Use of Constructed Wetlands for Urban Stream Restoration: A Critical Analysis

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ABSTRACT / Investigation of a delta marsh restoration project proposed for the Don River in Toronto, Ontario, underlines several concerns about constructed wetland projects designed for water quality improvement and aquatic habitat enhancement. The Don is a highly urbanized river that has undergone significant physiographic modifications and continually receives a complex mixture of conventional, metallic, and organic contaminants from multiple point and nonpoint sources. Rather than providing permanent removal of urban contaminants, wetland processes offer a limited capacity for temporary storage of contaminant inputs, and potential reactions may actually produce more toxic and/or bioavailable forms of some chemicals. These processes tend to result in the concentration of watershed contaminants in wetland vegetation and sediments. As the restored marsh would be available for spawning and feeding by aquatic fauna, the potential exists for chemical bioconcentration and biomagnification through the aquatic community. Accordingly, wetland systems are not suited to the dual purposes of water quality improvement and aquatic habitat enhancement. Upstream controls, including source reduction of contaminant inputs, are recommended as essential components of all constructed wetland projects.

Urban and agricultural development in North America have been historically characterized by the draining and filling of natural wetlands. Recently, however, the importance of ecological, hydrological, and chemical processes of wetland systems has gained increasing recognition among environmental management agencies (Young 1996). Accordingly, the use of constructed wetlands has become popular as a strategy for ecological restoration.

In terms of habitat rehabilitation, wetland vegetation provides cover, spawning, and feeding habitat for a range of aquatic and terrestrial species, and marsh establishment has been proposed for increased recruitment of fish and wading birds at degraded sites in various jurisdictions in North America (e.g., MDNR 1987, MTRCA 1992, OMNR 1986). Instream or riparian wetlands installed for stormwater management provide flood and erosion control through increased infiltration of surface runoff and subsequent slow release to groundwater flowpaths (Livingston 1989, Taylor 1992), and coastal wetland plantings have been used to buffer against wave action and provide enhanced shoreline stabilization (MTRCA 1992). Constructed wetlands may also be used for water quality improvement, as a range of biotic and abiotic wetland processes and reactions may transform and/or remove various dissolved and particulate contaminants from agricultural, industrial, and municipal sources (e.g., Breen and others, 1994, Moshiri 1993, Reddy and Smith 1987). Despite these benefits, the range of circumstances under which such undertakings may be effective and appropriate is limited, and objectives of habitat rehabilitation may not be compatible with applications for stormwater management or water quality improvement.

This paper examines a constructed wetland project proposed for the lower Don River in Toronto, Ontario. We explore potential consequences for water quality and the aquatic community and discuss whether the project is likely to meet its stated rehabilitative objectives. Broader conclusions are drawn relating to the applicability and/or limitations of constructed wetland projects for ecological restoration. We first introduce the study area, outline the project's rehabilitative objectives, and then analyze the objectives in light of evidence from the literature. The paper is not intended as a thorough review of the wetland literature, but rather our aim is to draw attention to inconsistencies and potential concerns related to the simultaneous use of wetlands for water quality improvement and habitat restoration.

KEY WORDS: Constructed wetlands; Water quality; Ecological restoration; Don River

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The Don River

The Don River (43°55′N,79°20′W) discharges at the northwestern shore of Lake Ontario, draining a water-

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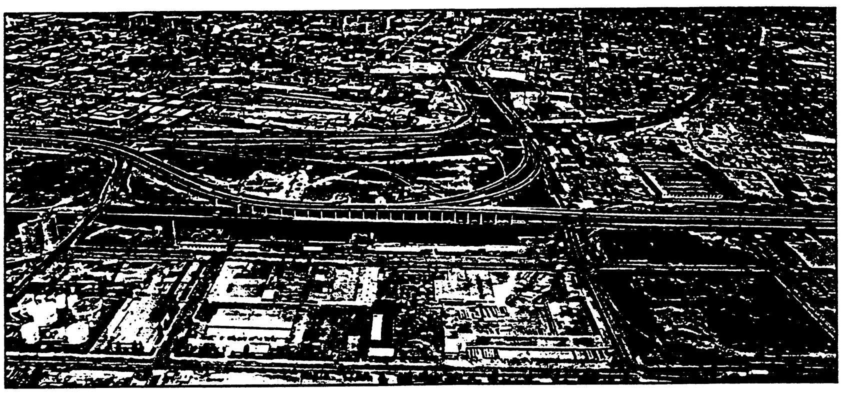

