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FIELD MONITORING OF PHYSICAL PROCESSES IN STORMWATER WET PONDS AND WETLANDS IN CALGARY ALBERTA

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Abstract: Stormwater wet ponds and wetlands are commonly used to control excess runoff in urban areas by temporarily storing surface runoff and then releasing it to the downstream storm sewer system at a controlled rate. They can also improve the water quality of stormwater runoff by removing sediments, nutrients and other pollutants before being discharged into receiving water bodies (e.g., rivers). As a result, there is an ongoing need to understand the complex physical, chemical and biological processes in stormwater facilities as a function of local weather conditions, hydrological conditions, and the design of each facility. A comprehensive 2-year field monitoring program is being undertaken to monitor two stormwater wet ponds and two stormwater wetlands in Calgary, Alberta. The field data will support the future application of computer models to investigate the physical and biogeochemical processes that govern suspended sediment transport and nutrient cycles in ponds/wetlands. Both the field monitoring data and computer modelling will be used to improve the design and operation guidelines of stormwater facilities. This paper presents preliminary results from the first year (2018) of the field monitoring program. The response of the four ponds/wetlands to atmospheric forcing has been examined. The occurrence of stratification and its impact on water quality are also discussed. Thermal stratification led to low DO in bottom waters and created vertical patterns of phytoplankton productivity. Photosynthesis and respiration also contribute to DO and pH fluctuations in stormwater ponds/ wetlands.

1 INTRODUCTION

The water quality in Alberta rivers has deteriorated in recent years largely due to increases in nutrient levels and suspended sediments (Alberta Environment 2007). Stormwater runoff is a major source of these contaminants. In 2005 a water quality study found that 90% of sediment that enters the Bow River from Calgary, Alberta, is from the stormwater system (City of Calgary 2005). Stormwater wet ponds and wetlands can be effective in improving the water quality by removing sediments, nutrients and pollutants in stormwater runoff before the runoff is discharged to receiving water bodies (e.g., rivers) (Kadlec and Knight 1996, Chavan and Dennett 2008). The proposed research aims to develop improved design and operation guidelines for existing and future Canadian stormwater ponds/wetlands to optimize their ability to reduce sediment and nutrient loadings discharged to receiving water bodies. This has the potential to have a major impact because numerous Canadian cities discharge their stormwater into rivers, lakes and oceans, with insufficient treatment, degrading the water quality and harming biota. The results from this study will assist municipalities such as the City of Calgary in reducing the cumulative effect of sediments and nutrients loadings from their stormwater ponds and wetlands. A deeper understanding of the factors that control sediment and nutrient cycling in stormwater ponds and wetlands will lead to better operation of existing

facilities and improve future designs. The results from this study will also be relevant to stormwater ponds/wetlands in operation in other regions.

The physical, chemical and biological processes involved in the transport and fate of sediments and nutrients in stormwater facilities are complex (Walker and Daniels 2001; Yuan 2008, Song et al. 2015). In order to be able to reduce the sediment and pollutant loadings to receiving waters, processes such as the settling and resuspension of sediments, the uptake of nutrients by vegetation and algae, and the release of nutrients from the bottom sediments in stormwater facilities need to be understood as a function of local conditions (e.g., climate, geological conditions, and drainage characteristics), and the design of each facility (e.g., physical dimensions, inflow/outflow design) (Olding et al. 2000, Song et al. 2013). As a result, a comprehensive 2-year field monitoring program is being undertaken to continuously monitor two stormwater wet ponds and two stormwater wetlands in Calgary, Alberta, during the ice free seasons (May - October). The field data will be used in the development of a watershed model (SWMM) to investigate the suspended sediment and nutrient loads entering the ponds/wetlands and will support the application of the Environmental Fluid Dynamics Code (EFDC) model to investigate the physical and biogeochemical processes that govern suspended sediment transport and nutrient cycles in ponds/wetlands. Both the field monitoring data and computer modelling will be used to improve the design and operation guidelines of stormwater facilities.

This paper presents preliminary results from the first year (2018) of the field monitoring program. The response of the four ponds/wetlands to atmospheric forcing (e.g., rainfall and air temperatures) has been examined. The occurrence of stratification and its impact on the water quality are discussed. Relationships between measured parameters such as DO and pH, and the seasonal changes and vertical variation of chlorophyll-a are presented.

