WASTEWATER AND STORMWATER APPLICATIONS OF WETLANDS IN CANADA

SUSTAINING wetlands

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by

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Summary

Municipalities and industries in Canada face many challenges in complying with environmental regulations, including increasingly stringent surface water discharge effluent limitations. Because of the diversity and magnitude of waste streams from domestic wastewater treatment facilities, multiple technologies must be evaluated to provide cost-effective and reliable effluent management in every case. As allowable effluent limitations become lower or more restrictive, innovative technologies may offer new and affordable methods of compliance.

Constructed wetlands provide one innovative approach to meet these growing challenges. Constructed wetlands have been found to effectively reduce many of the typical pollutants in industrial and municipal effluents, such as biochemical oxygen demand, suspended solids, and nutrients. As a "natural" technology, constructed wetlands rely on the naturally occurring energies of the sun and wind. Compared to many conventional technologies that rely on inputs of concentrated fossil fuels, the naturally occurring energies act over larger land areas.

Constructed wetlands use many of the same chemical, physical, and biological processes that occur in conventional treatment systems. Because these processes are distributed over a larger area, biological solids are degraded internally by microbial processes, and sludge or plant harvesting and disposal may not be necessary. Constructed wetland treatment systems do not use expensive energy and chemical inputs; therefore, their operating costs are lower than those for alternative treatment technologies. In addition, creating productive wetland plant communities and natural food chains can provide ancillary benefits to wildlife and adds value to industries that invest in this natural technology.

Canada has a growing number of municipalities and industries that are investigating the use of constructed wetlands to meet their effluent management responsibilities. Many industries, regulating authorities, and municipalities are holding workshops and training sessions to become more knowledgeable on wetland treatment capabilities, and are actively piloting the wetland treatment alternative. More than 45 full-scale constructed wetland treatment systems have been installed.

This report summarizes for the first time the status of constructed wetlands located strictly in Canada, and includes descriptions of the types of constructed wetlands, their applications, performance, costs, and their national distribution. Interviews held with over 100 Canadian individuals and agencies provided the basis for this understanding of the diversity of constructed wetland systems operating or planned in Canada. This report also provides guidelines for a feasibility assessment and for the construction of wetland treatment systems as well as an extensive bibliography on all aspects of wastewater treatment wetland systems.

With the large number of wetland treatment systems now in use in Canada and with the research and positive full-scale results reported to date, constructed wetlands will increasingly be considered as a viable and cost-effective alternative for the treatment of municipal, industrial, and agricultural wastewater and stormwater in Canada.

Preface

The effective management of wetlands and water quality are of vital importance to our nation. The pursuit of conservation goals for these systems has become a significant area of cooperative effort by the Secretariat to the North American Wetlands Conservation Council (Canada) and the Water and Habitat Conservation Branch of the Canadian Wildlife Service. The following report, *Wastewater and Stormwater Applications of Wetlands in Canada*, is a further example of our joint efforts to foster national awareness of wetland issues of interest to Canadians.

The Government of Canada remains committed to its objectives announced in the *Federal Policy on Wetland Conservation*. These include ensuring provision of tools and information on wetland resources to Canadians and fostering innovative research on methods for conservation and management of these habitats.

The application of natural and constructed wetlands technology to wastewater and stormwater treatment problems is increasingly becoming a daily land and water management issue for planners and habitat specialists across Canada. This report will serve as an effective entrée for Canadian practitioners, as well as the general public, to this subject. The report should, of course, complement effective research and in-depth environmental analysis which remain essential elements for environmental assessment. The report provides a rapid look at the emerging technology of wastewater treatment wetlands towards the improvement of the quality of the world we Canadians share with nature.

James D. McCuaig
Director, Water and Habitat Conservation
Canadian Wildlife Service
Environment Canada

An Overview of Canadian Wetlands

Wetland Development and Classification

Canadian wetlands are subdivided into five "classes": bog, fen, swamp, marsh, and shallow open water. Definitions of these terms and methods for wetland differentiation have been developed for Canada by the National Wetlands Working Group (1987, 1988). Each of the five classes can be further subdivided into various "forms" based on landscape, hydrological and other physical factors and "types" related to vegetation characteristics.

A detailed discussion of wetland classification is presented in *Wetlands of Canada* (National Wetlands Working Group 1988). A brief summary of the major wetland classes is presented below.

Bog an ombrotrophic peatland with the water table at or near the surface. Bogs may be treed or treeless. Vegetation species tend to show a limited diversity due to the acid, nutrient-poor environment with *Sphagnum* mosses and ericaceous shrubs common.

Fen a minerotrophic peatland with the water table usually at or just above the surface. Vegetation may include sedges, grasses, reeds, brown mosses, certain *Sphagnum* species, ericaceous shrubs, and trees.

Swamp a mineral wetland or peatland with standing or gently flowing waters occurring in pools or channels. The water table usually is at or near the surface. The vegetation is characterized by a dense cover of deciduous or coniferous trees or shrubs, herbs, and some mosses.

Marsh a mineral wetland that is periodically inundated by standing or slowly moving waters. Surface water levels may fluctuate seasonally and vary from fresh to highly saline. Vegetation includes emergent sedges, grasses, rushes and reeds, which may have interspersed areas of open water and aquatic plants.

Shallow Open Water a mineral wetland that is intermittently or permanently flooded and has open expanses of standing or flowing water. Shorelines, mud flats, shallow lakes, ponds, pools, oxbows, channels and similar features are included in this class. Vegetation, when present, consists of submerged and floating aquatic plant forms.

Distribution of Canadian Wetlands

These wetlands occur intermittently across all of Canada's landscapes along the shores of lakes, rivers, and streams, and in other areas where the water table is close to the surface. Marshes and swamps stay wet for much of the year and are what many people in Canada's southern region think of when the term "wetland" is used. The distribution of wetlands in Canada is controlled by many factors including surface hydrology and the interaction of climatic and topographic factors. Canada's 127 million hectares of wetland occur in all areas of Canada, with about 90% being classified as peatlands where peaty soils are predominant and over 40 cm deep at their surface. Major wetland and peatland inventory programs have been completed in several regions of Canada including the Pacific estuaries, the southern Prairies, southern Ontario, southern and eastern Quebec and most of the Atlantic Provinces excluding Labrador.

Climatic and topographic factors influence the type of wetland which occurs in a particular region. Twenty wetland regions, and a series of wetland subregions based upon climatic factors, are recognized in Canada (National Wetlands Working Group 1986). A detailed discussion of wetland distribution and of the characteristics of the wetlands in each wetland region is provided in *Wetlands of Canada* (National Wetlands Working Group 1988).

These wetlands provide many ecological functions and values and are an important ecological component of many landscapes. Many of the wetland functions meet human needs. Functions ascribed to wetlands include: (a) *life support* (climatic regulation, toxics absorption, stabilization of biosphere processes, water storage, cleansing, nutrient cycling, food chain support, habitat, biomass storage, and genetic and biological diversity); (b) *social and cultural* (research specimens, viewing, photography, birdwatching, hiking, canoeing, and community, religious or cultural traditions); and (c) *production* (natural production of birds, plants, fish, fibre, and soil supplements) (Cox 1993, Sheehy 1993, Bond *et al.* 1992, National Wetlands Working Group 1988).

The importance of wetland conservation, restoration, and protection in Canada has become a matter of public policy as exemplified federally in the *Federal Policy on Wetland Conservation* (Government of Canada 1991) and in provincial jurisdictions and other economic sectors across Canada (Cox 1993, Lynch-Stewart *et al.* 1993). In Canada, the construction of artificial wetlands has received increased attention as a potential means of compensating for losses of wetlands incurred by human activities. The use of wetlands as a cost-effective alternative to conventional advanced treatment of wastewater is also receiving wider acceptance.

Introduction to Wastewater and Stormwater Applications of Wetlands

There is an obvious role for wetland treatment of wastewaters in our northern environment. These low-tech, solar-driven systems are passive and user-friendly. There is no need for a skilled operator, which is a great advantage to a remote community with limited financial resources. The most important economic disadvantage of wetland treatment is the cost of land, for this is a land-intensive process. However, that may well be an advantage to a remote community that is land-rich, especially if the area is cash-poor, because operating costs are generally very low.

Design of artificial wetlands must account for hydraulic operability and correct size to achieve the specific regulatory goals of water quality improvement. Many regulated parameters are effectively treated in cold temperature conditions, but nitrogen reduction slows considerably. Designs are presently evolving to allow flow manipulation that decreases wetland size: vertical flow subsurface systems that run on intermittent mode are much more efficient for nitrogen removal.

However, it is not necessary to rely upon slow winter processes. There are many northern systems that store water for the duration of the non-growing season, and then discharge to the wetland during the warm spring, summer and fall months. The advantage of this is the wide availability of warm weather design information; the disadvantage is the cost of the storage lagoons.

Wetland Treatment Systems

Establishment of Constructed Wetland Treatment Systems

Wetlands are constructed to perform a broad range of functions, including enhancement of wildlife production, storage of flood waters, reduction and storage of pollutants, and general aesthetic benefits. The basic components of a wetland construction project include the following activities:

- Establishment of project goals and objectives.
- Determination of area requirement.
- Evaluation and selection of construction location.
- Preparation of preliminary design analysis.
- Obtaining permits.
- Preparation of final design and construction documents.
- Construction of the wetland.
- Conducting post-construction monitoring and maintenance.

Types of Systems

In addition to the use of natural wetlands, three types of artificial wetland systems are now being used for water treatment: (i) surface flow wetlands, (ii) subsurface flow wetland systems, and (iii) floating aquatic plant systems. Each of these alternatives is briefly described below.

Natural Wetlands

Natural wetlands have been used for the treatment and disposal of secondary wastewater effluent for many years in

Europe, the United States and Canada. There are many existing discharges to natural wetlands nationwide. While most of these systems were not designed for wastewater and stormwater treatment, studies have led to both a greater understanding of the potential of natural wetland ecosystems for pollutant assimilation and the design of new natural water treatment systems.

The proper use of a natural wetland system for the treatment of secondary wastewater or stormwater involves a number of considerations. Research indicates that matching hydraulic loads to the hydroperiod requirements and tolerances of the dominant wetland vegetation species limits changes in vegetation. Optimal treatment occurs when the pretreated water is well-distributed throughout the wetland. Ideally, alternative discharge areas or "treatment cells" are used so that portions of the wetland system can be taken "off line" periodically and allowed to undergo seasonal dry periods.

Monitoring the performance of natural wetlands for water quality enhancement is ongoing. The systems monitored to date demonstrate that, through careful design, some natural wetlands can consistently and cost-effectively provide advanced treatment of wastewater and stormwater constituents. Natural wetland wastewater treatment systems in the Yukon are prime examples.

Surface Flow Constructed Wetlands

Surface flow (SF) constructed wetlands usually are shallow, man-made impoundments planted with emergent, rooted vegetation. These wetlands may be planted manually or naturally colonized by "volunteer" plant communities. Some constructed wetlands contain monocultures of cattails (*Typha* spp.) or bulrushes (*Scirpus* spp.), while others are planted with more diverse plant communities that have greater stability under changing seasonal and water quality conditions.

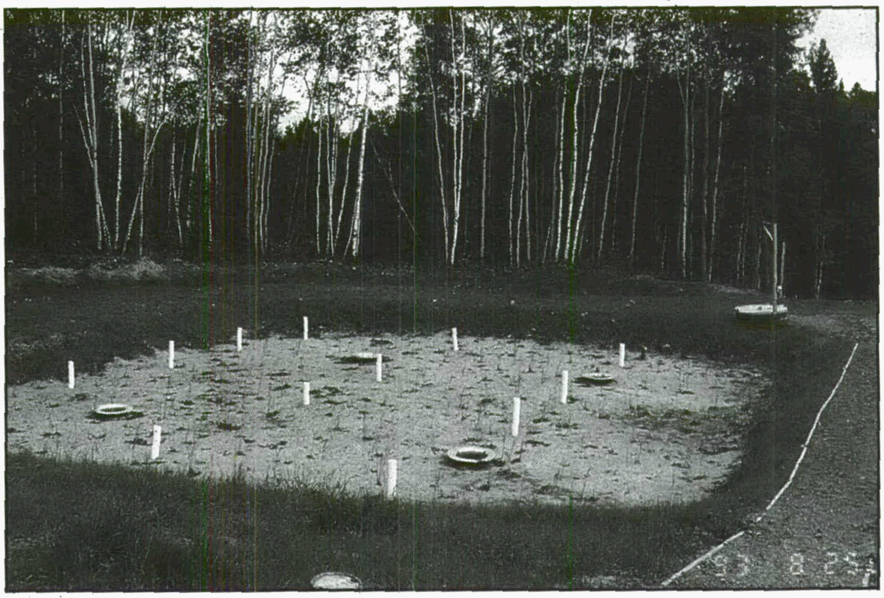
Photo: RSA Consultants

First stage vertical flow, planted site, Zoo at Saint-Felicien, Quebec.

Unlike a natural wetland system in which hydrology is largely fixed by the tolerance limits of the existing plant community, an SF constructed wetland system can be designed to regulate water depth and residence time, two of the most important factors in wetland treatment design. The design of a surface flow constructed wetland system can also feature parallel cells or cells in series. Such a system can be operated to rotate discharge points or to use slightly different treatment capabilities of the various available plant species groups. SF constructed wetland systems have relatively low construction, operation, and maintenance costs compared with conventional, advanced treatment technologies.

These constructed wetlands are usually not harvested to remove nutrients. Instead, the natural assimilatory capacity of the microbial flora (bacteria and fungi) that attach to the plants provides efficient and reliable removal of biodegradable organics and nitrogen (ammonia and nitrate). Metals and phosphorus can be sequestered in plant materials and wetland sediments. Because much of the treatment that occurs in wetlands is from microbial action rather than plant uptake, these systems continue to function during winter, but at a slower rate, with the temperature-buffering effect of water and ice cover.

Subsurface Flow Constructed Wetlands

Subsurface flow (SSF) constructed wetlands are similar to surface flow constructed wetlands in many respects, often using some of the same emergent plant species. However, SSF constructed systems are designed to achieve effluent flow through the porous substrate supporting the emergent vegetation, rather than above the substrate. The large surface area resulting from the porous medium and the plant roots provides ample sites for microbial activity. When treating an equivalent volume of flow, SSF constructed wetland systems may use less land area than do surface flow constructed wetlands.

SSF constructed wetland systems are advantageous in cooler climates because so much of the treatment occurs below the ground surface. Thus, these systems are less affected by cold air temperatures. Also, SSF constructed wetland systems may be relatively low in maintenance requirements and are less likely to have odour and mosquito problems than are lagoons. SSF constructed wetland systems are most effective at removing biodegradable organic matter and nitrate-nitrogen from wastewaters.

A major disadvantage of these SSF constructed wetland systems is their tendency for plugging; overall costs can be six to eight times higher than for a surface flow constructed wetland system.