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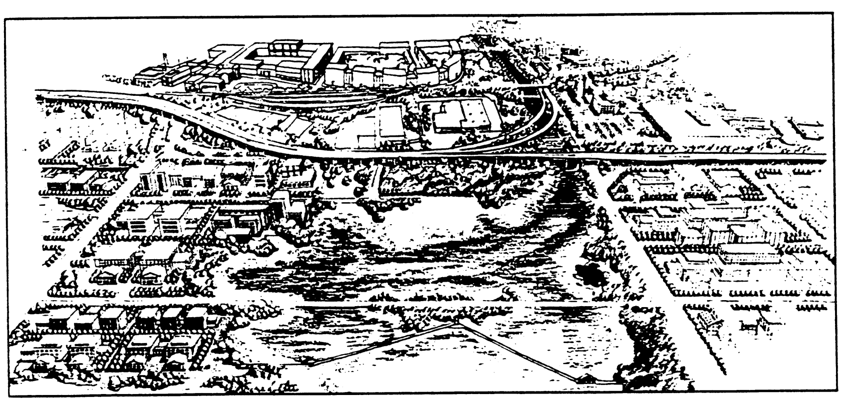

Figure 1. The mouth of the Don River in downtown Toronto, immediately north of its discharge to Lake Ontario (from Royal Commission 1992). (**a**) Existing conditions: the channelized river flows from the north (top center). The original marsh at the river's mouth has been filled (bottom center), and the river has been routed eastward through a right-angle turn to empty into the lake via the Keating Channel (left). (**b**) Artist's conception of the proposed delta marsh. Concrete is removed and the river opens into a restored marsh (bottom center).

shed of approximately 360 km^2 that lies within the Greater Toronto Area. The Greater Toronto Area is Canada's largest urban center, with a population of over 4 million and over 2.2 million in Metropolitan Toronto. Approximately 70% of the Don watershed is urbanized (OMOE 1988), and the river has long been subject to multiple anthropogenic stresses associated with urban development. The lower Don was channelized at the turn of the century to form a 5-km linear canal. The original delta marsh was then filled to create an industrial area, and the river mouth was routed through a right angle turn to empty into Toronto Harbour via the Keating Channel (Figure 1a).

Physiographic modifications have resulted in marked changes in the Don's hydrologic regime. The removal of watershed vegetation in favor of impervious surfaces has increased surface runoff and decreased infiltration and groundwater recharge, effects compounded by channelized tributaries and storm sewer systems designed for efficient downstream transport of drainage waters. As a result, the Don exhibits peak flows of significantly higher discharge and shorter duration following storm events, with baseflow significantly decreased between events, relative to preurbanized conditions (OMOE 1988).

Physiographic and hydrologic stresses have been compounded by inputs of contaminants from multiple point and nonpoint sources. Contaminant sources affecting the Don include urban runoff, combined sewer overflows, treated sewage effluent, industrial discharges and spills, landfill leachate, agricultural runoff, and atmospheric deposition (OMOE 1991a). Accordingly, the lower Don and Keating Channel receive elevated loadings of a complex mixture of chemicals (D'Andrea and Anderton 1996), to the extent that provincial water quality objectives (PWQOs), defined for the protection of human health and aquatic life, are frequently exceeded for a range of conventional, metallic, and organic parameters (D'Andrea and others 1993) (Table 1).

As a result of these influences, the lower Don features an extremely impoverished aquatic community, inhabited almost exclusively by generalists tolerant of a wide range of environmental conditions (OMOE 1988). The hydrologic, chemical, and ecological stresses affecting the Don correspond to those identified as characteristic effects of urbanization (Klein 1979, Leopold 1968), and in this respect the Don may be considered typical of many heavily impacted urban rivers.

Marsh Restoration: Rehabilitative Objectives

Within the context of anthropogenic stresses affecting the lower Don, a marsh restoration project has been proposed by the Task Force to Bring Back the Don, a citizens' group associated with the municipal government of the City of Toronto. The proposed wetland is to be established over 50.6 ha within the historical area of the river's delta marsh (Figure 1b). This is to be accomplished by removing concrete and fill materials and introducing aquatic vegetation. The lower channel and river mouth would also be regraded to encourage delta formation. Four main rehabilitative objectives are identified: (1) enhanced aesthetics and recreational uses; (2) natural flood control and correspondingly reduced maintenance costs; (3) enhanced aquatic habitat; and (4) improved water quality (Royal Commission 1992, Task Force 1991).

The establishment of publicly accessible parkland on what are now largely unused industrial lands will likely enhance aesthetic values and increase opportunities for outdoor recreation in the waterfront area. In so doing, this may help to increase public awareness of issues affecting the aquatic ecosystem and provide incentive for further conservation initiatives.

Allowing the river to naturally form its delta is expected to entail savings in maintenance costs, as dredging silt from the Keating Channel will no longer be required to prevent flooding (Royal Commission 1992). It should be recognized, however, that stormflow inputs may exceed the wetland's assimilative capacity given the urbanization of upstream reaches, particularly if the river's main channel is regraded to facilitate increased sediment delivery for delta formation. Some form of continuous maintenance may therefore be required for flood control if no measures are undertaken to promote increased infiltration and temporary storage of drainage waters upstream.

