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Pollutant Removal Dynamics of Three Wet Ponds in Canada

Communities in the Toronto metropolitan area have long relied on wet ponds and wet extended detention ponds to treat stormwater runoff from new development. According to provincial guidelines, wet ponds are sized based on two primary factors: the quality of fishery habitat present downstream (designated as fishery level one through four) and the amount of impervious cover present in the upstream catchment (OME, 1994). Based on these factors, engineers must achieve a numeric target for suspended sediment removal in the stormwater pond to protect the downstream fishery habitat (Table 1). The Ontario approach for sizing ponds results in wet ponds that often have more water quality storage than many of their American counterparts, given that many Ontario watersheds still contain high quality fishery habitat.

Over the last five years, a consortium of local and provincial stormwater agencies have investigated how various kinds of ponds perform under the demanding climatic conditions of the Toronto metropolitan region. This research program, known as the Stormwater Assessment Monitoring and Performance Program (SWAMP), has added greatly to our understanding of how modern ponds remove stormwater pollutants during both the summer and winter in northern latitudes. The SWAMP study is also notable because it commissioned a series of supplemental research studies to investigate the internal dynamics of stormwater ponds. These studies included monitoring wetland plant colonization over time, sediment deposition rates, sediment quality, the impact of chlorides from road salts, and the impact of ponds on stream warming. With apologies to our Canadian friends, we confess to being metrically challenged, and have converted some of their metric data into American units for the convenience of our stateside readers.

The basic design utilized in the SWAMP program involved sampling three ponds during both the growing season and more demanding wintertime conditions. Automated flow and water quality samplers were located at the inlet(s) and outlets from each pond during the summer and fall. Due to ice cover, grab samples of pollutant concentrations were collected at inlets and outlets to characterize how the ponds influenced pollutant concentrations during winter and snow melt conditions. Each of the three ponds selected for intensive monitoring employed several innovative pond design concepts, such as sediment forebays, extended detention over the permanent pool, generous water quality storage volumes, reverse-sloped pipes, multiple cells,

Table 1: Sizing Guidelines for Wet Ponds in Ontario (OME, 1994)

Watershed Protection Level	Required water quality storage for Ontario wet ponds (inches per acre)			
	35% imp	55% imp	70% imp	85% imp
Level 1 fishery (excellent habitat) 80% sediment removal	0.56	0.76	0.90	1.0
Level 2 fishery (good habitat) 70% sediment removal	0.36	0.44	0.52	0.60
Level 3 fishery (poor habitat) 60% sediment removal	0.24	0.30	0.34	0.38
Level 4 retrofit and redevelopment 50% sediment removal	0.24	0.24	0.24	0.26

Note: Indicated storage is allocated to permanent pool, except up to 0.16 inches which can be supplied as extended detention storage.

or ideal pond geometry (although not all of these design factors were incorporated into every pond).

Heritage Estates Wet Pond

The first pond investigated by the SWAMP program was a basic wet pond known as Heritage Estates (see Figure 1). The pond served a 130-acre residential catchment that had estimated impervious cover of 50%. Designed for Level 2 protection, the wet pond was a pool that provided 0.51 watershed-inches of storage. The pond was relatively shallow (about three to four feet in depth) and had a surface area of 1.85 acres (or about 1.4% of watershed area). The pond did not provide any storage for extended detention, but did provide control for the five-year storm. The pond was seven years old when monitoring began, and had two inlets, but no forebay. The outlet structure of the Heritage Estates pond was a rectangular weir discharging water from the surface of the pond.

The pond froze over during the winter months, and often had eight to 12 inches of ice cover. The roads in the catchment were heavily sanded and salted during the winter months, but were swept in the early spring, and monthly thereafter. The study team was able to monitor more than 20 storm events at Heritage Estates, with half of the samples obtained during the growing season, and the remainder collected during winter or spring snow melt conditions.