Floating Aquatic Plant Systems

Floating aquatic plant (FAP) systems use floating macrophytic plants such as duckweed (*Lemna* spp. or *Spirodela* spp.) for wastewater treatment. They have been modeled after small facultative wastewater lagoons that are naturally colonized by volunteer floating plants and provide improved removal efficiencies for meeting increasingly stringent effluent requirements. These systems have a significant potential for reducing concentrations of five-day biochemical oxygen demand, total suspended solids, nutrients, and metals.

"Surface flow constructed wetland systems have relatively low construction, operation, and maintenance costs compared with conventional, advanced treatment technologies."

One such duckweed system that uses floating barriers is a proprietary product. It is claimed to be one of several natural treatment systems that can consistently meet an effluent limit of one milligram per litre (mg/L) total phosphorous or lower, if the plants are harvested, without using in-plant modifications or chemical additions. Little information on the design, cost and performance of this type of system is available at this time, making it difficult to compare it to other natural system technologies.

The disadvantages of aquaculture systems are their sensitivity to cold temperatures and their general susceptibility to plant pests and pathogens. Polyculture systems that use a combination of floating aquatic plant species offer an alternative with less intensive pest management requirements. Aquaculture systems that use greenhouse enclosures in colder climates can also be considered.

Applications of Wastewater and Stormwater Treatment Wetlands

The intent of this report is to provide municipal planners, industry and the farming community with a range of information sufficient to consider wetlands as a wastewater and stormwater treatment alternative. However, there is potential for applying this technology to a wider spectrum of wastewater and stormwater sources. Federal and provincial lands could benefit considerably from this technology because it offers a low cost alternative to more conventional forms of wastewater and stormwater treatment. A brief description of several of these potential uses is provided below.

Municipal Wastewater

The use of wetlands for the successful treatment of primary and secondary effluent from both activated sludge and lagoon systems, landfill leachate, and septic tank effluent is well documented. Typically, these systems are applied to small communities where land is readily available at a reasonable cost. Many of the colder-climate constructed systems in Canada are designed for seasonal discharge or to meet the regulatory authority's guidelines prior to discharge to the wetlands and to provide tertiary treatment to the wastewater stream.

Industrial Wastewater

Many potential applications exist for treatment of industrial wastes including metals removal and pH adjustment of stormwater runoff from coal and ash piles at thermal generating stations, the biochemical oxygen demand (BOD) removal of milk product industry wastewater, ammonia and BOD removal from meat processing and rendering plants, refinery wastewater treatment, and contaminated groundwater treatment. High levels of contaminants may require pretreatment of the wastewater and innovative approaches for introducing the pretreated effluent to the wetland.

Farm Feedlot Runoff

Several projects are underway in Ontario that involve the use of constructed wetlands to prevent runoff from farm feedlots and milkhouse washwater discharge from entering open ditches. These wastewaters could eventually flow into nearby water courses or percolate into the ground affecting the surface water and groundwater quality. The costs associated with constructing a wetland have been estimated to be as little as one tenth that of building a liquid manure tank. These systems can be designed for zero discharge, relying on evaporation and irrigation for the disposal of the water.

Photo: C. Rubec, Environment Canada

An artificial wetland used for hotel wastewater treatment. Lac Simon, Quebec.

Agricultural Stormwater Runoff

Stormwater runoff from agricultural fields, particularly after spreading fertilizer, results in high nutrient loadings to the receiving streams and lakes. Building a buffer edge that allows stream, river, and pond banks to naturally vegetate provides treatment for field runoff. Preventing cattle from grazing in and around the water edge helps to ensure the survival of the vegetation. Routing of stormwater runoff and tile drainage to a central wetland treatment area can provide treatment prior to discharge to the environment and the potential to recycle the nutrients by spray irrigating the collected water back onto the fields where it originated.

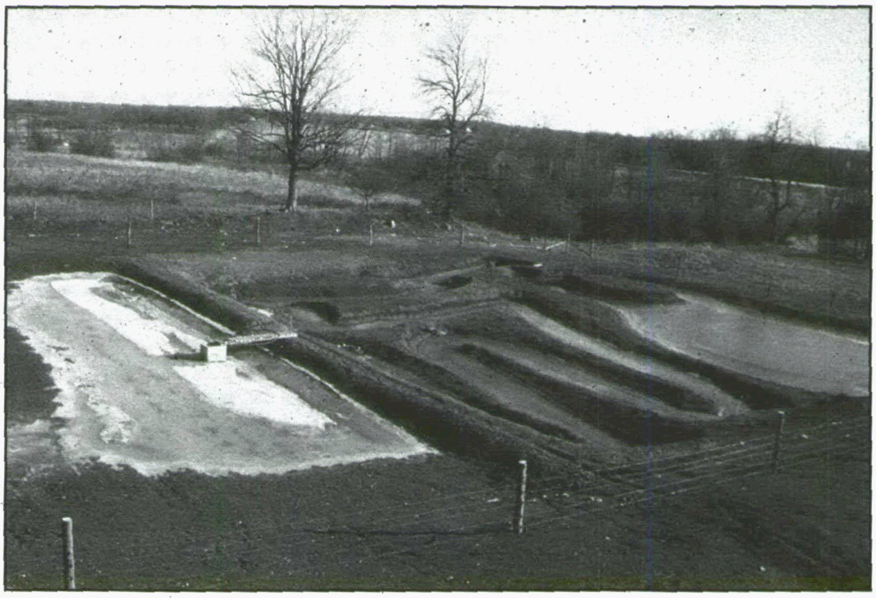

Photo: T. Davidson, Rideau Valley Conservation Authority

Farm feedlot wastewater wetland, Rideau Angus Farm near Burritt's Rapids, Ontario.

Airports – Glycol/Fire Training Stormwater

De-icing of airplanes, especially at Canada's major international airports, can result in large quantities of glycol being swept down the storm drains and eventually discharging to the nearest water course if no onsite treatment or collection system is in place. Wetlands, if properly sized and engineered, could provide treatment for the contaminated stormwater flow.

Stormwater containing fuel and fire retardant foam is also a candidate for wetland treatment, especially at sites where no recovery efforts of these compounds are being made. Hydrocarbon compounds similar to those found in jet fuel have undergone preliminary testing and have been found suitable for wetland treatment technology.

National/Provincial Parks

Campsites within national and provincial parks could benefit from wetland technology from several standpoints. Since most parks operate on a seasonal basis, the design of these systems would not need to be built to meet winter operation criteria and could easily be modified in the future if year-round operation was desired. Wetlands could be incorporated into the environmental education program although care would have to be taken to reduce the risk of campers coming into contact with the wastewater and the pathogens it may contain. Wetlands may be of particular interest to camp sites located in the northern reaches of Canada. A public beach in Quebec is using wetlands to treat the beach water to make it more suitable for use.

Aboriginal/First Nation Lands

Native settlements are often in remote locations, some of which have poorly functioning wastewater treatment facilities. Wetlands offer an opportunity for a wastewater and stormwater treatment alternative that will blend into the natural environment. Construction and management of these systems would provide an employment opportunity for the local residents as well as full control over every aspect of the wetland treatment project. Providing wildlife habitat could be another attractive benefit of such a wetland system. British Columbia has several sites where wetlands are being used for wastewater treatment for aboriginal communities.

Northern Communities

Many northern communities are currently using facultative storage lagoons for their wastewater treatment needs. Most have permits to discharge the lagoon contents during the summer months. A growing number of communities in the Yukon, Northwest Territories, northern British Columbia, and northern Alberta are incorporating wetlands into the existing wastewater treatment facilities to provide a better quality effluent and, in some cases, to extend the discharge period.

Stormwater

Stormwater treatment wetlands are constructed wetlands that improve water quality, modify flow rates (by storing water temporarily in shallow pools that create growing conditions suitable for emergent and riparian wetland plants), attenuate flow, and reduce downstream scouring and erosion (Ontario Ministry of Environment and Metropolitan Toronto and Region Conservation Authority 1992, Shueler 1992). Shueler (1992) describes five basic stormwater wetland designs: shallow marsh, pond/wetland, extended detention wetland, pocket wetland, and fringe wetland. All are essentially surface flow systems, with varying emergent marsh and deep pool habitat, hydraulic capacity, residence time, and travel routes.

In recent years, interest has shifted from providing stormwater attenuation with retention ponds alone, to incorporating vegetated wetland cells into the design to provide greater attenuation and contaminant removal and improved landscape aesthetics in urban environments. Many communities across Canada have installed wetlands as part of their stormwater management systems. Several additional installations are awaiting approval from the regulatory authorities and there are many others in the predesign or design phase.

Photo: J. Granger

Municipal wastewater lagoon and seasonal discharge wetland. Old Crow, Yukon.

Pulp and Paper

The use of wetlands for treating pulp and paper wastewater has been documented by wetland experts in the United States. This has sparked interest from the Canadian pulp and paper industry. Leachate from wood waste is currently being treated in a constructed wetland in British Columbia.

Sludge Drying/Biosolids Management

Dewatering and treatment of biological sludge using reed beds (*Phragmites* spp.) has been carried out in the United States and in Europe. This is being done to replace or improve sand drying beds. Reed beds have been found to provide shorter dewatering times and reduced sludge volumes and organic material (Cooper and Findlater 1990). There is considerable potential for applications of this type in Canada.

Acid Mine Drainage

Wetland systems have been developed for the passive treatment of contaminated coal mine drainage that incorporate one or more of an aerobic system, a compost wetland, and an anoxic limestone drain (Hedin and Nairn 1992). Aerobic wetlands are essentially surface flow wetlands as described above, but may be constructed without plants. The goal of aerobic wetland operation is to aerate the water and to retain the water long enough for oxidation and precipitation reactions to occur (Hedin and Nairn 1992).

"A growing number of communities in Canada are incorporating wetlands into their wastewater treatment."

Compost wetlands are similar to aerobic wetlands, but include a thick organic substrate that promotes chemical and microbial processes that generate alkalinity and neutralize the acidic components of mine drainage. The anoxic limestone drain (ALD) forces water through a buried bed of limestone, releasing alkalinity to the water in an anoxic environment without armouring the limestone (Hedin and Nairn 1992).

Acid mine drainage wetlands are not covered in detail in this document. Considerable documentation exists in the literature that describes Canadian, European, and American experience (see pages 38 to 48).

Photo: L. Leavens

Wastewater wetlands require careful design, species selection and construction.

Operational Considerations

General Performance of Wastewater Treatment Wetlands

Performance of constructed wetlands for wastewater treatment is measured by removal efficiency and effectiveness of treatment. Knight *et al.* (1993) summarized the removal efficiency of 97 sites, mainly in the United States, representing 127 separate systems for a wide range of flow and influent quality. Average removal efficiencies are presented in Table 1, for five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), ammonia-nitrogen (NH_3-N), total nitrogen (TN), and total phosphorus (TP). Surface flow (SF) constructed wetlands as well as subsurface flow (SSF) constructed wetlands are included in the data base.

Wetlands efficiently assimilate biochemical oxygen demand and total suspended solids through microbially-mediated decomposition of organic matter. BOD_5 removal efficiency is low at low input concentrations (5 to 10 mg/L) and increases to between 70 and 90 percent at higher input concentrations (Water Pollution Control Federation 1990). Subsurface flow wetlands may provide BOD_5 removal efficiencies in the range of 85 to 90 percent, if properly designed and maintained. Total suspended solids removal efficiencies are similar to BOD_5 removal potential (Water Pollution Control Federation 1990).

Wetlands transform nitrogen through microbial action and plant uptake (Water Pollution Control Federation 1990). Ammonia is transformed to nitrate through the nitrification process, and nitrate to nitrogen gas through denitrification. These process rates may be controlled by temperature, nitrogen concentration, oxygen concentration, toxic substances, and other factors. Total ammonia-nitrogen (NH_3-N) assimilation is generally high, but may be affected by short hydraulic retention times (HRT), high loading rates, and low temperatures.

Table 1

Average Constructed Wetland Performance Data

PARAMETER	IN (mg/L)	OUT (mg/L)	REMOVAL EFFICIENCY (percent)
BOD_5	38.8	10.5	73
TSS	49.1	15.3	69
NH_3-N	7.5	4.2	44
TN	14	5	64
TP	4.2	1.9	55

Source: *Knight et al. (1993)*

Notes: *BOD_5 = Five Day Biochemical Oxygen Demand*
TSS = Total Suspended Solids
NH_3-N = Ammonia Nitrogen
TN = Total Nitrogen
TP = Total Phosphorus

Total nitrogen assimilation is highly correlated with loading rates to 10 kg/ha/day, and is highly dependent upon HRT, decreasing significantly at design HRTs of less than about five days (Water Pollution Control Federation 1990).

Total phosphorus (TP) is removed from the water column through sedimentation and plant uptake, and is dependent upon the phosphorus adsorption capacity of the wetland soil. TP removal efficiency increases with higher input concentrations and with higher HRTs (Water Pollution Control Federation 1990).

Wetlands have significant potential to remove metals and other toxic chemicals (Water Pollution Control Federation 1990). Removal mechanisms are generally oxidation and precipitation from the water column. Pathogens such as coliform bacteria can be significantly reduced through wetland treatment, but may also be introduced by birds and other wildlife, and therefore show wide variability (Water Pollution Control Federation 1990). Table 2 summarizes projected long-term removal rates for stormwater wetlands in the mid-Atlantic region of the United States.

In Canada, the perceived problem associated with wetland technology is operation at cold temperatures. It seems logical that treatment processes will slow or stop at cold temperatures, as they do in conventional treatment plant operations. But wetlands are far more complex than conventional wastewater treatment plants. Conventional wisdom fails to apply; wetlands in fact perform many treatment functions very efficiently in winter.

The available information to answer questions on winter operation is now significant, and increasing rapidly. Canadian research has contributed in a major way to this knowledge. Pioneering work on surface flow wetlands was done in Listowel, Ontario from 1980 to 1984. The project data report (Herskowitz *et al.* 1986) contains a wealth of information. Five wetlands were kept in continuous operation throughout the winter by con-

Table 2

Projected Long-Term Pollutant Removal Rates for Stormwater Treatment Wetlands in the mid-Atlantic Region

POLLUTANT	REMOVAL RATE (PERCENT)
TSS	75
TP	45
TN	25
Organic Carbon	15
Lead	75
Zinc	50
Bacteria	2 log reduction

Source: Schueler (1992).

trolling the insulation in a way unique to wetland ecosystems. Water levels were raised at freeze-up, and a layer of ice allowed to form. The water level was then lowered to provide an insulating air gap above the water, but below the ice. The stems of the dense stand of emergent cattails served as supports to keep the ice layer elevated. The standing dead cattails then trapped snow and added an insulating snow blanket. Many northern wetlands exhibit this same behaviour; with unfrozen water below a snow blanket trapped by the plants. Temperature effects were significant for nitrogen reduction, slight for phosphorus, and nonexistent for biochemical oxygen demand and total suspended solids.

A subsequent companion project at Cobalt, Ontario reinforced much of the knowledge gained at Listowel (Miller 1989). Research on subsurface flow wetlands in winter operation is now in progress at Niagara-on-the-Lake, Ontario.