A newly established wetland community will likely differ from the original biotic community due to elevated nutrients and contaminant inputs (e.g., Hough and others 1989, Belanger and others 1989). Even if no other rehabilitative measures are undertaken to counter these effects, however, the establishment of aquatic vegetation and structural wetland habitat will likely increase recruitment of aquatic fauna, as Toronto area wetlands tend to be used for spawning and rearing by a relatively high number of fish species. This use occurs even where wetland areas are small and fragmented, and where anthropogenic stresses such as contaminant inputs are felt (Stephenson 1988). This is due to the importance of wetland habitat for the life cycles of aquatic fauna and the fact that more than 99% of historical wetland area along the Toronto waterfront has been lost to development since 1789 (Whillans 1982).

In terms of improved water quality, wetland biota and substrates may retain and/or transform various conventional, metallic, and organic pollutants loaded to the system (Figures 2a and 2b) (e.g., Hammer 1989, Moshiri 1993, Reddy and Smith 1987). It should be recognized, however, that some processes and reactions affecting water quality may entail effects detrimental to the aquatic community, and as such may ultimately prove counterproductive to other rehabilitative objectives, as discussed below. These concerns have been raised by several authors, yet insufficient data are

Table 1. Exceedance of provincial water quality objectives (PWQOs) in the lower Don River

Parameter	PWQO	Exceedance[a]	Comments
Suspended solids	≤10% decrease in Secchi depth	N/A	Objective designed for lakes rather than rivers, comparison difficult; loadings greatest during runoff events
Dissolved oxygen	47–63% saturation	Most samples meet minimum	Seasonal profile reflects temperature considerations: concentrations lowest in summer
Fecal coliforms	100 orgs/100 ml	>90%	Loadings greatest during runoff events
Total P	10–30 μg/liter	>95%	Objective based on nuisance algal growth, aesthetic deterioration rather than on threats to aquatic life resulting from oxygen depletion
Chloride	No objective for protection of aquatic life or human health	N/A	12 month avg. concentrations range from 120–250 mg/liter, as compared with avg. background levels of 5–10 mg/liter observed at comparable unurbanized sites; loadings peak in winter
Cu	5 μg/liter (unfiltered)	80%	Loadings greatest during runoff events
Cr	100 μg/liter (unfiltered)	0%	6.7% of samples in excess of federal guideline of 20 μg/liter for protection of fish, 100% of samples in excess of federal guideline of 2 μg/liter for protection of zooplankton and phytoplankton; loadings greatest during runoff events
Fe	300 μg/liter (unfiltered)	>95%	Potentially important in influencing partitioning behaviour of other metals; loadings greatest during runoff events
Pb	25 μg/liter (unfiltered, based on 200 mg/liter $CaCO_3$)	50%	Loadings greatest during runoff events
Hg	0.2 μg/liter (filtered)	21%	31.9% of samples in excess of 0.1 μg/liter (unfiltered) federal guideline; loadings greatest during runoff events
Zn	30 μg/liter (unfiltered)	30%	Loadings greatest during runoff events
Reactive phenolics	1 μg/liter	77%	
Polychlorinated biphenyls (PCBs)	0.02 μg/liter	8%	
Aldrin and Dieldrin	0.001 μg/liter	>9%	>30% exceedance in spring snowmelt
DDT	0.003 μg/liter	>5%	>41% exceedance in spring snowmelt runoff
Lindane	0.01 μg/liter	32%	
Methoxychlor	0.04 μg/liter	<5%	23% exceedance in spring snowmelt
Mirex	0.001 μg/liter	<9%	

[a]Percent exceedance is percentage of samples in excess of PWQO, based on regular monitoring 1980 to 1986 (OMOE 1991a,b).

available to allay or support them (e.g., Bastian and others 1989, Livingston 1989, Carlisle and others 1991).

Fate of Contaminant Inputs

Temporary Storage versus Permanent Removal

The most obvious limitation of constructed wetlands as used for water quality improvement lies in the fact that wetland processes remove only a fraction of total contaminant inputs. Microbial decomposition will transform some measure of organic chemical inputs, depending on factors such as metabolic rates, species composition, and chemical composition (e.g., Anderson and others 1993, Federle and Schwab 1989, Wetzel 1992, Wolverton and McDonald-McCaleb 1986). Aquatic macrophytes may sequester and metabolize dissolved nutrients from the water column, and some taxa may also take up soluble forms of heavy metals (Guntenspergen and others 1989, Meiorin 1989), organochlorines (Smith and Shore 1978, Smith and others 1977), and synthetic phenolic compounds (Okeefe and others 1987), yet uptake of toxic metals and organochlorines by com-

