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# **A COMPREHENSIVE WATER QUALITY MONITORING IN URBAN STORMWATER DETENTION PONDS**

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**Abstract:** During the summer of 2007, a monitoring program was carried out with comprehensive water sampling and deployment of YSI 2200V2 multi-sensor sondes for continuous water quality monitoring in two stormwater detention ponds in Regina, SK. One pond (referred to as the south pond) was built in a mature neighborhood with the primary function of detaining stormwater runoff during heavy rainfall events. The second pond (north pond) is located in a newly developing neighborhood and is a constructed wetland, built not only to detain stormwater runoff, but also to improve its quality before being discharged into a nearby creek. The north pond was planned to allow growth of vegetation and other aquatic species, which simulate a shallow prairie marsh. Chemical compositions of the water in the south pond were consistent between the inlet and the outlet. However, in the north pond significant reductions from the inlet to the outlet were observed in alkalinity, total hardness, total dissolved solids and nutrient levels. The south pond had lower average concentrations of suspended solids and major ions in comparison with the north pond. The north pond also had higher average concentrations in total nitrogen, nitrate and total phosphorus (TP), while the south pond had a significantly

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higher ortho-phosphorus, which seemed to relate to the difference in the maturity of the landscapes and fertilizer applications. The low nitrate and high TP seemed to contribute to severe blue-green algae blooming in the south pond in July. Peak concentrations of total coliform, *Escherichia coli* (*E. coli*) and fecal *streptococcus* in both ponds were closely related to the rainfall events that occurred during the monitoring period. A significant reduction in the bacterial quantities was observed from the inlet to outlet in both ponds. Test results also support the conclusion that the wetland design of the north pond is efficient in removing nutrients and some other urban contaminants.

## **Introduction**

In the City of Regina, stormwater runoff from all the City's proximities is transported into the Wascana Creek through outlet infrastructure, including smaller creeks, stormwater channels and storm trunk sewers. To manage the quantity of runoff and to reduce pressure to these outlet infrastructures, stormwater detention ponds were constructed to collect stormwater runoff from adjacent neighborhoods to retard the outflow during snowmelt and storm events. Some detention ponds were built with a primary function of detaining stormwater runoff during heavy rainfall events, while others were constructed not only to detain stormwater runoff but also aimed to reduce urban contaminant levels before discharging the water into the nearby creeks.

Besides aesthetically pleasing to adjacent community residents, stormwater detention ponds have become a significant part of the urban ecosystem and play a critical role not only in retarding stormwater outflow, but also in holding water that can be potentially used for various urban activities, such as irrigation of open space, landscaping and hosting other recreational activities, e.g. kayaking on the water and walking around the

ponds. However, stormwater contains various urban contaminants, including debris (e.g., pavement, wood, metals, salt, sand, silt, and leaves, biological agents (e.g. bacteria and virus from bird and animal wastes), chemicals (e.g. pesticides, herbicides and hydrocarbons), nutrients (nitrogen and phosphorus), lubricating oil and grease.

Stormwater pollution has resulted in severe degradation of urban receiving water (U.S. EPA, 1983; Massal, et al., 2007; Nazahiyah et al., 2007). As a result, government policies have been developed for management of stormwater and for the control of stormwater pollution (Bowen et al., 1993; City of Calgary, 2000) and many stormwater management practices have been proposed (Urbonas, 1993). A stormwater detention pond is one of most widely used management practices (City of Calgary, 2000; MOEE, 1994).

Increasing demands on municipal water use, particularly in semi-arid regions such as the Prairie regions in Canada and United States, and lack of source water supplies have presented stormwater as a viable resource in urban settings.

A comprehensive monitoring program was carried out in two stormwater detention ponds in Windsor Park, City of Regina, Saskatchewan. The distance between the two detention ponds is less than 1 km (Fig 1). The south pond was built in 1987 and is located in a well-established residential properties and parks with fully developed landscapes. The south pond is about 270 m long and runs in a south-north direction with two inlets located at the north and south ends separately and one outlet at the southwestern location. The pond has a surface water area of 21,000 m<sup>2</sup> and a constant operation depth of 1.8 m. The north pond is a new constructed wetland, built in 2005. The north pond is located in a developing residential neighborhood with intensive construction still ongoing. The pond is about 255 m long and runs in a direction from southeast to northwest. This pond also

has two inlets, one located at the east end and the other located in the middle part of north side. The outlet of the pond is located at the west end. The pond has a surface water area of 9,000 m<sup>2</sup> and a contoured bottom, resulting in operation depths varying 0.5 to 2.7 m. The deeper areas are near the inlet and the outlet locations. The objectives of this study include: 1) to monitor water quality in two different ponds as affected by storm events; 2) to compare the effects of different urban neighborhoods on pollutant loads, including nutrients, salt and pathogens (total coliform, *E. coli* and fecal streptococci as indicators); and 3) to measure water quality changes in the detention ponds and the growth of diatom and blue green algae (BGA). In this paper, we present the first year's results from this monitoring program.

### **Data collection**

Stormwater quality monitoring was conducted through analyses of collected water samples and the deployment of four YSI 2200V2 multi-sensor sonde systems that continuously measure water quality changes. Two water samples were taken from each pond every two weeks, one from the inlet area and the other from the outlet area. These samples were consistently taken from 10 cm depth below pond surface to avoid influences by floating debris and plankton. In addition, four sets of samples were also collected at three different depths (10 cm above pond bottom, mid-depth and 10 cm below the pond surface) to investigate the vertical variations of water quality in the detention ponds. The samples for water chemistry testing were collected in 4 L plastic containers, while the samples for bacteriological testing were collected in 220 mL sterilized containers, which are provided by the Saskatchewan Disease Control

Laboratory (SDCL). After collection, the samples were immediately stored in coolers and transported to the SDCL for physical, chemical and microbiological analysis. The test parameters include pH, conductivity, total alkalinity, total dissolved solids (TDS), total suspended solids (TSS), hardness, calcium, potassium, sodium, magnesium, sulfate, chloride, biochemical oxygen demand (BOD), dissolved organic carbon (DOC), nitrate, total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), total phosphorus (TP), chlorophyll-A, total coliform (TC), *E. coli* and fecal streptococci (FS).