The Scandinavian countries have espoused wetland technology for a variety of purposes, and are generating valuable operating and design information. Researchers have operated systems year-round near the Arctic Circle in Norway (Jenssen *et al.* 1992; Jenssen *et al.* 1994). Their conclusions challenge our conventional wisdom and offer the following:

"The results from the first two years of operation have shown an average reduction of 86%, 55%, and 98% of BOD, total nitrogen and total phosphorus. The results so far have shown a winter performance nearly on the same level as the summer performance."

Norway is also building wetland treatment systems in the Jaeren region at the rate of about 10 per year (Bakke 1994). These are multi-use treatment "parks," and produce 90% reductions in total phosphorus and ammonium nitrogen.

Sweden has reported year-round operation of both subsurface flow and submerged aquatic bed wetlands

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"Conventional wisdom fails to apply; wetlands in fact perform many treatment functions very efficiently in winter."

(Gumbricht 1992a, 1992b). Temperature effects in the subsurface system (2 to 21°C) were significant for nitrogen reduction (a 50% reduction in efficiency), slight for phosphorus (a 15% reduction in efficiency), and nonexistent for BOD. The same trends were noted for the submerged macrophyte system (-1 to 17°C). At present, Dr. Hans Wittgren at the Swedish Meteorological and Hydrological Institute in Norrköping is compiling a review of cold climate wetland treatment information.

TSS is removed by physical processes that have little to do with temperature; settling and filtration are not temperature sensitive. The author is unaware of any research that has attempted to clarify the reasons why BOD removal is not temperature dependent, but there are now numerous reports of the lack of a temperature coefficient. BOD is a lumped chemical category consisting of a multitude of carbon compounds. The wetland processes that consume BOD involve several different vertical zones in which a large number of chemical and biochemical processes take place. Some of these processes generate BOD by decomposition; others consume BOD. Wetlands frequently are of a sufficient size to reach the background BOD level created by the balance between generation and consumption of BOD. The net consumption is therefore the difference between two competing process categories. It is known that decomposition slows to a marked degree at cold temperatures. It is also likely that BOD destruction processes slow down, since these are a combination of aerobic and anaerobic microbial reactions. The difference between slow destruction and slow generation, as manifested by net removal, need not differ significantly from the difference under warmer, more rapid process conditions.

Not all BOD removal processes slow with decreasing temperature. A significant fraction of wetland BOD is particulate, and therefore susceptible to removal by particulate settling. This physical process is slightly temperature-dependent. Another important factor is the aerobic destruction of carbon compounds, which is dependent on the amount of oxygen available for the oxidation reactions. Most of the required oxygen comes from the dissolution of atmospheric O_2. The solubility of gaseous O_2 in water is higher at lower temperatures, with a two-fold increase as the temperature drops from 30°C to 0°C.

It would be inappropriate to extrapolate this behaviour to specific carbon compounds, especially those which are not normally found in wetlands. A compound that is not generated in the wetland will be subject to depletion alone, and may also require a specific microorganism. Under these conditions, a temperature dependence is a distinct possibility.

The nitrogen species comprising the total nitrogen load undergo a well known set of interconversion processes in wetland and pond environments. These processes are all temperature sensitive; to varying degrees. Wetland research confirms the same level of variability with temperature that is found in conventional processes. The reason is that the same microorganisms are involved in both cases.

A reasonable explanation for a lack of seasonal dependence for phosphorus uptake is found when the life style of the vegetation is taken into account. The Listowel wetlands are cattail monocultures (*Typha latifolia*). In a northern environment, *Typha* undergoes maximum growth in spring. In fall, it enters a period in which it translocates large amounts of nutrients and biomass to its rhizomes. Thus, the high values of spring and fall are plausible. Summer is a period of high biological activity in the wetland. However, the rate constant is a parameter in a lumped model, that describes a net transfer, which is the difference between uptake processes and release processes to and from the active compartments in the ecosystem. Although plant growth and microbial uptake may be operating in high gear, so are leaching and decomposition processes. High returns of phosphorus from the static compartments counterbalance high rates of uptake. Winter temperatures slow both uptake and return transfers, but the net transfer clearly remains high.

"Temperature effects were significant for nitrogen reduction, slight for phosphorus, and nonexistent for BOD and TSS."

Capital, Operation and Maintenance Costs

Wetland construction costs are determined by the cumulative cost of land, earthwork, planting, design, monitoring and maintenance. Surface flow constructed wetlands in the United States typically cost between US$10 000 and US$50 000 per hectare, depending upon system size (Kadlec and Knight, in preparation). The cost of surface flow constructed wetlands in most of the cases in Canada fell within this range. Costs that fell outside this range included those wetlands where a liner was required due to highly permeable soils. Because special attention was given to the removal and subsequent replacement of the topsoil, economy of scale was lost due to the small size of the installation, and special architectural features were incorporated into the wetland design to create a more attractive feature for the surrounding community.

The high cost of gravel fill can raise the price per hectare of subsurface flow constructed wetlands to as much as four to eight times the cost of surface flow constructed wetlands. However, subsurface flow constructed wetlands can handle greater contaminant loading rates than surface flow constructed wetlands thereby reducing the land requirements.

Operation and maintenance costs depend on the extent of monitoring data collection, exotic plant control, burrowing animal activity into the berms, and water management. A summary of wetland design guidelines is presented in Appendix A.

Space Requirements

The area required for a wetland depends on the goal of wetland construction, and is described in more detail in Appendix A. A wetland sizing calculation sheet is provided in Appendix B.

Permitting Requirements

Treatment and disposal of wastewaters is regulated by provincial and local regulations. In Canada, each provincial environment ministry sets treatment and discharge policies that directly affect the permitting and implementation of wetland wastewater treatment systems. A provincial Certificate of Approval is required for almost all point discharges of water and wastewater into the waters of Canada. Other potentially significant regulations are defined in the *Canadian Environmental Protection Act*, the *Canadian Environmental Assessment Act*, and the *Fisheries Act*.

Issues

Wetlands constructed for wastewater and stormwater treatment also provide ancillary beneficial functions for wildlife habitat, food chain support, enhanced ecological productivity, and flood attenuation (Kadlec and Knight, in preparation). Treated wastewater may be used to augment and restore hydrologically altered wetlands. Constructed wetlands establish a productive ecological food chain as they mature. Public awareness and environmental education may be factored into the overall system design, where feasible.

Effects on Biota

To date, no conditions in treatment wetlands of municipal wastewater and stormwater, have been lethal to fish or other wildlife in the United States (Kadlec and Knight, in preparation). The only documented cases of toxicity to wetland wildlife are releases from hazardous waste sites and discharges from agricultural irrigation return flows in the western United States (at the Kesterson National Wildlife Refuge). Where bioaccumulation or wildlife exposure has the potential to become a problem, measures are incorporated into the project design to minimize these risks.

Questions and Concerns

Over the years, numerous questions and concerns have surfaced with respect to the long-term effects of wetlands on wildlife and on the lives of 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 Table 3.

Photo: J. Pries, CH2M HILL

Blue heron on southern Ontario wetland.

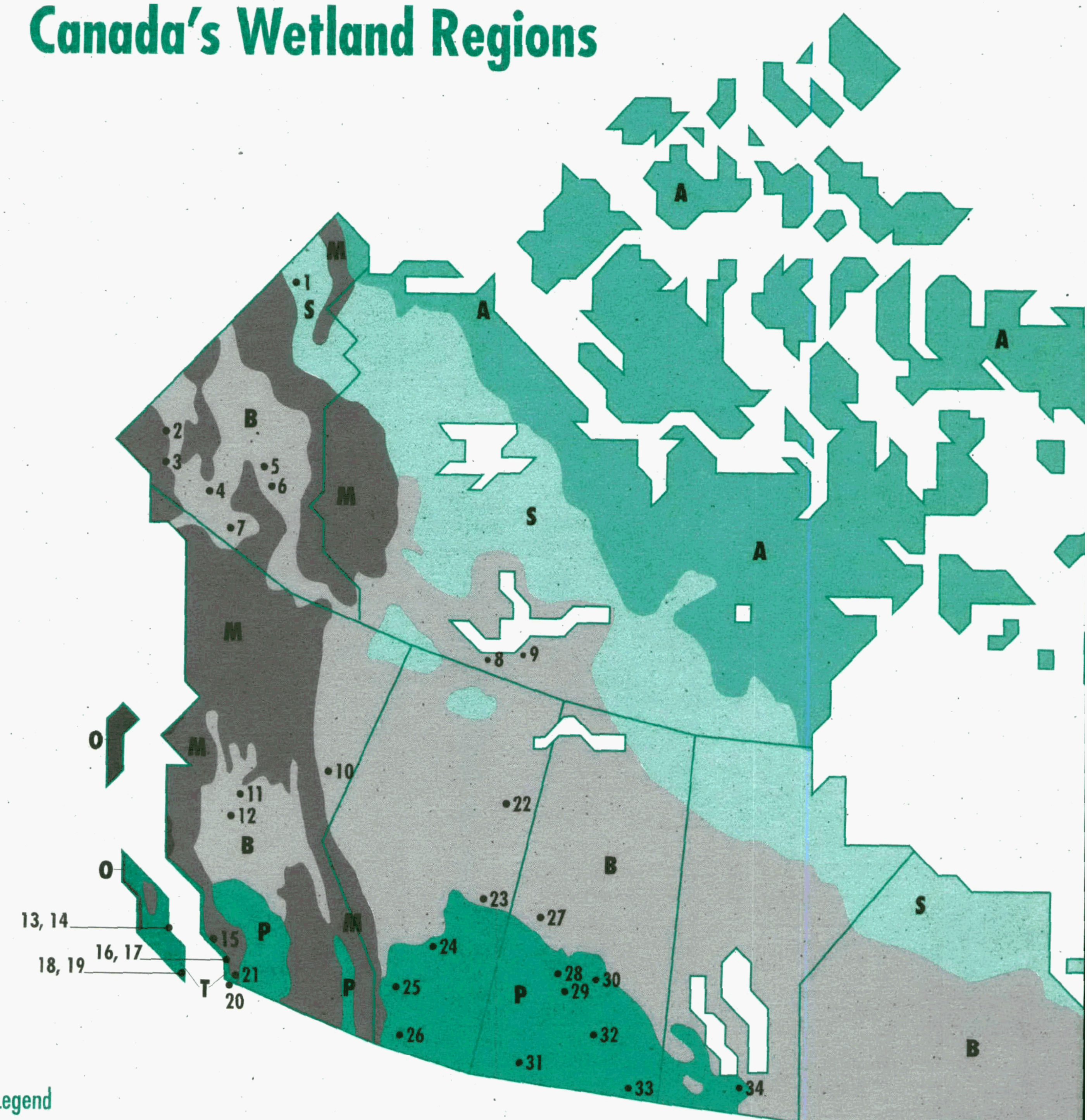
Table 3

Questions and Concerns about Wetlands used for Wastewater and Stormwater Treatment

Questions/Concerns expressed by Regulators and the General Public	Responses by the Wetland Engineers
Will it generate odours?	It has been found that if the wetland has been designed correctly, odours should not occur. The experience of wetland experts who have visited wetland sites around the World indicate that odour generation in constructed or natural wetlands has not occurred.
What about mosquitos?	Even though the wetland provides a greater water surface area for mosquitos to breed, this potential has effectively been kept in check at many wetland sites in several ways. The most effective is the use of mosquito fish that eat the mosquito larvae before they reach the adult stage. Nesting boxes can be set up for 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.
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 wetland systems around the World. Although more knowledge is still being gained and more data need to be collected and analyzed, there exists sufficient design criteria to properly engineer a wetland treatment system.

Will it work in winter?	Wetlands continue to perform many of their treatment functions very efficiently in winter. The first two years of operation of a system in Norway showed a winter performance almost at the same level as the summer performance.
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 tested in a biological wastewater treatment system should be approached with the same caution that would be exercised in a conventional wastewater treatment system.
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 wetland treatment 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 treatment effluent.
How long will it continue to remove the contaminants?	Although the oldest wetlands currently in operation have only been monitored for a few decades, experience indicates 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 in a decade.
Will the accumulated contaminants wash out of the stormwater wetland treatment system during rainstorms?	If the wetland is designed properly, the sediment should remain in the wetland. Appropriate wetland designs include trapping and retaining sediments in the wetland.
What about metals accumulation in the soil and plants?	Studies have shown that the accumulation of metals in the soil and plants can be quite variable. Some sites with no contaminated water flow showed levels of metals in the plants that were greater than those growing 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 is likely 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.

Canada's Wetland Regions

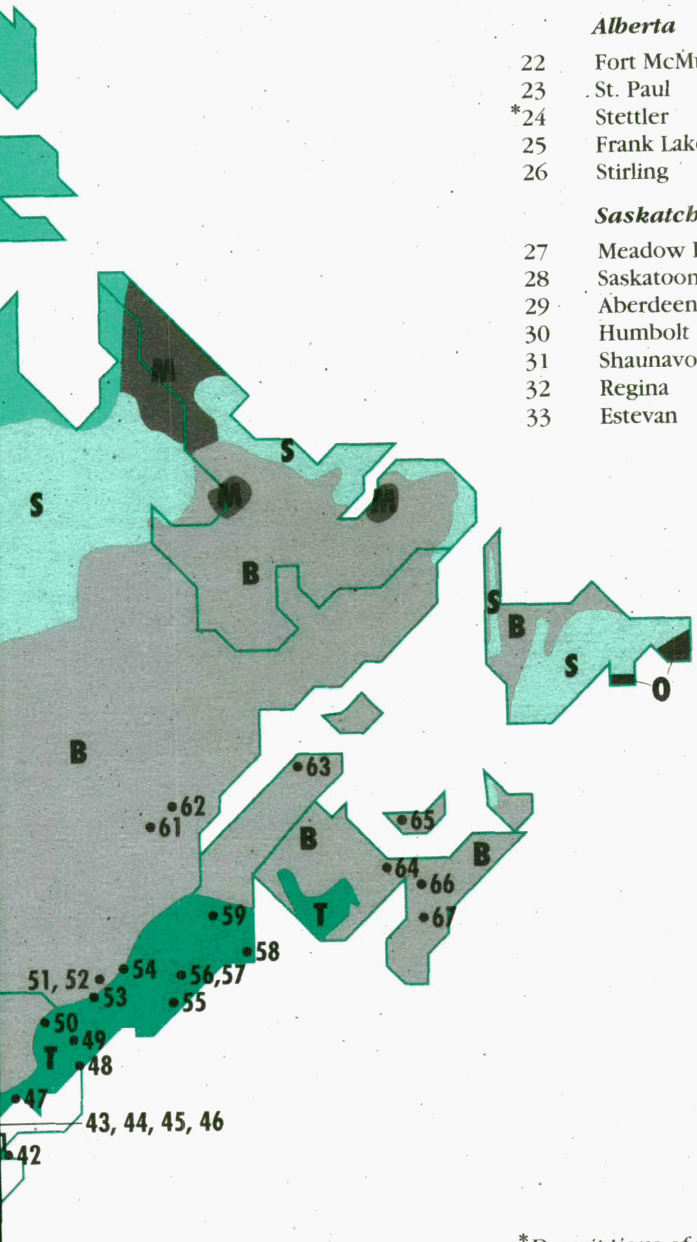


Legend

- A **Arctic** *(High Arctic, Mid Arctic, Low Arctic)*
- [redacted] **Prairie** *(Continental prairie, Intermountain prairie)*
- [redacted] **Temperate** *(Eastern temperate, Pacific temperate)*
- S **Subarctic** *(High subarctic, Low subarctic, Atlantic subarctic)*
- B **Boreal** *(High boreal, Mid boreal, Low boreal, Atlantic boreal)*
- **Oceanic** *(Atlantic oceanic, Pacific oceanic)*
- [redacted] **Mountain** *(Coastal mountain, Interior mountain, Rocky mountain, Eastern mountain)*