2 STUDY SITES

The study stormwater ponds/wetlands located in the City of Calgary, Alberta were selected in consultation with staff from the City of Calgary Water Resources. Study sites were chosen on the basis that they are not slated for rehabilitation during the study period and have a limited number of inlets and outlets. The selected facilities shown in Figure 1 are two stormwater wet ponds in the communities of Auburn Bay and Cranston in the southeast corner of Calgary, approximately 3 m deep each, and two shallow stormwater wetlands in the communities of Royal Oak and Rocky Ridge in the northwest corner of Calgary, approximately 0.8 m deep. Table 1 presents the characteristics of these facilities and their associated catchments.

The wet ponds, in Auburn Bay and Cranston, were constructed with long berms dividing them into a sediment forebay, where runoff enters the pond, and a main pool where the treated water is discharged into the downstream storm sewer system as shown in Figure 1. The Auburn Bay wet pond has one inlet collecting stormwater runoff from two sub-catchments. The first sub-catchment is 163 ha in size and drains directly to the Auburn Bay pond from the adjacent residential neighborhood and commercial centre lands. The remaining 69 ha drains to the pond in the form of controlled discharges from an upstream pond. The Cranston wet pond has two inlets serving four sub-catchments with a total area of approximately 122 ha. The Royal Oak wetland, has two inlets. Inlet No. 1 drains a very small area, almost negligible in size and has no sediment forebay, while Inlet No.2 drains an area of 14 ha and has a sediment forebay. The Rocky Ridge wetland has an inlet structure that directs the low flow and the first flush of a runoff event into a sedimentation vault while a by-pass pipe directs high flow directly into the wetland. All four facilities have an outlet control structure equipped with a weir or an orifice to regulate the outflow discharge.

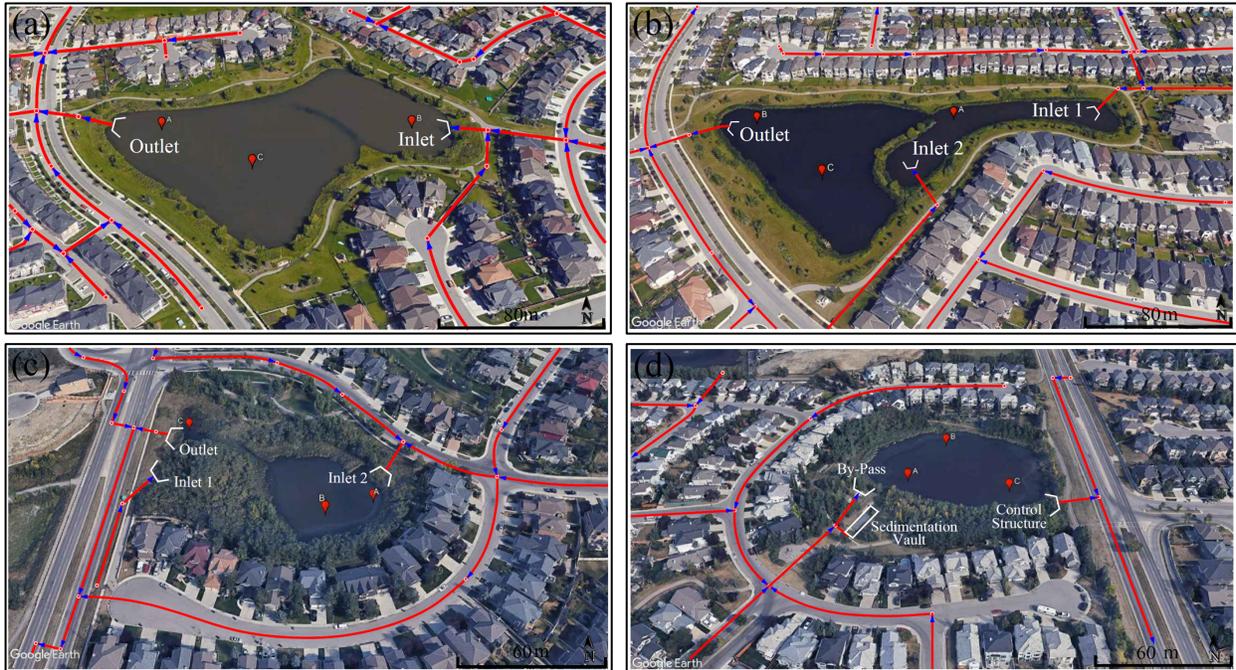


Figure 1: Aerial photos of the ponds/ wetlands (a) Auburn Bay, (b) Cranston, (c) Royal Oak, and (d) Rocky Ridge [Image source: Google Earth © 2018 Google]. The red lines in the photos indicate storm sewers, and the blue arrows show the flow direction. A, B and C in each pond give the in-pond monitoring locations.