Fig 1. The selected detention ponds and their inlet and outlet locations

Four battery-powered YSI 6600V2 multi-sensor sonde systems were deployed into the detention ponds for continuous water quality monitoring. Each sonde contains 2 electrode probes that measure temperature, pH, conductivity and total dissolved solids, and 4 optical sensors that measure turbidity, dissolved oxygen, blue-green algae and chlorophyll. Data are collected at a time interval of 15 min. to capture water quality changes, particularly during the storm events. The sonde probes can function at water temperatures from -5 to 45 °C, at a maximum depth of 9 m (30 ft.). The sonde locations were chosen in the general area of the inlet and outlet, near where the grab samples were taken (Fig 1). When deployed, the sonde was hidden and protected in a 0.9 m (3 ft.) open-end stainless steel pipe, with 10 rows of 25 mm (1 in.) diameter holes (22 holes in each row) drilled into the pipe to allow water to flow through them. The sonde house was vertically suspended at a depth of 1.2 to 1.5 m (4 to 5 ft) below the water surface, under a submerged buoy, which was anchored by 70-kg metal weights. The sonde housing unit was designed to provide a secure and stable docking station for free movement of water around the sensors while preventing theft, vandalism and incident damage. The vertical deployment allows for sensors to point downward, minimizing the effect of daylight on measurements, particularly the optical sensors. In the meantime, this also avoids settlement of suspended solids on the probes. The sondes stayed in the field for the entire monitoring season from June to October. Data downloads and battery changes took place every 2 weeks. During data download field work, the sensors were visually inspected and any necessary maintenance and calibrations were performed.



## Results and discussion

### *Climatic conditions*

Regina has a semi-arid continental climate with warm, slightly moist summers and cold, dry winters. Average annual precipitation is 390mm with the most rainfall occurring June to August. June is the wettest month with monthly average precipitation of 75mm. The average daily temperature for the year is 2.8°C, with July and August being the hottest months. In 2007, the total precipitation was 274mm with major rainfalls occurring in May. May had a total precipitation of 81.5 mm, which was almost 80% more than normal. August was also wetter than normal. The other months were drier than normal. For example, for the month of June, the total precipitation was only 21.4mm, which was only 30% of the normal rainfall (Table 1). The average temperature during this period was 0.83 °C higher than normal. In particular, July had an average temperature of 21.9°C, which was 3.2°C higher than the normal monthly average (Table 1). The relatively drier and hotter climatic conditions affected stormwater quality in the detention ponds as discussed in this paper.

Table 1. Rainfall events (with >4mm rainfall) during the monitoring period and comparison of 2007 climatic condition with long-term average

Month	May						June		July			Aug			Sep	Oct	
Day	3	13	14	21	23	31	14	17	9	21	25	6	10	18		5	6
Precipitation* (mm)	4.4	11.9	6.4	18.1	24	11.6	4.8	9.7	9.0	17.5	4.3	25.7	16.1	5.7		5.4	4.4
Total rainfall* 2007 (mm)	81.5						21.4		33.8			52.2			12.8	15.6	
Average rainfall (mm)**	45.4						71.3		55.0			43.6			34.4	18.4	
Average temp - 2007 (°C)*	11.5						16.0		21.9			16.5			11.7	6.1	
Normal temp (°C)**	10.9						15.6		18.7			17.5			11.3	4.7	

\*Data from Environment Canada. <http://www.climate.weatheroffice.ec.gc.ca/>.

\*\*Regina data derived from Global Historic Climatic Network between 1932 and 1989

### *Vertical variation*

Water samples that were taken near the inlet and the outlet locations from three different depths (top, mid- and bottom) were analyzed to examine the vertical variations of water quality in the detention ponds. Samples collection occurred on July 25, four days after a significant rainfall on July 21. Test results showed that the south pond had relatively uniform physical and chemical properties that did not change with depth (Table 2). The results reflect the construction feature of this pond, in which the unique depth allows stormwater runoff to be mixed well quickly, particularly the two inlets being located at the two ends. Higher than normal TKN and nitrate-N levels observed on July 25 were resulted from an application of 100 kg of ammonia nitrate ( $\text{NH}_4\text{NO}_3$ ) on July 23 by the City to control blue green algal growth. Before the application, the concentration of TKN had ranged from 1.2 to 1.8 mg/L and nitrate-N below detection limit ( $<0.04$  mg/L). Chlorophyll-A concentration and bacterial indicators (TC, *E. coli* and FS) were highly variable, and did not show a trend.

In the north pond, water quality varied with locations and depths (Table 2). Higher concentrations for most monitored parameters were observed near the inlet location compared to the outlet location. This is expected because the pond's design allows for physical settlement and biological activities to occur as the stormwater travels from the inlet to the outlet. During the process, concentration of any contaminants affected by these physical and biological processes would be expected to reduce. Vertically, a trend of concentration increase from top to bottom was observed for many of the tested parameters at both the inlet and outlet locations. This can be caused by many factors.

Table 2. Variation of water quality with depth on July 25<sup>th</sup>, four days after 17.5 mm rainfall on July 21.

