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Establishment and Evaluation of the Vegetative Community in A Surface Flow Constructed Wetland Treating Industrial Park Contaminants

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Abstract: A surface flow constructed wetland, designed to curve in a kidney shape in order to increase the length to width ratio to 5:1 was used to treat runoff from an industrial park. A natural wetland system located approximately 200 m downstream of the constructed wetland was selected to act as the vegetative community model for the constructed wetland. The selected model was a riparian, open water marsh dominated by emergent macrophytes. Baseline plant species surveying was conducted. In total, 21 emergent wetland plant species, 40 upland vascular plant species, 17 upland shrub species and 13 upland tree species were identified in the model site. The species from the model site were screened for suitability in the constructed wetland based on the following criteria: (a) phytoremediation potential (especially metal uptake), (b) sedimentation and erosion control, (c) habitat function, (d) public deterrent potential and (e) rate of plant establishment, tolerances and maintenance requirements. Transplantation was chosen as the main vegetation establishment methodology in the constructed wetland. The species woolgrass (*Scirpus cyperinus*) and soft rush (*Juncus effusus*) were chosen to dominate the interior berms and littoral edges of the constructed wetland cells. The buffer areas were dominated by meadowsweet (*Spiraea alba* var. *latifolia*) and the open water areas were dominated by cowlily (*Nuphar variegate*) and pickerelweed (*Pontederia cordata*) species. A diverse, self-sustaining vegetative community was successfully established in the constructed wetland. The transplant success was gauged by mortality census in the spring of 2003. Over all, 138 dead transplants were observed, many of which had died as a direct result of washout. These computes to an overall site establish success rate of about 87.3%. The species, which suffered the highest mortality rates, were the pickerelweed, with approximately 50 dead plants, the meadowsweet with 32 observed dead plants and woolgrass with 27 dead plants.

Key words: Constructed wetland, landfill leachate, industrial park, vegetative community

INTRODUCTION

Wetlands are broadly characterized as saturated land areas supporting aquatic processes as indicated by poorly drained soils, hydrophilic vegetation and various kinds of biological activity that are adapted to a wet environment[1]. Canada supports over 127 million hectares of wetland environments, which is approximately 14% of Canada's total land area. Their distribution across the country varies greatly, with most wetlands being situated in Manitoba, Ontario and the Northwest Territories[2].

Wetlands are nature's purifiers, cycling and retaining nutrients, pollutants and sediments through unique, naturally adapted mechanisms which include reduction/oxidation transformations, plant uptake of contaminants, microbial degradation and sedimentation[3,4]. Increasingly, these mechanisms have been adapted for use in constructed wetland systems designed and constructed to capitalize on the intrinsic water quality amelioration functions of natural wetlands for human use and benefits. When designed properly, constructed wetlands are capable of effectively purifying wastewater using the same processes carried out in natural wetland habitats[5,6].

Industrial parks are urban areas usually located on the outskirts of cities and zoned for industrial and business activities[7]. Unfortunately, as a result of their design and operational practices, industrial parks are notorious for high waste production, high energy and

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material consumption and air and water pollution and are consequently often linked with increased ecological health impacts[8]. There are over 12,600 industrial parks worldwide, with 1000 in Canada. One of these is the Burnside Industrial Park located in Dartmouth, Nova Scotia. It is the largest industrial park in the Atlantic Provinces with over 3000 acres and more than 1500 businesses supporting over 25,000 employees. These businesses are significant generators of solid waste, wastewater discharges and air pollution in the region[9,10]. Like most industrial parks, the Burnside Park was established in 1976 with no ecological health in mind and had limited regard for the natural landscape of the area. As a result, many forested and wetland areas were cleared to make way for its development[7]. Several landfills were hastily implemented where most convenient to accommodate increasing waste loads and were operated and decommissioned with little consideration for the environment[11].

The aim of this study was to establish a diverse, self-sustaining, locally-modelled, native vegetative community bearing biological integrity in the constructed wetland site that effectively decontaminates the leachate and stormwater input via phytoremediative, physiochemical and biophysical means. The specific objectives were to: (a) select the appropriate native vegetation for the site, (b) select the appropriate vegetation establishment strategy for the site, (c) establish plants in both the wetland and wetland buffer areas, (d) evaluate the plant establishment success of the site following one growing season and (e) evaluate the water purification ability of the site following one growing season.

BURNSIDE LANDFILL AND CONSTRUCTED WETLAND

The Burnside Drive landfill (now decommissioned and currently known as the Don Bayer Sports Field) is located near the northern boundary of the Burnside Industrial Park, at the corner of Akerley Boulevard and Burnside Drive (Fig. 1). This 13.4 acre open waste disposal site had accepted municipal, agricultural and industrial wastes, old tires, abandoned cars and demolition wastes (all of which were reportedly burned to reduce volume) from the Dartmouth Municipality. The dumpsite was graded, compacted and covered with two feet of soil upon closure, as was common in the day, with no regard for pollution control or aesthetics (Ghaly and Côté, 2001). Since its closure in the 1970's, leachate from the decomposing waste beneath the sports field, as well as stormwater draining from a 55.1 hectare watershed surrounding the landfill ultimately discharge into Wright's Brook through stormwater ditches located on the western, northern and eastern borders of the sports field. Wright's Brook traverses 4.6 km, passing through Enchanted and Flat lakes before discharging into the Bedford Basin of the Halifax Harbour. Water quality analyses of the stormwater ditches (Table 1) indicated that the wastewater contained elevated levels of iron, manganese, ammonia and suspended solids[12]. This wastewater discharge has had visible adverse effects on Wright's Brook and the associated ecosystems.