Figure 1: Location of Surveyed Wastewater and Stormwater Wetlands in Canada

Number	Location
	Yukon
*1	Old Crow
2	Destruction Bay
3	Haines Junction
4	Crestview
5	Faro
6	Ross River
7	Teslin
	Northwest Territories
8	Hay River
9	Pine Point
	British Columbia
10	West Moberly
11	Portage
12	Stellaquo
*13	Coal Creek
14	Rosewall Creek
15	Pinecrest Estates
16	Richmond
17	Burnaby
18	Frances Garden
19	Throup Road
20	Fishtrap Creek
21	Chilliwack
	Alberta
22	Fort McMurray
23	St. Paul
*24	Stettler
25	Frank Lake
26	Stirling
	Saskatchewan
27	Meadow Lake
28	Saskatoon
29	Aberdeen
30	Humbolt
31	Shaunavon
32	Regina
33	Estevan
	Manitoba
*34	Oak Hammock
	Ontario
35	Cobalt
36	Listowel
*37	Fullerton Township
*38	Sarnia
39	Lambton
40	Essex
41	Hamilton
42	Niagara-on-the-Lake
43	Mississauga
44	East York
45	North York
46	Scarborough
47	Port Perry
48	Storrington
49	Rideau Township
50	Kanata
	Quebec
51	Lac Simon
52	Lac Simon
53	Carillon
54	Mirabel
55	Rivière Beaudette
56	Île Ste. Hélène
57	Montreal (Biosphere)
*58	Stoke
59	Grand-Saint-Esprit
60	Fontages
61	Saint-Felicien
62	Saint-Henri de Taillon
63	Saint-Vianney
	New Brunswick
64	Moncton
	Prince Edward Island
*65	New Hannan
	Nova Scotia
66	River Hebert
67	Hwy. 101 Landfill



*Descriptions of these sites are given in the following "examples" section.

Examples of Canadian Constructed Wetlands for Wastewater Treatment

Pacific Temperate Wetland Region – Industrial Application

Coal Creek, British Columbia
Constructed Wetland for Fish Hatchery Wastewater Treatment at Rosewall United Fish Farms

At this Vancouver Island salmon hatchery, the wastewater originates as two streams. The first is heated rearing tank water derived from small fish tanks used for rapid development of fingerlings from the swim-up stage of development. The larger flow, from the main fish holding tanks, is unheated water and is used to grow fingerlings up to smolt size. Both waste streams are provided preliminary treatment by screening through TRIANGEL filters. The continuous flow of backwash water from the TRIANGEL filters is directed to a settler unit and the supernatant discharges into a small marsh. The filtered waters are passed through a biological filter and then into a larger marsh.

The system has been developed to maintain the high-quality fresh waters of Coal Creek and to protect an oyster fishery on the beach receiving the Coal Creek waters. Direct discharge of the fish hatchery waters has not been permitted. The treatment and disposal system maximizes removal of organic load and nutrients, and reduces the potential for transfer of diseases from the hatchery to wild stocks in the creek.

The backwash water flow rate is estimated at 111 m^3/day. The wetland required to treat this volume is approximately 40 m x 33 m, and the screened water ultimately discharges to a larger marsh. Both wetlands were constructed in 1991 from materials on site and cattail is the predominant plant species. Final discharge of the treated wastewater is dispersed through a drainage system that utilizes waste oyster shells to reduce the impact of fresh water on the salinity levels of the commercial oyster beach. No significant difference has been found between the quality of the treated waters exiting the marsh and the Coal Creek waters.

Continental Prairie Wetland Region – Agricultural Application

Stettler, Alberta
Slough Consolidation and Runoff Retention

A water management research and demonstration project (the Massey Research Project) near Stettler in central Alberta was initiated to test the technical and economic feasibility of storing excess runoff water on farms as an alternative to building conventional drainage ditches. Runoff, which accumulates in 15 sloughs on a typical quarter section, is collected by a subsurface pipe system and pumped into a three-hectare consolidation pond located in a corner of the property. The collection pipe network and automatic pumping system are designed to remove all water from the sloughs in time for spring seeding so the sloughs can be cropped as part of the adjacent field. The stored water is irrigated onto the cropland to empty the pond each fall.

It is important to clearly define the meaning and objectives of slough consolidation and to recognize the legal and technical implications of this water management concept. Slough consolidation involves "the amalgamation of several sloughs or water retention areas into one slough or storage pond to reduce the number of obstacles to farming." In the past, consolidation has been practised mainly on farms with large, deep sloughs into which smaller, higher elevation sloughs can be drained by gravity. The addition of a pumping system, as in this project, is a way to expand the application of the concept to those farms where little topographic difference exists between sloughs.

The consolidation pond and surrounding uplands were modified to provide enhanced wildlife habitat by construction of nesting islands and planting of trees and grass. Ongoing research will evaluate the agricultural and wildlife benefits of this slough consolidation concept and develop design criteria for on-farm runoff management in similar climatic regions of central Alberta.

Prairie Continental Wetland Region – Municipal Application

Stonewall, Manitoba
Oak Hammock Marsh Conservation Centre
Wastewater Treatment System

Oak Hammock Marsh Conservation Centre is serviced by a wastewater treatment system which was designed to meet and surpass the requirements of the Manitoba Environment Act Licence. A three-cell lagoon system was chosen over a mechanical treatment system because it is more reliable, has a lower maintenance cost, and a lower capital cost. The system accommodates the sewage treatment needs of the Oak Hammock Marsh Conservation Centre which holds a staff of 140, has a public cafeteria, and is expected to attract over 200 000 visitors annually.

The system consists of three cells, one more than traditionally constructed. The primary cell receives untreated wastewater and provides treatment through a "settling out" of the larger particles and biological breakdown of the remaining wastewater. The second cell receives overflow and provides additional treatment and storage through the winter months when no effluent is discharged. At this point, the two-cell system would have reduced the biochemical oxygen demand as well as levels of suspended solids and coliform in the effluent, prior to discharging effluent from the system. However, the Oak Hammock Marsh Conservation Centre system has been designed to include a third cell to further safeguard against impacting the environment. This third cell is an artificial, gravel-bottom marsh planted with cattails that removes phosphates and nitrates and further reduces the biochemical oxygen demand from the already treated sewage. It also provides additional wetland habitat for wildlife.

The system was chosen for the Oak Hammock Marsh Conservation Centre to act as a demonstration model that will hopefully encourage municipalities to incorporate a constructed marsh or artificial wetland in future lagoon developments.

The system will store wastewater between November 1 and July 15 of the following year in the primary and secondary cells. Liquid will be discharged into the third cell, or artificial marsh, held for two to three weeks, then discharged into Oak Hammock Marsh. Effluent will not be transferred into the third cell until the organic content (BOD <30 mg/L), the fecal coliform content (<200 per 100 mL), the total coliform content (1 500 per 100 mL), and the sodium content (<300 mg/L) meet the requirements of the Manitoba Environment Act Licence issued on January 28, 1991.

High Subarctic Wetland Region – Municipal Application

Old Crow, Yukon
Natural Wetland for Sewage Treatment

A small single-celled lagoon was constructed for the Department of Indian and Northern Affairs Canada by the Yukon Government in 1975. It was originally built to provide for disposal of educted sewage from federal institutional buildings in the community. Shortly after it was completed, responsibility for its operation and maintenance was transferred to the Yukon Government.

When full, it was periodically discharged by pumping the treated effluent to a surrounding swamp that flowed into the Porcupine River. In time, it became apparent the lagoon was too small for Old Crow, as an increasing number of new homes were built with sewage holding tanks. In 1984, the Yukon Government's Municipal Engineering Branch commenced planning for a larger facility to replace the existing lagoon. In 1986, predesign information for a new facility was included in the application for the Water Licence renewal. The new single-celled lagoon was larger and was to be located in the same swampy areas as the old lagoon.

The supporting documentation for the water licence renewal included a small amount of performance data collected from the old lagoon which examined the degree of further treatment and effluent polishing which occurred in the wetlands. On the strength of the submission, a new licence was issued which, for the first time, formally incorporated the concept of wetland sewage treatment.

Construction on the new lagoon commenced in 1987 and the system was commissioned in the Fall of 1988. With low water usage in the community (which utilizes trucked delivery), the lagoon has taken a long time to completely fill, but has had no problems meeting all licence conditions (Nairne 1992).

Low Boreal Wetland Region – Agricultural Application

Fullerton Township, Ontario
Constructed Wetland to treat Contaminated Barnyard Runoff

The first constructed wetland system for treating barnyard runoff in Ontario was installed by a dairy farmer in Fullerton Township near the City of Stratford, Ontario. In 1992, the landowner contacted the Upper Thames River Conservation Authority with the idea of installing a marsh system to treat barnyard runoff from his dairy operation. A system was designed by a Conservation Authority engineer and biologist. Construction was completed over a four-day period in June 1993.

The constructed wetland is 0.32 ha in size and consists of a three-stage treatment system. Runoff from the concrete yard and storage area is temporarily ponded in a grass settling area. Here the water drains slowly through a vertical pipe inlet to the second treatment cell. The second cell is designed to move the runoff water through a shallow 20 to 30-cm deep winding channel. Cattails, bulrushes, and other wetland vegetation were transplanted from a nearby pond into the channel. The majority of the transplanting took place in November, when the plants were dormant. However, 40 cattails planted in July survived surprisingly well and produced approximately 500 new shoots by September 1993. Water from the second cell flows into a third pond area which has a variety of shallow and deep vegetation.

Prior to construction, hydrogeological testing of the site was completed and the groundwater monitoring wells were installed. Both groundwater and surface water quality are being monitored for chemical and bacterial concentrations. As well, instrumented stations accurately monitor surface water flow, water temperature and rainfall.

Samples taken in the first six months of operation indicate that the constructed wetland has performed well to reduce contaminants in the runoff water. It is believed that much of the initial contaminant reduction is the result of solids settling, adsorption to the bottom sediments, and sunlight exposure. Although initial results show good removal efficiencies, it is too early to make any predictions on the system's future ability to treat contaminated water. Monitoring will continue for several years.

If the success of the wetland technology continues, agriculture will have an alternative low cost method for handling barnyard runoff that uses a passive natural system for treating contaminants.

Eastern Temperate Wetland Region – Municipal Application

Sarnia, Ontario
Landfill

The Sarnia Landfill Site consists of 21 ha of approved landfill area, as well as 40 ha to the south of the landfill area. In order to prevent the offsite migration of leachate generated within the landfill, the site is equipped with a perimeter leachate containment system.

The leachate containment system consists of a low permeable barrier and perforated tile collection system. Leachate is treated at an average rate of 13.6 m^3/day (3 000 IGPD). The effluent from the Leachate Treatment Facility is discharged via two storage lagoons and a sedimentation pond to the wetlands located east of the site.

The wetland is situated immediately to the east of the landfill site on 60 ha of land leased by the County of Lambton. It covers an area of approximately 6.5 ha and is situated in a basin about three metres below the surrounding landscape. The wetland is primarily wooded and is typically flooded from late winter into early summer, or for approximately 12 to 25 percent of the growing season. By late summer in most years, the wetland is dry. The wetland is the final biological treatment process that the treated leachate effluent undergoes before it enters Perch Creek and subsequently Lake Huron. Treated leachate effluent in the storage lagoon or the aeration lagoon can be discharged via a sedimentation pond to the wetland from March through November, as stated in the Certificate of Approval.

The maximum water depth in the wetland basin is between 0.5 and 1.0 m. Once the wetland basin is filled, the effluent is transported in an easterly direction to Perch Creek. The estimated minimum distance that the effluent must travel from the sedimentation pond to Perch Creek is 800 m. Flow of effluent from the lagoons is regulated to provide a minimum retention time of two to four weeks within the wetland.

Eastern Temperate Wetland Region – Municipal Application

Stoke, Quebec
Wetland Treatment System

The Municipality of Stoke completed a constructed wetland in the Fall of 1993 to treat the effluent from an existing septic system after carrying out a preliminary feasibility study of the wetland technology.

The subsurface flow wetland treatment system consists of four, 18 m long by 13.5 m wide cells planted with reeds (*Phragmites* sp.). It services a population of 130 people at a design flow rate of 41 m^3/day and is operated year-round.

This is the first system of its kind to be implemented in Quebec for the treatment of municipal wastewater. The wetland system is presently the focus of a research project that will evaluate the performance of the system over a period of three years.

Atlantic Boreal Wetland Region – Industrial Application

New Hannan, Prince Edward Island
Cavendish Farms, Biological Wastewater Treatment

One of the most complex and modern biological wastewater treatment plants in North America was completed in the Fall of 1993 at New Annan, near Summerside, Prince Edward Island. The complex treats wastewater from the Cavendish Farms potato processing plant which operates around the clock, seven days a week, all year. The plant produces french fries and frozen peas in season.

The artificial wetland is adjacent to the treatment plant and is used to further polish the wastewater treatment plant effluent. The complex is operated by the company and treats all of the wastewater from the processing plant. The polished, disinfected effluent from the advanced activated sludge system is sent to a 1.6 ha detention pond that has a two-day detention time. The effluent can be assessed at the detention pond and, if it doesn't meet the standards set for it, can be returned to the bioreactor for further treatment. If the effluent is satisfactory, it proceeds to an artificial wetland and finally to Malpeque Bay.

The wetland was seeded naturally with local emergent aquatic vegetation such as cattails, rushes, and reeds. The plants are both submerged and bank rooted. The wetland covers 1.6 ha and is designed with three cells operated in series. The wetland cells were constructed using earthen berms and construction followed existing contours using a balanced cut-and-fill technique. Overflow weir structures connect the cells enabling effluent level control in each cell. It is anticipated that each cell will be drained annually to permit harvesting of vegetation growth. By harvesting the plants, some of the nutrients removed from the wastewater will be removed from the system.

The effluent from the new wastewater treatment plant is of excellent quality prior to discharge to the wetland. The plant, immediately upon startup, met or exceeded all provincial and federal requirements. Since startup, effluent ammonia has been consistently below two ppm and five-day biochemical oxygen demand (BOD_5) has remained under 10 ppm. Chemical oxygen demand (COD) removals have been 99 percent plus. Suspended solids are averaging about 10 mg/L. These removals are being realized before the effluent reaches the wetland where further treatment is expected.

Wastewater and Stormwater Treatment Wetlands in Canada

National Distribution

An intensive survey was carried out by CH2M HILL Engineering Ltd. of Waterloo, Ontario in early 1994 to determine the locations of wetlands used for stormwater and wastewater treatment in Canada. Figure 1 shows the location of each of 67 sites that were identified in this survey (it has since been discovered that more sites exist). A copy of the questionnaire that was sent to each of the wetland authorities managing these sites is provided in Appendix C. Data on additional sites is invited. New reports can be filled out and mailed in for inclusion in future updates of the database that has been developed for the Secretariat to the North American Wetland Conservation Council (Canada) in Ottawa.