Parameter	South pond						North pond					
	Inlet			Outlet			Inlet			Outlet		
	Top	Mid-	Bottom	Top	Mid-	Bottom	Top	Mid-	Bottom	Top	Mid-	Bottom
pH	8.6	8.6	8.5	8.5	8.5	8.5	8.4	8.3	8.2	9.2	8.9	8.4
Conductivity ( $\mu\text{S}/\text{cm}$ )	1044	1045	1055	1057	1057	1057	989	1678	1932	1116	1131	1272
TDS <sup>1</sup> (mg/L)	788	786	800	797	800	797	712	1332	1559	784	809	939
TSS <sup>2</sup> (mg/L)	28.0	26.0	27.0	27.0	28.0	26.0	23.0	24.0	20.0	4.0	5.0	9.0
Cl (mg/L)	58.6	58.3	58.9	59.1	59.3	58.9	63.5	110.2	128.6	80.1	81.7	93.7
SO <sub>4</sub> (mg/L)	345	344	347	350	353	350	345	673	788	420	426	482
Ca (mg/L)	88.0	88.0	90.0	88.0	88.0	87.0	77.0	150.0	176.0	80.0	82.0	95.0
Mg (mg/L)	41.0	41.0	41.0	42.0	41.0	41.0	42.0	78.0	91.0	49.0	50.0	58.0
DOC <sup>3</sup> (mg/L)	12.8	12.8	13.0	12.9	12.9	12.7	18.4	21.1	20.4	16.3	16.4	18.2
BOD <sup>4</sup> (mg/L)	6.6	6.1	6.7	6.3	6.8	8.7	6.7	9.4	4.3	3.1	3.8	5.9
TKN <sup>5</sup> (mg/L)	2.00	2.10	2.20	1.90	2.00	2.00	0.90	1.40	1.30	1.00	1.20	1.50
NO <sub>3</sub> -N (mg/L)	0.29	0.29	0.30	0.33	0.32	0.35	1.16	3.22	3.63	0.16	0.15	0.06
TP <sup>6</sup> (mg/L)	0.21	0.22	0.22	0.20	0.20	0.20	0.10	0.15	0.12	0.07	0.09	0.14
Chlorophyll-A (mg/L)	48.0	47.4	46.8	52.0	55.4	48.6	24.8	93.7	37.0	19.6	33.7	72.9
TC <sup>7</sup> (cfu/100 mL)	23100	13500	51200	16100	32300	16000	79400	23800	22800	14600	14600	7701
<i>E. coli</i> (cfu/100 mL)	52	85	246	20	142	41	6131	1178	1046	98	122	20
FS <sup>8</sup> (cfu/100 mL)	470	320	30800	220	890	220	10200	3400	2500	130	330	120

<sup>1</sup> total dissolved solid; <sup>2</sup> total suspended solids; <sup>3</sup> dissolved organic carbon; <sup>4</sup> 5-day biochemical oxygen demand; <sup>5</sup> total Kjeldahl nitrogen; <sup>6</sup> total phosphorus; <sup>7</sup> total coliform; <sup>8</sup> fecal streptococci.

One of the factors could be vertical stratification in the relative deep areas. In particular, when the samples were taken only 4 days after a major rainfall, physical settlement was still undergoing. Another possible factor could be the different biological activities at various depths, such as the diatoms and water weeds growing at different depths. Given the vertical variations observed, water samples for this study were taken from 10 cm depth below the water surface to maintain consistency and reduce variability caused by sampling depth.

#### *Pond water general chemistry*

Chemical analysis indicated that the north pond contained higher concentrations of inorganic ions, including chloride, sulfate, calcium, magnesium and sodium, which caused overall elevated levels in other related parameters, such as conductivity, total dissolved solids and hardness in comparison with the south pond (Table 3). During the monitoring period, concentrations of these inorganic ions had been in a trend of slight to moderate increase in both detention ponds (Fig 2). This trend seems to related to lack of precipitation and hot conditions in the summer months, which caused inorganic ions to concentrate in the ponds as a result of evaporation. The elevated sulfate ( $\text{SO}_4^{2-}$ ) concentrations reflect the characteristics of local soils, which include high sulfate component in their profiles. The sulfate has been dissolved in the stormwater and transported to the pond through surface runoff or underground percolation.

Table 3. Seasonal water quality average based on grab samples from the detention ponds

Parameter	South Pond (mean $\pm$ sd)	North Pond (mean $\pm$ sd)
pH	8.6 $\pm$ 0.2	8.8 $\pm$ 0.4
Conductivity ( $\mu$ S/cm)	1017 $\pm$ 230	1454 $\pm$ 468
Total dissolved solids (mg/L)	754 $\pm$ 200	1079 $\pm$ 405
Total suspended solid (mg/L)	22.0 $\pm$ 7.8	14.5 $\pm$ 10.3
Alkalinity (mg/L as CaCO <sub>3</sub> )	140 $\pm$ 27	95 $\pm$ 35
Hardness (mg/L as CaCO <sub>3</sub> )	363 $\pm$ 102	554 $\pm$ 206
DOC (mg/L)	13.8 $\pm$ 2.7	18.2 $\pm$ 4.1
BOD (mg/L)	7.1 $\pm$ 2.0	4.0 $\pm$ 1.8
Chloride (mg/L)	61.7 $\pm$ 8.0	105.3 $\pm$ 35.9
Fluoride (mg/L)	0.2 $\pm$ 0.0	0.2 $\pm$ 0.0
Sulfate (mg/L)	316 $\pm$ 110	558 $\pm$ 222
Calcium (mg/L)	81 $\pm$ 22	111 $\pm$ 41
Magnesium (mg/L)	38.9 $\pm$ 11.5	67.0 $\pm$ 25.8
Sodium (mg/L)	92 $\pm$ 21	128 $\pm$ 45
Potassium (mg/L)	5.8 $\pm$ 0.7	8.4 $\pm$ 1.3
Chlorophyll A (mg/L)	53.0 $\pm$ 23.4	27.0 $\pm$ 18.8

The changes in inorganic ion concentrations were also affected by rainfall events. The initial increase was related to early rainfalls in the season, which occurred in the month of May (Table 1). The runoff collected all types of urban contaminants including the road salt that was used during the winter months. The road salt used in Regina was mainly sodium chloride (NaCl) and it is easily dissolved and transported by the stormwater runoff. Further increases in the inorganic ions were due to the lack of precipitation in the summer months. Strong evaporation caused by the hot conditions in these months also resulted in elevated ion concentrations of the pond water.