To address the problem, a seven celled surface flow constructed wetland (approximately 5000 m^2 in area) was constructed in the late fall of 2001 and

Table 1: Water quality results for samples taken from the Don Bayer sports field stormwater ditches in October, 2000[12]

Parameter	Concentration* (μg L^{-1})	Guidelines[14]
Elements		
Aluminum	10.00	5-100
Boron	57.33	200
Calcium	43300.00	NGA
Chloride	75370.00	NGA
Chromium	0.67	1-8.9
Cobalt	2.00	NGA
Iron	6166.67	300
Magnesium	4000.00	NGA
Manganese	1800.00	1000-2000
Potassium	2100.00	NGA
Sodium	41200.00	NGA
Strontium	190.00	NGA
Zinc	6.67	30
Compounds		
Ammonia (as N)	1258.18	NGA
Bicarbonate (as $CaCO_3$)	94281.00	NGA
Carbonate (as $CaCO_3$)	181.00	NGA
Sulphate	6330.00	NGA

*: Values are the average of four measurements. NGA = No guideline available

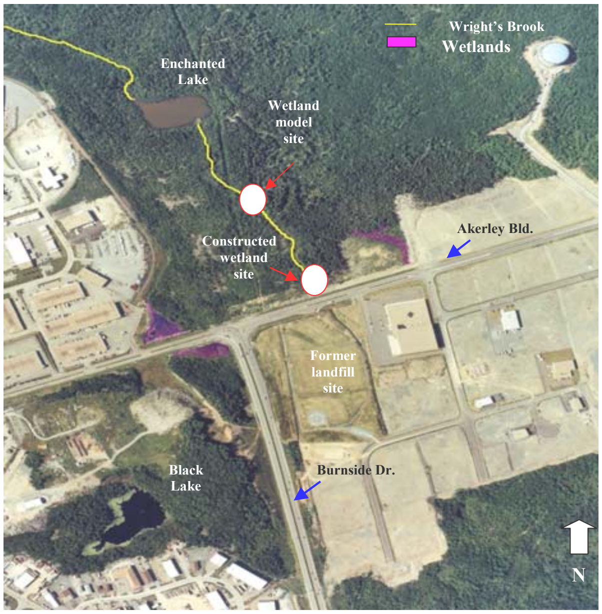

Fig. 1: Aerial photograph of the northern boundary of the Burnside Industrial Park, (scale 1:10000)[13]

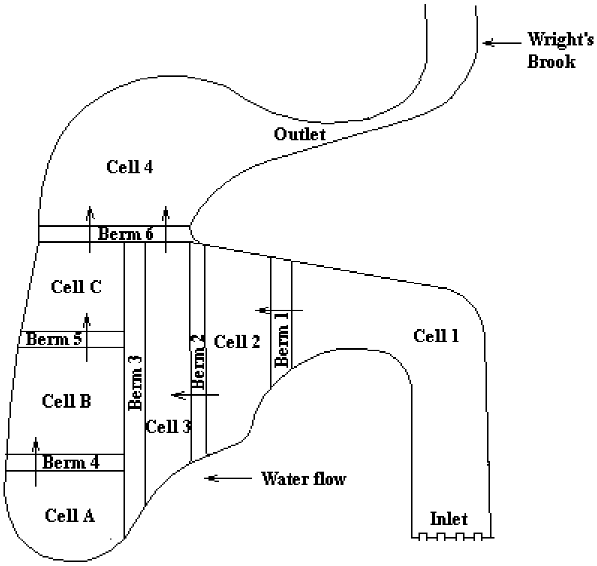

Fig. 2: Burnside wetland diagram

spring of 2002 (Fig. 2). The wetland consists of a deep-water (greater than 1m) system separated by shallow interior earth berms of 2 m width, which were constructed in the marshy area receiving the wastewater. The wetland was designed to curve in a kidney shape in order to increase the length to width ratio to about 5-1. The first cell was deeper than the others (approximately 1.5 m) in order to facilitate the settling and accumulation of suspended solids.

The till of the area was found to support 15-25% silt/clay with dense to very dense consistency and a permeability of 10^{-4}-10^{-6} cm sec^{-1}[15]. It was, therefore, concluded that compaction of the soil would provide adequate lining for the site. The natural gravitational flow facilitated by the site topography negated the need for any mechanical infrastructure such as pumps.

MATERIALS AND METHODS

Selection of wetland community model: A natural wetland system located approximately 200 m downstream of the constructed wetland (Fig. 1) was selected to act as the vegetative community model for the constructed wetland site. The selected model is a riparian, open water marsh dominated by emergent macrophytes (Fig. 3). Although thriving and appearing healthy and highly productive, the site did show many visual signs of disturbance including orange staining and iron particulate coagulations.

This site was selected as the vegetation model for the constructed wetland site for several reasons: (a) it supported many native wetland plant species adapted to local conditions, (b) it belongs to the same water system and therefore was similar in biophysical characteristics and environmental gradients (substrates, climate, etc.) to that of the constructed wetland, (c) as the marsh received high iron, manganese and ammonia loading, it was likely that plant species selected from the model site would be capable of surviving the contaminant loading received by the constructed wetland site, (d) species selected from the model would also likely have potential for hyperaccumulation of the contaminants of concern as per the principles of forensic phytoremediation[16] and (e) modelling the constructed wetland after a naturally occurring wetland area would ensure habitat continuity and preserve biological integrity by not introducing species to the system that would not occur there naturally and thus the constructed wetland would appear as a natural extension of the Wright's brook ecosystem.

Identification of vegetation in the model site: Baseline plant species surveying of the Wright's brook marsh took place in the spring of 2002. Identification commenced with the dominant species present, then was refined to include less abundant species. The

Fig. 3: Macrophytes in the selected wetland model

identification of species present in the model site were verified using several keys including: (a) Roland's Flora of Nova Scotia[17], (b) Aquatic and Wetland Plants of Northeastern North America[18] and (c) Newcomb's Wildflower Guide[19]. Species which proved too difficult to identify with absolute certainty were bagged, labelled and submitted to the Nova Scotia Museum of Natural History in Halifax for identification by qualified botanists. All species identified in the model site were recorded and organized into four categories (Emergent Wetland Plants, Upland Vascular Plants, Upland Shrubs and Upland Trees) and assigned coefficients between 1 and 5 indicating dominance, with a ranking of 5 representing very high abundance and a ranking of 1 indicating scarce abundance. Identified species which were non-native were immediately dismissed for potential use in the treatment site.

Plant species selection criteria: Not only do wetland plants work to reduce contaminant levels via phytoremediation processes, but also facilitate contaminant remediation and immobilization by supporting processes such as microbial growth, sedimentation and filtration of suspended solids and oxygenation of the water column and sediments. Therefore, the constructed wetland should be planted with a diverse arrangement of native, non-aggressive plant species because naturalized systems are more likely to: (a) be self-sustaining, (b) be more adapted to the local environment (i.e. climate, soils, pests etc.) and therefore more resistant and resilient to regionally common disturbances, (c) provide suitable wildlife habitat for local wildlife and (d) help maintain the ecological health and native biodiversity of natural systems in the region by eliminating the potential threat of biological pollution. According to Daigle and Havinga[20], biological pollution occurs when exotic and aggressive species spread to natural systems and out-compete native vegetation, causing habitat degradation. The plant selection for the constructed wetland commenced using the model plant list (derived from the vegetation survey) as a guide. The species from the model plant list were screened for suitability in the constructed wetland with regard to the following criteria: (a) phytoremediation potential (especially metal uptake), (b) sedimentation and erosion control, (c) habitat function, (d) public deterrent potential and (e) rate of plant establishment, tolerances and requirements.