The frequency of wetlands for wastewater and stormwater treatment in Canada, as seen in Table 4, is highest in the Temperate and Boreal Wetland Regions defined by the National Wetlands Working Group (1986). The High Boreal Wetland Region, which stretches into the central part of the Yukon and Northwest Territories (NWT), has at least ten wetlands for wastewater treatment that are operating on a seasonal basis, or have been approved by the regulatory authorities. The climate in this region is typified by long winters, high accumulations of snow, and short summers with short growing seasons. The status and location of each of the wetlands is summarized in Table 5.

Of the 67 wetlands identified, 67% are full-scale operating systems, 9% are pilot installations, 18% are designed and approved sites, and 6% are pilot- or full-scale systems that have "failed." A selected number of these projects are featured in this section. It is important to note that the "failed" systems are providing to wetland designers and researchers valuable data, experience, and knowledge that will help to develop better design data for the future. This is particularly true of the Listowel, Ontario project where extensive monitoring was carried out. It is very evident that since the installation of the "failed" systems of the late 1970s and early 1980s, wetland design criteria have undergone considerable changes and have evolved to ensure much more reliable wastewater and stormwater treatment performance.

Provincial and Territorial Summaries

This section gives a summary of the use of wetlands for wastewater and stormwater treatment in all Canadian provinces. Over 100 contacts were made with knowledgeable sources actively involved in wetland treatment issues. This yielded descriptions of a total of 51 operating wetland treatment systems, four that had been tested and abandoned, and 12 systems that were approved for installation in 1994. In general, those contacts with the most wetland experience and familiarity with the literature, were the most supportive of the technology.

"'Failed' systems have provided wetland designers and researchers with valuable data, experience, and knowledge."

Table 4

*Treatment Wetlands in Canada by Wetland Region**

WETLAND REGION	NO. OF SITES	EXISTING FULL-SCALE	EXISTING PILOT-SCALE	TESTED AND ABANDONED	PROPOSED	WETLAND POTENTIAL
Arctic						
High Arctic	0					L
Mid Arctic	0					M
Low Arctic	0					M
Subtotal	0					
Subarctic						
High Subarctic	1	1				M
Low Subarctic	1	1				H
Atlantic Subarctic	0					H
Subtotal	2	2				
Temperate						
Eastern Temperate	20	8	2	1	9	H
Pacific Temperate	8	6	2			H
Subtotal	28	14	4	1	9	
Boreal						
High Boreal	9	8	1			H
Mid Boreal	5	4		2	1	H
Low Boreal	7	4			1	H
Atlantic Boreal	5	4			1	H
Subtotal	26	20	1	2	3	
Mountain						
Coastal Mountain	1	1				H
Interior Mountain	0					H
Rocky Mountain	0					M
Eastern Mountain	0					M
Subtotal	1	1				
Prairie						
Continental Prairie	10	8	1	1		H
Intermountain Prairie	0					H
Subtotal	10	8	1	1		
Oceanic						
Atlantic Oceanic	0					H
Pacific Oceanic	0					H
Subtotal						
CANADA TOTAL	67	45	6	4	12	–

**Wetland Regions as defined by National Wetlands Working Group (1986).*

Wetland Potential: L = Low M = Medium H = High

Table 5

Location and Status of Treatment Wetlands

NUMBER	LOCATION	WETLAND REGION	APPLICATION	FULL-SCALE	PILOT-SCALE	DESIGNED[1]
	Yukon					
1	Old Crow	SH	Municipal, Lagoon	*		
2	Destruction Bay	BH	Municipal, Lagoon	*		
3	Haines Junction	BH	Municipal, Lagoon	*		
4	Crestview	BH	Municipal, Lagoon	*		
5	Faro	BH	Municipal, Lagoon	*		
6	Ross River	BH	Municipal, Lagoon	*		
7	Teslin	BH	Municipal, Lagoon	*		
	Northwest Territories					
8	Hay River	BH	Municipal, Lagoon	*		
9	Pine Point	BH	Municipal, Lagoon	*		
	British Columbia					
10	West Moberly	BM	Municipal, Lagoon			*
11	Portage	BM	Municipal, Lagoon	*		
12	Stellaquo	BM	Municipal, Lagoon	*		
13	Coal Creek	TP	Industrial, Fish Hatchery (two sites)	*		
14	Rosewall Creek	TP	Industrial, Fish Hatchery	*		
15	Pinecrest Estates	MC	Municipal, Wastewater Treatment Plant Secondary Effluent	*		
16	Richmond	TP	Landfill, Leachate	*		
17	Burnaby	TP	Stormwater, Rural		*	
18	Frances Garden	TP	Municipal, Wastewater Treatment Plant Secondary Effluent	*		
19	Throup Road	TP	Municipal, Wastewater Treatment Plant Secondary Effluent	*		
20	Fishtrap Creek	TP	Stormwater, Urban	*		
21	Chilliwack	TP	Industrial, Oil		*	
	Alberta					
22	Fort McMurray	BH	Industrial, Oil		*	
23	St. Paul	BM	Municipal, School	*		
24	Stettler	PC	Farm, Stormwater		*	
25	Frank Lake	PC	Industrial, Meat Packer Municipal, Lagoon	*		
26	Stirling	PC	Municipal, Lagoon	*		

Table 5 (continued)

Location and Status of Treatment Wetlands

NUMBER	LOCATION	WETLAND REGION	APPLICATION	FULL-SCALE	PILOT-SCALE	DESIGNED[1]
	Saskatchewan					
27	Meadow Lake	BM	Municipal, Lagoon	*		
28	Saskatoon	PC	Stormwater, Urban	*		
29	Aberdeen	PC	Municipal, Lagoon	*		
30	Humbolt	PC	Municipal, Lagoon		*	
31	Shaunavon	PC	Municipal, Lagoon	*		
32	Regina	PC	Stormwater, Urban	*		
33	Estevan	PC	Municipal, Lagoon	*		
	Manitoba					
34	Oak Hammock	PC	Municipal, Lagoon	*		
	Ontario					
35	Cobalt	BL	Municipal, Lagoon		*	
36	Listowel	BL	Municipal, Lagoon		*	
37	Fullerton Township	BL	Farm, Manure Runoff	*		
38	Sarnia	TE	Landfill, Leachate	*		
39	Lambton	TE	Stormwater, Industrial	*		
40	Essex	TE	Farm, Manure Runoff	*		
41	Hamilton	TE	Farm, Manure Runoff			*
42	Niagara-on-the-Lake	TE	Municipal, Lagoon		*	
43	Mississauga	TE	Stormwater, Urban	*		
44	East York	TE	Stormwater, Urban			*
45	North York	TE	Stormwater, Urban			*
46	Scarborough	TE	Stormwater, Urban			*
47	Port Perry	TE	Municipal, Lagoon	*		
48	Storrington	TE	Landfill, Leachate		*	
49	Rideau Township	TE	Farm, Manure Runoff	*		
50	Kanata	TE	Stormwater, Urban			*
	Quebec					
51	Lac Simon	BL	Municipal, Single Family Dwelling	*		
52	Lac Simon	BL	Municipal, Septic Tank	*		
53	Carillon	TE	Municipal, Septic Tank			*
54	Mirabel	TE	Municipal, Septic Tank	*		
55	Rivière Beaudette	TE	Municipal, Septic Tank			*
56	Île Ste. Hélène	TE	Recreational, Beach	*		
57	Montreal (Biosphere)	TE	Municipal, Septic Tank	*		
58	Stoke	TE	Municipal, Septic Tank	*		

Table 5 (continued)

Location and Status of Treatment Wetlands

NUMBER	LOCATION	WETLAND REGION	APPLICATION	FULL-SCALE	PILOT-SCALE	DESIGNED[1]
59	Grand-Saint-Esprit	TE	Municipal, Lagoon			*
60	Fontages	SL	Municipal, Lagoon	*		
61	Saint-Felicien	BL	Municipal, Zoo, Lagoon	*		
62	Saint-Henri de Taillon	BL	Municipal, Lagoon			*
63	Saint-Vianney	BA	Municipal, Lagoon	*		
	New Brunswick					
64	Moncton	BA	Municipal, Lagoon	*		
	Prince Edward Island					
65	New Hannan	BA	Industrial, Potato Processor Secondary Effluent; Wastewater Treatment Plant	*		
	Nova Scotia					
66	River Hebert	BA	Municipal, Lagoon			*
67	Hwy. 101 Landfill	BA	Landfill, Leachate	*		

[1]System has been designed and approved by the regulating authorities. Construction to begin when weather permits.

Legend/Notes:

Wetland Regions: *BA - Atlantic Boreal*
BH - High Boreal
BL - Low Boreal
BM - Mid Boreal
MC - Coastal Mountain
MI - Interior Mountain
OP - Pacific Oceanic
PC - Continental Prairie
SH - High Subarctic
SL - Low Subarctic
TE - Eastern Temperate
TP - Pacific Temperate

Applications: *Municipal - Treated (Primary/Secondary) Municipal Wastewater*
Lagoon- Primary/Secondary Lagoon Treatment (Facultative or Aerated)
Industrial - Treated Industrial Wastewater
Oil - Treated Wastewater from the Oil Industry
Fish Hatchery - Treated Fish Hatchery Wastewater

Yukon

Outside of the capital, Whitehorse (population 21 000), the communities range in size from 80 to approximately 1 600 residents. Most Yukon communities are situated in river valleys or beside lakes. During the past decade, there has been a concerted effort made by the Yukon and federal governments, municipalities, and the Territorial Water Board to upgrade and construct high standard sewage treatment facilities in the majority of Yukon communities. This has been accomplished despite limited funding, necessitating the investigation and utilization of cost-effective and innovative treatment technologies, including wetland treatment. Seven communities (see Table 5) are currently using natural or constructed wetlands in conjunction with pretreatment in facultative lagoons to meet their wastewater treatment needs (Grainger and Yaworsky 1992). Some of these wetlands were constructed in the mid-1960s and continue to operate. Most wetlands receive seasonal discharge between the months of June and September. A wetland feasibility study has been carried out for the City of Whitehorse (Klohn Leonoff Yukon Consulting Engineers Ltd. and NovaTec Consultants Inc. 1991).

Several challenges for wastewater treatment using wetlands in northern communities include permafrost (damage to berms), low precipitation, extreme temperatures, 24 hours of sunshine during the summer, and 24 hours of darkness during the winter that can lead to septic conditions.

Northwest Territories

The wetland search that was carried out revealed that at least two systems are operating in the Northwest Territories at Hay River and Pine Point. Both are natural wetland systems receiving municipal wastewater treatment lagoon effluent on a seasonal basis.

British Columbia

Full-scale or pilot-scale wetlands are being used in British Columbia at 12 separate sites (see Table 5). The applications include cleanup of stormwater at a diesel fuel truck filling station, coal mining wastewater and stormwater treatment, phosphorus removal from creeks entering several lakes, leachate control (including leachate control from wood waste material used in highway construction in soils having poor load bearing characteristics), fish hatchery wastewater treatment (at least two systems have been installed), and municipal wastewater treatment including two systems that have been installed on aboriginal lands.

Photo: J. Brunen

Wastewater wetland with constructed islands at Frank Lake, Alberta.

Wastewater wetland research in British Columbia has taken place for some time and there are several very knowledgeable contractors working within the province.

Alberta

The provincial regulatory authorities in Alberta view the use of wetlands for stormwater and wastewater treatment as a relatively new and untried technology that requires further study. The City of Calgary has set up a task force sanctioned by Alberta Environment to investigate the feasibility of using wetlands for stormwater treatment. Numerous potential sites have been identified and it is anticipated that of the eight to ten sites to be chosen, two sites will be highly monitored. A program called "Wetlands for Tomorrow" has been established in an effort to enhance wetlands, create habitat, store irrigation water, and treat sewage. At least five wetland wastewater treatment sites are now in operation (see Table 5).

Currently, lagoon and wastewater treatment plant effluents are required to meet the by-law objectives prior to discharge to the wetlands. Therefore, the wetlands are not considered to be an integral part of the wastewater treatment system. There is no required monitoring of the discharge of the wetlands because the discharge from wetlands is not regulated. Wetlands have been used in several pilot- and full-scale applications including the treatment of oil-contaminated water and clay-water suspensions (fine tails). Wetlands are being considered for treating feedlot stormwater runoff.

Saskatchewan

Constructed wetlands have been installed in at least seven communities in Saskatchewan (see Table 5) over the last decade following feasibility studies that showed promise for the wetland technology. In many cases, the wetland treatment capability has been inconclusive due to a lack of monitoring data. The

"An interpretive centre has been opened that will describe the wastewater treatment aspect of the wetland at Oak Hammock Marsh, Manitoba."

Saskatchewan Research Council in Saskatoon is carrying out a pilot study with a 20 m by 40 m wetland for phosphorus and blue-green algae removal.

The Town of Humbolt wetland is an example of a demonstration wetland system that apparently did not meet expectations. It was commissioned in 1979 and operated for several years. It received a seasonal discharge from a wastewater lagoon. After completion of the experimental period, the system was abandoned. One opinion that was offered by a town resident was that the wetland was considered to be unsuitable for the flow rate and for the climate. However, the data from the system were reviewed and were found to be comparable to those for similar systems that were operating well. The town may have had higher expectations than what was reasonable for this type of system.

The Town of Estevan wetland was constructed and is owned by Saskatchewan Power to treat the town's secondary lagoon effluent. The discharge is used for makeup water for the power plant after BOD and TSS reduction.

Manitoba

The Prairie Farm Rehabilitation Administration (PFRA) indicated that most of the wastewater treatment in

Manitoba is provided by lagoon developments. During the course of preparing this document, only one wastewater wetland for wastewater treatment was found. Ducks Unlimited Canada has constructed a wastewater wetland at the Oak Hammock Marsh Conservation Centre near Stonewall. It has been designed to treat secondary lagoon effluent that meets provincial water quality standards and federal phosphorus removal requirements. Oak Hammock Marsh is a restored 1 600 ha wetland of what was once an approximately 40 500 ha wetland that had been drained and reduced to about 40 ha by the mid-1970s. The constructed wetland treatment system, which has been in operation since 1993, is located on several hectares of land beside the marsh. Observation decks have been built in and around the wetland for wildlife viewing. An interpretive centre includes description of the wastewater treatment aspect of the wetland. A water quality monitoring program is in place to ensure optimal performance of the system.