Table 1. Stormwater ponds/wetlands and associated catchments characteristics

	Unit	Wet Ponds		Wetlands	
		Auburn Bay	Cranston	Rocky Ridge	Royal Oak
Catchment type	/	Residential & Commercial	Residential & Commercial	Residential	Residential
Catchment area	ha	232	122	14	14
Imperviousness ratio	%	58	52	60	51
Surface area at NWL ¹	m ²	24,700	22,000	9,300	5,500
Permanent wet pool volume	m ³	54,600	45,100	6,300	3,000
Active storage volume	m ³	56,500	52,700	10,600	10,900
Average permanent depth	m	3.0	3.0	0.8	0.8
Depth above NWL	m	2.0	2.0	1.0	1.5
1:100 Volume ²	m ³	50,710	38,400	8,201	9,570
Length to width ratio	/	2:1	2:1	1.25:1	2:1
# inlet / outlet	/	1 / 1	2 / 1	1 / 1	2 / 1

¹ Normal Water Level

² An event of 1% probability of occurring in any given year

3 METHODOLOGY

The field study included deployment of a weather station at each site. In the inlet/outlet structures of each facility, the flow rate, turbidity and water temperature were continuously monitored, and water samples were collected during rainfall events using auto samplers. In-pond moored instruments were also deployed at three locations in each pond/wetland at locations labelled A, B, and C in Fig. 1.

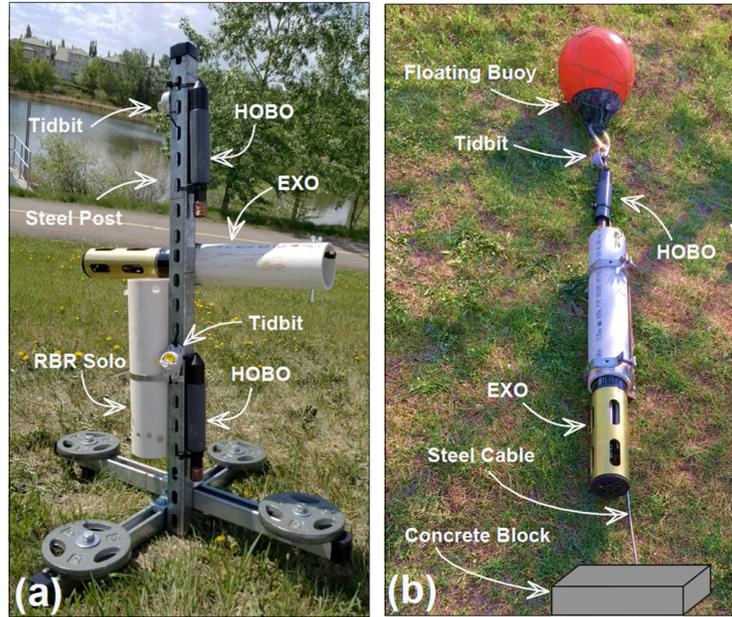


Figure 2: In-pond monitoring instrumentation for (a) wetlands, (b) wet ponds.

3.1 Weather Monitoring

The weather stations were configured to measure the following parameters at 5-minute intervals: rain depth, air temperature, atmospheric pressure, relative humidity, solar radiation, and wind speed and direction. The two ponds and the two wetlands are only 1.5 km and 0.25 km apart, respectively, which makes it reasonable to fill in any measurement gaps (if any) in the meteorological time series data from the nearby facility. During the 2018 field season, there were some gaps in the meteorological data at the Auburn Bay and Royal Oak facilities caused by installation issues and power failures, respectively. These gaps were filled using data from the neighboring weather station. Continuous time series of meteorological data were acquired from May 10 to October 25, 2018.

3.2 Inlets/Outlets Monitoring

Ten 6712 (Teledyne ISCO) portable samplers equipped with Model 750 area/velocity flow modules were installed in the inlets and outlets of the four ponds/wetlands. Six 2150 flow modules, and eight turbidity and temperature loggers were also deployed in the inlets/outlets. The 6712 samplers were programmed to automatically collect water samples using flow paced sampling. The samplers and other deployed instruments collected data from June 15 to October 30, 2018.

3.3 In-pond Measurements

In-pond moored instruments were deployed in each pond/wetland at three locations, A, B and C (see Fig. 1) to continuously capture the horizontal and vertical variability of various water quality parameters. The following instruments were used for the continuous measurements: Tidbits (for temperature), Divers (depth, temperature), EXO water quality sondes (temperature, conductivity, depth, chlorophyll-a, pH, turbidity, dissolved oxygen/DO), HOBO DO Logger (DO, temperature), and RBR Solo (turbidity). In the two wet ponds, the instruments were attached to steel cables and suspended in the water column using a concrete block anchor and floating buoy as shown in Fig. 2. In the shallow wetlands, the instruments were mounted to a vertical steel post attached to a horizontal base (see Fig. 2). The continuous in-pond measurements were collected between May 17 and October 27, 2018.