Establishment of vegetation: Transplantation was chosen as the main vegetation establishment methodology in the constructed wetland because the transplanted species are naturally adapted to local conditions and significant cost savings would be realized as nursery plants can be extremely expensive. In early May of 2002, several excellent donor sites within the wetland community model were identified as containing abundant plants for transplant. It has been suggested that 95% or more of a donor vegetation patch should be left to regenerate to minimize damage to the donor site[21].

Given the minor amount of species required and the large area of donor sites available, minimal damage to the donor sites resulted as less that 0.5% of the donor sites were harvested. In addition, only those species which had a dominance coefficient of 2 or higher in the model site were considered for transplant in the constructed wetland to minimize the potential over-harvestation of less common species. It was decided that seed collection and application of woolgrass (*Scirpus cyperinus*), soft rush (*Juncus effusus*) and fowl mannagrass (*Glyceria striata*), three dominant native species present in the model site, would also take place in the fall of 2002. Given the wide diversity and availability of wetland species in the donor sites, there was no need to purchase nursery plants for establishment in the site.

In May 2002, plant transplantation from the donor sites into the constructed wetland began. Species identified in the donor sites as desirable for establishment in the constructed wetland were dug out using shovels and a pick maddock. Care was taken to make ensure the root systems and surrounding soils of the extracted plants remained as intact as possible. Once the wheel barrel was full of plants, the plants were immediately brought to the constructed wetland and planted in the berms. Holes large enough to facilitate each plant root system were dug where the plants were to be established. Spacing of each species coincided with what the research indicated would be required to achieve uniform cover in one year. The roots of the plants were then placed into the holes, buried with the extracted soils and stomped securely into place. Topsoil was applied in areas which lacked sufficient stratum for planting. Since it was intended that the site should ultimately appear as indistinguishable as possible from that of a natural wetland site, care was taken to ensure plantings were relatively non-linear and non-horticultural. Planting continued through until August, 2002. During this time, water levels in the cells had to be lowered by diverting waters from the system via the culvert located beneath the eastern border of cell 1.

This was done because in surface flow constructed wetlands, water level can be the most critical aspect of plant survival during the first year after planting. Too much water can kill most immature aquatic macrophytes which need to receive abundant oxygen at their roots[3]. Buffer and riparian vegetation was also established around the perimeters of the cells during the course of the 2002 summer to minimize the effects of wind and water erosion on the edges of the site. In addition, straw was placed on any exposed edges of the site to mitigate erosion until the buffer areas became established.

Fairly intensive maintenance of the site was necessary during the course of the vegetative establishment. This included watering, weed pulling and the removal and replacement of species which were not establishing themselves adequately. Berm repair was also a common maintenance practice as high velocity water flows during rain events often caused breaks in the fragile, unvegetated berms.

Evaluation of vegetation establishment success: The survival rates of the plants in the constructed wetland (and hence the success of the vegetation establishment strategy), was tested on May 20, 2003 via visual observation. The exercise was not meant to be exhaustive; the location of deceased plants that were established the previous year were simply hand-plotted on site maps of the constructed wetland. Cause of mortality was also noted if obvious (i.e., washout, insect infestation, etc.).

Water sampling and analyses: On July 21, 2003 water samples were collected from cell 1 and the outlet of the constructed wetland and analyzed for iron, manganese, phosphorus (orthophosphate), pH, Dissolved Oxygen (DO), nitrogen (ammonia, nitrate, nitrite and TKN), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). The nitrogen, pH, COD, TSS, TDS and orthophosphate analyses were performed according to procedures described in Standard Methods for the Examination of Water and Wastewater[22]. Iron and manganese were analyzed in the Mineral Engineering Center, Dalhousie University using flame atomic adsorption spectroscopy (Varian Spectr AA, Model # 55B, Varian Inc., Mulgrave, Victoria, Australia) with a detection limit of 1 ppm.

RESULTS AND DISCUSSION

Model wetland plant community survey: One of the best ways to ensure effective naturalization is to model the vegetation populations to be established in the constructed wetland after a local, natural wetland of a similar type (Hoag, 2000). According to Daigle and Havinga[20], community modeling involves the surveying of plant communities inhabiting the natural wetland including vegetation composition, structure and abundance. The results of the model wetland vegetation survey are shown in Table 2-5.

The assigned abundance coefficients (with 5 representing high abundance and 1 scarce abundance) for each species identified during the survey are indicated in the Rank column. In total, 21 emergent wetland plant species, 40 upland vascular plant species, 17 upland shrub species and 13 upland tree species were identified in the model site. Of those identified, 2 emergent wetland species, 20 upland vascular plants and 1 upland shrub were disqualified as candidate species for the constructed wetland because of the aggressive or invasive nature of the plant or the plant being considered exotic or a weed. No trees were disqualified as candidate species for the site.

The native emergent wetland species dominating the wetter areas of the model site included fowl

Table 2: Model wetland emergent plants[17]

Scientific name	Common name	Rank (1-5)	Note*
Alisma plantago-aquatica	Water plantain	2	
Calamagrostis canadensis	Blue joint grass	3	
Carex brunnescens	Grey sedge	2	
Carex crinita	Fringed sedge	3	
Carex lurida	Yellow-green sedge	2	
Carex pseudocyperus	Cypernus sedge	2	
Carex stipata	Awl-fruited sedge	2	
Eleocharis acicularis	Needle spike rush	2	
Glyceria grandis	Reed manna-grass	2	
Glyceria striata	Fowl mannagrass	4	
Iris versicolor	Blue flag	1	
Juncus brevicaudatus	Tweedy’s rush	2	
Juncus canadensis	Canada sedge	2	
Juncus effusus	Soft rush	4	
Nuphar variegata	Cow-lily	1	
Polygonum pensylvanicum	Pinkweed	2	
Pontederia cordata	Pickerelweed	1	
Scirpus cyperinus	Woolgrass	4	
Scirpus pungens	Common three square	1	
Scirpus validus	Soft stem bulrush	2	
Typha angustifolia	Narrow-leaved cattail	1	aggressive
Typha latifolia	Broad-leaved cattail	4	aggressive

