Performance Assessment of a Flow Balancing and Wetland Treatment System - Toronto, Ontario

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Ministry of the Environment
Ontario

PERFORMANCE ASSESSMENT OF A FLOW BALANCING AND WETLAND TREATMENT SYSTEM - TORONTO, ONTARIO

a report prepared by the

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Great Lakes Sustainability Fund of the Government of Canada
Ontario Ministry of the Environment
Toronto and Region Conservation Authority
Municipal Engineers Association of Ontario
City of Toronto

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NOTICE

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THE SWAMP PROGRAM

The Stormwater Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, and the Municipal Engineer's Association. A number of individual municipalities and other owner/operator agencies have also participated in SWAMP studies.

During the mid to late 1980s, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in southern Ontario. The SWAMP Program was intended to address this need.

The SWAMP Program's objectives are:

* to monitor and evaluate new and conventional stormwater management technologies; and
* to disseminate study results and recommendations within the stormwater management industry.

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Additional information concerning SWAMP and the supporting agencies is included in Appendix A.

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This report was prepared for the Steering Committee of the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The SWAMP Program Steering Committee is comprised of representatives from:

- the Government of Canada's Great Lakes Sustainability Fund,
- the Ontario Ministry of the Environment,
- the Toronto and Region Conservation Authority,
- the Municipal Engineers Association of Ontario.

This study was jointly funded by the Ontario Ministry of the Environment (OMOE), the Great Lakes Sustainability Fund (formerly the Great Lakes 2000 Clean-up Fund) and the City of Toronto. The OMOE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOE provided laboratory analyses. Staff at the City of Toronto provided permission to conduct the monitoring study, and assisted with the installation and operation of monitoring equipment. The Toronto and Region Conservation Authority (TRCA) provided administrative support for the SWAMP program. An interim report and a series of technical memorandums were prepared by SWAMP staff. The final report was prepared by TRCA.

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EXECUTIVE SUMMARY

Background and Objectives

In 1990, the City of Scarborough (now part of the City of Toronto) undertook a feasibility study to examine the option of constructing a Dunkers Flow Balancing System (DFBS) at a storm sewer outfall discharging to Lake Ontario.[1] The Bluffers Park embayment, which receives stormwater and combined sewer overflows (CSOs) from the Brimley Road drainage area, was identified in the study as the most suitable of the six outfall sites for the DFBS. The study recommended that an Environmental Assessment (EA) be undertaken to determine the most appropriate strategy from a set of alternative options aimed at reducing the impacts of stormwater and CSO pollution to Lake Ontario.

An environmental assessment study was commissioned in 1993. The study reported on existing environmental conditions, identified potential impacts of stormwater and CSO discharges and evaluated alternative solutions and design concepts.[2] The preferred water quality enhancement strategies recommended for the Brimley Road Drainage area included pollution prevention (*e.g.*: water conservation, public education), roof downspout disconnection, and construction of a DFBS facility. One of the primary objectives of the flow balancing facility was to demonstrate the effectiveness of the technology in terms of contaminant reduction and habitat creation. Fulfilment of this objective was to be determined through an extensive post-construction monitoring program.

In 1999, the City of Toronto, the Ministry of the Environment and Environment Canada (Great Lakes 2000 Clean-up Fund) established a partnership to monitor the DFBS facility with respect to design and compliance parameters through the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The study was to assess the overall effectiveness of the facility in meeting its original design objectives through a detailed monitoring program conducted between May and November in 2000, 2001 and 2002. Specific objectives included:

(i) evaluating the water quality treatment efficiency of the system, with specific attention given to the concentrations of contaminants in water discharged from the facility;

(ii) assessing flow paths of stormwater discharge through the facility using dye tests; and

(iii) identifying predominant zones of settling through discrete monitoring of suspended solids and analysis of bottom sediments.

[1] Paul Theil Associates Limited. 1991. *Feasibility Study of the Dunkers Flow Balancing System*. Prepared for the City of Scarborough.
[2] Aquafor Beech Limited. 1994. *Environmental Study Report, Brimley Road Drainage Area – Water Quality Enhancement Strategy*. Prepared for the City of Scarborough.

The water quality sampling and dye tests were to provide the basis for making recommendations on potential design improvements, operation and maintenance needs (*e.g.* dredging intervals) and transferability of the technology to other locations. These activities, together with a separate multi-year fisheries habitat and vegetation assessment currently being undertaken by the Ontario Ministry of Natural Resources, are aimed at providing a complete and balanced evaluation of the environmental performance of the technology.

Study Site

The facility treats runoff from a 171 hectare drainage area, of which 159.1 hectares are serviced by storm sewers and 11.9 hectares are serviced by combined sewers. Approximately 60% of land use within the catchment is residential, and the remaining 40% is a combination of industrial, institutional, commercial and open space. In a typical year, the combined sewers overflow roughly 15 times and comprise less than 5% of the total annual runoff.

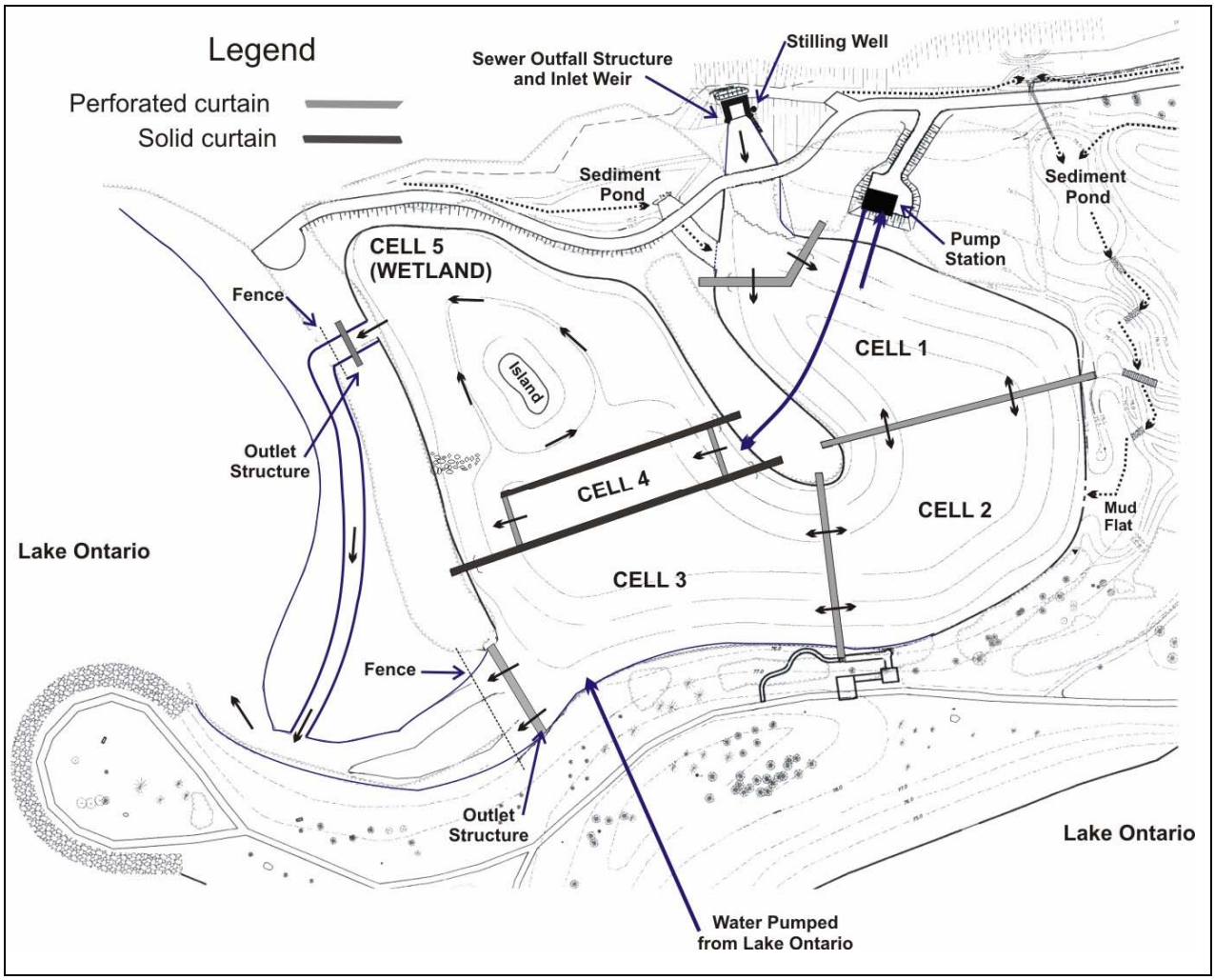

Figure 1: Flow balance and wetland treatment system schematic

The design of the City of Toronto facility was based on the Dunkers Flow Balancing System, developed in Sweden by Karl Dunkers. The facility consists of 5 cells built within a natural embayment and separated by pontoon-supported solid and perforated curtains anchored to the bottom with weights. The perforated curtains have variable width openings designed to promote plug flow conditions and minimize short-circuiting. During a rain event, stormwater enters the first cell, displacing the cleaner water into the second cell. Similarly, the remaining cells are filled in sequence before the polluted water can enter the lake. Retained water is pumped through a sedimentation cell (cell 4) and a wetland (cell 5) before being released to the lake. The volume pumped out of the storage cells is replaced by lake water that is pumped into cell 3.

The two pumps discharging into cell 3 and cell 4 operate at a constant rate of 4 m^3/min. A third pump operating at the same rate transfers water from cell 1 to cell 4 during and after wet-weather events. The second pump is triggered if the peak inflow rate exceeds 4 m^3/s. The normal hydraulic load on cells 4 and 5 is thus doubled, and the chance of discharging untreated stormwater/CSO from cell 3 is reduced. Once triggered, the second pump remains on for 60 hours. The total volume of water pumped out of cell 1 at 8 m^3/min over this period is approximately equal to the total storage volume of cells 1 to 3 (28,500 m^3).

The total storage volume of the five cells is 39,200 m^3, representing a volume per catchment hectare of 229 m^3/ha (cells 1 to 3 = 167 m^3/ha), including the 11.9 hectare CSO area. Based on a design runoff coefficient of 0.39, cells 1 to 3 would capture flow from a one-year rain event, estimated at approximately 42 mm.

Monitoring Program

Intensive monitoring was undertaken from May to December in 2000, 2001 and 2002. The monitoring program included measurements of rainfall, flow, water quality, sediment quality, water temperature and two detailed dye tests.

Flow data used in the study were determined from continuous measurements taken at the inlet flow control structure. The cell 3 outlet was not conducive to flow monitoring. Hence, for the purpose of estimating removal efficiencies, the volume of water entering and exiting the facility during rain events was assumed to be equal. Comparative inlet and outlet measurements during low flow periods confirmed this assumption to be reasonable. Water levels were also monitored continuously at 5 minute recording intervals in several cells.

Based on flow measurements at the cell 5 control structure, it was determined that approximately 25% of the total flow volume entering the facility exited via cell 5, and 75% exited cell 3. These proportions were assumed to be constant over all rain events. Varying the proportions had little effect on load-based removal efficiency estimates because effluent concentrations at the two stations were similar.

The cell 5 outlet channel was blocked by beach sediment for most of the early part of the 2000 monitoring season when lake levels were high, and over most of the 2002 season. During this period, flow through the cell 5 outlet was assumed to be zero or negligible.

Wet weather flow entering the facility overland through the sediment ponds (dotted lines in Figure 1) was discounted as it was observed to be a negligible proportion of total flow.

Water quality samples were collected with automated samplers at the inlet, the outlets of cells 3 and 5, and the inlet and outlet of cell 4. In 2001 and 2002, samples were also collected at the downstream end of cells 1 and 2. Sampling was conducted during dry and wet weather, as well as during the 'post event' period as the contents of cells 1 to 3 were pumped to cell 4 and out to the lake. Analysis was conducted by the Ontario Ministry of the Environment laboratories following standard methods for general chemistry (e.g. pH, alkalinity, conductivity), metals, nutrients (P and N), bacteria, polynuclear aromatic hydrocarbons (PAHs), herbicides/pesticides, and toxicity.

Water temperature was monitored continuously every 30 minutes at the inlet and at the cell 3 and cell 5 outlets. In 2002, temperature was measured at 10 minute intervals near the outlet to cell 1 at 0.5, 1.5 and 2.5 m below the dry weather water surface. The depth integrated measurements indicated the degree of thermal stratification present in the pond during the summer, and provided insights into flow dynamics during storm events.

Bottom sediment samples were collected on November 16th, 2001 in cell 1, cell 3, cell 4, cell 5, and in Lake Ontario, both downstream of the outlet channels and at a control site on the south side of the embayment. All sites were sampled in triplicate using an Ekman Dredge and processed according to established protocols. Samples were analyzed for general chemistry, metals, nutrients, PAHs, PCBs and organochlorine pesticides.

Two dye tests were conducted during the 2001 monitoring season. The first test was conducted during a wet-weather event on October 23rd to measure flow paths of stormwater through the facility. The second test, conducted on November 21st, traced the flow path of lake water being pumped into cell 3 during dry weather.

Study Results

Water quantity

Flow was monitored for 110 rain and snowmelt events. Combined sewer overflows occurred during 32 of these events, but represented only 1.6% of the total runoff volume. Average runoff coefficients were relatively consistent over the three monitoring seasons, with seasonal averages ranging from 0.29 to 0.32.

Comparison of continuous water level measurements on either side of the solid curtain separating cell 4/5 from cell 3 showed negligible differences in water level fluctuations during runoff events. If the pump station were the only source of flow into cell 4/5, a greater differential in water levels would have been expected. Dye tests in cell 4 later confirmed that flow around or under the curtain - and possibly flow through holes or tears in the curtain - were allowing significant runoff to enter cells 4 and 5 from cell 3.

Dye Tests

A wet weather dye test was conducted to assess the hydraulic efficiency of the system. This test was conducted during a relatively small but intense event (7.1 mm over 1.5 hours). Detailed sampling and volumetric calculations indicated that new influent water (represented by the dye) moved much further and over a shorter period of time than would be expected under plug flow conditions. Samples collected off two pontoons at various water depths revealed that the influent water was not vertically integrated. Instead of displacing water in the cells, the new influent water moves first across the surface and only later mixes with cell contents.

The purpose of the dry weather dye test was to chart the course of water pumped (at a rate of 4 m^3/min) into cell 3 from the lake. From cell 3 the water could either exit cell 3 or move back towards cell 1 where it would be pumped into cell 4 and flow through cell 5 out to the lake. Dry-weather test results demonstrated that, as intended, the majority of the lake water pumped into cell 3 moved toward cell 1 and was subsequently transferred to cells 4 and 5. However, residence time calculations indicated significant departure from plug flow conditions. Observations of dye patterns in cells 3 and 2 in particular revealed that the recirculation patterns are very complex and, at least at the surface, are strongly influenced by wind speed and direction.

Settling Dynamics

Discrete total suspended solids (TSS) monitoring during selected wet weather events at seven locations within the facility provided the basis for characterizing the movement of suspended solids through the facility, and identifying predominant zones of settling. Cell 1 was the major zone of deposition; at least 60% of the influent TSS load during wet weather events was removed in this cell. An additional 15-25% of the TSS load was removed in cells 2 and 3. Not all of the solid mass 'removed' in these cells was deposited there; a portion is pumped to cell 4 during and after the rain events.

As expected, mass peaks in TSS decreased with increasing distance from the inlet. During large events, a 15-20 minute time delay was typically observed between mass peaks at the inlet and cell 1, and between cell 1 and cell 2. Most events discretely sampled showed outlet suspended solids concentrations at or close to background levels over the duration of storm outflows, indicating that the facility was successful in storing and treating the majority of solids discharged into the facility.

Particle size analysis results demonstrated that the facility was effective in removing all particle sizes greater than 30 μm. The median suspended particle size of 7.5 μm in the influent was reduced to 3.5 μm at the pump intake to cell 4 and to 2 μm at the two outlet stations. Other studies of detention basins conducted by SWAMP suggest that even with larger permanent pools and longer settling times, it is not practical to expect reductions beyond a median effluent particle size of 2 μm.

Water Quality

The wet weather effluent water quality data set consisted of 52 and 38 samples collected at the cell 5 and 3 outlets, respectively. Water samples were analyzed for a wide range of water quality variables. As there are no effluent standards in Ontario, effluent concentrations were compared to provincial receiving water quality guidelines.

Only total phosphorus and *E.coli* had median effluent event mean concentrations (EMCs) above receiving water guidelines (Table 1). Concentrations of both constituents were at the low end of the range of effluent concentrations reported for other 'enhanced' protection level end of pipe facilities monitored in the GTA (see other SWAMP studies in this series).

Effluent concentrations of TSS were below levels considered detrimental to aquatic life. Average TSS event mean concentrations were 11 and 14 mg/L at the two outlets, with a range from 3 to 67 mg/L.

All samples tested for acute toxicity, including the facility influent, were found to be non-lethal to test organisms.

Table 1: Wet weather effluent quality and performance summary for selected constituents

Variable	Receiving Water Guideline	Median Effluent Concentrations[1]		Overall % removal[2]
		Cell 3	Cell 5	
Total suspended solids	n/a	11.2 mg/L	13.8 mg/L	81
Total phosphorus	0.03 mg/L	0.07 mg/L	0.06 mg/L	77
Lead	5 μg/L	< RMDL[3]	< RMDL[3]	73
Copper	5 μg/L	4.1 μg/L	3.4 μg/L	85
Zinc	20 μg/L	10 μg/L	7 μg/L	89
E. coli	100 CFU/100 mL	240 CFU/100 mL	60 CFU/100 ml	75

Notes: 1. n = 52 and 38 at the cell 3 and 5 outlets, respectively. The *E. coli* data set was smaller: n = 10 and 7, respectively.
2. Values represent load based removal efficiencies. n = 30 for TSS, n = 11 for all other variables except *E.coli* (n = 4).
3. RMDL = reporting method detection limit.

Although effluent concentrations of indicator bacteria were within the expected range, there was some concern that *E.coli* inputs to the lake from the facility could contribute to poor water quality at Bluffers Park beach, which is located less than half a kilometre east of the site. Comparison of *E.coli* levels in facility effluents with daily sampling results at the beach and grab samples collected in the lake downstream of the outlets did not suggest any connection between facility effluents and beach concentrations of *E.coli*.

Pollutant Removal

Total suspended solids removal efficiencies were calculated for 30 rain events, of which 14 were classified as small (<10 mm), 6 as mid sized (10 – 20 mm) and 10 as large (>20 mm). The average size of the 30 storm events was 14 mm, with a range between 3 and 31 mm.

The overall load based TSS removal efficiency for these storm events was 81% (Table 1). This rate compares favourably to the 60% design target for the facility. Storms with more than 20 mm of rain tended to have lower removal efficiencies (74%) and higher effluent TSS event mean concentrations (24 mg/L) than events with less than 20 mm (91% and 12 mg/L respectively).

The facility was designed to store and treat runoff from storms as large as 42 mm in size. A storm as large as 42 mm was not observed during the study period, however two back-to-back events, each with approximately 25 mm of rainfall, had removal efficiencies of 72 and 80%, indicating that if 50 mm falls over a 48 hour period, the facility would be reasonably effective in treating most of the volume discharged.

Sediment Quality

Sediment chemistry samples collected at various locations both in and downstream of the facility showed progressively better sediment quality with distance from the inlet. Among the samples collected within the facility, cell 5 sediment was the cleanest, and was the only cell where sediment quality met the MOE's 'lowest effect level' guidelines for the protection of aquatic life.

Average sediment particle size distributions (PSD) at the chemistry sampling sites indicated that influent sediment loads are settling out primarily in cells 1 to 4, and that only a small proportion of the very fine suspended solids entering cell 5 are being deposited in this cell.

Operation and Maintenance

Functional components in the Dunkers facility requiring on-going maintenance include the pontoons, cell divider curtains, recirculation pumps, weirs and outlet channels. The life expectancy for these components ranges from 15 years for the pumps to 35 years for pontoons if they are maintained appropriately.

The cell 5 outlet channel was originally designed to discharge to the lake westward via a short and straight channel section. However, natural coastal geomorphic processes resulted in beach sand being pushed or carried into the channel when lake levels were high, causing flow through this outlet to be blocked. The channel eventually formed its own channel parallel to the beach such that it discharges in a location sheltered from the waves (Figure 1). This longer, naturally formed channel has required less frequent maintenance and dredging than the original channel.

Other operational issues included holes and tears in the solid curtains caused by beavers, and damage to the lake inlet pipe from shore currents. These components of the Dunkers system must be carefully designed to avoid frequent and expensive repairs.

Periodic removal of contaminated sediments deposited in the facility is crucial to ensure the facility continues to function effectively. Based on measured sediment loads and removal rates, it was estimated that clean-out of deposited solids in cells 1 and 4 would be required after 32 and 22 years following construction, respectively. Other cells would need dredging less frequently.

Conclusions and Recommendations

The primary goal of the three year monitoring study was to evaluate the effectiveness of the Toronto Dunkers Flow Balancing System in reducing influent concentrations of suspended solids and associated contaminants from storm and combined sewage discharge. Fulfilment of this objective was achieved through co-ordinated monitoring of rainfall, flow and water quality, dye tests, sediment sampling, and discrete suspended solids monitoring at multiple locations within the facility. Although the pumps were not operating as designed for the entire study period, and the smaller of the two outlets was intermittently blocked with beach sediment, the system nevertheless performed exceptionally well, exceeding the original design targets with respect to water quality treatment.

The following recommendations are provided based on study results and observations made during the course of the monitoring study.

1. The outlet channel to cell 5 was periodically blocked with sediment throughout the study period, especially when lake water levels were high. Dredging the channel parallel to the beach appears to have been an effective and relatively low cost solution to this problem for the past two years. However, if the problem persists in future high lake water level years, consideration should be given to other alternatives, such as a buried pipe where the current channel lies, to ensure uninterrupted conveyance of cell 5 flows to the lake.

2. Bottom sediments should be removed every 4 to 6 years from the cell 1 and cell 4 forebays to avoid re-suspension and distribution of this sediment over the remaining cells, and to extend the period over which dredging of the entire facility would be required. The precise interval of sediment removal should be determined from direct measurements of sediment accumulation in these areas.

3. Sediment sampling results and dye test residence time calculations suggested that flow in cell 5 was short circuiting along the west side of the island. Extending the cobblestone spit immediately downstream of the cell 4 outlet would help to improve residence time by diverting flow around the east side of the island.

4. As mentioned earlier, there was significant flow across the solid curtain separating cell 3 from cells 4 and 5, even after the City repaired and re-anchored the curtain to the bottom in November, 2001. Despite the relatively pervious nature of the curtain, however, the facility provided excellent water quality treatment. Further, the quality of wetland sediments met provincial sediment quality standards, suggesting that the water that is entering from cell 3 (probably from the bottom of the cell) is relatively free of contaminated sediment. It is recommended, therefore, that no further attempts be made to repair the curtain, and that the facility continue to operate as a more connected unit than was intended in the original design.

5. Residence times in the original design brief for the facility were calculated on the assumption of plug-flow conditions (no mixing of the influent flow and facility contents). Dye tests and suspended solids monitoring demonstrated that the plug flow assumption is not valid, even as an approximation of actual conditions. In reality, considerable mixing occurs and influent sediment plumes travel much further than would be anticipated under strict plug flow conditions. Future flow balancing systems of a similar design should be based on conceptual and physical models that better represent the underlying complexity of the system and processes involved.

6. In the initial planning stages of the project, there was some discussion about whether the treatment effectiveness of the facility would be significantly compromised if cell 5 was entirely isolated from the system by impermeable barriers and functioned solely as wetland habitat. In this scenario, all stormwater flows would pass through cells 1 to 3 before exiting to the lake and the recirculation pumps would be removed or relocated. The findings of this study suggest that this change in design would likely reduce the capacity of the facility to treat flows. Cell 5 provides an important polishing function to flows that are pumped through cell 4. If flows were restricted entirely to cells 1 to 3, flow rates and volumes exiting cell 3 would increase, resulting in shorter residence times and poorer overall removal. The current design has been shown to provide reasonably good quality habitat for aquatic life while providing ancillary benefits in terms of treatment. Changes to the existing design are, therefore, not recommended.

7. Further study is required to determine whether the pumps provide an indispensable benefit to the system both in terms of increased residence times and better circulation during dry weather. The results collected thus far appear to suggest that the pumps are dispensable. There was, for instance, no difference in the quality of effluent or efficiency of removal when the lake pump was shut down for extended periods. Continuous influent baseflow of between 5 and 15 L/s provides a recirculation function, similar to that of the pumps (albeit at a considerably lower rate). If the cell 1 pumps were shutdown, flow would still enter cells 4 and 5 via cell 3 through the curtain; this flow path could be opened up further if necessary, preferably at the downstream end. Water entering cell 5 from cell 3 is relatively clean, since most of the treatment occurs in the first two cells. Hence, shut-down of the pumps would not jeopardize the function of the wetland as habitat for waterfowl and aquatic life. Further consideration of the utility of ‘pump-back’ in flow balancing systems should consider

monitoring results from the flow-balancing system in Etobicoke, which provides passive treatment through a series of interconnected cells separated by solid and perforated curtains attached to pontoons.

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1.0 BACKGROUND AND OBJECTIVES

In 1990, the City of Scarborough (now part of the City of Toronto) undertook a feasibility study to examine the option of constructing a Dunkers Flow Balancing System (DFBS) at a storm sewer outfall discharging to Lake Ontario (Paul Theil Associates Limited, 1991). The Bluffers Park embayment, which receives stormwater and combined sewer overflows (CSOs) from the Brimley Road drainage area, was identified in the study as the most suitable of the six outfall sites for the DFBS. The study recommended that an Environmental Assessment (EA) be undertaken to determine the most appropriate strategy from a set of alternative options aimed at reducing the impacts of stormwater and CSO pollution to Lake Ontario.

An environmental assessment study was commissioned in 1993. The study reported on existing environmental conditions, identified potential impacts of stormwater and CSO discharges and evaluated alternative solutions and design concepts (Aquafor Beech Ltd, 1994). The preferred water quality enhancement strategies recommended for the Brimley Road Drainage area included pollution prevention (*e.g.*: water conservation, public education), roof downspout disconnection, and construction of a DFBS facility. One of the primary objectives of the flow balancing facility was to demonstrate the effectiveness of the technology in terms of contaminant reduction from storm and combined sewers and habitat creation. Fulfilment of this objective was to be determined through an extensive post-construction monitoring program.

In 1999, the City of Toronto, the Ministry of the Environment and Environment Canada (Great Lakes 2000 Clean-up Fund) established a partnership to monitor the DFBS facility with respect to design and compliance parameters through the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The study was to demonstrate improvements from pre-construction conditions and assess the overall effectiveness of the facility in meeting its original design objectives. This report provides an assessment of the facility based on monitoring conducted between May and November in 2000, 2001 and 2002. Lessons from this project will help to guide future initiatives aimed at improving water quality in the City of Toronto.

1.1 Design Objectives and Regulatory Requirements

In 1997, the Ontario Ministry of Environment and Energy issued a Certificate of Approval to the City of Scarborough for construction of a Dunkers Flow Balancing System at Bluffers Park[1]. The C of A document included a stipulation that a monitoring program be conducted to measure the effectiveness of the system in water quality enhancement relative to the stormwater outfall from the Brimley Road drainage area. The minimum requirements included the undertaking of dye tests under both dry-weather and wet-weather conditions. Dye tests were intended to identify any dead zones and short-circuiting, and to determine flow patterns and hydraulic efficiency. Water quality monitoring was to include, as a minimum, grab samples for suspended solids analysis at the inlet, the wetland outlet and at the intake of the recirculation water system. Long-term monitoring of sediment accumulation and removal was also specified.

[1] Certificate of Approval, Sewage, Number 3-0136-97-006.

The City of Scarborough was also granted a permit to take water for water treatment purposes, with respect to the recirculation water supply.

The design brief that was submitted in conjunction with the C of A application indicated that the Dunkers Flow Balancing System was designed as a demonstration project, within an established urban tributary area. The project was not required to mitigate effects of other proposed works, such as a subdivision development. An average suspended solids removal efficiency of 60% was assumed, based on available settling rate data. Residence times were calculated on the assumption of plug-flow conditions (no mixing of the influent flow and the facility contents).

The federal Department of Fisheries and Oceans, under section 35(2) of the Fisheries Act, provided Authorization for Works or Undertakings Affecting Fish Habitat[2] with respect to the DFBS project. The Authorization required that a number of conditions be met, some as part of the design and some related to construction activities. Compensation for the loss of fish habitat due to construction of the facility in the existing embayment was achieved by inclusion of a wetland cell. The Authorization also required that a fish habitat monitoring plan be developed and implemented.

1.2 Study Objectives

The overall goal of the three year monitoring study was to evaluate the effectiveness of this innovative and transferable technology in removing solids and associated contaminants from storm and combined sewage discharge to a receiving water body. Specific objectives include:

(i) evaluating the water quality treatment efficiency of the system, with specific attention given to the concentrations of contaminants in water discharged from the facility;

(ii) assessing flow paths of stormwater discharge through the facility through dye tests; and

(iii) identifying predominant zones of settling through discrete monitoring of suspended solids and analyses of bottom sediments.

The water quality sampling and dye tests were to provide the basis for making recommendations on potential design improvements, operation and maintenance needs (*e.g.* dredging intervals) and transferability of the technology to other locations.

These activities, together with a separate multi-year fisheries habitat and vegetation assessment currently being undertaken by the Ministry of Natural Resources, are aimed at providing a complete and balanced evaluation of the environmental performance of the technology.

[2] Authorization No. 5250-351, dated January 18, 1995 and amended May 26, 1997

2.0 STUDY SITE

The study area (Figure 2.1) is located in Scarborough, within the City of Toronto. The area is roughly bounded by Lake Ontario to the south, St. Clair and Anson Avenues to the north, Brimley Road to the east and Birchlawn and Ridgemoor Avenues to the west. The total drainage area is 171 hectares, of which 159.1 hectares are serviced by storm sewers and 11.9 hectares are serviced by combined sewers. Approximately 60% of land use within the catchment is residential, and the remaining 40% is a combination of industrial, institutional, commercial and open space (Aquafor Beech, 1994).

Several years ago the City underwent a sewer separation program in which roadway catchbasins were disconnected from the original combined sewers and reconnected to new storm sewers. At about the same time, a voluntary roof leader disconnection program was implemented to reduce stormwater flow to combined and storm sewers.

Two pumping stations (Wirral Court and Midland Avenue) receive most of the combined and sanitary sewer flows. This flow is treated at the Ashbridges Bay Sewage Treatment Plant in Toronto, except during large rain events, when the capacity of the Midland Pumping station is exceeded. During these times, a portion of the combined sewer flows are directed east through the storm sewer where they mix with stormwater flows from the 159.1 hectare drainage basin and are discharged to the Dunkers Flow Balancing System. Prior to the roof leader disconnection program and various infrastructure improvements, the CSOs were estimated to occur approximately 30 times from April to October (Aquafor Beech, 1994). Less than 15 overflows per year were observed in 2000, 2001 and 2002.

2.1 Facility Design

The design of the facility was based on a stormwater/CSO treatment system originally developed and patented in 1978 by Karl Dunkers in Sweden. In its basic form, the Dunkers Flow Balancing System (DFBS) is a storage device consisting of series-connected cells that are created by suspending plastic curtains from pontoons (Figure 2.2). The DFBS is typically constructed on the shores of a lake or ocean. Construction costs are relatively low because the system does not require any land and because it is made from simple, light-weight materials.

When not in use, the DFBS storage cells contain lake water. During a rain event, stormwater or CSO enters the first cell, displacing the cleaner water into the second cell. Similarly, the remaining cells are filled in sequence before the polluted water can enter the lake. The location and configuration of the openings between the cells are designed to promote plug-flow conditions and minimize short-circuiting.

Figure 2.1: Brimley road drainage area, including CSO area

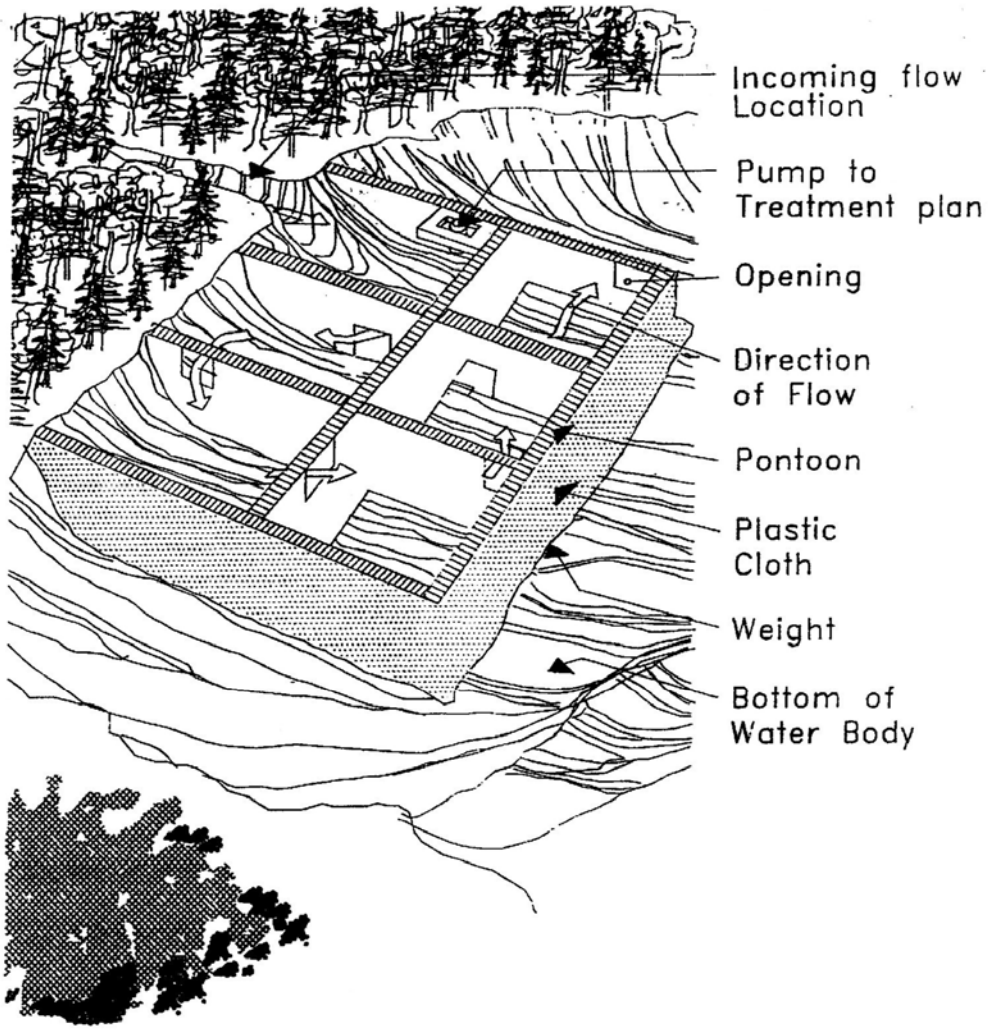


Figure 2.2: The original Dunkers flow balancing system concept

After the storm event, when the sewage treatment plant has sufficient spare capacity, the stored wastewater is pumped back into the sewer system from the first cell where it is directed to the wastewater treatment plant. Thus, the flow direction in the DFBS is reversed as lake water enters the last cell and moves back up the system replacing the volume of urban runoff that was pumped out.

The City of Toronto Dunkers facility consists of five cells (Figure 2.3). The outer perimeter consists of shoreline or artificial berm and one of the dividing walls between cells is a berm. Pontoon-supported solid and perforated curtains anchored to the bottom with weights provide the remaining cell dividers. The perforated curtains have variable width openings designed to extend residence times by reducing the

potential for short circuiting of flow. Unlike the original concept, the City of Toronto Dunkers facility incorporates both storage and treatment components. The first three cells function in the conventional storage mode. Stormwater enters cell 1 displacing the current contents of the storage cells into Lake Ontario through a swing gate overflow structure in cell 3. The collected runoff in cells 1 to 3 is pumped, not to the sewage treatment plant, but into the treatment system consisting of cells 4 and 5.

Cell 4 was designed as a long rectangular vessel, intended to serve as a sedimentation basin for the removal of suspended solids. Cell 5 is a wetland, intended to remove the lighter suspended pollutants and some dissolved pollutants. Cell 5 discharges to Lake Ontario through a separate outlet weir that is 1 cm lower than the cell 3 outlet (Figure 2.4). Cells 1 to 3 provide hydraulic buffering such that the flow through cells 4 and 5 can be controlled to provide optimum treatment.

The division of the facility into storage and treatment components is conceptual. In practice, the settling of suspended material and other pollutant removal mechanisms will affect the water quality wherever conditions are suitable. For example, much of the larger and heavier suspended particles are expected to settle out of the stormwater in the forebay and in the first storage cell.

The City of Toronto Dunkers facility does not rely on lake water flowing back into cell 3 via the outlet structure to replace the pumped-out volume. In fact, the swing gate outlet structure in cell 3 inhibits the flow of lake water into the facility, and protects the facility from turbulence caused by lake waves or storm surges. Lake water is pumped continuously into cell 3 and another pump continuously transfers water from cell 1 to cell 4. Thus, under dry-weather conditions, water is circulated continuously through the five cells. This circulation inhibits anaerobic conditions and helps maintain the health of the wetland. The two pumps operate at a constant rate of 4 m^3/min. At that rate, the time required for an element of water entering cell 3 to exit cell 5 would be approximately 7 days under plug-flow conditions.

A second 4 m^3/min pump was installed to transfer water from cell 1 to cell 4 during and after wet-weather events. The second pump is triggered if the peak inflow rate exceeds 4 m^3/s. The normal hydraulic load on cells 4 and 5 is thus doubled, and the chance of discharging untreated stormwater/CSO from cell 3 is reduced. Once triggered, the second pump remains on for 60 hours. The total volume of water pumped out of cell 1 at 8 m^3/min over this period is approximately equal to the total storage volume of cells 1 to 3 (28,500 m^3).

Table 2.1 lists some design features of the facility. The total storage volume of the five cells is 39,200 m^3, representing a volume per catchment hectare of 229 m^3/ha (cells 1-3 = 167 m^3/ha), including the 11.9 hectare CSO area. Rainfall accumulation depths were calculated using a design runoff coefficient for medium sized storms of 0.39 (Aquafor Beech, 1994). Based on this coefficient, cells 1 to 3 would capture flow from a one-year rain event, estimated at approximately 42 mm.