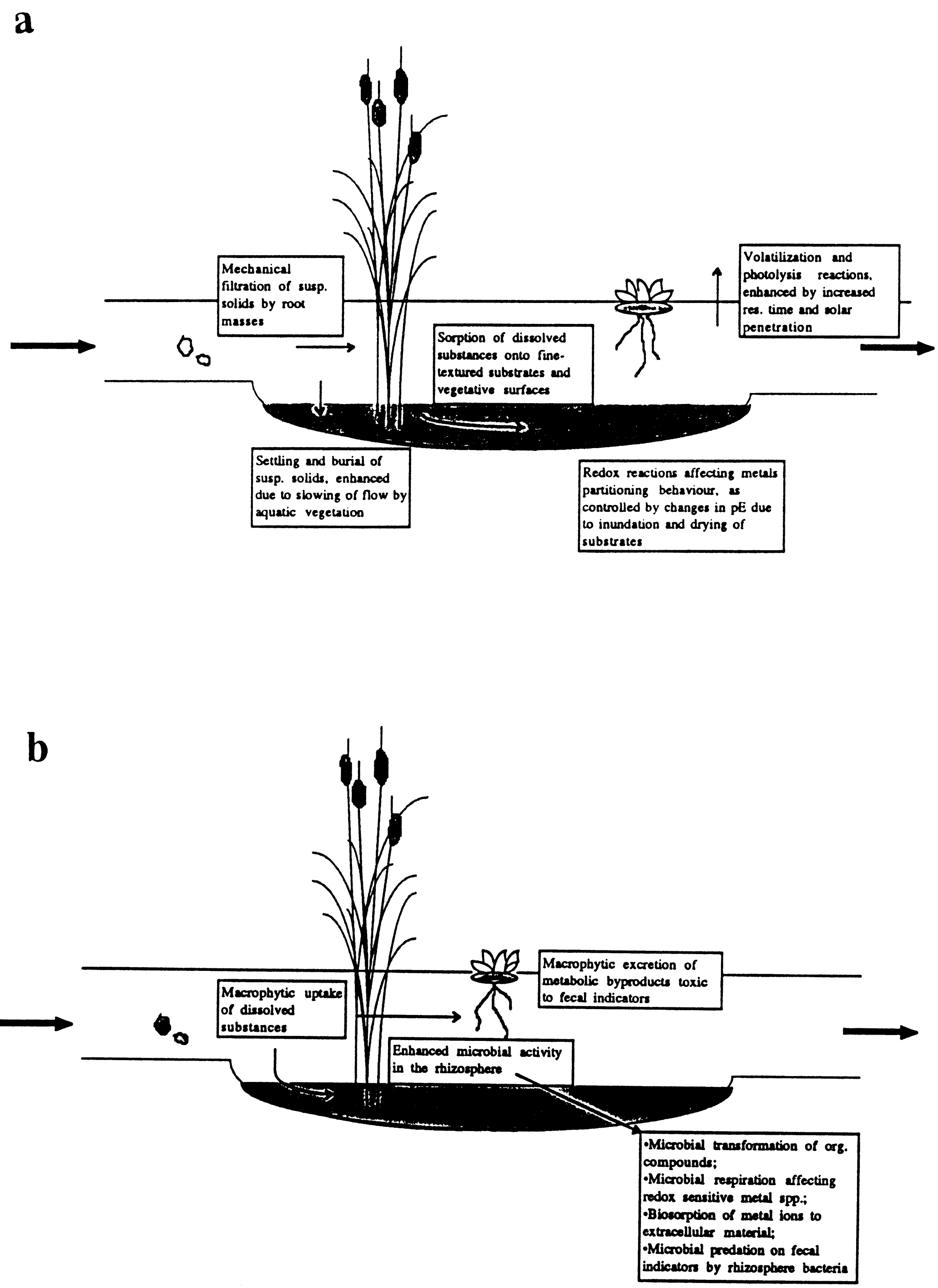

Figure 2. Wetland processes affecting water quality: (**a**) abiotic processes; (**b**) biotic processes.

monly occurring macrophytes is limited (Catallo 1993). Moreover, the uptake process does not provide permanent removal, but represents temporary storage as a stage in the cycling and recycling of chemicals between biotic and abiotic compartments of the wetland system.

Small amounts of chemical stored in macrophytic tissues may be excreted during plant metabolism, and a large percentage is released at senescence (Faulkner and Richardson 1989). Release of contaminants from vegetation may also limit capacities for biodegradation of organic compounds by rhizosphere microbial populations (Anderson and others 1993). Nutrients sequestered during the growing season are released from decaying plants primarily during the nongrowing season, and downstream waters are therefore likely to be less severely affected in terms of algae blooms and associated oxygen depletion (Hammer and Bastian 1989). However, in a delta marsh such as at the mouth of the Don, such internal loadings may remain within the wetland rather than be washed downstream, depending on flushing rates and lake circulation patterns at the river mouth. Chemicals released by plants may be accumulated by sediments and subsequently remobilized as hydrologic and redox conditions change (Devito and Dillon 1993a). Periodic harvesting of aquatic vegetation is therefore necessary for permanent removal from the system.

