasing the size of the sediment forebay to capture increased sediment load from road sanding in cold climates such as Saskatoon, or from watersheds with slumping soils or that are expected to see large areas of earth movement for construction over the life of the stormwater wetland.

The forebay is typically separated from the wetland by gabions, riprapped berm, or by an earthen berm with a controlled overflow with erosion protection. The height of the gabions or berm can be from NWL to 0.3 m above NWL elevation for an overflow type system (see Figure 2.13). For a system in which forebay storage is discharged to the receiving wetland through a level control and flow distribution structure as shown in Figure 2.14, the berm may be several metres in height. The separation berm should be constructed with a solid substrate approved by the design engineer and the bottom of the forebay may be hardened with concrete or compacted to facilitate removal of accumulated sediment and debris. Depending on the height of the berm, permitting based on dam regulations may apply and must be considered during the design phase.

Emergent vegetation can be planted/seeded along a separation berm at the normal low flow water line to promote filtration of water as it flows over the berm from the forebay into the wetland. The plants should be established on the top and side slopes of the berm to a maximum depth of 30 cm below the base flow water elevation.

FIGURE 2.13
Overflow Riprap Berm Separates Forebay (Foreground) from Wetland (Background)

The total length of the forebay flowpath should provide a length-to-width (L:W) ratio 2:1 for each basin. A L:W ratio less than 2:1 is undesirable since the storage area will not be used effectively. If a lesser length-to-width ratio is unavoidable, the addition of flow baffles, or other means of lengthening the flow path in the forebay could be considered. When lengthening methods are used, effective length is measured along the flow path. See Figure 2.14 for an example of flow lengthening in the Shepard Wetland forebay.

FIGURE 2.14
Forebay of the Shepard Wetland (Calgary, AB)
Looking southeast showing the flow extending interior berms. Flow enters from the lower right and is discharged from five level control structures to the five wetland cells.

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2.3.3 Hydrodynamic (Vortex) Separator

Where the land area is not available or conditions are not suitable for constructing a sediment forebay, pretreatment can be accomplished using a vortex separator. The vortex separator removes settleable solids as well as floatables (see Figure 2.15). There are many suppliers of this type of pretreatment system with varying configurations to meet specific needs. To determine the best option for a particular location, the City or their agent is encouraged to enter into discussions with the supplier/manufacturer who typically provides design guidance and drawings as a service along with the product purchase.

Advantages include a smaller footprint than that required for a forebay; no open water that may be a hazard, especially for children in a residential neighbourhood; reduced potential for generating mosquitoes; and if located close to an airport, reduced attractiveness to wildlife.

Disadvantages include reduced aesthetic and wildlife potential as open water will decreased, reduced water quality improvement potential, and requires more frequent cleaning (semi-annual).

Vortechs by Contech Engineered Solutions is an example of a commonly used hydrodynamic separator. It is a high-performance hydrodynamic separator that effectively removes finer sediment (such as, 50-microns [µm], oil, and floating and sinking debris. The swirl concentration operation and flow controls work together to minimize turbulence and provide stable storage of captured pollutants. Precast models can treat peak design flows up to 30 cfs (850 L/s); cast-in-place models handle even greater flows. A typical system is sized to provide a specific removal efficiency of a predefined particle size distribution (Contech, 2013).

This type of system is a passive technology that requires no power input, and operations and maintenance are straightforward. Inspection is key to effective maintenance and should be performed twice per year in spring and fall. Cleaning of the system should be done during dry weather conditions (no flow), ideally with a vacuum truck. Materials removed from this system should be disposed of in accordance with local regulations. Details for operation, design, performance, and maintenance can be found in technical data sheets at the Contech or similar website (For example: http://www.conteches.com/Products/Stormwater-Management/Treatment/Vortechs.aspx).

FIGURE 2.15
Hydrodynamic Separator Being Installed for a Stormwater Application in Syracuse NY Upgradient of a 1 ha Wetland Complex

2.4 Control Structures for Stormwater Inflow and Outflow

2.4.1 General Considerations and Guidance Summary Table

To integrate stormwater management sustainably with the existing wetland ecosystems, which Saskatoon is fortunate to have in abundance, it is key to understand the hydrology of the local prairie pothole wetlands, including hydrologic variability. The rate and volume of flows, and the resulting hydroperiod and residence time, set the optimal inflow rates as well as water depths and discharge rates, whether SFCW or ENW. The designed stormwater treatment wetlands thus mimic local natural wetlands, and the prairie pothole-like design will be the most successful design long term at accomplishing all of the functional services of benefit to the region. If possible, reference natural sites should be selected soon after adoption of this guidance document to increase understanding of the natural hydrology and variability through year-round and stormwater event flow and water depth monitoring. Selected reference wetlands should be in protected watersheds and should represent types range from deep pond-fringing marshes to shallow marshes to wet meadows. All of the recommended control structures described below can help the mimic the natural hydrology of these systems, with target hydrology identified from these reference sites.

Structures are needed to bring water into the wetland, maintain a desired water level, and to collect the discharge from the wetland. Stormwater is often conveyed to a CW system by a gravity pipeline or by an open channel. Once the stormwater is brought to the wetland site, it is typically distributed into the wetland via some distribution system consisting of pipes, channels, or coarse rock beds. Inlet control devices may be used to split the flow between parallel SFCW trains, with adjustable weirs for splitter structures to allow the flow split to be adjusted between the wetland trains. Proportional flow splits can be achieved by using weirs of different widths. Inlet and outlet structures should be located in the pond embankment for ease of operations and maintenance and for aesthetics.

The inlet and outlet structures for constructed wetlands can become a significant cost if over-designed, and can relinquish flexibility of control and make accurate monitoring difficult if under-designed. Various types of inlet and outlet structures and their operational control are described in this section.

2.4.2 Inlet Pipe Configuration

Given the nature of Saskatoon wetlands, an inlet pipe may by the preferred type of conduit to deliver stormwater into a stormwater wetland where street and sidewalk crossings do not allow the incorporation of an open riprapped swale. However, in situations where an open swale is practical, this adds benefits of aeration, wildlife habitat, and aesthetic features.

To provide water quality improvement, the flow must go through and across the entire wetland to the opposite end. Specific guidance regarding inlet pipe configuration includes the following:

- Inlets should be located with the longest flowpath possible between the inlet and outlet control structures to minimize short circuiting.
- Ideally there should only be one flow entry location, or inlet, into the wetland. Multiple inlets should be avoided where possible.
- It is preferable that all inlets be fully submerged (Figure 2.16) with the crown of the pipe a minimum of 0.8 m below receiving wetland normal water level (NWL). However, because of the shallowness of wetlands, this may not always be possible, so the expected duration of full submergence should be maximized.
- Unsubmerged inlets may be used provided the pipe invert is set at the maximum design level (high water level [HWL]) of the receiving wetland if a down gradient SFCW is separate from an SWMP. With this design, erosion control is required between the HWL and NWL. See Figure 2.17. If a receiving CW is integral with the SWMP and located on the bottom of the SWMP, then the inflow piping and structure will need to accommodate the base flow water level.

- Inlet pipe inverts are to be a minimum of 100 millimetres (mm) above the receiving wetland bottom; depths in excess of 100 mm are recommended to prevent sedimentation from blocking the inlet pipe. The invert elevation of the inlet pipe at the first manhole upstream from the wetland will be at or above the NWL of the receiving wetland/ SWMP to avoid deposition of sediments in the inlet and freezing problems.
- If the pretreatment of the stormwater flow through a forebay, vortex separator, or approved equivalent is not possible, a skimming type manhole or approved equivalent must be constructed on the first manhole upstream of the inlet(s). The purpose of the skimming manhole is to collect floatables (such as, hydrocarbons and paint) and debris prior to entering the receiving wetland.
- Inlet velocities should be limited to 1.5 m/s where possible to minimize erosion and scour, and re-suspension of sediments.
- Erosion control measures must be provided at the bottom of the inlet structure(s) to control erosion and scour. Erosion control measures should include the installation of a hard-bottomed surface, interlocking stone, or an approved concrete revetment/armouring system near the inlet pipe. Other enhancements such as dissipaters or deflection structures will help minimize scour and re-suspension, particularly important for high velocity-receiving systems and for inflow into all ENW.
- Controls should be provided to keep wildlife such as turtles out of the pipes as wildlife may, depending on their size, get stuck and cause the flow to back up.
- Unsubmerged inlets do require gratings. Gratings are not required on submerged inlets on the discharge end.

FIGURE 2.16
Submerged Pond Inlet (from MOE, 2003)

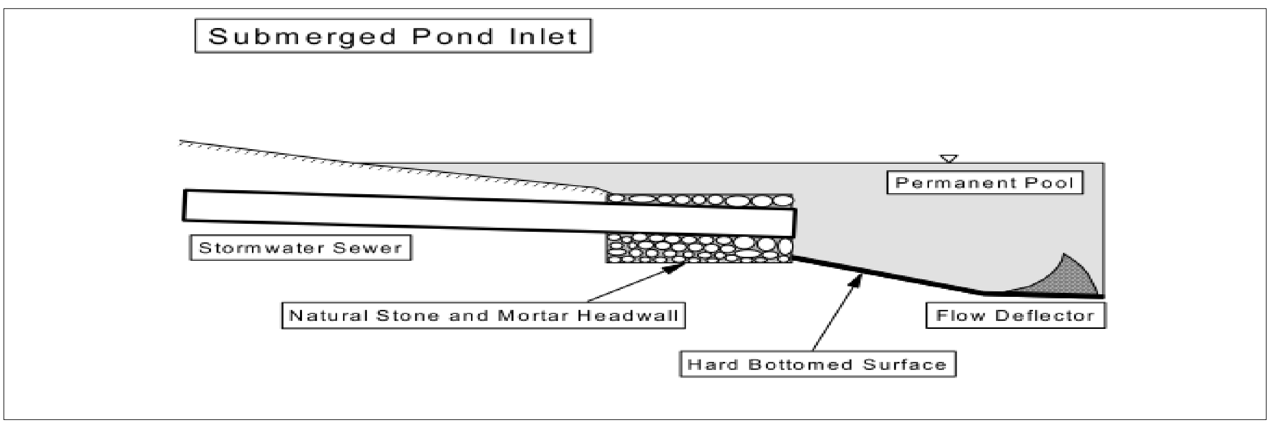
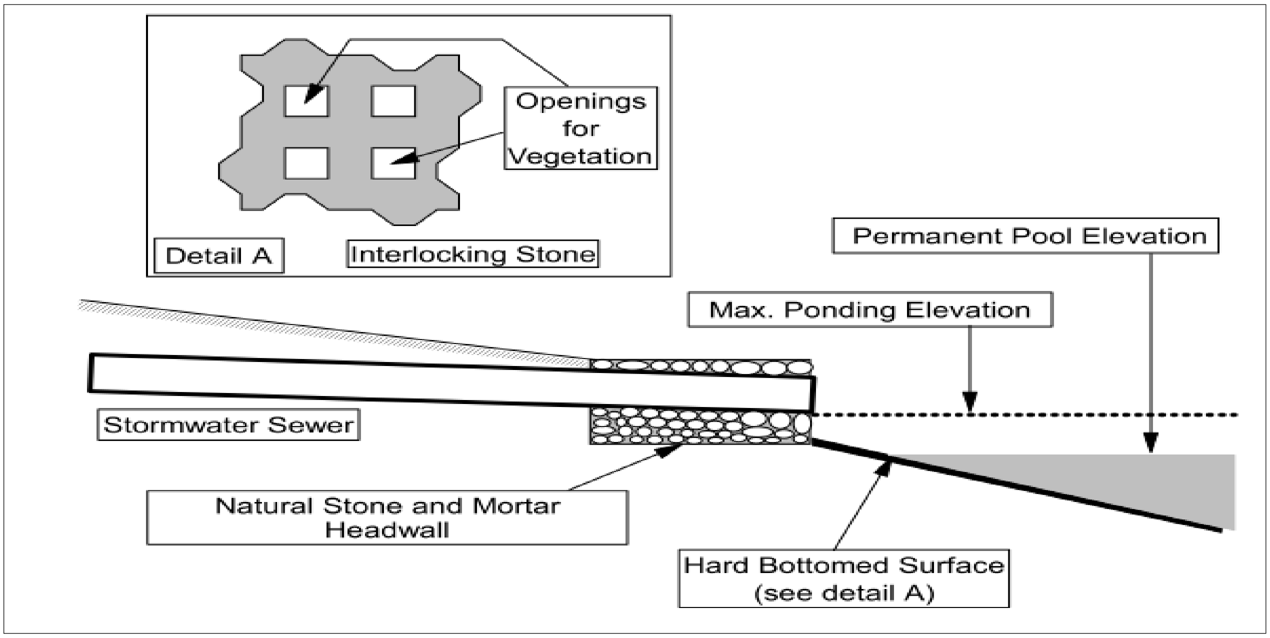


FIGURE 2.17
Non-submerged Pond Inlet (from MOE, 2003)



2.4.3 Outlet Configuration

Typically, the outlet structure serves as the source of control for the release of stormwater from the wetland and the preservation of the normal water level elevation. The outlet structure is commonly referred to as the control structure or the outlet control structure. It is important that the structure be properly designed and constructed to require minimal maintenance and enhance safety. The wetland outlet design is important for maintaining sheet flow distribution, controlling water level, and monitoring flow and water quality. Many outlet designs have been used in successful CW and ENW, ranging in complexity from a corrugated metal pipe embedded in a berm to remote-controlled motor-actuated gates. Following are the two main outlet flow structure designs that are appropriate for Saskatoon CW applications:

- Reverse sloped outlet pipe
- Perforated riser outlet pipe

In general, reverse sloped pipe configurations are recommended when the design incorporates a deep pool at the outlet. A perforated riser pipe is appropriate where a deep pool is not provided.

In combined facilities (incorporating quantity control), these types of outlet are usually combined with a weir structure that controls flow at the higher storage levels. Calculations of stage outflow should account for flow capacity of both the weir and the water quality/erosion control outlet.

Similar techniques to those described for inlets can be employed to integrate outlet structures into the overall landscape of the stormwater management facility. Natural stone and plant material can be used in place of concrete and hard structures to improve aesthetics and achieve other related objectives. Planted weirs are effective in controlling flows at the outlet of sediment forebays. Seepage outlets designed to infiltrate water and facilitate the slow release of water to augment base flow in receiving watercourses or wetlands can be constructed using a porous planted weir or hybrid structural/non-structural sand filter systems.

Following is general guidance for outlet control structures:

- It is preferable that all outlet pipes be fully submerged with the crown of the pipe a minimum of 0.8 m below discharging wetland NWL. However, because of the shallowness of wetlands, this may not always be possible, so the expected duration of full submergence should be maximized.

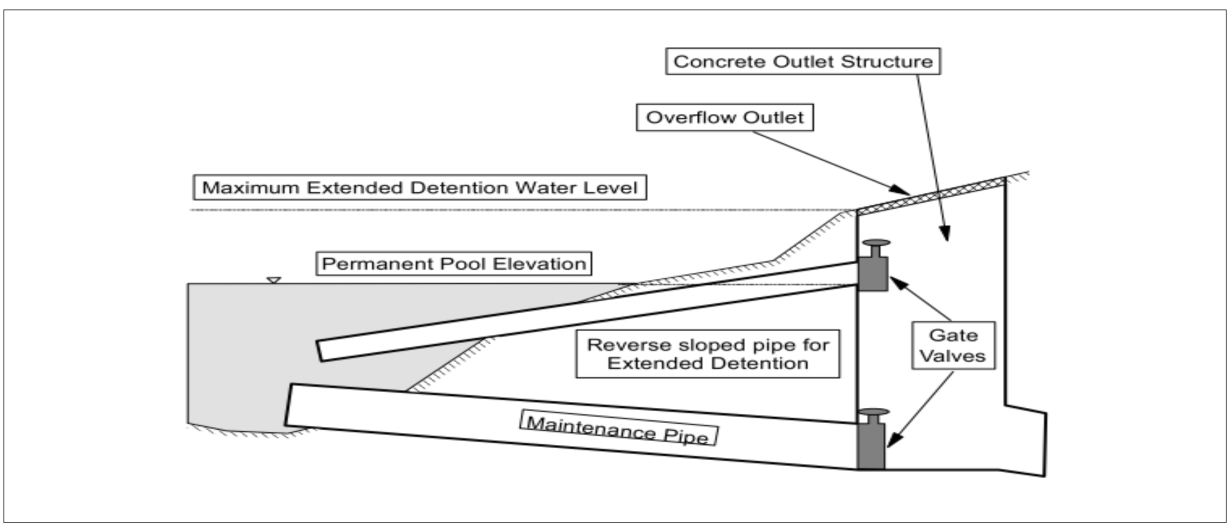
- Outlet control structure inverts are to be a minimum of 100 mm above the discharging wetland bottom; depths in excess of 100 mm are recommended to prevent sedimentation from blocking the inlet pipe.
- The maximum water level in the wetland and the SWMP will be less than upstream basement, road, and top of manhole elevations to prevent water backing up into homes or onto roadways or into ditches/yards. A hydraulic gradeline analysis is required to quantify the impact of the wetland normal and high water levels on the upstream conveyance system.
- Recommended outlet control structures are those that are resistant to freezing, in particular weirs or large-diameter pipes.
- The outlet control structure should be located in a deeper area at the downstream end of the wetland.
- When wetlands are to be installed on sloping ground, multiple cells are sometimes designed to reduce excavation and earthwork costs. Outlet control structures between cells can be combined with cascades to add aeration capabilities.

Following are different types of outlet control structures used for a stormwater wetland.

Reversed Slope Pipe – A reverse sloped pipe (Figure 2.18) is appropriate for ponds servicing all catchment areas and with outlet deep zones 1-m deep. The reversed slope pipe drains to an outlet chamber located in the embankment. The outlet chamber can contain openings for flood control detention and overflow protection. It is recommended that a gate valve be installed at the outlet end in the chamber. This valve will allow the extended detention drawdown time to be modified to improve pollutant removal if the wetland operating conditions vary from assumed design criteria limits and for maintenance.

A low flow maintenance pipe should be provided to drain a CW for maintenance purposes. The maintenance pipe should also drain to the outlet chamber. It is recommended that the maintenance pipe be sized to provide a reasonable time period in which to drain the entire CW for maintenance, recognizing that the outflow release velocity should not affect the downstream receiving waters or sediment.

FIGURE 2.18
Reversed Sloped Pipe Outlet Configuration (from MOE, 2003)



Perforated Riser Pipe – Although the perforated riser outlet design has been used for wet ponds, it is best suited to ponds with a shallow permanent pool (that is, wetlands) or to dry ponds.

A perforated riser pipe is the traditional outlet pipe that has been used historically throughout Ontario, Canada, although its use has diminished in recent years. The riser itself is perforated with holes and typical diameters range from 12 mm to 25 mm. The flow through the riser is controlled by an orifice plate located at the bottom of the riser structure. The smallest orifice diameter which should be used is 50 mm.

A design that is frequently used in Ontario incorporates a perforated riser pipe surrounded by a corrugated metal pipe standing on its end. Holes (50 mm in diameter) are drilled in the metal pipe such that it acts as a riser. Stone is placed around the metal pipe (minimum 75 mm in diameter) to act as a further filter. This design is shown in Figure 2.19.

Although this design is inexpensive, and should be resilient to clogging by suspended solids, there are the following drawbacks to keep in mind if this design is chosen:

- If the structure is not located in a chamber in the embankment it will have to be located in the pond itself. This type of outlet will look unnatural and is aesthetically unappealing
- Corrugated metal pipe with holes drilled in it will rust, resulting in a shorter life span compared to other materials
- Since the riser is above the permanent pool it will be more susceptible to clogging by trash

A similar outlet structure in the embankment (to address aesthetics and maintenance access) is provided in Figure 2.20.