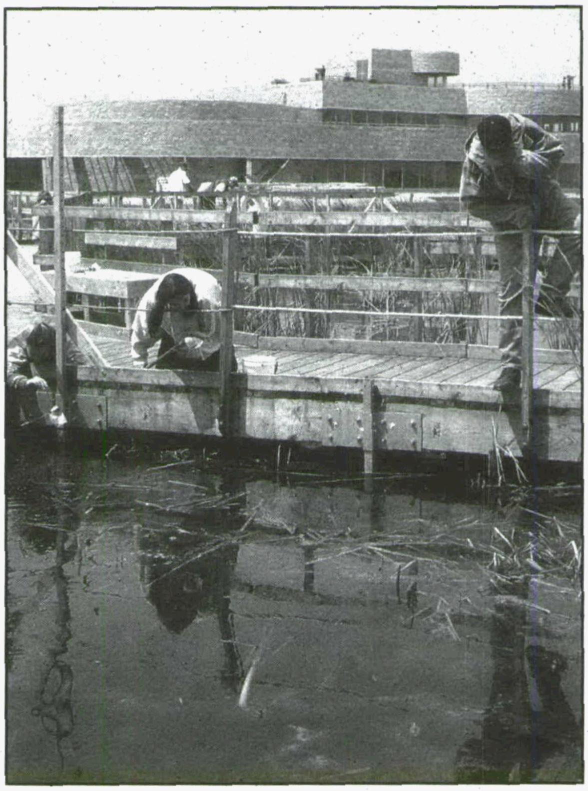


Photo: C. Rubec, Environment Canada

Education is a primary focus of the Oak Hammock Marsh Conservation Centre at Stonewall, Manitoba. The site includes a functioning wastewater wetland.

Ontario

The biggest push for the use of wetlands for wastewater treatment in this province is coming from the Ontario Ministry of Agriculture and Food. A program, initiated in 1993, will allow eight wetlands to be installed by the end of 1994 for agricultural applications across the province focusing, in particular, on stockyard runoff. Five of these are currently operational. The intent of this program is to provide a closed loop system that would result in no direct discharge of the wetland effluent to a water course. The systems will rely to a large extent on evaporation for disposal of the polished effluent and irrigation of any excess. This reduces the likelihood of a requirement for a Certificate of Approval for surface water discharge. The wetland systems will be established in differing climatic regions and will be evaluated over the next several years to determine their future applicability to the farming community in Ontario.

Other wetland treatment systems include treating wastewater from a high school in southwestern Ontario, a sewage treatment plant outfall bypass during rainstorm events in northern Ontario, parking lot stormwater treatment, treatment of ash and coal pile runoff at a thermal generating station, and various other small stormwater and wastewater treatment applications. At least 11 wastewater treatment wetlands have been installed in Ontario.

The Ontario Ministry of Environment and Energy maintains that wastewater should be treated to secondary standards at a minimum prior to discharge to the wetland. They are also concerned that phosphorus removal and then subsequent release by the wetland in the spring and fall must be accounted for in the design. It was also noted that an increase in the hydrogen sulphide concentration across the wetland could result in an anaerobic discharge. Seasonal discharge was considered to be more acceptable than continuous, year-round discharge.

Several pilot operations are being or have been monitored including Storrington Landfill (north of Kingston) for the treatment of leachate, Niagara-on-the-Lake for tertiary treatment of secondary lagoon effluent, and Listowel for the treatment of primary and secondary lagoon effluent. It is important to note that the large volume of data that was collected at the Listowel site is providing valuable design information to several wetland experts. Wetlands awaiting construction after gaining approval from the regulatory authorities include a stormwater wetland designed for the City of Kanata. Numerous wetland projects are in the predesign or the design phase and are under review by the clients.

Quebec

There are numerous constructed wetlands in this province, the majority of which are subsurface flow systems. The projects include treatment of the effluent from septic tanks, municipal lagoon effluent, tertiary treatment (phosphorus removal) of municipal wastewater, acid mine drainage, and treatment of high strength wastewater at a zoo. Several of these systems incorporate a vertical flow percolation unit prior to discharge to the wetland. Water quality improvement of a recreational swimming facility in Montreal is carried out using a constructed wetland. The system treating the wastewater from the Biosphere on Île Ste-Hélène will be an educational exhibit with appropriate signage explaining the wetland processes. Several more full-scale systems are operating in the Lac Simon-Papineauville area treating wastewater from single family homes, a hotel, and a golf course clubhouse.

New Brunswick

The regulatory authorities in New Brunswick are investigating natural treatment systems including wetlands for tertiary treatment of wastewater, non-point source pollution from farms, and stormwater treatment. The New Brunswick Department of Agriculture hosted a workshop in February, 1994 on constructed wetlands for agricultural runoff. Presentations were made by an American firm that had designed similar systems within 20 kilometres of the Canada-United States border over the past six years.

Currently, the New Brunswick Department of the Environment requires that lagoon wastewater treatment systems meet the discharge objectives prior to discharge to a wetland. Therefore, the few wetlands in operation to date are being used as tertiary treatment. A literature search of wetlands for wastewater

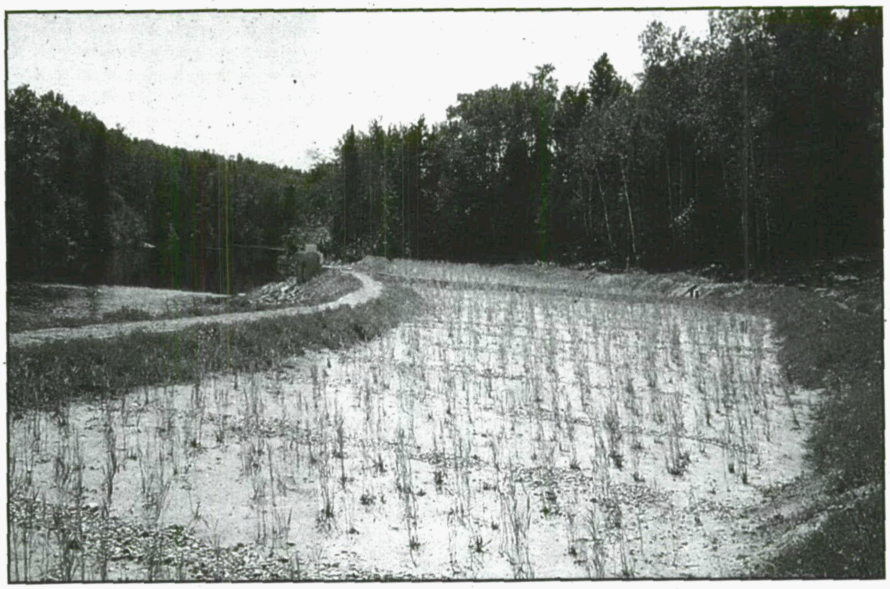


Photo: Les consultants RSA

Constructed wetland site, Quebec.

and stormwater treatment was carried out by the Eastern Canada Soil and Water Conservation Centre to gain a better understanding of the treatment processes and potential applications.

The Canadian Wildlife Service of Environment Canada in Sackville has indicated that constructed wetlands should be viewed as a technology that may be applicable to small community wastewater concerns for tertiary treatment but not for metals or toxics removal. Individuals within the province's regulatory authorities are interested in the use of wetlands for wastewater and stormwater treatment but are not willing to give blanket approval endorsing their use. They are willing to consider wetland applications on a case-by-case basis.

Other areas of interest in this province are: a trickling filter preceding a wetland; treating petroleum industry wastewater; the use of peat systems for wastewater treatment in small communities; landfill leachate treatment; and converting former cranberry production areas into constructed wetlands because the earthwork is already in place.

Nova Scotia

The Nova Scotia Department of the Environment considers development of wastewater wetlands to be a medium to high priority in the province. A workshop was held in Truro, Nova Scotia in August 1994 with emphasis on the treatment of milkhouse washwater and runoff from manure storage facilities at dairy farms. A literature review of wetlands for wastewater and stormwater treatment has been carried out by the Department of Environment.

Wastewater treatment wetlands are being actively explored in Nova Scotia. Ducks Unlimited Canada is undertaking the final design of a wetland treatment system. The Canadian Wildlife Service is awaiting approval to construct a wetland to treat secondary lagoon effluent. A geothermal greenhouse system for the year-round production of wetland plants for constructed wetlands is being considered. As many as 29 communities may require further wastewater treatment where constructed wastewater wetlands could be considered.

Prince Edward Island

In 1993, the Cavendish Farms potato processing plant began using a natural wetland to provide tertiary treatment for an already high quality effluent. They rely on populating the wetland by natural means with native vegetation.

The Prince Edward Island Fish and Wildlife Division recently completed a wetland inventory for the province. No wetlands for wastewater or stormwater treatment were identified although some of the waste stabilization ponds in the province are becoming wetlands as a result of unchecked wetland growth in the ponds.

The Prince Edward Island Department of Environment has had meetings with the Canadian Wildlife Service and Ducks Unlimited Canada regarding constructed wetlands for tertiary wastewater treatment. The Environmental Protection Service indicated that a new landfill site is using a natural wetland for treatment.

Newfoundland and Labrador

The Newfoundland and Labrador Sanitary Engineering Division indicated that, although no wetlands are currently being used for wastewater treatment in Newfoundland, wetlands and peat systems show potential for future application.

The Atlantic Coastal Action Program, at Humber Arm, noted that 28 outfalls from the coastal communities of Newfoundland are discharged to the ocean untreated. Several inland communities have some form of wastewater treatment and some homes have septic tanks. The issue of wastewater treatment is high on the priority list for action by this province.

Conclusions

This survey of Canadian agencies and jurisdictions involved in management of wastewater and stormwater treatment systems indicates that significant interest and acceptance of the range of wetland technology for wastewater and stormwater treatment now exists in Canada. These systems include use and enhancement of a narrow group of natural wetlands as well as construction of surface flow, subsurface flow and floating aquatic plant wetland systems. Across Canada, wastewater and stormwater treatment wetland systems are in place or under development in at least 67 locations, spanning all our provinces and territories. These systems are being applied to municipal and industrial wastewater and farm, agricultural, and municipal stormwater runoff. Potential applications for airports, parks, isolated communities, pulp and paper facilities and other areas are also discussed.

The potential impacts of wastewater and stormwater treatment wetlands on biota are examined. It is felt that most environmental concerns or risks identified to date can be dealt with through effective project design and use of current and evolving technology. Only 6% of the systems developed to date in Canada, specifically systems designed in the late 1970s and early 1980s, are deemed to have "failed". However, these systems have proven to be important models providing vital information relevant to improved design of more recent systems in our northern climate. The remaining 94% of these sites are success stories so far. Continued improvements in technology and research will likely enhance the value of wastewater and stormwater constructed wetlands technology.

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Additional Reading

A search was carried out to identify Canadian literature that has been written on wetlands for wastewater and stormwater treatment. Some American and European references were also included because much of the design and research documentation that is currently available originates from these sources. Literature is presented in two sections: Canadian and foreign sources.

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Appendices

Appendix A Methods to Design and Construct Wetland Systems

Overview of Design Criteria

Wetland design requires careful consideration of wetland type, configuration, size, water source, soils, and vegetation. Wetland design methods and criteria are continually being improved. The wetland designer should review references and obtain reviews of all design and construction plans prior to proceeding with construction. Wetland design references can be found in the "Additional Reading" section of the main text.

Type

The type of constructed wetland system desired may depend upon the feasibility of using natural wetlands for treatment, treatment performance requirements, estimated cost, and availability of required land area, among other site-specific conditions. No general consensus exists on the advantages of surface flow wetlands over subsurface flow wetlands (Water Pollution Control Federation 1990), but subsurface flow wetlands may be desired where land is limited or too expensive.

Area

Because wetland construction is inherently land-intensive, the total area required for wetland construction may be the single most important parameter for wetland feasibility, particularly in urban areas where land is limited and expensive. Sizing criteria described below should be used during conceptual and final designs to assist in determining project feasibility.

Natural and constructed wetlands have been used for removal of pollutants from domestic, industrial, and non-point source wastewaters. The area required by either type of wetland to meet the specific design objectives depends on a wide range of factors. Total area required for natural and constructed wetland treatment systems will vary as a function of the volume and quality of influent to be treated, desired wetland effluent quality, and allowable hydraulic loading rate.

Total wetland area should be based upon published or empirical pollutant mass removal data for the pollutant parameter of concern with the lowest pollutant removal efficiency. Wetland area requirements to achieve target pollutant concentrations in the effluent are available in Water Pollution Control Federation (1990), Reed *et al.* (1988) and Kadlec and Knight (in preparation).

Natural Wetland Treatment Systems: A maximum hydraulic loading rate of 1 to 2 cm/d and a minimum size requirement of 5-10 ha/1000 m^3/d have been recommended by the Water Pollution Control Federation (1990).

Constructed Surface Flow Wetland: A maximum hydraulic loading rate of 2.5 to 5 cm/d and a minimum size requirement of 3-4 ha/1000 m^3/d have been recommended by the Water Pollution Control Federation (1990).

Subsurface Flow Wetland: A maximum hydraulic loading rate of 6 to 8 cm/d and a minimum size requirement of 1.2 to 1.7 ha/1000 m^3/d have been recommended by the Water Pollution Control Federation (1990).

Stormwater Wetland: The Ontario Ministry of Environment and Metropolitan Toronto and Region Conservation Authority (1992) recommended that stormwater wetland area be determined as five percent of the watershed area. Schueler (1992) indicated that a smaller wetland area of one percent of the total watershed area was considered acceptable for wetlands with deep zones and longer hydraulic residence times.

Acid Mine Drainage Wetland: American criteria for sizing wetland systems for the passive treatment of acid mine drainage have been summarized by Hedin and Nairn (1992).

Configuration

Constructed wetlands are typically designed as single- or multiple-cell compartments in series or parallel to allow redistribution of flows, maintenance of plant communities, and flexibility of operation (Water Pollution Control Federation 1990). Multiple input points allow for more complete mixing of effluent within the wetland (Water Pollution Control Federation 1990). An aspect (length:width) ratio of at least 2:1, a gradual wetland slope on the order of 0.05 percent, and deep zones oriented perpendicular to the wetland flow provide even distribution of the wetland flow.

Water Source and Management

Predictability of water source availability, quality and management is important to maintain design hydroperiods, to assure long-term viability of wetlands, and to attain pollutant removal performance criteria in constructed wetlands. Water depth, hydraulic residence time, and inlet distribution and outlet structures are critically important engineering considerations. The majority of flow into constructed wetlands designed for treatment of wastewater will be effluent, with seasonal and typically smaller contributions from precipitation. By design, inflow to stormwater treatment wetlands will be dominated by runoff. The wide variability in the quantity and timing of these water sources needs to given careful consideration in design. Examples of design guidance for treatment wetland hydrology can be found in Kadlec and Knight (in preparation), Water Pollution Control Federation (1990), and Schueler (1992).

Shallow wetland water depths maintain dissolved oxygen concentrations sufficient to support nitrification. For optimum performance, experience suggests that maximum water depth for a surface flow wetland is 50 cm (Water Pollution Control Federation 1990). Subsurface flow wetland water levels are designed to be below the ground surface. Natural wetland water depths may vary over a wider range than surface flow wetlands, but are most effective if they do not exceed 50 cm. Minimum hydraulic retention time for surface flow and subsurface flow wetlands of 5-10 days, and 14 days for natural treatment wetlands are typical.

A minimum of primary treatment in surface flow and subsurface flow wetlands (Water Pollution Control Federation 1990), and secondary with nitrification and phosphorus reduction will provide the necessary pretreatment prior to discharge to natural wetland treatment systems.