During the field program the research team also conducted a total of eleven (11) bi-weekly field trips to the ponds/wetlands between Jun 6 and October 26, 2018. During these trips, water samples were collected at locations A, B and C in each pond and then sent to ALS Environmental Lab for water quality testing. Water

samples were also collected for taxonomic identification of algae species. During the same field trips, high resolution vertical profiling using an EXO2 water quality sonde was conducted at the three mooring locations in each facility.

4 RESULTS AND DISCUSSION

The stormwater wetlands in Royal Oak and Rocky Ridge are relatively small open water bodies that experience a smaller range of water level fluctuation than the two wet ponds as shown in Fig. 3. This reflects design practice which allow for greater variations in water depth in wet ponds compared to wetlands (City of Calgary Stormwater Management & Design Manual 2011). For instance, in the Rocky Ridge wetland water levels fluctuated less than 5 cm on average due to most rainfall events. However, during the biggest rainfall event in late June which had a total rainfall of 34.6 mm, the water level rose by approximately 10 cm (see Fig. 3a). The Auburn Bay wet pond experienced a much higher range of water level fluctuations with increases of 1.25 m and 0.6 m during the big rainfall events in late June and late July which has a total rainfall of 102.2 mm and 30.8 mm, respectively (see Fig. 3b). In the Rocky Ridge wetland, between August and October, the water surface elevation was observed to be lower than the design normal water level (1259.0 m), which may indicate that evaporation losses were significant during this time period. Starting early October, the water surface elevation in all ponds and wetlands stabilized at the design normal water level since there were no significant runoff events and likely negligible evaporation. The noise, in Fig. 3a, of approximately 1 to 2 cm in the water level time series reflects the depth sensor accuracy which is specified by the manufacturer to be on the order of ± 1.0 cm. Similar noise exists in Fig. 3b but doesn't show up clearly as a result of the higher range of water surface elevation in the Auburn Bay wet pond.

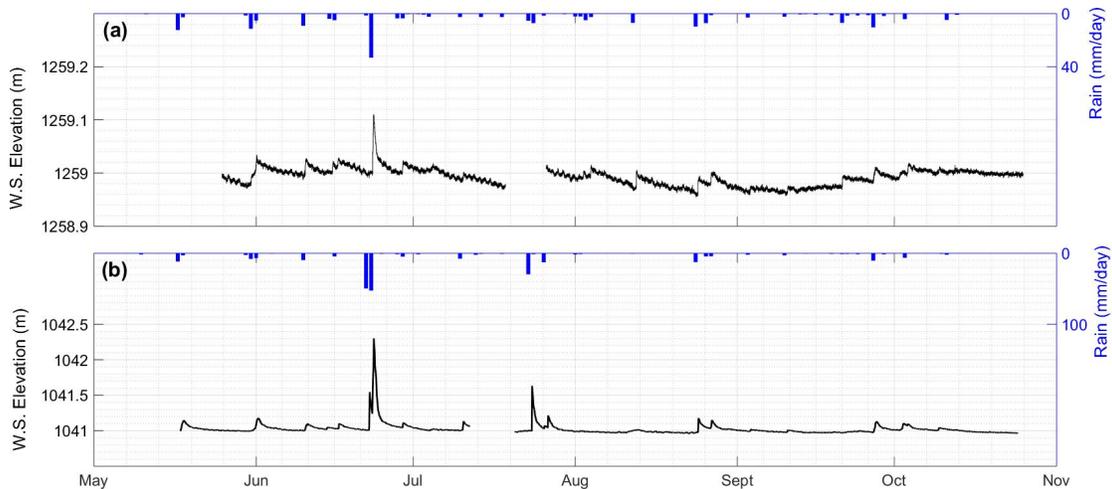


Fig. 3: Water surface elevation (black line) versus daily rainfall depth (blue bars) in a) Rocky Ridge Wetland, b) Auburn Bay Wet pond.