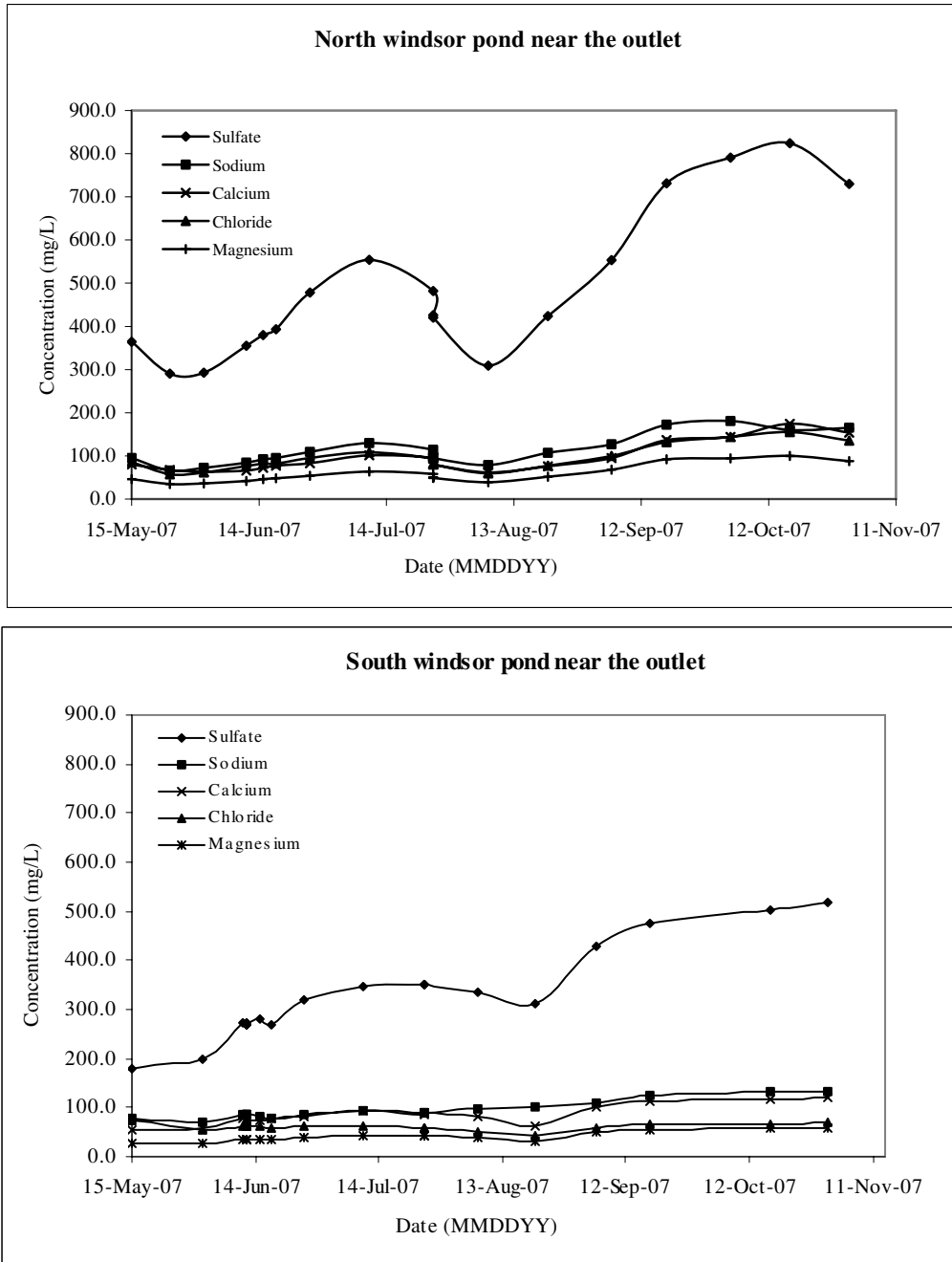


Fig 2. Inorganic ion concentrations change during the monitoring season.

During the monitoring period, a decrease in the inorganic ion concentrations was observed (Fig 2). This decrease responded to the three rainfall events, which occurred on July 21, August 6 and August 10. The runoff from these storm events may contain less soluble ions

compared with those from earlier storm events, as road salt had been dissolved and transported away. Due to this reason, the inorganic ion concentrations in detention ponds were actually diluted when this runoff reached the ponds. The ion concentrations in the ponds gradually increased after these rainfall events in responding to hot conditions and strong evaporation and transpiration between later August and early October.

The north pond contained a higher level of DOC, reflecting the runoff erosion of the surface soils into the pond, as observed in this site under construction. In comparison, the south pond had higher BOD concentrations. The north pond had a higher DOC and lower BOD in comparison with the south pond. This may be related to the nature of organic materials coming from communities of different maturity. In the north pond, the DOC may have come from eroded soils that contain less degradable humic materials. However, this merits further investigation in the future.

#### *Nutrient levels*

Both ponds had similar levels of total nitrogen (TN), with an average in the range of 1.7 to 1.9 mg/L (Fig 3). However, during the monitoring period, the nitrate level in the south pond was mostly below detection limit. In the south pond, less than 5% TN occurred as nitrate that was readily available for plankton or other plants to uptake. Over 95% TN existed in TKN form, which is dominated by organic form. This low nitrate level in the south pond was further offset by application of nitrate fertilizer (100 kg of  $\text{NH}_4\text{NO}_3$ ) on July 23, as a practice of biological manipulation to control the growth of BGA. It was evident that a significant increase in nitrate level from below detection limit ( $<0.04$  mg/L) before fertilizer application to 0.35 mg/L on July 25, 2 days after the application (Fig 3). In the north pond

about 40% TN was nitrate and the other 60% occurred as TKN. Higher nitrate concentrations in the north pond may have been caused by runoff from exposed soils that were previous nutrient-enriched farmland. Even with highly variable levels of nitrate, an average concentration during the monitoring period still only reached 0.75 mg/L (Table 4).