Maximum BOD_5 loading rates of 100-110 kg/ha/d are recommended for surface flow wetlands, 80-120 kg/ha/d for subsurface flow wetlands, and 4 kg/ha/d for natural wetlands (Water Pollution Control Federation 1990). Recommended maximum total nitrogen loading rates are 60 kg/ha/d for surface flow and subsurface flow wetlands, and 3 kg/ha/d for natural wetland treatment systems.

Water distribution and collection structures should be simple to maintain, operate, and replace. Pipes should be slightly oversized. Trash racks or other suitable barriers should be erected before pipes to prevent clogging.

Soils

Soils should be suited to support wetland vegetation and to support the desired hydrology of the wetland. Soils for constructed wetlands should include salvaged wetland or upland topsoil to facilitate the establishment of wetland vegetation. Topsoil use in constructed wetlands should be considered as an option, but is not necessary as long as the exposed soils are capable of supporting the planted vegetation. Berms should be constructed from stable materials and protected by erosion control materials and methods.

Vegetation

Wetland vegetation should be selected for their tolerance of inundation and oxygen-poor, reduced environments. Desirable characteristics include tolerance of prolonged inundation, low oxygen concentrations in the water and soils, and rapid dense growth to shade surface waters and reduce algal production. Planting stock originating from the project region will increase survival potential.

Planting centres may range from 0.65-1.0 m for constructed wetlands. Vegetative diversity in the wetlands should be encouraged through the use of topsoil as mulch where feasible, and additional species plantings. Constructed wetlands planted with dense vegetation provide optimum conditions for contaminant removal. High plant diversity is optimal for ancillary benefits.

Planting rooted stock is one of several alternatives for wetland establishment and it is the most expensive. Recruitment from natural seedbanks, or broadcast seeding, are cheaper alternatives but have a time penalty for establishment.

Feasibility Analysis and Design

The technical, regulatory and economic feasibility of a wetland construction project should be thoroughly evaluated prior to proceeding to final design and construction. It is important that the landowner or proponent understand that wetland technology is still in a developing phase, and that it is not possible to predict wetland performance with high precision. It is equally important that the designer identify and take into consideration existing and known potential constraints to successful wetland construction and operation in order to provide reasonable assurance that project objectives will be met. The following section outlines the basic steps and information needs of a wetland construction feasibility analysis. It is assumed that the goals and objectives of the project have been clearly identified and agreed to by the landowner or proponent, designer, and concerned regulatory staff, if applicable.

Site Selection Criteria

Selection of an appropriate location for wetland construction should be based upon an analysis of identified alternative locations and the extent that they satisfy stated siting requirements, or criteria.

Criteria for locating a wetland will vary depending upon whether a wetland is being constructed to replace or restore lost ecological functions, enhance existing wetland functions, or constructed or enhanced to provide a new ecological function, as in a constructed or natural wetland treatment system. Guidelines proposed here are intended for siting constructed wetland treatment systems.

Possible wetland site selection criteria may include the following:

- Proximity to desired location.
- Availability of sufficient contiguous area.
- Availability of suitable long-term wetland water source.
- Favourable site hydrogeology.
- Acceptable site geotechnical constraints.
- Presence of existing or potential limiting land use, natural wetlands, protected species, historical or archaeological resources on or adjacent to site.
- Potential ease and cost of acquisition of ownership rights, easement, or other controlling interest.
- Ease of access for construction and maintenance.
- Availability of sufficient construction materials and labour resources.

Proximity: This criterion will vary depending upon the type of wetland to be constructed. Wetlands designed for stormwater treatment may need to be located at an appropriate topographic elevation in order to maximize gravity flow. Natural and constructed wetland treatment systems may need to be designed on or adjacent to the location of the pollution source in order to minimize land and pumping costs, and to control or limit public access.

Area: Total area requirements will vary with wetland goals, but in general, sufficient contiguous area should be available to allow the wetland to be constructed at one location to minimize construction, operation, and maintenance costs. Preliminary estimates of the required area may be determined for the site selection phase as described below under "Conceptual Design."

Wetland Water Source: Constructed wetland viability will be determined by the continued availability of wastewater effluent.

Hydrogeology: Site hydrogeology should be favourable for wetland construction. Excessively drained soils may not be suitable for wetland construction without the installation of an aquitard of clay or other materials of low hydraulic conductivity. Shallow depths to the surface of bedrock may also constrain wetland excavation.

Geotechnical Constraints: Wetland berm and substrate materials should be suitable for wetland construction and not lead to excessive erosion, sediment loss, or potential for failure under normal design extremes.

Limiting Land Uses and Other Siting Constraints: Human land use may constrain the suitability of a wetland construction location. Care should be taken to locate the wetland in areas with compatible zoning and other land uses in full recognition of the wetland design goals. The presence of natural wetlands, protected species habitats, and historical or archaeological resources on or adjacent to the site may pose additional, significant design constraints.

Ownership and Land Cost: Sites not currently under the ownership of the project owner will need to be assessed for ease of acquisition of ownership rights, easement, or other controlling interest. Because wetlands are land-intensive, land costs will significantly affect the total project cost.

Access: Each site should be evaluated for existing and potential ease of access for construction and future maintenance. Local land use regulations should be consulted to identify possible constraints to construction and maintenance traffic.

Materials: Availability of sufficient construction materials and labour resources should be evaluated within a regional context to minimize project cost and to maintain standards of quality for materials. The availability of skilled contractors, plant nurseries, and acceptable wetland construction materials should be assessed.

Table A.1 is designed to be filled in to describe the candidate wastewater treatment wetland and to predict the suitability of a candidate site for wastewater treatment using constructed or natural wetlands.

Data Collection

Sufficient data should be collected from each proposed construction site(s) to respond to the information needs of site-selection criteria, and to evaluate the potential for successful wetland permitting, construction, and operation.

Information categories yielding useful information for site selection, wetland design, and construction, include:

- Geography
  - Location
  - Temperature
  - Topography
  - Cover Type
  - Site Land Use, Zoning, and Ownership
  - Adjacent Site Land Use, Zoning, and Ownership
- Geology
  - Aquifers
  - Aquitards
  - Soils
- Hydrology
  - Precipitation
  - Watershed and Surface Drainage
  - Surface Waters
  - Soil Hydraulic Conductivity
  - Pan Evaporation
- Water Quality
  - Physical-Chemical Parameters
  - Biological Parameters
- Wetlands
  - Distribution and Jurisdiction
  - Type, Function and Quality
- Wildlife
  - Habitat Type and Function
  - Federal and Province Protected Species
- Historical and Archaeological Sites

Site Selection

The site selection process should result in a location that provides the greatest probability that the wetland will cost-effectively achieve the intended design goals. Costs should include long-term operations and maintenance costs as well as initial land and construction costs.

The site selection process for constructed wetlands should emphasize identification and selection of a location that provides the greatest potential for performance towards achieving water quality improvement goals at the lowest cost of initial construction and long-term operation and maintenance. Selection of a suitable site for construction of a natural wetland treatment system will be strongly limited by the type and location of existing site wetlands.

Table A.1 Description of Candidate Wastewater Treatment Wetland

Potential Wetland Location Site Data

Site Name: ____________________

Country: ____________________

Province/Territory: ____________________

City/Community: ____________________ *Population:* ________

Wastewater Source: *Municipal:* ____________________

(describe) *Industrial:* ____________________

Other: ____________________

Other anticipated Wetland Uses: *nature study*____ *hunting*____ *aquaculture*____

other (describe) ____________________

Wastewater Pretreatment: ____________________

Stormwater: *Watershed Area:* ____________________ *Units:* ________

% Impervious (roofs, parking lots, etc.): ____________________

Design Flow: ____________________ *Units:* ________

Site Substrate Material (e.g. sand, clay, muck, sandy clay, clayey sand, etc.): ____________

Permeability: ____________________

Vegetation Cover Type: ____________________

Land Area Available: ____________________ *Units:* ________

Proximity to Water/Wastewater Source: ____________________

Site Land Use: ____________ *Zoning:* ____________ *Ownership:* ________

Adjacent Site Land Use: ____________ *Zoning:* ____________ *Ownership:* ________

Presence of: *Existing or Potential Limiting Land Use:*____ *Natural Wetlands:*____

*Protected Species:*____ *Historical or Archaeological Resources On or Near Site:*____

*Aquifers:*____ *Aquitards:*____

Site Topography: ____________________

Table A.1 (continued)

Wastewater Treatment Plant/Stormwater Discharge Monitoring Data

Operating Season (months): ____________________

Period of Record: *Start (Year)* ____________________ *End (Year)* __________

Years in Service: ____________________

Average Flow: ____________________ *Units:* __________

BOD_5 (mg/L): ____________________

TSS (mg/L): ____________________

TDS (mg/L): ____________________

Turbidity: ____________________ *Units:* __________

NH_3-N (mg/L): ____________________

NO_3-N+NO_2-N (mg/L): ____________________

Total Nitrogen (mg/L): ____________________

TKN (mg/L): ____________________

Organic Nitrogen (mg/L): ____________________

Total P (mg/L): ____________________

Filtered P (mg/L): ____________________

Dissolved Oxygen (mg/L): ____________________

Redox Potential: ____________________ *Units:* __________

Sulphate/Sulphide (mg/L): ____________________

Conductivity: ____________________ *Units:* __________

Alkalinity (mg/L): ____________________

pH: ____________________

Temperature (degC): ____________________

Chloride (mg/L): ____________________

Metals (list): ____________________ *Units:* __________

____________________ *Units:* __________

____________________ *Units:* __________

Pesticides/Herbicides: ____________________ *Units:* __________

Organics (list): ____________________ *Units:* __________

____________________ *Units:* __________

____________________ *Units:* __________

Fecal Coliform (col/100 ml): ____________________

E. coli (col/100 ml): ____________________

(Others can be added to comments section)

Wetland System Outflow Permit Limits (A copy of the permit would be satisfactory)

Dissolved Oxygen (mg/L): ____________________

pH: ____________________

BOD_5 (mg/L): ____________________

TSS (mg/L): ____________________

NH_3-N (mg/L): ____________________

Total Nitrogen (mg/L): ____________________

Total P (mg/L): ____________________

Fecal Coliform (col/100 ml): ____________________

Permitted Flow (per day, week, month, year): ____________________

Permit Duration: *annual*___ *seasonal*___ *monthly*___ *other* (describe) __________

Permitting Agency: ____________________

Table A.1 (continued)

Contact Details

Last Name: ____________________

First Name: ____________________

Role: *Operator*____ *Eng. Design/Study*____ *Research & Development*____ *Performance Monitoring*____

Organization: ____________________

Address: ____________________

____

____

Phone No.: ____________________

Fax No.: ____________________

Climatic Factors

Average Number of Frost Free Days: ____________________

Average Annual Temperature: ____________________ *Units:*__________

Average Winter Temperature: ____________________ *Units:*__________

Annual Snowfall: ____________________ *Units:*__________

Annual Rainfall: ____________________ *Units:*__________

Annual Precipitation: ____________________ *Units:*__________

Elevation: ____________________ *Units:*__________

Comments

____

Conceptual Design

It is important to note that successful wetland design is an iterative process that requires the technical input of biologists, engineers, construction contractors, resource regulatory staff, and the project owners or proponents. A conceptual design should be prepared during the site selection process with available information in order to achieve the greatest realism in site selection. Key conceptual design elements include an approximate determination of wetland area, hydrologic requirements, ability to meet performance objectives, and cost of land and construction. These are discussed below by wetland type, with reference to the types of available site-specific information.

Area

Conceptual area requirements for natural and constructed wetland treatment systems should be conservatively determined as a function of hydraulic loading rate, pollutant loading rate, and performance objectives from published or experimentally-determined design criteria, as described in the section entitled "Establishment of Constructed Wastewater Treatment Wetlands."

Types of information that will be needed to determine this criterion for the Conceptual Design Phase include the average influent water quality and flow rate, effluent water quality objectives and flow limitations, and receiving water quality and hydraulic capacity. Results of more detailed pollutant mass balances are required during the Final Design Phase to determine which pollutant will require the most area to achieve the wetland water quality objectives.

Hydrology

Careful consideration must be given to the hydrology of the wetland treatment system. Meeting regulatory constraints without overdesign is important for this land-intensive technology. This means careful consideration of the seasonal effects of evapotranspiration and precipitation as well as the potential seasonality of discharge.

Water balances in wetland treatment systems for wastewater are critical when site soil permeability is potentially great enough for infiltration to be a significant hydrologic output from the wetland, or groundwater quality concern. A reliable and controllable hydraulic loading rate is one of the critical conceptual hydrologic design criteria for constructed wetlands for wastewater treatment. Stormwater wetland treatment systems experience less controllable and less reliable hydraulic loading.

Wetland Performance Objectives

Most natural or constructed wetland treatment systems will be designed to remove as much of a particular nutrient or suite of pollutants from wastewater as possible. Performance objectives in the form of mass removal rates should be established early in the Conceptual Design process to guide wetland sizing and configuration.

Cost Estimates

Conceptual estimates should be prepared for land costs based upon local real estate appraisals (if necessary), earthwork costs based upon approximate cut and fill volumes, planting costs based upon the product of an average plant cost determined from local nursery operators and the total estimated wetland area, culverts and pipes as needed, and long-term operations and maintenance costs.

Regulatory Feasibility And Permitting

Regulatory Feasibility

Regulatory Jurisdiction Determination: A master list of regulatory agency jurisdictions should be prepared, and specific information needs and design constraints identified.

Meetings: Meetings should be held with regulatory agency staff prior to permit submittal to confirm jurisdiction and permit information requirements. Return correspondence should be requested that verifies topics covered and conclusions drawn from each meeting.

Fatal Flaw Analysis: Fatal flaws in the wetland design or construction possibly resulting from regulatory restrictions should be identified through meetings with regulatory agency staff and critical review of conceptual design.

Permitting Requirements

Provincial, territorial and municipal constraints and requirements on wetland construction should be thoroughly investigated prior to beginning final design.

Final Design

Final design should essentially be a much more detailed presentation of the accepted conceptual design, in conformance with such comprehensive guidance as Soil Conservation Service (1992) and Water Pollution Control Federation (1990) with special consideration given to cold climate operation if applicable. Detail on earthwork calculations, hydraulic characteristics, slopes, depths, and possible site constraints should be developed into a detailed construction package. Emphasis on detail should be placed on hydraulic structures and overall simplification of operation and maintenance requirements. Regulatory confirmation of design details should be sought prior to completion of the final design. A senior review should be conducted of the complete design.

Construction Management and Monitoring

Construction Plans and Specifications

Wetland construction plans and specifications should be sufficiently detailed for bidding purposes, engineering and biological review, and verification of "as-built" conditions (Garbisch 1990).

General: Wetland construction plans should include a table of contents, a detailed location map, a sheet key index, and a table of quantities. Individual sheets should include a compass arrow, scale bar, date of preparation, and a record of reviewers and revision dates.