Harding Park Wet Extended Detention Pond With Wetland

The second pond, known as Harding Park, was a retrofit, and was much more complex in its design (see Figure 2). Harding Park had three cells, including a shallow forebay, a six-foot deep permanent pool and a small wetland. In addition, extended detention storage was provided above each cell. The pond was designed for Level 2 protection, and contained about 0.66 watershed-inches of water quality storage. About two-thirds of its water quality storage was devoted to extended detention, with the remaining third allocated to a small permanent pool (about 0.22 inches). The average detention time achieved by the pond was not ideal, averaging about six to 12 hours for most storm events.

The Harding Park pond served a 42-acre residential catchment that was estimated to be 45% impervious. The entire facility had a surface area of 1.7 acres (or about 4% of the watershed area). The retrofit, which was only one year old when monitoring began, encountered some early operational problems. A berm which separated the pond and the small wetland collapsed shortly after construction and was not repaired for many months. Consequently, the first year of monitoring data could not be used. Still, the SWAMP study team was able to collect more than 20 storm samples after the berm was repaired. Once again, half of the storm samples were collected in the growing season, and the remaining half were collected under winter and spring snow melt conditions.

Rouge River Wet Extended Detention Pond

The last pond that was monitored was a wet extended detention pond, known as the Rouge River Pond. Designed for Level 1 protection, the retrofit pond served a 320-acre catchment that was dominated by some of the more heavily traveled roads in the Toronto region. The catchment also included some residential