In general, thermal stratification in wet ponds/wetlands is controlled by surface heating, wind, turbulent heat transfer and the delivery of salts and associated concentrations of dissolved solids (Marsalek et al. 2000). In Fig. 4, a time series of vertical temperature variations measured at eight heights above the bed (i.e. from 28 to 301 cm) at location C in the Cranston wet pond is plotted in a 2D contour plot. The water surface temperature was found to be strongly correlated to the air temperature recorded at the pond's weather station and this can be seen most clearly in the shorter duration contour plot shown in Fig. 5. Diurnal fluctuations in air temperature typically generated diurnal fluctuations in near-surface water temperatures. In mid-June the thermocline was at a depth of approximately 1.5 m and it deepened to 2.5 m by mid-August. The water column became isothermal and well-mixed in mid-September likely due to convective vertical mixing induced by the abrupt drop in air temperatures. Later in the fall slightly higher air temperatures produced a weakly stratified water column. In Fig. 5 it can be seen that the large rainfall event that occurred on June 22nd caused the pond to cool significantly weakening the stratification.

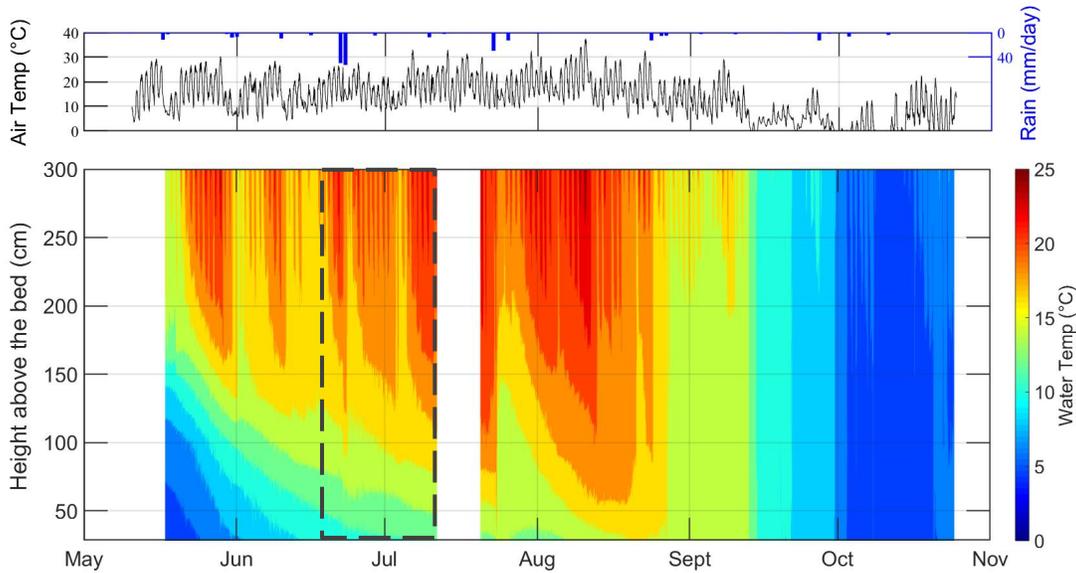


Fig. 4: A 2D contour plot showing temporal and vertical variations in water temperature and the corresponding air temperature (black line) at the middle of the Cranston wet pond (location C in Fig. 1), data in the black dotted window is plotted in Figure 5. Blue bars show the daily rainfall depth.