In addition to release from vegetation, sediment-sorbed chemicals may be remobilized and internally loaded to the water column. Potential pathways for remobilization include sediment resuspension, molecular diffusion, and pore water ventilation, as well as various biochemical reactions (e.g., DePinto and others 1993, Diamond 1995). Studies of Keating Channel substrates have cited bioturbation by benthic invertebrates as a potentially important process mobilizing sediment contaminants (MTRCA 1983). The relative importance of these processes depends on the nature of the sediment–water interface, sediment characteristics, and the physical–chemical properties of the chemical in question (Diamond and others 1990). If sediment for the proposed marsh is composed largely of silts carried by the lower Don to the Keating Channel, it will have significant levels of some metals (MTRCA 1983, Warren 1994) and would represent a net source of pollution to the wetland ecosystem.

Dredging, which would be necessary for removal of contaminants from the system, frequently exacerbates contaminant mobility through resuspension. Dredging and vegetation harvesting may significantly disturb the wetland community and offset potential benefits associated with contaminant removal. It should also be recognized that, once removed from the system, contaminant-laden vegetation and sediments must be disposed of somehow, an undertaking that may be difficult and expensive as well as politically contentious.

Assimilative Capacity

The capacity for even temporary retention of contaminants by wetland systems is finite in itself. Wetland biota and sediments subjected to continuous contaminant loadings will eventually reach saturation. Once saturated, a steady state will be reached whereby system inputs equal outputs. This occurs in natural wetlands where total chemical inputs and outputs closely approximate each other and relatively small measures of annual net export or retention are due to fluctuations in system hydrology (Devito and others 1989, Devito and Dillon 1993a,b). The time required for newly established wetlands to reach steady state remains in question. An example of this process occurring is in water conservation areas in the Florida Everglades, where increasing nutrient inputs are being met by increasing rates of nutrient export (Walker 1991).

There are two components to wetland assimilative capacity. The first is the hydrologic assimilative capacity required for the retention and infiltration of surface water inputs. The second is a chemical assimilative capacity characterized by net capacities for macrophytic uptake, microbial transformation, and sorption of chemical inputs by bed sediments.

Wetland area is a major factor controlling hydrologic assimilative capacity. Wetland area must be sufficient to retain volumes of stormflow input at depths and durations not exceeding vegetative tolerance (Hammer 1992, Taylor 1992). For example, a cattail or reed marsh may tolerate an increase of 0.2–0.5 m in water depth for 2–3 weeks during the growing season, but more intense flooding may affect ecological processes (Hammer 1992). Regardless of average input volumes, loadings to the Don are dominated by pulses of high discharge following storm events (OMOE 1988), at which times input rates will likely exceed the hydrologic capacity of the wetland. Accordingly, a greater proportion of loadings will exceed the wetland's assimilative capacity than if the system were subjected to continuous low or medium level inputs.

Wetland area also affects chemical retention. For effective chemical retention, wetland area must accommodate maximum discharges and chemical loading per unit time (Brodie 1990, Hammer 1993). Guidelines for the attainment of water quality objectives have been developed for specific parameters based on studies of wetlands used for treatment of municipal wastewaters and acid mine drainage, as well as natural wetland transformation and assimilation processes (e.g., Brodie and others 1988, Hammer 1993). Given total phosphorus (P) loadings of 61,000 kg/yr to the lower Don (Table 2) (MTRAP 1989), approximately 110 ha of wetland area would be required to reduce P levels to meet regulatory objectives. The proposed 50.6 ha of wetland area at the mouth of the Don would therefore be insufficient for adequate processing of P inputs. It should be recognized that this analysis is based on annual loadings and neglects temporal pulses of chemical, during which retention would be relatively low. This

Table 2. Total annual loadings of selected chemicals to the lower Don (MTRAP 1989)

Parameter	Loadings (kg/yr)
Total Susp. Solids	9.9×10^6
Total P	6.1×10^4
Cu	3700
Pb	6300

analysis also fails to take into account P accumulation in sediment and subsequent release during periods of anoxia, as well as the attainment of steady-state conditions, and is therefore likely to underestimate the wetland area required.

Wetland chemical assimilative capacities are controlled largely by hydrologic regime and metabolic or growth rates of wetland biota. Assimilation is low when chemical inputs exceed metabolic rates. Devito and Dillon (1993a,b) demonstrated this in studies of wetlands in central Ontario, in which positive monthly retention of P and nitrogen (N) coincided with high biotic assimilation and low discharge during the growing season, chemical inputs being positively related to discharge. Thus, chemical retention was inversely correlated to runoff. Devito and coworkers also concluded that nutrient budgets calculated only during the growing season will confirm that wetlands retain nutrients, whereas nutrient budgets compiled from year-round data indicate no net retention (Devito and others 1989, Devito and Dillon 1993a,b). Based on average values for 1990–1993, 67% of total annual discharge and, consequently, chemical loading to the lower Don occurs between fall and spring, when vegetative productivity and growth rates are low (Figure 3). As a result of this temporal mismatch between maximum vegetative activity and contaminant loadings, wetlands in temperate and northern latitudes with restricted growing seasons may offer relatively low annual chemical retention.