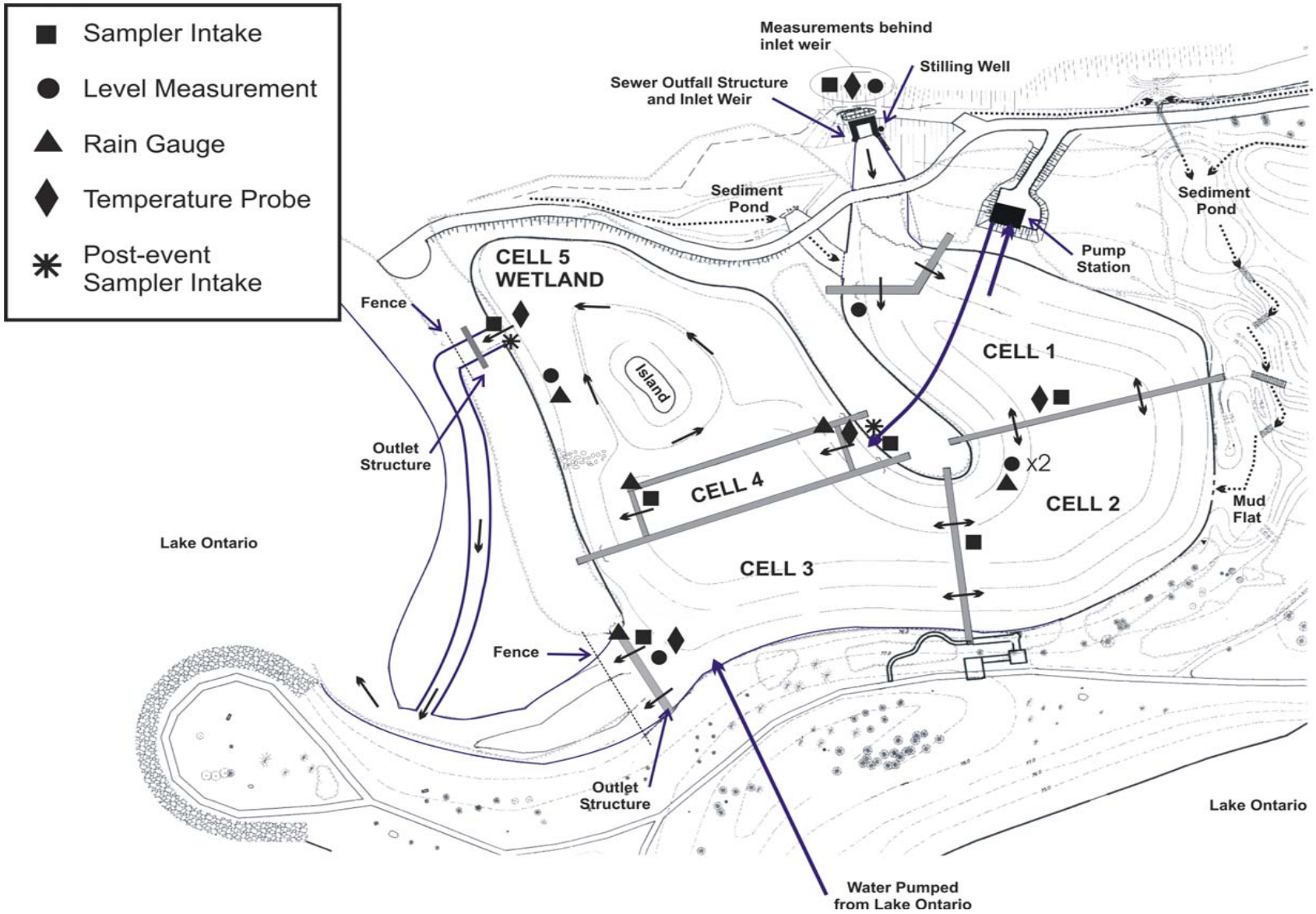


Figure 2.3: The City of Toronto Dunkers flow balancing system, indicating the location of re-circulation pumps and monitoring stations.

Figure 2.4: Outlet structures at cell 3 (top) and cell 5 (bottom).

Table 2.1: Storage volumes, average cell depths, pump-out times and equivalent rainfall depths for the Dunkers flow balancing system

Cell #	Storage volume (m^3)	Cell area (m^2)	Maximum cell depth (m)[1]	Pump-out time (hrs)[2]	"Retention time" (hrs)[3]	Rainfall depth (mm)[4]
1	7,900	4,720	2.6	32.9	16.5	11.6
2	9,400	5,440	2.6	39.2	52.5	13.8
3	11,200	5,510	3.2	46.7	95.5	16.5
4	2,900	1,220	3.2	12.1	12.1	4.3
5	7,800	7,060	2.0	32.5	32.5	11.5
Total	**39,200**	**23,950**	**----**	**----**	**104.0** [5]	**57.8**

Notes: 1. Determined from bathymetric survey. 2. Calculated as the cell storage volume divided by the pump rate, assuming only one pump is running at 4 m^3/min. 3. Theoretical value based on plug-flow conditions and an event volume equal to the storage volume. 4. Equivalent to the cell storage volumes, but expressed in millimetres based on a design runoff coefficient of 0.39 for mid-sized storms. 5. Overall residence time = volume-weighted average of residence times in cells 1 to 3 plus residence times in cells 4 & 5.

The theoretical retention times shown in Table 2.1 were determined for an event volume that exactly filled the three storage cells. The theoretical values were based on plug-flow conditions and were calculated only for the pump-out operation, ignoring the fill time. In reality, the hydraulic behaviour of the system would be very complex and would include short-circuiting and dead space.

For events that discharge runoff through the cell 3 outlet structure, estimation of both the flow-through and pump-out residence times would be necessary. The former component could be estimated based on plug-flow conditions through cells 1 to 3.

In addition to providing treatment of stormwater runoff, the facility was also designed to restore the *productive capacity* of terrestrial and aquatic environments for fish and wildlife, an activity in keeping with the Remedial Action Plan (RAP) objective of offsetting past wetland losses in the central waterfront area wherever shelter areas exist. The cell 5 wetland was the primary means of fulfilling this goal. The extent to which the facility provides improved fish habitat in the surrounding area as compared with pre-construction degraded conditions will serve as a measure of the effectiveness of the various habitat enhancement and creation efforts.

3.0 MONITORING APPROACH

This section describes the wet and dry weather monitoring program conducted in 2000, 2001 and 2002. Section 4 summarizes monitoring results for the study period.

3.1 Rainfall

Rainfall data were collected during the summer/fall and winter/spring periods using a continuous tipping bucket rain gauge, maintained by the City of Toronto, and located at the St. Augustine Seminary, south-west of Kingston and Brimley Roads (Figure 2.1). Rainfall data were also collected during the summer/fall period using similar instruments at the Dunkers facility.

3.2 Runoff

Flows are delivered to Dunker's through 1350 and 1500mm diameter sewers that combine upstream of a drop shaft and subsequently discharge through an outlet pipe/inlet chamber at the base of the Scarborough bluffs. A compound weir (Figure 3.1) at this location was used by the City of Toronto, in conjunction with continuous water level measurements and a semi-calibrated rating curve[3], to determine flow into the system both before and after construction of the facility.

Flows were also monitored continuously at 5 minute intervals in the two main feed sewers at the top of the bluffs using flow loggers and area velocity probes. However, these measurements were determined to be less reliable and consistent than the weir measurements and were therefore not used to generate study results. Since flow measurements at the weir were typically greater than those measured in the sewers, potential errors in flow measurement are likely to be conservative (*i.e*. flows are more likely to have been overestimated than underestimated). From a receiving water protection perspective, overestimation of flow (and sediment loads) is preferable to underestimation as it leads to more frequent inspections of sediment accumulation in the facility and shorter cleanout intervals. Removal efficiency estimates are not significantly affected by flow measurement errors because influent and effluent stormflow volumes are assumed to be equal (see below).[4]

During the early part of the summer of 2000 and 2001, and during most of 2002, observations of the facility before and after most storms indicated that the cell 5 outlet channel was blocked by beach deposits washed into the channel when lake water levels were high. During that time no flow was observed to occur through

[3] Flow characteristics of the weir openings were established by hydraulic testing at the Canada Centre for Inland Waters and the University of Waterloo. The resulting rating curve used to convert head to flow was calibrated on site by dye dilution tests for low flows but not high flows.

[4] A minor removal efficiency error can result if flow measurement errors are not of the same magnitude and direction for all events monitored - for example, if event runoff volumes for some storms were overestimated and others were underestimated. Runoff coefficients, however, were relatively consistent for the 30 events analyzed for removal, suggesting that this type of error was probably not significant (see section 4.2).

the cell 5 outlet. The alternative outlet for cell 5 would be under, or through possible holes or tears in the curtains separating cell 5 from cells 3 and 4. For the purpose of data analysis, the flow out of cell 5 was assumed to be zero when the outlet channel was blocked.

Ideally, both the influent and effluent flows should be measured in a monitoring study of this type. However, the design of the cell 3 and cell 5 outlets is not conducive to flow measurement. Therefore, it was assumed that the quantity of flow entering the facility was the same as the quantity of flow exiting the facility (*i.e.* a perfect flow balance is assumed during rain events). This was thought to be a reasonable assumption as measured baseflow influent and effluent flow rates were similar when the lake pump was shut off.

Outflow was proportioned between cell 3 and 5 based on approximations using a standard weir equation and continuous water level measurements at cell 5. These calculations revealed that, on average, roughly 25% of the total flow entering the facility during storm events exited cell 5 when the channel was clear of beach sediment. It was therefore assumed that 25% of the total flow volume entering the facility exited via cell 5, and 75% exited cell 3. The potential error in removal efficiency estimates associated with varying these relative percentages is very small because effluent concentrations at the two stations are similar (see section 3.7).

Figure 3.1: Sewer outfall structure

3.3 Storage

Water level changes were measured at 5-minute intervals with Telog pressure transducers (1 psi) at the forebay, cell 2, cell 3 and at cell 5 (Figure 2.3). Water level data were combined with cell areas to determine the volume of water temporarily stored within the facility during storm events. Cell areas (m^2) are based on the permanent pool elevation, 75 meters above sea level (m.a.s.l.), as estimated from a bathymetric survey of the facility in 1998.

3.4 Dye Tests

Two dye tests were conducted during the 2001 monitoring season. The first test was conducted during a wet-weather event on October 23rd to measure flow paths of stormwater through the facility. The second test, conducted on November 21st, traced the flow of the lake water being pumped into cell 3 during dry weather.

Table 3.1: Fluorometer calibration

Dye Concentration (ppb)	Fluorometer Dial Reading	Visibility (subjective)	Scale Factor	Adjusted Fluorometer Reading*
4760	293.9	high	1.0	9286.6
4327	287.6	high	"	9086.9
3808	286.0	high	"	9037.0
3173	273.3	high	"	8637.5
2856	268.6	high	"	8487.8
2380	246.5	moderate	"	7788.8
1904	230.7	moderate	"	7289.5
1269	178.5	moderate	"	5641.9
952	148.5	moderate	"	4693.2
476	82.2	moderate	"	2596.3
428	70.0	moderate	3.16	700.0
381	66.0	moderate	"	660.0
333	58.0	moderate	"	580.0
286	50.0	moderate	"	500.0
238	42.0	moderate	"	420.0
190	35.0	moderate	"	350.0
143	26.7	moderate	10.0	84.4
95.2	18.6	low	"	58.9
85.7	18.0	low	"	56.9
71.2	16.1	low	"	50.9
66.6	14.5	low	"	45.9
57.1	12.3	low	"	38.9
47.6	11.1	low	"	34.9
38.1	9.0	faint	31.6	9.0
28.6	7.2	faint	"	7.2
19	5.0	none	"	5.0

* adjusted to use the dial reading at the greatest multiplication factor as baseline

3.4.1 Calibration

A series of dilutions were performed to prepare samples of the Rhodomine WT dye for analysis. The results are summarized in Table 3.1. These observations have been referenced to the lowest concentration range, at which the instrument applies a multiplier of 31.6 in order to obtain a reportable value on the read-out dial. Hence, all other observations are divided by the respective multiplier and multiplied by 31.6 to produce the adjusted reading. Visibility tests were conducted in order to relate field observations to approximate concentrations.

The complete fitted curve is illustrated in Figure 3.2. Because all samples but the first bottle collected at the inlet were highly diluted, a second calibration curve was produced for the low-concentration range (Figure 3.3). The regression equation associated with this low-concentration range was used to convert fluorometer readings to dye concentrations.

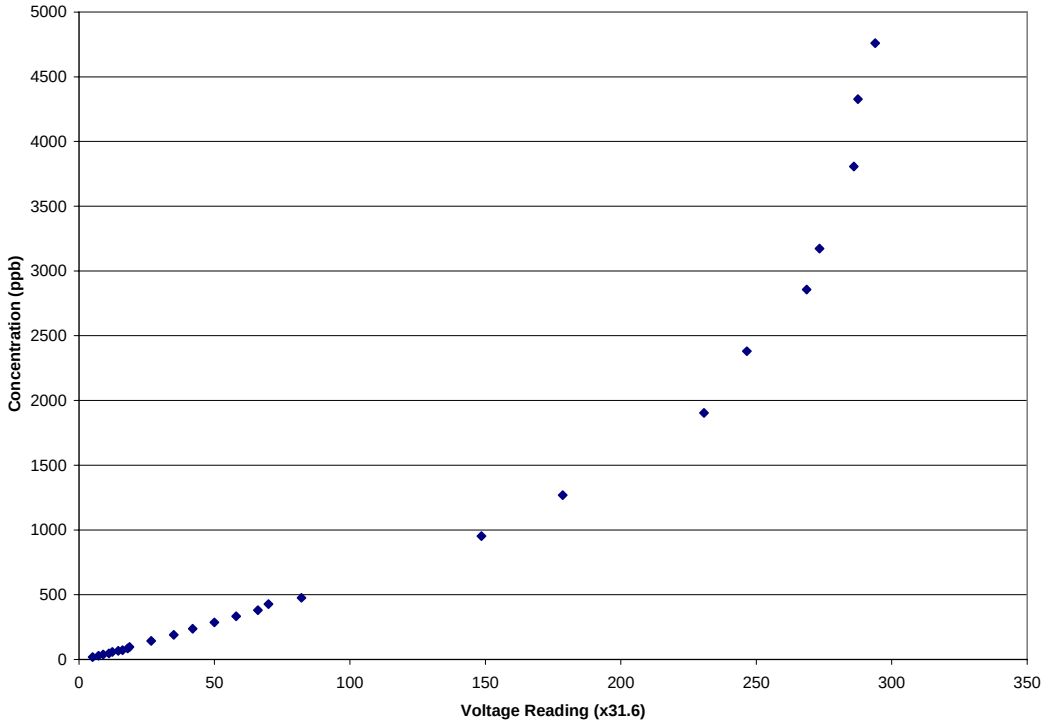


Figure 3.2: Complete calibration curve

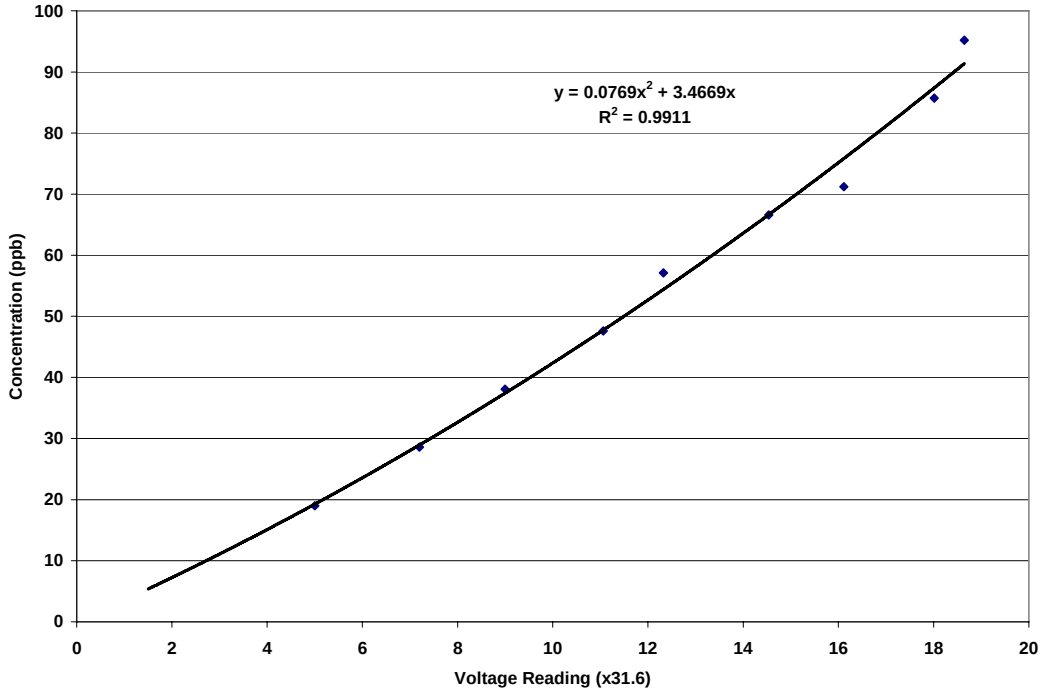


***Figure 3.3*:** Low-range calibration curve

3.4.2 Wet Weather Test

A volume of Rhodomine WT dye (1.5 litre) was poured into the Undercliff Drive storm sewer, upstream of the drop shaft.

The automatic samplers used in the regular sampling program (see figure 2.3 and section 3.5) were configured to take discrete samples at 20-minute intervals. The inlet sampler was activated by a water level change and other samplers were activated by rain gauges. The initial samples in the cells were collected after 8 hours. Samples were collected subsequently at the cell 4 inlet and the cell 3 and cell 5 outlets based on the selected sampling frequencies (1 hour for the cell 4 inlet and 2 hours for the other locations). Depth profiles of dye were determined at specific locations along the cell 1-2 pontoon and the cell 2-3 pontoon in order to detect areas where short circuiting may be occurring.

Immediately following collection, samples were transported to the Ministry of the Environment laboratory for analysis. The fluorometer used for these tests was a Turner model CIO-005. The instrument includes a flow-through detection cell; a peristaltic pump was used to withdraw water from the 24 1-litre sample bottles in each sampler base, pass the sample through the instrument and return it to the sample bottle. Between samples, the tubing and detection cell were flushed with demineralized water and purged with air.

3.4.3 Dry Weather Test

A volume of Rhodomine WT dye (2.0 litres) was poured into the well to which lake water is pumped before being discharged through the forcemain into cell 3.

Automatic discrete samplers were used for the dye test. They were positioned as in the normal monitoring program. The samplers were configured to take discrete samples at various intervals, with higher frequency sampling selected for the initial part of the test. The samplers were activated manually. The samples were collected after each 24-bottle set had been filled. As in the wet weather test, depth profiles of dye were measured at specific locations off the cell 2-3 and cell 1-2 pontoons.

Once collected, samples were transported to the Ministry of the Environment laboratory and analyzed according to procedures described in section 3.4.2.

3.5 Water Quality Sampling

Samples for wet-weather water quality analysis were collected using ISCO 3700 and 6700 automated wastewater samplers at the inlet, the outlets of cells 3 and 5, the inlet and outlet of cell 4, and during 2001 and 2002, at the cell 1 and cell 2 outlets (Figure 2.3). The inlet auto-sampler was initiated by an increase in water level behind the weir; all other auto-samplers were connected to rain gauges and enabled when rainfall intensity exceeded 2 mm/hr. Start-time delays were programmed into each unit based on the observed lag between rainfall initiation and flow initiation at each of the monitoring stations.

The sampling protocol was refined over the course of the study period as new information became available and additional research questions emerged. The following sub-sections provide a summary of the water quality sampling approaches employed during each of the three monitoring seasons.

3.5.1 June to December, 2000

In 2000, all samples were time-weighted composites, collected every 5 minutes at the inlet (over a period of 120 minutes, or as long as water depths behind the weir remained 50 mm above baseflow levels), and every 10 minutes (over a maximum period of 4 hours) at cell 3, cell 5, cell 4 inlet and cell 4 outlet.

The intent of the sampling program was to attain average pollutant concentrations over a substantial portion of the event duration using unattended, automated samplers. However, during large events, influent flows may have exceeded the 120-minute sampling period and effluent flows from cell 3 and cell 5 may have exceeded the 4-hour sampling period. Also, since the influent composite samples were not flow-proportioned, substantial variation in the hydrographs and pollutographs may have resulted in errors in the estimation of average influent concentrations and pollutant mass. Potential errors in influent concentrations averaged over several events using this approach were estimated to be within ±10% (see analysis in Appendix B).

Errors in the estimation of effluent concentrations using a time paced method are less than ±2% because: (i) hydrographs are not flashy; (ii) hydrographs and pollutographs do not peak simultaneously, and (iii) discrete sampling results from 2001 and 2002 monitoring indicate that concentrations are relatively uniform over the duration of most flow events (see Appendix B). At the cell 4 inlet, samples are collected from within the inlet pipe where flows are constant, either at 4 or 8 m^3/min, depending on whether the second pump has been activated. A flow weighting error occurs at this station only when the second pump has been activated after the sampler has been triggered.

3.5.2 May to December 2001

Based on data analysis from the first year of monitoring, several changes to the sampling protocol were implemented at the start of the 2001 monitoring season. These changes included:

- increasing maximum sampling durations to 8 hours at all monitoring stations (20 minute sampling intervals);
- adding samplers at the downstream ends (or outlets) of cells 1 and 2, and 'post-event' samplers at the cell 4 inlet and cell 5 outlet; and
- flow proportioning samples for TSS based on discrete turbidity measurements and TSS-turbidity correlations.

The increase in the maximum sampling period to 8 hours more closely approximates the average duration of inflow and outflow observed in 2000. Unfortunately, time integrated composite samples collected at the inlet over an 8 hour period provide a significant underestimate of the average influent concentration because of substantial variations in pollutant concentrations and hydraulic loading, especially during the 'first flush'. Thus inlet samples were analyzed discretely for turbidity, converted to TSS using an empirical relationship between turbidity and TSS generated from samples analyzed at each of the stations over the study period (see Figure 3.4), and then later proportioned according to flow to determine the EMC for each event. The same method was used at cells 1 and 2, but because flow was not measured at these locations, discrete turbidity samples were proportioned based on cell water level measurements.[5] At the outlets to cells 3, 4 and 5, time integrated and flow proportioned composite sample results did not differ significantly, hence the 8 hour composite was taken to represent the event mean concentration for all water quality variables analyzed.

The addition of auto-samplers at cell 1 and 2 was intended to help identify where sediment and associated pollutants were settling out and how these deposition locations varied during events of different sizes and durations. Samples collected at these stations were analyzed primarily for turbidity and suspended solids.

[5] Proportioning (or weighting) discrete sample concentrations based on water levels is not as accurate a representation of the EMC as proportioning discrete samples according to flow, but considerably more accurate than not proportioning at all. When pollutographs and hydrographs peak at, or close to the same time, water level proportioning typically results in an underestimate of the true EMC. This general tendency towards underestimation should be borne in mind when interpreting cell 1 and cell 2 water quality results.

The intent of the 'post event' sampling was to characterize the change in water quality after a runoff event as water stored in cells 1 to 3 was being pumped into cells 4 and 5, and out to the lake. The additional auto-samplers were initiated with a time delay of 8 hours to correspond with the end of event sampling. Samplers were programmed to collect samples every hour at the inlet to cell 4 for a period of 24 hours, and every two hours at the cell 5 outlet for a period of 48 hours. Selection of sampling intervals was based on the expectation that the majority of suspended solids would settle over a 48 hour sampling period.

3.5.3 May to December 2002

In the 2002 season, the monitoring protocol was further improved to include discrete TSS analysis of all samples (instead of turbidity) and a second inlet sampler. The second sampler was programmed to collect samples every 10 minutes (4 hour duration) so that the 'first flush' into the facility could be better characterized. The sampling interval of the first sampler was maintained at 20 minutes (8 hour duration) both as a back-up to the second sampler in case of malfunction and to ensure that the entire event hydrograph was sampled.

The sampling protocol at the other monitoring stations was the same as during 2001, except that all samples for events larger than 5 mm were analyzed discretely for TSS.

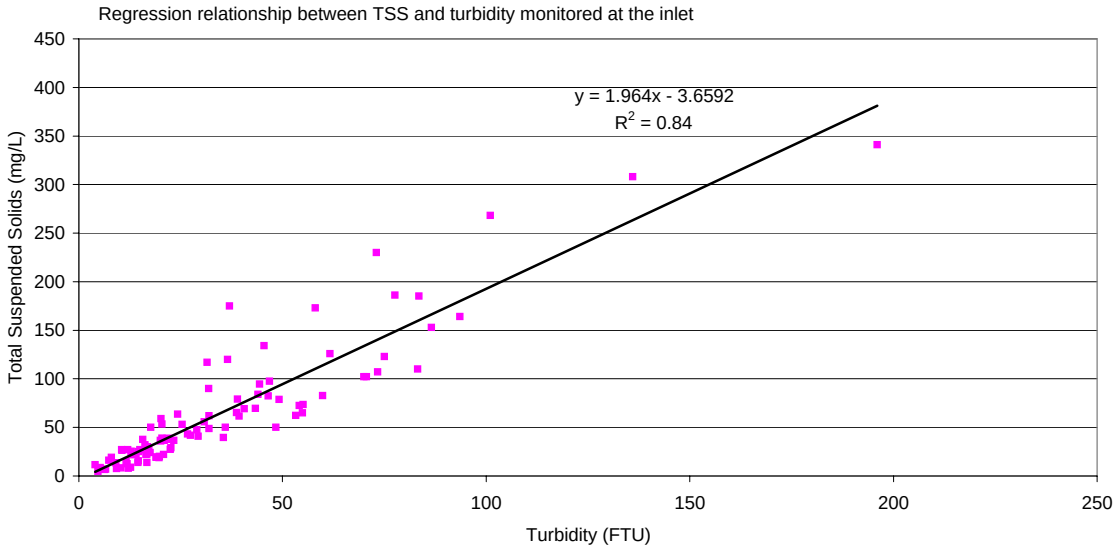
Samples collected over the entire study period were preserved and submitted to the Ontario Ministry of Environment laboratory at 125 Resources Road in Etobicoke. Analysis was conducted following principles outlined in standard methods (Eaton et al., 1995) for metals, nutrients (P and N), bacteria, polynuclear aromatic hydrocarbons (PAHs), herbicides/pesticides and general chemistry (e.g. pH, alkalinity, conductivity). A portion of the discrete TSS samples analyzed in 2002 were conducted by the City of Toronto's Dee Avenue laboratory.

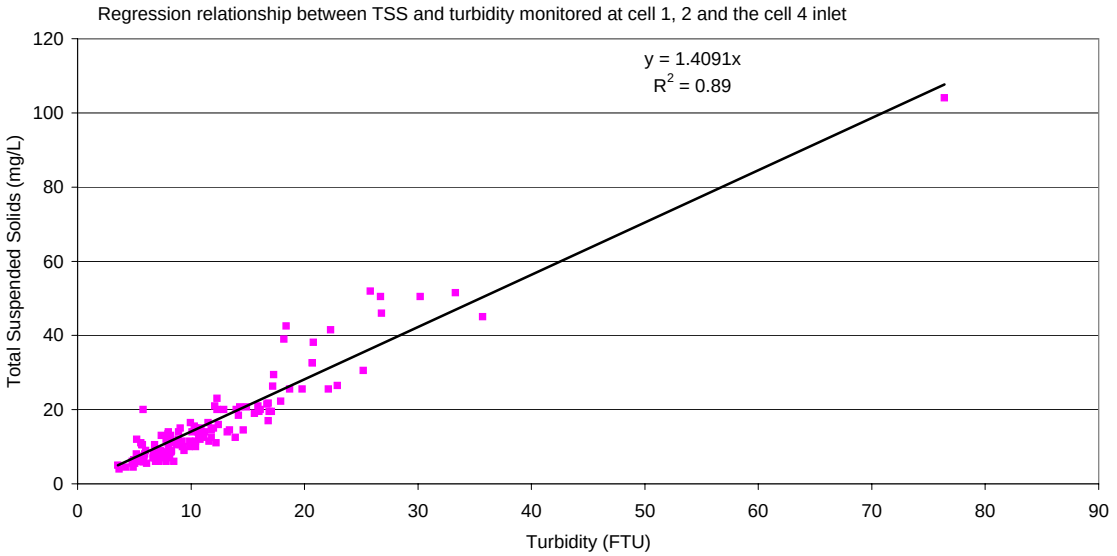
3.5.4 Dry weather sampling

Grab samples were collected at the inlet, cell 3 outlet, cell 5 outlet and the lake (*i.e.* pumped lake water entering cell 3) during dry weather periods throughout the summer and fall of 2000 and the winter of 2001.

3.5.5 Temperature monitoring

Temperature was monitored continuously every 30 minutes at the inlet and at the cell 3 and cell 5 outlets with Ryan Temperature Monitors (RTM). In 2002, temperature was measured with the same monitors at 10 minute intervals near the outlet to cell 1 at 0.5, 1.5 and 2.5 m below the dry weather water surface. The depth integrated measurements indicated the degree of thermal stratification present in the pond during the summer, and helped to better understand flow dynamics during storm events.





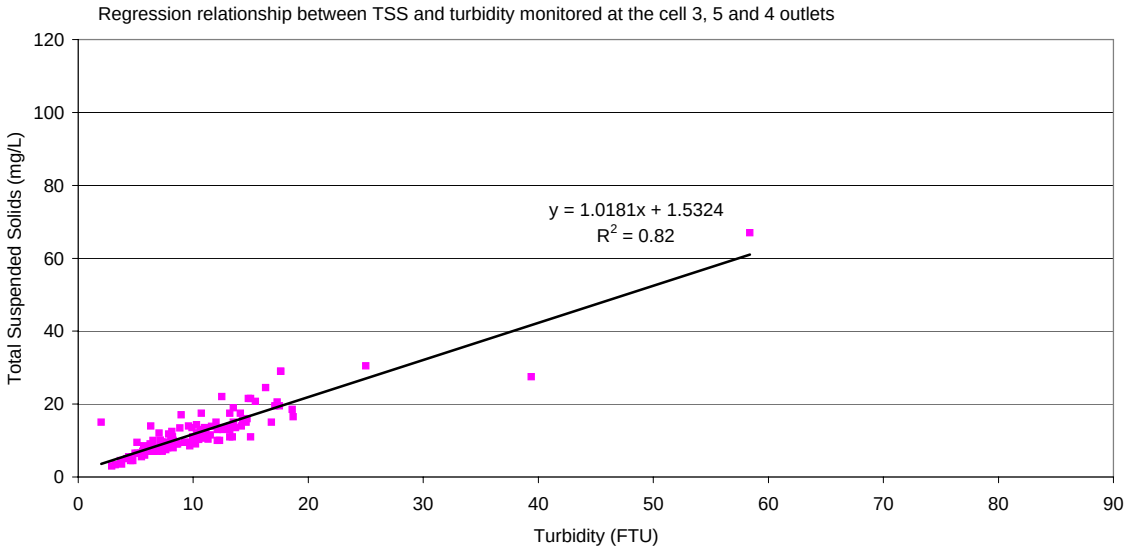


Figure 3.4 **:** Regression relationships used to convert turbidity measurements to TSS concentratio

3.6 Sediment Sampling

Bottom sediment samples were collected on November 16th, 2001 in cell 1, cell 3, cell 4, cell 5, and in Lake Ontario, both downstream of the outlet channels and at a control site on the south side of the embayment. All sites were sampled in triplicate using an Ekman Dredge. Sediment was placed in a pyrex pan to form a composite mixture and then placed into sample jars. A Teflon coated scoop was used for organic compounds and a stainless steel scoop for metals. Samples were analyzed by the MOE laboratory at 125 Resources Road for general chemistry, metals, nutrients, PAHs, PCBs and organochlorine pesticides. The location of sampling stations is presented in section 4.6.

3.7 Statistical Methods

Stormwater concentrations were summarized using parametric, non-parametric and log transformed statistics (mean, geometric mean, median, standard deviations, 95% confidence intervals). Data below the detection limit were assigned values equal to half the detection limit. Since there was an apparent relationship between individual event flow volumes and their respective concentrations at the various monitoring stations, average event mean concentrations were calculated as flow-weighted means (FWM), as follows:

$$FWM = \frac{\sum_{j=1}^{n} V_j \text{ x } EMC_j}{\sum_{j=1}^{n} V_j}$$

where: subscript *j* refers to an individual event, for a total of *n* events
V = event flow volume
EMC = event mean concentration

Treatment efficiency was determined on the basis of pollutant mass removal. The load-based efficiency (LE) for individual events is calculated as:

$$LE = \frac{V_{in} \times EMC_{in} - \left(V_{3\ out} \times EMC_{3\ out} + V_{5\ out} \times EMC_{5\ out}\right)}{V_{in} \times EMC_{in}} \times 100\%$$

where: subscripts 3 and 5 represent the respective cell numbers

Similarly, the long-term (or seasonal) load-based efficiency (SLE) is:

$$SLE = \frac{\sum_{i=1}^{n}\left[V_{in_i} \times EMC_{in_i} - \left(V_{3\ out_i} \times EMC_{3\ out_i} + V_{5\ out_i} \times EMC_{5\ out_i}\right)\right]}{\sum_{i=1}^{n}\left[V_{in_i} \times EMC_{in_i}\right]} \times 100\%$$

where: subscript *i* refers to an individual event, for a total of *n* events

As noted above, outflow was assumed to be equal to inflow during rain events and the proportion of outflow exiting cell 3 and 5 was estimated, based on cell 5 flow measurements, to be constant at 75 and 25% of the total inflow, respectively. Since concentrations were not significantly different at the two outlets, modifying the proportion of flow exiting cell 3 and 5 resulted in relatively small changes in overall removal efficiencies. For instance, varying the proportion of flow exiting cell 5 by ±20% (*i.e.* from an assumed 25% downwards to 10% and upwards to 40%, and a corresponding change in cell 3 proportions) resulted in a difference in the overall (sum-of-loads) TSS removal efficiency for the same events of only ±1.7%. If events during which the cell 5 channel was blocked (*i.e.* when all flow exited cell 3) are included in this calculation, the error range falls from ±1.7 to ±0.6%. On this basis, a general proportioning assumption based on cell 5 flow estimates was considered to be reasonable, and efforts to establish a more precise stage-discharge curve at cell 5 were abandoned.

4.0 STUDY FINDINGS

4.1 Summary of Events Monitored and System Operation

Table 4.1 summarizes the sample collection history at each monitoring station and documents changes to system function based on the operation of recirculation pumps and flow through the cell 5 outlet. Samples were collected during 64 wet-weather and 27 dry-weather events from March, 2000 to November, 2002. Among the wet-weather events monitored, not all stations were sampled, often because rainfall intensity did not exceed levels required to trigger all of the autosamplers, but also due to equipment malfunction or vandalism. Cell 1 and cell 2 stations were not monitored in 2000.

The continuous recirculation pumps (cell 3 and cell 4 feeds) were shut off for repair at various intervals over the study period. The cell 3 pump was shut down for all events monitored in 2002. Pump records indicate that the second pump at cell 1 was triggered during 11 of the storms, all of which had recorded peak inflows close to or greater than 4 m^3/s. The cell 5 outlet channel was blocked by beach sediment for most of the early part of the 2000 monitoring season when lake levels were high, and over most of the 2002 season. During this period, flow through the cell 5 outlet was assumed to be zero or negligible.

When water levels in Lake Ontario are below the elevation of the two facility outlet structures, flow occurs in only one direction from the facility to the lake. As lake water levels rise above the elevation of the outlet structures, a direct two-way hydraulic connection exists between the lake and stored water in the facility. During these periods, flow continues to be discharged to the lake in response to storm runoff from the drainage catchment, but after the event, water may enter or exit the facility depending on the trend in lake levels. If, for example, lake water levels are rising over the course of a runoff event, the reduced hydraulic gradient towards the lake will help to retain the stormwater influent within the facility. Conversely, if lake water levels are declining, the increased hydraulic gradient will serve to draw new runoff water from the facility out to the lake. The lake water levels relative to the outlet structure elevations were monitored during field visits to help characterize the potential influence of lake levels on system performance (Table 4.1). Facility water level data provide in Appendix C show the trend of lake water levels during specific events.

4.2 Water Quantity

4.2.1 Rainfall and Runoff

A summary of rainfall and runoff statistics for each of the monitoring seasons is presented in Tables 4.2 to 4.4. Average rainfall over the study period ranged from 8.2 mm in 2002 to 12.3 mm in 2000. Many of the events with less than 5 mm of rain were not sampled. The 2002 monitoring season was a particularly dry year.