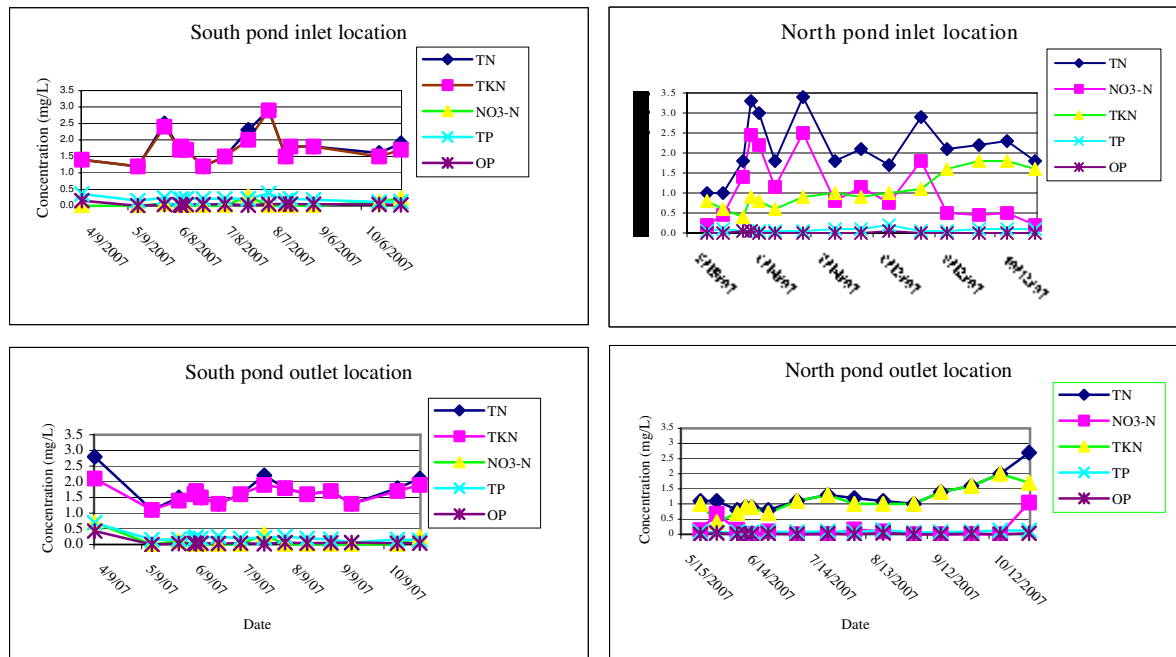


Fig 3. Variations of TN, TKN, NO<sub>3</sub>-N, TP and OP during the monitoring period.

Table 4. Average levels of nutrients and NO<sub>3</sub>-N to TP ratio during monitored pond

Parameter	South Pond		North Pond	
	Mean	Range	Mean	Range
TN (mg/L)	1.71	0.90 to 2.90	1.90	0.80 to 4.90
TKN (mg/L)	1.62	0.80 to 2.90	1.16	0.40 to 2.00
NO <sub>3</sub> -N (mg/L)	0.08	<0.04 to 0.70	0.75	<0.04 to 3.63
TP (mg/L)	0.20	0.06 to 0.69	0.09	0.04 to 0.22
OP (mg/L)	0.05	<0.02 to 0.43	0.02	<0.02 to 0.13
NO <sub>3</sub> -N to TP ratio	0.4	0.0* to 1.8	9.9	0.0* to 54.8

\* The NO<sub>3</sub>-N concentration was treated as 0 mg/L when it is below the method detection limit (<0.04 mg/L).



The south pond had relatively high TP levels, with an average of 0.20 mg/L, ranging from 0.06 to 0.69 mg/L. In comparison, the north pond had an average TP of 0.09 mg/L, ranging from 0.04 to 0.22 mg/L. The low nitrogen and high phosphorus in the south pond was believed to be the cause of severe growth of BGA in mid-July. The ratio of nitrate-N to TP is one of the important factors that affect phytoplankton community structure. A low nitrate-N to TP ratio would favour BGA growth. In the south pond, this ratio ranges from 0.0 to 1.8, with an average of 0.4, but this ratio was greater in the north pond, ranging from 0.0 to 54.8, with an average of 9.9 (Table 4).

#### *Bacteriological quality*

Total precipitation and duration of a rainfall event controls the runoff intensity that in turn affects the chemical and microbiological quality of the stormwater, along with antecedent conditions. As indicators of bacteriological quality of the pond water, total coliform (TC) and *E. coli* concentrations varied greatly during the monitoring season. In the south pond, TC concentrations ranged from <100 cfu/100 mL to 111,200 cfu/100 mL, and *E. coli* varied from 0 to 3,654 cfu/100 mL. Fecal streptococcus (FS) level was in a range from non-detectable to 30,800 cfu/100 mL. The north pond showed similar variation patterns in these bacteriological parameters.

Indicator bacteria were extremely low in early spring despite the initial spring runoff, and many samples contained no detectable *E. coli* and FS. The numbers started to increase in the middle of May as the weather warmed up, and the first concentration peak occurred in early June following rainfalls May 21, 23 and 31, respectively. A second concentration peak came

on August 7 following a heavy rainfall on August 6 (Fig 4). A significant increase in *E. coli* level was also observed in the north pond on July 25, 4 days after a rainfall on July 21.