*: These plants were disqualified for the reasons noted

mannagrass (*Glyceria striata*), broad-leaved cattail (*Typha latifolia*), soft rush (*Juncus effusus*) and woolgrass (*Scirpus cyperinus*). These four plants were dispersed in clusters (especially the cattail) and were not heterogeneous throughout the site. The native vascular plants dominating the drier, upland portions of the model site were wild sarsaparilla (*Aralia nudicaulis*), bunchberry (*Cornus canadensis*), bracken fern (*Pteridium aquilinum*), goldenrod (*Solidago spp.*) and smooth cordgrass (*Spartina alterniflora*). Goldenrod and smooth cordgrass were dispersed in clusters while the remaining species were spread more evenly throughout the site. The upland shrub species dominating the model site were sheep laurel (*Kalmia angustifolia*), rhodora(*Rhododendron canadense*), meadowsweet (*Spiraea alba* var. latifolia) and blueberry (*Vaccinium angustifolium*). The meadowsweet was notably the most dominant shrub in the site and was often observed growing in the wet areas of the marsh, sometimes in completely submerged conditions. The remaining species were mostly present homogenously throughout the drier upland portions of the site.

Selection of plant species for the constructed wetland: The final plant list for the constructed wetland was developed using the model plant list as a guide. However, the abundance proportions and structures observed in the model site were altered using selection criteria designed to screen the species in the model list for characteristics which were most conducive to the specific goals of the site. The selection criteria included phytoremediation potential, sedimentation and erosion control, habitat function, public deterrent potential, rate of growth, tolerances and maintenance requirements.

The results of the phytoremediation screening of these plants are shown in Table 6-8. The species selected as having excellent sediment stabilization and erosion minimization capabilities are shown in Table 9 and 10. Species identified as supporting superior habitat facilitation and public deterrence capability are shown in Table 11 and 12. Seven species were found to have high phytoremediation potential, eleven species were found to be effective at sediment and soil stabilisation, nine species were found to be suited to habitat facilitation, three species were found to be suited to the purpose of public deterrence and thirty-six species were found to increase diversity and enhance habitat. Woolgrass and soft rush were selected as the species to dominate the constructed wetland site for several reasons: (a) they have thick, rhizomous roots which are capable of penetrating to a depth of 2.5-3.0 feet and are thus extremely useful in sediment stabilisation and oxygenation, (b) they provide greater surface area for facilitation of microbial growth and (c) they have limited litter and do not contribute much detritus to a system[23,24].

Cattails were not selected because: (a) they are not likely to extend roots down to depths greater than one foot and therefore are not efficient in providing aerobic surface area for microbes and biogeochemical cycling, (b) they contributes much litter to the water body every autumn releasing much of the contaminants taken up back into the system, (c) they notoriously take over when competing with other plants for space and resources[23,24]. However, given their effectiveness at cleansing contamination, it was decided that Typha would not be planted in the site until all other populations were established.

One of the secondary goals of the constructed wetland project was to facilitate the creation of habitat. It was intended that the aquatic macrophytes, shrubs and trees which make up the vegetative community of the site, would provide both a source of food and a range of habitats for aquatic and terrestrial fauna including: amphibians, birds and mammals. Rushes, bulrushes and cattails provide denning and nesting sites, as well as shelter in harsh weather.

Dense, woody shrubs and trees such as alders and spruces established in buffer zones reduce faunal disturbance from noise, movement, light and other aspects of the surrounding urban environment. Fruiting shrubs and trees such as blueberry and wild cherry are used by birds and mammals as food. Foliage supports insect populations that aid in the cycling of contaminants as well as provide a valuable link to the food chain[6]. Care was taken to ensure slow growers were given equal opportunity to establish themselves in

Table 3: Model wetland upland vascular plants[17]

Scientific name	Common name	Rank (1-5)	Note*
Aralia nudicaulis	Wild sarsaparilla	4	
Aster spp.	Asters	3	
Bidens discoidea	Common beggar ticks	2	exotic
Brassica rapa	Field mustard	1	invasive
Capsella bursa-pastoris	Shepherd's-purse	1	weed
Chrysanthemum leucanthemum	Oxeye daisy	3	exotic
Cichorium intybus	Chicory	1	exotic
Cornus canadensis	Bunchberry	4	
Cypripedium acaule	Pink lady’s slipper	1	
Equisetum arvense	Field horsetail	4	aggressive
Erigeron annuus	Daisy fleabane	2	exotic
Frageria virginiana	Strawberry	3	
Galium palustre	Common bedstraw	2	
Hesperis matronalis	Dame’s rocket	2	exotic
Hieracium florentinum	Yellow hawkweed	2	invasive
Maianthemum canadense	Wild lily-of-the-valley	1	
Oenothera biennis	Evening primrose	2	
Onoclea sensibilis	Sensitive fern	3	
Osmunda cinnamomea	Cinnamon fern	2	
Phalaris arundinacea	Reed canary grass	2	exotic and invasive
Phleum pratense	Timothy hay	2	exotic
Potentilla simplex	Common cinquefoil	1	
Pteridium aquilinum	Bracken fern	4	
Ranunculus acris	Creeping buttercup	2	poisonous to grazers
Rorippa sylvestris	Creeping yellow cress	1	invasive
Rumex crispus	Curled dock	1	exotic
Senecio jacobaea	Tansy ragwort	1	exotic
Solanum dulcamara	Bittersweet	1	
Solidago spp.	Goldenrod	4	
Spartina alterniflora	Smooth cord grass	4	exotic
Thalictrum pubescens	Meadow rue	3	
Thlaspi arvense	Stinkweed	1	
Trientalis borealis	Starflower	3	
Trifolium pratense	Red clover	2	exotic
Tussilago farfara	Colt’s foot	4	invasive
Verbascum thapsus	Common mullein	1	weed
Vicia cracca	Cow vetch	2	invasive
Viola conspersa	Dog violet	1	
Viola macloskeyi	Small white violet	1	

*: These plants were disqualified for the reasons noted

Table 4: Model wetland upland shrubs[17]

Scientific name	Common name	Rank (1-5)	Note*
Alnus viridis	Speckled alder	2	
Amelanchier arborea	Shadbush/wild pear	3	
Aronia arbutifolia	Red chokeberry	1	
Comptonia peregrina	Sweet fern	2	
Diervilla lonicera	Bush honeysuckle	2	
Kalmia angustifolia	Sheep laurel	4	
Ledum groenlandicum	Labrador tea	2	
Prunus virginiana	Choke cherry	1	
Rhododendron canadense	Rhodora	4	
Rosa multiflora	Multiflora rose	3	exotic
Rosa nitida	Bristly-rose	2	
Rosa palustris	Swamp rose	2	
Rosa virginiana	Common wild rose	2	
Rubus strigosus	Raspberry	2	
Spiraea alba var. *latifolia*	Meadowsweet	5	
Vaccinium angustifolium	Blueberry	4	
Viburnum cassinoides	Witherod	3	