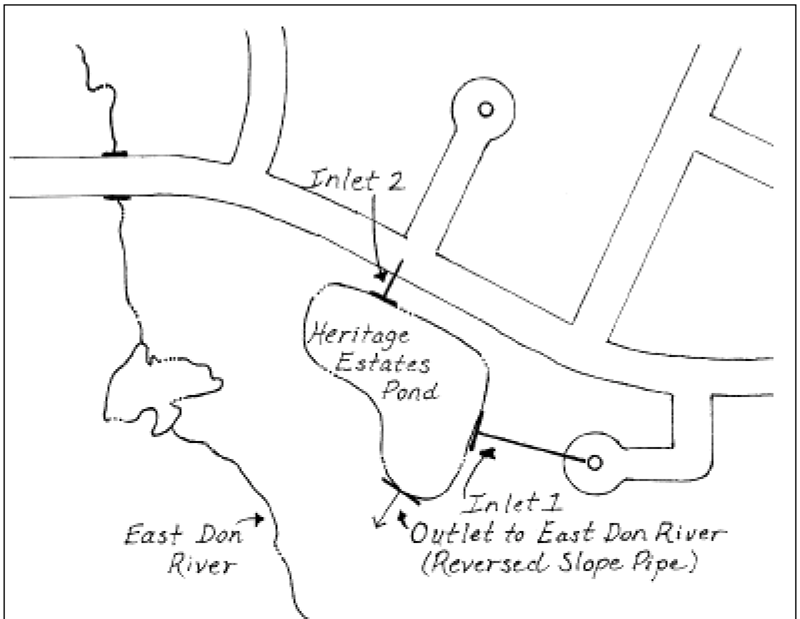

Figure 1: Heritage Estates Wet Pond

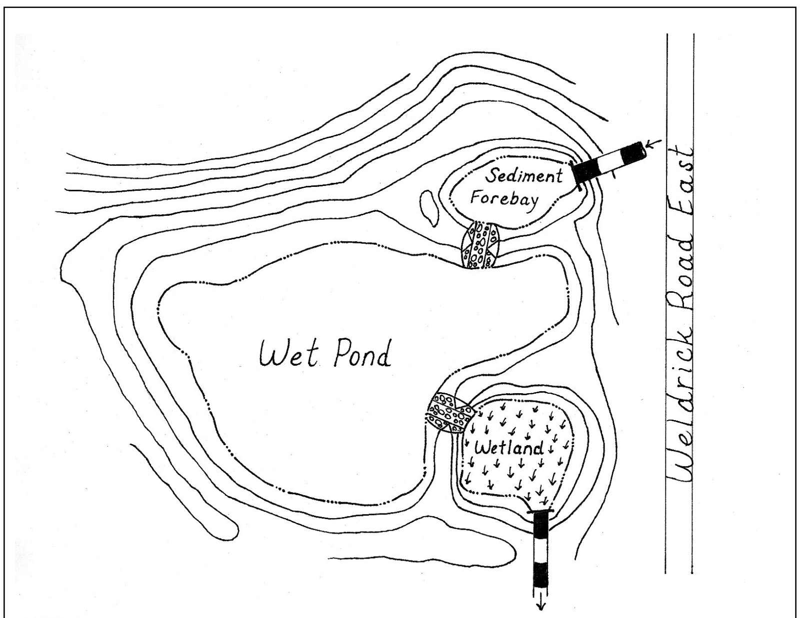

Figure 2: Harding Park Wet Extended Detention Pond With Wetland

development, and was estimated to be 60% impervious. The retrofit pond provided a total of 0.64 watershed-inches of water quality storage, which was equally split between the permanent pool and extended detention. Linear in shape, the pond had an extraordinary length to width ratio of ten to one (see Figure 3). The wet pond was quite deep (eight foot average depth), and was equipped with a reverse slope pipe outlet that withdrew water about three feet below the normal pool. The pond also had a sediment forebay at its single inlet that comprised about 15% of the total water quality storage for the pond. The retrofit was also equipped with a flow splitter to bypass all storm flows that exceeded the two-year storm event around the facility.

The pond was less than two years old when monitoring began, and several early problems were encountered. The sediment forebay was completely filled shortly after construction, and the main pond cell experienced very high turbidity, as a result of sediment loads from upstream roadway construction and severe bank erosion. Sampling commenced after the forebay was dredged and upstream erosion problems were stabilized, and the SWAMP team collected 18 storm events after these problems were corrected.

Comparative Performance of the Three Canadian Stormwater Ponds

Pollutant Removal During the Growing Season

The comparative capability of the three stormwater ponds to remove stormwater pollutants during the growing season is presented in Table 2. As can be seen, all of the ponds were able to remove most urban pollutants at a reasonably high level. For example, each of the ponds was able to remove at least 80% of the incoming suspended sediment load during the growing season, which met or exceeds provincial guidelines for sediment removal. Indeed, particle size analysis conducted at two of the ponds indicated that they were effective in removing most particles larger than 10 microns.

The results were more mixed for nutrient removal. Each of the three ponds did an exceptional job of removing soluble phosphorus (range 69% to 91%), and two of the three ponds averaged about 80% for total phosphorus, as well. A high rate of phosphorus removal in the ponds was also indicated by the very low phosphorus concentrations measured at the pond outlets (see Table 4). On the other hand, the three ponds showed a much lower ability to remove nitrogen from stormwater. While each pond was capable of removing a modest amount of nitrate-nitrogen due to algal uptake, the removal of organic nitrogen was low, and in some cases, negative. Overall, removal of total nitrogen ranged from about 15 to 40% in the three ponds.

Each of the ponds was reasonably effective in removing total copper, lead and zinc, but was not very effective in removing cadmium from stormwater runoff. The study also measured the ability of the ponds to remove many trace elements not frequently monitored by other investigators. Removal rates of 50% or greater were consistently attained during the growing season for aluminum, beryllium, chromium, cobalt, iron, nickel and vanadium at each of the ponds. In contrast, low or negative removal rates were routinely reported for barium, calcium, magnesium, silicon, strontium and titanium. The ponds were also found to have a moderate to high ability to remove oil and grease and pentachlorophenol from stormwater runoff (the latter are associated with the use of wood preservatives).