Water can be conveyed to the chamber by either a positively sloped pipe (above 1 percent) or a reverse sloped pipe (below 1 percent). If a positively sloped conveyance pipe is used, it should be larger than 250 mm diameter to minimize the risk of clogging.

The fittings and the riser itself should be constructed of a durable plastic or similar material. Holes should be drilled into the riser (13 mm to 25 mm in diameter) along its entire length. The diameter of the pipe, and hence the number of openings, should be sufficient so that the openings do not provide the extended detention control. The riser should be connected to the outlet pipe discharging from the chamber.

If the riser does clog, there should be a maintenance gate or valve in the outlet chamber. A bypass pipe that routes flows directly to the outlet pipe around the chamber is preferable, but more expensive.

FIGURE 2.19
Perforated Riser Pipe Pond Outlet Configuration (from MOE, 2003)

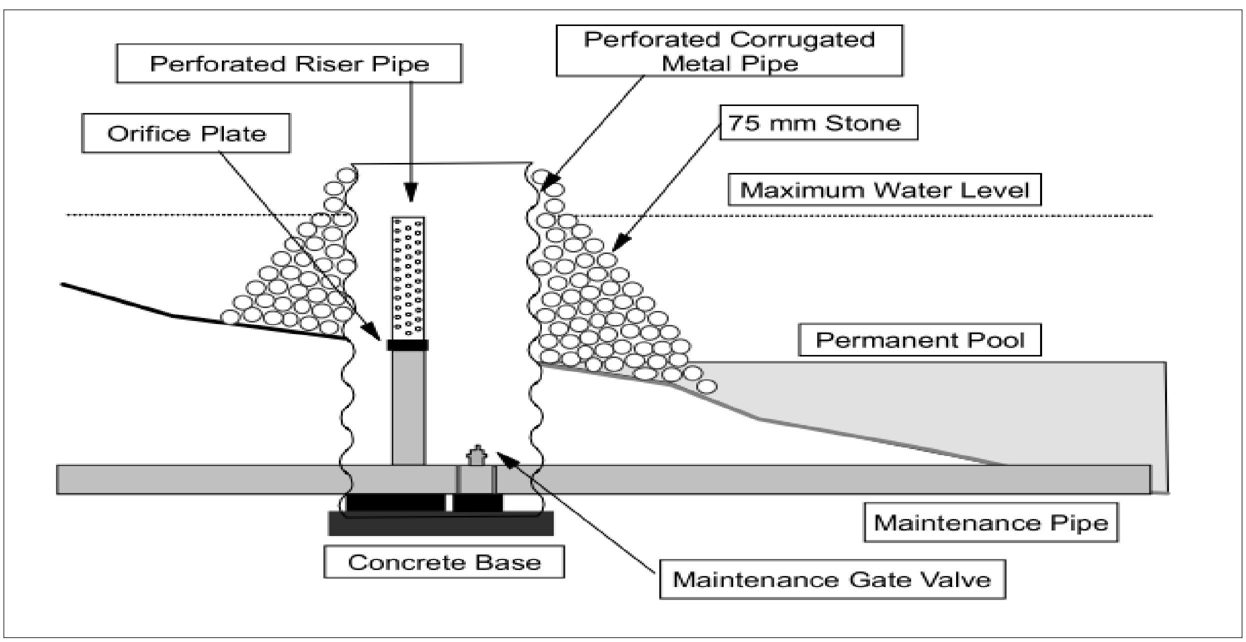
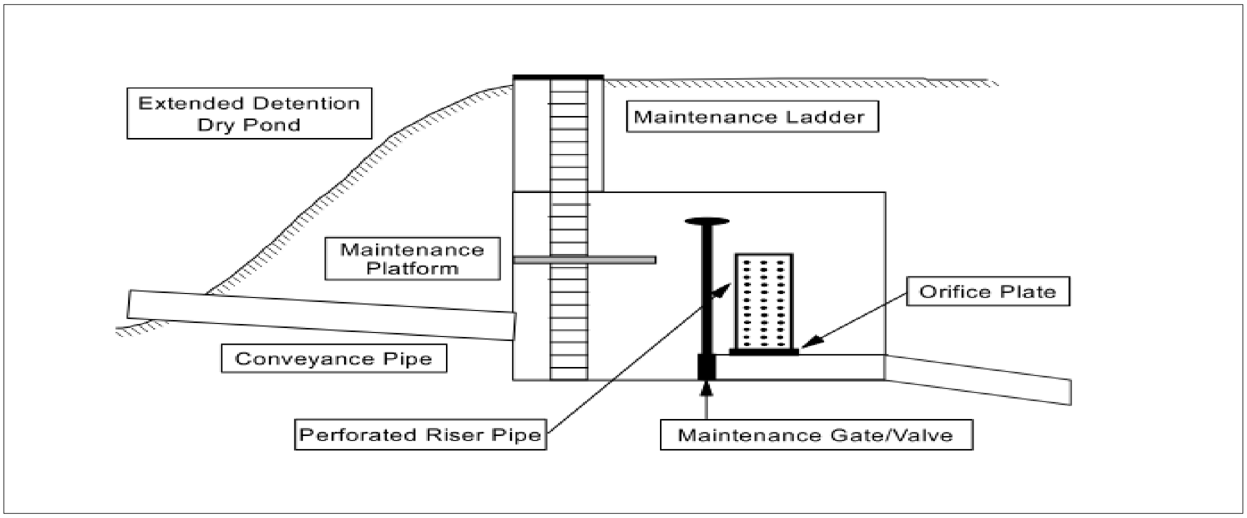
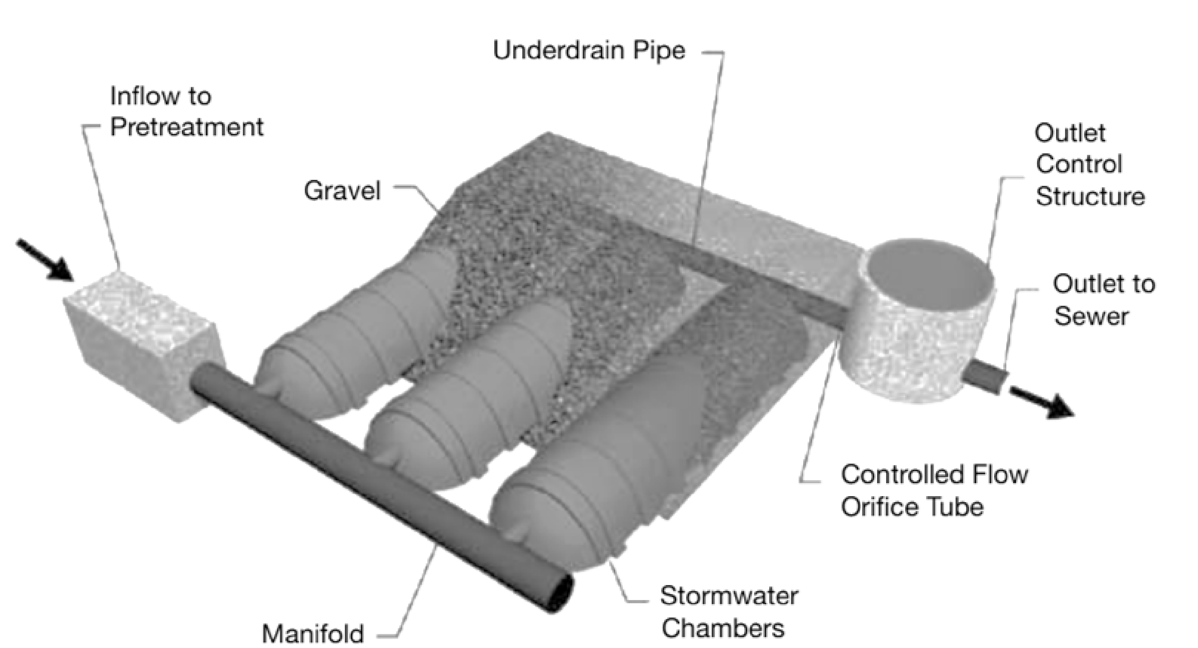


FIGURE 2.20
Perforated Riser Outlet in Embankment (from MOE, 2003)



Three-chamber Structure – This type of outlet control structure is most commonly used. In the three-chamber structure, there are usually two weir walls, one to control the NWL and one to control the HWL or at the calculated hydraulic grade line elevation, and provide a source of overflow from the discharging wetland in the event of an orifice blockage. Other outlet control structure designs may include just two chambers. In some cases a single stepped weir can provide both functions for baseflow discharge and for storm flow discharge as the water level rises. For maintenance purposes, the size of each chamber should be 1.8 m, with a minimum of 1.2 m.

FIGURE 2.21
Stormwater three-chamber structure (from NYC DEP, 2012)



Orifice – Usually an orifice provides the control for the permitted release rate from a CW. The preferred minimum diameter is 100 mm, no less than 75 mm, to minimize the occurrence of outlet clogging. Where small orifices are required, consideration should be given to providing an overflow outlet that would operate in the event of blockage of the primary orifice. The orifice plate should be constructed of stainless steel or an approved equivalent.

Gate Valves – All wetland outlet control structures require a gate valve. The gate valve is used as a bypass for the orifice in the event the orifice plugs and for maintenance purposes. Although there is no set size specified, a minimum gate size of 300 mm diameter should be targeted where possible. Consideration should be given to not exceeding the design flow in the downstream storm pipe, except in emergency situations. With the three chamber design, two bypass gate valves are required, one in the NWL weir wall and one in the HWL weir wall. In the reversed slope pipe design, the maintenance pipe should drain to the outlet chamber, with a gate valve on the end of this pipe. Outlet flows can be controlled by setting and fixing in-place gap openings (this is, partially opening the gate valve to throttle peak flows to the desired discharge rate). All gates should have non-rising stems that are operated mechanically or manually with a T-wrench, stored on the downstream end of the control structure in an easily accessible (but not easily dislodged) location.

Descriptions of auxiliary structures that might be needed in association with the outlet control structures follow.

Extreme Event Bypass Conveyance – Footprint availability even for a CW and SWMP combination may be limited such that only the first flush and low return stormwater flows can be accommodated. In this case, a bypass conveyance for these could be a riprap, paver, or concrete lined channel or a pipe sized for the predicted extreme event flows.

Trash Rack – A trash rack may be required depending on the design of the outlet pipe and/or outlet control structure. A submerged outlet pipe and/or outlet control structure will not require a trash rack. For an exposed outlet control structure, a trash rack must be installed to protect the orifice when the diameter is less than 200 mm. Since the drainage area to a wetland is usually large, the diameter of the orifice is usually large enough so that a trash rack is not required. Small systems higher in a watershed may especially be in need of trash racks. A trash guard must be large enough so that velocities through it are less than 0.6 m/s to reduce clogging problems (Schueler, 1992). The trash rack must be galvanized and include an access to the orifice for maintenance purposes. The openings in the trash rack must large enough to prevent clogging on a frequent basis, yet small enough to provide protection to the orifice. Typically, an opening of 25 to 50 mm smaller than the orifice diameter is suitable.

2.5 Constructed Wetland Configurations

2.5.1 General Considerations and Guidance Summary Table

The configuration of CW is determined by treatment performance goals within the context of topography, hydrology, and area constraints. The primary design drivers for the Saskatoon stormwater wetlands in addition to water quality include flow attenuation, plant community establishment, wildlife habitat creation, and public enjoyment. Each of these features has its unique set of design considerations. Each of these features is considered in the following subsections.

2.5.2 Flow Attenuation

In the undisturbed environment, wetlands provide natural flow attenuation in low lying areas by slowing flow velocity and storing water for gradual release via surface flow and/or infiltration. Constructed wetlands and ENW are designed to provide a similar benefit. This is illustrated in Figure 2.2, where the post development hydrograph has a reduced peak flow rate and longer recession time, providing a response curve more similar to that of a natural, undisturbed condition. The sizing and configuration of the wetland aims to detain the first flush with a minimum detention time of 30 minutes. For treatment and hydrograph curve adjustment, the system should store the average annual storm volume for a minimum of 3 to 5 hours and optimally for 10 to 15 hours (Malaviya and Singh, 2012). The duration of attenuation and peak discharge rate are highly dependent on the nature of the receiving system. For example, a longer attenuation time is required to enhance TSS removal. The fluvial geomorphology of the receiving system (that is, erosion threshold) also determines what the shape of the discharge hydrograph should look like. If designed into the bottom of an SWMP, the SFCW may frequently be inundated for 24 to 48 hours, depending on the local flow detention and hence downstream flood control requirements. For larger and less frequent return stormflow events, water detention in the wetland could last several days to a week or more, depending on the length of time between storm events.

2.5.3 Vegetation Community Health and Establishment

In ENR and CW, vegetation establishment and the diversity of species and habit of the resulting plant communities provide the foundation for flow patterns, water quality improvement, and habitat, as well as aesthetics. Because permit requirements typically limit changes to ENR plant communities, hydraulic, organic, and nutrient loads must be carefully considered in the ENR wetland design to minimize potential impacts. Research indicates that matching hydraulic loads to the hydroperiod requirements and tolerances of established dominant wetland vegetation reduces the potential for vegetation changes (AENV, 2000). Additionally, a flow rate that increases high enough to cause channelization and erosion may also cause physical damage to wetland vegetation communities. Depending on a wetland's vegetation community's tolerance to changes in temperature, and chemical, sediment, and nutrient loads from incoming stormwater, the species assemblages and diversity of the vegetation community may shift. For example, increased nutrient loading promotes cattail (*Typha spp.*) growth. While predicting a vegetation community's response to introduced stresses is not an exact science because of the number of simultaneous direct and indirect responses that can occur (EPA, 1993), the conditions under which a plant is found locally (such as, water depth, nutrient status, soil type, and texture) and its associates give a reliable indication of whether it will tolerate identified loadings.

Of the wetland plants, persistent emergent species have stems that remain even after the growing season, which provide year-round resistance to water flow. These plants include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), rush (*Juncus* spp.), prairie cordgrass (*Spartina pectinata*), reedgrass (*Calamagrostis* sp.), and switchgrass (*Panicum virgatum*). Woody plants, such as highbush cranberry (*Viburnum trilobum*) and willow species (*Salix* spp.) are useful edge species with persistent stems. Submerged aquatic vegetation removes nutrients seasonally, but does not offer significant frictional resistance to flow to drop out suspended sediment (Jones, 1996). Experience suggests that the typical stormwater nutrient loadings and winter salinity from road salts tends to favour the heartier and more aggressive species including cattail (*Typha* spp.), tall reed grass (*Phragmites* spp.), and bulrush (*Scirpus* spp.).

FIGURE 2.22
SFCW Before and After Vegetation Establishment

The same principles apply to selecting the plant palette for a CW wetland and designing the landform grading and planting locations and densities. Local species are preferred over introduced species and planting and seeding take place at a greater density to initially block colonization by weedy species.

Around the inner berm of the wetland, the terrestrial-aquatic boundary should have a very gradual slope, to allow for the establishment of a continuum of emergent plant species and reduces the erosive effects of waves hitting a sharp shoreline boundary (Jones, 1996). Steps to achieve vegetation establishment and maintenance are further described:

Wetland vegetation can be established by several methods, including allowing volunteer vegetation to become established from within an existing prairie pothole (if an ENW), transfer of wetland muck containing seed bank and rhizomes, planting nursery stock, and broadcast/hydro seeding. The highest diversity wetland likely uses all of these techniques and is downwind of another highly diverse natural wetland. Emergent plants from a nursery should be planted as early as possible during the growing season (not during late summer or fall) to allow vegetation to store food reserves for their dormant period. The U.S. EPA (1999) recommends selecting five to seven plants native to the area and designing the depth zones in the wetland to be appropriate for the type of plant and its associated maximum water depth; in reality, for stormwater wetlands the expected water depth and grading of the SFCW bottom dictates the hydroperiod, and native plants that tolerate that hydroperiod should be selected for planting in identified locations.

After excavation, grading, and 7.5 to 15 cm topsoil placement, if manually planting emergent vegetation as bareroot, plugs, or potted material, the wetland should be kept flooded (saturated) until planting. At least 48 hours prior to planting, the wetland should be drained and, after planting, the soil must be kept saturated with minimal standing water (1-2 cm) until the plants are well established and have growth to more than 0.5 m height, after which the wetlands can return to normal functionality as a NWL. If a storm event fills the wetland to the NWL, the wetland will need to be drained if the vegetation has not yet matured to the point where it can tolerate standing water. Typically the outfall structure on wetlands are designed so that stoplogs can be removed or an orifice cut into a stoplog that can then be placed such that the wetland will naturally drain to a predetermined level. Minimum drain time should be kept to less than 48 hours to protect the viability of young plants. Regular inspection (at minimum twice weekly) of the planted/seeded vegetation will be required to monitor the growth, to maintain the saturated soil conditions, and to maintain vigilance from grazing by waterfowl. Protection of the planting in a stormwater system requires that flow velocity into the wetland must be such that there is no scouring of the wetland bottom. Bypassing of flow is ideal, but not always attainable.

Experience suggests that from the time of germination to the time when the wetland can be brought up to the NWL is about 6 to 8 weeks. Germination of seeds planted in the fall can be as late as mid-July. Local nurseries will be able to provide information on expected germination timing.

Maintaining saturated conditions requires that there is some standing water on the site in lower lying areas to a depth of a few centimeters. This can be done by pumping water into the wetland if dry conditions are forecast or allowing storm events to provide the water. This is particularly important if using wetland soils containing viable rhizomes/roots otherwise they will desiccate and die. If the wetland is being constructed with non-wetland soils, the wetland can remain dry until about one week before planting at which time the water level must be increased to and maintained at a depth of several centimeters to ensure deep percolation of the water.

When establishing or restoring vegetation, inspections every 2 weeks of vegetation health, density, and diversity should be performed, including dominant and volunteer species, during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons, in total four times annually. If vegetation has greater than 50 percent damage or death, the area must be re-established in accordance with the original specifications, or the specifications revised to account for different conditions, and the inspection continue.

Wetland planting/seeding scenarios should be based on the recommendations of the suppliers and the associated warranties they offer. General considerations include:

- If the earthworks can be completed in the summer/fall period, the wetland can be seeded in the fall. This will stratify the seed (seeds need to go through a period of freezing to make them viable to germinate) so that the seeds will germinate and grow in the spring/summer period.
- If the wetland bottom elevation will not change and the existing soils are tight enough that the hydraulic conductivity is similar to that of clay compacted to 95 – 98% Proctor, consideration can be given to retaining the wetland soils undisturbed in the areas that are at the correct bottom elevation
- Spring planting of plugs or bareroot vegetation.
- Potted vegetation can be installed into the summer months, but must be watered
- Seeds and plants supplied must come from the same climatic zone as Saskatoon and preferably from within 100 km radius.

Appropriate steps must be taken to achieve and maintain an acceptable balance of original and volunteer species, if appropriate, in accordance with the intent of the wetland's original design. Wetlands established for their aesthetic appeal may require a higher level of maintenance because of the need to remove undesirable species and/or replanting of showy flowering species.

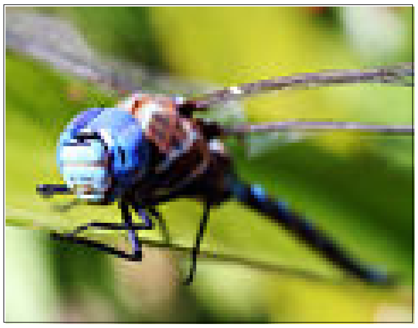
The use of fertilizers, mechanical treatments, pesticides, and other means to establish initial plant communities will not compromise the intended purpose of the constructed stormwater wetland. However, to the extent possible, vegetation deficiencies should be addressed without the use of fertilizers, herbicides, and pesticides.