Table 4.1a **: Summary of sample collection, pump logs, status of the cell 5 outlet and facility-lake water connections from May 11 to November 20, 2000.**

Sampling Date		Monitoring Locations								Cell 1 pumps*		Lake Ontario pump		Cell 5 outlet		Two-way Hydraulic Connection btwn Cell 3 and the Lake	
		Inlet	Cell 1	Cell 2	Cell 3 outlet	Cell 4 inlet	Cell 4 outlet	Cell 5 outlet	Lake	ON	OFF	ON	OFF	Clear	Blocked	Yes	No
2000																	
March 15	dw	C			C						X		X		X	X	
June 12	dw								G	X		X			X	X	
June 13					C					X		X			X	X	
June 15									G	X		X			X	X	
June 21		C								X		X			X	X	
June 24		C								X		X			X	X	
June 25					C					X		X			X	X	
June 26		C				C				X		X			X	X	
June 29		C								X		X			X	X	
June 29		C								X		X			X	X	
July 3		C			C					X		X			X	X	
July 14		CC			C	C				XX			X		X	X	
July 17		C			C	C	C			XX			X		X	X	
July 27	dw	G			G					X			X		X	X	
July 31		C			C	C	C	C		XX			X	X		X	
August 1	dw	G			G	G				X			X		X	X	
August 7		C								X		X			X	X	
August 8		C			C	C	C	C		XX		X			X	X	
August 11		C								X		X			X	X	
August 23		C			C		C	C	G		X	X		X		X	
September 2		C			C	C	C			X			X		X	X	
September 7	dw	G			G				G	X			X		X		X
September 10		C			C	C	C	C		XX		X		X		X	
September 11									G	X		X		X		X	
September 14		C			C	C	C	C	G	X		X		X		X	
September 20	dw	G			G			G	G	X		X		X		X	
September 22		C			C	C	C	C		X			X	X			X
October 3	dw	G			G			G	G		X		X	X			X
October 4		C			C	C	C			X			X	X			X
October 6		C								X			X	X			X
October 18	dw	G			G			G	G	X			X	X			X
October 27		C			C	C	C	C		X			X	X			X
November 7	dw	G			G			G	G	X			X	X			X
November 10		C			C					X			X	X			X

* two X's indicates second pump was triggered during rain event

Legend

C = Composite Sample dw = Dry weather sample

G = Grab sample

***Table 4.1b*: Summary of sample collection, pump logs, status of the cell 5 outlet and facility-lake connections from January 17, 2001 to October 25, 2002.**

Sampling Date		Monitoring Locations								Cell 1 pumps*		Lake Ontario pump		Cell 5 outlet		Two-way Hydraulic Connection btwn Cell 3 and the Lake	
		Inlet	Cell 1	Cell 2	Cell 3 outlet	Cell 4 inlet	Cell 4 outlet	Cell 5 outlet	Lake	ON	OFF	ON	OFF	Clear	Blocked	Yes	No
2001																	
January 17	dw	G			G			G			X		X	X		?	
February 5	dw	G			G			G			X		X	X		?	
February 15	dw	G			G			G			X		X	X		?	
February 27	dw	G			G			G			X		X	X		?	
March 8	dw	G			G			G			X		X	X		?	
March 16	dw	G			G			G			X		X	X		?	
April 4	dw	G			G			G			X		X	X		?	
April 10	dw	G			G			G			X		X	X		?	
May 9	dw	G			G			G			X		X	X		X	
June 3		C,D	C,D	C,D	C,D	C,D	C,D	C,D		X		X		X			X
June 11		C,D	C,D	C,D	C,D	C,D	C,D	C,D			X	X		X		X	
June 13	dw	G			G			G		X		X		X		X	
June 20		C,D	C,D	C,D	C,D	C,D	C,D	C,D		X		X		X		X	
June 28	dw	G			G	G		G	G	X		X		X			X
June 30*		C,D	C,D	C,D	C,D	C,D	C,D	C,D		X		X		X			X
July 17		C,D	C,D	C,D	C,D	C,D	C,D	C,D		X		X		X		X	
July 19	dw	G			G	G		G	G	X		X		X		X	
July 31	dw	G			G	G		G	G	X		X		X			X
August 16		C	C		C			C		X		X		X		X	
August 19		C,D	C,D		C,D	C,D	C,D	C,D		X		X		X			X
August 26		C,D	C,D	C,D	C,D	C,D	C,D	C,D		XX		X		X		X	
August 30	dw	G			G	G		G	G	X		X		X			X
September 18	dw	G			G	G		G	G	X			X	X			X
September 27	dw	G			G	G		G	G	X			X	X			X
September 3		C	C	C	C	C	C	C		X		X		X			X
September 19		C.D	C,D	C,D	C,D	C,D	C,D	C.D		X			X	X			X
September 21		C,D	C,D	C,D	C,D	C,D	C,D			XX			X	X			X
September 24		C								X			X	X		X	
September 25		C								X			X	X			X
October 2	dw	G			G	G		G	G	X		X		X			X
October 5			C	C	C			C		X		X		X			X
October 5		C	C	C	C	C	C	C		X		X		X			X
October 11		C,D		C,D	C,D	C,D	C,D	C,D		X		X		X			X
October 12		C	C	C	C	C	C	C		X		X		X			X
October 14		C,D		C,D	C,D	C,D	C,D	C,D		X		X		X			X
October 16		C,D			C,D			C		X		X		X			X
October 16		C	C	C	C	C	C	C		X		X		X			X
October 22	dw	G			G	G		G	G	X		X		X			X
October 23		C,D	C,D	C,D	C,D	C,D		C,D		X		X		X			X
November 2		C	C	C	C		C	C		X		X		X			X
November 8		C	C		C		C	C		X		X		X			X
November 19		C	C	C	C			C		X		X		X			X
November 25		C,D	C,D	C,D	C,D	C,D	C,D	C,D		XX		X		X			X
November29		C	C	C	C		C	C		X		X		X			X
December 6		C			C	C	C	C		X		X		X			X
December 12		C			C	C	C	C		X		X		X			X
2002																	
May 31		C,D	C,D	C,D	C,D	C,D				X			X		X	X	
June 21		C,D	C,D	C,D	C,D	C,D				X			X		X	X	
July 9		C,D	C,D	C,D	C,D	C,D				X			X		X	X	
July 21		C,D	C,D	C,D	C,D	C,D				XX			X		X	X	
July 22		C,D	C,D	C,D	C,D	C,D				XX			X		X	X	
August 22		C,D	C,D	C,D	C,D	C,D	C,D			XX			X		X		X
September 20		C	C	C	C	C	C	C		X			X		X		X
September 27		C	C	C		C	C	C		X			X		X		X
October 19		C	C		C	C		C		X			X		X		X
October 25		C	C		C		C	C		X			X		X		X

* two X's indicates second pump was triggered during rain event; '?' indicates status unknown.

Legend

C = Composite Sample
G = Grab sample
D = Discrete Sample (TSS and/or turbidity)
dw = Dry weather sample

Table 4.2 **:** Hydrologic summary of events from June 13 to November 18, 2000

Date	Time	Rain				Flow Volume (m^3)						Runoff Coeff.[2]
		depth	max. 5 min int.	mean int.	duration	Inlet			Outlets[1]		CSO	
		(mm)	(mm/5 min)	(mm/hr)	(hrs)	Total	Baseflow	Runoff	cell 3	cell 5	vol.	
13-Jun-00	3:25	33.8	2.2	3.7	9.2	29247	444.6	28802	29247	0	1017	0.50
18-Jun-00	7:40	9.2	0.8	1.7	5.3	4244	562	3682	4244	0	0	0.25
21-Jun-00	2:15	7.4	1.2	0.9	8.5	3697	723	2974	3697	0	0	0.25
22-Jun-00	11:40	5.6	1.8	1.1	5.3	1640	294	1346	1640	0	0	0.15
24-Jun-00	17:55	1.0	0.4	3.3	0.3	349	97	252	349	0	0	0.16
24-Jun-00 b	21:05	30.6	3.0	3.1	9.8	20401	1509	18892	20401	0	219	0.36
26-Jun-00	21:10	3.6	0.4	1.8	2.0	1857	444	1413	1857	0	0	0.25
29-Jun-00	8:35	7.8	2.0	0.8	9.9	3095	659	2436	3095	0	27	0.18
3-Jul-00	2:05	3.2	0.2	0.2	12.9	1923	559	1364	1923	0	0	0.27
14-Jul-00	11:00	21.6	4.6	2.0	10.6	19342	629	18713	19342	0	659	0.51
15-Jul-00	20:40	5.5	2.0	7.3	0.8	4115	346	3769	4115	0	0	0.43
16-Jul-00	7:25	12.2	3.8	1.2	10.1	6550	542	6008	6550	0	362	0.29
17-Jul-00	19:20	31.2	4.2	23.5	1.3	29148	2283	26865	29148	0	980	0.50
30-Jul-00	22:40	30.2	7.2	8.8	3.4	18987	880	18107	14240	4747	1126	0.35
7-Aug-00	4:00	3.1	1.3	2.2	1.4	965	208	757	965	0	0	0.15
8-Aug-00	15:20	19.4	4.0	2.8	7.0	11993	659	11334	11993	0	413	0.34
11-Aug-00	3:10	7.2	2.4	9.6	0.8	2110	230	1881	2110	0	0	0.16
23-Aug-00	1:05	23.2	2.2	3.1	7.5	12166	475	11691	9125	3042	280	0.29
2-Sep-00	14:25	5.5	0.7	0.8	6.9	2551	394	2157	2551	0	0	0.25
10-Sep-00	18:15	18.0	5.4	6.5	2.8	10555	175	10380	7916	2639	685	0.34
11-Sep-00	0:25	11.0	3.0	1.7	6.6	7093	543	6550	5320	1773	0	0.37
14-Sep-00	12:45	22.0	2.0	2.9	7.5	10263	655	9608	7697	2566	0	0.27
22-Sep-00	22:40	18.6	1.0	1.1	17.0	10154	487	9667	7616	2539	45	0.30
23-Sep-00	18:10	5.8	5.4	23.2	0.3	3346	403	2943	2510	837	18	0.30
4-Oct-00	4:50	6.6	0.8	1.2	5.4	2500	250	2250	2500	0	0	0.21
5-Oct-00	16:50	2.4	0.2	0.4	5.5	1819	486	1333	1819	0	0	0.35
6-Oct-00	17:30	3.2	0.2	0.2	17.3	168	84	84	168	0	0	0.02
24-Oct-00	12:05	4.2	0.6	0.4	10.6	1346	112	1234	1346	0	0	0.18
27-Oct-00	8:55	2.6	1.2	1.0	2.6	1034	104	930	1034	0	0	0.22
10-Nov-00	3:20	13.8	0.6	1.6	8.8	8194	410	7784	6146	2049	0	0.35
Averages												
all storms		12.3	2.2	3.9	6.6	7695	522	7174	7022	673	194	0.29
storms with rain > 5mm		15.2	2.6	4.7	6.8	9709	614	9096	8832	878	254	0.32

1. When the cell 5 outlet channel was clear of sediment, outflow through cell 3 and 5 was assumed to be 75 and 25% of total inflow, respectively.
2. Catchment area with and without combined sewer overflow is 171 and 159.1 ha, respectively.

Table 4.3 **:** Hydrologic summary of events from January 30 to November 30, 2001

Date	Time	Rain				Flow Volume (m^3)						Runoff Coef.[2]
		depth	max. 5 min int.	mean int.	duration	Inlet			Outlets[1]		CSO	
		(mm)	(mm/5 min)	(mm/hr)	(hrs)	Total	Baseflow	Runoff	cell 3	cell 5	vol.	
30-Jan-01	4:40	5.6	0.2	0.8	7.3	3460	7	3453	2595	865	15	0.36
8-Feb-01	23:10	24.6	1.2	1.3	18.7	31884	1322	30562	23913	7971	1360	0.73
25-Feb-01	0:50	18.4	1.6	4.3	4.3	17524	1078	16446	13143	4381	0	0.56
13-Mar-01	5:25	8.4	0.8	1.4	6.0	6242	651	5591	4682	1561	50	0.39
7-Apr-01	8:10	1.6	0.2	0.8	1.9	739	124	615	554	185	0	0.24
7-Apr-01 b	21:20	8.2	3.2	4.3	1.9	5146	452	4695	3860	1287	92	0.33
9-Apr-01	11:15	6.6	1.0	1.7	3.8	7671	460	7211	5753	1918	0	0.69
12-Apr-01	3:25	2.6	0.8	0.4	5.8	1728	333	1395	1296	432	0	0.34
21-May-01	12:25	7.4	1.0	3.2	2.3	3399	189	3210	2549	850	0	0.27
21-May-01	23:05	9.4	0.8	3.1	3.0	5959	443	5516	4469	1490	0	0.37
22-May-01 b	16:35	21.4	1.4	3.2	6.6	14981	1006	13975	11236	3745	351	0.38
27-May-01	12:50	16.4	2.0	5.7	2.9	8015	370	7645	6011	2004	0	0.29
28-May-01	4:25	0.8	2.2	0.1	7.5	1169	749	420	877	292	0	0.33
1-Jun-01	10:35	6.4	0.8	0.7	9.8	3326	519	2807	2495	832	0	0.28
3-Jun-01	0:45	5.2	1.4	4.3	1.2	2378	206	2172	1784	595	0	0.26
11-Jun-01	0:45	18.2	1.7	2.0	8.9	8555	590	7965	6416	2139	0	0.28
20-Jun-01	2:05	4.1	1.3	0.8	5.3	1344	239	1105	1008	336	0	0.17
22-Jun-01	1:25	2.6	0.4	0.4	6.2	1156	389	767	867	289	0	0.19
30-Jun-01	20:10	5.6	2.2	7.0	0.8	2041	242	1799	1531	510	0	0.20
1-Jul-01	9:00	10.8	5.8	36.0	0.3	5072	254	4818	3804	1268	345	0.26
17-Jul-01	0:15	12.4	1.6	1.7	7.5	4646	514	4132	3485	1162	0	0.21
16-Aug-01	17:50	5.2	0.6	0.5	11.4	2682	435	2247	2012	671	0	0.27
19-Aug-01	7:05	9.2	0.6	1.5	6.1	6035	663	5372	4526	1509	0	0.37
26-Aug-01	13:40	11.2	5.0	2.9	3.8	5202	419	4784	3902	1301	248	0.25
3-Sep-01	21:55	4.0	1.2	0.6	6.8	2379	467	1912	1784	595	0	0.28
19-Sep-01	14:30	24.4	1.8	2.1	11.5	15520	1010	14510	11640	3880	0	0.37
21-Sep-01	13:40	22.4	2.6	2.6	8.6	14030	724	13306	10523	3508	279	0.35
25-Sep-01	6:15	2.2	0.4	0.9	2.4	1887	691	1196	1415	472	0	0.34
26-Sep-01	1:20	2.0	0.2	0.9	2.3	1216	399	817	912	304	0	0.26
26-Sep-01 b	19:10	2.0	0.2	0.5	4.1	768	297	471	576	192	0	0.15
4-Oct-01	22:15	7.0	0.6	1.0	7.3	2355	286	2069	1766	589	0	0.19
5-Oct-01	7:10	38.8	0.6	5.3	7.3	21407	1600	19807	16055	5352	0	0.32
11-Oct-01	17:15	19.2	0.6	1.2	15.9	9878	675	9203	7409	2470	0	0.30
14-Oct-01	9:50	7.6	1.2	0.8	10.0	4722	859	3863	3542	1181	0	0.32
16-Oct-01	5:30	11.4	0.4	0.9	12.2	7608	984	6624	5706	1902	0	0.37
23-Oct-01	11:40	7.1	1.8	5.1	1.4	3255	338	2917	2441	814	0	0.26
2-Nov-01	7:25	10.0	0.6	2.0	5.0	6145	437	5708	4609	1536	0	0.36
25-Nov-01	2:40	25.2	4.5	4.5	5.6	15000	301	14699	11250	3750	452	0.34
29-Nov-01	1:35	11.4	0.4	0.8	14.4	6830	277	6553	5123	1708	0	0.36
29-Nov-01	20:50	16.0	0.4	1.2	13.3	10409	1943	8466	7807	2602	0	0.33
Averages												
all storms		10.8	1.4	3.0	6.5	6844	573	6271	5133	1711	80	0.32
storms with rain > 5mm		13.0	1.6	3.6	7.1	8242	616	7626	6182	2061	100	0.34

1. Outflow through cell 3 and 5 was assumed to be 75 and 25% of total inflow, respectively.

2. Catchment area with and without combined sewer overflow is 171 and 159 ha, respectively.

Table 4.4: Hydrologic summary of events from February 20 to November 5, 2002

Date	Time	Rain				Flow Volume (m^3)						Runoff Coeff.[2]
		depth	max. 5 min int.	mean int.	duration	Inlet			Outlets[1]		CSO	
		(mm)	(mm/5 min)	(mm/hr)	(hrs)	Total	Baseflow	Runoff	Cell 3	Cell 5	vol.	
20-Feb-02	6:10	13.2	0.6	1.1	11.8	21242	2980	18262	21242	0	10	0.81
3-Mar-02	20:05	14.0	0.8	2.1	6.6	18279	885	17394	18279	0	52	0.73
12-Apr-02	13:05	22.0	2.8	2.2	10.2	11954	894	11060	11954	0	302	0.29
13-Apr-02	12:20	6.0	0.6	1.5	3.9	6578	2683	3895	6578	0	0	0.41
28-Apr-02	3:00	11.4	0.4	0.7	17.0	12176	2075	10101	12176	0	4	0.52
2-May-02	3:45	8.2	1.0	2.6	3.1	8364	831	7533	8364	0	178	0.54
2-May-02 b	21:30	3.6	2.4	1.4	2.5	1767	638	1129	1767	0	0	0.20
13-May-02	15:10	8.0	0.4	1.1	7.0	8646	2365	6281	8646	0	0	0.49
16-May-02	8:10	2.4	0.4	1.4	1.8	1303	428	875	1303	0	0	0.23
16-May-02 b	17:25	16.8	0.8	2.9	5.8	12277	2592	9685	12277	0	40	0.34
31-May-02	5:00	6.8	1.5	3.8	1.8	3577	421	3156	3577	0	0	0.29
11-Jun-02	21:45	3.0	0.6	2.3	1.3	1040	184	856	1040	0	0	0.18
12-Jun-02	3:35	3.0	0.8	1.2	2.6	1480	279	1201	1480	0	0	0.25
14-Jun-02	10:25	4.4	1.2	1.2	3.8	2685	360	2325	2685	0	0	0.33
15-Jun-02	9:50	1.4	0.4	2.8	0.5	505	170	335	505	0	0	0.15
15-Jun-02 b	17:20	6.2	0.8	1.3	4.6	2643	343	2300	2643	0	0	0.23
16-Jun-02	5:05	2.4	0.4	0.8	3.1	1429	277	1152	1429	0	0	0.30
16-Jun-02 b	12:15	3.6	1.6	9.0	0.4	1427	284	1143	1427	0	0	0.20
21-Jun-02	14:55	12.7	5.1	3.2	4.0	5704	494	5210	5704	0	0	0.26
26-Jun-02	20:20	2.0	0.4	1.8	1.1	661	153	508	661	0	0	0.16
9-Jul-01	3:30	5.0	1.5	1.8	2.8	2157	375	1782	2157	0	0	0.22
18-Jul-02	16:25	6.2	1.0	5.6	1.1	3592	351	3241	3592	0	0	0.33
21-Jul-02	22:40	25.7	4.3	10.7	2.4	12338	466	11872	12338	0	364	0.27
22-Jul-02	14:45	23.3	5.7	6.1	3.8	12603	443	12160	12603	0	1771	0.31
23-Jul-02	1:15	3.4	1.0	0.8	4.3	2018	514	1504	2018	0	0	0.28
28-Jul-02	9:25	3.8	0.4	3.2	1.2	1883	297	1586	1883	0	0	0.26
29-Jul-02	21:00	2.0	0.4	2.9	0.7	1133	261	872	1133	0	0	0.27
22-Aug-02	9:50	7.5	3.5	4.7	1.6	3850	440	3410	3850	0	58	0.27
14-Sep-02	20:55	15.7	3.2	1.9	8.2	10525	645	9880	10525	0	0	0.40
15-Sep-02	18:35	2.0	0.2	1.1	1.8	1008	323	685	1008	0	0	0.22
20-Sep-02	6:20	3.0	0.8	2.7	1.1	1249	248	1002	937	312	0	0.21
21-Sep-02	3:45	1.2	0.2	0.5	2.3	553	234	319	415	138	0	0.17
27-Sep-02	7:45	36.8	1.2	3.8	9.6	23397	713	22684	17548	5849	115	0.36
2-Oct-02	2:00	2.2	0.8	0.6	3.4	1481	367	1114	1111	370	0	0.32
4-Oct-02	22:00	4.2	0.8	2.3	1.8	2263	297	1966	1697	566	21	0.27
16-Oct-02	12:55	3.4	0.2	0.5	6.5	1101	344	757	826	275	0	0.14
18-Oct-02	20:15	10.8	0.6	0.7	15.7	5013	573	4440	3760	1253	0	0.26
22-Oct-02	4:50	5.4	0.4	0.8	7.1	3203	722	2481	2402	801	0	0.29
25-Oct-02	20:30	8.8	0.4	1.4	6.5	4813	310	4503	3610	1203	0	0.32
5-Nov-02	21:00	4.8	0.2	0.7	6.8	2338	175	2163	1754	585	0	0.28
Averages												
all storms		8.2	1.2	2.4	4.5	5506	686	4821	5223	191	73	0.31
storms with rain > 5mm		13.3	1.8	2.9	6.6	9539	1061	8477	9083	455.3	145	0.39

1. Inflow and outflow volumes were assumed to be equal during storm events. The cell 5 outlet channel was blocked with beach sediment for the entire 2002 monitoring season.

2. Catchment area with and without combined sewer overflow is 171 and 159.1 ha, respectively.

Influent baseflow was continuous throughout the monitoring period with typical dry weather summer values between 5 and 10 L/s. Combined sewer overflows occurred during 32 of the 110 events monitored, but represented only 1.6% of total runoff volumes. Average runoff coefficients were relatively consistent over the three monitoring seasons ranging from 0.29 to 0.32. Runoff coefficients were particularly high during the winter when rain combined with snow melt can result in high runoff values. Significant departures in individual runoff coefficients from seasonal averages during non-winter periods (e.g. Oct 16, 2002; July 17, 2000) reflect a combination of errors in rainfall and flow measurements, differences in antecedent moisture conditions (especially in the spring) and the statistical tendency for larger events to generate proportionately more runoff than smaller events.

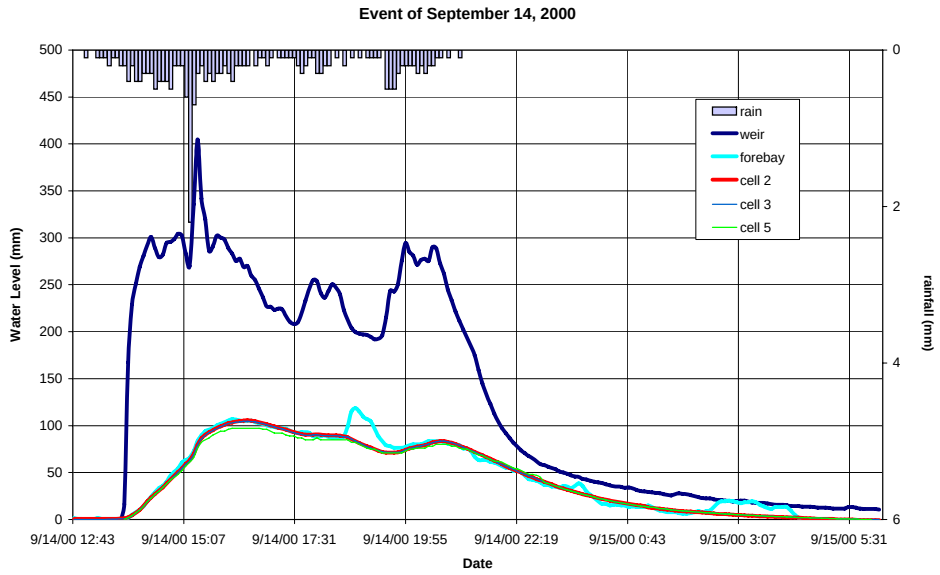
Event based water level changes at the inlet chamber and cells 1, 2, 3 and 5 are presented in Figure 4.1. The time delay between level increases at the inlet chamber and cell 3 averaged less than 10 minutes during rain events. As expected, level fluctuations in cells 2 and 3 were almost identical. Cell 1 changes were also similar, but, during high flow, the permeable curtain immediately upstream of the measurement point tended to produce erratic water level fluctuations (*i.e.* waves) when flow input exceeded the hydraulic capacity of the curtain to conduct water. The time required for water levels to return to baseflow levels was similar at cells 1, 2 and 3, averaging approximately 11 hours (Figure 4.1).

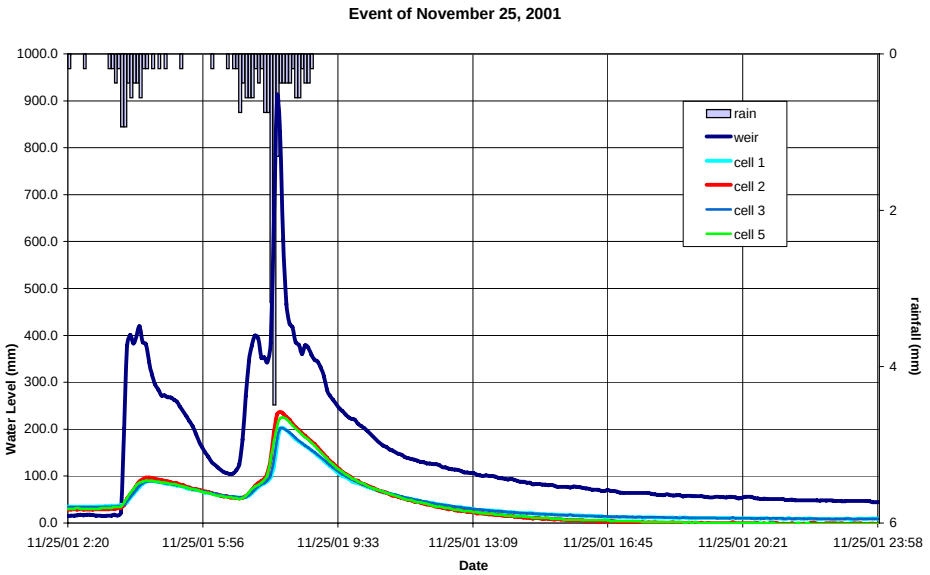
Throughout the study period, there was little difference in water level fluctuations between cell 4/5 and cells 1 to 3 during runoff events (Fig. 4.1).[1] If the pump station were the only source of flow into cell 4/5, a greater differential in water levels would have been expected. Flow around or under the curtain - and possibly flow through holes in the curtain created by beavers - were apparently allowing the runoff to enter cells 4 and 5 from cell 3. Raising the cell 3-4 curtain to eliminate obvious gaps near the banks in September 2000, and repair and re-anchoring of the curtain in late 2001 had little effect on creating even short-term water level differentials between cell 5 and cells 1 to 3 during storm events.[2]

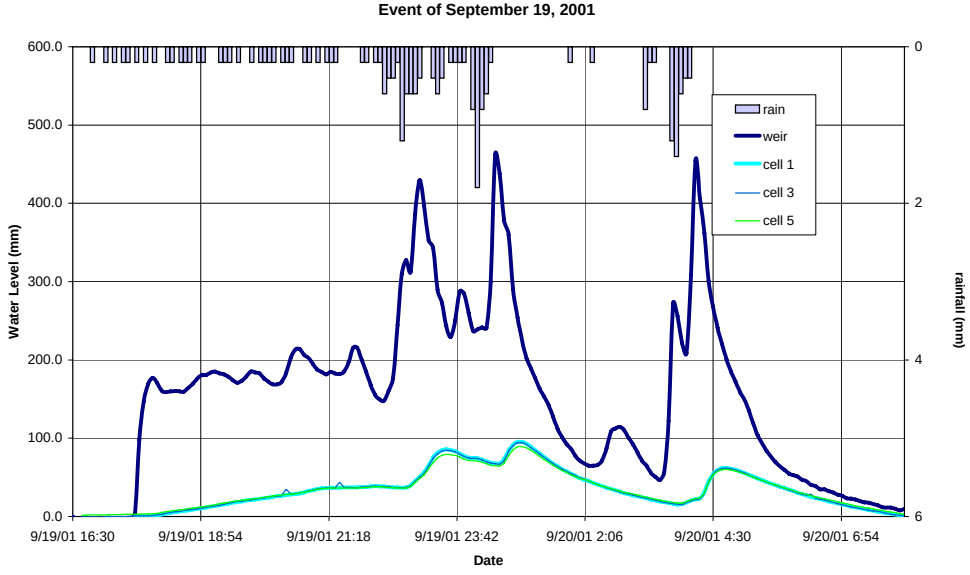
Figure 4.2 shows flow hydrographs at the inlet, cell 5 outlet and at the curtain separating cell 3 and 4 for events on August 23rd and September 14th, 2000. Flow volumes through the curtain represent the product of incremental storage volumes in cell 4 and 5 (area = 8280 m^2) and estimated flow from cell 5 to the lake. Short-term fluctuations in the curve resulting from small variations ($\pm$1 to 2 mm) in level measurements (perhaps due to wave action) were reduced by pooling each set of three data points (5 minutes each) into 15 minute moving averages. The graphs indicate that cell 5 provided significant peak flow attenuation. Note that the water elevations and flows are presented relative to the dry-weather baseline; baseflow is not shown.

[1] A previous interim report indicated minor differences in peak water levels between cell 3 and cell 5 in August and September 2000. These differences were later determined to have been caused by the location of the sensor in the narrow cell 5 channel where some throttling of flow occurs. In 2001 and 2002 the sensor was relocated to the open water portion of cell 5.

[2] Note that the solid curtain was not intended to be completely impervious to flow. However, there was an expectation that the solid curtain would prevent flow from entering cells 4 and 5 during large runoff events, creating an observable difference in surface water fluctuations on short time scales.







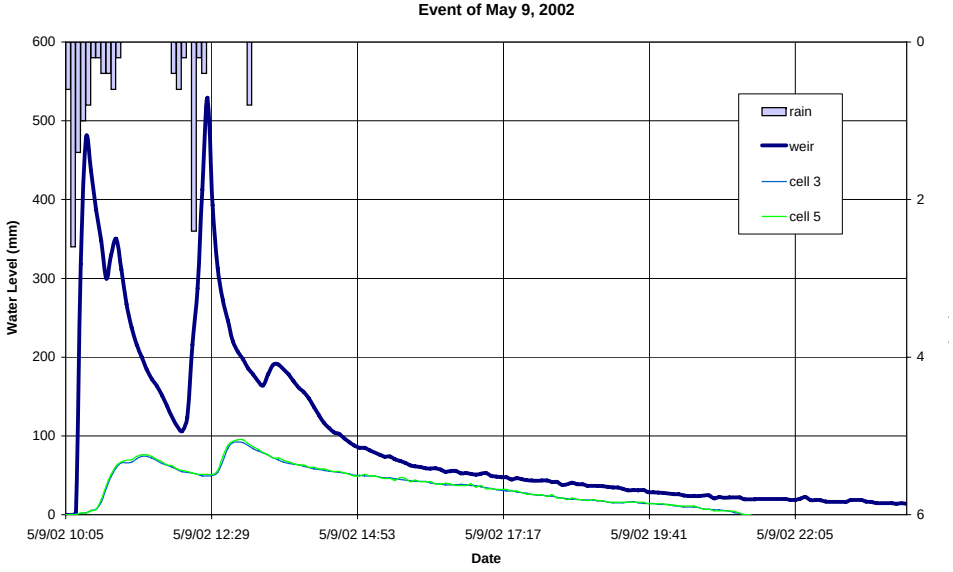


Figure 4.1 **: Water level hydrographs for selected events in 2000, 2001 and 2002. Note differences in horizontal and vertical scales.**

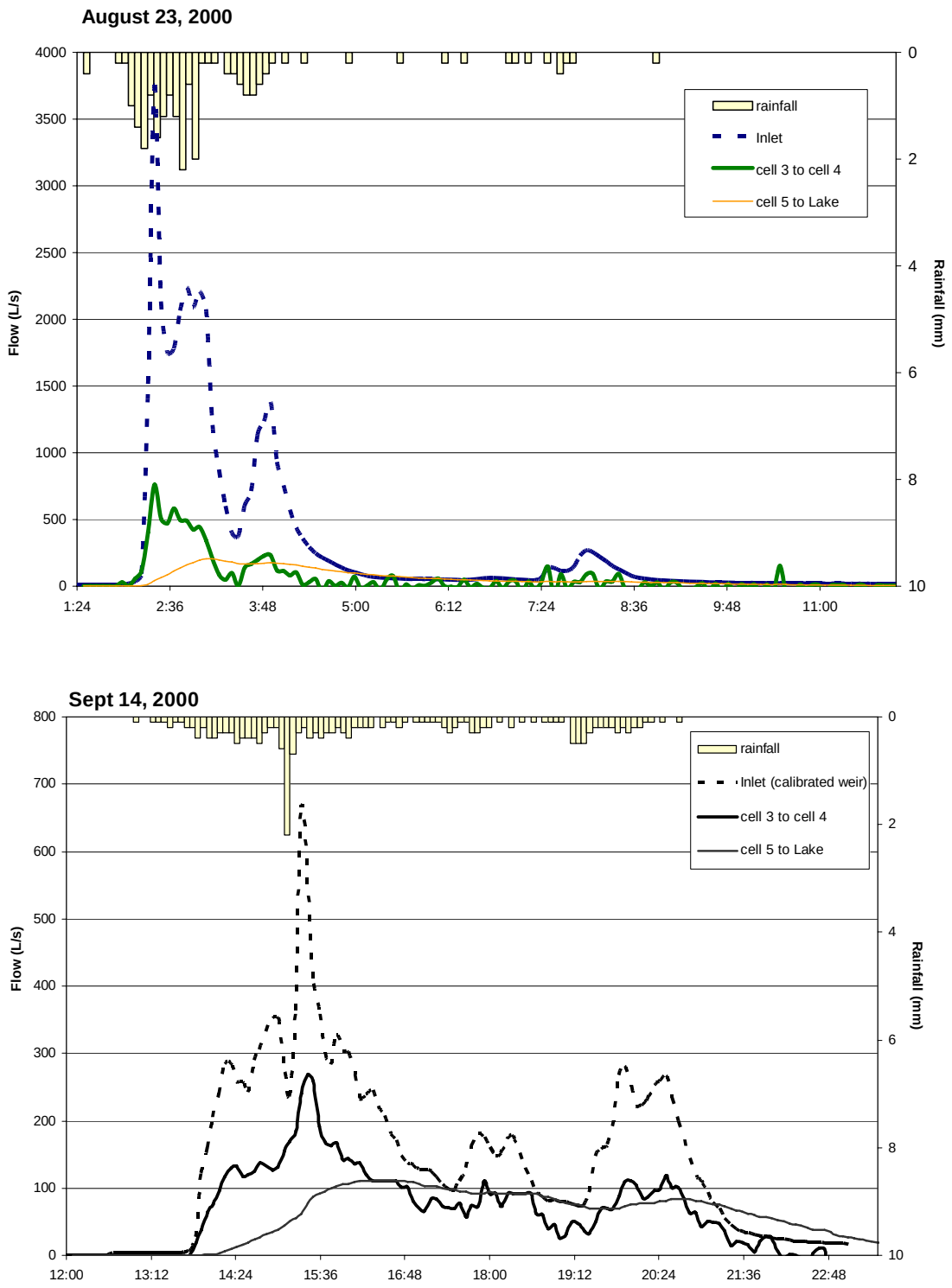


***Figure 4.2*: Hyetographs and hydrographs at the inlet, cell 5 outlet and at the curtain separating cells 3 and 4 for events on August 23 and September 14, 2000.**

(Flow through the curtain was calculated from cell 5 outflow and incremental storage changes in cells 4 & 5.)

4.3 Dye Tests

Two dye tests were conducted in 2001: one during wet weather and one during dry weather. The purpose of the wet weather test was to delineate flow paths of stormwater through the facility and identify dead zones (if any) or areas of short circuiting. The dry weather test aimed to trace the path of lake water being pumped into cell 3 in order to characterize the nature and efficiency of the post-event recirculation process.

4.3.1 Wet Weather Dye Test

On October 23rd, a rain event began at 12:10 (daylight savings time) but the initial precipitation was minor. The wind was moderate and from the west. The dye was applied to the storm sewer upstream of the dropshaft at 12:49 when a more intense period of rain began. The total rainfall was 7.1 mm, of which 6.7 mm fell in less than one hour. The rain event ended at 13:30.

Figure 4.3 shows the hyetograph, inlet hydrograph, facility water levels and dye concentrations during the initial period of runoff. The location of sampler intakes is the same as that for the regular monitoring program (see Figure 2.3). Over this period, dye was detected at all stations except the cell 3 and cell 5 outlets. Dye did reach these stations, but only after baseflow had been re-established, as discussed below.

The sampler information was supplemented with detailed visual observations. These visual observations and a chronology of the test are summarized in Table 4.5. Figures 4.4 and 4.5 show photographs taken during the test. Figure 4.6 illustrates the progression of the dye through the system based on visual observations (Table 4.5) and initial detection in the samplers (Figure 4.3). The dye wave-front lines in this figure were obtained by interpolation. The lines representing approximately the first two hours are based mostly on visual observations and are reasonably accurate. Later wave-front line shapes are estimated, with the time scale based on sampler data. Note that the wavefront line interval varies in this Figure. During the initial part of the event, the interval is 5 minutes; it increases to 10 minutes as the event slows and subsequently transitions to 1 hour after the event.

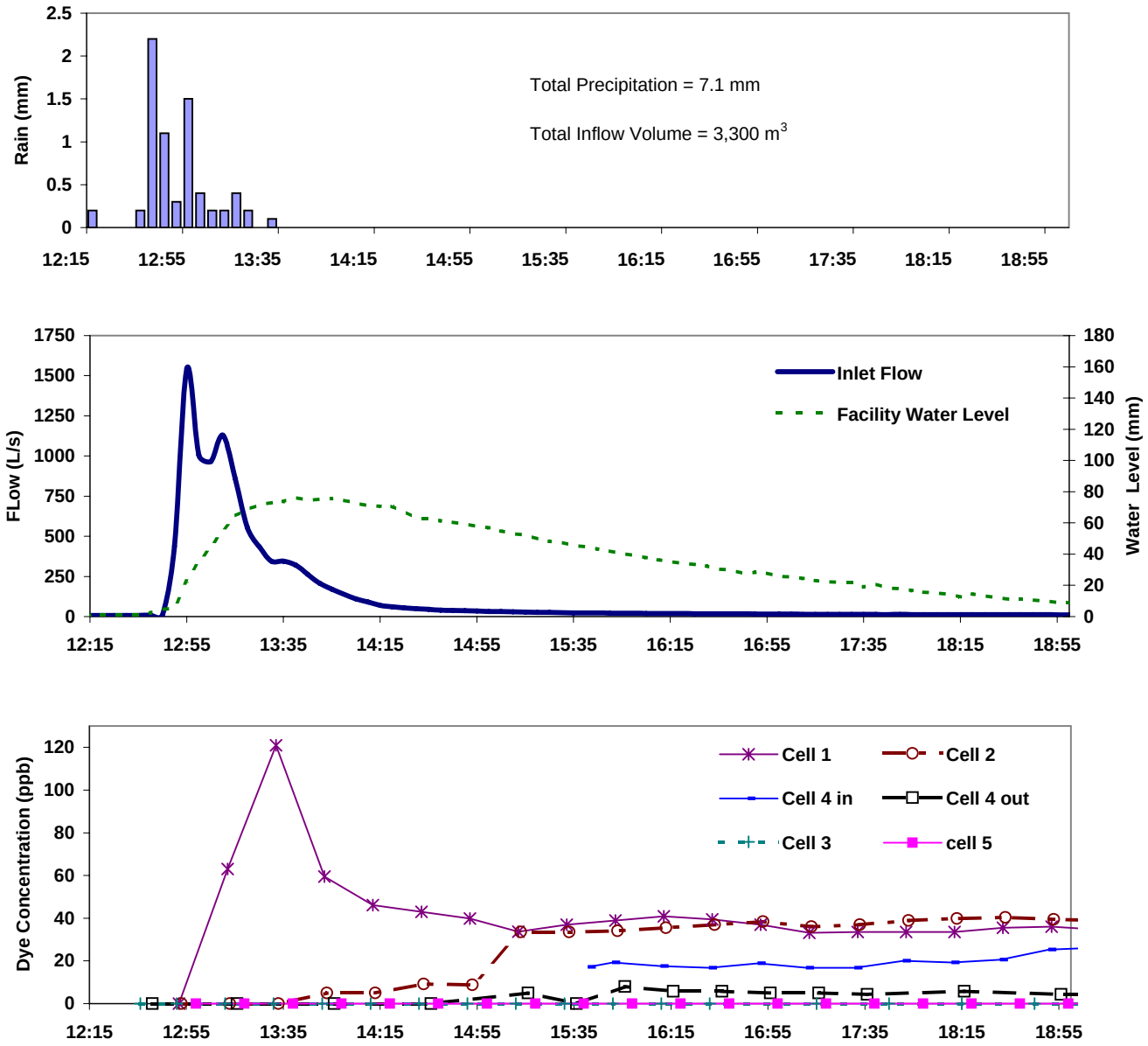


Figure 4.3: Hydrographs, hyetographs and dye concentrations during the initial period of runoff. Note that the cell 4 inlet sampler malfunctioned and was initiated manually 3 hours after the start of runoff.