*: These plants were disqualified for the reasons noted

Table 5: Model wetland upland trees[17]

Scientific name	Common name	Rank (1-5)	Note
Abies balsamea	Balsam fir	2	
Acer rubrum	Red maple	2	
Betula papyrifera	White birch	2	
Betula populifolia	Grey birch	4	
Fraxinus americana	White ash	2	
Larix laricina	Tamarack	1	
Picea glauca	White spruce	2	
Picea mariana	Black spruce	2	
Picea rubens	Red spruce	2	
Pinus strobes	White pine	2	
Populus grandidentata	Large toothed aspen	4	
Populus tremuloides	Trembling aspen	1	
Quercus rubra	Red oak	2	

Table 6: Phytoremediation capability of woolgrass (*Scirpus cyperinus*)

Contaminant	Conclusions	Source
Iron and Manganese	-Abundant in successful AMD treatment site, but not specifically studied	Ye *et al*.[25]
Iron	-Abundant in successful treatment wetland; wetland reduced total iron discharge from 10-1 mg L^{-1}	Campbell and Ogden[23]
Metals	-Abundant in successful treatment wetland, but not specifically studied	Tousignant *et al*.[26]
Acid Mine Drainage (AMD)*	-Abundant in successful AMD treatment site, but not specifically studied	Demchik and Garbutt[27]
Ammonia, Domestic wastewater	-Woolgrass and cattail treatment wetlands reduced ammonia and TKN 18-67.5% depending on location	Demchik and Garbutt[27]
Manganese and Zinc, AMD metals	-Mn, Zn, Cu, Ni, B and Cr accumulated in Woolgrass, but only accounted for small % of overall removal	Mays and Edwards[28]

*: AMD wastewater is typically high in iron, manganese and ammonia

the constructed wetland as suggested by Davis[3]. Spreading rates as indicated by the planting distance required for uniform cover to be achieved in 1 year (or UC1), for the species identified as potential candidates for the constructed wetland site were researched. In general, of the emergent aquatic species, sedges (*Carex spp.*) and rushes (*Juncus spp.*) appeared to be the slowest spreaders and cattails (*Typha spp.*) appeared species tend to support small biomass. However, sedge could not be dismissed as they support high habitat value and are often prone to hyperaccumulate metals and nutrients[23,37]. The aquatic emergent species chosen to dominate the interior berms of the treatment wetland site were woolgrass (*Scirpus cyperinus*) and soft rush (*Juncus effusus*). Soft rush is a very slow spreader (UC1 = 15 cm), while woolgrass is a moderate spreader

Table 7: Phytoremediation capability of soft rush (*Juncus effusus*)

Contaminant	Conclusions	Source
Iron, Manganese and AMD	-Soft rush and cattail pond 99% effective at Fe removal and 58% effective at Mn removal. -Aboveground and belowground tissues of soft rush had higher concentrations of S, Fe, Mn, Zn, Cd than cattail. -Concentrations of Fe and Mn in soft rush shoots approximately 4x greater cattail shoots. -Notably, overall uptake by both only accounted for less than 2.5% of the annual element loading rates: sediments were primary sink.	Ye *et al*.[25]
Iron	-Fe uptake by common wetland plants potentially key metal removal process in polishing treatment applications (where wetland removing last few mg L^{-1}) -future studies to concentrate on *Typha latifolia, Juncus effusus*	Younger and Batty[29]
TSS, BOD, TKN, Ammonia, Phosphate	Soft rush 1 of 3 species in wetland which collectively removed 70% TSS and BOD, 60-60% TKN, ammonia and phosphate.	Coleman *et al*.[30]
AMD	-Soft rush and cattail dominated successful AMD treatment site, but not specifically studied.	Treacy and Timpson[31]
Manganese and Zinc, AMD metals	-Mn, Zn, Cu, Ni, B and Cr accumulated in soft rush, but only accounted for small % of overall removal.	Mays and Edwards[28]

Table 8: Phytoremediation capability of broad-leaved cattail (*Typha latifolia*)

Contaminant	Conclusions	Source
Iron and Manganese	-Series of 4 *Typha* wetland cells decreased Fe and Mn from inlet water by 94 and 94%, respectively. -Notably, overall uptake by plants only accounted for less than 0.91 and 4.18 % of Fe and Mn uptake: Sediments were primary sink.	Ye *et al*.[32]
Iron and Manganese	-*Typha* wetlands effective removers of iron and manganese.	Snyder and Aharrah[33]
Iron	-*Typha* wetland reduced iron concentrations from 20-25 mg L^{-1} to 1 mg L^{-1}.	Kleinmann[34]
Ammonia	-Ammonia concentration reductions by laboratory-grown cattail shoots in tailings water of 40 mg L^{-1} to 3.7 mg L^{-1} in 1 day. -Cattail islands removed 0.8-0.9 g of ammonia from 300 L of mine water in 24 h.	Boojum Research Limited[35]
TSS, BOD, TKN, Ammonia, Phosphate	-Cattail 1 of 3 species in wetland which collectively removed 70% TSS and BOD, 60-60% TKN, ammonia and phosphate.	Coleman *et al*.[30]
Iron	-Fe uptake by common wetland plants metal removal process in polishing treatment key applications (where wetland removing last few mg L^{-1}) potentially-future studies to concentrate on *Typha latifolia, Juncus effusus*.	Younger and Batty[29]
Ammonia, Domestic wastewater	-Woolgrass and cattail treatment wetlands reduced ammonia and TKN 18-67.5% depending on location	Huang *et al*.[36]

Table 9: Sediment stabilizer candidates for the constructed wetland[17,18,37]

Common name	Scientific name	Rationale
Woolgrass	*Scirpus cyperinus*	Dense root systems
Soft rush	*Juncus effuses*	Dense root systems
Pickerelweed	*Pontederia cordata*	Dense and prolific around littoral zones
Canada bluejoint grass	*Calamagrostis Canadensis*	Dense root systems

at UC1 = 30 cm[37]. Consequently, in order to allow soft rush a better chance at competing with the established woolgrass, soft rush individuals were placed at tighter intervals and more individuals were used. Notably, both species are tolerant of permanent inundation, support prolific roots, produce abundant seed and have high habitat value. However, woolgrass appeared to be the more hardy of the two as it is shade, drought and flood tolerant, as well as tolerant of waters and soils with varying pHs[17,37,38].