It is noted that if an existing wetland will be used for flow attenuation and needs to be excavated to provide the necessary storm event volume, the existing bottom soil should be tested for a range of constituents including nutrients (nitrogen compounds, phosphorus, and potassium), metals scan, organics, herbicides, pesticides, mercury, salinity, and pH. If these constituents are within reasonable limits as determined by a reputable soils testing laboratory (ALS Laboratories in Saskatoon is one option), then these soils can be removed to a depth of about 15 cm and stockpiled. These soils will contain a seedbank and rhizomes/roots of wetland and transition plants that will, if spread out onto the constructed wetland bottom within one week of excavating the topsoil and then kept saturated (not flooded), germinate/re-grow to help re-vegetate the wetland. However, if the wetland vegetation contains a large percentage of undesirable plants, then importing of clean topsoil is recommended. An alternative is to heavily seed and densely plant the existing soils with desired vegetation to help outcompete the undesirable vegetation.

2.5.4 Wildlife Habitat Creation

CW and ENW both attract a range of resident and migrating wildlife. These prairie pothole areas are essential for migrating species and have been greatly diminishing, thus this is a high value rationale for protecting and creating more such wetlands. Deep zones that provide flow distribution across the width of the wetland also provide open water for waterfowl, refugia for fish in the winter, and re-aeration of the water by wind action for the benefit of aquatic organisms. Including design elements such as small islands, shallow edge littoral zones, nesting boxes, and bat roosting boxes improves the habitat potential. It also, in the case of swallow nesting boxes and bat roosting boxes, attracts natural predators for mosquito control. Reptiles and amphibians will also benefit from the wetland and features like rock piles for snake habitat and sand boxes for turtles to lay eggs in will help keep them off roads where they are often crushed by passing vehicles.

In siting a CW within a development, consideration should be given to wildlife corridors that allow access and connectivity to the wetland from surrounding natural areas.



Dragonflies provide natural mosquito control

Least Bittern hunting for fish and frogs in the wetland

Mosquito (Larvae and Pupa) controlled by aquatic and aerial predators

Tree swallow and nesting box provide natural mosquito control

2.5.5 Aesthetics, Recreation, and Education

In residential and commercial areas where there is a high level of interest in viewing wildlife and/or recreation and exercise in a naturalized area, a range of features can be added to a CW or an ENR to increase the aesthetic and recreation value. The design of the wetland can include perimeter walking trails, boardwalks, viewing platforms (Figure 2.23), informational signage, and cascades for auditory aesthetics (where there is sufficient relief).

FIGURE 2.23
Wildlife Viewing Platform at a Constructed Wetland in Southern Ontario

Discussions with local stakeholders such as walking and running clubs, naturalist organizations, and the nearest schools help to formulate aesthetic and pragmatic preferences. With these indications, a local landscaper who has experience with local natural systems will help the project match these preferences.

2.6 Length-to-width (Aspect) Ratio and Berm Design

2.6.1 General Considerations and Guidance Summary Table

The aspect ratio conceptually frames the outline of a CW or ENR, while the berms in practice frame the CW wetland itself, setting the wetted boundary of the system.

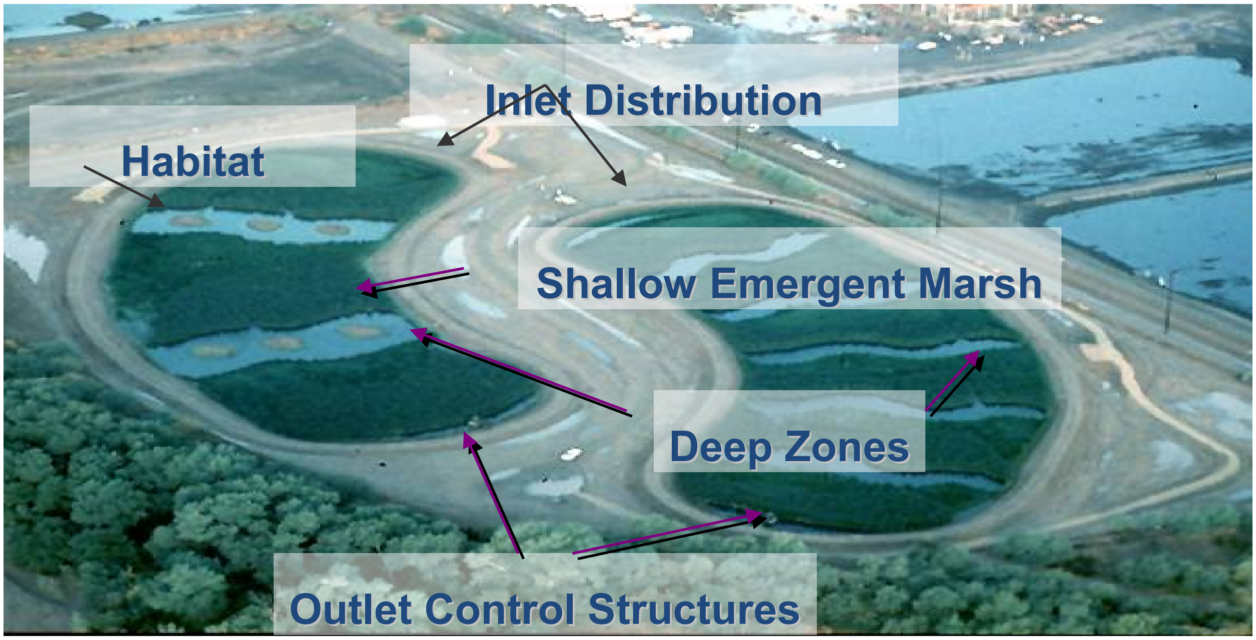
2.6.2 Aspect Ratio

The literature contains some recommendations for aspect ratio (L:W ratios) to be used in design. The U.S. EPA (2000a) comments that, in general, SFCW wetlands should be built with L:W > 1:1. Crites et al. (2006) recommend 2:1 < L:W < 4:1, while the *Wisconsin Storm Water Manual: Technical Design Guidelines for Storm Water Management Practices (G3691-P) (I-1/2000-.6M-1500)* (2000) recommends a L:W ratio of at least 3:1 for adequate detention times. For the U.S. EPA (1999), the recommended minimum L:W ratio of the wetland is 2:1. If a ratio of less than 2:1 is necessary because of site constraints, the use of baffles, islands, and peninsulas can minimize short circuiting (allowing runoff to escape treatment) by maintaining a long distance from inlet to outlet. The ITRCW (2003) indicates that for surface flow wetlands, multiple cells per train are recommended to minimize short-circuiting, and several trains per system are suggested. For each cell, the recommended L:W should be within 3:1 to 5:1 range to minimize short-circuiting (USEPA, 2000). Water Security Agency (2014) guidance recommends an overall minimum L:W ratio for constructed wetlands of 3:1, and for the forebay, a minimum L:W ratio of 2:1.

Kadlec and Wallace (2009) conclude that there is not much quantifiable and documented water quality improvement to select one L:W over another, as long as it stays in a reasonable range, such as 2 < L:W < 10. Lower system aspect ratios may be used provided cells in parallel are used. Data from wastewater SFCW studies indicate somewhat better performance for higher L:W ratios (Herskowitz, 1986; CH2M HILL, 2003a), but the margin is not large when the pollutant reductions are low-to-moderate (0 to 50 percent). This supports Kadlec and Wallace's conclusions that other design factors may have much greater effect on treatment performance than L:W ratio.

Higher L:W ratios increase the area of external berms that must be constructed to enclose a given wetland area, which is a major cost of a CW. Therefore, economics may argue for low L:W ratios especially given similar performance. Additional methods for maintaining effective flow distribution, such as deep zones (Figure 2.24), may be considered as lower cost alternatives to high L:W ratios.

FIGURE 2.24
Aerial Photo of a SFCW Showing Deep Zones, Kidney Shape, Habitat Islands, and L:W of About 2:1



Site conditions frequently constrain the L:W ratio, prompting the use of design techniques to optimize uniform flow distribution through odd shaped sites. Innovative use of habitat islands, shallow zones, or large woody debris flow barriers in addition to deep zones can be used to route water through wetland layouts.

2.6.3 Berm Design

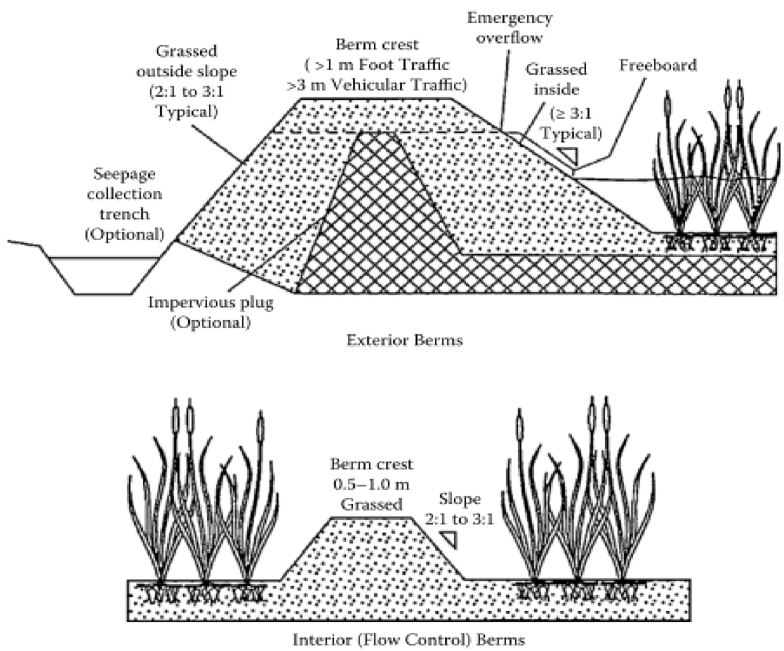
Berm side slopes can have a significant impact on flow routing and short circuiting in many wetland shapes, especially if the wetland water surface elevation fluctuates over a wide range and the changing shoreline changes volume and cross sectional area for flow. In the areas where the public will have access to the wetland edge, side slopes must be adjusted to meet public health and safety guidelines. Side slope is also a powerful tool for designers to use in creating specific habitats or vegetation diversity.

Berm slope is dictated by geotechnical considerations and slope-stability analysis. Maximum berm slopes typically used in CW are 2:1 (horizontal: vertical). However, to meet the City of Saskatoon Parks Department minimum standard for safety, it is best to keep slopes at 3.5:1 or lower angle to minimize sloughing of the slopes into the wetlands while maximizing wetted area in the wetlands. Slopes up to 10:1 or 20:1 are used when a shallow littoral shelf is desired to create vegetation and habitat diversity. The side slopes may be rip-rapped with stone to reduce the potential for erosion or rodent burrowing (Kadlec and Wallace, 2009). Figure 2.25 shows a typical berm cross section. A requirement of side slopes of 5:1 or greater below the base flow water elevation for any water impoundment has been encountered in the construction guidelines for some municipalities and industries as a safety consideration. This low slope provides easier egress in case someone falls into the wetland.

Interior berms must provide sufficient freeboard above the base flow water elevation of at least 1 m, so that the berm does not become saturated and begin to slump during a storm event when the water level rises and may flood to the top of the divider berms. The top width of interior berms is usually dictated by maintenance or public access requirements (see Section 2.10). That said, berms that are greater than about 5 m in width are less likely to be fully penetrated by muskrats. The side slopes of these are typically at a three-to-one slope and may be riprapped with stone to reduce the potential for erosion and/or rodent burrowing.

Controlled overflow points that are riprapped dips in the surface or concrete weirs should be incorporated into the top of the berm of each wetland cell so that if the wetland is overtopped the flow exiting the wetland does not cut channels into the top of the berm that could compromise the integrity of the berm.

FIGURE 2.25
Design Considerations for Constructed Wetland Berms (from Kadlec and Knight, 1996)



2.7 Allowable Active Storage Depth Fluctuations

2.7.1 General Considerations and Guidance Summary Table

The accuracy of predicting and designing for the active storage depth is crucial for a successful ENW or CW.

2.7.2 Active Storage Depth

Stormwater quality targets can be difficult, if not impossible, to meet in extreme storm events such as the 100-year return period event. Stormwater systems often meet water quality targets on a long-term average basis as opposed to a per event basis. During extreme events, it is the first flush that requires treatment and will be the focus of the design. The water quality improves during the course of the storm event because of dilution by stormwater and therefore bypass of extreme flows can be built into the design.

Design for active storage is based on the following guidelines:

- Water flow rate and depth are critical aspects for quality improvement. Flow velocity should be low (less than 0.3 m/s) and laminar in SFCW and ENW to provide sufficient residence time to achieve the target removal rates of contaminants.
- The design of the constructed wetland system must establish depth of water throughout the wetland for hydraulic control. In SFCW systems, as has been discussed previously in this document, the use of spaced, deep open-water sections across the width of the wetland cell can reduce flow channelization, resulting in better overall water quality improvement efficiency. The bottoms of the open-water sections should be graded flat across the width to avoid creating preferential flow channels.
- Average permanent pool depth in a SFCW or ENW should range from 150 mm to 300 mm. As previously discussed, inlet and outlet areas should be deeper (greater than 1 m) to minimize re-suspension and discharge of settled sediment from the facility. The maximum depth in the inlet and outlet areas should be restricted to 3 m. Deeper pools may be scattered throughout the SFCW and ENW in such a way as to limit short circuiting. Deeper water areas will be open water with only aquatic vegetation since they will be too deep to sustain emergent vegetation. As such, deep areas should be limited to 25 percent of the total surface area so that the majority of a SFCW or ENR sustains emergent vegetation. Alternatively, such deep water areas may incorporate FWI systems to increase treatment effectiveness.

- Active storage depth (above the permanent pool) is typically 1 to 2 m to accommodate the most major storm events. However, for larger CW and SWMP combinations, storm event water depths may need to be increased to accommodate the flow volume capture requirements. An example is the 200 ha Shepard SWMP in Calgary, Alberta, that has an active storage depth of more than 5 m for the 100-year return storm event. Appropriate robust vegetative species must be considered if annual or more frequent inundation at a greater storage depth than 2 m is needed.
- A minimum of 1 m freeboard should be provided above the design HWL. However, for long term planning and accounting for trends indicating increasing climatic variability 2 m freeboard could be incorporated.
- Event flows create large instantaneous loads on constructed wetlands that, if not contained, will cause diminished water quality improvement. The peaking factor (PF) may be defined in a manner similar to that used to describe the fluctuations in continuous flows, namely, as the ratio of the peak flow to the mean flow
- Active storage depth must also take into consideration wildlife that may use the berms or the tops of berms for nesting or as burrows. Wading birds and ducks will use the tops of berms in multi-cell wetland systems as preferred nesting sites since berms allow limited access to predators. Flooding conditions will destroy nests, as will vehicular movement (trucks, mowers) by maintenance staff. Siting CW in regional waterways (a river and its tributaries) offers particular constraints. CW located in floodplains with extreme flood conditions, such as along major rivers, must have dikes that are designed to allow the passage of floods through the CW and/or that are sized to exclude flood waters. CW have typically been allowed in floodplains under limited conditions. Designs should avoid damage from high-frequency recurrence events, and therefore are usually be built to withstand the 25-year flood event without impairment of function, and designed to withstand the 100-year flood event without severe damage. Floodplains may be jurisdictional wetlands, thus posing regulatory questions related to fill from berms and other introduced materials. Information regarding local hydrogeological conditions is necessary to confirm groundwater levels and flows relative to proposed wetland operating levels and to mitigate impacts as necessary. If a wetland is built in a floodplain, it may be necessary to demonstrate that its presence will not back up floodwaters upstream of the project or added compensatory storage will need to be provided. In other words, the project should not block the floodway of the river. For most major rivers, there exist published maps showing the boundaries of the 100-year floodplain and the floodway. If constructing a CW within a floodplain it must be approved by the appropriate agencies.

2.7.3 Regional Climate Considerations

The water budget should demonstrate that there will be a continuous supply of water to sustain the CW or ENW. The water budget needs to be developed during site selection and checked after preliminary site design. Tables 2.2 and 2.3 provide the climate data that are typically used to determine wetland sizing based on water quality discharge targets using the P-k-C* sizing model. Drying periods of longer than 2 months have been shown to adversely affect plant community richness, so the water balance should confirm that the seasonal dry period will not exceed 2 months (Carleton et al., 2001). Some jurisdictions may require that during dry weather, flow must be adequate to provide a baseflow and to maintain the vegetation. However, natural wetlands often dry out for short periods of time and the vegetation will become dormant with the top growth dying off. The leaves will re-emerge once the soils again become hydrated from storm events.

If constituents are retained within the sediment of the CW under anoxic conditions and the wetland soils become dried and exposed to air, these conditions can cause sediment oxidation and become released from the soil to be discharged with a subsequent storm event. In this case, provision should be made to keep the wetland flooded. Solutions may include adding a liner to reduce percolation rates through the wetland bottom soils and, if the wetland is located in an area or is designed such that there will be limited or no human contact, consideration can be given to supplementing the flow during dry periods with treated wastewater treatment plant effluent or, in an industrial area, using non-contact once-through cooling water that would normally be discharged to the storm or sanitary sewer.

TABLE 2.2
Monthly and Annual Total Precipitation for Saskatoon (MM)

Month	Total Precipitation (mm)	Total Precipitation as Rainfall (mm)	Total Precipitation as Snowfall (cm)
January	17.9	0.5	17.6
February	13.1	0.3	12.8
March	16.2	2.1	14.1
April	24.2	15	9.2
May	43.6	41.5	2.1
June	60.5	60.5	0
July	57.3	57.3	0
August	35.4	35.4	0
September	30.6	28.9	1.7
October	16.9	7.7	9.2
November	13.7	2.1	11.7
December	18.9	1	17.9
Yearly	348.3	252.3	96.2

TABLE 2.3
Daily Extreme and Average Air Temperatures in Saskatoon (°C)

Month	Daily Maximum	Daily Minimum	Daily Average	Extreme Maximum	Extreme Minimum
January	-11.1	-21.6	-16.4	7	-43.9**
February	-7.5	-17.4	-12.5	7.9	-41.1
March	-0.7	-10.6	-5.6	19.5	-38.9
April	10.8	-1.5	4.7	31.5	-27.8
May	18.7	4.8	11.8	35	-10
June	22.6	9.4	16	41*	-3.3
July	25	11.5	18.3	39.3	1.7
August	24.6	10.4	17.6	39.7	-2.8
September	18	4.9	11.5	35.6	-7.8
October	10.9	-1.4	4.8	28.5	-21.5
November	-1.1	-10.1	-5.6	19.4	-33.5
December	-9	-18.8	-13.9	11.2	-42.2
Yearly	8.4	-3.4	2.5	NA	NA

[a] Based on data recorded at the Saskatoon climate station from 1971 to 2000 retrieved from: http://climate.weather.gc.ca
NA – Not Applicable
*Extreme maximum of 41°C occurred on June 5, 1988
**Extreme minimum occurred on January 22, 1966

Average annual potential evapotranspiration in Saskatoon is within the 50.8 cm to 61 cm range. Potential evapotranspiration is defined as the potential for water loss by evaporation and transpiration whether there is a continuous vegetation cover (National Atlas of Canada, 2003).

Average annual water deficit as defined by the amount by which precipitation and soil moisture, during parts of the growing season, fail to supply sufficient water to theoretical full plant growth. Areas with defects have seasonal aridity to varying degrees. For the Saskatoon area, the average annual water deficit is 30.5 cm or more (National Atlas of Canada, 2003).