***Table 4.5*: Dye Test Observations**

Elapsed Time	Time*	Description
00:00	12:49	Dye was injected into the drop shaft.
00:01	**12:50**	Sediment plume entering the forebay
00:03	**12:52**	Dye entering the forebay
00:06	12:55	Dye reached the pontoon bridge separating the forebay from cell 1.
00:08	12:57	Dye spikes through half of cell 1, with lesser movement (1/4) on each side.
00:09	**12:58**	Photo of dye entering cell 1
00:16	13:05	Dye is half-way through cell1, advancing on the west side.
00:21	13:10	Dye is entering the forebay of cell 4.
00:23	13:12	The cell 1 sampler detected the first measurable dye concentration.
00:24	13:13	Dye is entering cell 2, only on the west side.
00:40	13:19	Dye is moving well into cell 2 but has not entered cell 3.
00:41	**13:30**	Photo of dye entering cell 2 - across ¾ of the curtain length.
00:48	13:37	West wind appears to be blowing dye away from the cell 2-3 pontoon.
01:02	13:51	Dye has reached the pontoon bridge between cell2 and cell 3.
01:04	13:53	The cell 2 sampler detected the first measurable dye concentration.
01:06	13:55	Dye is visible in cell 3.
01:29	**14:18**	Photo shows dye has almost covered cell 2 – maybe some dye in cell 4
02:14	15:03	Dye has penetrated well into cell 3.
02:27	15:16	The cell 4 outlet sampler detected the first measurable dye concentration.
02:34	**15:23**	Photo of dye entering cell 3
02:36	*15:25*	similar to previous
02:38	*15:27*	similar to previous
02:40	*15:29*	similar to previous
02:42	*15:31*	some colour in cell 4
02:45	*15:34*	last photo – no evidence of colour in effluent
06:56	19:45	The cell 3 outlet sampler detected the first measurable dye concentration.
07:30	20:19	The cell 5 outlet sampler detected the first measurable dye concentration, but it was very close to background levels.
15:48	04:37	The cell 5 outlet sampler detected a significant dye concentration. (October 24th)

* Selected photos shown in figures 4.4 and 4.5 are bolded; additional digital photographs available on file but not shown are italicized.

***Figure 4.4*:** Photographs of dye entering the forebay and cell 1

Notes:
1. These photographs were taken looking southward.
2. Dye was added to the storm sewer upstream of the drop shaft at 12:49.

***Figure 4.5*: Photographs of Dye Entering Cells 2 and 3**

Notes:

1. The sampler on the cell 1 side of the cell 1-2 curtain first detected the dye at 13:12.
2. The sampler on the cell 2 side of the cell 2-3 curtain first detected the dye at 13:53.
3. Subsequent photographs provide little additional information because of the overcast conditions, the dilution of the dye and the slow progression of the dye beyond this time.

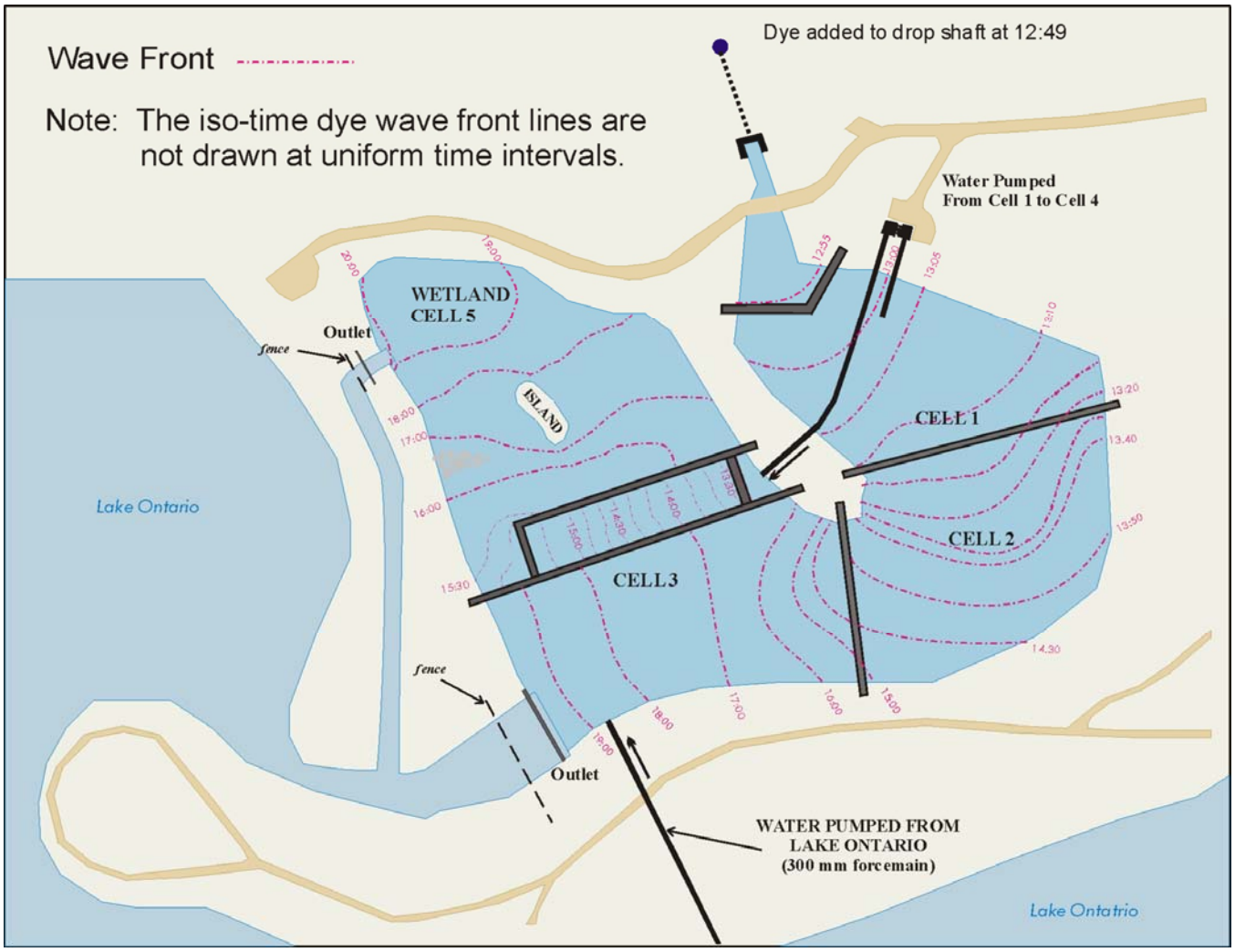


***Figure 4.6*:** Interpolated Dye Wavefronts

The principal observations during the initial period of runoff were as follows:

- The dye was well dispersed in the forebay, and moderately well dispersed in cells 1 and 2. It reached the forebay-cell 1 curtain 6 minutes after injection, and the cell 1-2 curtain 23 minutes after injection. Water levels in the facility peaked 51 minutes after injection (Figure 4.3).
- The dye required 64 minutes to reach the cell 2-3 curtain. Beyond that point it moved more slowly. The inlet hydrograph had a middle portion of moderate flow lasting until about 1 ½ hours after the dye addition, and did not reach baseflow level until about 2 ¾ hours. By contrast, facility water levels were elevated above base flow levels for a period of 7.6 hours.

- The dye dispersion pattern at the surface for the initial hour suggested that the desired horizontal plug-flow conditions of the storage facility were achieved, within the practical constraints of the system geometry.
- Visual observations at the surface indicated that dye reached the cell 1 pump station intake location in about 10 minutes, but was visually detected at the forcemain headwall in the cell 4 forebay only after 21 minutes. Since the intake is located near the bottom of cell 1, the 11 minute difference suggests that dye was moving more quickly across the surface than at the bottom of the pond (i.e. vertical plug flow conditions were achieved only after a delay). Dye was detected at the cell 1-2 curtain two minutes after detection at the cell 4 headwall.
- The previous observation is also confirmed through simple volume calculations. The total volume of inflow during the event was approximately 3300 m^3. If plug flow conditions prevailed, the water would enter the facility, and travel only as far as would be required to displace an equivalent volume of water. Since the volume of cell 1 is 7900 m^3, one would expect, under strict plug flow conditions, that the dye would progress through only half of the cell. This was, of course, not the case, indicating that a plug flow assumption drastically underestimates the distance that new influent runoff will travel in wet pond type facilities.
- The dye required a little more than 2 hours to move through cell 4 and be detected at the cell 4 outlet sampler. Plug flow in this cell (volume = 2,900 m^3) at a pumping rate of 4 m^3/min would require approximately 12 hours to move from one end to the other. With two pumps running, the theoretical residence time would be 6 hours; however, the second pump was not triggered during this event. There are two possible explanations for the reduced residence time in cell 4: (i) flow through cell 4 was not uniform in cross-section (*i.e.* flow moved more quickly across the surface where the sampler intake was located), or (ii) flow was entering cell 4 from cell 3 through holes in or beneath the curtain causing the dye to move at a faster rate than it otherwise would have. This is not to suggest that dye was entering cell 4 from cell 3 (the timing of dye observations in cell 3 would not support that interpretation), but rather that flow into cell 4 caused by a head differential across the leaky curtain pushed the dye through the cell at a rate faster than could be explained by pump discharge alone.
- The dye required 5.9 hours to cross cell 3 (6.5 hours after dye was added to the storm sewer). After dye entered cell 3 from cell 2, facility water levels were receeding (Figure 4.3), causing the dye to move more slowly than at the beginning of the event. The dye was detected at the cell 3 outlet only 25 minutes before facility water levels returned to pre-event baseflow levels. Flow through the cell would have been opposed by the pumped lake water that moves in the opposite direction, although the actual two-directional flow pattern, and the pattern of dye movement, would depend on many factors including wind and water temperature.
- The dye required approximately 5 hours to cross cell 5 (7.5 hours after dye was added to the sewer). However the initial fluorometer readings were so close to background levels that it was uncertain whether dye was indeed present. Significant dye concentration occurred at the cell 5 outlet 13.3 hours after detection at the cell 4 outlet (15.9 hours after dye was added to the sewer). Dye transport would have been caused by diffusion and the pumped flow rate (plus or minus any leakage through or under the cell 3-4-5 curtain). The fact that the dye concentration increased

significantly about 8.5 hours after first detection (13.5 hour residence time) may have been due to additional precipitation. There was some rain on the morning of the 24th, more during the early hours of the 25th and traces of precipitation on the 26th.

The dye tracer fluorometer results for the event and post event period are presented in Figure 4.7. Post event sampling was conducted at the two facility outlets and at the cell 4 inlet. Sampling was not continued for a sufficient period of time to provide a complete dye tracer curve. A discussion of the results follows:

- The event on October 23rd was followed by three other smaller rain events: 2 mm from 10:40 to 11:40 on October 24th, 4.8 mm from 0:15 to 3:15 on October 25th, and 0.8 mm from 14:50 to 15:15 on October 26th (Figure 4.7).
- At approximately 8:10 on the 24th of October, water levels in the facility started to rise independently of rainfall within the catchment. These levels continued to rise until midnight on the 29th (see Appendix C) and are attributed to rising lake levels. Once the lake level rises above the base of the cell 3 and 5 outlet structures, water level fluctuations in the facility parallel those of the lake.
- The concentration peaks at the cell 1, cell 2 and cell 3 sampling locations follow a progression as would be expected.
- The second peak in the cell 3 outlet curve corresponds with the decline in water level after the small event on October 24th. As the water level declines, dye exits the facility. When the direction of flow reversed (beginning at roughly 20:00, October 24th) lake water starts to flow into the facility, and cell 3 concentrations begin to decline.
- The cell 4 influent curve reflects the fact that the stormwater was being held in cell 1 and transferred to cell 4 by pump. The rainfall event on the morning of the 24th also seems to have influenced the curve shape by causing a second peak.
- The weak concentration in the cell 4 outlet curve suggests dilution from water entering cell 3 through the cell 3-4 curtain (see Figure 4.7). If cell 4 had been isolated, the conservative dye should have appeared almost as concentrated in the effluent as it was in the influent, but with the time of appearance shifted by an amount equal to the residence time in cell 4.
- On October 25th, when 4.8 mm of rain fell between 00:15 and 03:15, the cell 4 influent dye concentration again appears to have responded to the residual dye in the forebay and cell 1. Only the cell 5 outlet concentration was being monitored when a small rainfall event occurred on the 26th.

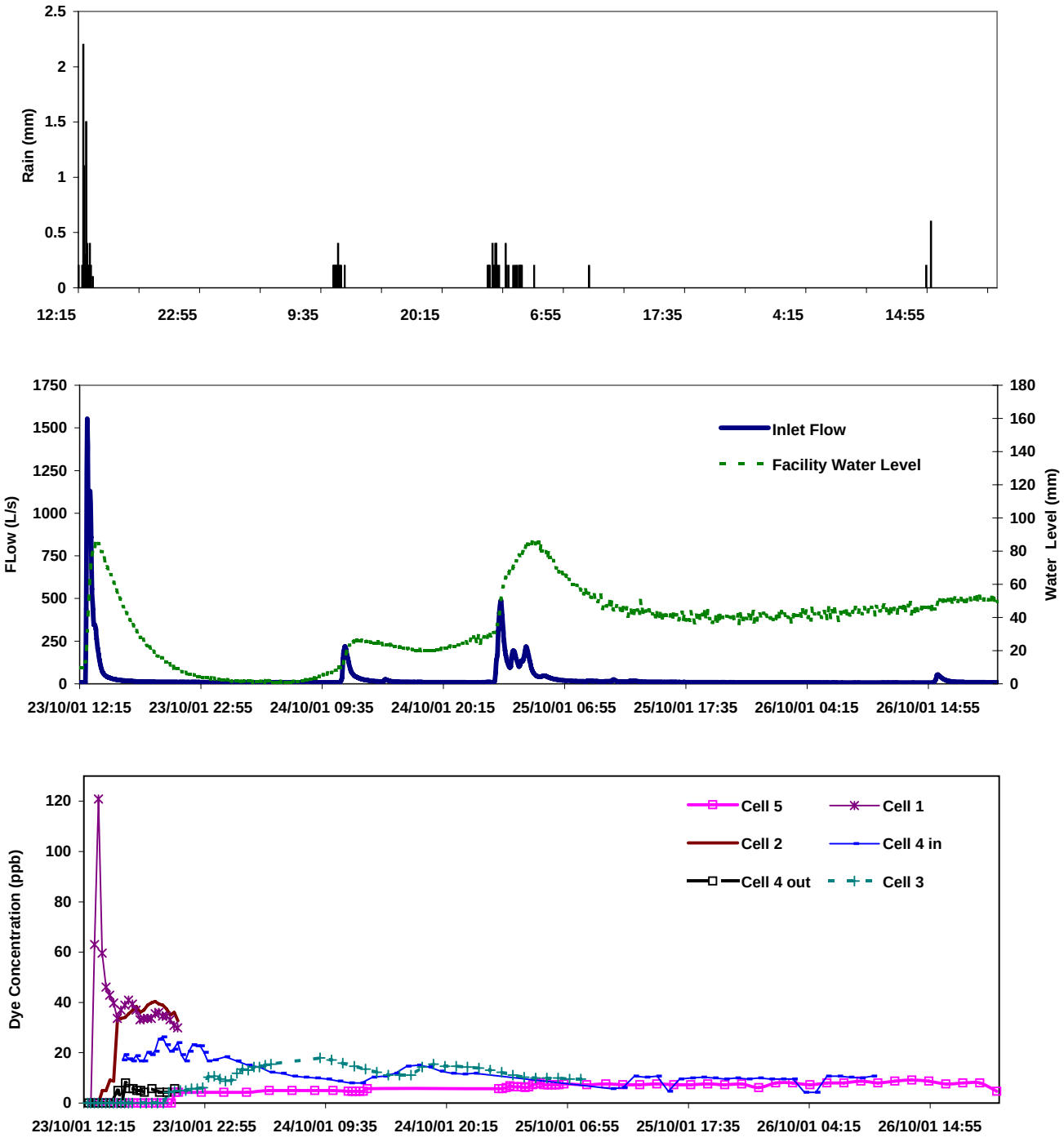


Figure 4.7: Hyetographs, hydrographs and dye concentrations over the monitoring. Note the effect of rising lake water levels on facility water levels after 19:00 on October 24th, and again after approximately 19:00 on October 25th.

4.3.1.1 Residence Times

Since most of the tracer curves were incomplete, most of the residence times can not be calculated, and no material balance could be determined. However, an approximate mean residence time was determined for the flow path through cells 1 to 5 based on available data.

- The event began with the addition of 1.5 L of dye at 12:49 on October 23rd.[3]
- The minimum residence time for the flow path through cells 1 to 5 was 7 hours and 30 minutes, with dye first appearing at 20:19 on the 23rd.
- The maximum residence time may be approximated by the end of the sampling program at 20:48 on October 26th. The corresponding elapsed time was 79 hours and 59 minutes.
- The mean residence time determined by locating the centroid of the tracer curve was 51 hours and 24 minutes. The centroid of the curve was found at 16:13 on October 25th.
- The theoretical plug-flow residence time in cells 4 and 5 at a pump rate of 4 m^3/minute is 44.6 hours. This is a moot point, however, since simultaneous water level monitoring on both sides of the cell 3-4 curtain has shown that considerable flow into cells 4-5 occurs across the cell 4 curtain during storm events.

The peak dye concentration at the cell 1-2 curtain was approximately 120 ppb, or 1.5 litre of dye in 12,500 m^3 of water. The peak concentration observed at the cell 2-3 curtain was approximately 40 ppb, or 1.5 litre of dye in 37,500 m^3 of water. The peak concentration was 18 ppb at the cell 3 outlet. The peak concentrations in the cell 4 and cell 5 outlets were roughly 8 and 9 ppb, respectively. The cell 4 inlet peak concentration could not be determined because the first plug of flow, when dye concentrations would have been highest, was not sampled.

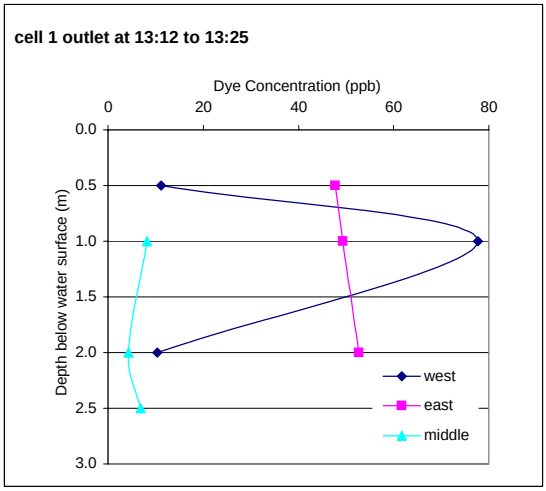
Since the volume of the forebay plus cell 1 is approximately 8 to 9 thousand m^3, and flow is continuously being pumped out of cell 1 to cell 4, the dye concentration observed at the cell 1-2 curtain (1.5 litre of dye in 12,500 m^3) is probably realistic for the test conditions.

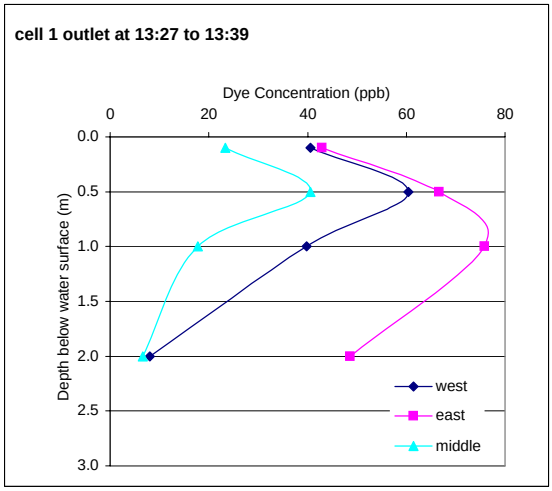
4.3.1.2 Depth profiles

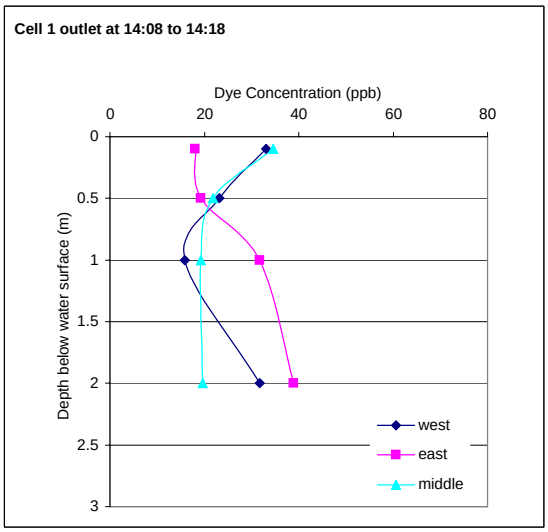
Dye measurements were also made to provide depth profiles at specific locations along the cell 1-2 boundary and the cell 2-3 boundary (Figure 4.8).

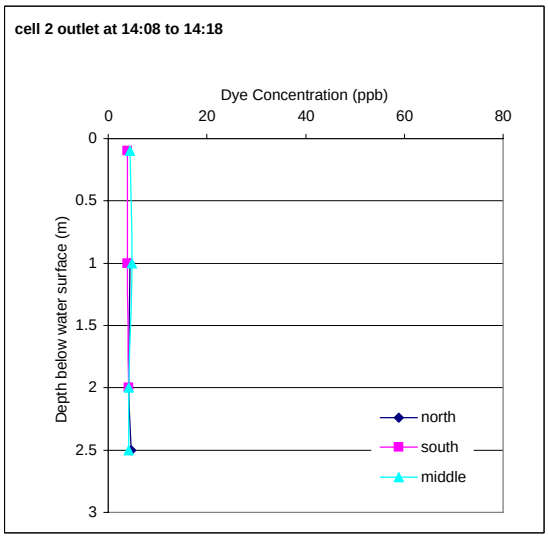
The first set of observations made at the cell 1-2 boundary (cell 2 side of the curtain) occurred before the dye had penetrated into cell 2 across the full length of the curtain. The first set of observations at the cell 2-3 boundary (cell 3 side of the curtain) was premature.

[3] A small quantity of the 1.5 L jar of dye spilled before being applied to the sewer









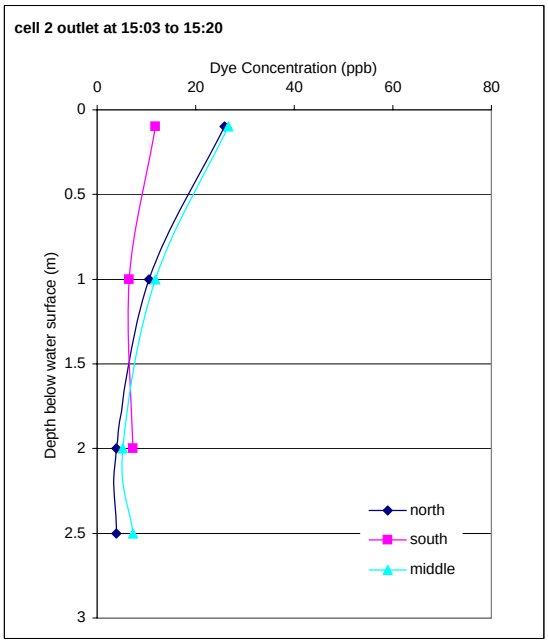


Figure 4.8 **:** Depth profiles conducted on October 23rd

Notes:

1. The first cell 1-2 test was conducted when the dye had not penetrated cell 2 uniformly across the curtain.

2. The first cell 2-3 test was undertaken before dye had penetrated into cell 3.

The depth profiles suggest that the dye (i.e., the influent) initially moves across the top of the cell contents, which is consistent with earlier observations. While the new fluid remains in the system, and the farther it moves through the system, it tends to sink toward the bottom. This effect is probably influenced by system geometry, inertia and temperature/density factors. Since the influent enters the system near the surface, inertia will tend to keep it there, as long as structures are not put in place to create a more uniform vertical distribution. The curtains that were designed to restrict and distribute flow consist of vertical panels with spaces between them. The spaces extend from the pontoons to the bottom of the cells and would not be expected to impose much vertical redistribution of the flow. If the influent were warmer than the system contents, it would tend to remain on top, assuming that the temperatures are above the maximum density point of 4°C. If the influent is colder than the cell contents, or when it cools, it will eventually sink to the bottom.

Temperature data were not available for the date of the dye test; the record stops on October 18th in 2001. The records show that the influent was colder than the pond contents prior to October 9, but warmer than the pond contents after that date. However, most of that data pertained to baseline or dry-weather flow.[4]

4.3.1.3 Summary

The wet weather dye test showed that for a 7.1 mm event with a maximum intensity of 6.7 mm/hr, the facility was effective in retaining the influent for at least seven hours before measurable discharge through one or both of the outlets occurred. This 7 hour period roughly corresponds to the initial period during which the facility water levels were elevated above baseflow levels (i.e. the period of high discharge to receiving waters). Once dye started to be detected at the cell 3 outlet, effluent flows had returned to baseflow levels and thus pollutant loading rates would have been small.

Upon first inspection, the dispersion patterns through the forebay, cell 1 and cell 2 were consistent with the principle of establishing plug-flow-like conditions with the displacement of cell contents by the new influent flow. However, the combination of depth profiles and consideration of the runoff volume indicate that the influent flow can not be well-distributed vertically, such that some of the influent flow exits the cells before all of the current contents have been displaced.

This observation is consistent with simple volume displacement calculations. Approximately 3,300 m^3 of stormwater was discharged during the event. If the new water simply displaced the contents of each cell sequentially, then it would not have moved further than cell 1, which has a volume of 7,900 m^3. Instead, the dye is observed to penetrate through cell 2 and into cell 3 (combined volume of cell 1 and 2 is approximately 17,300 m^3) before the end of the runoff event.

[4] Season 2002 observations include continuous depth-profiles of water temperature (see sections 4.4, 4.4.5 and Appendix G).

Monitoring of this test was not conducted for a sufficient period of time to establish a material balance or to determine residence times for all cells. In addition, a small but unknown quantity of dye was lost. The approximate residence time (51.5 hours) determined for the flow path from the influent to the cell 5 outlet appears to be good relative to the design of the system, but one must consider that a substantial volume of water was passing through or under the cell 3-4 curtain in response to a head differential across the curtain. It is somewhat of a coincidence that the calculated residence time based on dye measurements roughly correspond with theoretical residence time assuming plug flow conditions and no flow across the cell 3-4 boundary, since both assumptions are known to be fundamentally incorrect.

4.3.2 Dry Weather Dye Test

There was no rain on November 21st, the day of the test. A moderate wind was blowing from the west or west-southwest. Precipitation was measured four days after the test when dye concentrations in the facility were still being monitored. Influent baseflow was approximately 3 L/s. Figure 4.9 shows the hyetograph and the inlet flow data for the entire monitoring period.

The lake water feed pump was accidentally turned off for two minutes at the very beginning of the test. Restarting the pump resulted in the transfer of sediment into the system.

The visual observations and test chronology are summarized in Table 4.6. Figures 4.10 to 4.12 contain photographs taken during the test. Figure 4.13 illustrates the progression of the dye through the system based on visual observations. The dye wave-front lines in this figure were obtained by interpolation.

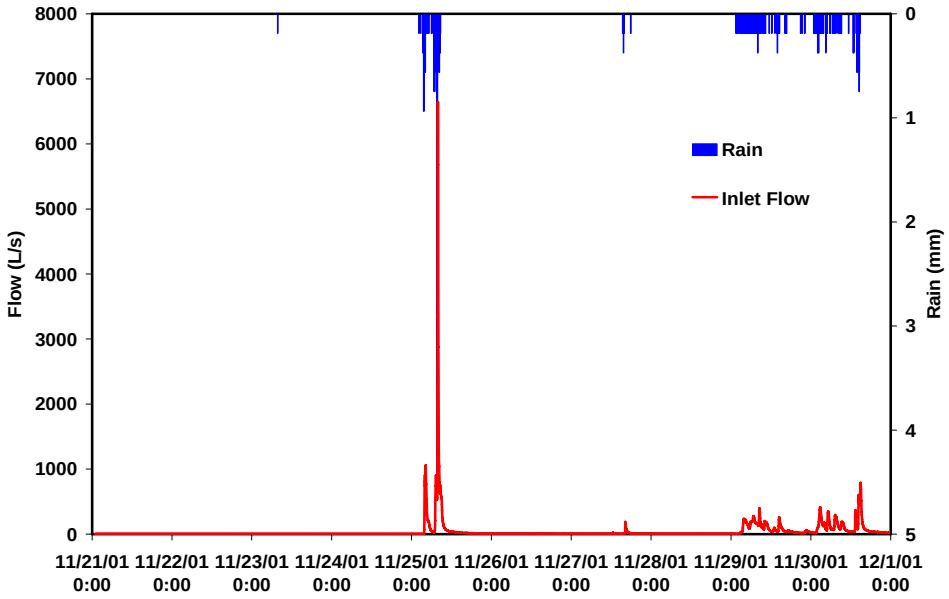


Figure 4.9: Hyetograph and inlet hydrograph for the dry weather dye test – Nov 21 to Nov 30, 2001

***Table 4.6*:** Dye test observations and key to photographs

Elapsed Time	Time*	Description
00:00	**10:00**	Two litres of dye was injected into the lake water entering cell 3
00:00	*10:00*	Dye was injected into the lake water entering cell 3 (close-up). The dye is spreading radially with some bias toward the east. Turbulence is causing foam formation.
00:01	**10:01**	Photo of dye moving eastward along the south shore in cell 3
	10:05	The lake water feed pump was accidentally shut off for 2 minutes.
00:09	**10:09**	Photo of dye about ½ way to the cell 2-3 curtain.
10:10	10:10	Red foam has floated/blown to the cell 2-3 curtain.
00:32	**10:32**	Photo of dye reaching the cell 2-3 curtain, still mostly along the south shore
00:34	**10:34**	(close-up, similar to previous)
10:40	10:40	Dye enters cell 2.
00:41	*10:41*	Dye moves diagonally (north-westerly) toward the cell 3 outlet. This flow pattern may indicate an interaction with the dry-weather baseflow.
00:51	**10:51**	Photo of dye distribution pattern in cell 3
00:51	*10:51*	Close-up photo of the dye entering cell 2
00:58	*10:58*	Similar to previous photo
01:38	*11:38*	Dye dispersion in cells 2 and 3
01:39	*11:39*	Dye pattern along the south shore of cell 2
01:45	**11:45**	Dye dispersion in cells 2 and 3
01:47	*11:47*	Dye moves along the east shore of cell 2
01:52	*11:52*	Dye diffusion increases in cell 3
01:53	*11:53*	Dye moves along the south and east shores of cell 2
02:06	**12:06**	Dye is in the vicinity of the mud flat Dye has reached the cell 1-2 curtain at the westerly end.
02:25	12:25	Dye exits cell 3 to the outlet channel.
02:32	*12:32*	Dye leaves cell 3 through the outlet gate
02:35	*12:35*	Dye is observed in the cell 3 outlet channel
02:39	12:39	Dye enters cell 1
02:49	*12:49*	Dye enters the mud flat
03:00	**13:00**	Dye moves westward along the cell 1-2 curtain
03:46	*13:46*	Dye spreads throughout cell 2
04:17	*14:17*	Dye is well-distributed in cell 3
04:37	*14:37*	Same as previous
04:39	*14:39*	Photos (almost identical) of cells 1 and 2, with faint colour but good dispersion in cell 2 and possibly some colour in cell 1
04:45	*14:45*	Dye is well-dispersed in cell 3
26:09	*Nov 22*	Photos taken on November 22nd show good dye dispersion in cells 1, 2 and 3, with possibly a trace of dye in cells 4 and 5

* Selected photos shown in figures 4.10 to 4.12 are bolded; additional digital photographs available on file but not shown are italicized.

Figure 4.10: Photographs of dye in cell 3 - first few minutes of test

Notes:

1. These photographs were taken looking southward.
2. Dye was added at the holding well between the lake and cell 3 at 10:00.

***Figure 4.11*:** Photographs of dye approaching the cell 2-3 curtain

Notes:

1. Dye was observed entering cell 2 adjacent to the south shore at 10:40.
2. The sampler on the cell 2-3 pontoon, with its intake located on the cell 2 side of the curtain, first detected a concentration above baseline at 11:50.

***Figure 4.12*:** Dye patterns in cells 3 and 2

Notes:

1. Dye was observed reaching the cell 1-2 curtain adjacent to the west shore at 12:06.
2. The dye was seen entering cell 1 near the west shore at 12:39.
3. The sampler located on the cell 1 side of the cell 1-2 curtain was initiated at 13:50, at which time it detected a dye concentration approximately twice that of the background.

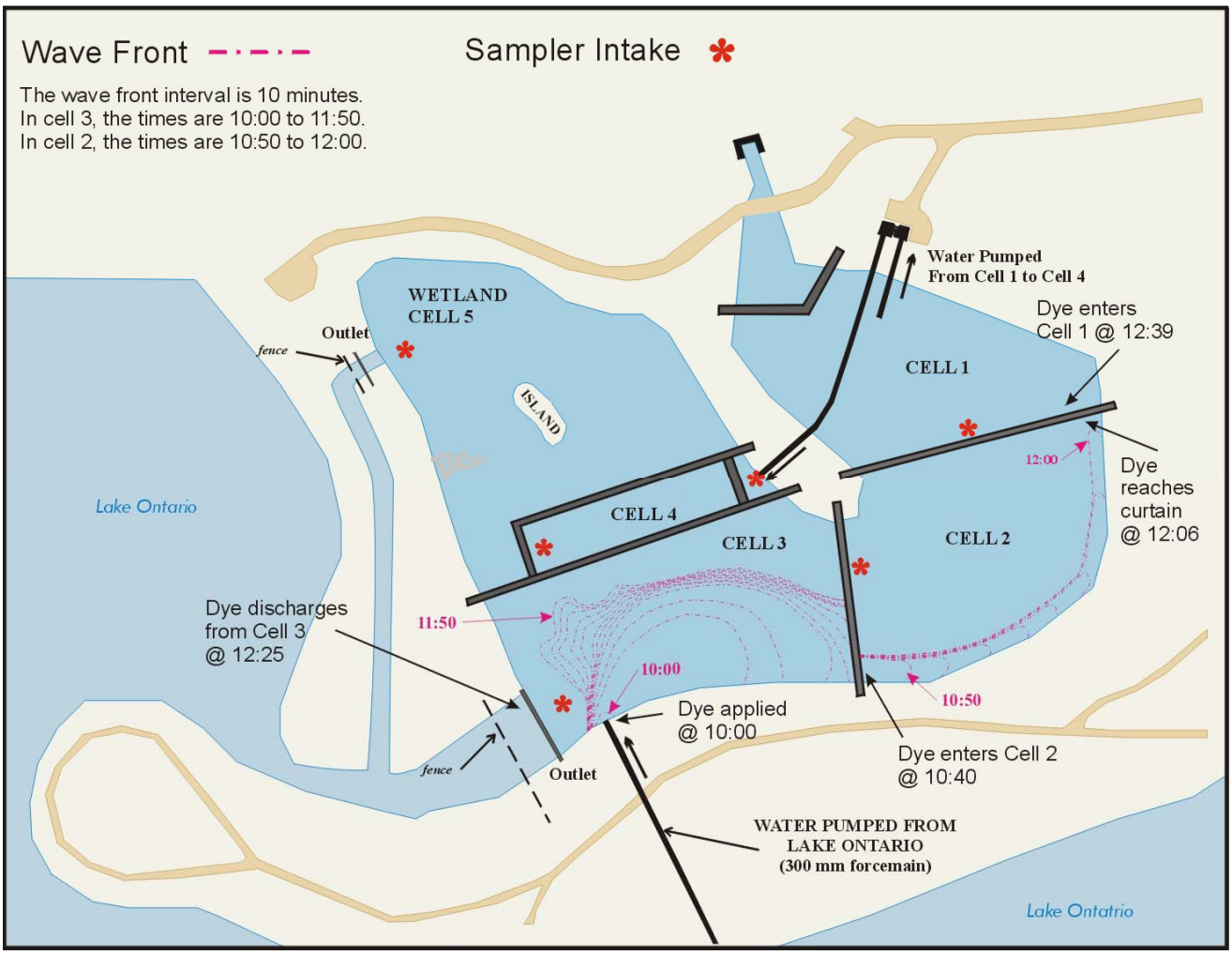


***Figure 4.13*:** Interpolated dye wavefronts

The principal visual observations were:

- Shortly after addition, the dye moved easterly along the south shore of cell 3, and moved north toward the centre of cell 3 at a slower rate. Some dye-bearing foam was blown in an easterly direction, reaching the cell 2-3 curtain 10 minutes after dye addition.
- The dye reached the cell 2-3 curtain after 40 minutes, still predominantly adjacent to the south shore of cell 3.
- The dye moved east in cell 2, remaining close to the south shore, then moved northerly following the east shore. There was no visual evidence of dye migrating toward the centre of cell 2.
- The dye required 86 minutes to travel between the cell 2-3 curtain and the cell 1-2 curtain (2 hr. 6 min. elapsed time).
- Upon reaching the cell 1-2 curtain, the dye moved west along the curtain. No dye was seen in cell 1 until approximately 30 minutes after it had reached the cell 2 side of the cell 1-2 curtain.

- In cell 3, over a time period of about two hours, some dye was seen moving north from the point of addition in the general direction of the north end of the cell 3 outlet structure. After approximately 2 ½ hours, some dye was observed in the outlet channel.

The flow patterns observed in cells 2 and 3 are interesting. Conceptually, there are two opposing flows during dry weather. One flow consists of the lake water entering cell 3 at 67 L/s and moving to cell 1 where water is pumped at the same rate into cell 4. The second flow consists of a smaller dry-weather flow, at an average rate of approximately 3 L/s, which moves from the inlet structure, through cells 1 to 3 and into the lake. Obviously, these flows will mix to some extent but the dominant flow will be from the much greater volume of lake water entering cell 3.

The relative temperatures of the pond contents, the lake water, pumping at cell 4 and the influent water would all be expected to influence the flow patterns. Wind is also a significant factor.[5]

The circular flow pattern in cell 2 may have resulted from the near-shore (tangential) input(s) reinforced by the coriolis effect. However, when considering the pumping rate, the apparent reluctance of the dye to enter cell 1 is unexpected. Perhaps a circular flow similar to that observed in cell 2 is occurring in cell 1, causing a tangential flow on both sides of the cell 1-2 curtain. The combination of influent flow directed into the centre of cell 1, wind from the west, and pumping of water near the east shore of the cell may encourage a circular flow pattern. The gaps in the curtain would be expected to distribute the flow and, hence, would also have contributed to the dispersion along the length of the curtain.

The dye tracer concentrations are presented in Figure 4.14. The sampler intake locations used for this test were the same as those employed for the monitoring of runoff events, as illustrated in Figure 2.3. The cell 3 sample station was intended to represent the outlet water quality. The sampler intake was located at the mid-point of the outlet gate structure, and about 4 metres upstream of the gate. The offset was chosen to avoid possible turbulence and sediment resuspension at the shallow end of cell 3 when sampling runoff events. Although visual observations showed a slow progression of dye toward the outlet, the sampler intake was located relatively close to the dye plume and has measured significant concentrations of dye.

Sampling was continued until mid-December using a combination of automated and grab sampling techniques. A discussion of the results follows:

- There was a progression of concentration peaks between cells 2 and 1, with the latter curve being broader and having a lower peak, as would be expected.
- The cell 4 influent curve, the cell 4 effluent curve and the cell 5 effluent curve initially have the relative shapes that may be expected for this system.

[5] It is conceivable that if wind were from the east instead of the west, much more of the dye (*i.e.* lake water) would have exited through the cell 3 outlet. Higher influent baseflows would also contribute to this result.