Aerial Photography: If available, construction plans should include current aerial photographs at a scale sufficient to completely show the outline of the project work area on one or more images. Locations of key landmarks, water bodies and drainage pattern, wetlands and other restricted or protected areas (i.e. endangered or threatened species) should be indicated. Larger scale aerial photographs may be used as a background for the detailed plan set if interpretive clarity is not sacrificed.

Scale: A scale of 1 cm = 10 m or larger is recommended (Garbisch 1990).

Topography: Wetland construction plans should be overlaid on a topographic map of existing site elevation contours. A 0.25 m contour interval is recommended as a minimum contour interval. Benchmark location and elevations should be clearly indicated (Garbisch 1990).

Cross Sections: Typical cross sections of all earthwork should be prepared to scale clearly indicating all design elevations, slopes, and dimensions. The number of cross sections should be sufficient to identify typical and atypical conditions.

Geotechnical Information: Locations of test borings and soil pits should be identified within the plan set so that they may be relocated, if desired. Soil profile illustrations should be identified and presented within the plan set and should include information on soil chroma profile elevations and observed water elevations.

Wetland Boundaries: Wetland boundaries should be clearly and accurately identified on the site topographic map, negotiated, if necessary, with the regulatory agencies.

Hydrology: Plans should indicate existing and expected water levels and identify adjacent water bodies to establish major surface drainage patterns at the construction site. All elevations should be made relative to the standard geodetic datum, or an elevation conversion should be supplied. Site hydrological data should include seasonal high and average water elevations determined from vegetative indicators, soil indicators, or hydrological monitoring data for existing wetlands, if any, and at adjacent upland sites. Sufficient information should be developed to determine seasonal elevations of receiving waters. If necessary and feasible, provision should be made on a site-specific basis to divert water temporarily to the wetland and constructing temporary or permanent structures to provide inundation.

Planting Specifications: Construction plans should indicate zones or areas to be planted. A planting list should be prepared for each wetland zone that includes quantities, elevation ranges, and acceptable conditions. Special considerations or requirements should be noted and described in sufficient detail. These may include fertilizer specifications, pre-planting conditioning, geographic constraints on plant sources, performance and irrigation requirements (Garbisch 1990). Plants should be planted at intervals sufficiently dense to assure rapid growth of vegetative cover. Only plants native to the wetland region should be used.

Vegetation Maintenance: Construction plans should require control of exotic or nuisance plants within the wetland during and after construction. Details on control methods should be provided for expected nuisance species. Control of herbivory by animals may be required and should be anticipated in the construction and monitoring phases. Provisions should be made for irrigation during construction with available water sources or effluent for constructed wetlands.

Land Use: Locations of restricted areas, structures, utility lines, or other infrastructure within or adjacent to the construction area should be indicated. Special construction restrictions or contractor coordination requirements should be indicated.

Erosion and Sediment Control: Construction plans should indicate the location, quantities, and maintenance of acceptable and appropriate sediment control methods. Possible sediment barriers include staked haybales, geotextile siltscreens, sod, and plant seeding. Barriers should be placed at the construction periphery and within the wetland in such a manner as to minimize sedimentation and erosion of wetland berms or edges.

Grading Plan: A grading plan should be included with the plan set that identifies the location, elevations, and dimensions of project earthwork. The plans should include sufficient information on radii, turning points, and baseline offsets for the contractor to accurately locate and build the wetland. Plans should specify soil quality requirements, soil sources and disposal areas, and means of transporting soil. Grading specifications should indicate the allowable tolerance in wetland grade elevation. Constructed wetlands require strict adherence to wetland grade specifications.

Site Preparation: Construction plans should include removing the top 0.5 m of substrate from the project site and stockpiling of that material to use as cover for the site to provide a seed bank or propagule source.

Contractor Selection Criteria

Contractor selection criteria should include the following minimum requirements. Contractors should be able to demonstrate prior successful wetland construction experience. Contractor staff should include a person with a background in wetland creation/restoration design with practical wetland construction experience. The contractor or contractor's insurer should be able to secure a performance bond equal to the cost of construction, planting, and a period of maintenance and monitoring.

Construction Management

The contractor should be willing to meet with the project owner or representative on a routine basis during the course of the project to discuss status and review project problems and solutions. The contractor should provide project status reports on schedule during the course of the project.

Maintenance During Construction

Nuisance and exotic plants should be controlled during wetland grading and planting. Trash and litter should be prevented from accumulating in the wetland. Wetland vegetation should be irrigated or kept watered as needed during the initial dry season of the first year if not inundated to design depths. Water control structures and culverts should be kept free of debris and soil, and repaired if broken.

"Time Zero" Report and Final Record Drawings

"As-built" drawings should be prepared and certified by the earthwork contractor or general contractor prior to installation of planting materials, and submitted for approval and acceptance by the project engineer. Final "as-built" drawings should be prepared at the conclusion of construction that verify design elevations, water depths, and elevations and extent of planting zones. These should be submitted with a "Time Zero" Report at the completion of the project, which would include descriptions of the major wetland plant communities, densities, species and photographs taken at a sufficient number of stations to adequately cover the project (Erwin 1991).

Original mylar or other media should be annotated and prints certified by a licensed surveyor. Variations from design, and their rationale, should be noted on the plans.

Post-Construction Monitoring

In southern Canada, it is anticipated that approximately two years will be required to fully develop the vegetation cover and litter layer. During this period it is critical that the wetland designer stay involved in the monitoring process to aid in assessing the progress of the system.

Construction and permitting documents should include a detailed description of the post-construction monitoring required to measure and evaluate whether a wetland has attained its intended goals. Sampling methods, frequency, and monitoring station locations should be described in sufficient detail to permit monitoring to be conducted by qualified individuals unfamiliar with the project. Monitoring plans should include descriptions of methods and goals of collecting data on water levels and plant species cover and diversity. Photographs of the wetlands should be taken at fixed locations as part of the post-construction monitoring process.

Monitoring Options

Additional data that may be collected will depend upon the goal of wetland construction. Periodic biological surveys of vertebrate and invertebrate communities may be performed to document wildlife habitat and ecological productivity in the wetland. Water quality sampling may be performed to document pollutant assimilation, organic matter production and export, and sediment retention. Flood retention and groundwater recharge functions may be documented by installation of monitoring wells, and water stage and rainfall recorders. Specialized input from biologists, hydrologists, hydrogeologists, and engineers should be sought before designing and implementing any monitoring.

Performance Criteria

Wetland performance after construction should be determined by comparison of measured wetland conditions at selected time intervals against specific criteria. Criteria to be measured should reflect project goals. For example, specific criteria for a treatment wetland might include target effluent concentrations and expected pollutant removal efficiency, as well as other indications of wetland condition, such as percent cover by planted and volunteer plant species.

Wetland Maintenance

Corrective action should be taken if monitoring indicates that performance criteria are not being met, or if other indications are found that the wetland is not functioning as designed. Wetlands performance can be adversely affected by inundation less than or greater than required by design. Flow, residence time, pollutant removal efficiency, and compliance with wetland discharge standards may be adversely affected. Wetland vegetation may be adversely affected. Possible solutions may include changing the volume, quality or timing of water deliveries to the wetland, the invert elevations of water control structures, the wetland grade elevation, and the species of vegetation to be planted. Corrective actions should be coordinated with permitting agencies.

Appendix B Wetland Sizing Estimate for Wastewater Facilities Design

This calculation sheet is designed to provide the potential user with a rough estimate of the land area required for a free water surface (surface flow) constructed wetland exclusive of the area required for the berms. It is intended as an aid in determining whether sufficient land area is available to handle the wastewater or stormwater flow. Final design should be carried out by a wetland expert to ensure optimal performance of the system for meeting discharge criteria.

Wastewater

Hydraulic Loading (Flow)

Design Flow (Q) = __________ m^3/d

Design Surface Area Requirement = 3.5 ha/1000 m^3/d

Approximate Land Area Required = 3.5 ha/1000 m^3/d x _____ m^3/d (Q)

= __________ ha wetland

(excluding area required for berms)

Nutrient Loading

	TP	TN	TSS/BOD
Influent Concentration, mg/L; Ci=	_____	____	_____
Wetland Lower Limit, mg/L; Cl=	0.05	2.00	5.00
Desired Effluent Concentration, mg/L; Ce=	_____	_____	_____
Fraction Remaining or Limit Fraction; F= (the greater of F=Ce/Ci or F=C l /Ci)	_____	_____	_____
Areal Rate Constant, m/yr; k=	10	15	35
Required Wetland Area, ha; A= where A = (0.0365xQ/k)xln(1/F)	_____	_____	_____

The estimated wetland area with the greatest value based on hydraulic and nutrient loadings should be used as the first cut at determining the potential for incorporating wetland technology into the wastewater treatment system design.

Stormwater

Watershed Area (A) = __________ ha

(A) __________ ha x .05 = __________ ha wetland

Table A.1 will provide to the consultant critical information needed to give a more accurate estimate of the land area requirement and help determine other factors including further pretreatment that may be necessary and the need for a liner.

Terms

m^3 = cubic metres
mg/L = milligrams per litre
TP = total phosphorus
TN = total nitrogen
TSS = total suspended solids
BOD = biochemical oxygen demand

Appendix C Data Sheet for Survey of Canadian Wastewater and Stormwater Treatment Wetlands

Publications

___Yes ___No *Please indicate if a publication or paper has been written on the wetland.*

___Yes ___No *Please indicate if you will send a copy of the publication or paper (If 'No', please provide a reference in the space below.)*

Author: ____________________

Affiliation: ____________________

Title: ____________________

Publication/Journal: ____________________

Year: ____________________

Potential Wetland Location Site Data

Site Name: ____________________

System Name: ____________________

Country: ____________________

Province/Territory: ____________________

City/Community: ____________________ *Population:* ________

Wastewater Source: *Municipal:* ____________________
(describe) *Industrial:* ____________________
Other: ____________________

Other Wetland Uses: *nature study*___ *hunting*___ *aquaculture*___

other (describe) ____________________

Wastewater Pretreatment: ____________________

Stormwater: *Watershed Area:* ____________________ *Units:* ________

% Impervious (roofs, parking lots, etc.): ____________________

Wetland Hydrologic Type:
___*Free Water Surface*
___*Vegetated Submerged Bed*
___*Hybrid*
___*Other* (describe)________
___*Unknown*

Wetland System Status:
___*Final Design*
___*Pilot Study*
___*Full-scale*

System Origin: *constructed*___ *natural*___ *other* (describe) ____________________

System Area: ____________________ *Units:* ________

Design Flow: ____________________ *Units:* ________

Number of Cells: ____________________

Cell Area: ____________________ *Units:* ________

Cell Vegetated Type:
___*Marsh*
___*Shrub*
___*Open water*
___*Other* (describe)________
___*Unknown*
___*Forest*
___*Floating Aquatic*
___*Hybrid*

Dominant Plant Species: ____________________

Cell Length: ____________________ *Units:* ________

Cell Width: ____________________ *Units:* ________

Cell Depth (average): ____________ *Range:* ____________ *Units:* ________

Cell Bottom Slope (%): ____________________

Substrate Material (e.g. sand, clay, muck, sandy clay, clayey sand, etc.): ____________________

Capital Cost: ____________________

Annual Operating/Maintenance Cost: ____________________

Database for Canadian Wetlands for Wastewater and Stormwater Treatment (continued)

Wetland Monitoring Data

Operating Season (months): ______________________

Period of Record: *Start (Year)* ______________ *End (Year)* ______________

Years in Service ______________________

Average Flow: *In:* ________ *Out:* ________ *Units:* ________

BOD_5 (mg/L): *In:* ________ *Out:* ________

TSS (mg/L): *In:* ________ *Out:* ________

TDS (mg/L): *In:* ________ *Out:* ________

Turbidity: *In:* ________ *Out:* ________ *Units:* ________

NH_3-N (mg/L): *In:* ________ *Out:* ________

NO_3-N+NO_2-N (mg/L): *In:* ________ *Out:* ________

Total Nitrogen (mg/L): *In:* ________ *Out:* ________

TKN (mg/L): *In:* ________ *Out:* ________

Organic Nitrogen (mg/L): *In:* ________ *Out:* ________

Total P (mg/L): *In:* ________ *Out:* ________

Filtered P (mg/L): *In:* ________ *Out:* ________

Dissolved Oxygen (mg/L): *In:* ________ *Out:* ________

Redox Potential: *In:* ________ *Out:* ________ *Units:* ________

Sulphate/Sulphide (mg/L): *In:* ________ *Out:* ________

Conductivity: *In:* ________ *Out:* ________ *Units:* ________

Alkalinity (mg/L): *In:* ________ *Out:* ________

pH: *In:* ________ *Out:* ________

Temperature (deg C): *In:* ________ *Out:* ________

Chloride (mg/L): *In:* ________ *Out:* ________

Metals (list): *In:* ________ *Out:* ________ *Units:* ________

In: ________ *Out:* ________ *Units:* ________

In: ________ *Out:* ________ *Units:* ________

Pesticides/Herbicides: *In:* ________ *Out:* ________ *Units:* ________

Organics (list): *In:* ________ *Out:* ________ *Units:* ________

In: ________ *Out:* ________ *Units:* ________

In: ________ *Out:* ________ *Units:* ________

Fecal Coliform (col/100 ml): *In:* ________ *Out:* ________

E. coli (col/100 ml): *In:* ________ *Out:* ________

(Others can be added to comments section)

Wetland System Outflow Permit Limits (A copy of the permit would be satisfactory)

Dissolved Oxygen (mg/L): ______________________

pH: ______________________

BOD_5 (mg/L): ______________________

TSS (mg/L): ______________________

NH_3-N (mg/L): ______________________

Total Nitrogen (mg/L): ______________________

Total P (mg/L): ______________________

Fecal Coliform (col/100 ml): ______________________

Permitted Flow (per day, week, month, year): ______________________

Permit Duration: *annual*____ *seasonal*____ *monthly*____ *other (describe)* ______________

Permitting Agency: ______________________

Database for Canadian Wetlands for Wastewater and Stormwater Treatment (continued)

Contact Details

Last Name: ____________________

First Name: ____________________

Role: *Operator*____ *Eng. Design/Study*____ *Research & Devel.*____ *Performance Monitoring*____

Organization: ____________________

Address: ____________________

____

Phone No.: ____________________

Fax No.: ____________________

Climatic Factors

Average Number of Frost Free Days: ____________________

Average Annual Temperature: ____________________ *Units:* __________

Average Winter Temperature: ____________________ *Units:* __________

Annual Snowfall: ____________________ *Units:* __________

Annual Rainfall: ____________________ *Units:* __________

Annual Precipitation: ____________________ *Units:* __________

Elevation: ____________________ *Units:* __________

Other – Please provide the following information

1. A map showing the wetland location in proximity to the nearest large city.
2. Copies of photographs (including negatives) and/or slides of the wetland under construction and/or operation that might be used in publications or presentations. Please indicate who took the photo.

This material may not be returned; therefore, do not send originals.

Comments

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The North American Wetlands Conservation Council (Canada)

The mandate of the North American Wetlands Conservation Council (Canada) is to provide a national forum for leadership on matters relating to the North American Waterfowl Management Plan; facilitate the development and implementation of wetland conservation policies and programs; and facilitate Canadian involvement in international wetland conservation initiatives.

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