2.8 Water Quality Improvement

As noted earlier, one of the beneficial characteristics of all wetlands is that they provide some degree of water quality improvement. By engineering CW or re-engineering natural wetlands to create ENW, this treatment aspect can be optimized without compromising habitat, and aesthetic benefits, which in the same process can be enhanced. The design of stormwater CW is often limited by a number of site constraints, including soil types, depth to groundwater, contributing drainage area, and available land area. When planning for these systems, a water budget, design configuration, system bottom, and control structure elevations and hydraulic grades, a site soils analysis, and estimated depth of deep zones should be determined. Base flows to the stormwater wetland need to be sufficient to maintain the vegetation and to maintain the aerobic conditions within the water column and the anoxic conditions within the sediment and soils of the wetland cells. Drying out a wetland can result in exposure to aerobic conditions and subsequent release of bound contaminants that could become flushed out into the receiver during a subsequent storm event. The target wetland plant density of up to 80 percent coverage should also be considered when planning for stormwater wetland design. When designing for water quality improvement, the plant species is less critical than the plant density, other than that it must tolerate the planned hydroperiod.

2.8.1 Documented Treatment Wetland Performance

Wetlands are among the most effective practices for removing stormwater pollutants. Since the 1950s when wetland treatment systems were installed in Germany, hundreds of research studies have estimated the pollutant removal effectiveness of various types of wetlands. Wetlands have removal rates for many pollutants in the range of 80 to 99 percent by concentration or load, and are very effective when compared with other passive stormwater BMPs at removing nitrate and bacteria. Table 2.4 provides pollutant removal data derived from the Centre for Watershed Protection's National Pollutant Removal Database for Stormwater Treatment Practices. An assortment of additional references showing expected removal efficiencies and sediment accumulation can be found in Appendix F.

TABLE 2.4
Typical Pollutant Removal Rates of Wetlands (Adapted from Winer, 2000)

Pollutant	Stormwater Treatment Practice Design Variation (%)			
	Shallow Marsh	Extended Detention Wetland[a,b]	Pond/Wetland System	Submerged Gravel Wetland[a,c]
TSS	83±51	69	71±35	83
TP	43±40	39	56±35	64
TN	26±49	56	19±29	19
NOx	73±49	35	40±68	81
Metals	36 - 85	(-80) - 63	0 - 57	21 - 83
Bacteria	76[a]	NA	NA	78

[a] Data based on fewer than five data points
[b] An extended detention wetland consists of both pool and marsh zones within an extended detention basin
[c] Submerged gravel wetland is a type of SSFCW

Stormwater CW may receive a variety of pollutants, and thus can be designed to focus on specific or an entire suite of potential pollutants, depending on the known or expected contaminants in a given watershed during the life of the system. TSS is a pollutant found in virtually all stormwater, and as shown in Table 2.4, and is very effectively removed in stormwater CW. Active storage detention time for TSS removal is a critical design factor and is very dependent upon the specific density of particles and particle size. Physical processes play a primary role in TSS. Gravitational settling is responsible for most of the removal of suspended solids. Gravity promotes settling by acting upon the relative density differences between suspended particles and water. Efficiency of TSS removal is proportional to the particle settling velocity and length of the wetland.

Wetland layout, depth, and volume as well as vegetation type and density, also have large impacts on TSS removal rates. Wetlands promote sedimentation by decreased water velocity and the filtering effect of plant stems and leaves. While settling and sedimentation are often used interchangeably (Tchobanoglous and Burton, 1991), sedimentation referred to in this document represents physical compression and consolidation of settled solids in the detritus (litter layer). The compression is caused by the ever-increasing mass of particles landing in this area. Although sedimentation is usually irreversible, re-suspension may occur from the high water flow rate, wind-driven turbulence, bioturbation, and gas lift (resulting from oxygen, methane, carbon dioxide production during photosynthesis, and organic matter decomposition). Typical design detention time within a CW is between 24 and 48 hours for the storm event flow i.e. the water level within the wetland is reduced to the base flow condition level.

While there is considerable variability in the effectiveness of wetlands for water quality improvement, as indicated by the processes responsible for TSS removal, proper design and maintenance will improve their performance potential. Studies suggest that wetland performance in treating stormwater is generally a function of inflow or hydraulic loading rate and detention time, which are in turn functions of storm intensity, runoff volume, and wetland size (area and volume; Barten, 1987; Carleton et al., 2001; Meiorin, 1989). Inflow rate can influence retention of constituents by affecting the degree of bottom scouring and re-suspension of settled solids if the design does not account for maintaining a velocity of less than 0.6 m/s. Wetland volume, including freeboard and dead storage, determines the fraction of a runoff event captured, and hence made available for treatment, especially during base flow periods between events.

Another approach to optimizing wetland water quality benefits involves activities during construction. Many constructed wetlands lose organic matter in the soils, which plays an important role in pollutant removal by providing exchange sites for pollutants. Replacing or adding organic matter after grading and berms are in place improves performance.

A best practice for an initial feasibility sizing of a stormwater SFCW is a minimum area ratio of 2 percent (or 1 percent for wetlands with extended detention) of the total catchment area, and a volume large enough to capture 90 percent of all storm events. For example, with purely hydraulic loading, a 10-ha catchment area may require an approximately 200 m^2 SFCW. This would need to be confirmed through modelling.

However, where there are specific target pollutant removal efficiencies identified, a more detailed sizing exercise is required using the P-k-C* sizing model developed by Dr. Robert Kadlec (Kadlec and Wallace, 2009).

2.8.2 Conveyance within Constructed or Enhanced Natural Wetlands to Optimize Treatment Performance

Proper flow distribution for uniform flow to every part of the wetland and reducing short circuiting potential provides maximum water quality improvement. Multiple wetland cells and/or the use of deep zones within the cells are recommended to reduce the potential for short circuiting and increase hydraulic efficiency. Other design considerations also can improve outflow concentrations and decrease the variability in outflow concentrations.

Factors that help to optimize wetland water quality improvement functions are presented in Table 2.5.

TABLE 2.5
Features in Conveyance Design that Optimize Water Quality Improvement

Design Aspect	Benefits/Discussion
L:W ratio	Avoid very low L:W ratios since flow distribution will be difficult to maintain (as discussed in Section 2.5.1)
Lay out wetland cells in series	If the slope and layout of the development allows, incorporating an existing series of prairie pothole wetlands into the stormwater management system provides several benefits, including the following: • Quickly re-establishes the plant community from an existing seed bank and rhizomes (roots) • Adds an aesthetic benefit to the adjacent development with rounded edges and connected flow paths • Reduces cost of soil excavation/earthworks • Limits the disturbance of existing wildlife use including predators of mosquito larvae
Create deep zones	Use of deep zones for distributing and redistributing the flow across the width of the cell at several locations within a SFCW or ENW has long been determined to reduce flow short-circuiting. Deep zones are typically 1.3 m deep or more and can be designed to be up to about 40% of the wetted surface area of the wetland. A common, effective configuration is to site one deep zone at the point of inflow, one or several within the shallow marsh area of the wetland, and then one at the point of outflow. The deep zones help avoid blind spots in the corners of inflow and outflow zones. Refer to Figures 2.26 and 2.28.
Maintain a flat and level wetland bottom	By constructing the wetland bottom flat and level this optimizes the flow path through the wetland reducing the potential for the formation of topographic channels parallel to flow that can result in preferential flow paths that can lead to reduced water quality improvement efficiency
Enhance vegetation density and coverage	Shallow zones require a dense and uniform cover of vegetation to provide sufficient living and dead (detritus) plant material as media for the growth of bacteria and regeneration of sorption sites. When planting or seeding the wetland, leaving unvegetated areas leads to preferential flow paths which need to be avoided. See Figure 2.28
Re-route high storm flows around the wetland after allowing the first flush to be conveyed through the wetland	Depending on the available footprint for the SWMP and a CW or ENW, to reduce the potential for flushing settled solids and accompanying contaminants, a stepped weir should be incorporated into the inflow control structure that would allow flows up to some predetermined storm event return period to enter and flow through the wetland. As the flow increases, the flow that is in excess of the design flow is diverted by way of pipe or channel past the wetland. Design flow velocity for minimizing disturbance of wetland bottom sediment is less than 0.3 m/s (1 feet/sec).
Incorporate shallow marsh SFCW into the shelf of a stormwater management pond	Many CW designed for stormwater treatment have been built into SWMP along the margins or in the inflow end. While this is not the most efficient wetland treatment system, it will improve the performance of the overall SWMP, especially useful where structures are already in place or suitable land area is limited. See Figure 2.26.

TABLE 2.5
Features in Conveyance Design that Optimize Water Quality Improvement

Design Aspect	Benefits/Discussion
Incorporate floating wetland islands into the stormwater management pond	Floating wetland islands, which do not need to be designed into the bottom of the wetland, are commercially available or can be fabricated using off-the-shelf materials. They are installed across the width of the pond as noted in Section 1.3.2 such that the flow travels through their root system that provides sites for bacterial attachment and for sorption of contaminants. Cost effectiveness needs to be weighed for each application. In some communities that have concrete or high density polyethylene (HDPE) lined SWMPs, a retrofit of the SWMP with FWI might be beneficial, however installation costs may be greater than constructing an SFCW or an ENW.
Convert conveyance swales to sinuous constructed wetlands	Swales that a convey stormwater between wetlands and/or to the receiving water body provide an opportunity to optimize treatment in the entire system. Maximizing the width and minimizing the longitudinal slope within the limits of the upstream and downstream hydraulic boundary conditions controls the overland movement of water (hydrologic attenuation) and associated sediments, nutrients and contaminants. By adding occasional small rises across the swales to detain water and encourage growth of emergent vegetation, the swale becomes a sinuous wetland and augments flow attenuation, habitat, aesthetics, and improved water quality functions. Modified swale design must be sized appropriately for flow attenuation, to avoid erosion, and to limit the potential for overtopping the swale banks. Where flows and flow variability is high and bank storage occurs, but riparian vegetation is lacking, benching may be an alternative approach to enhance water quality; however, in lower order swales and creeks, creating a sinuous wetland system is more effective.

FIGURE 2.26
How Vegetation Patterns Can Affect Flow Distribution (Kadlec and Wallace, 2009)

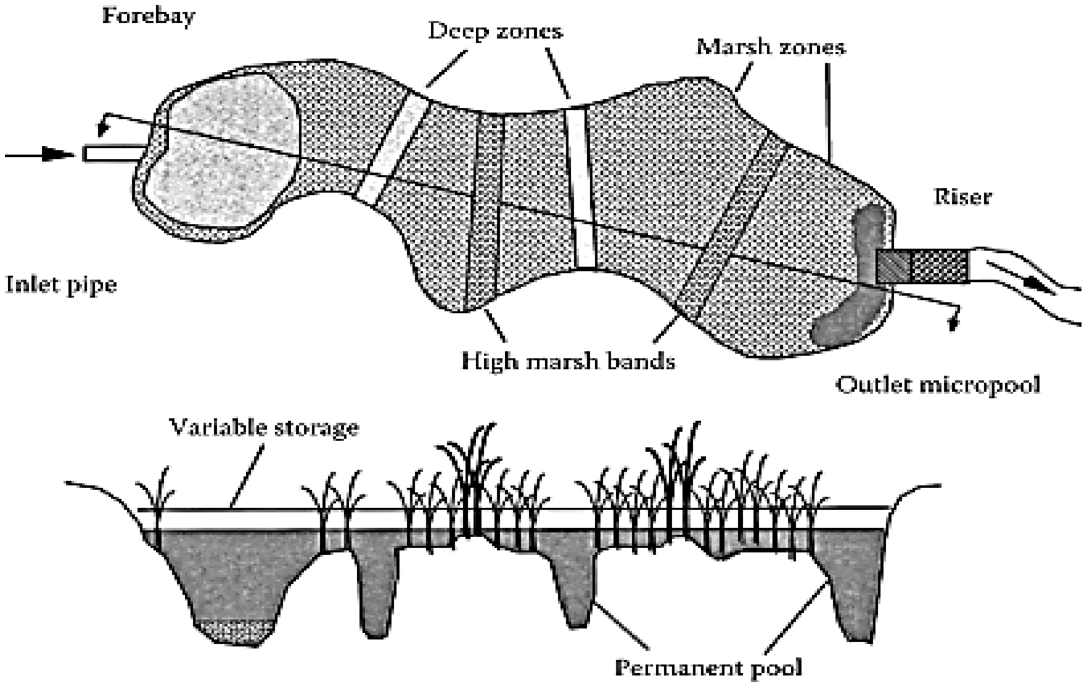


FIGURE 2.27
Concepts of Cell Internal Vegetation Patterns (Kadlec and Wallace, 2009)

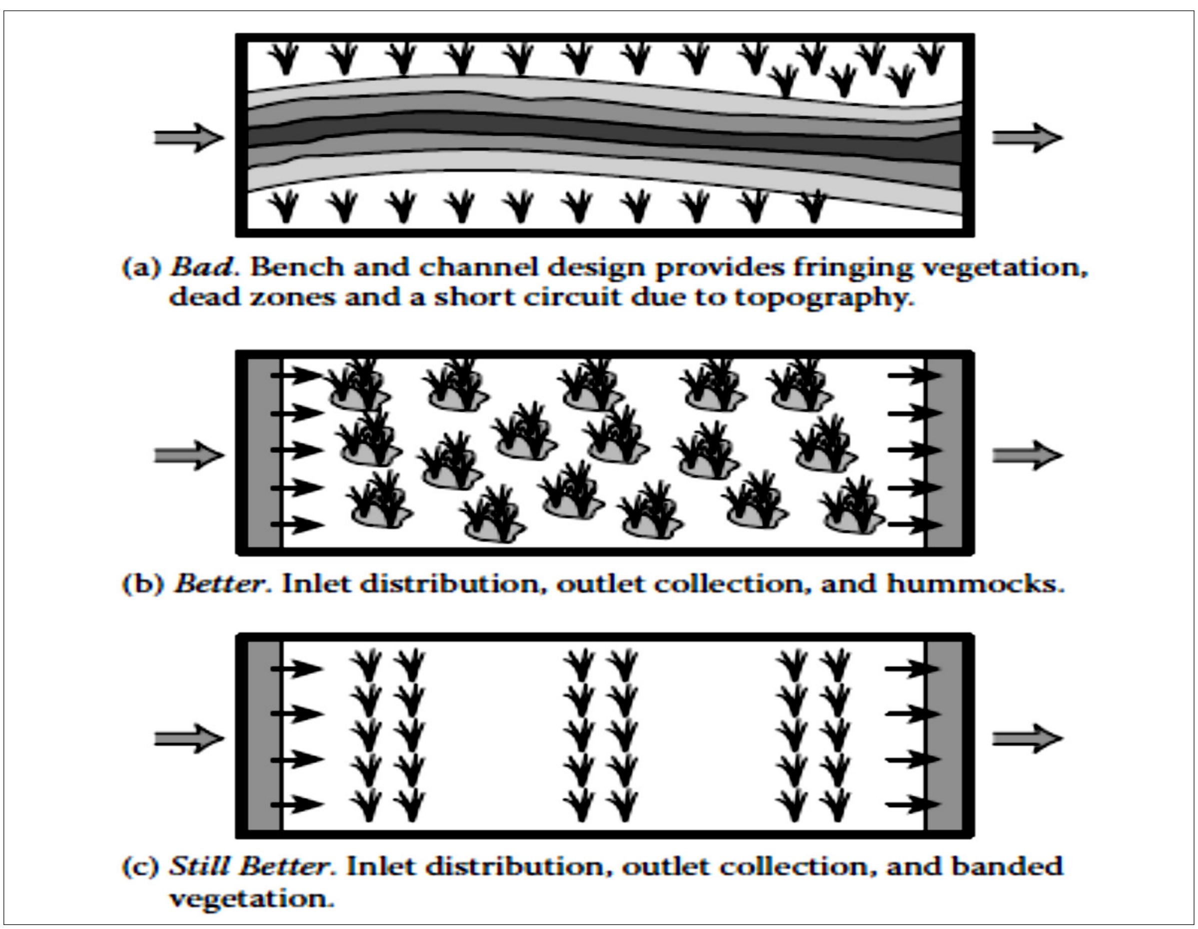


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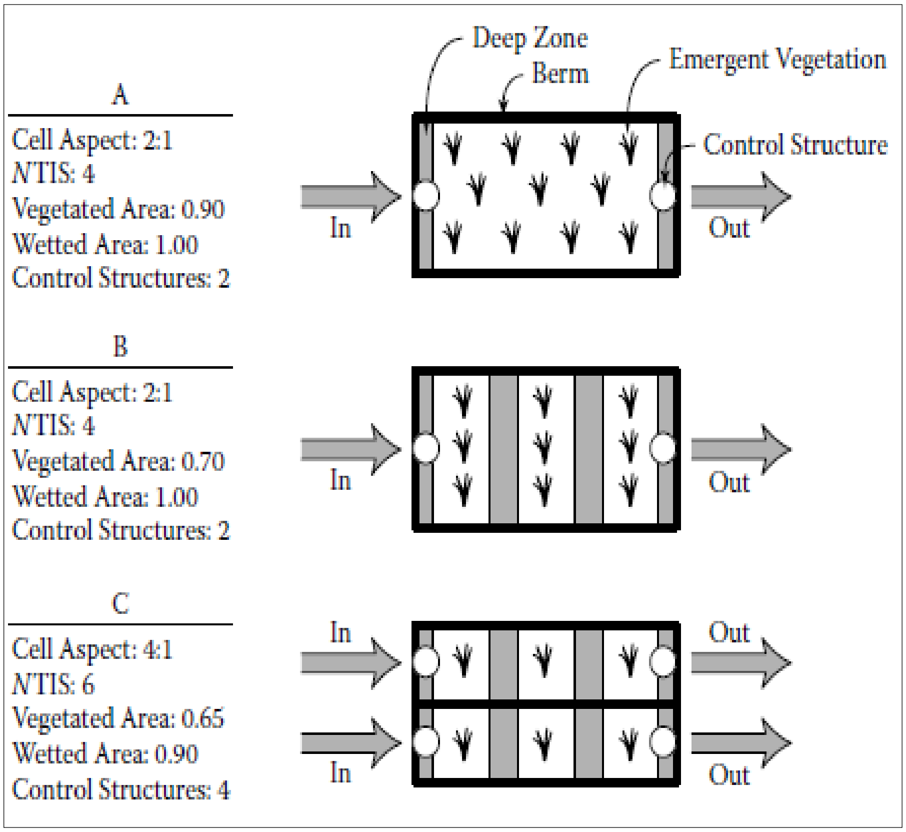
FIGURE 2.28
Options for Deep Zones in Series and Parallel (Kadlec and Wallace, 2009)



2.9 Buffer distances

While buffers adjacent to high quality natural wetlands and water bodies are commonly recommended to be 33 to 100 m in depth, and there are Canadian data that suggest land use effects may extend well beyond this distance (Houlahan and Findlay, 2004). Buffers around stormwater CW take into account the limited land availability in urban settings. The following incorporates the recommendations of several entities with respect to buffers around stormwater constructed wetlands:

- The wetland design should include a buffer to separate the wetland from surrounding land both to isolate the constructed wetlands from developed areas, and to reduce potential impacts on wildlife. Fencing surrounding the wetland should include appropriate gates and sufficient space around the perimeter for vehicle and person access. Buffers may mitigate some potential wetland nuisances, such as accumulated floatables, odours, muskrats, and geese. A buffer of 8 m is recommended measured from the high water level, plus an additional 8 m when protection of adjacent wildlife habitat is a goal. Leaving trees and shrubs undisturbed in the buffer zone covering up to 75 percent of the area will minimize the disruption to wildlife. If tree and shrub removal is necessary, the buffer area should be replanted with native trees and shrubs.
- When possible, integrate the stormwater facility with other natural resource features to provide wildlife corridors and open space. The buffer itself should provide habitat with a diversity of native species comparable to those found in plant communities bordering natural wetlands in the region.
- The *NJ Stormwater Management Technical Manual* (CH2M HILL, 2011) mandates that safety ledges must be constructed on the slopes of all stormwater CW with a permanent pool of water deeper than 0.8 m. This would typically apply to the deep zones used for flow distribution. Two ledges must be

constructed, each 1.3 to 2 m wide. The first or upper ledge must be located between 0.3 and 0.5 m above the normal standing water level. The second or lower ledge must be located approximately 0.8 m below the normal standing water level.