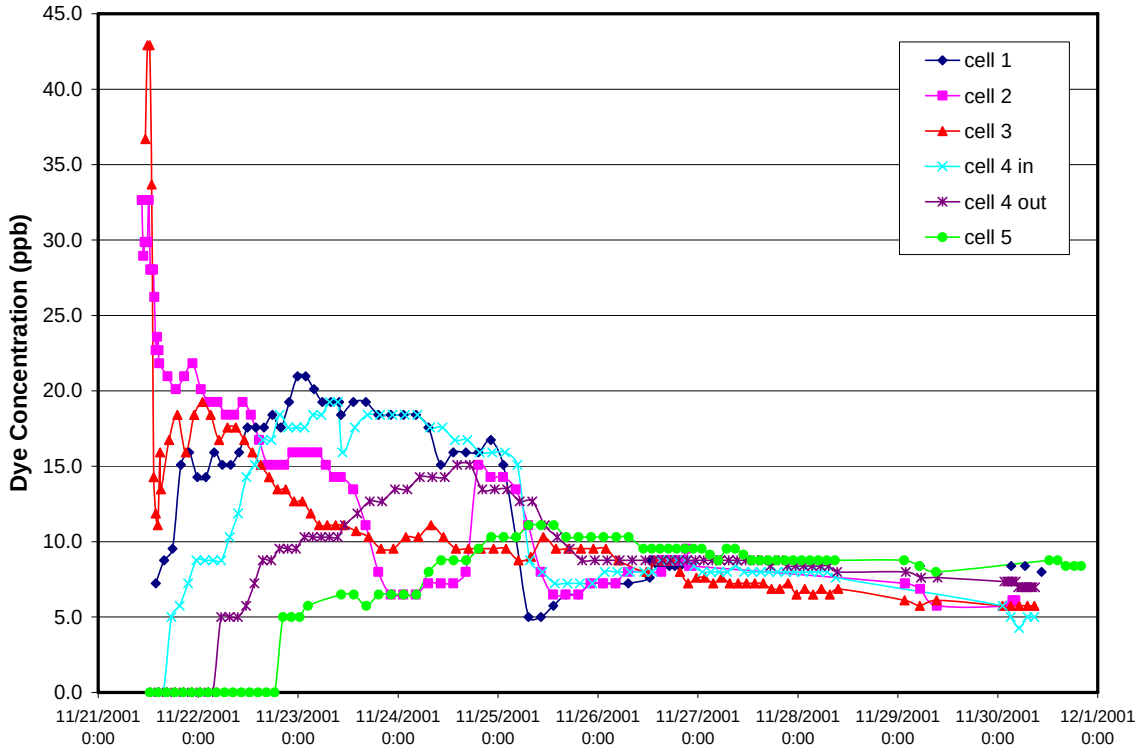


***Figure 4.14*:** Dye concentrations -- all stations (detection limit = 5 ppb)

- The dye required approximately 30 minutes to reach the cell 2 intake and 3 hours and 20 minutes to reach the cell 1 intake and cell 4 inlet (see Figure 2.3 for location of intakes).
- The time lag between the first appearance of dye at the cell 4 inlet and the cell 4 outlet was approximately 10 hours. Plug flow conditions, with one pump operating would have resulted in a lag of 12 hours. Dye may have reached the cell 4 outlet earlier, but at concentrations below detection limits.
- The average dye concentration entering cell 4 was 11.1. The average concentration leaving cell 4 was 9.4. The difference may be attributed to mixing and minor leakage from cell 4 through or under the 3-4 curtain.
- The time delay between first detection of dye at the cell 4 outlet and the cell 5 outlet was roughly 15 hours. Plug flow retention in this cell with one pump operating is 32 hours.
- The short travel time through cells 4 and 5 during the October wet weather dye test (2 and 5 hours respectively) suggests that, as hypothesized earlier, inflow through the 3-4-5 curtain during storm events contributes to considerably shorter residence times in these cells.
- The first dye concentration above baseline observed at the cell 5 outlet occurred approximately 20.5 hours after the test began. The last observation above baseline occurred approximately 15 days after the start of the test. The centroid of the cell 5 mass curve found at 16:18 on November 26th, or about 5 days and 6 hours from the time of dye addition.[6] A different residence time may

[6] Calculation of the centroid assumes that flow is from the cell 1 pumps only. Two pumps were running at a combined rate of 8 m^3/min for a duration of 60 hours following peak flow (7:55) during the November 25th storm event.

have resulted if there had been no rain during the monitoring period. Theoretical plug flow conditions through cells 3, 2, 1, 4 and 5 at a flow rate of 4 m^3/minute would result in a residence time of 6.8 days.

- Samples collected up to November 30th indicated significant residual concentrations at all locations except possibly cell 1. Grab samples collected at the cell 3 and cell 5 outlets on December 4th, 6th and 13th indicated that the dye concentrations did eventually return to baseline conditions, but only after 22 days.

4.3.2.1 Depth Profiles

Dye concentration depth profiles were also measured at 3 intervals along the cell 2-3 and cell 1-2 curtain (Figure 4.15). Initially, the dye approaching cell 2 was concentrated at mid-depth on the cell 3 side of the curtain. Twenty minutes later, on the cell 2 side of the curtain, dye was more concentrated near the surface. Later observations in cells 1 and 2 showed fairly uniform depth distributions.

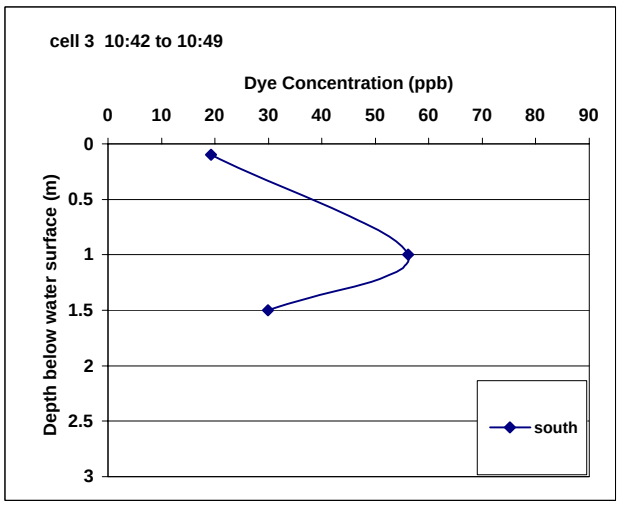
4.3.2.2 Rain Events

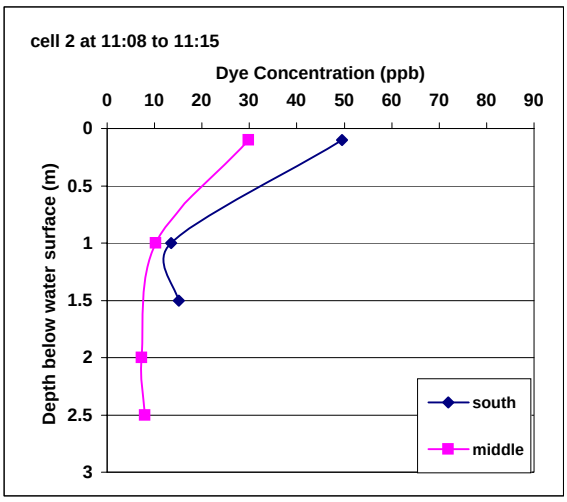
Figure 4.17 shows the movement of dye within the facility in response to the rain event on the 25th of November, almost 4 days after dye injection. Total rainfall and flow during this event was 25.2 mm and 15,000 m^3, respectively . A second pump at cell 1 was triggered at 7:55 for a period of 60 hours when the peak inflow rate exceeded 4000 L/s causing the pumping rate to increase from 67 to 133 L/s.

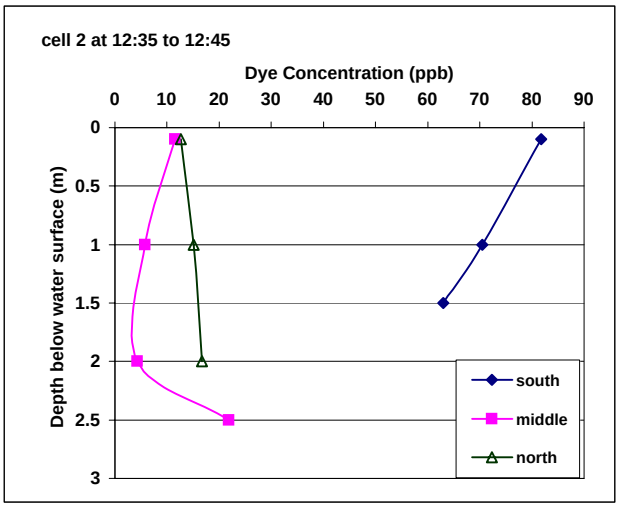
The influent runoff flushed the residual dye out of cells 1 and 2. Consequently, the dye concentration in these cells and the cell 4 influent decreased suddenly. The displacement of dye from cells 1 and 2 resulted in a minor increase in dye concentration at the cell 3 outlet station. Mixing of new and old water may explain subsequent decreases in dye concentrations at 3 and the cell 4 and 5 outlets. Identical water levels on either side of the cell 3-4-5 curtain indicated that considerable flow through or under the curtain was occurring throughout the event.

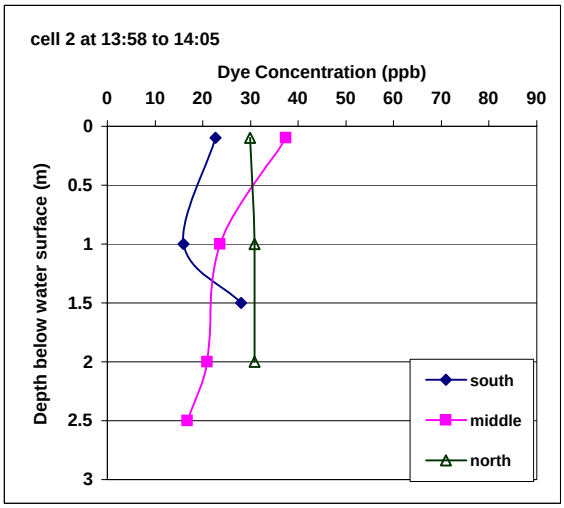
After facility water levels had reached a steady state, the dye stored in cell 3 was subsequently drawn back into cells 2, 1 and 4 as seen by a concentration decrease in cell 3, and concentration increases at the other monitoring stations. During this period, water was being transferred from cell 1 to cell 4 at double the rate that lake water was entering cell 3, resulting in a stronger reverse hydraulic gradient than would have been the case if only one pump was running.

The dye concentrations in cells 1 and 2 can also be seen to respond in a similar fashion to the much smaller rainfall events on November 29th and November 30th.









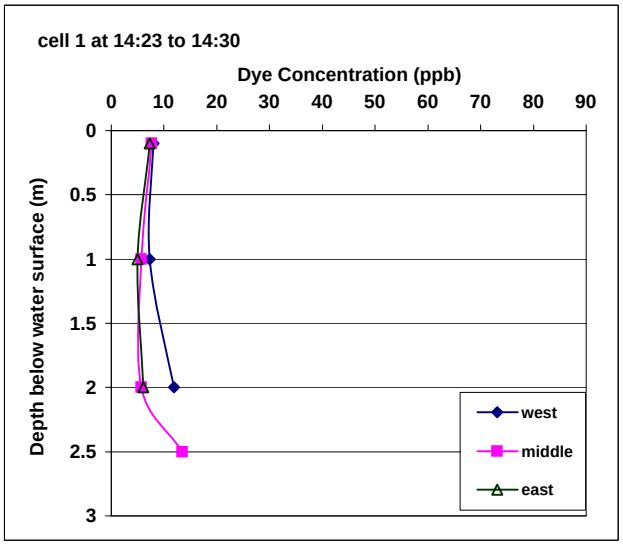


Figure 4.15 : Dye tracer depth profiles -- dry weather test

Notes:

1. The first set of observations was made on the cell 3 side of the cell 2-3 curtain.
2. All other cell 2 observations were made on the cell 2 side of the cell 2-3 curtain.
3. The cell 1 observations were made on the cell 1 side of the cell 1-2 curtain.

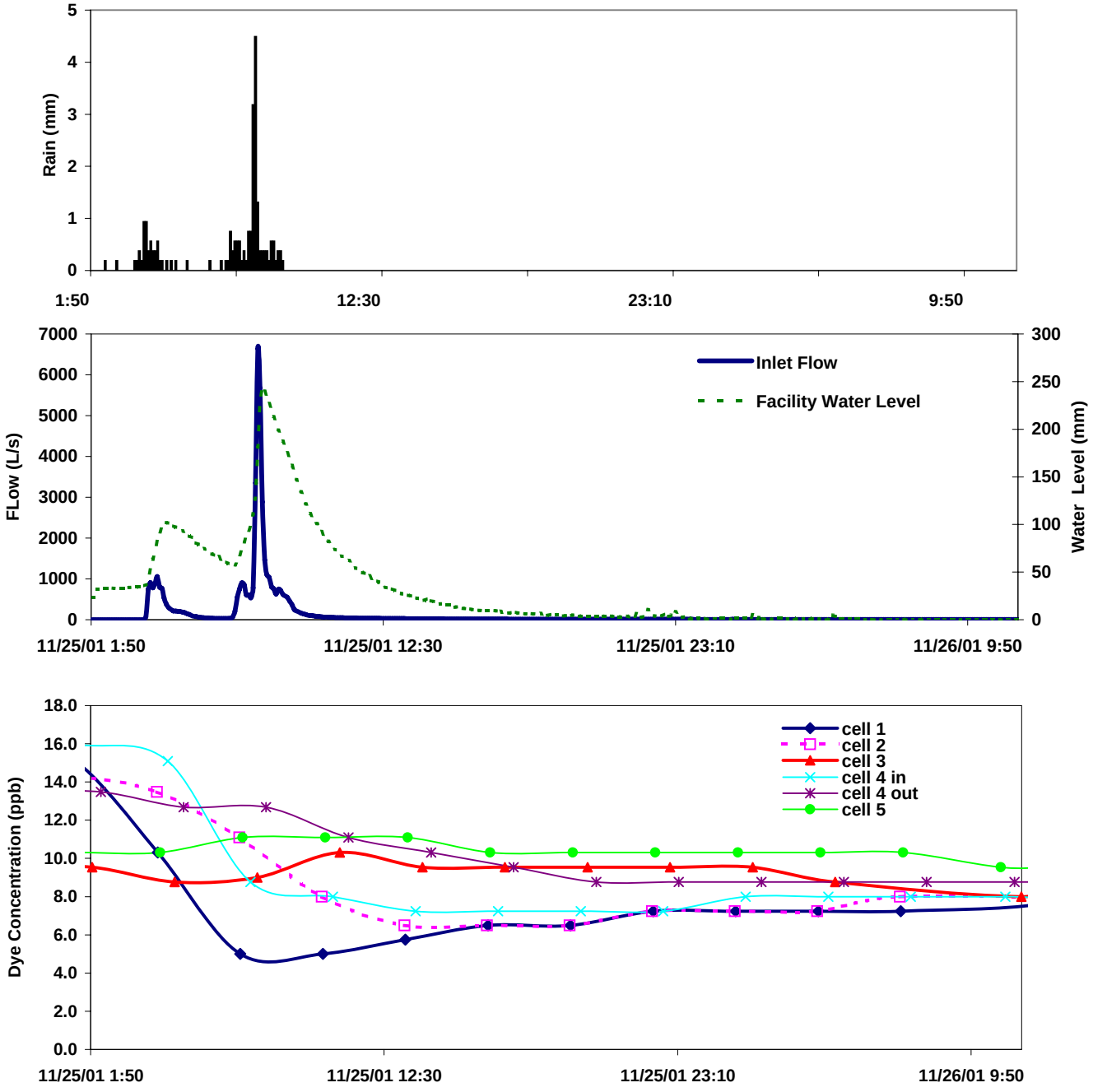


Figure 4.16 : Hyetograph, hydrographs and dye concentrations for the event on November 25, 2001, almost four days after the start of the dry weather dye test

4.3.2.3 Summary

The dry-weather and wet-weather flow patterns observed in the dye test demonstrated that the facility was performing generally as intended, retaining runoff and processing it through cells 4 and 5.

Visual observations and dye concentration measurements indicated significant departure from plug flow conditions. Dye was first detected at cell 5 less than a day after the start of the test, and continued to be detected 15 days later. At a pump rate of 4 m^3/minute, theoretical plug flow through cells 3, 2, 1, 4 and 5 would result in a residence time of 6.8 days. The dye patterns observed in cells 3 and 2 confirmed that the hydraulic conditions were very complex.

The hydraulic performance of cell 4 - based on initial lag time and average concentrations – was considerably longer than observed during the wet weather dye test. After dye was first detected at the cell 4 inlet, approximately 10 hours passed before it first appeared at the cell 4 outlet. Plug flow conditions, with one pump operating indicate a theoretical lag time of 12 hours. The short travel time through cells 4 during the October wet weather dye test (2 hours) suggests that, as hypothesized earlier, inflow through the 3-4 curtain during storm events contributes to considerably shorter residence times in these cells.

The dry-weather flow from the sewer system and the pumped flow appear to remain separate to a large extent. Hence, the dry-weather flow would be expected to displace some of the stormwater from the storage cells into the lake through the cell 3 outlet gate. Simultaneously, the pumped lake water would be displacing stored stormwater toward cell 1 for transfer to cells 4 and 5. Some pumped lake water would intermix with the dry-weather flow and the stored stormwater, diluting the effluent from cell 3, but the amount of intermixing appears to be minor.

Although this test did not provide exclusively dry-weather data, the system's response to the rain event of November 25th was very informative. Analysis suggested that during a large event of this nature, the facility was effective in storing most of the new influent water. This interpretation is consistent with the analysis of discrete suspended solids data discussed in later in this chapter. After the event, the displaced residual dye in cells 1 and 2 was subsequently returned to cell 1 and transferred to cells 4 and 5 by pumping.

If additional dye tests are to be conducted, tracing of the dry-weather flow by adding dye to the influent would be informative. Different dyes may be considered for the influent and lake water in a simultaneous test of the two streams, assuming that the dyes can be measured at different wavelengths in a common sample. An additional change is recommended: the cell 3 effluent should be sampled in the outlet channel to avoid sampling the lake water plume in cell 3.

4.4 Settling Dynamics

The dye tests provided an understanding of flow patterns and the path that dissolved constituents may follow during dry and wet weather periods. The movement of particulate matter in the facility was determined through discrete sampling of suspended solids at seven stations. This information helps to assess the function of the facility with respect to solids removal and to identify the relative magnitude of deposition in each of the cells. Particle size distribution data during wet and dry events are also discussed in this section.

Table 4.7 summarizes the hydrologic and sediment characteristics of the four events selected for analysis and discussion in this section. The events include one small intense rain event (Oct. 23/01), one medium size event (June 21/02) and two large back-to-back events (July 21 and 22/02).

Table 4.7: Characterization of events selected for discrete TSS analysis

Date	Total Rain (mm)	Rain Duration (hrs)	Inflow Volume (m^3)	Peak Flow Rate (L/s)	Runoff Coeff.	Removal Eff. (%)	TSS Effluent EMC (mg/L)
Oct 23/01	7.1	1.5	3,255	1,544	0.26	93	7.6
June 12/02	12.2	4.0	5,704	2,034	0.26	95	9.2
July 21/02	25.7	2.4	12,338	6,612	0.29	72	28.8
July 22/02	23.3	3.8	12,603	7,953	0.33	80	18.3

Unfortunately, the facility was not operating as designed during the three events sampled in 2002. In particular, the cell 5 outlet was blocked with beach sediment and the lake-cell 3 pump was in disrepair. Although neither of these deficiencies would be expected to significantly compromise overall system performance, they would have exerted some influence on sediment dynamics and should be borne in mind when interpreting results.

4.4.1 Event of October 23, 2001

The October 23rd storm event was the event during which the wet weather dye test was conducted. TSS concentrations were determined indirectly from turbidity analysis of discrete samples and regression relationships between TSS and turbidity (see section 3.5.2). Total rainfall was 7.1 mm during this event, 5 mm of which fell within a period of 25 minutes. Figure 4.17 presents the hyetograph, hydrograph, dye concentrations and TSS pollutograph for the event.

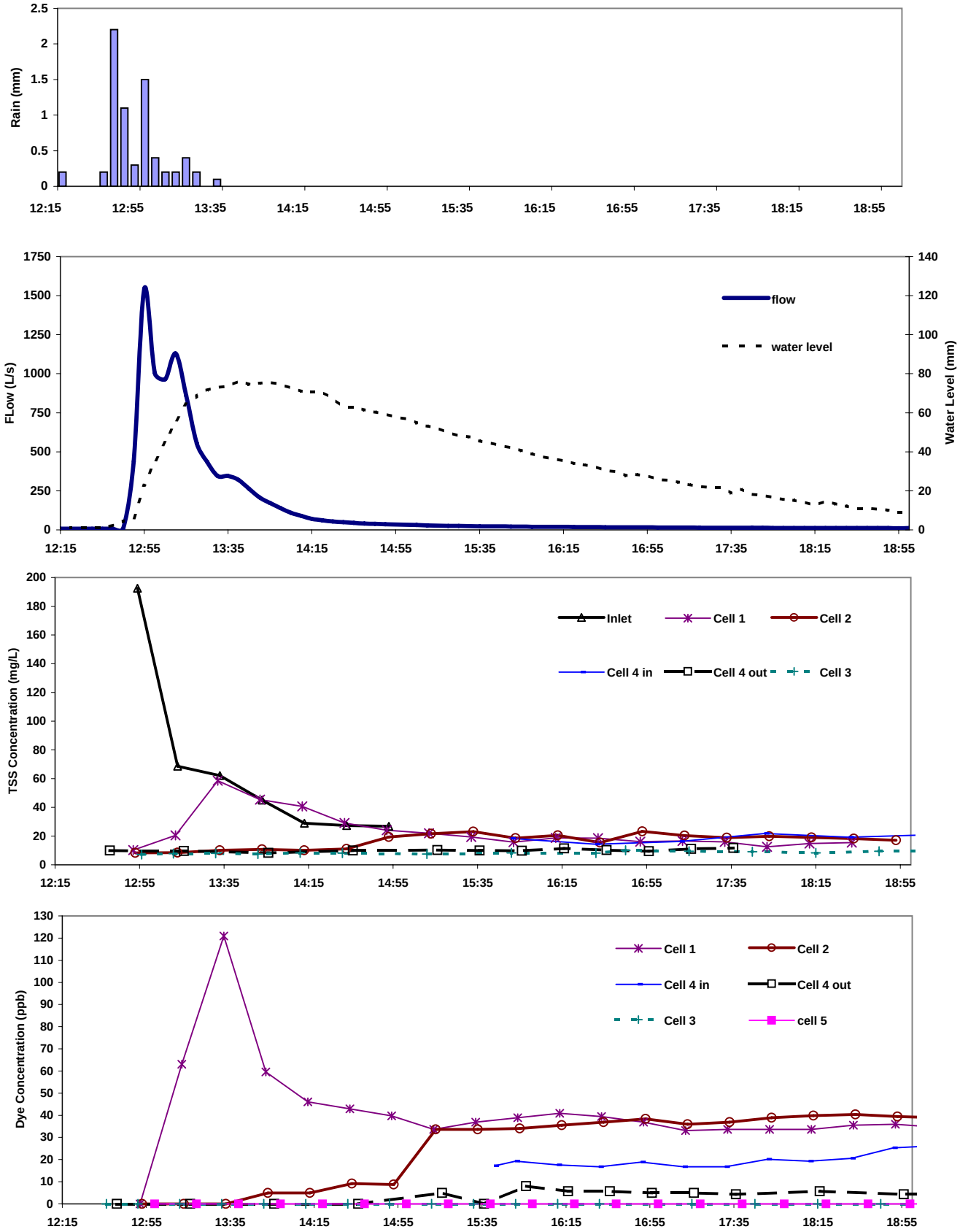


Figure 4.17 : Hyetograph, hydrograph, dye and TSS concentrations for the event on October 23rd, 2001

The influent hydrograph and pollutograph peaked simultaneously, resulting in a flow weighted mean influent concentration for the event of 116 mg/L. Water levels peaked approximately 1 hour after the peak of the inflow hydrograph, and at roughly the same time as the peak of the cell 1 TSS pollutograph. The dye and suspended solids concentrations at the cell 1 station showed a similar pattern during the first 2 hours of runoff. After this time, TSS concentrations in cell 1 declined considerably, whereas the dissolved dye increased slightly and remained at higher levels relative to baseline, as would be expected.

Under strict plug flow conditions (i.e. no mixing), the entire inflow volume from the storm (3220 m^3) would have been captured in cell 1 (volume = 7900 m^3), and there would have been no evidence of suspended solids or dye in cell 2. In reality, however, there is considerably mixing between new influent and stored water, and not all of the available storage is being used to maximum effect. Therefore, it is not surprising to see a modest jump in suspended solids at the cell 2 outlet after the first two hours of the storm. The similarity of the observed concentrations to those in cell 1, and the extended length of the peak suggest that the cell 2 concentrations are comprised primarily of relatively fine particles that settle out of suspension only under highly quiescent conditions. Dye concentrations in cell 2 experience a rapid rise about 20 minutes after the jump in cell 2 TSS concentrations, although the first signs of dye at the monitoring location occurred roughly an hour earlier.

The cell 4 inlet sampler malfunctioned during the storm and had to be initiated manually, resulting in a significant delay in sample collection. TSS concentrations at this station during the last three hours of outflow were in the same range as at the cell 1 and 2 stations. Dye concentrations at the cell 4 inlet were lower than at the other two stations over the same period. Since the intake to the cell 4 inlet pump is located near the bottom of cell 1, upstream of the cell 1 intake, it may be assumed that the dissolved dye, which is not subject to settling, was more concentrated near the surface.

The cell 3 outlet showed no significant change in TSS concentrations. This was also true of the cell 4 outlet, although dye concentrations at that location show a minor increase about 3 hours after the start of runoff. Turbidity measurements were not measured on cell 5 samples, but TSS concentrations of 4 composite samples collected during and two days after the event were not significantly different.

4.4.2 Event of June 21, 2002

Figure 4.18 shows the hydrographs, pollutographs and a depth profile of water temperature during the June 21st event. The temperature depth profile was measured on the downstream side of the cell 1-2 curtain near the centre.

This event had 12.2 mm of rain distributed as three peaks approximately one hour and 30 minutes apart. Approximately 67% of the total mass of suspended solids was discharged over the first 30 minutes of the storm. The flow weighted influent TSS concentration for the event was 197 mg/L.

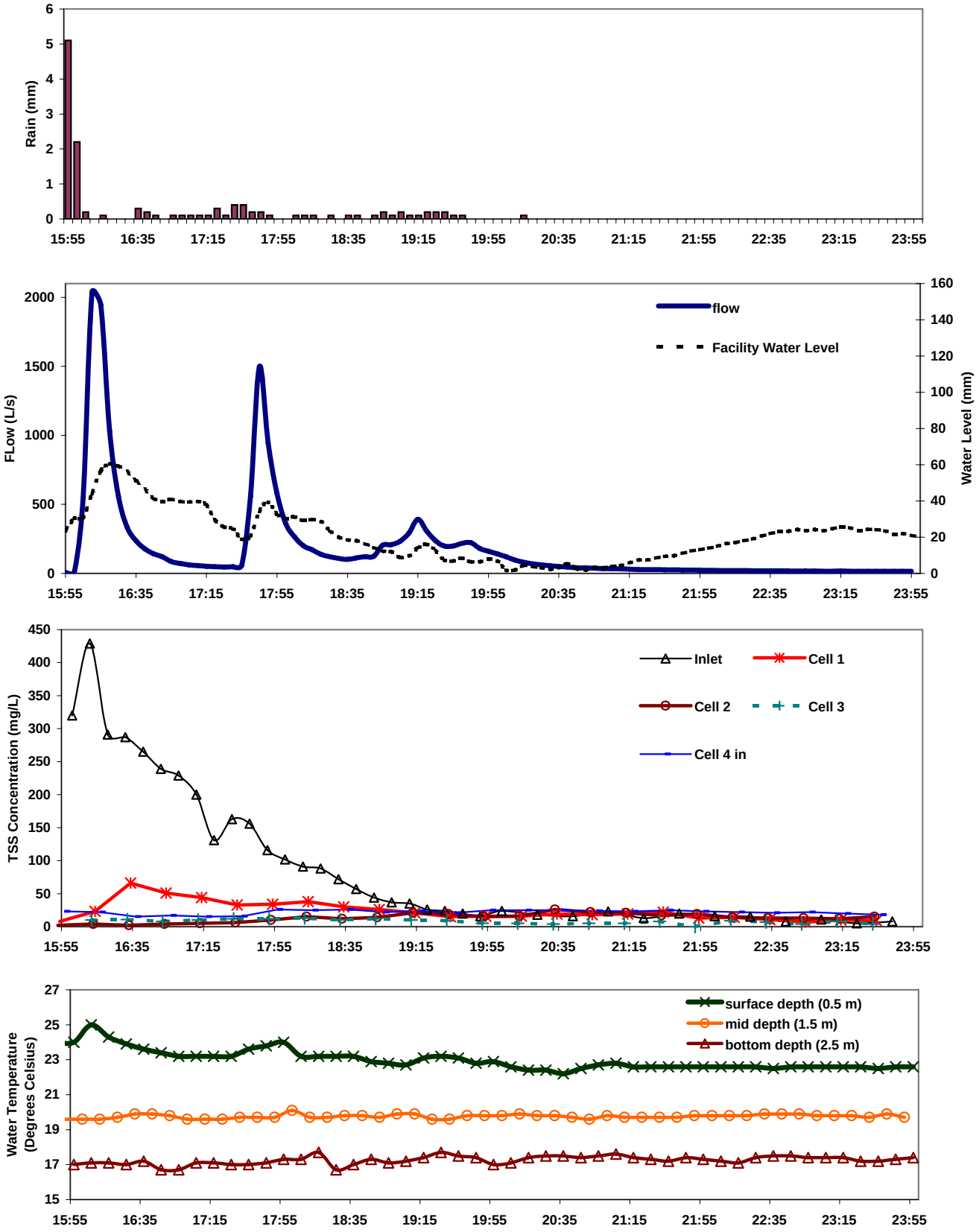


Figure 4.18 : hyetograph, hydrographs, TSS concentrations and depth profiles of temperature at the cell 1-2 curtain for the event on June 21, 2002

Lake levels were above the concrete sill of the cell 3 outlet weir during this event. Prior to the event, lake water was flowing into the facility through the cell 3 weir, as seen by the rising facility water levels. Event runoff reversed the direction of flow from the lake into the facility to the facility out to the lake.[6] Over the course of the event, lake waters decreased by about 2 cm below pre-event levels, then started to increase again.

Cell 1 was the only station within the facility that showed distinct variations in discrete TSS concentrations. The peak concentration at this station occurred 23 minutes after the influent peak and corresponded with the maximum facility water level. The absence of a similar rise in TSS concentrations at the cell 4 inlet station suggests that new runoff may have short circuited across the top of the cell. The relatively constant temperatures at the 1.5 and 2.5 m depths during the initial stages of the storm lend support to this interpretation.

After the second plug of flow, a small but distinguishable rise in TSS concentrations can be observed at the cell 4 inlet and the cell 2 outlet. A small change in cell 2 inlet water temperatures (all depths) can be observed at roughly the same time. Overall, however, the pre-event thermal stratification is maintained throughout the event, suggesting minimal vertical mixing.

The absence of any change in cell 3 concentrations indicates that the entire influent volume (5,704 m^3) was stored and treated.

4.4.3 Event of July 21, 2002

During the July 21st event, 26 mm of rain fell over a period of 2 hours and 25 minutes (Figure 4.19). The total flow volume of 12,338 m^3 was sufficient to fill all of cell 1 (7900 m^3) and part of cell 2 (9400 m^3). The second pump transferring water to cell 4 was automatically triggered 1 hour and 15 minutes after the initiation of runoff, in response to peak inflow exceeding 4000 L/s. The second pump remained on for 60 hours. The combined transfer rate of the two pumps to cell 4 was 8 m^3/min or 480 m^3/hour.[7] A mass based analysis of this event and a second large event occurring on the following day is provided in Appendix D.

The influent hydrograph had two peaks occurring one hour and 20 minutes apart. Mass loading of suspended solids was greatest during the second hydrograph peak. The mean flow weighted influent TSS concentration for the event was 104 mg/L.

[6] The cell 3 gates swing out towards the lake to protect the facility from storm surges, but water can still enter at the interface between the gate and concrete sill. The uneven response of water levels to runoff during this event may reflect the resistance that high lake levels exert on the gates.

[7] Note that even with two pumps running, the total volume of water transferred to cell 4 during the period of runoff is less than 10% of the total inflow volume.

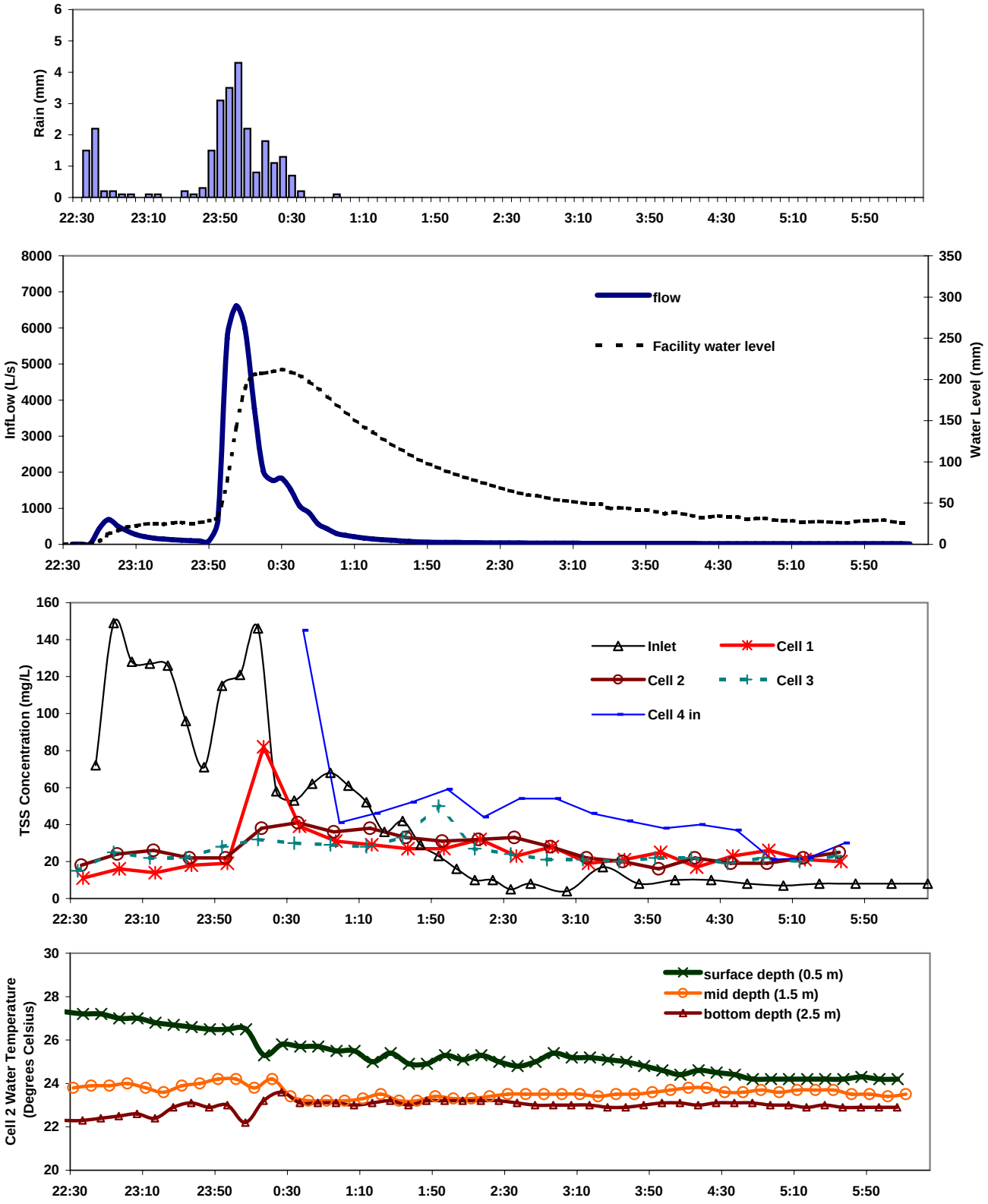


Figure 4.19 : Hyetograph, hydrographs, TSS concentrations and temperature depth profiles at the cell 1-2 curtain for the event on July 21, 2002

The peaks of the TSS pollutographs at the cell 4 inlet and cell 1 stations corresponded with peak water levels in the facility. The cell 2 pollutograph peaked 20 minutes later. As during the October 23rd event, the rise and fall of TSS concentrations at cell 2 were slower and less pronounced than in cell 1, suggesting a finer particle size distribution at this station.

All of the effluent exited through cell 3. There was a gradual rise in cell 3 TSS concentrations from 15 to 30 mg/L during the initial stages of the storm. The cause of this early rise was probably related to the re-suspension of previously settled solids as the flow rate through the gates increased. Another jump in concentrations from 30 to 50 mg/L occurred later in the storm. It is tempting to attribute this increase to the effect of new influent water. However, the rise is brief and may be simply the result of wash off from the pontoons or suspended material from elsewhere in the facility *(e.g.* sediment ponds) that was mobilized during high flow.

Although influent temperature was not measured, the cell 2 temperature response suggests an average influent temperature of roughly 23°C, which is lower than the pre-event 0.5 and 1.5 m temperatures in cell 2 and higher than the temperature at 2.5 m. The water temperature starts to change slowly after the first hour of flow. Sharp temperature fluctuations occur over a period of 43 minutes from 23:53 to 0:36, corresponding to the second and larger plug of stormwater runoff. The drop in surface water temperature corresponds with the peak in the cell 1 and cell 4 inlet suspended solids concentration. Temperatures stabilize 10 minutes earlier at the surface than at the two lower depths, suggesting marginally faster flow across the surface, but overall the flow appears to be well integrated vertically. Unlike the June 21st storm, temperatures continue to change until about 4:40 in the morning, when a stable, relatively well mixed equilibrium is reached.

4.4.4 Event of July 22, 2002

The July 22nd event arrived before inflow rates from the previous event had returned to baseflow levels. Another 23 mm of rain fell during this event, most of concentrated in a single hydrograph peak (Figure 4.20). Peak flow would have been sufficient to trigger the second pump at cell 1 but this was not necessary because the pump was still on from the previous event.

Despite significant wash off from the earlier rain event, the first flush phenomenon was still recognizable. Within the facility, TSS pollutographs at the cell 4 inlet and cell 1 outlet peaked before the influent TSS peak. The peak of the cell 2 and 3 pollutographs occurred 0.7 and 2.3 hours later, respectively. In this case, the peaks may be interpreted as the progress of influent water as it travels through the system, a small portion of which is eventually discharged to the lake (also see mass based analysis in Appendix D).