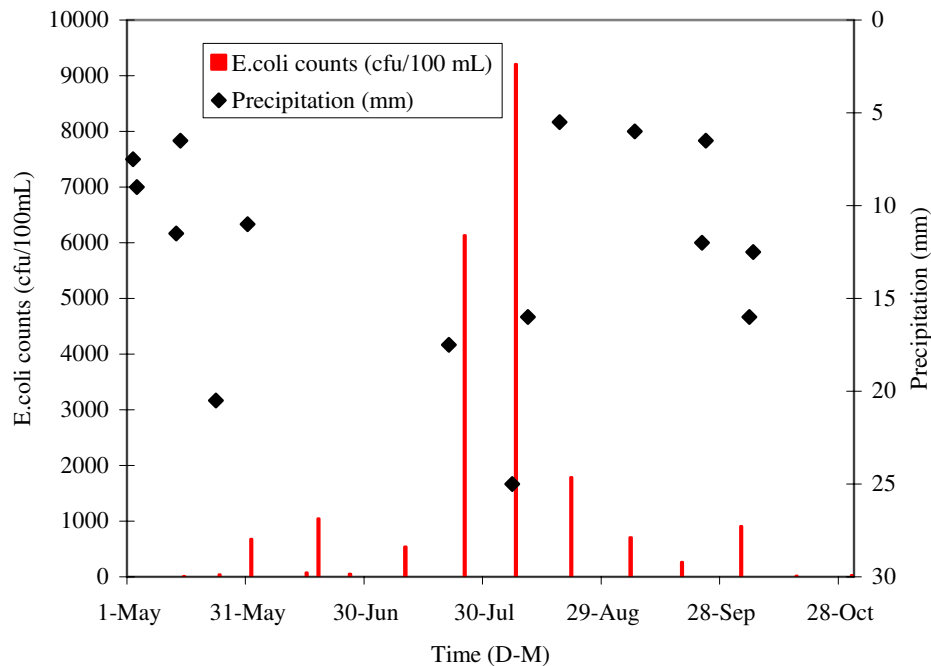


Fig 4. *E. coli* counts during the monitoring season near the inlet location in the north pond.

The bacteriological contamination in the pond water, particularly in the inlet areas was closely related to the storm events, as demonstrated by the variation of *E. coli* counts near the inlet location in the north pond (Fig 4). As both *E. coli* and FS are originated from fecal sources, counts of these bacteria reflected the degree of contamination level of the pathogens that were carried into the retention ponds by storm runoff.

Similar levels of TC and FS were observed in the north pond. However, significant reductions in both *E. coli* and FS from the inlet to the outlet indicated that these retention ponds had indeed substantially removed the pathogens. When storm runoff enters the ponds, it carries the pathogens into the inlet areas of the pond. As water flows from the inlet towards

the outlet areas, the pathogen level decreases, because the pathogens were dying off in the process. To evaluate the effectiveness of the pond in reducing a contaminant concentration, removal efficiency is calculated using the following equation:

$$\text{Efficiency} = \frac{C_{\text{inlet}} - C_{\text{outlet}}}{C_{\text{outlet}}} \cdot 100\% \quad (1)$$

Where the efficiency is the pond removal efficiency for a particular contaminant,  $C_{\text{inlet}}$  in the contaminant concentration at inlet area (e.g. indicator bacteria counts), and  $C_{\text{outlet}}$  is the contaminant concentration at the outlet area (e.g. indicator bacteria counts).

Table 5. Bacteriological parameters in the monitored ponds

Parameter	South pond			North pond		
	Inlet area	Outlet area	Efficiency	Inlet area	Outlet area	Efficiency
TC <sup>1</sup> *	12,636	11,696	7%	15,968	4,032	75%
EC <sup>2</sup> *	323	80	75%	1,353	102	93%
FS <sup>3</sup> *	1,887	257	86%	2,201	454	79%

<sup>1</sup> TC: total coliform, <sup>2</sup>EC: *E. coli*, <sup>3</sup>FS: fecal Streptococcus, \*in cfu/100 mL.

In general, the removal efficiencies ranged from 75% to 93% for the south pond, and 79% to 92% for the north pond (Table 5). In the south pond, similar removal efficiencies, 75% and 86%, respectively were observed for the *E. coli* and FS, but TC bacteria stayed almost the same near the inlet and outlet locations with a removal efficiency of only 7%. This difference can be caused by many factors, including sampling error and possible regrowth of some strains coliform bacteria, which come from the environment sources, not a fecal origin.

#### *Multi-sensor sonde data*

Sonde sensors responded to water quality changes and reflected the physical, chemical and biological processes that occurred in the pond, as affected by the storm events. For example, the temperature sensor recorded daily variation of the water temperature at 1-m depth for the

period of July 14 to 23, 2007, with a maximum around 25 °C between 21:00 and 23:00 pm and a minimum of 22 to 23 °C between 9:00 and 11:00 am (Fig 5). This temperature variation reflected the daily atmospheric temperature changes, but showed a delay response as the heat transfer to the monitored depth. The dissolved oxygen (DO) sensor responded to the DO level in the water, which can be affected by many factors including temperature and biological activities, such as photosynthesis and respiration. Storm events could temporarily disrupt the variation patterns of temperature and DO as illustrated in Fig 5. For instance, a sudden drop in temperature and a disrupted DO pattern on July 21 was a result of a storm event with 17.5 mm rainfall. However, after the storm, the cycles were quickly re-established in several hours.