- The *NJ Stormwater Management Technical Manual* (CH2M HILL, 2011) also stipulates that the following minimum setback requirements apply to stormwater wetland installations:
  - Distance from a septic system leach field = 15 m
  - Distance from a septic system tank = 8 m
  - Distance from a property line = 3 m
  - Distance from a private well = 15 m

2.10 Access

Well-designed and maintained wetlands can function as designed for at least 20 years but typically much longer. To install an effective and long-term robust CW, limited but regular maintenance is required. Thus, wetland maintenance consideration actually begins during the design phase.

Access to wetlands for operating the system and carrying out maintenance and monitoring typically needs to be addressed in designs at the level control and overflow locations to adjust gates, collect water samples, and measure and record water depth and flow. Occasional mowing of berms and adjacent land may require an access gate. If public viewing is encouraged, access via trails and to viewing platforms must be considered in the layout and landscaping. If local schools/universities will be using the wetland for student projects, then access may be required to monitoring stations that they may set up.

Designs also need to provide direct access for twice yearly surveys of vegetation in the initial years of wetland establishment. Related maintenance requirements may include replacement planting and removal of invasive species as a result. Similarly, sediment depths will be monitored during the establishment period in the first wetland deep zone, and direct access for sediment removal in case pretreatment is not sufficient for the range of loadings experienced.

Dikes/berms are used for walking or driving access. A vehicle access dike needs to be more than 3-m wide on the top; interior divider berms designed for pedestrian access may be as narrow as 1 m on the top. Dikes need to be inspected several times per year to identify erosion and animal borrowing issues. Dikes that are greater than about 5 m in width are less likely to be fully penetrated by muskrats. The side slopes of these are typically at a three-to-one slope and may be riprapped with stone to reduce the potential for erosion and/or rodent burrowing.

One maintenance issue is the growth of trees in wetland berms, such as cottonwood (*Populus deltoides*) and willow (*Salix* spp.). These trees are most easily controlled by mowing, which requires that berms be designed with flat enough side slopes for mowing equipment. Systems that are designed for public use will require that walking trails and other public facilities be kept in a safe and useable condition.

One potential maintenance concern in stormwater wetlands is clogging of outlets. Wetlands should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack, as previously described in Sections 2.3.1, 2.4.3, and 2.10. Because these outlets draw water from below the level of the micropool, they are less likely to be clogged by floating debris.

2.11 Constructed Wetlands Guidelines by Others

A web search was done to determine which communities in Saskatchewan had stormwater wetland guidelines similar to those prepared for this document. In tandem with this effort, other selected Canadian and US cities that have prepared guidelines were reviewed, Saskatchewan municipalities were contacted, and a chart prepared to compare and contrast these guidelines.

A total of 11 cities or municipalities were contacted to determine the existence of municipal guidelines and standards for the integration of wetlands into urban developments. Some municipalities responded that their particular geography did not necessitate the development of such guidelines, while others commented that they were looking to the City for leadership in the matter.

A summary of comments from those contacted is as follows:

- No guidelines specific to their city are being used. They were not aware of the existence of provincial guidelines.
- Several bylaws and guidelines manuals for stormwater/drainage exist, but do not integrate wetlands.
- Looking to the City for the development of these guidelines. Stormwater ponds are being used but not wetlands.
- No guidelines/standards for use specific to their city exist. The existing stormwater guidelines pertain only to pipes.
- No guidelines/standards for use or zoning bylaws exist for the integration of wetlands into new developments. Constructed wetlands is a new idea.
- No guidelines/standards for use exist for stormwater management.
- All engineering services are contracted out by the city.
- Bylaw exists for the construction of catch basin for stormwater drainage only.
- Consideration has been given for using wetlands for stormwater management.
- Engineering guidelines for stormwater management are in draft form. The city has a 5–year plan for stormwater improvements as an outcome of major flooding in 2010. No specific integration of wetlands into stormwater management is planned at this time.

Several cities in both Canada and US have stormwater management plans that specifically discuss using constructed wetlands. Table 2.6 summarizes cities with stormwater management plans that include design guidelines for constructed wetlands and respective guideline elements. As Saskatoon considers preparing a companion document to the design guidelines covering the monitoring requirements for these wetlands, Table 2.7 provides the range of parameters required by these same cities and provinces that Saskatoon may wish to consider.

TABLE 2.6

Comparison of Elements of Stormwater Constructed Wetlands Design Guidelines in Cities and Provinces

Management Plan	Water Balance	Length to Width Ratio and Side Slopes	Configurations	Active Storage Depth Flux	Storm Pipes	Pre-treatment Options	Storage Detention time	Buffer Distances	Conveyance	Control Structures
Ontario, Ministry of the Environment[a]	X	X	X	X	X	X	X	X	X	X
Government of Alberta, Canada[b]	X	X	X	X	X	X	X	X	X	X
City of Calgary, Alberta, Canada[c]	X	X	X	X	X	X	X	X	X	X
City of Eugene, Oregon[d]		X	X	X		X		X	X	
State of Oregon[e]	X	X				X	X	X		
Saskatoon, SK	X	X	X	X	X	X	X	X	X	X

[a] Stormwater Management Planning and Design Manual (March 2003) http://www.ene.gov.on.ca/environment/en/resources/STD01_076363.html

[b] Stormwater Management Guidelines for the Province of Alberta (1999) http://environment.gov.ab.ca/info/posting.asp?assetid=6786&searchtype=asset&txtsearch=stormwater

[c] Stormwater Management and Design for City of Calgary (2011) http://www.calgary.ca/UEP/Water/Pages/Water-and-wastewater-systems/Storm-drainage-system/History.aspx

[d] Stormwater Management Manual: Constructed Treatment Wetland (2008) https://www.eugene-or.gov/index.aspx?NID=477

[e] Biofilters for Storm Water Discharge Pollution Removal (2003) www.deq.state.or.us/wq/stormwater/docs/nwr/biofilters.pdf

TABLE 2.7

Comparison of Design Guidelines Water Quality Monitoring Criteria for Stormwater Constructed Wetlands

City/Province	Water Quality	TSS	Phosphorus	Nitrogen	Heavy Metals	Trace Metals (Pb, As, Fe, Mn)	Biochemical Oxygen Demand	Temperature Regulation	Erosion control	Pesticides (DDT, Dieldrin, Aldrin)	PCB	2,3,7,8 TCDD (Dioxin)	PAH	Peak flow rate	Oils, greases, and hydrocarbons
Ontario, Ministry of the Environment[a]	X	X	X				X	X	X					X	
Government of Alberta, Canada[b]	X	X	X				X	X	X					X	
City of Calgary, Alberta, Canada[c]	X	X	X				X	X	X					X	
City of Eugene, Oregon[d]	X	X	X	X		X	X	X		X	X	X	X	X	
State of Oregon[e]	X	X	X	X	X	X	X	X		X					X

[a] Stormwater Management Planning and Design Manual (March 2003) http://www.ene.gov.on.ca/environment/en/resources/STD01_076363.html

[b] Stormwater Management Guidelines for the Province of Alberta (1999) http://environment.gov.ab.ca/info/posting.asp?assetid=6786&searchtype=asset&txtsearch=stormwater

[c] Stormwater Management and Design for City of Calgary (2011) http://www.calgary.ca/UEP/Water/Pages/Water-and-wastewater-systems/Storm-drainage-system/History.aspx

[d] Stormwater Management Manual: Constructed Treatment Wetland (2008) https://www.eugene-or.gov/index.aspx?NID=477

[e] Biofilters for Storm Water Discharge Pollution Removal (2003) www.deq.state.or.us/wq/stormwater/docs/nwr/biofilters.pdf

SECTION 3

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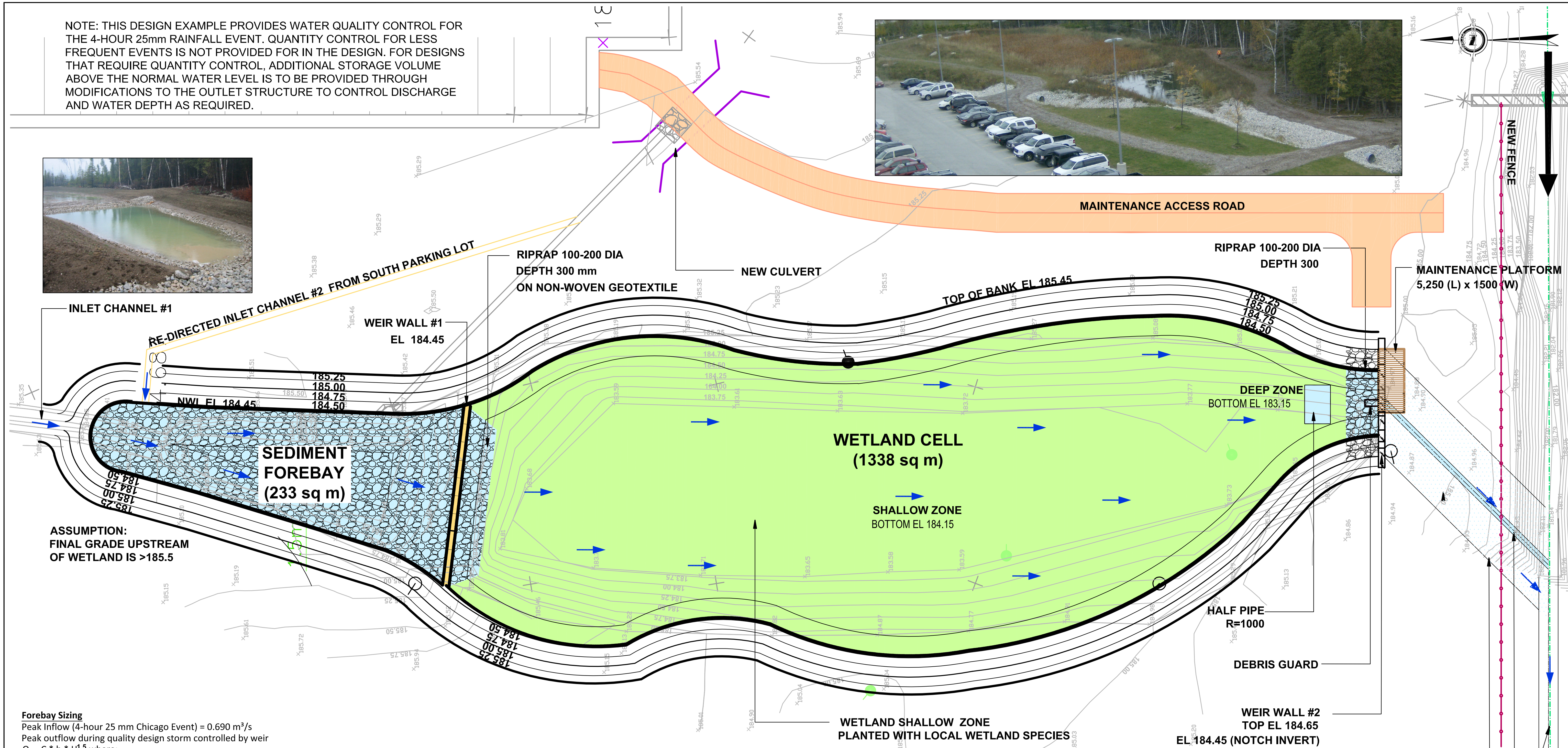
Appendix A
Design Example

NOTE: THIS DESIGN EXAMPLE PROVIDES WATER QUALITY CONTROL FOR THE 4-HOUR 25mm RAINFALL EVENT. QUANTITY CONTROL FOR LESS FREQUENT EVENTS IS NOT PROVIDED FOR IN THE DESIGN. FOR DESIGNS THAT REQUIRE QUANTITY CONTROL, ADDITIONAL STORAGE VOLUME ABOVE THE NORMAL WATER LEVEL IS TO BE PROVIDED THROUGH MODIFICATIONS TO THE OUTLET STRUCTURE TO CONTROL DISCHARGE AND WATER DEPTH AS REQUIRED.



Forebay Sizing

Peak Inflow (4-hour 25 mm Chicago Event) = 0.690 m^3/s

Peak outflow during quality design storm controlled by weir

$Q_p = C * b * H^{1.5}$ where:

- Q_p = flow (m^3/s)
- C = weir coefficient = 1.5 (broad crested weir)
- b = crest length (m) = 0.12 m
- H = maximum height above crest (m) = 0.20 m

Therefore, Q_p = 0.016 m^3/s

Forebay Length (dispersion length) = $8Q/dV_f$ where:

- Q = inflow (m^3/s) = 0.690 m^3/s
- d = depth (m) = 1.0 m
- V_f = velocity (m/s) = 0.4 m/s

Therefore, minimum required forebay length = 13.8 m

Forebay Length (settling length) = $(r\,Q_p/V_s)^{1/2}$ where:

- r = length-to-width ratio of forebay = 3:1
- Q_p = peak flow rate from pond during quality design storm = 0.016 m^3/s
- V_s = settling velocity = 0.0003 m/s

Therefore, minimum required forebay length = 12.6 m

Design length = 20.0 m (note: intentionally exceeds required minimum length based on client discussions)

Design width = 6.7 m

Length-to-Width ratio = 3:1

Forebay Permanent Pool (from CAD 3-D model) = 98 m^3 (13% of total Permanent Pool)

Forebay sideslope = 5:1

Wetland Design

Catchment Area =7.7 ha

Percent Impervious = 85%

Required Storage Volume (80% long-term S.S. removal) = 140m^3 /ha - Ref. Table 3.2 MOE

Total Volume Required = 1078 m^3

Extended Detention (40 m^3 /ha) = 308 m^3

Permanent Pool (Total Volume - Extended Detention) = 770 m^3

Sideslope below Normal Water Level = 5H : 1V (Table 4.7, MOE SWMP&D Manual)

Sideslope above Normal Water Level = 3H : 1V (Table 4.7, MOE SWMP&D Manual)

Freeboard = 0.5 m

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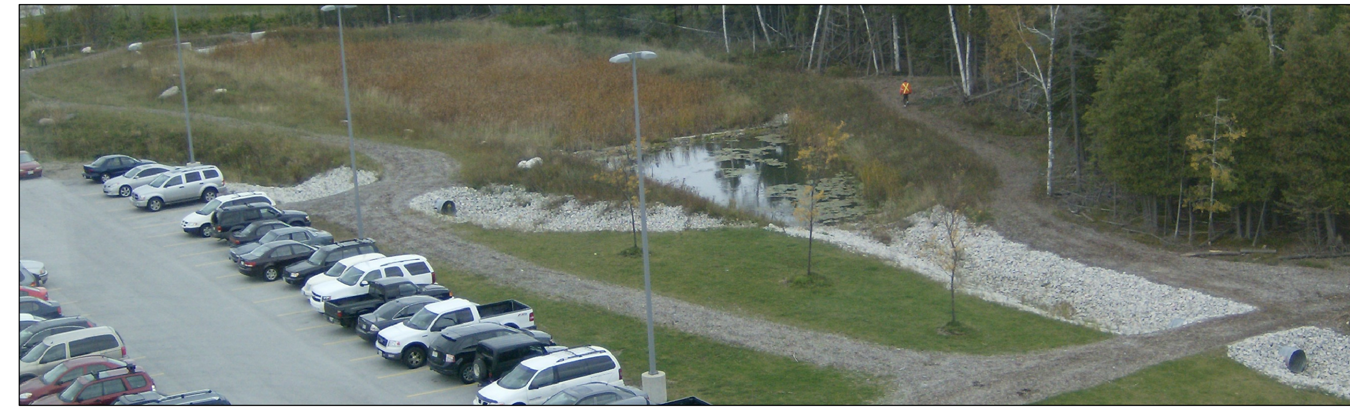
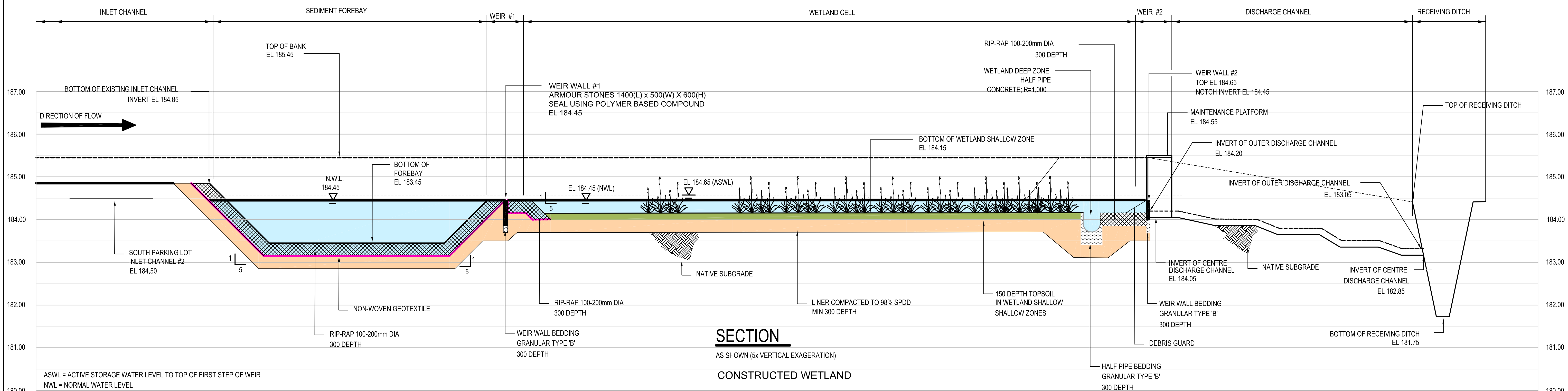
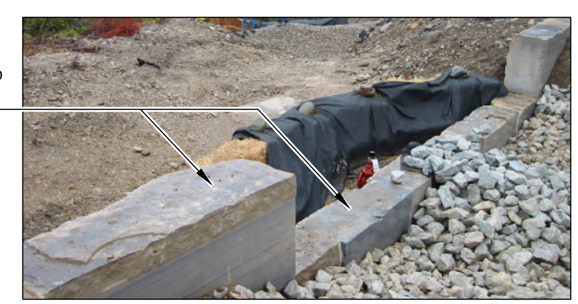
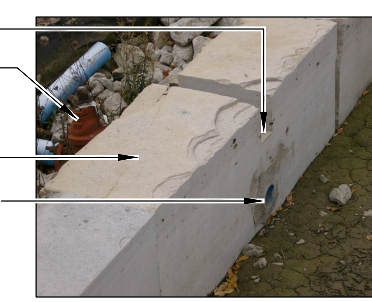
PROJECT No. 480988

CONSTRUCTED WETLAND CONCEPT DESIGN PLAN









NOTE:
THIS PROJECT WAS DESIGNED AND CONSTRUCTED TO MEET THE STORMWATER REQUIREMENTS WITHIN THE SITE CONSTRAINTS. WHILE THE DETAILS PROVIDE DO NOT EXACTLY MATCH ALL THE CRITERIA SET OUT IN THE GUIDELINES, THIS PROJECT DOES HIGHLIGHT THAT DESIGNS OFTEN ARE PREPARED TO MEET AVAILABLE FOOTPRINT AND SITE RELIEF THAT THEN DRIVE THE HYDRAULICS OF THE SYSTEM.