The ponds showed some promise in removing bacteria, with 50 to 90% removal reported for fecal

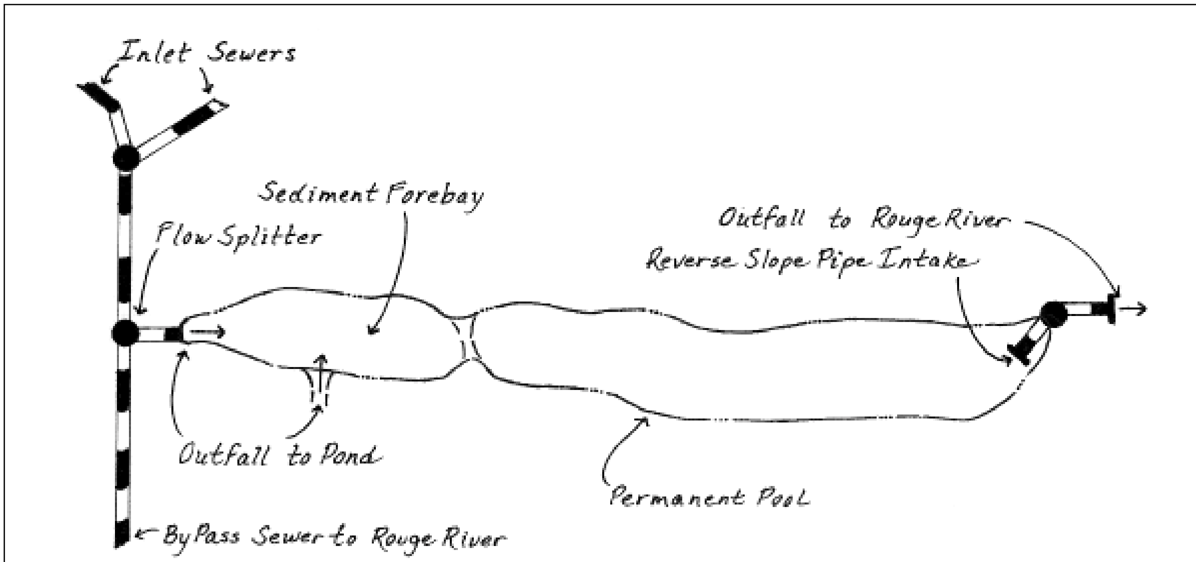

Figure 3: Rouge River Wet Extended Detention Pond

coliform and E. coli during the growing season. Even at this level of stormwater treatment, however, outflow concentrations were typically five to 10 times above bacteria standards (see Table 4). The study team also discovered that dissolved inorganic carbon (DIC) and chlorides were exported from each of the ponds during the growing season. The export of chlorides was thought to reflect the gradual release of dissolved salts that had entered the pond during the winter as a result of road deicing.

The study team conducted a series of bioassays to determine if one of the ponds (Rouge River) could reduce potential toxicity of stormwater for zooplankton and trout test organisms. Most of the bioassays indicated that the stormwater entering and leaving the pond was non-lethal. A few bioassays caused mortality, which was primarily attributed to high chloride and copper concentrations. The Rouge River pond did appear to reduce copper concentrations to non-lethal levels, but had little effect on chloride levels.

Pollutant Removal During Winter Conditions

A key study objective was to characterize how the ponds worked during snow melt conditions in the winter. This effort was limited by the unavoidable problem of collecting grab samples of pollutant concentrations, since ice cover prevented the team from collecting reliable flow measurements in the winter. Still, the SWAMP team was able to collect more than 30 samples at the three ponds.

Overall, winter removal rates were surprisingly high, and were almost as great as those observed during the growing season (Table 3). Sediment removal ranged from 75 to 86%. Nutrient removal was slightly lower, which was expected given the lack of biological uptake in the winter. Still, average phosphorus removal ranged from 56 to 67%, and TKN removal was about 30%, as well. Slightly negative removal was reported for soluble forms of nitrogen. The concentration of total phosphorus and total nitrogen in pond effluent was typically 30 to 50% higher in winter than in the growing season. Removal of copper, lead and zinc also tended to be slightly lower in the winter months than during the

Table 2: Comparative Pollutant Load Reduction at Three Ontario Stormwater Ponds During Growing Season