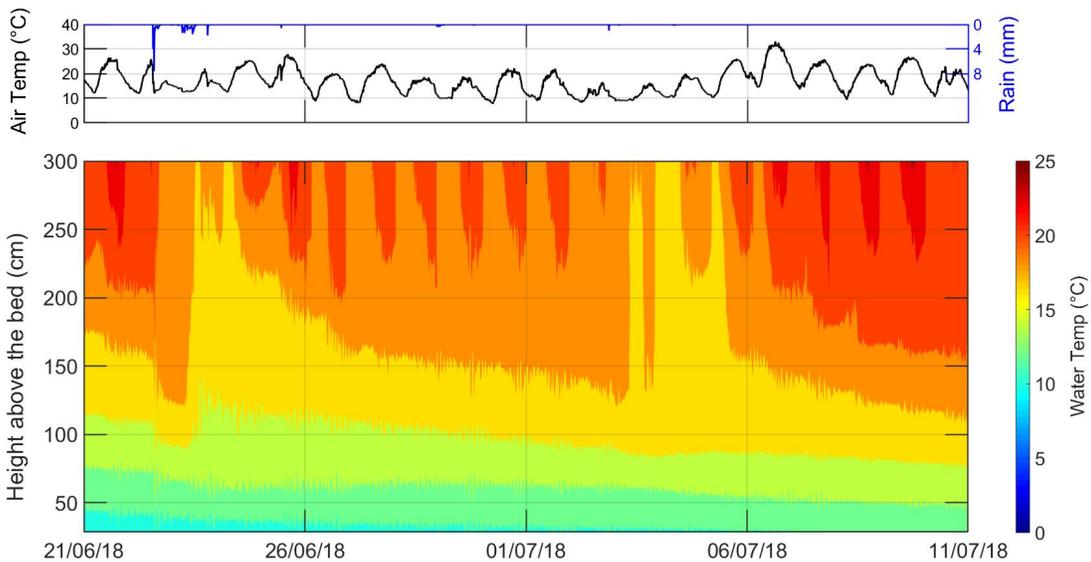


Fig. 5: A 2D contour plot showing temporal and vertical variations in water temperature and the corresponding air temperature (black line) at the middle of the Cranston wet pond (location C in Fig. 1). Blue bars show the rainfall depth on 5-minute readings.

Figure 6 shows a contour time series plot of DO concentrations in the Cranston wet pond measured near the inlet. The DO concentrations were recorded using four DO HOBO loggers mounted at heights of 28, 73, 117 and 160 cm above the bed. The average DO concentrations for the entire time period at the four levels were 0.8, 0.9, 2.25 and 4.30 mg/L, respectively. Note that the highest DO sensor mounted at 160 cm above the bed was 60 cm below the water surface. Higher values of DO likely occurred near the surface (i.e. at depths less than 60 cm) due to air-water gas transfer, wind-driven surface mixing and the photosynthetic potential of the surface chlorophyll exposed to light. Near the end of May, vertical patterns of DO concentration were observed with high concentrations of DO observed at mid-depth. Low oxygen in

bottom waters was also observed during majority of the time. This may occur as a result of sediment oxygen demand, high turbidity within the water column inhibiting light and thermal stratification reducing vertical mixing. Significant runoff events were found to be followed by spikes in DO levels that extended from near the bed to the surface waters. This was probably due to hydraulic mixing and the resulting thermal destratification following each storm event.

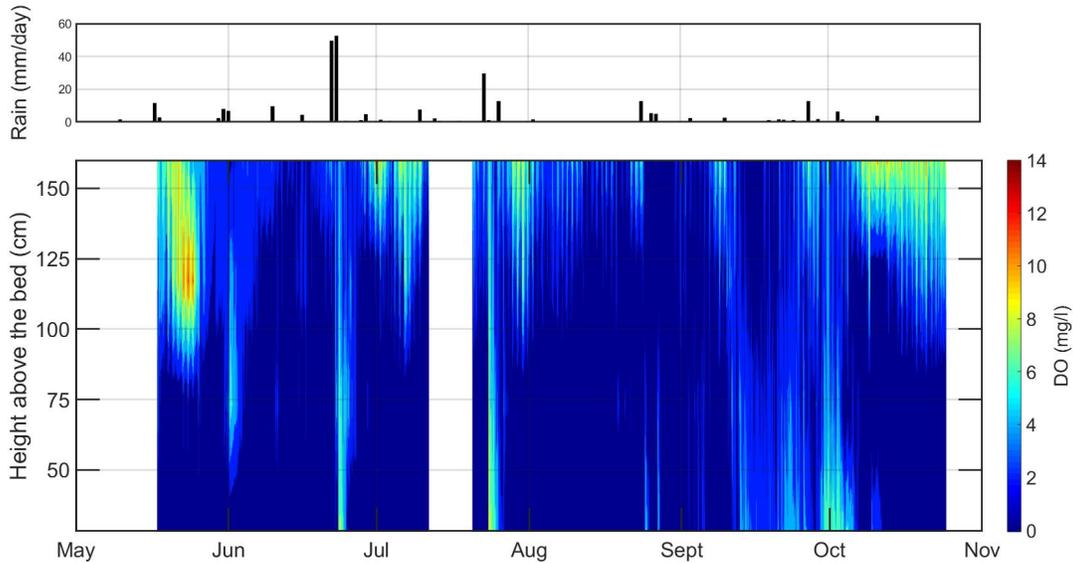


Fig. 6: A 2D contour plot showing temporal and vertical variations in DO concentrations near the inlet (location A in Fig. 1) at Cranston wet pond. The DO concentration was recorded using four DO HOBO loggers mounted at heights of 28, 73, 117 and 160 cm above the bed. Black bars show the daily rainfall depth.