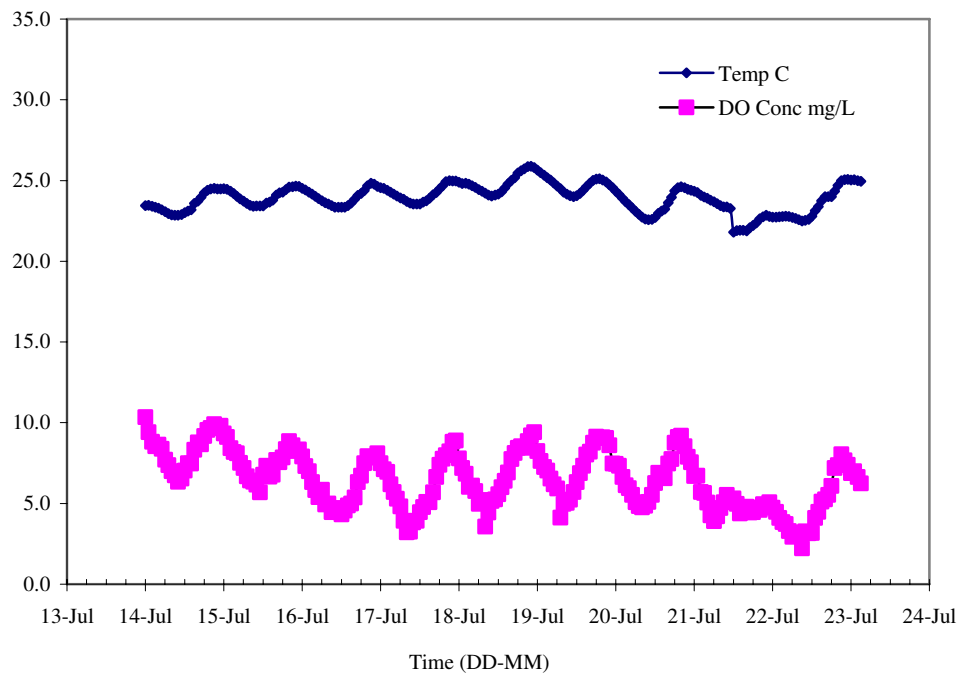


Fig 5. Variation of temperature and DO near the outlet of the south pond. Interruption on July 21 was caused by 17.5 mm rainfall event that day.

Blue green algae (BGA) (also known as *Cyanobacteria*) and chlorophyll levels in the detention ponds were monitored with the fluorescence-based, continuous measuring sensors during the summer months. Although other diatoms are unicellular organisms and capable of photosynthesis, BGA can grow well under extreme nitrogen deficient environments due to their capability of fixing nitrogen from the atmosphere. Some species produce toxins that pose health risks to the environment and public.

We chose global calibrations for the BGA and chlorophyll sensors, in which BGA population was measured in cells/mL, and chlorophyll concentration was determined in  $\mu\text{g/L}$ . As the sensors were located at a consistent depth approximately 1 m below the water surface throughout the monitoring program, the results in general represent the levels of biomass of the diatom group of interest, and less subject to variation of floating plankton on the surface. The peaks of BGA in both detention ponds were observed during late July and early August, corresponding to the high temperatures in that period. The south pond where the level was almost 10 times that of the north pond (Fig 6) indicated that the environment conditions, particularly the low ratio of available nitrogen to total phosphorus favoured the BGA to grow. This observation was consistent with earlier conclusions from different lakes, rivers and seas (Smith, 1983; Stahl-Delbanco et al., 2003; Lagus et al., 2004). As a management practice to control BGA growth by the City, 100 kg of nitrogen fertilizer ( $\text{NH}_4\text{NO}_3$ ) was applied to the south pond on July 23<sup>rd</sup>, aiming to promote other diatom growth and to suppress the BGA. After fertilizer application, BGA levels in the pond continued to increase until July 27, with a peak population around 120,000 cells/mL. After it reached this peak, the population started to decrease sharply to almost one third of its peak level in less than 10 days. Although there were several smaller blooms observed, BGA peak populations were

fluctuating between 3,500 and <6,000 cells/mL. In the north pond, BGA level was substantially lower than the south pond, with a peak level below 60,000 cells/mL. The BGA population reached a peak level on August 1 and stayed on this peak until August 8. The high available nitrogen supply in the north pond was believed to be a factor that had maintained BGA at a lower level. After the August peak, the BGA population was consistently low (<28,000 cells/mL) in both ponds for rest of the summer months (Fig 6).

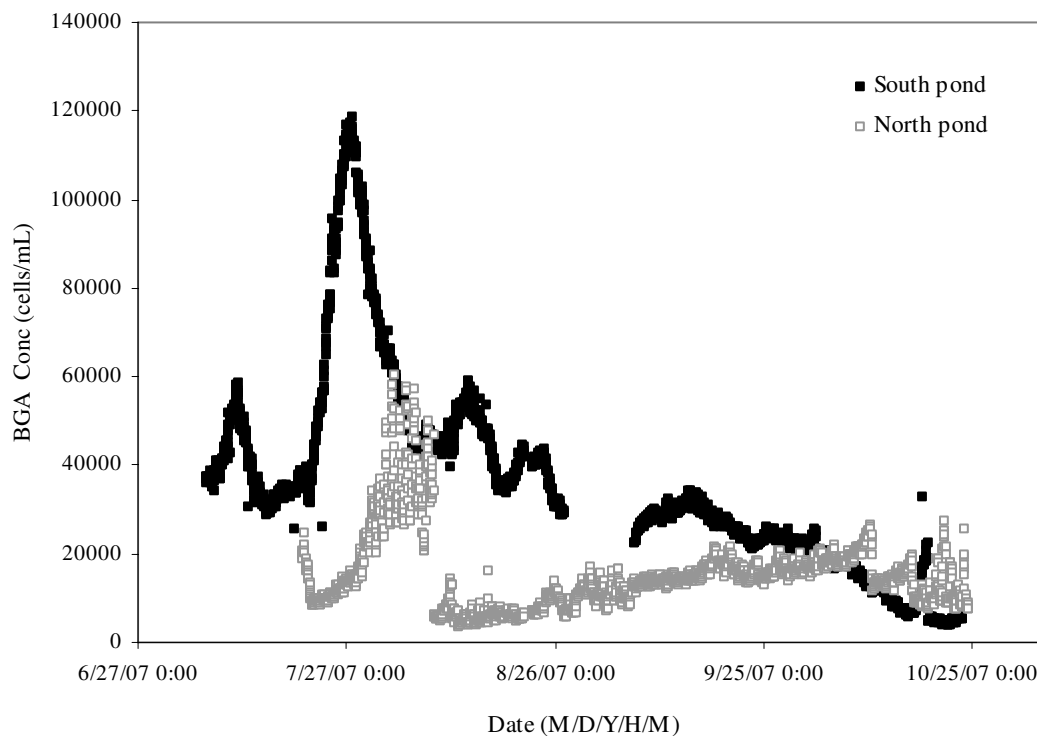


Fig 6. Variation of blue green algae (BGA) near outlet locations during monitoring period.