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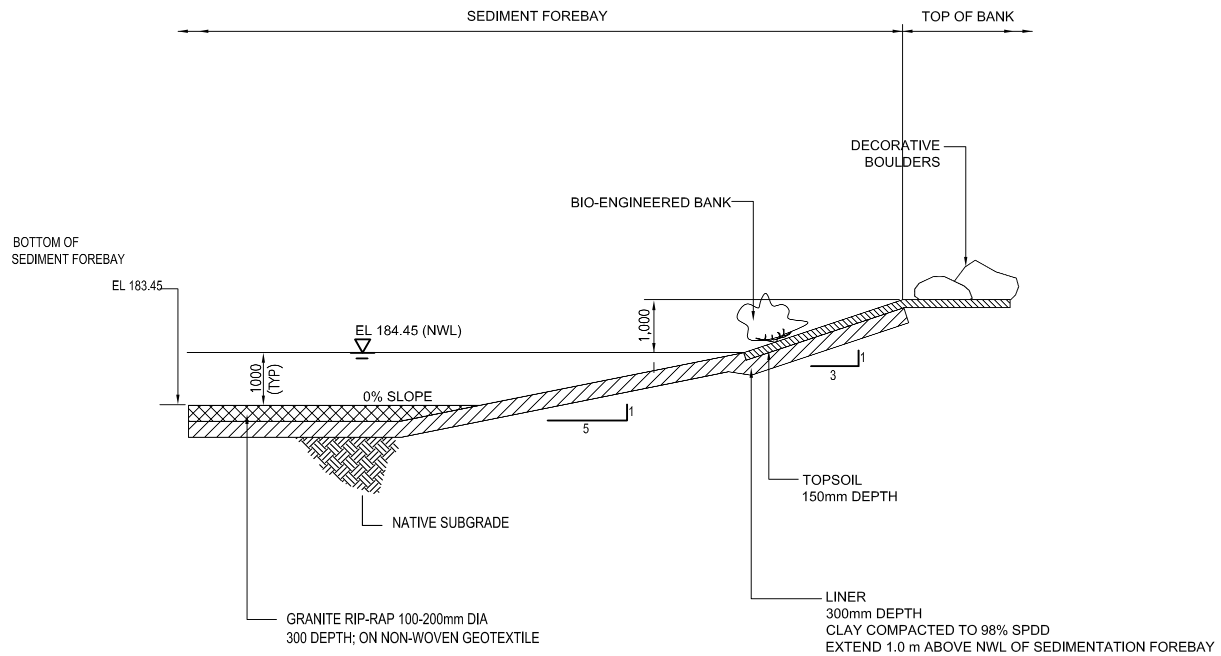
PROJECT No. 480988

CONSTRUCTED WETLAND CONCEPT DESIGN LONGITUDAL SECTION



SECTION
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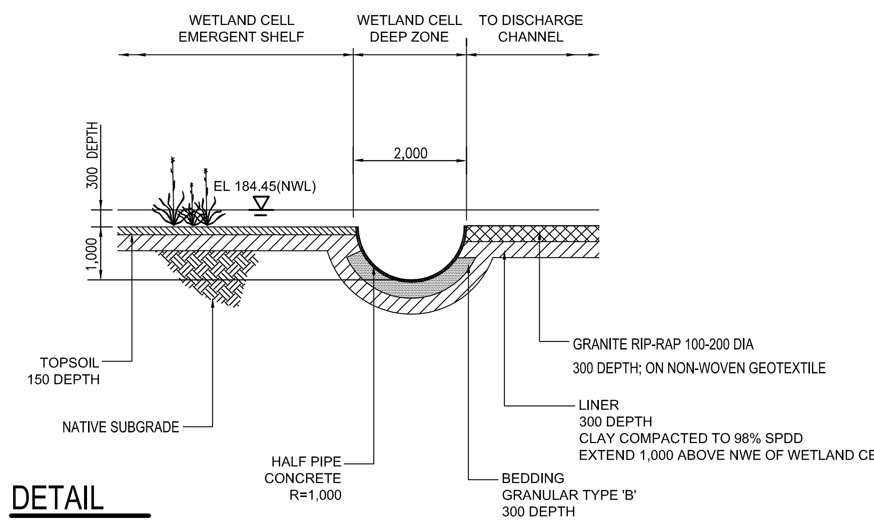
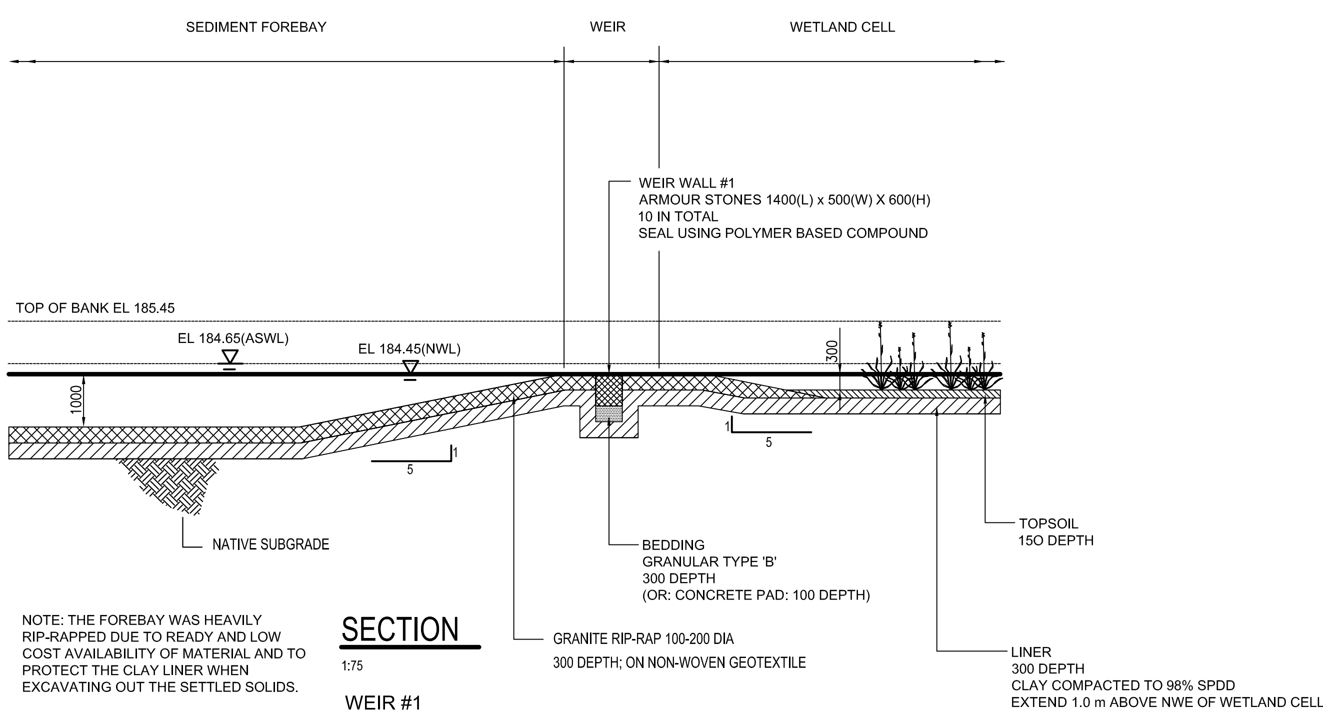
SEDIMENT FOREBAY EDGE



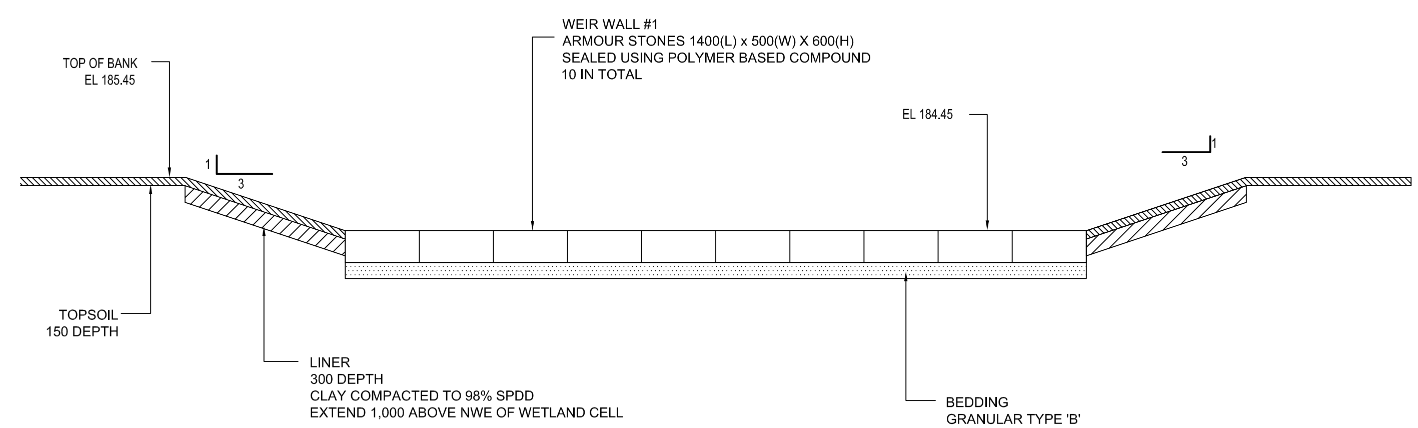
DETAIL
1:75
WETLAND CELL DEEP ZONE



NOTE: THE FOREBAY WAS HEAVILY RIP-RAPPED DUE TO READY AND LOW COST AVAILABILITY OF MATERIAL AND TO PROTECT THE CLAY LINER WHEN EXCAVATING OUT THE SETTLED SOLIDS.

ASWL = ACTIVE STORAGE WATER LEVEL TO TOP OF FIRST STEP OF WEIR
NWL = NORMAL WATER LEVEL

SECTION
1:75
WEIR #1



DETAIL
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WEIR #1

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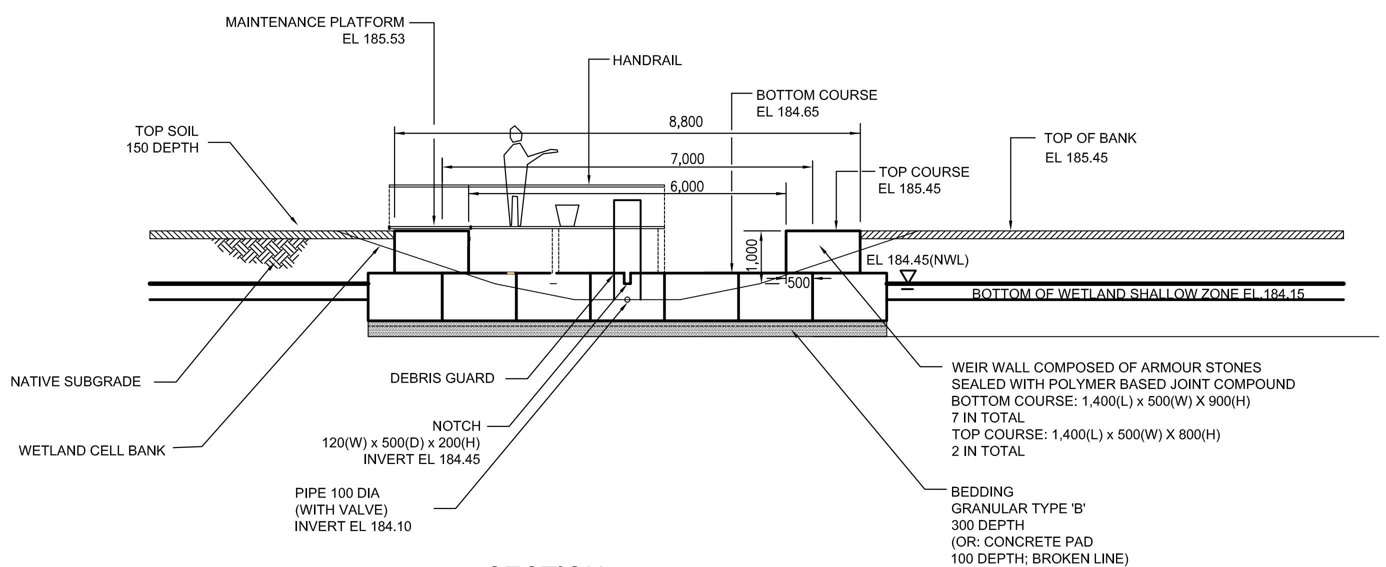
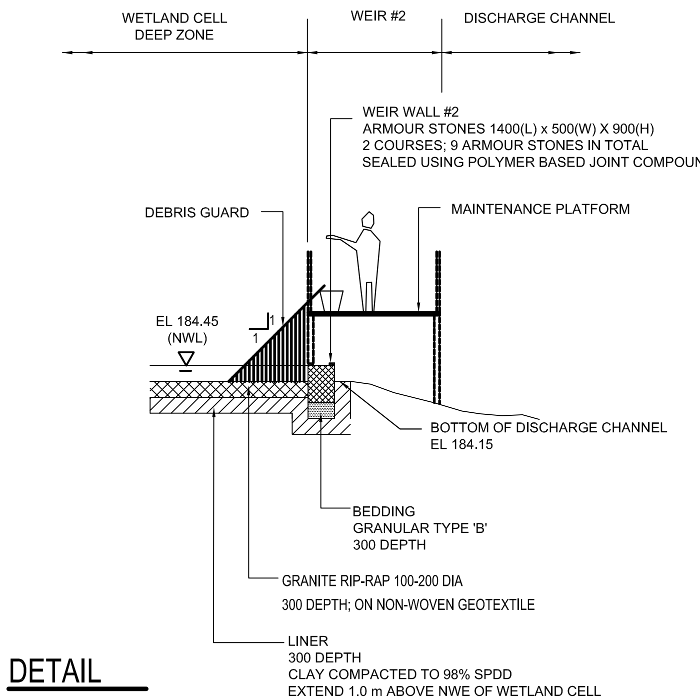
CONSTRUCTED WETLAND
CONCEPT DESIGN
SECTIONS AND DETAILS (1)

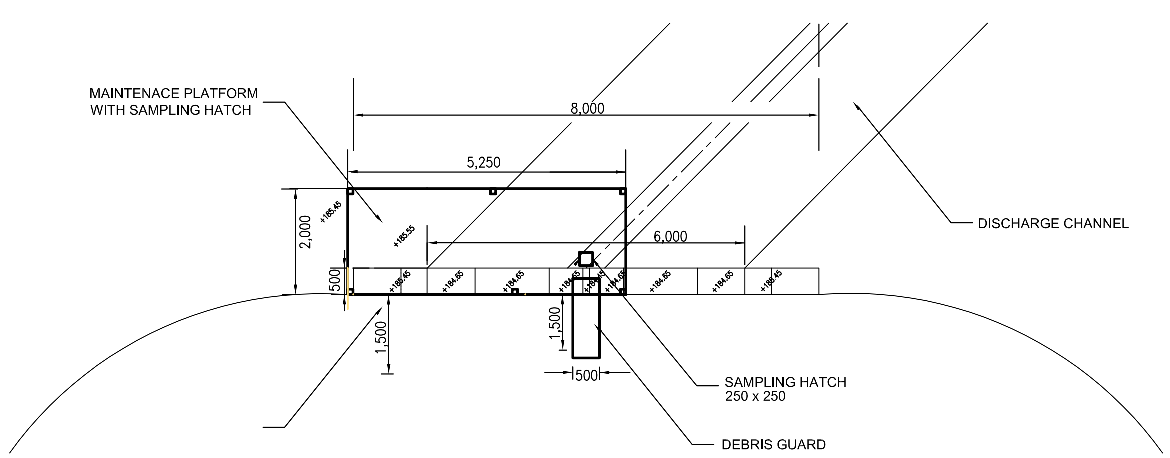
PROJECT No. 480988



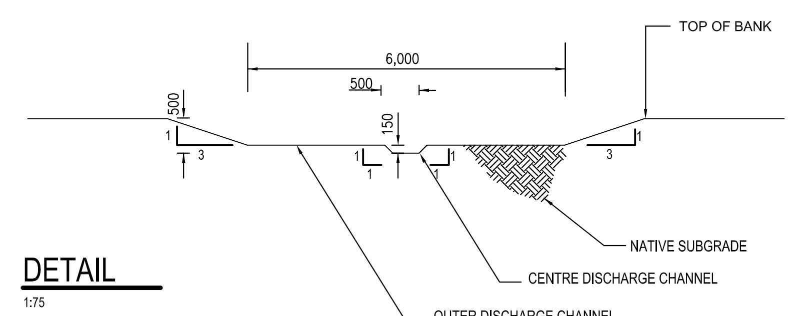
SECTION
1:75
WEIR #2



DETAIL
1:75
WEIR #2



PLAN DETAIL
1:75
WEIR #2



DETAIL
1:75
DISCHARGE CHANNEL

CH2MHILL

CONSTRUCTED WETLAND
CONCEPT DESIGN
SECTIONS AND DETAILS (2)

PROJECT No. 480988

January 16, 2014

PLANT LIST

TREES

COMMON NAME	BOTANICAL NAME
TREES - Deciduous	
White oak	*Quercus alba*
Bur Oak	*Quercus macrocarpa*
Red Oak	*Quercus rubra*
Paper Birch	*Betula papyrifera*
White Ash	*Fraxinus americana*
TREES - Coniferous	
White Spruce	*Picea glauca*
Black Spruce	*Picea mariana*
Red Pine	*Pinus resinosa*
Balsam Fir	*Abies balsamea*
TARGET QUANTITY: 20	

SHRUBS

COMMON NAME	BOTANICAL NAME
Choke Cherry	*Prunus virginiana*
Smooth Serviceberry	*Amelanchier laevis*
Snowberry	*Symphoricarpos albus*
Purple Flowering Raspberry	*Rubus odoratus*
Narrow-leaved Meadowsweet	*Spiraea alba*
High-bush Cranberry	*Viburnum trilobum*
TARGET QUANTITY: 250	

SEEDLINGS

COMMON NAME	BOTANICAL NAME
TREES - Deciduous	
Trembling Aspen	*Populus tremuloides*
Balsam Poplar	*Populus balsamifera*
Bur Oak	*Quercus macrocarpa*
Paper Birch	*Betula papyrifera*
TREES - Coniferous	
White Spruce	*Picea glauca*
Black Spruce	*Picea mariana*
Red Pine	*Pinus resinosa*
Balsam Fir	*Abies balsamea*
SHRUBS	
Silky Dogwood	*Cornus amomum*
Gray Dogwood	*Cornus racemosa*
Red Osier Dogwood	*Cornus stolonifera*
Common Elderberry	*Sambucus canadensis*
TARGET QUANTITY: 500	

LIVE STAKES

COMMON NAME	BOTANICAL NAME
Red Osier Dogwood	*Cornus stolonifera*
Beaked Willow	*Salix bebbiana*
Pussy Willow	*Salix discolor*
Sandbar Willow	*Salix exigua*
Shining Willow	*Salix lucida*
Heart-leaved Wilow	*Salix rigida*
TARGET QUANTITY: 1,200	