In Fig. 7, a time series of pH levels near the surface measured at location B near the outlet of the Cranston wet pond during May and July show high pH levels that coincided with the high DO concentration observed near surface in Fig. 6. Low and approximately constant values of pH of ~ 7.5 were observed near the bed where the DO concentrations were observed to be very low in Fig. 6. Higher near surface pH that occurred at the end May and in July coincided with higher near surface DO concentrations, see Fig. 6. This correlation between the DO and pH levels in the near surface water was similar to the results reported by Wium-Andersen et al. (2013) in their study of two stormwater wet ponds in Denmark. They concluded that the correlation was most probably due to photosynthesis acting to increase both DO and pH by producing oxygen while at the same time consuming carbonate (Wium-Andersen, et al. 2013). This also explains the diurnal variation of the pH near the surface as a result of photosynthesis during the day (high pH) and respiration during the night (low pH).

Seasonal variations in the chlorophyll-a concentration are governed by variations in solar radiation, stormwater inflows and the depth of the euphotic zone exposed to intense sunlight (Masson and Pena 2009). In Fig. 8, time series of relative chlorophyll-a levels measured at heights of 41 cm and 228 cm above the bed near the outlet in the Cranston wet pond are plotted. High levels of chlorophyll-a were observed in late May which persisted in the deep water of the pond until early June. At this time there was probably low turbidity within the water column which allowed sufficient light to reach the chlorophyll in the deep water causing photosynthetic primary production. Starting in July chlorophyll-a concentrations at both depths were comparable and diurnal fluctuations are evident in both time series. This indicates that the euphotic zone extended to 41 cm above the bed or to a depth of 290 cm.

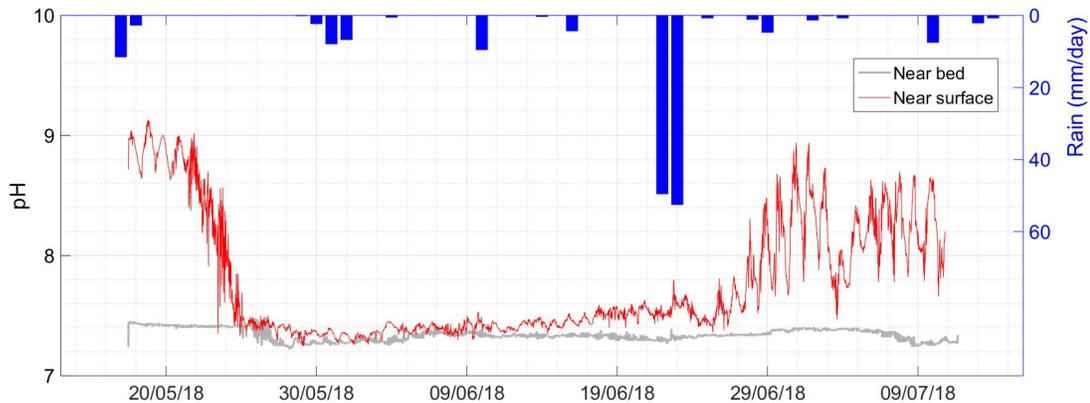


Fig. 7: Time series of pH measured at height of 41 cm (grey line) and 228 cm (red line) above the bed at Cranston wet pond near the outlet (location B in Fig. 1) where the water depth is 330 cm. Blue bars show the daily rainfall depth.

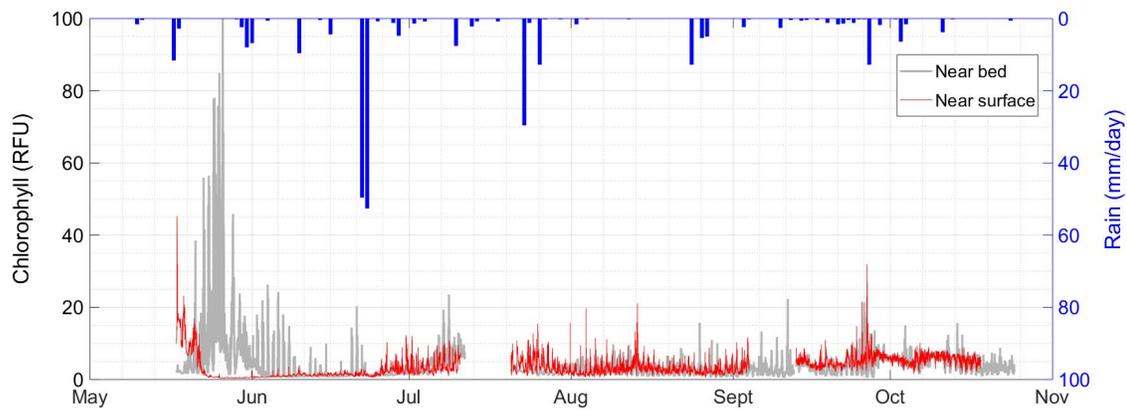


Fig. 8: Time series of Chlorophyll-a measured at height of 41 cm (grey line) and 228 cm (red line) above the bed at Cranston wet pond near the outlet (location B in Fig. 1) where the water depth is 330 cm. Blue bars show the daily rainfall depth.