Phytoplankton can be used as an indicator organism for the health of a water body and chlorophyll is essential to the existence of phytoplankton. Therefore, monitoring chlorophyll levels is a direct way of tracking the health of an aquatic system. Typically, surface water with high chlorophyll conditions indicates a strong algal growth and high nutrient level, including nitrogen and phosphorus. Severe algal growth in a water body can reduce DO

levels and also affect other aquatic life and habitats. The north pond had a much higher level of chlorophyll than the south pond (Fig 7). The high nutrient concentrations, particularly nitrate in the pond seems to be the major factor for the algal growth. In comparison, low nitrate concentration in the south pond has resulted in lower chlorophyll concentrations, even with a relatively high phosphorus content. Chlorophyll concentration in the south pond did respond to the fertilizer application, showing a gradual increase from July to August (Fig 7).

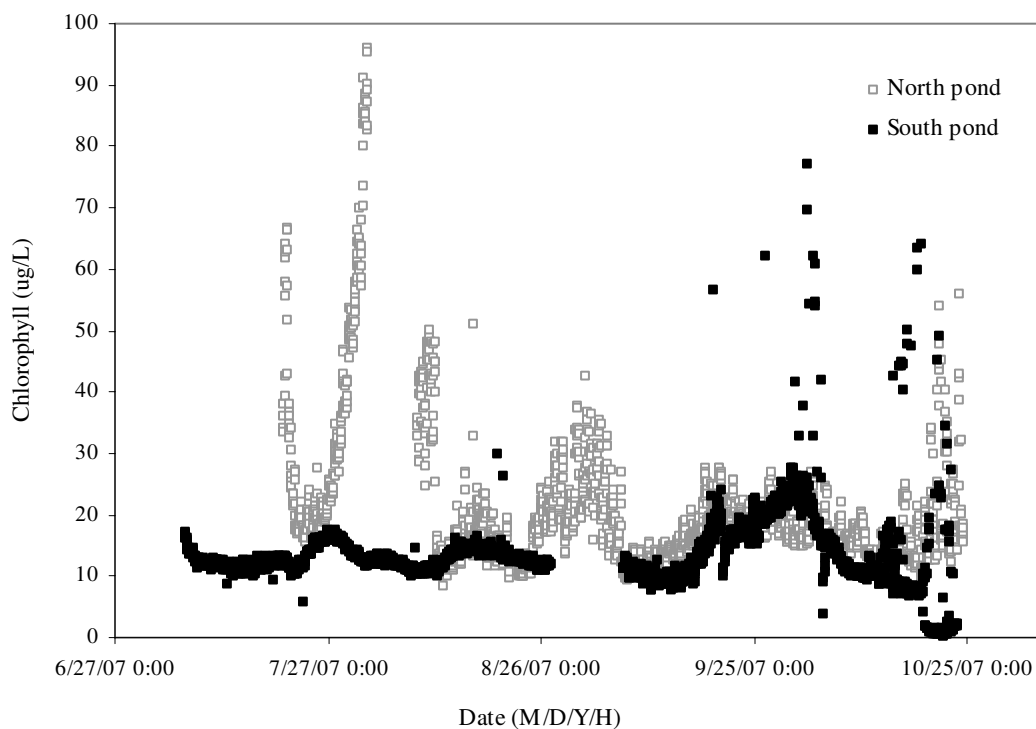


Fig 7. Variation of chlorophyll in the detention ponds during the monitoring period.

It should be pointed out that the multi-sensor sonde with probes and optical sensors placed directly in the water body can suffer from two potential problems. First, it is not possible to check the calibration of each probe without taking the instrument out of the water. Therefore, measurement drifts can occur between calibrations. Second, the probes need regular maintenance to remove bacterial slimes and algal growths that can interfere with their

performance and occasionally, erroneous results can be produced. Best practice is to bring the sonde back for data download and perform calibration and maintenance biweekly. As the process may take several days to complete, therefore, an additional sonde system may be required.

Although the multi-sensor system can be used for continuous stormwater quality monitoring and measuring pollutant loads, laboratory analysis of the grab samples provides important complementary information and becomes an important component of a comprehensive monitoring program. The combination of these two techniques will supply complete information for understanding the physical, chemical and biological activities in the detention ponds.

## **Conclusions**

The results from the first year's monitoring program indicated that a combination of grab sampling and multi-sensor sonde systems provides a good understanding of stormwater quality changes in the detention ponds. Test results from grab samples indicated that the water quality in the south pond was consistent between the inlet and the outlet locations. The south pond had lower average concentrations of suspended solids and major ions in comparison with the north pond. However, in the north pond significant reductions from the inlet to the outlet areas were observed in alkalinity, total hardness, total dissolved solids and nutrient levels. The relatively higher OP and low nitrate in the south pond had caused more blue-green algal growth during late July and early August. Concentrations of total coliform, *E. coli* and fecal *streptococcus* in both ponds were closely related to the rainfall events that occurred during the monitoring period. The preliminary monitoring results also suggest that



both ponds have some capability to remove certain types of contaminants, particularly the microbial contaminants. The shallow marsh design with emerging water-loving vegetation in the north pond seems to be able to remove nutrients and other urban contaminants as well. Multi-sensor sonde systems provide continuous measurements of water quality changes, including detailed information on how monitored parameters vary with storm events, seasonal changes and biological processes in the aquatic systems. For the first time, BGA and chlorophyll dynamics in these urban detention ponds have been monitored continuously 24/7, which clearly indicated that low ratio of nitrogen to total phosphorus in the south pond is the cause of the severe BGA growth in the hot summer months.

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