Chemical Transformations

An important benefit of wetlands is their ability to transform anthropogenic contaminants through redox reactions and microbial processes (e.g., Faulkner and Richardson 1989, Portier and Palmer 1989), yet these processes may also lead to more toxic and/or bioavailable forms of some chemicals (Shiaris 1985). Whereas many organic contaminants may be transformed to less toxic compounds, others can be transformed to more toxic by-products. Examples of the latter situation occurring in natural systems are the transformation of trichloroethylene to vinyl chloride and that of DDT to the metabolites DDE and DDD. Prediction of metabolic pathways and transformation products is difficult (Shiaris 1985), particularly for systems subjected to complex mixtures of chemicals such as are loaded to the Don. Reducing conditions in anoxic wetland sediments will reduce metals such as arsenic (As) and chromium (Cr) to more toxic oxidation states (Forstner and Wittman 1981). Alternating reducing and oxidizing conditions due to periodic inundation and drying of wetland substrates may also enhance the bioavailability of metals in the system, as chemical species sorbed to hydrous oxides of iron (Fe) and manganese (Mn) under oxic conditions are solubilized under reducing conditions. High concentrations of Fe observed in the lower Don (Table 1) may therefore be an important factor influencing the partitioning behavior of other metals in a restored marsh.

Given the occurrence of mercury (Hg) in the lower Don (Table 1) and many other urban systems, enhanced methylation represents another detrimental consequence of marsh establishment. High levels of microbial activity in wetlands have been observed to result in net methylation and subsequent biomagnification of Hg (Portier and Palmer 1989, Wood and others 1968). Bioaccumulation of methylmercury (CH_3Hg^+) in aquatic biota has been linked to high humic content and low levels of dissolved oxygen in water (Weis and others 1986), the latter possibly due to increased methylation under conditions of low oxygen. These conditions are likely to be met in a restored marsh, as the establishment of aquatic vegetation will result in increased concentrations of humic matter and biological activity consuming oxygen near the sediment–water interface. Net methylation also increases with increasing temperature (Bodaly and others 1993), which is also likely as a result of shallower waters and correspondingly increased solar penetration. In addition to biotic methylation processes, abiotic methylation may be important in wetlands. For example, the presence of humic acids and metals acting as catalysts appears to be sufficient for abiotic methylation of Hg (Zillioux and others 1993). This potential effect in an urban wetland should not be overlooked, given that nearshore fish throughout the Great Lakes regularly exceed consumption guidelines of 0.5 ppm for Hg (Environment Canada and others 1991, OMOEE and OMNR 1995).

The lower Don receives significant chloride (Cl^-) inputs from road salts in urban runoff and from treated sewage effluent (OMOE 1991b, Warren 1994), resulting in concentrations significantly higher than background levels observed in nonurbanized Ontario streams (Table 1). Such inputs, combined with increased concentrations of organic matter from aquatic vegetation and detritus in a restored marsh, may result in natural production of chlorinated organic compounds (Gribble

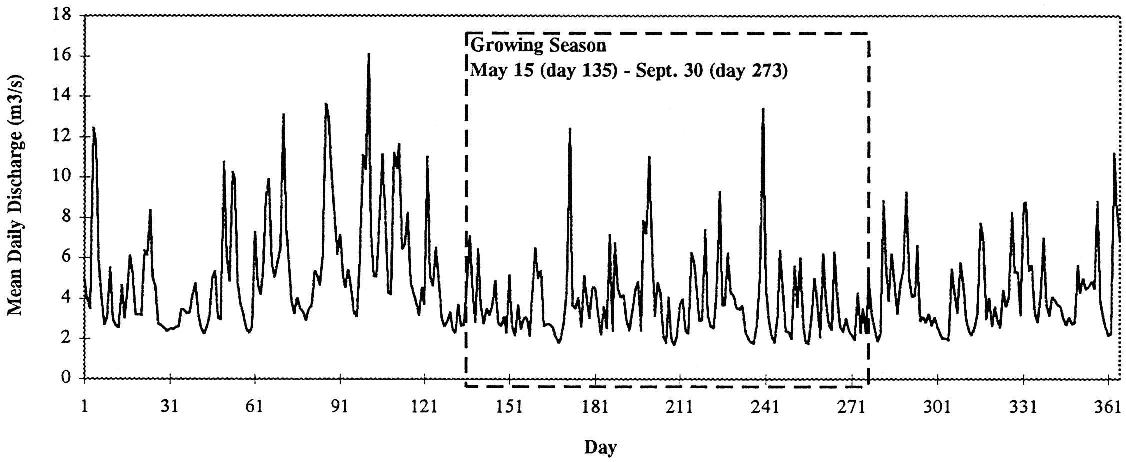

Figure 3. Mean daily discharge to the lower Don River and growing season. Discharge data are average values for 1990–1993, from Water Survey of Canada, station no. 02HC024.