Parameter[1]	Heritage Park Wet Pond	Harding Park Wet ED Pond w/marsh	Rouge River Wet ED Pond
Total Suspended Solids	80%	80%	87%
Total Phosphorus	80	37	79
Ortho-phosphorus	91	87	69
Nitrate-nitrogen	62[2]	29	24
TKN	0	(-24)	59
Ammonium	(-68)	(-24)	70
Cadmium	10	0	46
Copper	70	41	79
Lead	15	84	84
Zinc	68	69	79
Fecal Coliform	90	64	ns
E. Coli	86	51	ns
Chloride	(-188)	(-545)	(-169)
Pentachlorophenol	80	ns	46
Oil/Grease	ns	37	79

Notes: 1. Growing season removal based on 10 or more paired samples at each pond.
2. Nitrate removal calculated using average mean concentration methods
ns = not sampled

Table 3: Comparative Pollutant Removal at Three Ontario Stormwater Ponds in Wintertime Conditions (removal rates based on average event mean concentration reduction method)			
Parameter[1]	**Heritage Park Wet Pond**	**Harding Park Wet ED Pond w/marsh**	**Rouge River Wet ED Pond**
Total Suspended Solids	86%	78%	75%
Total Phosphorus	65	56	67
Ortho-phosphorus	30	66	74
Nitrate-nitrogen	(-1)	(-12)	(-18)
TKN	34	31	31
Ammonium	(-68)	(-18)	14
Cadmium	49	80	63
Copper	65	22	41
Lead	27	11	73
Zinc	72	38	25
Fecal Coliform	83	(-3)	ns
Chloride	(-73)	(-3)	(-17)
Pentachlorophenol	45	ns	20
Oil/Grease	ns	29	51
DOC	ns	(-90)	1
Notes: 1. Winter removal based on 10 or more paired samples at each pond. ns = not sampled			

Table 4: Comparative Outflow Concentrations From Three Ontario Stormwater Ponds During Growing Season			
Parameter	**Heritage Park Wet Pond**	**Harding Park Wet ED Pond w/marsh**	**Rouge River Wet ED Pond**
Total Suspended Solids	16	48	37
Total Phosphorus	0.07	0.11	0.06
Ortho-phosphorus	0.03	0.014	0.006
Nitrate-nitrogen	0.65	0.66	0.97
Total Nitrogen	1.60	1.66	1.58
Copper	0.008	0.005	0.010
Zinc	0.010	0.016	0.067
Fecal Coliform	1779	2858	783
Chloride	81	71	580
Oil/Grease	nd	0.8	1.5
DIC	nd	30.7	49.1
Notes: all units in mg/l except for fecal coliform which is in units of colonies per 100 ml. Winter outflow concentrations were generally in the same range as growing season concentrations, with the exception of chlorides, total nitrogen and phosphorus.			

growing season. The three ponds were unable to remove chloride during the winter months, and chloride levels in pond outflow were two to three times higher in the winter than during the summer months. Still, the overall winter performance of the three ponds was much higher than that reported for other ponds and pond/wetland systems in cold climates (see article 71).

Winter chloride inputs continued to have a strong influence on the ponds during the summer months. There was evidence of gradual accumulation of chlorides in the bottom of the permanent pool over time, and a strong chemical stratification was observed at two of the ponds during the summer. The stratification was caused by a dense layer of chloride-rich water that entered the pond in the winter and persisted at the bottom of the pond throughout the summer months.

Stream Warming

Each of three catchments produced about 0.1 cfs of base flow that continuously flowed through the ponds most of the year. Other researchers have demonstrated that wet ponds can dramatically increase base flow water temperatures during the summer. This “delta-T effect” has the potential to harm aquatic species adapted to cold and cool water conditions, but has not been studied extensively in northern latitudes. The SWAMP team reported high delta-Ts during the months of July and August for the Heritage Estates wet pond (nine to 13 degrees F), the Harding Park wet ED pond (nine to 18 degrees F) and the Rouge River wet ED pond (11 to 14 degrees F). One of the ponds (the Rouge River pond) had an outflow pipe situated several feet below the permanent pool, but this design feature did not appear to greatly influence the ponds’ delta-T.