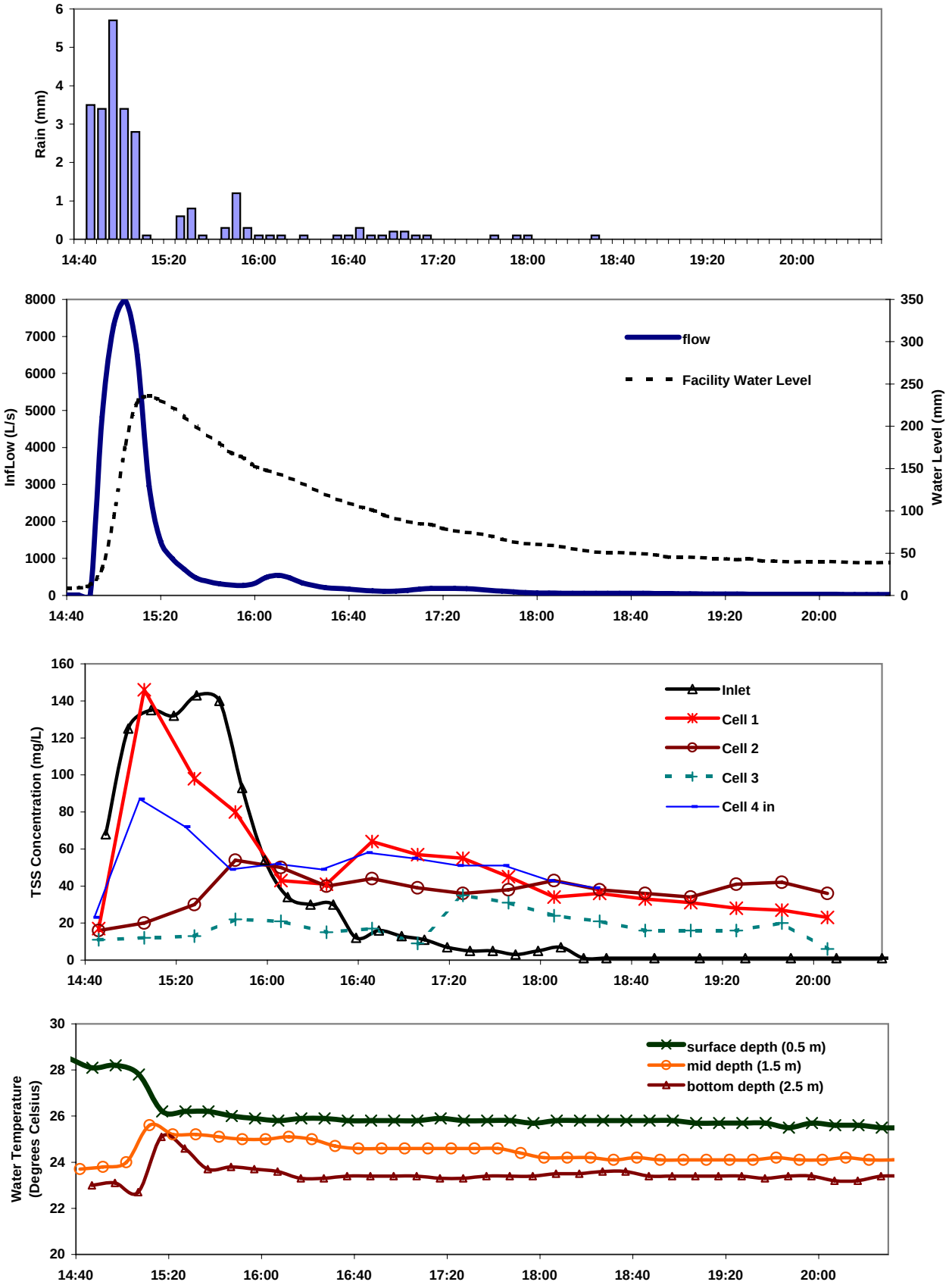


Figure 4.20 : Hyetograph, hydrographs, TSS concentrations and temperature depth profiles at the cell 1-2 curtain for the event on July 22, 2002

Water temperatures at all depths in cell 2 respond (*i.e.* rise at 1.5 and 2.5 m and decline at 0.5 m) to the influent at the same time suggesting a plug flow that is relatively well integrated vertically. That the surface water temperature does not drop as far as during the previous event (26 vs 24 °C) may be explained by the timing of the events: the first event occurred in the early morning whereas this event occurred in the late afternoon, when influent temperatures would be expected to be warmer.

4.4.5 Particle size distributions

Figures 4.21 and 4.22 compare average particle size distributions at each of the monitoring stations during wet and dry weather. Only data from the 2000 monitoring season were available.[8] Distributions for individual events are presented in Appendix E.

During wet weather, the average particle size distributions at cells 3, 4 and 5 were all significantly different than that of the inlet at the 95% confidence level. The median particle size was approximately 7.5 μm at the inlet, compared to 3.5 μm at the pump intake at cell 4 and 2 μm at the two outlets.[9] Particle size ranges at the inlet and outlets were 0.17 - 175 and 0.17 - 30 μm, respectively, indicating that the system was effective in removing all particle sizes greater than 30 μm.

During dry weather, 6 of the 20 grab samples collected had particle concentrations less than that required to undertake particle size analysis by the method employed in the laboratory. Among the remaining samples, outlet and inlet average size distributions had high standard deviations and were not found to be significantly different at the 95% confidence level. The median particle size was approximately 5.5 and 2 μm at the inlet and two outlets, respectively. Note that the dry and wet median effluent particle sizes were both 2 μm. Other studies of detention basins conducted by SWAMP suggest that even with larger permanent pools and longer settling times, it is not practical to expect reductions beyond a median effluent particle size of 2 μm.

[8] Samples were submitted for analysis of particle size during the 2001 and 2002 seasons, but after the 2000 monitoring season, the laboratory dramatically raised the threshold beyond which samples were considered to be too clear for analysis. Hence, only a small number of influent and cell 1 samples were analyzed.
[9] An influent median particle size of 11 μm was used in the design of the facility (Aquafor Beech, 1994).

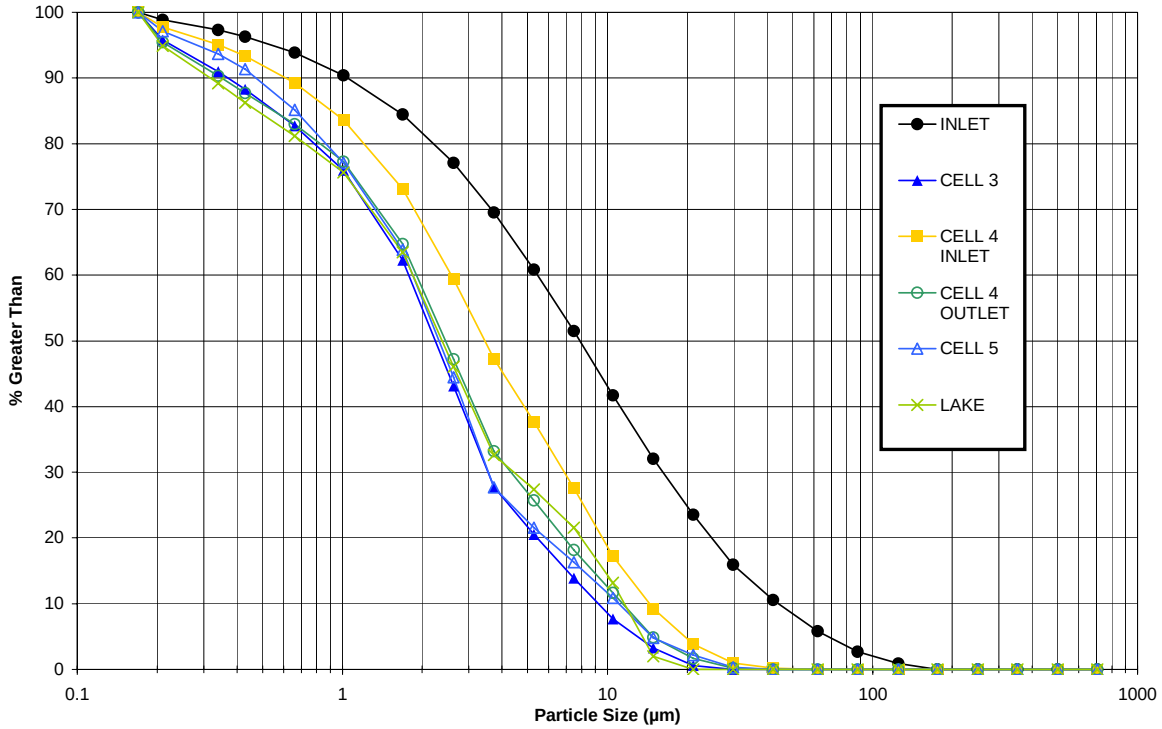


***Figure 4.21*:** Average cumulative particle size distributions of wet weather samples collected from May 10 to November 16, 2000

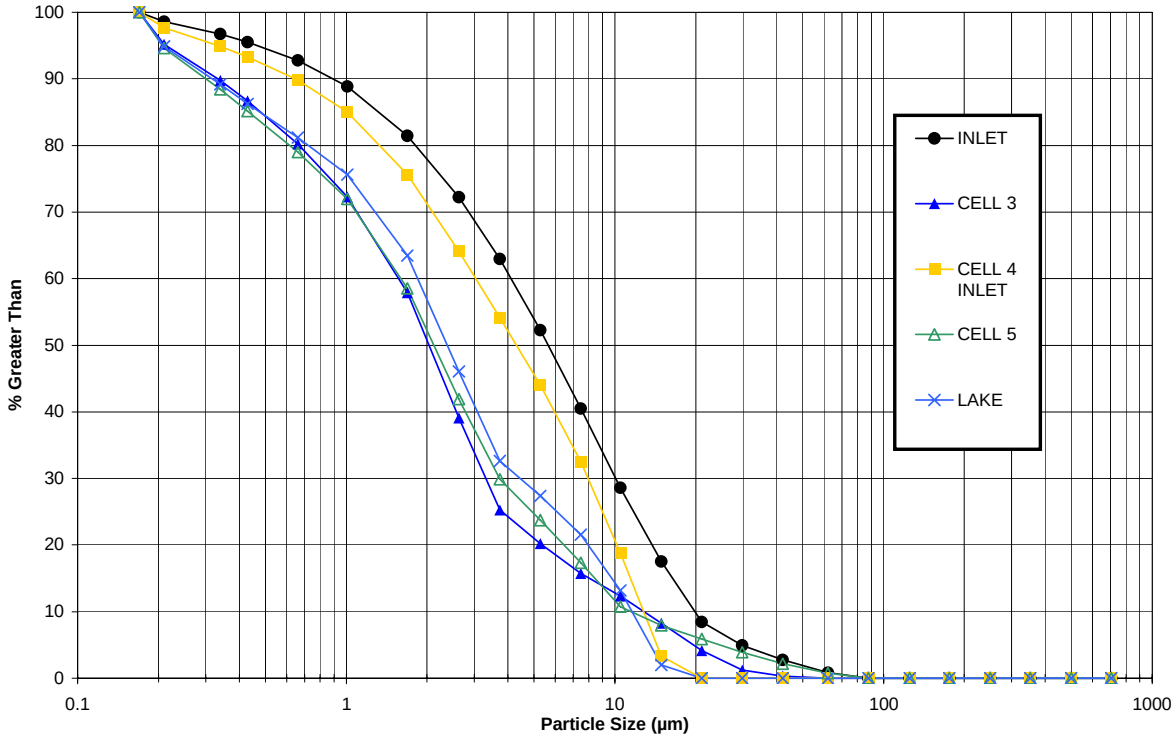


***Figure 4.22*:** Average cumulative particle size distributions of dry weather samples collected from May 10 to November 16, 2000

4.5 Water Quality

The following sections summarize water quality and temperature monitoring results for wet and dry weather, and during the post event period. Detailed water quality summary statistics are provided in Appendix F.

4.5.1 Wet weather concentrations

4.5.1.1 Effluent

Comparison of wet weather effluent concentrations with receiving water standards developed by government agencies for a range of water quality variables provides an indirect measure of the potential impact that facility discharges may have on the health of receiving waters with respect to aquatic life and other recreational uses. While effluent concentrations are not necessarily expected to meet receiving water guidelines, the comparison provides a general indication of which variables may be of concern and allows for a qualitative assessment of whether or not the observed concentrations are likely to cause impairment of lake water quality once discharge has occurred.

Table 4.8 summarizes average event mean concentrations (AEMCs), ranges and detection frequencies at each of the two outlet stations during wet weather. Only those organic compounds (PAHs, OC pesticides) that were detected above the reporting method detection limit (RMDL) were included in the table. Appendix F lists all organic parameters analyzed, their detection limits, and associated Provincial Water Quality Objectives (PWQOs) (MOEE, 1994). Metals with low detection frequencies include vanadium, lead, selenium, arsenic, beryllium, chromium, cobalt, molybdenum, nickel and cadmium.

The only water quality variables with average effluent event mean concentrations above provincial water quality objectives (PWQOs) were total phosphorus, copper and *E.coli*. The detection limit for lead (10 ug/L) exceeded the PWQO. Lead was above the detection limit in only 2 and 5% of samples collected at the cell 3 and 5 outlets. Mean concentrations of iron exceeded the PWQO at cell 5 only. Other variables that occasionally exceeded available guidelines in facility effluents included cadmium, cobalt and 2,4-D. Although, there is no provincial receiving water guideline for TSS, a value of approximately 30 mg/L (25 mg/L + background levels) in suggested in the Canadian Water Quality Guidelines. Only two of the effluent samples (one at cell 3, the other at cell 5) had concentrations that exceeded this value; both of which occurred during storms with greater than 30 mm of rainfall in less than 4 hours.

Use of the facility by wildlife, particularly birds, was thought to be a factor contributing to the presence of phosphorus and faecal bacteria in the effluents. Geese, sea gulls and other waterfowl enjoyed perchering on the gated pontoons, resulting in the accumulation of large quantities of faecal matter, some of which would invariably wash off during rain events. This result is not unique to this facility; other studies of ponds and wetlands in the GTA have shown similar results with respect to phosphorus and *E.coli* (SWAMP 2002, 2003).

Table 4.8 : Effluent water quality statistics. Shading represents values exceeding receiving water guidelines

Category	Variable	Cell 3 outlet							Cell 5 outlet							GUIDE-LINE
		N	%>DL	MIN	MAX	MEDIAN	FLOW WEIGHTED MEAN[1]	% > GUIDE LINE[2]	N	%>DL	MIN	MAX	MEDIAN	FLOW WEIGHTED MEAN[1]	% > GUIDE-LINE[2]	
General Chemistry	Suspended Solids (mg/L)	53	100	3.3	67	11.0	18.8		38	100	6	37	13.5	17.9		
	Dissolved Solids (mg/L)	53	100	160	486	232	257		38	100	190	506	236	272		
	Total Solids (mg/L)	53	100	170	495	244	275		38	100	202	528	250	290		
	Oil and grease (mg/L)	50	36	0.25	4	0.95	1.17		36	39	0.25	2	0.5	1.04		
	Conductivity (uS/cm)	52	100	247	748	362.5	397.0		37	100	292	779	364.0	421.8		
	pH	52	100	7.41	8.56	8.1	8.0	4	37	100	7.9	8.45	8.1	8.1	0	6.5-8.5
	Alkalinity (mg/L CaCO3)	52	100	53.5	217	97.5	96.7		37	100	84	110	98.0	95.0		
	Turbidity (FTU)	53	100	2.01	58.4	8.2	14.8		37	100	5.79	31.8	12.6	15.4		
	BOD (mg/L)	12	100	1.2	4.4	2.7	2.9		5	100	0.4	4	3.4	3.1		
	Chloride (mg/L)	52	100	23.8	212	38.5	53.8	0	37	100	28.2	165	38.8	60.1	0	250
	Carbon (DOC) (mg/L)	52	100	2	8.2	2.9	3.3		37	100	2.3	7.8	3.0	3.5		
	Carbon (DIC) (mg/L)	52	100	18	31.2	22.8	22.9		37	100	18.8	25.6	22.6	22.2		
	Silicon (mg/L)	52	98	0.02	1.08	0.46	0.53		37	100	0.16	1.08	0.52	0.53		
Metals	Aluminum (ug/L)	52	98	7.14	736	84.6	130.08		38	100	46.5	297	97.3	129.90		
	Arsenic (ug/L)	52	0	0.5	0.5	0.5	0.50	0	37	0	0.5	0.5	0.5	0.50	0	5
	Barium (ug/L)	52	100	20.1	39.9	26.4	28.47		38	100	21.3	41.1	27.85	30.06		
	Beryllium (ug/L)	52	0	7E-04	0.1	0.1	0.05	0	38	0	0.009	0.1	0.1	0.07	0	1100
	Cadmium (ug/L)	52	6	0.04	0.88	0.30	0.37	10	38	3	0.23	0.69	0.30	0.32	5	0.5
	Calcium (ug/L)	52	100	29700	50200	37000	37753		38	100	29200	45900	37650	37481		
	Chromium (ug/L)	52	6	0.073	3.01	0.7	0.79		38	0	0.322	1.24	0.7	0.74		
	Cobalt (ug/L)	52	2	0.33	5.36	0.65	1.02	2	38	0	0.47	0.98	0.65	0.68	3	0.9
	Copper (ug/L)	52	94	0.8	52.3	3.95	5.21	37	38	92	0.8	67	3.18	9.77	24	5
	Iron (ug/L)	52	100	2.76	1450	192	270	17	38	100	114	711	236	304	21	300
	Lead (ug/L)	52	2	0.14	15.7	5	5.19	4	38	5	5	14.6	5	5.68	5	5
	Magnesium (ug/L)	52	100	5160	11900	7880	7554		38	100	5550	9980	7720	7675		
	Manganese (ug/L)	52	98	0.134	206	33.3	56.0		38	100	22.2	82.7	31.9	43.7		
	Mercury (ug/L)	37	3	0.01	0.2	0.02	0.02	0	27	0	0.01	0.02	0.02	0.02	0	0.2
	Molybdenum (ug/L)	52	27	0.223	10.1	0.8	1.14	0	38	26	0.8	9.56	0.8	1.76	0	40
	Nickel (ug/L)	52	35	0.053	3.84	0.65	1.09	0	38	26	0.65	8.22	0.65	1.01	0	25
	Selenium (ug/L)	52	0	0.5	0.5	0.5	0.50		37	0	0.5	0.5	0.5	0.50		
	Strontium (ug/L)	52	100	121	237	165	159		38	100	125	198	164	162		
	Titanium (ug/L)	52	98	0.25	13.4	3.095	3.85		38	100	1.28	11.6	4.55	5.63		
	Vanadium (ug/L)	52	2	0.164	3.08	0.75	0.79	0	38	0	0.557	1.4	0.75	0.82	0	6
	Zinc (ug/L)	52	100	2.23	106	5.855	11.68	2	38	97	0.3	15.5	5.11	6.35	0	20
Nutrients	Nitrogen (NH3+NH4) (mg/L)	52	98	0.001	0.506	0.123	0.15		37	97	0.002	0.237	0.15	0.13		
	Nitrogen (NO2) (mg/L)	52	100	0.003	0.528	0.035	0.07		37	100	0.002	0.22	0.032	0.04		
	Nitrogen (NO2+NO3) (mg/L)	52	100	0.121	1.16	0.448	0.47		37	100	0.008	1.28	0.371	0.37		
	Phosphate (mg/L)	52	69	3E-04	0.039	0.0085	0.01		37	62	0.002	0.039	0.008	0.01		
	Total Phosphorus (mg/L)	52	100	0.028	0.156	0.052	0.08	98	37	100	0.028	0.129	0.06	0.08	97	0.03
	TKN Nitrogen (mg/L)	52	100	0.4	1.76	0.63	0.77		37	100	0.48	2.16	0.7	0.80		
Bacteria	*E. coli (c/100mL)**	11	100	10	9000	240	279	64	7	100	8	650	60	74	29	100
	*F. strep. (c/100mL)**	11	91	4	5700	500	235		7	100	12	500	60	66		
	*P. aeruginosa (c/100mL)**	11	64	2	290	28	21		7	14	2	300	4	6		
Herbicides and Pesticides	2,4,6 -trichlorophenol (ng/L)	30	7	20	48	20	21		26	4	20	28	20	20		
	Pentachlorophenol (ng/L)	30	7	10	19	10	11	0	25	4	10	170	10	13	0	500
	Dicamba (ng/L)	30	13	50	340	50	68	0	25	20	50	910	50	89	0	200000
	2,4 -D (ng/L)	38	58	100	2300	140	200	0	29	38	100	9700	100	532	3	4000

1. See section 3.7 for the method used to calculate flow weighted means. 2. '% > Guideline' represents the percentage of samples collected that have concentrations exceeding the receiving water guideline. 3.Geometric mean was used instead of the flow weighted mean for bacteria variables.

In general, Cell 5 effluents were marginally cleaner than those of Cell 3. For example, at cell 5, only 29% of samples had *E.coli* densities above the provincial guideline, compared to 64% at cell 3. Copper, which is one of the most common road runoff contaminants, was also observed less frequently above the guideline at the cell 5 outlet. These results are not unexpected since the dominant flow path for new event water is through cells 1 to 3 (see mass-based analysis in Appendix D).

4.5.1.2 Sedimentation Cell

As indicated earlier, cell 4 was intended to remove contaminants from water pumped out of cell 1during and after storm events. Water exiting cell 4 subsequently passes through the cell 5 wetland and out to the lake. Table 4.9 shows the cell 4 influent and effluent concentrations for key water quality variables of concern. Only events with paired samples at the inlet and outlet of cell 4 were included. At this location flow proportioning or load based analyses is not required since pumping occurs at a constant rate.[1]

Table 4.9: Wet weather concentrations for selected water quality variables at the inlet and outlet of cell 4

	Cell 4 Inlet				**Cell 4 Outlet**			
	Min	**Max**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**
TSS (mg/L)	6.0	50.5	19.6	15.5	3.0	35.5	11.1	10.0
TP (mg/L)	0.04	0.20	0.11	0.11	0.03	0.15	0.07	0.06
Copper (ug/L)	2.1	40.0	7.4	7.4	0.8	81.3	6.5	3.7
Zinc (ug/L)	3.4	28.8	16.3	14.5	0.7	24.4	6.3	5.8
***E.coli* (c./100 mL)**	76	30000	2343**	1535	20	17000	275**	380

*n = 29 for TSS, TP, Cu, Zn; n = 6 for *E.coli ;* ** geomean

Results indicate that cell 4 reduced the concentration of all water quality variables measured in the study. Cell 4 effluent concentrations were similar to those reported for the cell 5 outlet, indicating that pollutant loading into cell 5 from cell 4 was relatively minor and that the wetland does not significantly augment treatment provided by upstream cells. There also appeared to be no significant increase in cell 4 effluent concentrations during large events when the second pump was running, even though the increase in discharge

[1] The pump rate varies only when a second pump is triggered by high influent discharge after the cell 4 auto-sampler has begun to collect samples (see section 2.1). This did not occur during any of the events summarized in Table 4.9. Removal efficiencies are not reported because influent concentrations are below the level at which this indicator of performance provides meaningful results (see for example Strecker, 1994).

associated with two pumps significantly reduces cell 4 residence time. These results are encouraging since the wetland was partly intended to provide healthy habitat for aquatic organisms and wildlife.

4.5.1.3 Acute toxicity

Large volume samples were collected at the inlet (n = 3) and cell 4 outlet (n = 3) during the 2000 monitoring season to test for acute toxicity to rainbow trout and *Daphnia Magna*. All samples were found to be non-toxic to test organisms (Table 4.10). Based on these results, toxicity testing was discontinued in 2001 and 2002.

***Table 4.10*:** Summary of toxicity results

Date	Inlet		Cell 4 outlet	
	Rainbow trout	***Daphnia Magna***	**Rainbow trout**	***Daphnia Magna***
September 23/00	--	--	*non-lethal*	*non-lethal*
October 4/00	*non-lethal*	*non-lethal*	*non-lethal*	*non-lethal*
October 27/00	*non-lethal*	*non-lethal*	*non-lethal*	*non-lethal*
November 10/00	*non-lethal*	*non-lethal*	--	--
November 20/00	*non-lethal*	*non-lethal*	--	--

Note: rainbow trout 96 hour acute lethality test; daphnia magna 48 hour acute lethality test

4.5.1.4 Beach impact assessment

One of the reasons that a stormwater facility was built in Bluffers Park was to protect the swimming area approximately half a kilometre east of the facility from high loads of bacteria (Figure 2.1). Historically, the beach has been closed for much of the season because of bacterial contamination. The facility does not appear to have significantly improved this situation, despite significant reductions in *E.coli* through the facility during rain events (see section 4.7).

To assess the potential impact of effluent *E.coli* concentrations on beach closings, the geometric mean of five *E.coli* samples collected at the beach area are compared to effluent event mean concentrations from the facility on the same day (Table 4.11). The data do not suggest any connection between facility effluents and beach concentrations of *E.coli*. On some occasions, effluent concentrations are high but beach concentrations are low and vice versa. An adverse impact of facility effluent on the beach would likely require much higher concentrations than were observed because of significant dilution in Lake Ontario.

Table 4.11: Comparison of facility effluent and Bluffers Park beach *E.coli* densities.

Date	***E.coli* Concentrations (coliforms/100 mL)***		
	Cell 3	**Cell 5**	**Bluffers Park Beach**
June 13, 2000	3400	blocked (no flow)	1105
June 15, 2000	80**	blocked (no flow)	777
July 17, 2000	9000	blocked (no flow)	50^{++}
August 8, 2000	700	blocked (no flow)	580^{++}
September 11, 2000	4000**	650	762
October 4, 2000	10	n/a	11
June 11, 2001	180	n/a	1238
June 20, 2001	16	60	434
July 17, 2001	1400	620	3365
August 16, 2001	n/a	50	80
October 16, 2001	80	60	1086

Provincial guideline for body contact recreation is 100 coliforms/100 mL
*Dunkers samples are 24 bottle composites collected over 4 hours; Bluffers Park beach sample concentrations represent the geometric mean of 5 grab samples collected along the shore of the beach.
**Grab samples collected from Lake Ontario immediately downstream of the facility had *E.coli* concentrations of 80 and 72 c./100 mL on June 15th and September 11th, respectively.
$^{++}$The storm occurred late in the day. Beach samples were collected the following morning.

4.5.2 Post Event Sampling

Sampling after runoff events (hereafter referred to as 'post event sampling') was conducted for selected events in 2001 to determine changes in effluent water quality as runoff stored from a previous event was pumped continuously into cell 4, through cell 5 and out to the lake. Complete pump-out of water in cells 1, 2 and 3 requires roughly 120 hours; or 60 hours with both cell 4 pumps running. Automated 'post event samplers' were stationed next to event samplers at the cell 4 inlet and cell 5 outlet and were programmed with an 8 hour delay (representing the event duration) to collect 24 discrete samples over a period of 24 and 48 hours respectively. The discrete samples were subsequently divided into 3 composites, representing 8 hour time intervals at cell 4 and 16 hour time intervals at cell 5.

Table 4.12 presents the results of event and post event sampling for two mid-sized events and two large events. The event sample composites were collected during the runoff event (8 hour duration). The post event samples at the cell 4 inlet and cell 5 outlet were collected after the end of runoff over 3 consecutive 8 and 16 hour time periods, respectively. The second pump at cell 1 was triggered during the August 26th and September 21st events, causing a doubling of the rate at which water was transferred from cell 1 to cell 4.

All events show a gradual decline in suspended solids over time to a background concentration consisting primarily of very fine particles of between 8 and 12 mg/L. Concentrations of other constituents that are strongly adsorbed by suspended solids, such as phosphorus, copper and zinc, displayed a more significant reduction at the cell 4 station. The same is true for oil and grease, which was below detection levels at cell 5. These results demonstrate the water quality benefit associated with incremental increases in the settling period, as well as the concentration limits (sometimes referred to as 'irreducible concentrations') beyond which further reductions are either impossible or very slow (given a fixed baseflow rate and in-pond sources of these pollutants).

4.5.3 Dry Weather Concentrations

Table 4.13 summarizes average event mean concentrations (AEMCs) and detection frequencies at the inlet and outlet during dry weather. Under dry-weather conditions, the influent is storm sewer baseflow that consists primarily of groundwater that has infiltrated into the pipes through cracks and fissures; it contains little suspended material but can contain somewhat elevated concentrations of constituents related to alkalinity, salinity and soluble metals. The storage and treatment cells contain residual suspended material from previous runoff events. The suspended material in the wetland (cell 5) may also originate from algae growth and sediment resuspension induced by wind, fish or waterfowl.

During dry weather, outlet AEMC detection frequencies below 20% were noted for arsenic, beryllium, cadmium, chromium, cobalt, lead, mercury, selenium vanadium, 2-4-6 trichlorophenol, dicamba, 2-4-D and several other organic parameters not included in Table 4.13, but listed in Appendix F. Suspended solids displayed a slight increase through the pond, while other common stormwater contaminants, including zinc, copper, phosphorus and bacteria showed significant reductions. Chloride was reduced because it is denser than water and tends to concentrate at the bottom of stormwater ponds during dry periods (*i.e.* it shows net removal); this constituent is flushed from the facility during large storm events.

Despite these reductions, average concentrations of total phosphorus, iron and *E.coli* exceeded PWQOs (MOEE, 1994) at one or both of the two outlets. All lake water pollutant concentrations were consistently less than their respective PWQO values.

Table 4.12 : Event and post event composite samples for selected water quality variables

	Cell 4 Inlet Composite Samples				Cell 5 Outlet Composite Samples			
	Event	Post Event			Event	Post Event		
Hours from start of runoff	**0 - 8 hrs**	**8 - 16 hrs**	**16 - 24 hrs**	**24 - 32 hrs**	**0 - 8 hrs**	**8 - 24 hrs**	**24 - 40 hrs**	**40 - 56 hrs**
Aug 19/01 (rain = 9.2 mm)								
TSS (m/L)	25.5	18.0	13.5	11.5	19.5	16.0	14.0	12.5
Total Solids (mg/L)	236	214	210	218	256	250	242	240
TDS (mg/L)	212	196	196	206	236	232	228	228
Oil and Grease (mg/L)	1.2	1.4	1.4	1.2	<dl	<dl	<dl	<dl
Total Phosphorus (mg/L)	0.11	0.09	0.08	0.07	0.07	0.06	0.06	0.06
TKN (mg/L)	0.82	0.76	0.72	0.72	0.80	0.72	0.76	0.72
Copper (ug/L)	6.8	6.5	5.1	4.1	4.1	2.7	3.0	2.5
Iron (ug/L)	419	427	295	264	310	246	236	186
Zinc (ug/L)	19.6	17.2	14.0	9.1	7.0	6.9	6.3	5.3
Aug 26/01 (rain = 11.2 mm)								
TSS (m/L)	50.5	29.0	18.0	8.5	16.0	12.5	11.0	10.0
Total Solids (mg/L)	266	232	218	320	238	238	232	230
TDS (mg/L)	216	202	200	312	220	226	220	220
Oil and Grease (mg/L)	1.4	n/a	n/a	n/a	<dl	n/a	n/a	n/a
Total Phosphorus (mg/L)	0.17	0.17	0.12	0.07	0.08	0.06	0.08	0.07
TKN (mg/L)	1.20	1.04	0.92	0.76	0.80	0.68	0.80	0.68
Copper (ug/L)	7.5	6.5	4.6	2.8	2.5	2.1	2.5	2.6
Iron (ug/L)	367	213	158	87	121	92	98	97
Zinc (ug/L)	27.6	20.2	12.4	6.6	5.6	4.1	4.8	3.9
Sep 19/01 (rain = 24.4 mm)								
TSS (m/L)	16.5	13.5	10.0	8.5	24.5	17.0	14.5	10.5
Total Solids (mg/L)	172	160	164	178	250	240	228	224
TDS (mg/L)	156	146	156	170	226	224	214	212
Oil and Grease (mg/L)	1.0	1.4	1.4	1.2	<dl	<dl	<dl	<dl
Total Phosphorus (mg/L)	0.11	0.10	0.08	0.07	0.06	0.06	0.07	0.05
TKN (mg/L)	0.72	0.72	0.68	0.68	0.76	0.64	0.68	0.64
Copper (ug/L)	9.1	7.6	5.9	5.1	3.0	2.4	2.6	2.3
Iron (ug/L)	275	238	197	188	284	265	263	168
Zinc (ug/L)	21.5	17.9	12.8	12.9	4.5	5.4	6.1	4.4
Sep 21/01 (rain = 22.4 mm)								
TSS (m/L)	23.0	20.0	19.0	15.5	n/a	14.5	13.5	8.0
Total Solids (mg/L)	172	154	156	166	n/a	210	198	180
TDS (mg/L)	148	134	136	152	n/a	196	184	172
Oil and Grease (mg/L)	1.8	1.6	1.5	1.4	n/a	<dl	<dl	<dl
Total Phosphorus (mg/L)	0.11	0.10	0.09	0.08	n/a	0.08	0.07	0.05
TKN (mg/L)	0.80	0.76	0.76	0.78	n/a	0.76	0.72	0.64
Copper (ug/L)	7.2	7.0	5.7	4.9	n/a	3.4	2.6	2.6
Iron (ug/L)	340	332	296	244	n/a	254	221	165
Zinc (ug/L)	24.7	23.4	18.4	13.2	n/a	8.1	7.2	6.6

* Cell 4 and 5 event composites were collected over 8 hours. Cell 4 and 5 post event samples were collected over 24 and 48 hour periods. Each post event composite sample represents a period of 8 and 16 hours, respectively.

Table 4.13 : Dry weather median concentrations and detection frequencies

			Inlet		Cell 4 inlet		Cell 3 Outlet		Cell 5 Outlet		Lake Ontario		GUIDE-
Category	**Variable**	**RMDL**	**%>RMDL**	**MEDIAN**	**%>RMDL**	**MEDIAN**	**%>RMDL**	**MEDIAN**	**%>RMDL**	**MEDIAN**	**%>RMDL**	**MEDIAN**	**LINE**
General	Suspended Solids (mg/L)	2.5	46	2.5	100	11.25	93	8	100	11	29	1.25	
Chemistry	Dissolved Solids (mg/L)	10	100	913	100	226	100	254	100	294	100	192	
	Total Solids (mg/L)	10	100	918	100	239	100	266	100	308	100	196	
	Oil and Grease (mg/L)	1	41	1	30	0.5	27	0.5	35	0.5	21	0.5	
	Conductivity (uS/cm)	1	100	1505	100	348.5	100	391	100	453	100	296	
	pH	0.1	100	8.2	100	8.1	100	8.2	100	8.2	100	8.3	
	Alkalinity (mg/L CaCO3)	2.5	100	219.5	100	98.25	100	97	100	107	100	92	
	Turbidity (FTU)	0.01	100	2.1	100	10	100	7.1	100	11.5	100	0.78	
	BOD (mg/L)	0.2	89	2.2	100	2.8	100	2.2	100	3	100	0.7	
	Chloride (mg/L)	0.2	100	315	100	36.6	100	52.8	100	56.8	100	21.8	250
	Carbon (DOC) (mg/L)	0.1	100	3.5	100	3	100	3.4	100	3.4	100	1.9	
	Carbon (DIC) (mg/L)	0.2	100	51.4	100	22.3	100	23.2	100	24.6	100	21.6	
	Silicon (mg/L)	0.02	100	4.02	100	0.38	100	0.7	100	0.6	100	0.13	
Metals	Aluminum (ug/L)	11	100	64.05	100	77.5	100	64.1	100	102	71	19.1	
	Arsenic (ug/L)	1	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0.1
	Barium (ug/L)	0.2	100	57.95	100	26.4	100	26.7	100	31.1	100	21.35	
	Beryllium (ug/L)	0.2	0	0.1	0	0.1	0	0.1	0	0.1	0	0.1	1100
	Cadmium (ug/L)	0.6	14	0.3	0	0.3	0	0.3	4	0.3	0	0.3	0.5
	Calcium (ug/L)	5	100	112500	100	36900	100	36400	100	42300	100	33500	
	Chromium (ug/L)	1.4	25	0.7	0	0.7	19	0.7	22	0.7	14	0.7	
	Cobalt (ug/L)	1.3	4	0.65	0	0.65	0	0.65	0	0.65	0	0.65	0.9
	Copper (ug/L)	1.6	100	8.87	60	1.74	70	3.41	78	2.82	36	0.8	5
	Iron (ug/L)	0.8	100	100.6	100	182.5	100	126	100	216	100	29.6	300
	Lead (ug/L)	10	4	5	0	5	4	5	0	5	7	5	5
	Magnesium (ug/L)	8	100	16650	100	7790	100	8130	100	8640	100	8455	
	Manganese (ug/L)	0.2	100	18.6	100	37.5	100	44.9	100	49.5	100	2.315	
	Mercury (ug/L)	0.02	4	0.02	0	0.02	0	0.02	0	0.02	0	0.02	0.2
	Molybdenum (ug/L)	1.6	46	0.8	30	0.8	56	1.69	52	1.65	7	0.8	40
	Nickel (ug/L)	1.3	36	0.65	30	0.65	48	0.65	39	0.65	21	0.65	25
	Selenium (ug/L)	1	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	
	Strontium (ug/L)	0.1	100	347	100	162	100	166	100	181	100	160.5	
	Titanium (ug/L)	0.5	43	0.25	100	2.515	89	1.89	100	3.97	43	0.25	
	Vanadium (ug/L)	1.5	4	0.75	0	0.75	4	0.75	0	0.75	0	0.75	6
	Zinc (ug/L)	0.6	100	16.3	100	5.65	100	6.17	100	7.58	79	1.0285	20
Nutrients	Nitrogen (NH3+NH4) (mg/L)	0.002	93	0.109	100	0.136	93	0.128	96	0.098	86	0.03	
	Nitrogen (NO2) (mg/L)	0.001	100	0.064	100	0.035	100	0.037	100	0.034	100	0.012	
	Nitrogen (NO2+NO3) (mg/L)	0.005	100	2.725	100	0.3555	100	0.364	100	0.437	100	0.362	
	Phosphate (mg/L)	0.005	96	0.076	50	0.006	48	0.005	43	0.0025	7	0.0025	
	Total Phosphorus (mg/L)	0.002	100	0.127	100	0.053	100	0.054	100	0.06	100	0.012	0.03
	TKN Nitrogen (mg/L)	0.02	100	0.64	100	0.65	100	0.68	100	0.72	100	0.27	
Bacteria	*E. coli (c/100mL)*	4	100	1400	100	140	100	50	100	70	100	42	100
	F. streptococcus (c/100mL)	4	100	2050	100	50	100	50	100	25	70	40	
	P. aeruginosa (c/100mL)	4	100	70	37.5	4	29	4	17	4	10	4	
Herbicides &	2,4,6 -trichlorophenol (ng/L)	20	11	20	0	20	11	20	5	20	11	20	
Pesticides	Pentachlorophenol (ng/L)	10	11	10	0	10	22	10	17	10	0	10	500
	Dicamba (ng/L)	50	33	50	25	50	22	50	39	50	0	50	2E+05
	2,4 -D (ng/L)	100	39	100	25	11.25	59	205	53	11	13	100	4000
PAHs	none detected												

Note: see Appendix F for detailed dry weather statistics.

4.5.4 Water Temperature

Table 4.14 compares the average, minimum, maximum and frequency above 21°C at each monitoring station for the 2000 to 2002 monitoring seasons. The generally accepted limit for cold water fisheries habitat is 21°C. Graphs of continuous temperature data are provided in Appendix G. As indicated earlier, the 2002 temperature measurements were taken at three depths on the cell 2 side of the cell 1-2 pontoon.