1992, 1994). The extent to which this transformation will occur is a function of dissolved organic matter and Cl^- concentration, although a measurable amount of chlorinated organic by-products may be produced even at relatively low concentrations of Cl^- (Meyer and others 1993, Rook 1977). For example, chlorine used to treat drinking water has been observed to react with fulvic acids to produce trihalomethane compounds such as chloroform ($CHCl_3$) in surface and subsurface waters (Meyer and others 1993, Miller and others 1993). Chlorination of peat extracts has also been found to produce a wide range of volatile chlorinated organics including polychlorinated acetones, chlorinated butanol, trichloroethylene, and dichloroethylbenzene, with specific reactions and by-products varying according to Cl^- concentrations (Rook 1977). A high proportion of these chemicals will volatilize from surface waters because of increased temperatures, shallow water depth, and a large air–water interface, but it should be recognized that this pathway does not represent actual loss so much as transfer of contaminants. Semivolatile and nonvolatile organohalogen by-products undergo sorption, photolysis, and limited biodegradation in natural waters, but higher molecular weight, hydrophilic chlorofulvic acids may be expected to be more mobile and persistent (Meyer and others 1993). Those compounds of intermediate molecular weight may pass through the membranes of wetland biota and will therefore be most bioaccumulative (Kenaga and Goring 1980, Muir and others 1985).

Toxicity to Wetland Biota

The concentration of urban contaminants and convergence of aquatic biota at the restored marsh represents an important concern, as wetland fauna exposed to toxic substances may experience toxicological responses. Uptake and retention of heavy metals and chlorinated organics by aquatic macrophytes may result in effects ranging from decreased biomass accumulation to plant death (Faulkner and Richardson 1989, Meiorin 1989). Similarly, heavy metals and decompositional by-products of some organic compounds may limit and/or kill microbial populations (Portier and Palmer 1989). These effects generally increase with uptake rates, although responses vary in intensity according to the toxicity and mix of chemicals, and the tolerance of the organisms. Conventional pollutants may also cause adverse effects, as excessive nutrient inputs may limit vegetative productivity through various processes, promote rapid root and leaf turnover, and alter species composition (e.g., Guntenspergen and others 1989, Hough and others 1989, Shaver and Melillo 1985, Wetzel and Hough 1973).

In addition to threatening the viability of the vegetative community and decreasing the system's capacity to process additional contaminant inputs, contaminants sequestered in wetland vegetation and substrates may bioconcentrate and biomagnify through the aquatic food web. Anderson and others (1993) cite the potential for transport of organic compounds from substrates into plant tissue and subsequent faunal exposure as an important consideration for wetland projects. Other authors have cited the convergence of both contaminants and biota at wetland sites as a concern (e.g., Bastian and others 1989, Livingston 1989), but relatively few data are available to characterize potential consequences. Studies of the lower Don and Keating Channel have cited bioaccumulation of heavy metals and organochlorine compounds in fish and wading birds via direct uptake from the water column, ingestion of sediment particles, or ingestion of contaminated biota (MTRCA 1983). Studies at other locations have also yielded evidence of contaminant uptake (Campbell 1994, Custer and others 1996, Gebauer and Weseloh 1993). Faunal uptake rates are controlled by factors such as age or life stage, trophic level, and season.

In most cases, contaminant residues in biota occur at levels below those linked to subacute effects in controlled toxicological studies. It is therefore difficult to establish a direct cause–effect relationship between contaminant residues in biota and population health. As Frederick and Spalding (1994) and Friend (1985) have suggested, however, contaminant residues may cause subtle effects such as impairment of the immune system and other physiological changes leading to increased susceptibility to primary and secondary diseases. The concern over faunal susceptibility to microbial pathogens is heightened due to the high levels of fecal coliforms and other bacterial contaminants routinely detected in urban runoff (Field and others 1993, OMOE 1991a). Frederick and Spalding (1994) also speculate on other subtle toxicological effects, such as behavioral changes induced by elevated Hg concentrations in wading birds, which may affect reproductive success through impaired foraging and reproductive skills.

A restored marsh at the mouth of the Don is intended to serve as a focal point for the feeding and reproductive activities of fish and wading birds ranging across the northern shore of Lake Ontario (Royal Commission 1992). However, the use of aquatic vegetation for habitat enhancement and water quality improvement at the same site seems counterproductive, as habitat benefits related to feeding and reproduction by aquatic fauna are threatened in areas subject to substantial loadings of heavy metals, organic compounds and microbial pathogens. The potential scope of ecological repercussions could be significant, as are the moral implications of a project designed to increase recruitment of aquatic fauna to a site which may concentrate toxic and bioaccumulative substances.