According to Thunhorst[37], Runesson[39] and Rook[40], the fastest spreading candidate shrubs for placement in the constructed wetland are meadowsweet (*Spiraea alba* var. *latifolia*) and speckled alder (

Table 10: Erosion minimizing candidates for the constructed wetland[17, 37]

Common name	Scientific name	Rationale
Meadowsweet	*Spiraea latifolia*	Prolific growth, deep, dense rooting
Speckled alder	*Alnus viridis*	Prolific growth, deep, dense rooting
Trembling aspen	*Populus tremuloides*	Great in steep areas. Also effective hydrocarbon removers via evapotranspiration in upper 2-3 metres of soil (Raskin and Ensley, 2000).
Pinkweed	*Polygonum pensylvanicum*	Dense rooting
Large toothed aspen	*Populus grandidentata*	Great in steep areas. Also effective hydrocarbon removers via evapotranspiration in upper 2-3 metres of soil (Raskin and Ensley, 2000).

Table 11: Habitat facilitator candidates for the constructed wetland[37]

Common name	Scientific name	Rationale
Broad-leaved cattail	*Typha latifolia*	Food and cover
Narrow-leaved cattail	*Typha angustifolia*	Food and cover
Raspberry	*Rubus strigosus*	Food
Meadowsweet	*Spiraea latifolia*	Cover and noise barrier
Speckled alder	*Alnus viridis*	Cover and noise barrier
White spruce	*Picea glauca*	Cover and noise barrier
Black spruce	*Picea mariana*	Cover and noise barrier
Red spruce	*Picea rubens*	Cover and noise barrier
Witherod	*Viburnum cassinoides*	Food
Blueberry	*Vaccinium angustifolium*	Food
Choke cherry	*Prunus virginiana*	Food
Red chokeberry	*Aronia arbutifolia*	Food
Shadbush/wild pear	*Amelanchier arborea*	Food

Table 12: Deterrent candidates for the constructed wetland[17,20,37]

Common name	Scientific name	Rationale
Speckled alder	*Alnus viridis*	Dense and very difficult to traverse through
Meadowsweet	*Spiraea latifolia*	Dense and difficult to traverse through
Swamp rose	*Rosa palustris*	Thorns
Bristly-rose	*Rosa nitida*	Thorns
Common wild rose	*Rosa virginiana*	Thorns

Alnus viridis). These species were selected to dominate the buffer zones in order to quickly and effectively facilitate bank stabilization. However, the slower spreaders, which include the larger fruiting shrubs such as red chokeberry (*Aronia arbutifolia*) and witherod (*Viburnum cassinoides*), were also included in the buffer as these species provide high habitat value as a result of their abundant fruit. In addition, stouter, less prominent shrubs such as sweet fern (*Comptonia peregrine*), Labrador tea (*Ledum groenlandicum*), rhodora (*Rhododendron canadense*), sheep laurel (*Kalmia angustifolia*) and blueberry (*Vaccinium angustifolium*) were also included in the buffer areas as these species are notoriously tolerant of harsh soil conditions.

Vegetation establishment: Figure 4 shows that general planting plan for the site whereas Fig. 5 shows the planting layout for the location of each species established in the site in 2002. In total, approximately 1080 plants were transplanted into the wetland cells and buffer areas. Transplant success was high, with few mortalities observed over the course of the spring and summer of 2002. It should be noted that the locations of the species are approximate and the representative symbols do not account for the size of the plants. In addition, the layout does not include incidental plantings associated with transplanted species (grasses naturally intertwined with transplanted soft rush), nor does it include the many natural wetland plants which found their way to the wetland site on their own via wind dispersion of seeds, rhizomes and seed stock in existing and transplanted soils. By the fall of 2002, the constructed wetland site had already begun transformation from a barren landscape to a lush wetland environment.

Transplanting of mature plants from local donor sites was selected as it is by far the most ideal site establishment methodology for several reasons: (a) it is very cost effective, (b) plants are already genetically adapted to local environmental conditions, increasing their survival success and habitat significance, (c) transplantation can generally be carried out three season of the year, (d) plants establish themselves readily and have the highest survival success of all the plant establishment techniques, (e) by planting adult plants, site establishment occurs much more quickly than with seeding or other means, (f) transplanted species contain soil around their roots holding dormant seeds of plants which will naturally add to the diversity and total vegetative cover of the area and (g) transplant soils also contain microbes, invertebrates and eggs, which accelerate the establishment of microbial, insect and reptile communities in the site[6,20,21].

For their inherent phytoremediation capabilities, sediment stabilisation abilities, large aboveground and belowground biomass and abilities to facilitate microbial growth and effectively aerate sediments, the species woolgrass (*Scirpus cyperinus*) and soft rush (*Juncus effusus*) were chosen to dominate the interior berms and littoral edges of the constructed wetland cells. The planting of these species was complimented by additional aquatic species from the final planting list to increase diversity and provide other functions characteristic to those species.

Woody species were purposely excluded from the interior berms as the roots of shrubs and trees can create channels and subsequent leakages through berms. The pickerelweed was established in the littoral zones of these cells. The buffer areas were dominated by meadowsweet (*Spiraea alba* var. *latifolia*) plantings