These temperature data indicate an average temperature rise of between 7.1 and 8.7°C as water passes through the facility. The maximum temperature observed at the inlet was 25°C, compared to 29°C at the outlets. Only rarely did inlet temperatures rise above 21°C, whereas outlet temperatures were frequently above the threshold. Fortunately, warm water discharges from the facility do not affect the lake in the way they would affect small streams, and are therefore not a concern from a receiving water protection perspective. These discharges do, however, influence the type and diversity of aquatic species that may find their way into the wetland.

The temperature depth profile conducted in 2002 indicates a difference in maximum temperature measured at the surface (0.5 m) and that measured at 1.5 and 2.5 m depths of 5.0 and 6.4°C, respectively. During especially warm periods, the temperature differential between the surface and bottom temperatures increases to as much as 9°C.

Water temperature in the facility responded primarily to diurnal fluctuations in air temperature and solar radiation. Inlet water temperatures, by contrast, fluctuated mostly in response to surface runoff during rain events.

***Table 4.14*:** Water temperature statistics

Monitoring station	Average °C	Minimum °C	Maximum °C	Frequency above 21°C (%)
July 13 – August 9, 2000[+]				
Inlet	15.5	13.4	25.0	1
Cell 3	22.6	18.7	28.6	78
Cell 5	23.0	18.7	29.4	85
June 12 – August 31, 2001[+]				
Inlet	14.1	11.8	23.5	0.1
Cell 4 inlet	21.8	16.5	27.8	65
Cell 5	22.8	17.4	28.9	77
June 6 – August 31, 2002*				
Cell 2 (0.5 m)	24.5	15.6	31.5	88
Cell 2 (1.5 m)	22.4	15.6	26.5	77
Cell 2 (2.5 m)	20.9	14.1	25.1	68

[+]Temperature measurements in 2000 and 2001 were taken 0.5 m below the water surface at locations shown in Figure 2.3.
*Measurements in cell 2 were taken off the cell 1-2 pontoon and represent depths below the water surface. During wet weather, the pontoon and measurement locations float up and down as water levels in the facility fluctuate.

4.6 Sediment Quality

The quality and particle size distribution of bottom sediments were determined in order to characterize the location and relative magnitude of contaminant deposition within each of the cells, and to assess potential impacts of effluent discharges on receiving waters. Figure 4.23 shows the location of sediment sampling conducted on November 16, 2001.

4.6.1 Sediment Chemistry

Table 4.15 presents the mean sediment chemistry data at each sampling location and compares these to provincial sediment quality guidelines. Sediment chemistry within the facility are not required or expected to meet these guidelines; they are provided only as a standard of comparison. All of the sediment chemistry data are presented in Appendix H.

Sediment chemistry results show that quality generally improves as distance from the inlet increases, which is consistent with characterizations of the depositional environment reported in section 4.4. Although water is continuously transferred directly from cell 1 to cell 4, the latter cell has considerably cleaner sediment and lower organic carbon levels. The exception is oil and grease (solvent extractable), which had much higher levels in cell 4. Oil and grease, unlike most other contaminants reported, is lighter than water and therefore may remain in the water column longer after a storm where it is more susceptible than other contaminants to capture by the cell 1 pump. Sample A, collected closest to the cell 4 pump outfall, had much higher levels of oil and grease and other contaminants relative to downstream samples (see Appendix H).

Individual samples at cell 3 showed a similar pattern to that of cell 4, with poorer sediment quality in samples A and B relative to sample C, indicating that most contaminants were removed in the upstream portions of cell 3. Cell 5 had the lowest sediment contaminant levels and can be considered suitable for aquatic habitat based on Provincial Sediment Quality Guidelines for Aquatic Life (MOE, 1993). Interestingly, among individual cell 5 sediment samples, sample C, collected closest to the outlet, had marginally higher contaminant levels than samples B and A. Dye test results indicated that flow is short circuiting through cell 5 along the west side of the island, which may explain the slightly higher contaminant levels in sample C. Extending the cobblestone spit located downstream of the cell 4 outlet (Figure 4.23) would help to improve residence time by diverting flow around the east side of the island.

Lake Ontario sediments were collected immediately downstream of the facility outfalls and on the south side of the embayment (control) (Figure 4.23). As expected, the Lake Ontario sediment samples were substantially cleaner than the facility sediments. Relative to the Lake Ontario outfall site, the control had less copper, similar levels of zinc, lead and nutrients, and higher levels of PCBs, iron and oil and grease. Lake sediments are highly mobile and thus the relatively clean sediments at the Lake Ontario outfall station should not be

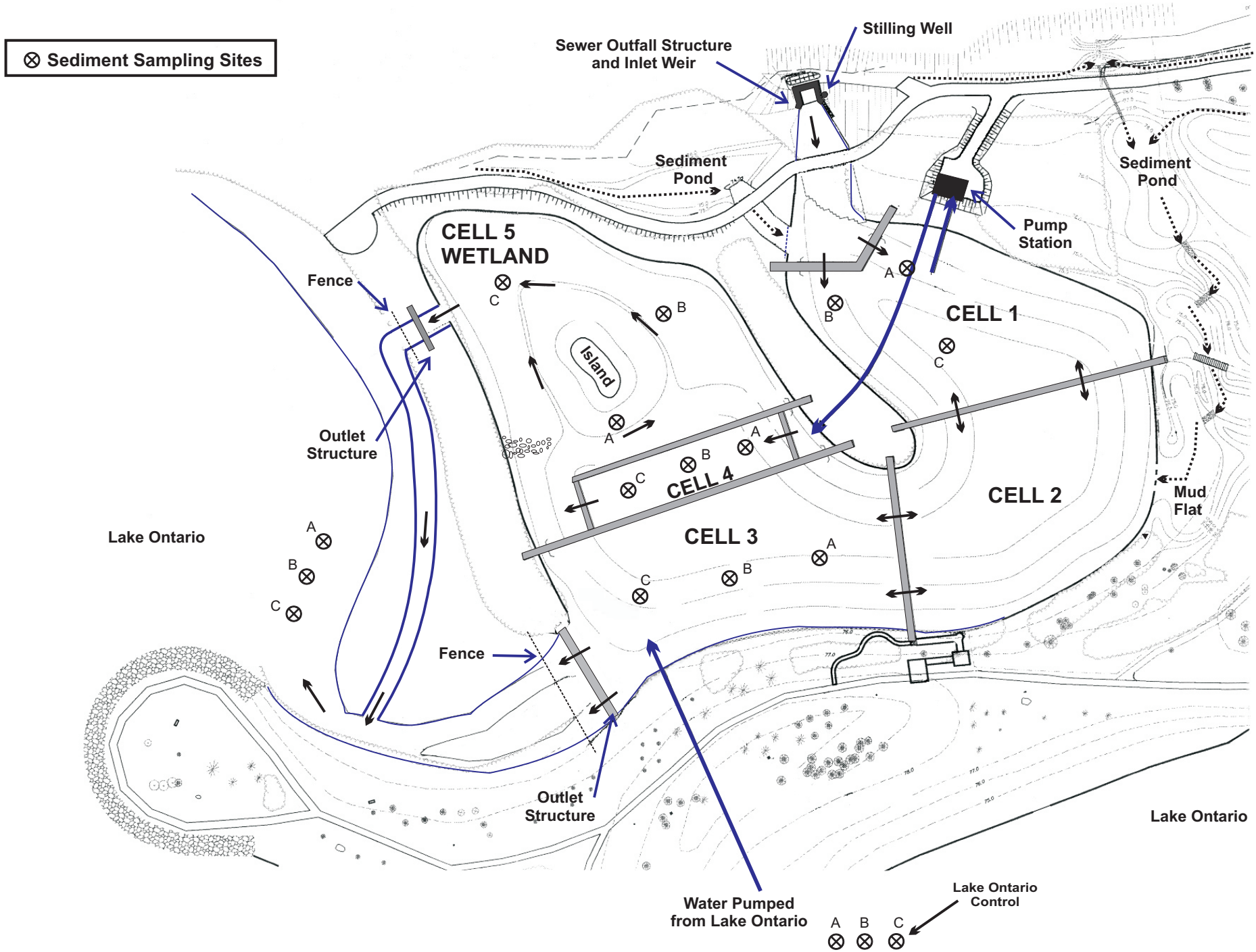


Figure 4.23: Sediment sampling sites

Table 4.15: Mean sediment chemistry results, provincial sediment quality guidelines (PSQG) and soil background concentrations in Ontario

Group	Variable	Units	Mean Concentrations (n=3)					Lake Ont.	PSQG		Background Conc.	
			C ell 1	Cell 3	Cell4	Cell 5	Lake Ontario	Control	LEL	SEL**	Agr.	Non Agr.
General Chemistry	Carbon; total organic	mg/g dry	30.0	31.7	21.0	5.3	1.7	2.0	1%	10%		
	Total Solids; loss on ignition	mg/g dry	57.0	58.7	49.0	10.4	6.2	4.2				
	Oil and grease	mg/L	8600	6000	18800	420	113	217				
Metals	Mercury	ug/g dry	0.16	0.04	0.02	0.01	0.01	0.01	0.20	2.00	0.16	0.23
	Beryllium	ug/g dry	0.5	0.7	0.6	0.5	0.5	0.5			1.2	1.2
	Magnesium	ug/g dry	14667	12200	13000	5533	3767	3833				
	Aluminum	ug/g dry	12000	14933	16333	4700	3567	2500				
	Calcium	ug/g dry	96333	88333	87000	44333	43667	57000				
	Vanadium	ug/g dry	35.3	38.7	41.7	18.0	13.0	18.7			91	91
	Chromium	ug/g dry	39.3	34.7	36.7	10.3	7.3	7.0	26	110	67	71
	Manganese	ug/g dry	453	460	503	217	170	183	460	1100		
	Iron	ug/g dry	19333	14267	24000	9333	6467	8000	2%	4%		
	Cobalt	ug/g dry	8.1	9.2	10.2	4.1	2.9	2.7			19	21
	Nickel	ug/g dry	21.3	24.3	25.7	8.6	6.4	4.5	16	75	43	43
	Copper	ug/g dry	66.0	49.7	46.7	9.0	5.7	1.3	16	110	56	85
	Zinc	ug/g dry	233.3	166.3	156.7	29.0	12.0	13.0	120	820	150	160
	Molybdenum	ug/g dry	0.7	0.7	0.5	0.6	0.5	0.5			2.5	2.5
	Cadmium	ug/g dry	1.3	1.1	1.0	0.4	0.4	0.3	0.60	10.00	1	1
	Barium	ug/g dry	78.3	82.0	89.0	19.3	11.7	8.3			190	210
	Lead	ug/g dry	53.0	35.7	36.3	7.7	4.3	5.3	31	250	55	120
	Strontium	ug/g dry	146.7	139.7	136.7	75.3	78.0	84.0				
	Titanium	ug/g dry	643	690	743	460	357	590				
	Arsenic	ug/g dry	3.3	4.2	4.3	1.4	1.0	1.4	6.0	33.0	14	17
	Selenium	ug/g dry	0.3	0.5	0.4	0.2	0.2	0.2				
Nutrients	Nitrogen; total Kjeldahl	mg/g dry	1.7	2.2	1.6	0.6	0.2	0.2	0.55	4.80		
	Phosphorus; total	mg/g dry	0.81	0.83	0.78	0.51	0.48	0.49	0.60	2.00		
PCBs and OC	PCB; total	ng/g dry	60.0	73.3	66.7	33.3	20.0	33.3	70	15900	300	300
Pesticides*	Hexachlorobenzene	ng/g dry	1.3	1.0	1.3	1.0	1.0	1.0	20	720		
	pp-DDE	ng/g dry	5.7	3.3	3.7	1.0	1.0	1.0	5	570		
PAHs	Naphthalene	ng/g dry	20	20	20	20	20	20			50	90
	Acenaphthylene	ng/g dry	33	20	20	20	20	20			80	80
	Acenaphthene	ng/g dry	40	20	20	20	20	20			50	70
	Flourene	ng/g dry	100	20	20	20	20	20	190	4800	50	120
	Phenanthrene	ng/g dry	1567	273	200	73	20	20	560	28500	190	690
	Anthracene	ng/g dry	173	33	20	20	20	20	220	11100	50	160
	Flouranthene	ng/g dry	3600	713	633	113	20	20	750	30600	240	1100
	Pyrene	ng/g dry	2767	553	480	100	20	20	490	25500	190	1000
	Benzo(a)anthracene	ng/g dry	1113	207	173	47	20	20	320	44400	100	740
	Chrysene	ng/g dry	1833	413	360	67	20	20	340	13800	180	690
	Benzo(b)fluoranthene	ng/g dry	2267	527	480	73	20	20			300	470
	Benzo(k)fluoranthene	ng/g dry	787	180	160	27	20	20	240	40200	50	480
	Benzo(a)pyrene	ng/g dry	1233	253	227	53	40	40	370	43200	100	490
	Indeno(1,2,3-c,d)pyrene	ng/g dry	1247	320	307	53	40	40	200	9600	110	380
	Dibenzo(a,h)anthracene	ng/g dry	253	67	40	40	40	40	60	3900	150	160
	Benzo(g,h,i)perylene	ng/g dry	993	267	240	40	40	40	170	9600	200	680
	d8-naphthalene	%R	40	46	46	59	70	62				
	d10-phenanthrene	%R	95	91	89	90	97	103				
	d12-chrysene	%R	69	70	69	84	81	85				

*none of the other 32 pesticides/herbicides analyzed were detected above laboratory analytical detection limits

** SEL values for PAHs and PCBs/Organochlorine Pesticides are converted to bulk sediment values based on a total organic carbon content of 3%.

interpreted as evidence that discharge water is clean (although in conjunction with other data the sediment chemistry results may lend support to this notion).

4.6.2 Sediment Particle Size Distributions

Average sediment particle size distribution (PSD) results showed a distinct difference between cells 1,3 and 4 and the Lake Ontario and cell 5 sampling locations (Figure 4.24). The latter sites were characterized by very coarse distributions characteristic of the native beach sand. The upstream cell 3A location PSD was similar to cell 5 PSDs, otherwise the cell 3 sites had relatively fine size distributions characteristic of stormwater sediment deposition zones (see Appendix H for all sample PSDs). The upstream cell 4A sample had a similar distribution to two of the cell 1 samples (1A and 1C); other cell 4 sites had finer distributions. The sediment PSD data in primary deposition zones (*i.e*. cells 1, 4 and 3) suggest that the median size of particles removed was between 6 and 13 µm, which is consistent with the stormwater PSD data discussed in section 4.4.5.

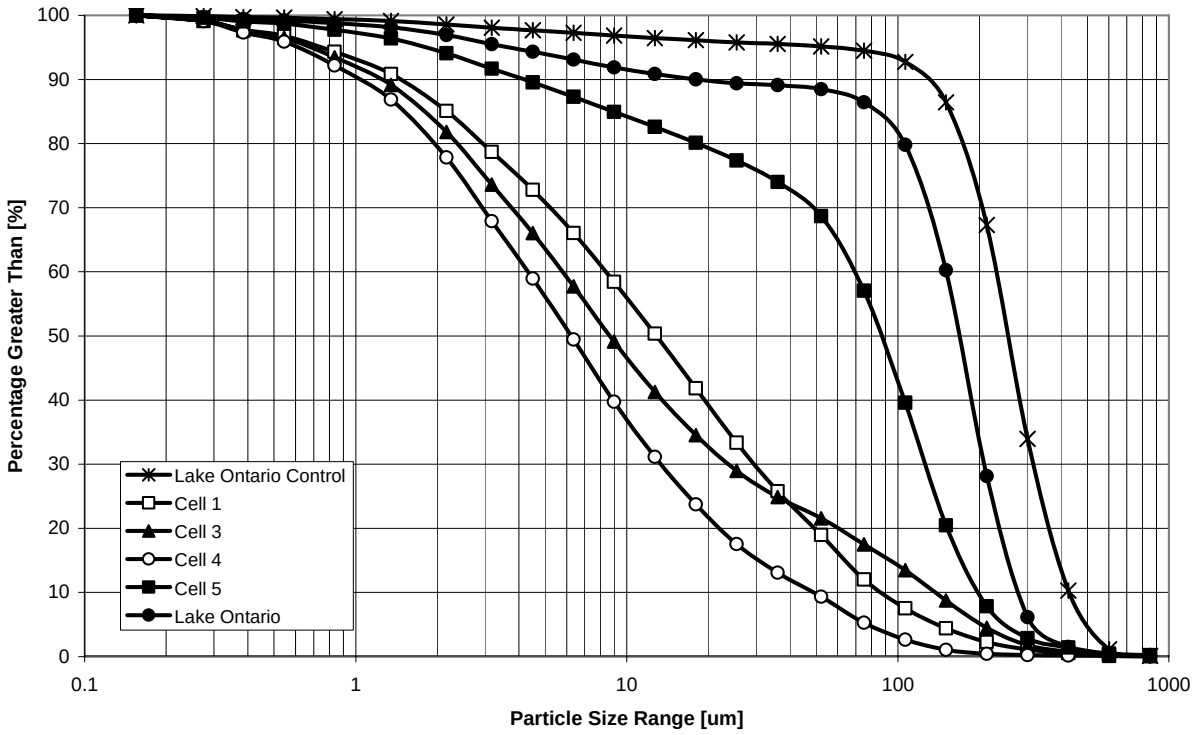


Figure 4.24: Average cumulative particle size distributions of sediment samples collected in November 2001.

4.7 Pollutant Removal

Removal efficiencies were determined for all chemical constituents in 2000 and for TSS only over the remainder of the study period (see section 3.5 for rationale).[11] TSS was selected as the most relevant variable for assessing removal rates because the system is designed based on its capacity to remove suspended particles and other pollutants of concern (e.g. metals, phosphorus, bacteria, organic compounds) that bind readily to suspended solids.

Table 4.16 presents TSS loads and removal efficiencies for 30 events ranging in size from 2.6 to 31.2 mm. Overall load based removal was 81% for the three monitoring seasons. Removal in 2000 was lower than other seasons, possibly due to the larger average size of events monitored. Storms greater than 20 mm in size tended to have lower removal efficiencies (74%) and higher effluent TSS event mean concentrations (24 mg/L) than events under 20 mm (91% and 12 mg/L respectively).

Estimates of removal rates to the cell 1 and 2 outlets assume that the samples collected (and proportioned according to water level) at a single point along the entire cell 1-2 and cell 2-3 boundary represent the mean TSS concentration of all flow passing these boundaries. The analysis also excludes consideration of TSS loads pumped to cell 4 (from cell 1) and from the lake to cell 3 during rain events.[12] With these simplifying assumptions acknowledged, removal rates in 2001 and 2002 at the outlets of cell 1, cell 2 and cell 3 are 68, 78 and 84%, respectively. A portion of the solids captured in these cells is transferred to cell 4 during and after rain events.

Although the sample size was relatively small, removal rates were weakly correlated to runoff volumes, with coefficients of determination (R^2) at cells 1, 2 and 3 of 0.47, 0.45 and 0.35, respectively (Figure 4.25). There was also a weak correlation between runoff volumes and TSS event mean concentrations at the outlets of the three cells, as shown in Figure 4.26. Other factors that may affect removal rates may include rainfall intensity and TSS influent loading (which relates to interevent duration).

There appeared to be no discernable influence on wet weather performance caused by operational factors, such as the periodic shutdown of the recirculation pumps and blockage of the cell 5 outlet channel with beach sediment. System performance (removal efficiencies and effluent EMCs) during the 2002 season, when the cell 5 and lake pump were not operating, was roughly the same as performance in 2001, when the system functioned largely according to design (see table 4.1). It is not known whether shutting down both the cell 1 and lake pumps during rain events would produce a similar result. This occurred only once over the 3 year study period, and the event (October 4, 2000) was too small (6.6 mm) to determine whether wet weather performance may be compromised under these circumstances.

[11] Effluent event mean concentrations for the entire study period are presented and discussed in section 4.5.
[12] The influent TSS load transferred to cell 4 during the period of high flow is a relatively minor proportion of total TSS load through cell 1 over the same period (see Appendix D).

Table 4.16 : TSS loads and removal efficiencies

Event	Precipitation		Flow	TSS Concentration (mg/L)				TSS Load (kg)				TSS Removal Efficiency (%)		
Date	Total (mm)	Duration (h)	Volume (m^3)	Inlet	Cell 1	Cell 2	Outlet**	Inlet	Cell 1*	Cell 2*	Outlet**	Cell 1	Cell 2	Outlet
14-Jul-00	20.9	3.1	19342	230.0	n/a	n/a	29.0	4448.7	n/a	n/a	560.9	n/a	n/a	87.4
17-Jul-00	31.2	1.3	29148	117.0	n/a	n/a	67.0	3410.3	n/a	n/a	1952.9	n/a	n/a	42.7
30-Jul-00	30.2	3.4	18987	134.0	n/a	n/a	23.5	2544.3	n/a	n/a	446.2	n/a	n/a	82.5
8-Aug-00	19.4	7	11993	341.0	n/a	n/a	20.5	4089.6	n/a	n/a	245.9	n/a	n/a	94.0
23-Aug-00	23.2	7.5	12166	120.0	n/a	n/a	17.5	1459.9	n/a	n/a	212.9	n/a	n/a	85.4
2-Sep-00	5.5	6.9	2551	268.0	n/a	n/a	14.0	683.7	n/a	n/a	35.7	n/a	n/a	94.8
10-Sep-00	18	2.8	10555	79.0	n/a	n/a	13.8	833.8	n/a	n/a	145.1	n/a	n/a	82.6
14-Sep-00	22	7.5	10263	38.5	n/a	n/a	15.5	395.1	n/a	n/a	159.1	n/a	n/a	59.7
23-Sep-00	5.8	0.3	3346	63.5	n/a	n/a	12.8	212.5	n/a	n/a	42.7	n/a	n/a	79.9
4-Oct-00	6.6	5.4	2500	97.5	n/a	n/a	6.5	243.8	n/a	n/a	16.3	n/a	n/a	93.3
27-Oct-00	2.6	2.6	1034	74.5	n/a	n/a	10.0	77.0	n/a	n/a	10.3	n/a	n/a	86.6
3-Jun-01	5.2	1.1	2376	61.6	14.5	14.5	18.0	146.4	34.5	34.5	42.8	76.5	76.5	70.8
11-Jun-01	18.2	8.9	8555	71.9	25.3	12.6	8.7	615.1	216.4	107.8	74.4	64.8	82.5	87.9
20-Jun-01	4.1	5.2	1344	86.6	7.0	8.0	14.4	116.4	9.4	10.8	19.4	91.9	90.8	83.4
30-Jun-01	5.6	0.8	2041	155.9	n/a	n/a	6.6	318.2	n/a	n/a	13.5	n/a	n/a	95.8
17-Jul-01	12.4	7.5	4646	68.9	8.0	13.5	9.4	320.1	37.2	62.7	43.6	88.4	80.4	86.4
19-Aug-01	9.8	6.1	6035	51.0	12.5	n/a	10.5	307.8	75.4	n/a	63.4	75.5	n/a	79.4
26-Aug-01	7	3.1	5202	251.0	36.3	19.5	10.8	1305.7	188.8	101.4	55.9	85.5	92.2	95.7
19-Sep-01	24.4	11.5	15520	43.5	14.3	8.9	11.8	675.1	221.9	138.1	183.1	67.1	79.5	72.9
21-Sep-01	22.4	8.6	14030	58.4	20.5	13.2	10.4	819.4	287.6	185.2	145.9	64.9	77.4	82.2
11-Oct-01	19.2	15.9	9878	31.5	n/a	6.5	11.3	311.2	n/a	64.2	111.1	n/a	79.4	64.3
16-Oct-01	8.6	3.9	4890	52.1	26.4	14.5	10.2	254.8	129.1	70.9	49.9	49.3	72.2	80.4
23-Oct-01	6.2	1.3	3255	115.7	27.2	15.3	7.6	376.6	88.5	49.8	24.8	76.5	86.8	93.4
25-Nov-01	25.2	5.6	15000	79.7	52.9	33.0	14.7	1195.5	793.5	495.0	220.5	33.6	58.6	81.6
31-May-02	6.8	1.8	3577	131.7	32.8	n/a	13.5	471.1	117.3	n/a	48.3	75.1	n/a	89.7
21-Jun-02	12.7	4	5704	197.4	28.0	9.5	9.2	1126.0	159.7	54.2	52.5	85.8	95.2	95.3
9-Jul-02	5	2.8	2157	188.0	12.0	8.7	10.2	405.5	25.9	18.8	22.0	93.6	95.4	94.6
21-Jul-02	25.7	2.4	12338	104.3	34.6	32.4	28.8	1286.9	426.9	399.8	355.3	66.8	68.9	72.4
22-Jul-02	23.3	3.8	12603	92.8	62.7	39.9	18.3	1169.6	790.2	502.9	230.6	32.4	57.0	80.3
22-Aug-02	7.5	1.6	3850	107.5	10.0	11.0	14.0	413.9	38.5	42.4	53.9	90.7	89.8	87.0
Summary	**Mean**		**Mean**		**Mean**				**Total**			**Load-based Total**		
2000	16.9	4.3	11080	142.1	n/a	n/a	20.9	18398.7	n/a	n/a	3828.0	n/a	n/a	79.2
2001	12.9	6.1	7136	86.8	22.3	14.5	11.1	6762.1	2082.4	1320.4	1048.3	66.0	78.5	84.5
2002	13.5	2.7	6705	137.0	30.0	20.3	15.7	4872.9	1558.5	1017.9	762.6	68.0	76.9	84.3
2001 and 2002	13.1	5.0	7000	102.6	25.0	16.3	12.5	11635.0	3640.9	2338.3	1810.9	67.8	77.8	84.4
events >20 mm	24.9	5.5	15939.7	101.8	37.0	25.5	23.7	17404.7	n/a	n/a	4467.5	n/a	n/a	74.3
events < 20mm	9.3	4.5	4774.5	124.7	20.0	12.1	11.6	12629.0	n/a	n/a	1171.4	n/a	n/a	90.7
all events	14.5	4.8	8496	117.1	25.0	16.3	15.6	30033.7	n/a	n/a	5638.9	n/a	n/a	81.2

Note: See section 3.5 for details on how Event Mean Concentrations were determined.

*Loads at cell 1 and 2 are calculated based on total inflow volumes and do not consider volumes pumped to cell 4 during the event.

** Outlet values represent a weighted average of the cell 3 and cell 5 outets, as discussed in section 3.7. During the 10 events when cell 5 was blocked with beach sediment all flow was assumed to exit through cell 3.

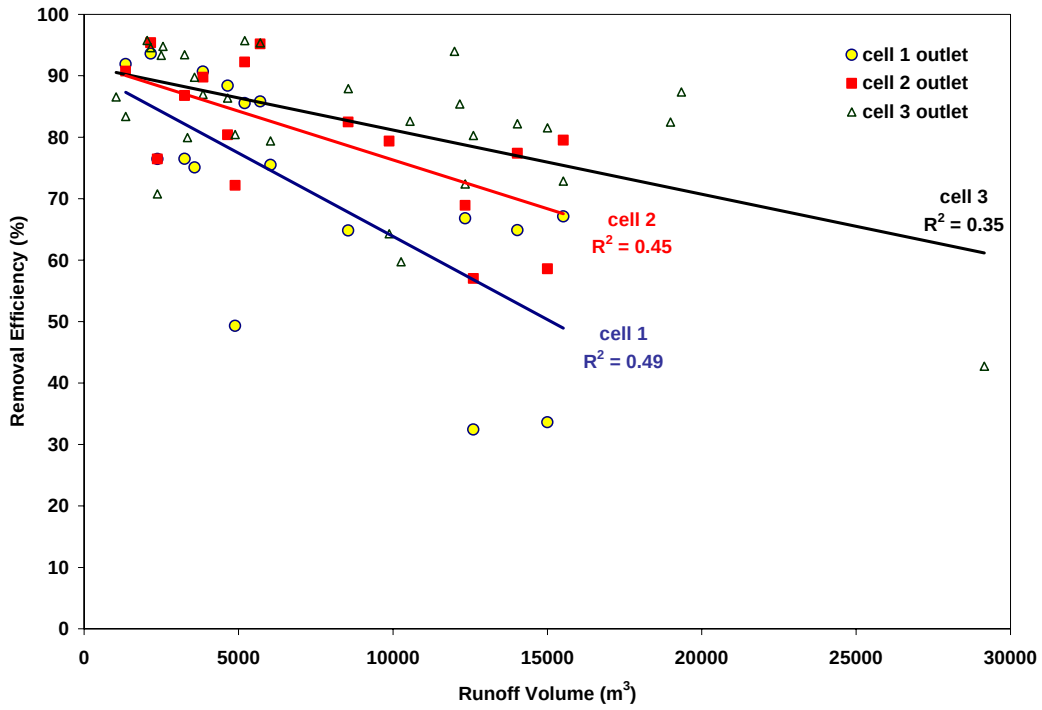


Figure 4.25: Relationship between runoff volume and removal efficiencies

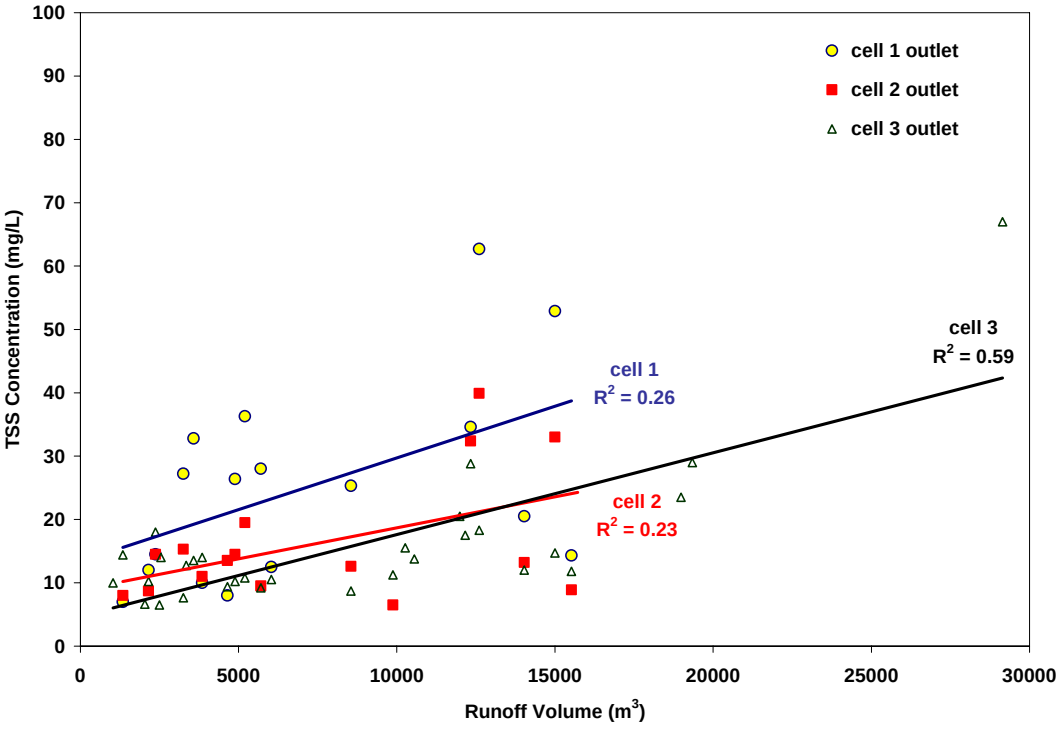


Figure 4.26: Relationship between runoff volume and TSS event mean concentrations

Figure 4.27 presents removal efficiencies for all water quality variables based on 11 events monitored in 2000. These results indicate overall removal of 79% for TSS, 77% for total phosphorus, and 75% for *E.coli* (n = 4).

Performance for most metals exceeded 70%, except magnesium and calcium, which would not necessarily be expected to decline, and trace metals that had very low inlet concentrations (*e.g.* titanium, barium, arsenic, cobalt, molybdenum). Cadmium is one of the few heavy metals that is found mostly in dissolved form. Hence, BMPs such as the Dunkers FBS that rely on sedimentation for treatment are often not effective in removing this constituent. Effluent concentrations for this metal did not exceed receiving water guidelines.

Negative removal rates were rare but can occur if the effluent concentration of a particular constituent is greater than its respective influent concentration due to in-facility sources of contaminants that are either present naturally in native soils or were deposited during dry weather (or previous events). These negative removal rates are only a concern if effluent concentrations are elevated above guideline levels, which was not the case in the Dunkers facility.

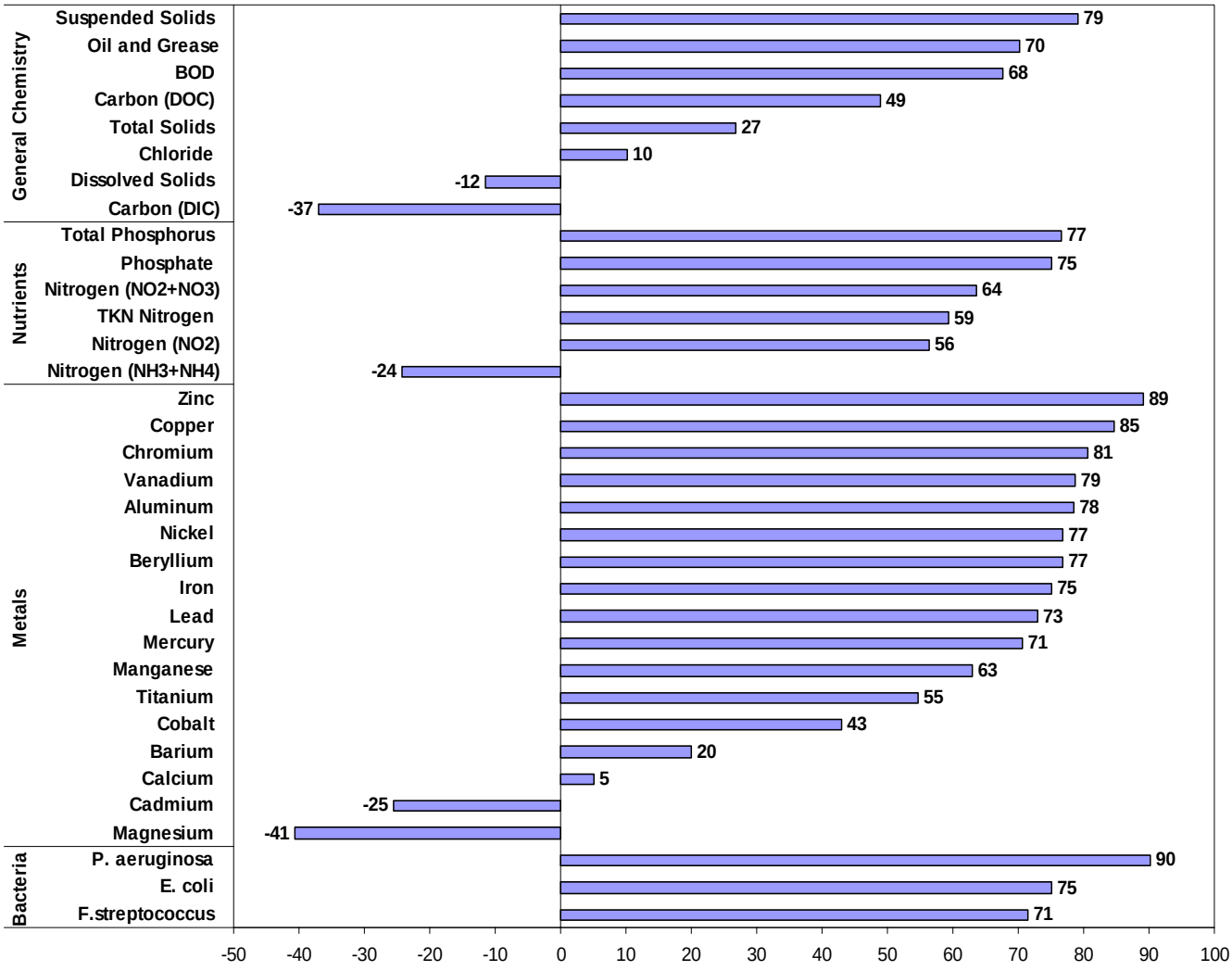


Figure 4.27: Load based removal efficiencies for storm events (n=11) in 2000. See Appendix I for individual event removal rates. Table 4.16 provides TSS removal rates for the entire study period.

5.0 OPERATION AND MAINTENANCE CONSIDERATIONS

Components of the Dunkers FBS, such as recirculation pumps, curtains, and pontoons, require ongoing maintenance and eventual replacement as the system ages. Contaminated sediment must also be removed periodically to ensure that the treatment capacity of the system is maintained and that downstream receiving waters are adequately protected. The following sections provide a general discussion of these operation and maintenance considerations.

5.1 Recirculation pumps

The DFBS includes three recirculation pumps that run continuously during the ice free period from April to December. The pumps are inspected and logs are downloaded 2 to 4 times per month. Sludge accumulation in the pumphouse requires periodic removal. The two pumps at cell 1 are rotated every 6 months.

Reported problems causing shutdown of the pumps during the study period included electrical outages, pump or phase voltage monitor malfunctions, and damage to the lake intake by shore currents. Lake inlet pipes must be designed carefully to withstand the forces of The pumps have an expected life span of 15 years (Aquafor Beech, 1994).

5.2 Pontoons and Curtains

The pontoons were a favourite roosting location for geese and other waterfowl, resulting in substantial build-up of faecal matter, especially in areas shut off from public use. Hosing down the pontoons became a required maintenance activity at the site. The pontoons otherwise required little maintenance and appeared to stand up to winter conditions very well. The expected life span of the pontoons is 35 years (Aquafor Beech, 1994).

The solid curtains separating cell 4 from cell 3 and cell 5 were damaged early in the study by beavers. The animals were successfully trapped and removed from the area, but new pairs appeared the following season. Apparently the beavers are attracted to the sound of running water created by the recirculation pumps. Divers were contracted by the City of Toronto to repair the holes and re-anchor the curtain in November 2001, however continuous water level measurements on either side of the cell 3/4 curtain indicated that substantial volumes of water continued to flow across the curtain (likely underneath) during rain events. The anticipated life span of the curtains is 20 years (Aquafor Beech, 1994).

5.3 Outlet Channels

Stormwater and baseflow exits the facility through two channels at cell 3 and cell 5. The cell 3 channel is well sheltered from lake wave action and required very little maintenance. Cell 5 effluent was designed to

discharge directly westward to the lake via a short and straight channel section. However, natural coastal geomorphic processes resulted in beach sand being pushed or carried into the channel when lake levels were high, causing flow through this outlet to be blocked.

Ultimately this was a problem that even frequent maintenance could not correct. Attempts to dredge the channel solved the problem for a short time, but invariably the beach sediment would refill the channel at the whim of lake levels and currents.

A new channel formed naturally parallel to the shoreline to join up with the cell 3 outlet channel behind a protective headland (see Figure 2.3). The new channel is an improvement since dredging requirements are considerably less frequent. After formation, the new channel was dredged in May 2003 and may require additional dredging in the near future due to the recent grow of vegetation in the channel.