Baseflow water temperatures were typically in the low 60s to 70s when they entered the pond in the summer, but warmed to the high 70s to mid 80s by the time they exited the pond. The baseflow water temperatures consistently violated provincial temperature criteria to protect cold water fisheries. However, the study team noted that in each case downstream water temperatures quickly recovered as a result of groundwater inflows, riparian forest cover, and the confluence with larger streams.

Sediment Deposition and Sediment Quality

The study team measured the average rate of sediment deposition within two of the ponds. The stabilized residential drainage at the Heritage wet pond had a very low deposition rate of about 0.1 inch/year, whereas the Rouge River wet ED pond had a deposition rate of about one inch per year. Sediment deposition rates for these ponds were at the lower range reported in a wider study of deposition for other stormwater ponds in the Toronto region (0.5 to 10 inches per year, GIC, 1999). Extrapolating their data using a pond simulation model, the study team predicted a 30 to 50 year sediment clean out cycle would be sufficient to maintain the sediment removal rates for the three ponds.

Pond sediments were tested to evaluate whether they could meet provincial quality criteria for safe sediment disposal. Sediments from the Heritage Estates wet pond were found to be suitable for land application, whereas the sediments of the main cell of the Rouge River wet ED pond were not (primarily because of high metals from roadway runoff). According to current OME sediment disposal criteria, sediments from this pond will ultimately need to be land-filled. Testing of sediments in the pond’s forebay revealed coarse sands that were not contaminated by pollutants.

Plant Community

Unique to the study was a detailed investigation of how wetland plants colonized the ponds and their buffers after they were constructed. The Harding Park pond was initially planted with 11 wetland species shortly after construction, while the Rouge River pond was started with five species. As might be expected, the initial coverage and density of wetland plants were rather poor, both above and below the permanent pool. However, within two years after construction, more than 75 aquatic and meadow wetland plant species were found within each facility, and plant coverage was quite dense. Most of the originally planted species were still found in the wetland community after three years. About a third of the colonizing species were found to be nonnative species, and the plant community was showing signs of dominance by more aggressive species, such as purple loosestrife, cattail and water plantain. Still, the considerable wetland diversity attained in such a short time by natural colonization has led some to question the notion of requiring elaborate pondscaping plans at the time of construction.

Summary

The performance of the three Canadian ponds compares favorably to the median performance of 36 wet ponds and wet ED ponds that had been monitored in the 1980s and early 1990s (see article 64), particularly with respect to suspended sediment, total phosphorus and trace metals, such as copper and zinc. Indeed, as a group, the Canadian ponds performed comparably to Texas wet and wet ED ponds (article 74). The pollutant removal performance of both groups of ponds ranks among the highest recorded for any stormwater practice, despite the dramatic differences in climate between the two regions. Clearly, their high performance can be partly attributed to their large water quality storage volumes, and possibly to their more progressive design features, as well.

At this point, it is difficult to infer exactly which pond design features promote higher pollutant removal.

For example, the Harding Park extended detention wet pond/marsh was clearly the most complex pond design in the Canadian study, but it actually performed slightly worse than the two more simply designed ponds. It is worth noting that the Harding Park pond allocated a much greater proportion of its water quality storage volume to temporary extended detention rather than permanent pool, which suggests that permanent pool volume can be a very important factor controlling removal rates. Still, the key lesson from recent stormwater pond monitoring is that reliable pollutant removal can be achieved even in demanding climates, when enough permanent pool volume is provided and innovative design and landscaping features are incorporated into pond designs. As a consequence of the SWAMP monitoring program, the province of Ontario is refining its pond design criteria, and expects to issue a new provincial stormwater manual later this year. **See also article 71.** ***–TRS***

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