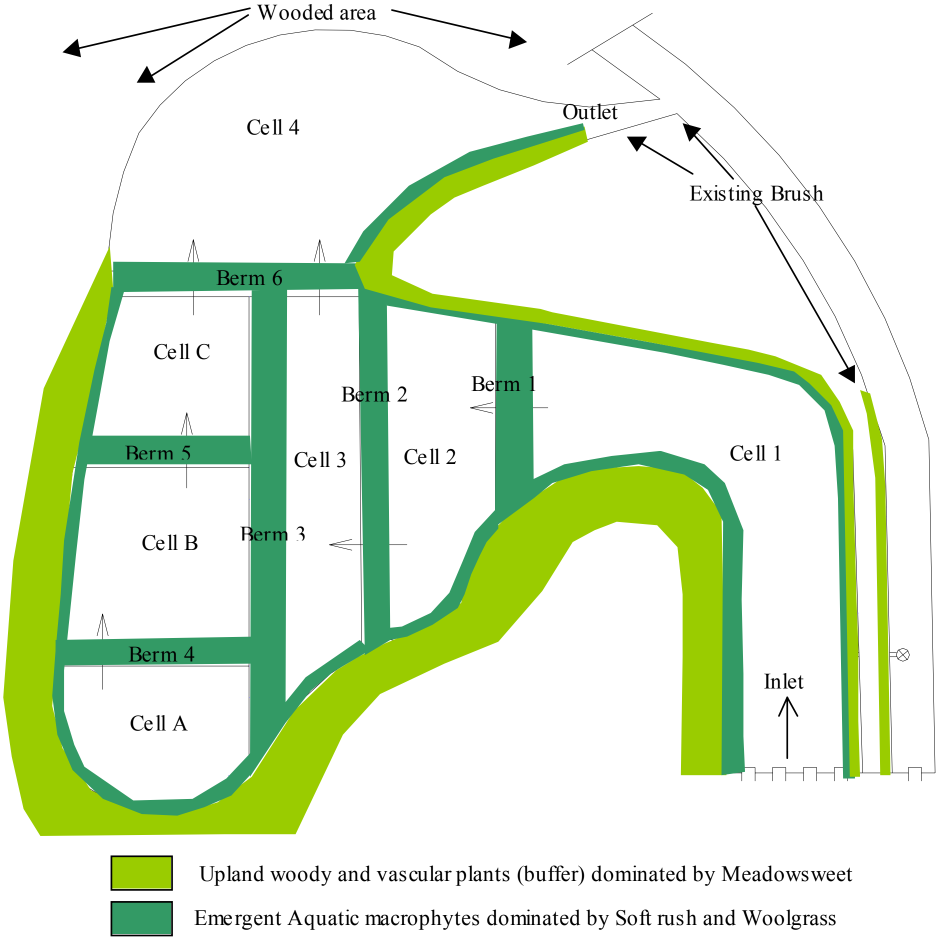

Fig. 4: General planting plan

due in part to their availability and ease of removal from the model site.

Vegetation establishment success: The vegetation establishment success of the constructed wetland site is demonstrated in Fig. 6. Overall, 138 dead transplants were observed, many of which had died as a direct result of washout. This computes to an overall site establish success rate of about 87.3%. The species which suffered the highest mortality rates were the pickerelweed, with approximately 50 dead plants, the meadowsweet with 32 observed dead plants and woolgrass with 27 dead plants. Next were the sheep laurel (7 dead plants), grey birch (6 dead plants), soft rush, large-toothed aspen, the roses and speckled alder (tied with 4 dead plants). According to Environment Canada[21], seeding in wetland projects typically results in a 30% survival rate. The seeding success of the woolgrass, soft rush and fowl mannagrass could never be accurately gauged, as the observed new shoots could be the result of natural spreading. However, new shoots of the three seeded species were notably abundant in the wetland, particularly in the latter cells of the site.

According to Daigle and Havinga[20], in all site establishment projects, it is inevitable that plants will die and that replanting will be necessary. Despite some observed mortalities, overall, the site establishment strategy chosen effectively yielded a successfully established site. Those plants which did see mortality in the site are pickerelweed (*Pontederia cordata*), meadowsweet (*Spiraea alba* var. *latifolia*), woolgrass (*Scirpus cyperinus*), sheep laurel (*Kalmia angustifolia*), soft rush (*Juncus effusus*), rose species (*Rosa spp.*), trembling aspen (*Populus tremuloides*), grey birch (*Betula populifolia*) and speckled alder (*Alnus viridis*).

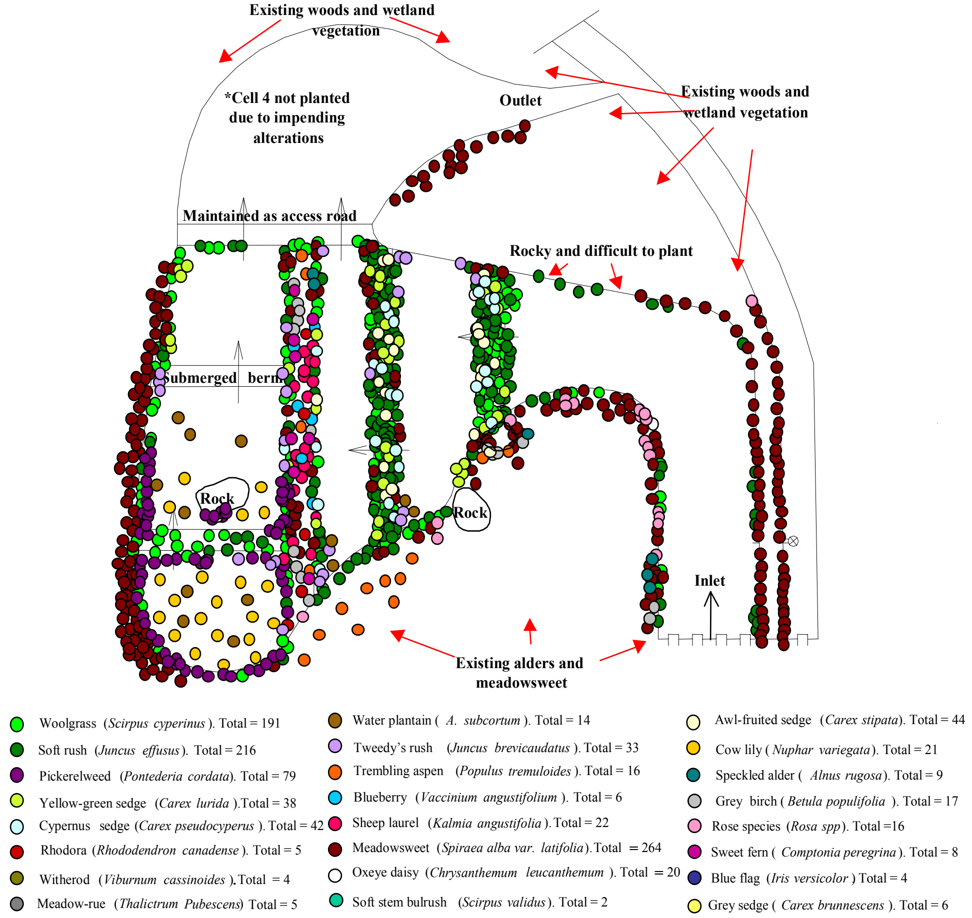

Fig. 5: Final planting layout, September 2002

Water quality: On July 21st 2003, reductions of 49.66, 66.66, 1.91, 46.37 and 8.33% were obtained for manganese, orthophosphate, TSS, TDS and COD, respectively as water flowed through the constructed wetland (Table 13). There was an increase of 52.94% in the TKN concentration between cell 1 and the outlet. There are no water quality guidelines reported by the Canadian Council for Ministers of Environment (CCME) for the protection of aquatic life for manganese, orthophosphate, TSS, TDS, TKN and COD[14].