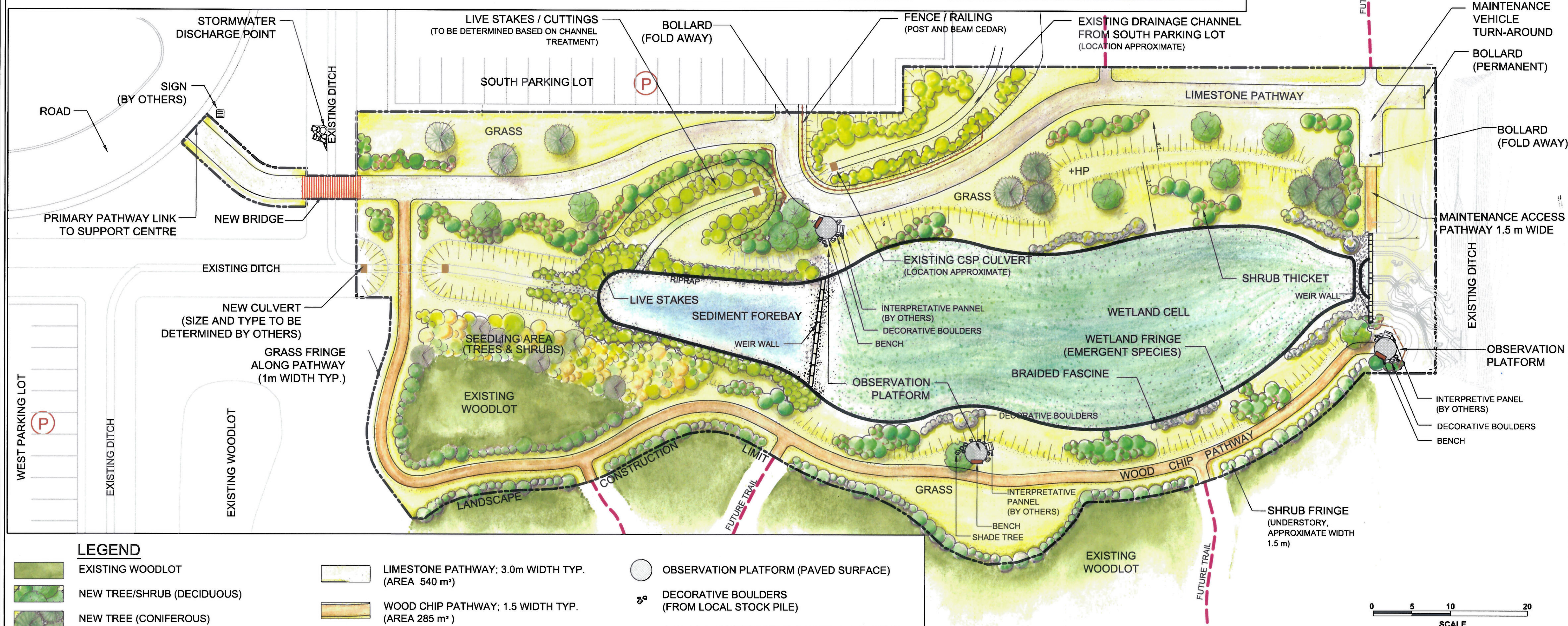
BRAIDED FASCINES

COMMON NAME	BOTANICAL NAME
Sandbar Willow (50%)	*Salix exigua (50%)*
Beaked Wilow (30%)	*Salix bebbiana (30%)*
Pussy Willow(20%)	*Salix discolor (20%)*
TARGET QUANTITY: 45 m	

SEED LIST

GRASS

COMMON NAME	BOTANICAL NAME
LOW MAINTENANCE GRASS MIX	
Brigade Hard Fescue	
Sandpiper Chewings Fescue	
AREA: 3600 m²	



LEGEND

- EXISTING WOODLOT
- NEW TREE/SHRUB (DECIDUOUS)
- NEW TREE (CONIFEROUS)
- SHRUB THICKETS
- BRAIDED FASCINES
- SHRUB FRINGE ALONG EXISTING WOODLOT (UNDERSTORY SPECIES)
- LIVE STAKES / CUTTINGS (AREA 300 m²)
- LIMESTONE PATHWAY; 3.0m WIDTH TYP. (AREA 540 m²)
- WOOD CHIP PATHWAY; 1.5 WIDTH TYP. (AREA 285 m²)
- LOW MAINTENANCE GRASS SEED MIX (AREA 3600 m²)
- P PARKING LOT
- +HP HIGH POINT
- OBSERVATION PLATFORM (PAVED SURFACE)
- DECORATIVE BOULDERS (FROM LOCAL STOCK PILE)
- SIGNAGE / INTERPRETIVE PANNEL (BY OTHERS)
- BENCH
- FENCE / RAILING (POST AND BEAM CEDAR)
- LANDSCAPING CONTRACT LIMIT
- FUTURE TRAIL (BY OTHERS)

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CONSTRUCTED WETLAND LANDSCAPE DESIGN CONCEPT

PROJECT No.

LAP02

Appendix B
Wetland Policy Project

CITY OF SASKATOON
COUNCIL POLICY

NUMBER
C09-041

POLICY TITLE	ADOPTED BY:	EFFECTIVE DATE
Wetland Policy	*City Council*	*November 4, 2013*
ORIGIN/AUTHORITY *Clause 2 , Report 18 – 2006 of the Planning and Operations Committee, Clause 4, Report No. 16-2013 of the Planning and Operations Committee; Hearing 3b, dated November 4, 2013.*	**CITY FILE NO.** *CK. 421-C09-041*	**PAGE NUMBER** *1 of 9*

1. PURPOSE

1.1 To implement the Official Community Plan Bylaw No. 8769 concerning wetlands conservation and management.

1.2 To provide guidance to landowners, developers and City of Saskatoon (City) staff on achieving responsible integration of wetlands into the urban environment.

2. DEFINITIONS

2.1 Buffer – is an area of relatively undisturbed vegetation adjacent to a wetland and its riparian area that serves to reduce adverse effects to wetland function from adjacent development and activities.

2.2 Compensatory Mitigation – measures used to offset any impacts to wetlands and/or wetland function that may result from urban development. Compensatory mitigation can include measures such as wetland buffers, landscaping, wetland restoration, enhancement, preservation and/or constructed wetlands.

2.3 Constructed Wetland – a constructed and/or modified water body that fluctuates with water drainage but holds water at all times. Constructed wetlands are designed to mimic some or all of the functions of naturally-occurring wetlands, including filtering pollutants from storm water runoff, and providing habitat with associated buffers/riparian areas.

2.4 Dedicated Land – comprises buffer strips, Municipal Reserve, Environmental Reserve and Municipal Utility Parcels as defined in *The Planning and Development Act, 2007*.

2.5 Enhancement – modification of one or more physical, chemical or biological features of wetlands to achieve improved function within a degraded wetland.

2.6 Naturalized Park – as defined by the City's Park Development Guidelines Administrative Policy No. A10-017.

2.7 Riparian Area – transitional areas between aquatic and terrestrial ecosystems. The plants and soils within riparian areas are strongly influenced by the presence of water.

2.8 Significant Wetland Resources – wetlands classified as "Preserve" in accordance with the Minnesota Routine Assessment Method and any wetlands located within significant wetland complexes as identified in the City's Wetland Inventory and Functional Assessment.

2.9 Wetland – lands having water at, near or above the land surface or land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, aquatic vegetation and various kinds of biological activity which are adapted to a wet environment. Wetlands can hold water temporarily or permanently, with water levels fluctuating over the course of a single year and over many years with climactic cycles.

2.10 Wetland Complex – a combination of individual wetlands and surrounding riparian areas that have complementary functions and have greater significance when viewed together compared to individual significance.

2.11 Wetland Function - a natural process or series of natural processes that take place within a wetland and can be grouped broadly as physical, biological and chemical. Typically, these processes can include the storage of water, transformation of nutrients, growth of living matter and the value these processes have for the wetland itself and the surrounding ecosystems.

2.12 Wetland Functional Assessment – a process used to measure or quantify the level or quality of function of an existing wetland. For the purposes of this policy, the Minnesota Routine Assessment Method will be used for any required wetland functional assessments.

2.13 Wetland Impact – infilling, altering or physically draining a wetland, any impact to the riparian area and any type of interference with the hydrological function of the wetland.

3. POLICY

3.1 Wetland Inventory and Functional Assessment

a) The City will maintain an inventory of wetland resources that includes both classification and functional assessment of wetlands and the identification of any significant wetland complexes. The inventory will be comprised of existing data where available, and information obtained from supplementary studies in new growth areas or where applicable data is absent. This inventory will be comprised of maps and tabular data for all growth areas of the city.

b) Identification and Classification – the Wetland Inventory will include the identification and classification of all wetlands within the identified area according to the Steward and Kantrud Wetland Classification System.

c) Functional Assessment – where conditions are conducive to a high level of wetland function, the Wetland Inventory will include a functional assessment of selected Stewart and Kantrud Class 3, 4, and 5 wetlands to be conducted using the Minnesota Routine Assessment Method. If not previously existing as part of the Wetlands Inventory, or if conditions may have changed significantly from a previous assessment, a functional assessment should be conducted as part of Natural Area Screening during the Area Sector Plan or Area Concept Plan process. Conditions that can trigger a functional assessment include:

i. primarily natural surroundings/limited adjacent cultivation;
ii. existence as part of a wetland complex; and
iii. previous identification or known presence of rare or endangered species or suitable habitat.

d) Wetland Complexes – The Wetland Inventory will include identification of wetland complexes and associated riparian areas that are significant based on the above functional assessment. Regardless of the functional class of individual wetlands contained within them, wetland complexes identified as significant shall have the highest priority for protection and preservation.

3.2 Wetland Mitigation Plan

a) A Wetland Mitigation Plan:

i. is required by the City as an integral part of any Area Concept Plan or Area Concept Plan Amendment that has the potential to impact wetlands identified as Preserve, Manage 1 and Manage 2 according to the functional assessment categories as identified in the City's Wetland Inventory; and

ii. may, at the discretion of the Planning and Development Branch and in consultation with the Environmental Services Branch, be required for any other development proposal that requires City approval, including the development of civic facilities and infrastructure, and any public or private utilities, if the development has the potential to impact wetlands identified as Preserve, Manage 1 and Manage 2 according to the functional assessment categories as identified in the City's Wetland Inventory.

b) In conjunction with the Administrative review of an Area Concept Plan, the included Wetland Mitigation Plan will be reviewed for compliance with this policy and the demonstration of a reasonable balance between anticipated impacts to wetland resources resulting from a proposed development, and measures taken to mitigate for those impacts.

c) Significant wetland resources identified in the Wetland Inventory should be the primary focus of preservation efforts. Unavoidable impacts to significant wetland resources will require compensatory mitigation.

d) A Wetland Mitigation Plan must include:

i. An account of anticipated impacts to all wetlands in the Concept Plan area identified as Preserve, Manage 1 and Manage 2 according to the functional assessment categories as identified by the City's Wetland Inventory, with a focus on any wetland resources identified as significant;
ii. An explanation of all measures, which must be consistent with the Wetland Development Guidelines, that will be taken to mitigate for impacts as part of the proposed development;
iii. If applicable, an explanation of any impacts for which mitigation is not proposed;
iv. For all retained wetlands, an explanation of how development will interface with wetlands and their associated riparian areas and how successful establishment of vegetation communities will be ensured;
v. A description of measures to be taken to ensure that impacts on wetlands are minimized while development is underway;
vi. A monitoring strategy to ensure the measures outlined in the Wetland Mitigation Plan are implemented; and
vii. A proposed allocation of wetlands, associated riparian areas and buffers into categories of Dedicated Lands. The allocation will be subject to the review and approval of the City.

e) Possible compensatory mitigation measures to offset impacts to wetlands include:

i. Permanent preservation of wetlands;
ii. Restoration or enhancement of wetlands;
iii. Replacement of wetland function through the development of constructed wetlands or the re-establishment/restoration of historical wetlands;
iv. Development of sensitive recreational, educational and/or interpretive infrastructure adjacent to retained wetlands and associated riparian areas;
v. Development, within the Concept Plan area, of sediment forebays, bioswales, rain gardens and other storm water management features that may provide for pre-treatment of runoff and/or reduce the need for traditional storm water management infrastructure.

f) For any development that requires City approval, where a Wetland Inventory has not been completed, the City may require the developer to undertake a Wetland Inventory for the subject development area in accordance with Section 3.1 of this policy.

g) The City may, at the time of subdivision and in accordance with *The Planning and Development Act, 2007*, enter into a servicing agreement with the developer to ensure the measures proposed in the Wetland Mitigation Plan are completed.

3.3 <u>Wetland Development Guidelines</u>

a) Wetland Development Guidelines will be established to provide guidance for:

i. general establishment and management procedures for constructed and preserved wetlands;
ii. buffer widths;
iii. erosion and sediment control measures;
iv. pre-treatment, treatment and conveyance to maintain acceptable water quality and quantity levels, including maintenance reduction measures where wetlands are integrated into the storm water system;
v. maintenance of hydrologic function;
vi. protection of wetland resources during development;
vii. management regime for initial establishment of wetland and riparian plant communities;
viii. harvest and reuse of wetland and riparian soils where wetlands are modified or lost to development;
ix. types of vegetation to be planted and timelines for establishment recognizing that native plants should be used if possible; and
x. low impact development techniques.

b) The construction process is critical to the establishment and growth of the vegetative community of a wetland. Any alteration or development within a wetland should be sequenced such that plant growth is maximized during the first growing season.

c) Where wetlands are being used for storm water storage and treatment, measures such as the installation of suitable control structures should be taken to mimic the natural hydrologic cycles wherever possible.

d) In the absence of Wetland Development Guidelines, development proposals impacting significant wetland resources should address each of the elements identified in Clauses 3.3 a) and 3.3 b) above, as part of the Wetland Mitigation Plan, along with supporting documentation based on advice from a Qualified Wetland Aquatic Environment Specialist, or suitable alternative as determined by the Development Officer and/or demonstration of adherence to best practices used in other jurisdictions.

3.4 Wetland Management

a) Retained wetlands, including Constructed Wetlands and associated riparian areas should normally be integrated into the City's parks system and managed as Naturalized Parks.

b) Management efforts will focus on ensuring that wetlands and associated riparian areas maintain or improve the level of ecological function and water quality over the long term and should include a program for regular monitoring and evaluation.

c) Where wetlands provide a storm water management function in an area, necessary maintenance on the wetland in support of this system should be sensitive to the wetland management regime and should strive to avoid and/or minimize negative impacts to the ecological function and water quality of the wetland.

4. RESPONSIBILITIES

4.1 General Manager, Community Services Department – shall be responsible for:

a) Administering this Policy and recommending updates to this Policy;

b) Maintaining, and developing where necessary, a wetlands inventory and functional assessment for all growth areas of the city;

c) Ensuring incorporation of this Policy in the Official Community Plan and other statutory documents;

d) Reviewing and approving Wetland Mitigation Plans in conjunction with the administrative review of any Area Concept Plans or other development proposal where required;

e) Undertaking and maintaining Servicing Agreements to ensure appropriate compensatory mitigation measures are taken.

4.2 General Manager, Infrastructure Services Department – shall be responsible for:

a) Informing supervisors and managers in affected branches of the procedures relative to this policy;

b) Ensuring that other policies administered by the department are consistent with this policy;

c) Reviewing and approving Wetland Mitigation Plans in conjunction with the Administrative review of any Area Concept Plans or other development proposal where required;

d) Developing and implementing a management strategy for the ongoing operation and maintenance of preserved and constructed wetlands; and

e) Recommending annual budget requirements to implement the procedures relative to this policy.

4.3 General Manager, Utility Services Department – shall be responsible for:

a) Assisting in the administration of this policy and recommending updates to this policy;

b) Informing supervisors and managers in affected branches of the procedures relative to this policy;

b) Ensuring that other policies administered by the department are consistent with this policy;

c) Reviewing and approving Wetland Mitigation Plans in conjunction with the Administrative review of any Area Concept Plans or other development proposal where they are required;

d) Developing and maintaining Wetland Development Guidelines;

e) Developing and implementing a management strategy for the ongoing operation and maintenance of preserved and constructed wetlands; and

f) Recommending annual budget requirements to implement the procedures relative to this policy.

4.4 Planning and Operations Committee – shall be responsible for:

a) Reviewing proposed policies and policy revisions and referring such policies to City Council for approval.

4.5 City Council – shall be responsible for:

a) Reviewing and approving any proposed policies and policy revisions as recommended by the Planning and Operations Committee.

Appendix C
Responses to Questions and Concerns That Have Been Raised About Wetlands

L. Responses to Questions and Concerns That Have Been Raised About Wetlands

Over the years, numerous questions and concerns have surfaced with respect to the long-term effects of wetlands on wildlife and on local residents whose homes are located close to a wetland site. Some of those questions and the response to each by the wetland engineers are presented in the following table.

QUESTIONS AND CONCERNS THAT HAVE BEEN RAISED ABOUT WETLANDS

Questions/Concerns Expressed by Regulators and the General Public	Response by the Wetland Engineers
Will it generate odours?	A wetland that has been designed correctly and is receiving sufficiently pretreated water will not generate odours. This has been the experience of wetland experts who have visited wetland sites around the world.
What about mosquitos?	Even though the wetland provides a large water surface area for mosquitos to breed, this potential has effectively been kept in check at many wetland sites in several ways. Wind action on wetlands located in open areas has reduced incidents of mosquitos. Stocking the wetland deep zones with mosquito fish that eat larvae before they reach the adult stage is also effective. Nesting boxes can be set up for purple martins and swallows that consume adult mosquitos as they emerge from the wetland. Maintaining the design water level will reduce the formation of stagnant, mosquito hatching sites. Chemical spraying may be required if natural means of control are not effective enough.
Do we know enough about this technology?	Wetlands have been intentionally incorporated into wastewater and stormwater treatment systems for more than 25 years. Volumes of literature have been written on the subject based on experience gained from hundreds of pilot- and full-scale treatment wetland systems around the world. Although more knowledge is still being gained and more data needs to be collected and analyzed, there exists sufficient design criteria to properly engineer most treatment wetland systems.
Will it work in winter?	Treatment wetlands that are required to operate through the winter months can be designed to allow year-round water flow into and out of the system by seaonal adjustment of water level and incorporating frost protection in the design and construction. The functions of a wastewater or stormwater treatment system that rely fully or in part on physical and/or chemical processes (settling or adsorption) are unaffected by the water temperature. This would include parameters such as biochemical oxygen demand (BOD_5), total suspended solids (TSS), and total phosphorous (TP) removal. However, the treatment functions, such as ammonia nitrogen (NH_4-N) and nitrate and nitrite nitrogen (NO_3+NO_2-N), that rely on microorganisms for contaminant reduction are affected by temperature and this must be factored into the design of the wetland system.

Will it work in the far north?	The application of wetlands in cold climates has successfully met effluent criteria across Canada as far north as the Yukon and the Northwest Territories.
Will it work for all nutrient and chemical types?	Wetlands have been used to effectively treat a wide range of municipal and industrial effluents. Each waste stream requires careful, individual consideration. Concentrations and types of chemicals that have not been previously tested in a treatment wetland system should be approached with the same caution that would be exercised when determining the most appropriate conventional wastewater treatment system for a given wastewater. Pilot testing may be required to provide a level of comfort for the regulators, local community, and the client.
Will this technology be applicable to all situations?	There are many potential wetland applications. However, experience has shown that after carrying out an initial investigation, only about 50% of the potential sites would be considered feasible for the treatment wetland technology.
Has this technology been applied to a large-scale installation?	In Canada, at Frank Lake, Alberta, a 1246 ha system has been installed to treat municipal and industrial tertiary treated effluent.
How long will it continue to remove the contaminants?	Although the oldest known treatment wetlands currently in operation have only been monitored for a few decades, experience indicates that that the life expectancy will be related to the type and strength of effluent being treated. Specific wetlands treating low strength municipal wastewater have been estimated to have a life expectancy of centuries if properly maintained. However, the removal capacity of high strength industrial systems may be less, possibly within the span of a decade.
Will the accumulated contaminants wash out of a stormwater treatment wetland system during rainstorms?	If the wetland is designed properly, the sediment should remain in the wetland depending on the storm intensity that it was designed for. Appropriate wetland design approaches includes trapping and retaining sediments in the wetland and bypassing flows that exceed the design.
What about metals accumulation in the soil and plants?	Studies have shown that the accumulation of metals in the soil and plants is variable. Some sites with no contaminated water flow showed levels of metals in the plants that were greater than those in a contaminated water stream. Investigations continue to determine the impact of metals accumulation on the surrounding environment.
Will wildlife be adversely affected by the accumulated contaminants?	Based upon the scientific knowledge gained to date, the risk to wildlife that frequent or live in treatment wetlands is considered by many scientists to be remote. Where bioaccumulation or wildlife exposure has the potential to become a problem, measures can be incorporated into the project design to minimize these risks. Research is continuing on this subject.