Stormwater runoff was also found to directly affect various water quality parameters. In Fig. 9, a time series of seasonal pH and DO variations were measured at location A near the outlet in the Auburn Bay wet pond along with the daily rain intensity measured by the pond’s weather station. From mid-May to later in June, the pH was found to be relatively high probably due to the consumption of dissolved carbonate by photosynthesis when low turbidity allowed enough light to reach the chlorophyll at this depth. During the big rainfall event in June, a significant decrease in DO and pH levels was observed. This may be because a relatively large volume of stormwater of relatively low pH flowed into the pond. At the same time the DO concentration dropped abruptly and the amplitude of its diurnal fluctuation also decreased which would be consistent with an increase in water turbidity and a decrease in photosynthesis following the runoff event. The DO and pH time series appear to be correlated to some degree, as a result of the influence of photosynthesis on both dissolved oxygen and carbonate concentrations (Wium-Andersen, et al. 2013). During the August field trips, green suspended algae particles and floating dead algae were observed in the pond. The suspended algae may have led to high turbidity and this combined with the effect of decomposing dead algae could be the explanation for the low levels and reduced diurnal fluctuation of the measured DO.

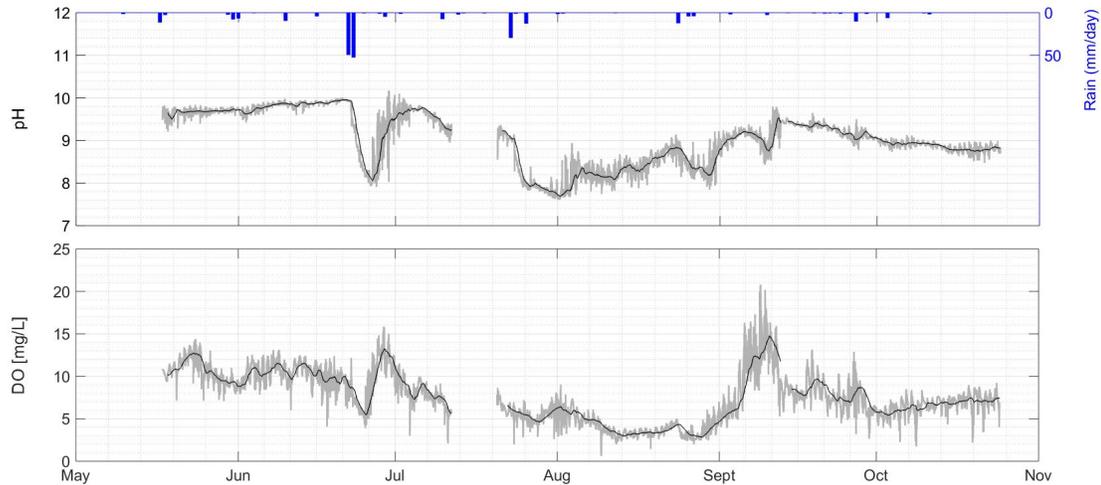


Fig. 9: Time series of pH and DO measured at height of 152 cm and 225 cm, respectively, above the bed of the Auburn Bay wet pond near the outlet (location A in Fig. 1). The grey lines in the graph show the short-term variation based on 5-minute readings, and the black lines show the daily running average. Blue bars show the daily rainfall depth.

5 CONCLUSIONS

Field monitoring of two stormwater wet ponds and two stormwater wetlands was conducted in Calgary, Alberta. Persistent thermal stratification was observed in both wet ponds from mid-May to the end of August. The thermocline depth increased from ~1 m to ~2.5 over this time period. Hydraulic mixing generated by large runoff events periodically weakened the stratification. Low DO concentrations were observed in the wet ponds with average values less than 1.0 mg/l within a meter of the bed and 4.3 mg/l at a depth of 60 cm below the water surface. Trends in time series of DO concentrations and pH were consistent with previous research that found that photosynthetic primary production caused increases in both DO and pH. Photosynthesis during the day and respiration at night caused diurnal fluctuations in pH and DO. Chlorophyll-a levels were observed to be high in late May at a depth of 2.9 m indicating that there was sufficient light reaching this depth to cause photosynthesis. Beginning in mid-July chlorophyll-a levels were comparable at depths of 1.0 m and 2.9 m. In addition, diurnal fluctuations were evident in both time series indicating that the euphotic zone likely extended to a depth of 2.9 m.

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