Discussion

The proposed marsh restoration is probably inappropriate for the lower Don because the project's four stated objectives are not likely to be met. In terms of improving water quality, wetland processes offer a limited capacity for net retention of contaminant inputs, and although chemical transformations may eliminate some fraction of chemical loadings, more toxic and/or bioaccumulative forms of some chemicals may be produced. Given the potential for toxicological effects and bioaccumulation of urban contaminants through the aquatic food web, marsh establishment may ultimately prove detrimental to the aquatic community, and goals of habitat enhancement will not be met in the long term. Goals of reduced maintenance costs are not likely to be met, as flooding will continue if stormflow inputs exceed the marsh's infiltrative capacity, and periodic dredging and harvesting of vegetation will be required for contaminant removal. Even aesthetic and recreational objectives may not be met in the long term, as effects detrimental to the aquatic community may also be expected to eventually impair aesthetic values and recreational uses.

The use of wetland systems for the treatment of contaminated surface water is generally incompatible with goals of aquatic habitat enhancement, as contaminant inputs are at least as degradative to the wetland community as draining or infilling. This is particularly true for urban environments featuring complex mixtures of metallic and organic contaminants. Constructed wetlands may retain conventional pollutants such as suspended solids, dissolved nutrients, and bacteria with relatively few toxicological effects, but there are few effluent scenarios in developed watersheds that involve only these pollutants and not some measure of metals and organic compounds.

For this reason, researchers have recommended that wetland systems used by aquatic fauna should not be used for water treatment (Hammer and Bastian 1989, Olson 1993). Constructed wetlands receiving contaminant inputs should be conceived of as biotechnical treatment facilities rather than viable ecological centers. Where wetland cells are designed to function in a controlled environment to which wetland fauna are denied access, process variables may be monitored and manipulated to maximize performance efficiency and minimize impacts on natural systems.

Regardless of process efficiency or potential effects on the aquatic community, it should be recognized that the use of constructed wetlands for water treatment is essentially an end-of-pipe strategy that addresses the symptoms rather than the causes of environmental degradation. As such, marsh establishment represents only a partial strategy for environmental restoration. In recognition of this fact, the Task Force to Bring Back the Don (1991) and the Royal Commission on the Future of the Toronto Waterfront (1992) have proposed more comprehensive and preventative measures to be undertaken throughout the watershed in conjunction with marsh restoration (e.g., upstream riparian plantings and Best Management Practices designed to mitigate the hydrologic effects of urbanization, source reductions of road salts, pesticides, automobile by-products, and household contaminants). Unfortunately, these initiatives have not been as highly publicized as the proposed marsh restoration. Constructed wetland projects, if they are to be effective and appropriate, must be informed by a comprehensive understanding of wetland processes and relationships within the broader context of watershed ecosystem interactions. As the chemistry, hydrology, and ecology of delta and riverine wetlands are controlled largely by upstream factors, upstream controls must be assigned priority for funding and implementation equal to, if not greater than, that assigned to marsh establishment. Reduction at source remains the only complete solution to the problem of anthropogenic contaminants in surface waters.

Conclusions

A delta marsh has been proposed to restore the mouth of the Don River in downtown Toronto. The river receives high loadings of conventional pollutants and some metals, as well as lesser amounts of organic chemicals from many sources, including urban runoff. The proposed marsh restoration project is not likely to result in a sustained improvement in water quality at the mouth of the Don, and potential effects may actually prove detrimental to the aquatic community. Accordingly, the project's four stated rehabilitative objectives are unlikely to be met, and the project may be considered inappropriate. Wetland systems are generally not suited to dual applications for water quality improvement and aquatic habitat enhancement, and nonengineered wetlands would seem better suited to the processing of conventional pollutants than heavy metals or organic contaminants. Regardless of the nature of contaminant input, upstream controls, including source reduction, constitute an essential component of all constructed wetland projects.

The loss of a delta marsh was one of the main stressors contributing to the degradation of the Don, and its reestablishment represents an important step toward the river's restoration. There is an intangible yet important benefit associated with this acknowledgment of the importance of reestablishing and maintaining the natural features of the waterfront and river systems. Official rejection of traditional, degradative patterns of urban development can only have a positive effect on future developments and the ways in which the citizens of Toronto relate to their aquatic environment. Given the need for comprehensive, preventative measures addressing the fundamental causes of anthropogenic stresses throughout the watershed, initiatives directed towards such an attitudinal shift may be extremely important in preserving the ecological integrity of the Don and the Toronto area in general. Nonetheless, without defined action to reduce contaminant inputs at source, marsh establishment must be considered at best an incomplete and largely symbolic undertaking and, at worst, a potentially degradative cultural development designed to achieve entirely anthropocentric ends. Without consideration of long-term ecological consequences affecting nonhuman as well as human populations, such projects cannot rightfully be termed rehabilitative.

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