Appendix D
Potential Adverse Environmental Impacts and Mitigating Measures

E. Potential Adverse Environmental Impacts and Mitigating Measures

Direct effects	Indirect Effects	Mitigation
Increase in nutrient input		
Replacement of plants adapted to nutrient-poor conditions (e.g. bog, fen, shoreline and prairie plants; many rare) with plants adapted to nutrient-rich conditions (e.g. cattails, bulrushes; generally more common spp.).	Increase in nutrient input may result in eradication of some native plant communities, which are often adapted to a narrow range of nutrient conditions; weedy species which out-compete native species may invade.	Further pretreatment of incoming wastewater; construct multi-cell treatment wetland in series to reduce nutrient loadings in the initial cells to levels typical of pre-wastewater conditions.
Weedy species which out-compete native species may invade and establish dense stands.	Characteristically low sedge brood and/or foraging habitat for waterfowl, shorebirds and aquatic mammals may be replaced by dense tall stands; possible positive impact by increasing concealing cover.	Further pretreatment of incoming wastewater; weed control unlikely to be effective; construct multi-cell treatment wetland in series to reduce nutrient loadings in the initial cells to levels typical of pre-wastewater conditions.
Algal blooms shade out floating and submergent species.	Forage species for some waterfowl killed; impacts on rare submergents; unsightly, which may reduce public acceptance of treatment wetland.	Algae control; further pretreatment of incoming wastewater; construct multi-cell treatment wetland in series to reduce nutrient loadings in the initial cells to levels typical of pre-wastewater conditions.
Contaminated surface water may enter local aquifer through recharge.	Contamination of groundwater and nearby shallow wells.	Ensure constructed wetland is not in an area of significant recharge, or place liner to increase retention time before water enters aquifer; further pretreatment of incoming wastewater.
Change in water chemistry may decrease population of aquatic organisms (fish, invertebrates).	Higher trophic level animal populations may decrease since the affected aquatic organisms may be prey species for these animals.	Further pretreatment of incoming wastewater; construct multi-cell treatment wetland in series to reduce nutrient loadings in the initial cells to levels typical of pre-wastewater conditions.
General decrease in plant species diversity.	Concomitant decrease in wildlife species diversity.	Restoration of habitat by creating low grade slopes (no more than 1:10) in some areas where a variety of plants can recolonize, replanting shrubs and trees in areas peripheral to the wetland; confinement of impacts to least diverse areas.
Necessity of restricting access to the wetland.	Possible negative affects on public acceptance; but positive affects for wildlife.	Education and signage; provision of public access in acceptable (e.g. peripheral) parts of the wetland; enhancement of access elsewhere by provision of trails, other amenities.
Increase in hydroperiod		
Woody species tend to be killed off and replaced by herbaceous species.	Reduction of habitat for forest-dependent species; potential elimination of habitat for species requiring large tracts of unbroken habitat (i.e. protected interior areas away from forest edge); potential effect on rare forest species.	Enlarge habitat by tree planting or allowing vegetation at forest edge (increasing the area of forest-interior); improve linkage with other habitats; incorporate upland areas that will support woody species into wetland design.

Direct effects	Indirect Effects	Mitigation
	Tree removal will affect the amount of sunlight reaching water and affect plant productivity and increase watercourse temperatures.	Plant trees in strategic parts of the wetland to minimize impact on water temperature; incorporate upland areas that will support woody species into wetland design.
Increase in flooded area; water levels are more consistent, with fewer fluctuations.	Potential positive impact for waterfowl by increasing permanence of wetland, area of standing water.	If waterfowl are to be discouraged from using the site due to stringent effluent requirements, design the wetland to minimize open water, grazing, nesting, and brooding areas.
	Flooding of nests over or near water; flooding of low bank burrows/nests; erosion of banks.	Create stable habitat above the floodline; specifically restore lost habitat.
	Downstream flooding at periphery of wetland with attendant social cost; reduced acceptance of treatment wetland.	Calculate hydraulic effects and determine if wetland area is sufficient to receive wastewater and natural inputs; construct storage to increase capacity; reconfigure outflow area to increase outflow capacity.
Flooding of lower littoral zone and potential elimination of zone of annual plant species (often rare) which germinate when water levels fall.	Elimination of brood habitat, mudflats used as foraging areas by shorebirds, waterfowl; increase in inundation time may eliminate some invertebrates.	Engineer shoreline (at periphery of wetland or on created habitat islands) with gradual grade (no more than 1:10) to promote zonation of emergent plant species; provide storage or alternate outfall during some seasons to simulate natural water level fluctuations; divert water to avoid mud flats and areas of late-germinating vegetation.
Creation of larger, deeper water body.	Invasion by larger predatory or destructive aquatic species which may eliminate existing species; e.g. bullfrogs may be a cause of decline in leopard frogs; carp have widespread impacts on wetland vegetation.	Erect carp barriers as appropriate; reconfigure outflow area to increase outflow capacity and reduce water levels.
Construction activities to improve treatment capability		
Soil disturbance promotes invasion by non-native species, which tend to eliminate native species and communities.	Potential elimination of shorter annual vegetation or mud flats; which often provide foraging and brood habitat for waterfowl, shorebirds.	Plant native vegetation soon after construction is finished, confine soil disturbance to already disturbed areas if possible.
Siltation of watercourses during construction resulting in "smothered" plants and animals due to the deposition of silt.	Impacts on germinating plants, fish, invertebrates; impacts on organisms at higher trophic levels.	Control siltation during construction with standard construction techniques.
Blasting may expose rocks soluble minerals that could potentially contaminate surface water supply.	Toxicity for many organisms.	Conduct geochemical analysis of bedrock, avoid blasting in contaminated areas.
Construction may impact disturbance-sensitive species	Reduction in population.	Avoid construction during times when most sensitivity to disturbance occurs (mainly during breeding season).

Appendix E
Sawmill Creek Detail

Water Resources

Constructed Wetlands

Client
City of Ottawa

Location
Ottawa, Ontario

Project Value
Capital Costs: $10,000,000

"The Sawmill Creek Subwatershed Study Update and Environmental Study Report Addendum were completed to the City's satisfaction, on time and on budget. The project team worked closely with the City's project manager ensuring study scope, direction and deliverables were kept on track."

Susan Murphy, City of Ottawa, Environmental Management, Development Services.

Sawmill Creek Subwatershed Study and Constructed Wetlands Design

Project Background

In response to growing public concern over the health of the Sawmill Creek Watershed, the Rideau Valley Conservation Authority retained CH2M HILL to complete the Sawmill Creek Watershed Study in 1992.

The study provided a comprehensive overview of the characteristics of the watershed and produced a watershed management plan and implementation strategy following an extensive public consultation process. One of the core components of the management plan included a proposed creek diversion and constructed-wetland facility to improve water quality, attenuate peak flows, minimize creek erosion, and naturalize the north-south corridor in the watershed.

In 1997, an Environmental Study Report (ESR) was prepared by CH2M HILL to review alternative designs of the proposed facility. Public consultation was completed. Design/construction of the facility was not feasible at that time.

In 2002, the City of Ottawa retained CH2M HILL to complete the Sawmill Creek Subwatershed Study Update and ESR Addendum. The updated strategy confirmed that the constructed-wetland and flow-diversion project should proceed as part of the watershed-based water-management strategy.

Constructed Wetland Design and Tender

In 2007 CH2M HILL was retained by the City of Ottawa to complete the EA and detailed design for this stormwater management facility, including sewers, control structures and ponds to receive stormwater diverted from two urban creeks and large storm sewers. Approximately 1,000 m in length, with a peak volume of 189,000 m3, the facility serves a catchment area of 1,420 ha, with peak inflows of 13 m3/s.

Completed in 2007 at a capital cost of approximately $10,000,000, it is among Ottawa's largest stormwater projects. Tender documents were prepared using a combination of the City's PWMS system, City Standard Specification, and specially prepared custom specifications.

The project included virtually all aspects and engineering disciplines associated with integrated infrastructure projects, such as:

- Storm sewers, sanitary sewers, watermains:

  - 170 m of 1350-mm-diameter concrete sewer, including a deep CIP diversion chamber and weir on an existing 2130-mm-diameter concrete sewer, 2400-mm-diameter MH, and open-cut crossing of the Airport Parkway and CIP outlet headwall.

  - Three 1200-mm-diameter x 55-m-long steel culverts, installed by jack & bore under the Ottawa Central Railway, 7 m deep CIP inlet weir/drop structure, 5-m-high CIP outlet headwall. Three 1200-mm-diameter x 85-m steel culverts, installed by jack and bore under Capital Railway and South Keys Transit station.

- 310 m of 525-mm-diameter PVC storm sewer, including 6 pre-cast MHs and inlet sluice gate.

- Hydraulic analysis using XP-SWMM to evaluate the diversion structures, existing culverts, and conveyance. The conveyance of individual culverts and sewer sections was cross-checked with CulvertMaster software.

- Ten major CIP concrete structures were completed – 4 headwalls (one incorporating 5 sewer outlets), 3 weirs, a buried culvert/sewer transition chamber, an outlet weir/drop chamber, and a diversion chamber. Four structures were specially designed to tie-in to existing sewers and box culverts. Weirs included bypass drain sewers and sluice gates for flow control.

- 100 m of existing CSP sanitary sewer, 6.5 m deep, were relocated with 600-mm-diameter PVC, including 2 pre-cast MHs. 100 m of 400 mm dia. reinforced concrete pressure pipe watermain were relocated, deepened, and upsized to 600 mm.

- Transportation/Landscaping/Streetscaping

  - Open-cut crossing of Airport Parkway; 3.1 km of paved pathways; pre-cast concrete culvert bridge system for light vehicle/pedestrian, extensive natural landscaping (4,000 trees and shrubs, 16,000 seedlings, 100,000 m2 of various seeding covers); asphalt reinstatement; and drainage improvements and upgrades to a portion of the parking lot of South Keys Mall

- Approvals / Coordination

  Approvals - We completed extensive agency consultation for this project, particularly with the NCC. We completed a Federal Canadian Environmental Assessment Agency (CEAA) screening and Phase I ESA in support of a sewer easement acquisition on NCC lands, and incorporated landscaping design elements based on design review comments from NCC. We prepared permit applications and coordinated communication with MOE for a CofA and Rideau Valley Conservation Authority for a Letter of Authorization. We completed the EA, including public open houses during the study and design.

  Coordination - Coordination with Ottawa Hydro for relocation of two buried (100 m and 30 m) and one pole-mounted line (90 m), and fibre-optic cable relocation. Negotiation support for City of

Ottawa Real Property Asset Management (RPAM) with Hydro One for property acquisition under major tower transmission line. Negotiations/coordination with South Keys Mall management for construction staging, traffic control strategy, meeting attendance, and presentations for mall tenants.

Notable Design Features

- A combination of open wet pond and wetland (for example, marsh-like) cells
- An offline wetland facility—a specially designed fish-friendly creek diversion structure that diverts storm flows from the creek to the facility while maintaining baseflow downstream
- Extensive landscaping and re-vegetation using native species
- Pathways and bridge crossings to create recreational opportunities
- Good use of vacant land surrounded by major transportation corridors
- The design of the wetland took into consideration the inclusion of recreational pathways, as well as the effect of major transportation corridors on the location of the cells themselves and site access

Challenges/Solutions

- New storm sewers required to cross major transportation corridors including the Transitway, the Airport Parkway, and two railways. Trenchless installation using jacking and boring was employed for installation of large diameter sewers.

- Utility interferences such as hydro lines, watermains, and sewers that required careful consideration during design. The facility footprint was modified to avoid utilities while still providing the required volume and providing the proper flow regime in the pond system.
- Flat terrain that posed hydraulic challenges for designers. Detailed hydraulic analyses were undertaken during design to maximize the conveyance capacity of sewers and specially designed chambers.
- Integration of recreational pathways and planting of over 20, 000 tree, shrubs and seedlings to create a natural, park-like setting.

Project Status/Schedule

The project was completed in 2007

Appendix F
Contaminant Removal Efficiency Examples from Various Sources

Appendix F – Contaminant Removal Efficiency Examples from Various Sources

TABLE 14.5
Suspended Solids Reduction in Constructed Urban Runoff Treatment Wetlands

Name	Location	Reference	WWAR Area Ratio (%)	HLR (cm/d)	Reduction (%)
Crookes	Australia	Raisin *et al.* (1997)	0.1	21.83	12
Mays Chapel	Maryland	Carleton *et al.* (2001)	0.6	5.55	11
Shop Creek	Colorado	Carleton *et al.* (2001)	0.6	—	25
Franklin Farms	Virginia	Carleton *et al.* (2001)	0.8	17.16	62
Lake Munson	Florida	Maristany and Bartel (1989)	1.1	5.19	93
Slovenia Highway	Slovenia	Bulc and Sajn Slak (2003)	1.1	—	74
DUST Marsh	California	Meiorin (1989)	1.8	—	64
Crestwood	Virginia	Carleton *et al.* (2000)	2.4	3.69	58
Greenwood	Florida	McCann and Olson (1994)	2.5	2.57	68
Queen Anne	Maryland	Carleton *et al.* (2001)	3.8	—	65
Clear Lake	Minnesota	Carleton *et al.* (2001)	4.9	1.71	76
Tampa Office Pond	Florida	Carleton *et al.* (2001)	5.1	8.16	55
West Lafayette	Indiana	Harbor *et al.* (2000)	6.3	—	75
Lake McCarrons	Minnesota	Carleton *et al.* (2001)	6.6	7.38	83
Hidden River	Florida	Carr and Rushton (1995)	19.5	1.04	86
Elbow Valley	Calgary	Arnell (2004)	—	—	72
Hallam Valley Low	Australia	Wong *et al.* (2006)	—	400	94
Hallam Valley High	Australia	Wong *et al.* (2006)	—	220	94
Kaohsiung	China	Kao *et al.* (2001a)	—	7.10	37
Villanova	Pennsylvania	Rea (2004)	—	8.16	70
Median				**7.10**	**68**

Note: All are FWS except for Slovenia, which is HSSF.

TABLE 14.9
Removal Performance of Constructed, Gravity-Fed, Urban Stormwater Wetlands

System	Location	Wetland Area (ha)	Drainage Area (ha)	Area Ratio (%)	NH_3 (%)	NO_x-N (%)	TN (%)	Reference
Clear Lake	Minnesota	21.4	433	4.94	55	—	—	Carleton *et al.* (2001)
Crestwood	Virginia	0.070	2.90	2.41	55	39	22	Carleton *et al.* (2001)
DUST	California	22	1,200	1.83	10	15	—	Carleton *et al.* (2001)
Franklin County	Ohio	6.1	260	2.35	—	—	—	Carleton *et al.* (2001)
Franklin Farms	Virginia	0.125	16.2	0.78	−1	60	—	Carleton *et al.* (2001)
Greenwood	Florida	5.24	213	2.46	10	−13	−11	Carleton *et al.* (2001)
Lake McCarrons	Minnesota	2.50	38.0	6.58		35	35	Carleton *et al.* (2001)
Lake Tahoe	California	0.066	1.0	1.84	−53	85	—	Carleton *et al.* (2001)
Mays Chapel	Maryland	0.240	39.3	0.61	22	28	—	Carleton *et al.* (2001)
Queen Anne	Maryland	0.240	0.64	3.75	56	55	23	Carleton *et al.* (2001)
Shop Creek	Colorado	1.42	223	0.64	—	21	41	Carleton *et al.* (2001)
Spring Lake	Minnesota	26	2,260	1.15	−86	—	−14	Carleton *et al.* (2001)
Tampa Office	Florida	0.129	2.55	5.08	39	65	—	Carleton *et al.* (2001)
Motorway	Slovenia	0.009	0.75	1.13	89	76	80	Bulc and Sajn Slak (2003)
Kaohsiung	Taiwan	0.120	—	—	91	—	—	Kao *et al.* (2001a)
Blacktown, NSW	Australia	0.450	75	0.60	−6	16	58	Knoll and Bavor (2004)
Calamvale, QLD	Australia	0.187	160	0.12	50	50	30	Greenway and Jenkins (2004)
Coorparoo, QLD	Australia	0.800	197	0.41	—	78	—	Greenway and Jenkins (2004)
Median				**1.83**	**31**	**45**	**30**	

Note: All are FWS except for Slovenia and Taiwan.

TABLE 14.11
Metals Reduction in Constructed Urban Runoff Treatment Wetlands

Name	Location	Reference	Percent Reduction Cd	Cu	Pb	Ni	Zn	Area Ratio	HLR (cm/d)
Shop Creek	Colorado	Carleton *et al.* (2001)	—	−15	—	—	24	0.6	—
Lake Munson	Florida	Carleton *et al.* (2001)	—	−4	56	—	59	1.1	5.19
Slovenia Highway	Slovenia	Bulc and Sajn Slak (2003)	100	93	100	—	98	1.1	—
DUST Marsh	California	Meiorin (1989)	—	31	88	—	33	1.8	—
Crestwood	Virginia	Carleton *et al.* (2000)	28	66	75	—	29	2.4	3.69
Greenwood	Florida	McCann and Olson (1994)	0	59	60	—	69	2.5	2.57
Tampa Office Pond	Florida	Carleton *et al.* (2001)	—	—	—	—	51	5.1	8.16
Lake McCarrons	Minnesota	Meiorin (1989)	—	—	74	—		6.6	7.38
Hidden River	Florida	Carr and Rushton (1995)	88	79	83	—	84	19.5	1.04
Kaohsiung	China	Kao *et al.* (2001a)	—	—	85	—	95	—	7.10
Sanford	Florida	Harper *et al.* (1986)	71	40	55	70	41	—	—
Norco	Louisiana	Hawkins *et al.* (1997)	—	33	—	—	78	—	—
Aiken	South Carolina	Nelson *et al.* (2004)	—	83	—	—	60	—	—
Orlando	Florida	Kent *et al.* (1997)	—	—	—	34	—	—	—
Orlando	Florida	Kent *et al.* (1997)	—	—	—	44	—	—	—
Orlando	Florida	Schiffer (1989)	—	—	—	25	—	—	—
Irondequoit Creek	New York	Coon *et al.* (2000)	—	—	29	—	—	—	—
Median			**71**	**49**	**74**	**39**	**60**	**2.4**	**5.2**

Note: All are FWS except for Slovenia, which is HSSF.

TABLE 14.12
Metals Accumulation in the Sediments of Stormwater Pond Sediments (mg/kg)

Metal	Age 6–8 Years	Age 10–17 Years	LEL	SEL
Cd	<1	1.4	0.6	10
Cr	12.2	19.0	26	110
Cu	27.8	45.7	16	110
Fe	10,800	13,700	20,000	40,000
Ni	8.8	13.4	16	820
Pb	39.4	90	31	250
Zn	194	300	120	820

Note: LEL = lowest effect level, SEL = severe effect level.

Source: Data from Wren *et al.* (1997) *Wildlife and contaminants in constructed wetlands and stormwater ponds: current state of knowledge and protocols for monitoring contaminant levels and effects in wildlife*. Technical Report Series No. 269, Canadian Wildlife Service: Burlington, Ontario, Canada.

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