Although a reduction of 67.36% in iron was achieved, the outlet concentration of 2.51 mg L^{-1} was higher than the 0.3 mg L^{-1} guideline established by CCME[14]. The nitrate concentration was below the water quality guideline for the protection of aquatic life of 13 mg L^{-1} established by CCME[14].

The nitrite concentration exceeded the guideline concentration of 0.06 mg L^{-1} for protection of aquatic life. The high nitrite levels obtained in the outlet may be correlated with the stagnation observed in the site that day as nitrite can persist in waters, which suffer from oxygen depletion. The dissolved oxygen obtained at the site was below the minimum guideline of 5.5 mg L^{-1} established by the CCME for the protection of aquatic life[14].

Generally, ammonium decreased by 67% and was not detected in some of the samples. NH_4 is fairly harmless whereas NH_3 can be lethal at high level. No NH_3 was produced as the pH was below 8.5. The pH value was within the range established by CCME for freshwater (6.5-9.0)[14].

CONCLUSION

A natural wetland system located approximately 200 m downstream of the constructed wetland was selected to act as the vegetative community model for the constructed wetland. The selected model was a riparian, open water marsh dominated by emergent macrophytes. Baseline plant species surveying was conducted. In total, 21 emergent wetland plant species, 40 upland vascular plant species, 17 upland shrub species and 13 upland tree species were identified in the model site. The species from the model site were screened for suitability in the constructed wetland based on the following criteria: (a) phytoremediation potential (especially metal uptake), (b) sedimentation and erosion control, (c) habitat function, (d) public deterrent potential and (e) rate of plant establishment, tolerances and maintenance requirements. Transplantation was chosen as the main vegetation establishment methodology in the constructed wetland. The species woolgrass (*Scirpus cyperinus*) and soft rush (*Juncus effusus*) were chosen to dominate the interior berms and littoral edges of the constructed wetland cells.

The buffer areas were dominated by meadowsweet (*Spiraea alba* var. *latifolia*) and the open water areas were dominated by cowlily (*Nuphar variegate*) and pickerelweed (*Pontederia cordata*) species. A diverse, self-sustaining vegetative community was successfully established in the constructed wetland. The transplant success was gauged by mortality census in the spring of 2003. Over all, 138 dead transplants were observed, many of which had died as a direct result of washout. This computes to an overall site establish success rate of about 87.3%.

Table 13: Water quality parameters of the constructed wetland

	Values (mg L^{-1})		Reduction
Parameters	Cell 2	Outlet	(%)
Fe (mg L^{-1})	7.69	2.51	67.36
Mn (mg L^{-1})	1.45	0.73	49.66
NO_2 (mg L^{-1})	0.09	0.59	(555.55)
NO_3 (mg L^{-1})	5.73	4.28	25.31
NH_4 (mg L^{-1})	3.00	0.25	91.67
TKN (mg L^{-1})	4.25	6.50	(52.94)
PO_4 (mg L^{-1})	0.03	0.01	66.66
TSS (mg L^{-1})	523	513	1.91
TDS (mg L^{-1})	509	273	46.37
COD (mg L^{-1})	1092	1001	8.33
DO (mg L^{-1})	4.1	4.4	(7.32)
pH	7.2	7.2	0.00

( ) = increase

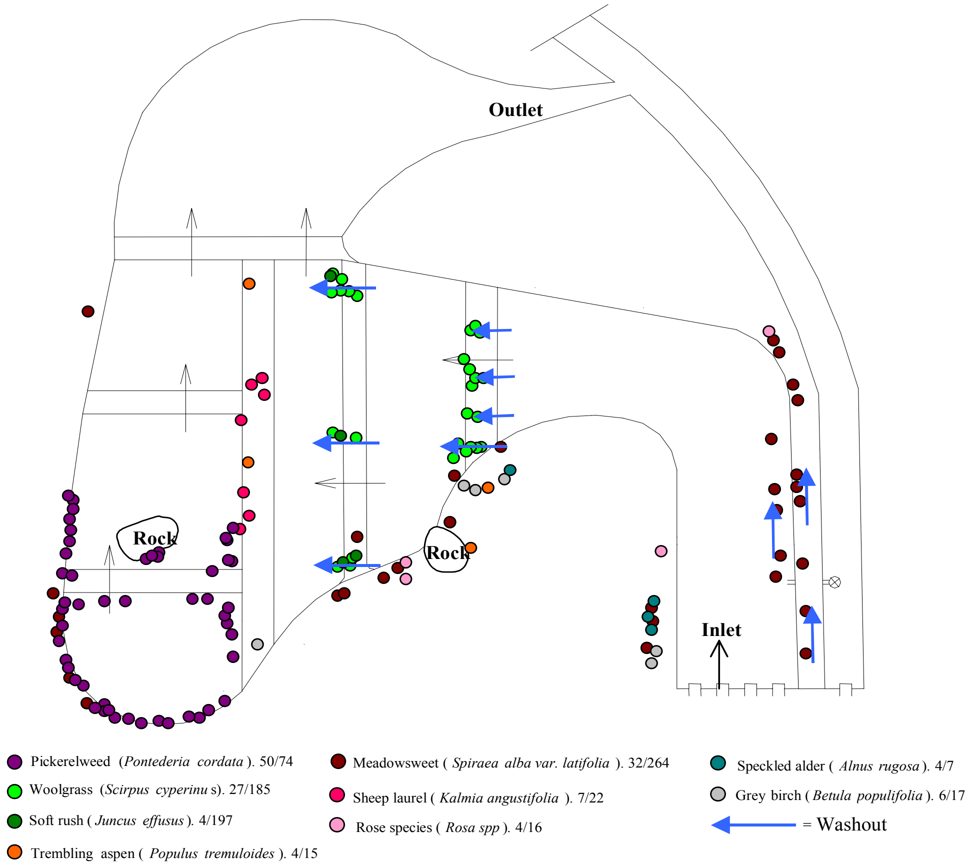

Fig. 6: Transplant mortalities and washout, 2003

The species which suffered the highest mortality rates an overall site establish success rate of about 87.3%. The species which suffered the highest mortality rates were the pickerelweed, with approximately 50 dead plants, the meadowsweet with 32 observed dead plants and woolgrass with 27 dead plants.

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