5.4 Sediment Removal Requirements

Sediment removal is the most costly maintenance activity for stormwater ponds. Removal frequency requirements depend on rainfall, sediment loads, and the distribution of sediment loads in each of the cells. The Ontario Stormwater Management Planning and Design Manual suggests removal of sediment when TSS removal rates decline by 5%. At the Dunkers facility, this recommendation translates into a storage volume reduction of approximately 25 m^3/ha (OMOEE, 1994), or a decrease in permanent pool storage of 11%.

Annual TSS loading into the facility was estimated from flow measurements and TSS average event mean concentrations. Annual flow volume for a typical year (based on Pearson airport 30 year normals) was calculated to be roughly 550,000 m^3, of which 61% occurs during storm events and the remainder during dry periods. Wet and dry weather TSS average event mean concentrations were 117 and 7 mg/L, respectively. Distribution of the total sediment load over the various cells was determined from individual cell influent/effluent loading and removal rates provided in section 4.7.[1] The sediment load input from the lake pump was judged to be too small to warrant inclusion in the calculations.

Assuming a wet sediment bulk density of 1230 kg/m^3 (OMOEE, 1994), the total mass of sediment loading to each cell converts to sediment accumulation rates of approximately 6 and 12 mm/yr in cells 1 and 4, and less than 2 mm/yr in each of the remaining cells. This calculation assumes equal distribution of accumulated sediment over the bottom of each cell. If clean out is required after a permanent pool storage reduction of 11% (as suggested above), cell 1 and cell 4 will require sediment removal after approximately 32 and 22 years, respectively, whereas the other cells will need to be cleaned out much less frequently. Of course, as sediment accumulates in the upstream cells, the opportunity for re-suspension increases, and subsequent cells

[1] Cell 4 loading was determined from cell 4 influent/effluent TSS loading and pumping rates. It was assumed that the second pump is activated 3 times during a typical year for a duration of 180 hours. Sediment transfer with flow through the cell 3/4 curtain was not considered

will receive a rising portion of the influent sediment load over time. For this reason, it would be both more effective and cheaper to clean-out the cell 1 and 4 forebays at roughly 5 year time intervals.

The intent of these simple calculations is to provide a rough estimate of sediment accumulation under specified conditions as a general maintenance guide. Direct measurements of sediment accumulation should be performed at regular intervals to verify these estimates, especially in the forebays, where sediment accumulation may be 2 or 3 times that estimated for the entire cell. Other factors, such as the distance between the cell 1 pump intake and the bottom of the cell should also be considered when determining sediment removal intervals.

Sediment disposal options are limited by the quality of the soil to be removed. Sediment chemistry data provided in section 4.6 indicate that quality improves with increasing distance from the influent source. The sediment chemistry data also indicate that cell 1 and cell 4 sediments would likely require disposal in a registered non-hazardous waste disposal facility. Other options such as land spreading may be considered for downstream cells depending on the quality of sediments at the time of dredging. For detailed methods of sediment removal, regulatory criteria and disposal options, the reader is directed to the following two documents: *Stormwater Management Facility Sediment Maintenance Guide* (Greenland Int., 1999) and Mississauga's *Stormwater Pond Sediment Management Strategy* (Golder, 2003).

6.0 CONCLUSIONS AND RECOMMENDATIONS

The primary goal of the three year monitoring study was to evaluate the effectiveness of the Toronto Dunkers Flow Balancing System in reducing influent concentrations of suspended solids and associated contaminants from storm and combined sewage discharge. Fulfilment of this objective was achieved through co-ordinated monitoring of rainfall, flow and water quality, dye tests, sediment sampling, and discrete suspended solids monitoring at multiple locations within the facility. Although the pumps were not operating as designed for the entire study period, and the smaller of the two outlets was intermittently blocked with beach sediment, the system nevertheless performed exceptionally well, exceeding the original design targets with respect to water quality treatment. The following provides a summary of the main study findings.

6.1 Water quantity

Unlike other wet-pond type BMPs, quantity or erosion control was not a significant concern in the design of the Dunkers facility because the receiving water is a large lake, not a river or stream. Consequently, design targets and monitoring were focussed primarily on water quality and habitat creation.

Catchment runoff and baseflow rates were monitored continuously from a weir constructed at the base of the bluffs. Combined sewer overflows occurred during 32 of the 110 events monitored for flow, but represented only 1.6% of total runoff volumes. Runoff coefficients were relatively consistent among events, with seasonal averages ranging from 0.29 to 0.32.

There was greater flow than expected across the solid curtain separating cell 4/5 from cell 3. Continuous water level measurements on either side of the curtain showed negligible differences in water level fluctuations during runoff events. Flow around or under the curtain - and possibly flow through holes in the curtain created by beavers - were apparently allowing the runoff to enter cells 4 and 5 from cell 3.

6.2 Dye Tests

A wet weather dye test was conducted to assess the hydraulic efficiency of the system. This test was conducted during a relatively small (7.1 mm) but intense event. Photographs of the test from the top of the bluffs appeared to suggest that influent water moves through the facility as a concentrated plug of water, as assumed in the design of the facility. However, water sampling and volumetric calculations indicated that influent water (represented by the dye) travelled much further and faster then would be predicted under plug flow conditions. Samples collected at various water depths off the pontoons revealed that the influent water was not vertically integrated. Instead of displacing the contents of the cells, influent water moved first across the surface and only later mixed with cell contents.

The purpose of the dry weather dye test was to chart the course of water pumped (at a rate of 4 m^3/min) into cell 3 from the lake. Test results demonstrated that, as intended, the majority of the lake water pumped into cell 3 moved toward cell 1 and was subsequently transferred to cells 4 and 5. Only a relatively small quantity exited cell 3. However, residence time calculations indicated significant departure from plug flow conditions. Observations of dye patterns in cells 3 and 2 in particular revealed that the recirculation patterns are very complex and, at least at the surface, are strongly influenced by wind speed and direction.

6.3 Settling Dynamics

Discrete suspended solids monitoring during selected wet weather events at seven locations within the facility, provided the basis for characterizing the movement of suspended solids through the facility, and identifying predominant zones of settling. Cell 1 was the major zone of deposition; at least 60% of the influent suspended solids load during wet weather events was removed in this cell. An additional 15-25% of the suspended solids load was removed in cells 2 and 3, respectively. Not all of the solid mass 'removed' in these cells was deposited there; a portion (varying with event size) was pumped to cell 4 during and after the rain events.

As expected, mass peaks in suspended solids decreased with increasing distance from the inlet. During large events, a 15-20 minute time delay was typically observed between mass peaks at the inlet and cell 1, and between cell 1 and cell 2. Most events discretely sampled showed only minor variations in outlet suspended solids concentrations over the duration of storm outflows, indicating that the facility was successful in capturing and treating the majority of suspended matter discharged into the facility.

Particle size analysis results demonstrated that the facility was effective in removing all particle sizes greater than 30 μm. The median suspended particle size of 7.5 μm in the influent was reduced to 3.5 μm at the pump intake to cell 4 and to 2 μm at the two outlet stations. Other studies of detention basins conducted by SWAMP suggest that even with larger permanent pools and longer settling times, it is not practical to expect reductions beyond a median effluent particle size of 2 μm.

6.4 Water Quality Treatment

Total suspended solids removal efficiencies were calculated for 30 events, of which 14 were classified as small (<10 mm), 6 as mid sized (10 – 20 mm) and 10 as large (>20 mm). The average size of storm events monitored was 14 mm, with a range between 3 and 31 mm. The data set also includes two large discretely sampled back-to-back events.

The overall load based TSS removal efficiency for these storm events was 81%, which is considerably greater than the 60% design target for the facility. Individual event removal efficiencies tended to be lower during larger events; the reverse was true for effluent suspended solids concentrations.

The facility was designed to store and treat runoff from storms as large as 42 mm in size (Aquafor Beech, 1994). A storm as large as 42 mm was not observed during the study period, however removal efficiencies for two back-to-back events, each with approximately 25 mm of rainfall, had removal efficiencies of 72 and 80%, indicating that if such an event occurs over a period of a day or two, the facility would be reasonably effective in treating most of the volume discharged.

The wet weather effluent water quality data set consisted of 52 and 37 samples collected at the cell 3 and 5 outlets, respectively. Effluent concentrations were compared to provincial or federal receiving water quality guidelines, while recognizing that effluent quality would not normally be expected to meet these guidelines. Only total phosphorus and *E.coli* had median event mean concentrations above receiving water guidelines. Concentrations of these two constituents were at the low end of the range of effluent concentrations reported for other 'enhanced' protection level end of pipe facilities monitored in the GTA (see other SWAMP studies in this series). TSS concentrations were also very low, averaging 11 and 14 mg/L at the two outlets with a range from 3 to 67 mg/L. Based on this analysis, the overall quality of discharges from the facility was judged to be very good.

Although effluent concentrations of indicator bacteria were within the expected range, there was some concern that *E.coli* inputs to the lake from the facility could contribute to poor water quality at Bluffers Park beach, which is located less than half a kilometre east of the site. To assess potential links between the two sites, facility effluent *E.coli* levels were compared with daily sampling results at the beach and grabs collected in the lake immediately downstream of the facility. The data did not suggest any connection between facility effluents and beach concentrations of *E.coli*. On several occasions, facility effluent levels of bacteria were lower than those observed at the beach.

6.5 Sediment Quality

Sediment chemistry samples collected at various locations both in and downstream of the facility showed progressively better sediment quality with distance from the inlet. Among the facility samples collected, cell 5 sediment was the cleanest, and was the only cell where sediment quality met the MOE's 'lowest effect level' guidelines for the protection of aquatic life. Lake sediment samples collected downstream of facility outlets and at a control site on the south side of the embayment had similar chemical compositions.

Average sediment particle size distributions (PSD) at the chemistry sampling sites showed a distinct difference between primary deposition zones (cells 1,3 and 4), and the Lake Ontario and cell 5 sampling locations (cell 2 PSD was not determined). Whereas the Lake Ontario and cell 5 sites were characterized by very coarse distributions characteristic of native beach sand (median PSDs between 85 and 250 microns), the upstream locations in cell 1, 3 and 4 consisted primarily of finer sediments (median PSDs ranging from 6 to 13 microns), similar to those observed in influent runoff. These data indicate that influent sediment loads are settling out primarily in cells 1 to 4, and that only a small proportion of the very fine suspended solids entering cell 5 are being deposited in this cell.

6.6 Operation and Maintenance

The Dunkers system contains several functional components that require on-going maintenance. These include the pontoons, cell divider curtains, recirculation pumps, weirs and outlet channels. The life expectancy for these components ranges from 15 years for the pumps to 35 years for pontoons if they are maintained appropriately (Aquafor Beech, 1994).

The original cell 5 outlet channel was frequently blocked by sediment carried onto the beach during high lake water levels, despite periodic dredging of the channel. The channel eventually formed its own channel parallel to the beach such that it discharges in a location sheltered from the waves. This longer, naturally formed channel has required less frequent maintenance and dredging than the original channel.

Other operational issues included holes and tears in the solid curtains caused by beavers, and damage to the lake inlet pipe from shore currents. These components of the Dunkers system must be carefully designed to avoid frequent and expensive repairs.

Periodic removal of contaminated sediments deposited in the facility is crucial to ensure the facility continues to function effectively. Removal frequencies were estimated from measured sediment loading into and out of each cell and storage-removal efficiency relationships developed by the Ministry of the Environment. Assuming equal distribution of deposited sediment over the bottom of each cell, sediment removal in cells 1 and 4 were estimated to be required after 32 and 22 years following construction, respectively. Other cells would need dredging much less frequently. Forebays (cell 1 and cell 4) should be inspected and cleaned out regularly to avoid re-suspension of accumulated sediment.

6.7 Site Selection Criteria

This study has demonstrated that flow balancing systems can be an effective means of pollution control and, as such, are suitable for replication elsewhere along the waterfront. The following criteria should be considered in selecting other potential locations for implementation of the technology:

- sheltered embayments where waves and lake surges will not interfere with quiescent settling processes within the facility;
- the area to be replaced by the proposed facility does not currently provide high quality fish or wildlife habitat;
- discharges to be treated by the proposed facility have been demonstrated to adversely impact receiving waters, and are composed of no more than 5% CSO, unless pump-back to a water pollution control plant is included as part of the system;

- sufficient space is available to accommodate a facility that has at least a 3:1 length-to-width ratio and permanent pool storage requirements in line with MOE enhanced level criteria (125 m^3/ha at 45% imperviousness) for wet ponds; and
- the proposed location is not immediately adjacent to areas designated for swimming.

These criteria should not be interpreted as hard and fast rules, but rather as general guidelines that may be flexible depending on specific design features of the facility.

6.8 Recommendations

The following recommendations are provided based on study results and observations made during the course of the monitoring study.

1. The outlet channel to cell 5 was periodically blocked with sediment throughout the study period, especially when lake water levels were high. Dredging the channel parallel to the beach appears to have been an effective and relatively low cost solution to this problem for the past two years. However, if the problem persists in future high lake water level years, consideration should be given to other alternatives, such as a buried pipe where the current channel lies, to ensure uninterrupted conveyance of cell 5 flows to the lake.

2. Bottom sediments should be removed every 4 to 6 years from the cell 1 and cell 4 forebays to avoid re-suspension and distribution of this sediment over the remaining cells, and to extend the period over which dredging of the entire facility would be required. The precise interval of sediment removal should be determined from direct measurements of sediment accumulation in these areas.

3. Sediment sampling results and dye test residence time calculations suggested that flow in cell 5 was short circuiting along the west side of the island. Extending the cobblestone spit immediately downstream of the cell 4 outlet would help to improve residence time by diverting flow around the east side of the island.

4. As mentioned earlier, there was significant flow across the solid curtain separating cell 3 from cells 4 and 5, even after the City repaired and re-anchored the curtain to the bottom in November, 2001. Despite the relatively pervious nature of the curtain, however, the facility provided excellent water quality treatment. Further, the quality of wetland sediments met provincial sediment quality standards, suggesting that the water that is entering from cell 3 (probably from the bottom of the cell) is relatively free of contaminated sediment. It is recommended, therefore, that no further attempts be made to repair the curtain, and that the facility continue to operate as a more connected unit than was intended in the original design.

5. Residence times in the original design brief for the facility were calculated on the assumption of plug-flow conditions (no mixing of the influent flow and facility contents). Dye tests and suspended solids

monitoring demonstrated that the plug flow assumption is not valid, even as an approximation of actual conditions. In reality, considerable mixing occurs and influent sediment plumes travel much further than would be anticipated under strict plug flow conditions. Future flow balancing systems of a similar design should be based on conceptual and physical models that better represent the underlying complexity of the system and processes involved.

6. In the initial planning stages of the project, there was some discussion about whether the treatment effectiveness of the facility would be significantly compromised if cell 5 was entirely isolated from the system by impermeable barriers and functioned solely as wetland habitat. In this scenario, all stormwater flows would pass through cells 1 to 3 before exiting to the lake and the recirculation pumps would be removed or relocated. The findings of this study suggest that this change in design would likely reduce the capacity of the facility to treat flows. Cell 5 provides an important polishing function to flows that are pumped through cell 4. If flows were restricted entirely to cells 1 to 3, flow rates and volumes exiting cell 3 would increase, resulting in shorter residence times and poorer overall removal. The current design has been shown to provide reasonably good quality habitat for aquatic life while providing ancillary benefits in terms of treatment. Changes to the existing design are, therefore, not recommended.

7. Further study is required to determine whether the pumps provide an indispensable benefit to the system both in terms of increased residence times and better circulation during dry weather. The results collected thus far appear to suggest that the pumps are dispensable. There was, for instance, no difference in the quality of effluent or efficiency of removal when the lake pump was shut down for extended periods. Continuous influent baseflow of between 5 and 15 L/s provides a recirculation function, similar to that of the pumps (albeit at a considerably lower rate). If the cell 1 pumps were shutdown, flow would still enter cells 4 and 5 via cell 3 through the curtain; this flow path could be opened up further if necessary, preferably at the downstream end. Water entering cell 5 from cell 3 is relatively clean, since most of the treatment occurs in the first two cells. Hence, shut-down of the pumps would not jeopardize the function of the wetland as habitat for waterfowl and aquatic life. Further consideration of the utility of ‘pump-back’ in flow balancing systems should consider monitoring results from the flow-balancing system in Etobicoke, which provides passive treatment through a series of interconnected cells separated by solid and perforated curtains attached to pontoons.

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APPENDIX A

Historical Context of the SWAMP Program

HISTORICAL CONTEXT OF THE SWAMP PROGRAM

In the latter part of the 20th century, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management programs have been developed in the Great Lakes basin.

A number of complementary programs have been established at the international, national, provincial and municipal levels to protect the Great Lakes ecosystem. The SWAMP program and the study that is the subject of this report are parts of the overall effort.

International Joint Commission

The International Joint Commission (IJC) prevents and resolves disputes between the United States of America and Canada under the Boundary Waters Treaty of 1909. The IJC pursues the common good of both countries as an independent and objective advisor of the two governments.

In particular, the IJC rules upon applications for approval of projects affecting boundary or transboundary waters and may regulate the operation of these projects; it assists the two countries in the protection of the transboundary environment. Among the responsibilities of the IJC is the implementation of the Great Lakes Water Quality Agreement.

Great Lakes Water Quality Agreement

The first Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States was signed in 1972 in recognition of the urgent need to improve environmental conditions in the Great Lakes. The focus of the agreement was to improve water quality through pollution control programs. Objectives included the reduction of nuisance conditions and control of toxic substances. Specific numerical targets were included for the reduction of phosphorus loadings.

The Great Lakes Water Quality Agreement was amended in 1978 to include the objective of controlling persistent toxic substances. The new agreement also incorporated the ecosystem approach to environmental management.

In 1987, the Canadian and U.S. governments signed a protocol that identified local Areas of Concern (AOC's) where beneficial uses of the ecosystem had been significantly degraded. Remedial Action Plans (RAP's) were to be prepared by various levels of government for the AOC's. The plans would contain

strategies to clean up problem areas in the Great Lakes region. In addition, the 1987 protocol included annexes addressing specific subjects such as non-point contaminant sources and contaminated sediments.

In total, 43 Areas of Concern were identified throughout the Great Lakes basin. Of the total, 17 AOC's were in Canada.

Great Lakes Sustainability Fund

The Canadian federal government's commitment to the Great Lakes ecosystem was initially managed through the Great Lakes Action Plan (GLAP). In 1990, the Great Lakes Cleanup Fund (GLCuF) was created to provide support for environmental projects designed to benefit the Great Lakes basin ecosystem.

In 1994, GLAP was replaced by the Great Lakes 2000 Program. GLCuF was extended and renamed the Great Lakes 2000 Cleanup Fund. In 2000, the Great Lakes Basin 2020 Action Plan was introduced in addition to the successor to the GLCuF, the Great Lakes Sustainability Fund (GLSF). The new plan and fund place priority on the restoration of environmental quality in Canada's remaining 16 Areas of Concern.

The GLSF supports the implementation of remedial actions falling within federal responsibilities that will lead to the restoration of beneficial uses in the Canadian Great Lakes Areas of Concern. The five-year, $30 million GLSF builds on past successes and is administered by Environment Canada on behalf of eight Government of Canada departments.

To restore these beneficial uses in the Great Lakes Areas of Concern, joint Canada-Ontario teams work in consultation with local Public Advisory Committees to develop Remedial Action Plans (RAPs) aimed at eliminating or reducing the major sources of contamination in these areas. When all beneficial uses in an AOC have been restored, the area is delisted. The RAPs have had some important successes. Collingwood Harbour was delisted in 1994, and Spanish Harbour was designated an Area of Recovery in 1999.

Canada – Ontario Agreement

Canada and Ontario have had Great Lakes environmental agreements in effect since 1971. The latest version of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) was signed in June, 2002. The agreement provides the framework for systematic and strategic coordination of shared federal and provincial responsibilities for environmental management in the Great Lakes basin. The main objectives are to restore degraded areas, to prevent and control pollution, and to conserve and protect human and ecosystem health.

Ontario Ministry of the Environment

The Ontario Ministry of the Environment (OMOE) manages a number of programs that contribute to the protection and clean-up of the Great Lakes basin. The Provincial Water Protection Fund assists municipalities to address water and sewage treatment problems and to undertake related studies. The Ontario Great Lakes Renewal Foundation, established in 1998, provides seed money to support local projects that include habitat restoration and stormwater management. The OMOE works in partnership with federal and state agencies and municipal governments to achieve numerous environmental goals; the Great Lakes Remedial Action Plans have been a prominent example of such work.

Toronto and Region Conservation Authority

The Toronto and Region Conservation Authority (TRCA) is one of 38 conservation authorities in Ontario that develop and implement programs for the management of water and natural resources on a watershed basis. Conservation authorities are created and given their mandate under the Conservation Authorities Act and involve a partnership of the municipalilties within a watershed and the Province of Ontario. The TRCA jurisdiction includes nine watersheds in the Toronto Region.

The TRCA and the Waterfront Regeneration Trust are the local coordinating agencies for the Toronto and Region Remedial Action Plan. The two agencies help the provincial and federal governments fulfill their obligations under the Great Lakes Water Quality Agreement and Canada-Ontario Agreement. The TRCA's general RAP role is to focus implementation activities on an individual watershed basis and provide technical expertise to its implementation partners. Stormwater management and the remediation of combined sewer overflows are integral to the restoration of the Toronto and Region Area of Concern.

SWAMP

In 1995, the Storm Water Assessment Monitoring and Performance Program (SWAMP) was created as a cooperative initiative of agencies interested in monitoring and evaluating the performance of various stormwater management technologies. The SWAMP program acts as a vehicle whereby federal, provincial, municipal and other interested agencies can pool their resources in support of shared research interests.

The objective of SWAMP is to collect data and report on the performance of stormwater treatment facilities. SWAMP is supported by the Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, the Municipal Engineers Association, a number of individual municipalities in Great Lakes Areas of Concern, and other owner/operator agencies.

A variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. Prior to the creation of SWAMP, these technologies had been

studied using computer models and pilot-scale testing, but had not undergone extensive field-level evaluation in southern Ontario.

The objectives of the SWAMP Program are:

- to monitor and evaluate the effectiveness of new or innovative stormwater management technologies,
- to disseminate study results and recommendations within the stormwater management community.

Technologies that have been addressed by the SWAMP program include:

- wet ponds and constructed wetlands,
- underground storage tanks,
- flow balancing systems,
- oil and grit separators,
- conveyance exfiltration systems.

A number of people have been part of the SWAMP team since the inception of the program. In alphabetical order, the staff members have been:

David Averill	Program Co-ordinator [July 2001 to May 2003]
David Fellowes	
Rene Gagnon	
Dajana Grgic	
Weng Liang	Program Co-ordinator [1995 to 2000]
Serge Ristic	
Derek Smith	
Sheldon Smith	
William Snodgrass	Program Co-ordinator [December 2000 to June 2001]
Michael Thompson	
Tim Van Seters	

In addition, several student employees contributed to the success of the projects. Staff of the Ontario Ministry of the Environment, Standards Development Branch, provided administrative and facility support.

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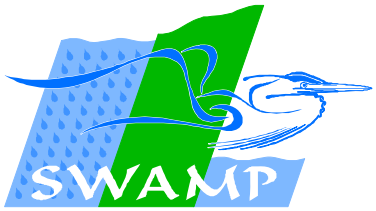


APPENDIX B

Sampling Method Error Analysis

Sampling Method Error Analysis

Water quality sampling methods used in this study were as follows:

- *2000 monitoring season:* influent samples were collected at 5 minute intervals over a period of 2 hours; effluent samples were collected at 10 min intervals over 4 hours. All samples were combined to form time-weighted composites and submitted for analysis of water quality.

- *2001 and 2002 monitoring seasons:* influent samples were collected at 10 or 20 minute intervals over the duration of flow (8 hours maximum). Discrete samples (up to 36) were later analyzed individually for TSS (or turbidity) and proportioned according to flow. Effluent samples (24) were collected at 20 min intervals over 8 hours and combined to form time-weighted composites. These samples were submitted for analysis of water quality. Effluent samples were also analyzed discretely for TSS (or turbidity) and proportioned according to water level. The influent and effluent flow proportioned samples were used with flow estimates to calculate load based removal efficiencies.

Flow proportioned samples provide the most accurate estimate of the Event Mean Concentration (EMC). Table B1 shows the range of potential errors associated with using simple non-flow proportioned composites to represent the EMC. The events selected for this analysis were taken from the 2002 season because this was the only season during which TSS was analyzed discretely. In 2001, discrete samples were analyzed for turbidity and later converted to TSS based on regression analysis; an additional step that introduces further errors into the EMC measurement.

This comparison clearly indicates that, at the inlet, where flows vary dramatically over short time periods, time-weighted composite samples provide a better estimate of the actual event mean when the sample collection interval is shorter. While 10 and 20 minute time composites consistently underestimated the EMC, 5 minute interval composites showed mixed results with some concentrations above the flow weighted mean and some below. The average difference between the 5 minute composite and the flow weighted mean was 10%; underestimates of the true mean were more frequent than overestimates.

Effluent composite results were similar no matter which method was used. This result is primarily a consequence of: (i) the more even distribution of flow at the outlet, (ii) the tendency for outlet peak flow and peak concentrations to occur at different times, and (iii) the absence of significant variations in discrete effluent concentrations (see section 4.4). Whereas influent TSS concentrations ranged from 5 to 500 mg/L, effluent concentrations rarely exceeded 40 mg/L.

TableB1: Comparison of TSS concentrations determined by different methods.

Date	Rain (mm)	Influent TSS Conc. (mg/L)				Effluent TSS Conc. (mg/L)		
		Simple Average~			Flow Proportioned	Simple Average~		Flow Proportioned+
		5 min; 2 h	10 min. 4 h.	20 min. 8 h.		10 min. 4 h.	20 min. 8 h.	
May 31/02	6.8	142.0	80.7	46.2	131.7	13.3	13.5*	13.4
June 21/02	12.7	231.0	143.2	79.1	197.4	10.7	8.1	9.2
July 9/02	5.0	121.9	98.7	54.2	188.0	10.0	10.2	10.6
July 21/02	25.7	104.5	69.8	37.2	104.3	29.1	25.2	28.8
July 22/02	23.3	81.9	44.6	24.2	92.8	19.8	17.9	18.3
Aug 22/02	7.5	65.9	51.1*	51.5*	107.5	13.0	15.0	14.0
Sept 21/01++	22.4	48.0	45.3	31.5	58.5	14.3	12.0	10.4
Mean	**14.8**	**113.6**	**76.2**	**46.3**	**125.7**	**15.7**	**14.6**	**15.0**

+ Flow was not measured. Samples were proportioned according to outlet water level.

* Samples collected over 5 hours (May 31) and 3.3 hours (Aug 22), but include the period of major flow.

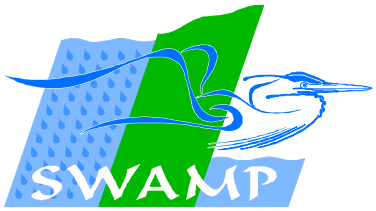
~ Mean composite sample concentrations are based on 24 samples collected at the indicated time interval and duration, except where otherwise noted.

++ TSS concentrations are based on the conversion of discrete sample turbidity measurements to TSS (see section 3.5 for turbidity – TSS relationships)

Overall, this analysis suggests that time weighted effluent concentration data provides a reasonably accurate depiction of the true mean effluent concentration and should, therefore, be relied upon as a central component of this performance assessment.

The 2000 removal efficiency data is more prone to error. If the analysis provided here is representative of the 2000 season, and time weighted influent concentrations exceed flow weighted EMCs, then the reported results for the 2000 year of monitoring likely underestimates true removal.

The removal efficiency data for the 2001 and 2002 season are based on flow proportioned samples and are, therefore, not subject to the errors associated with 2000 removal efficiency estimates.



APPENDIX C

Water Level Data

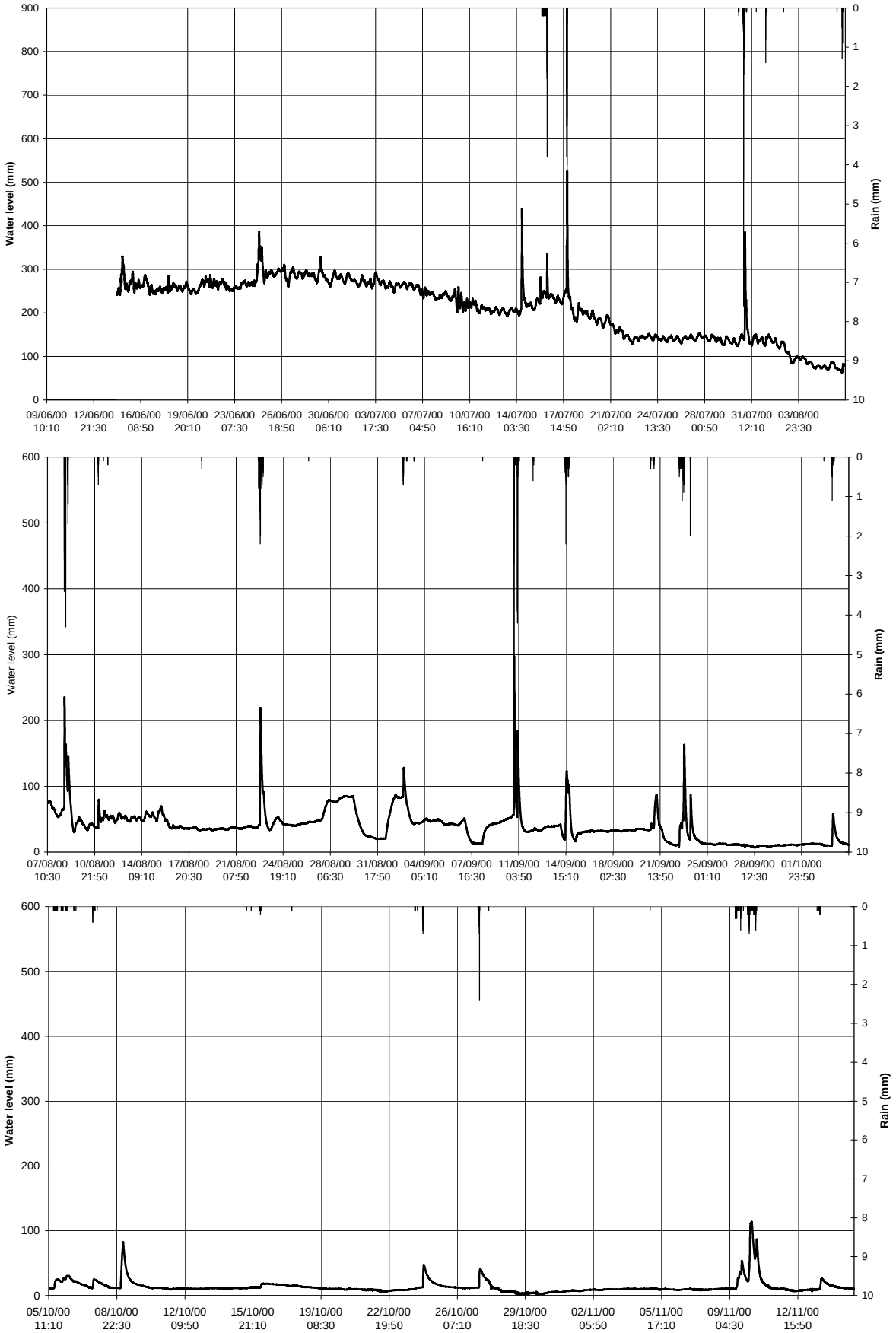


Figure C1: Water level fluctuations in cells 1 to 3 during the 2000 monitoring season. Note that the water elevations are presented relative to an arbitrary dry-weather baseline.

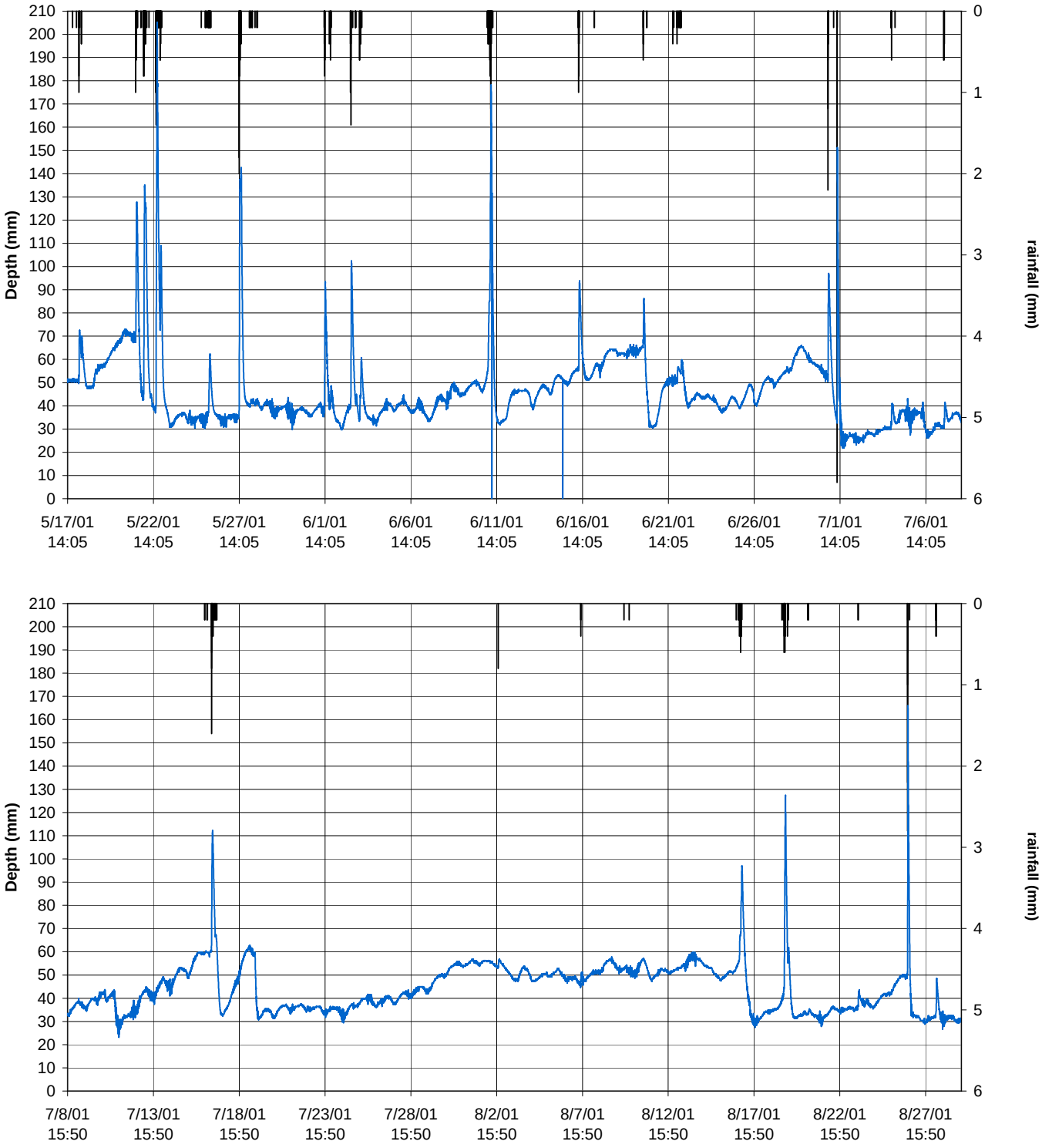
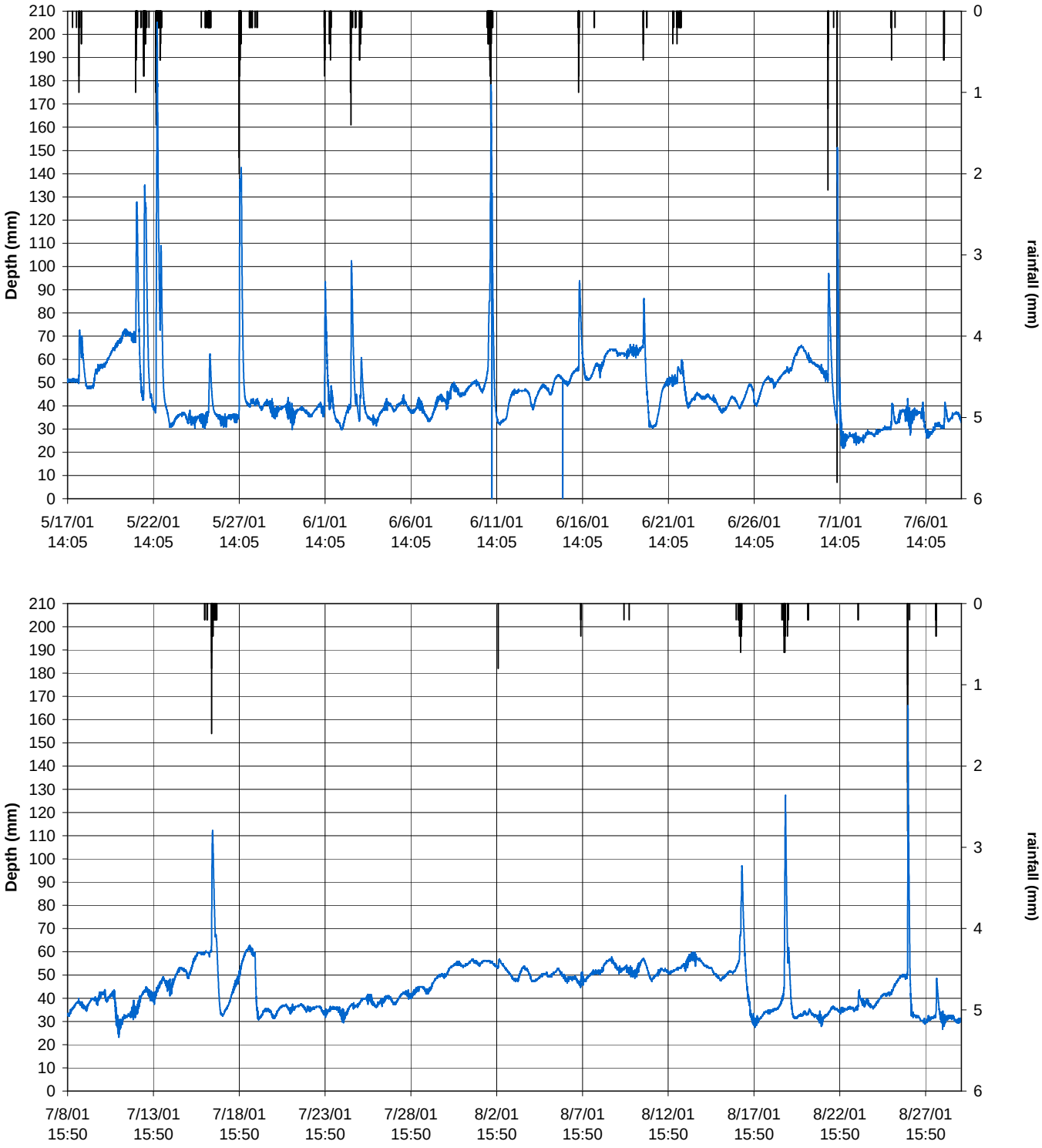


Figure C2 : Water level fluctuations in cells 1 to 3 during the 2001 monitoring season (May to August). Note that the water elevations are presented relative to an arbritrary dry-weather baseline.



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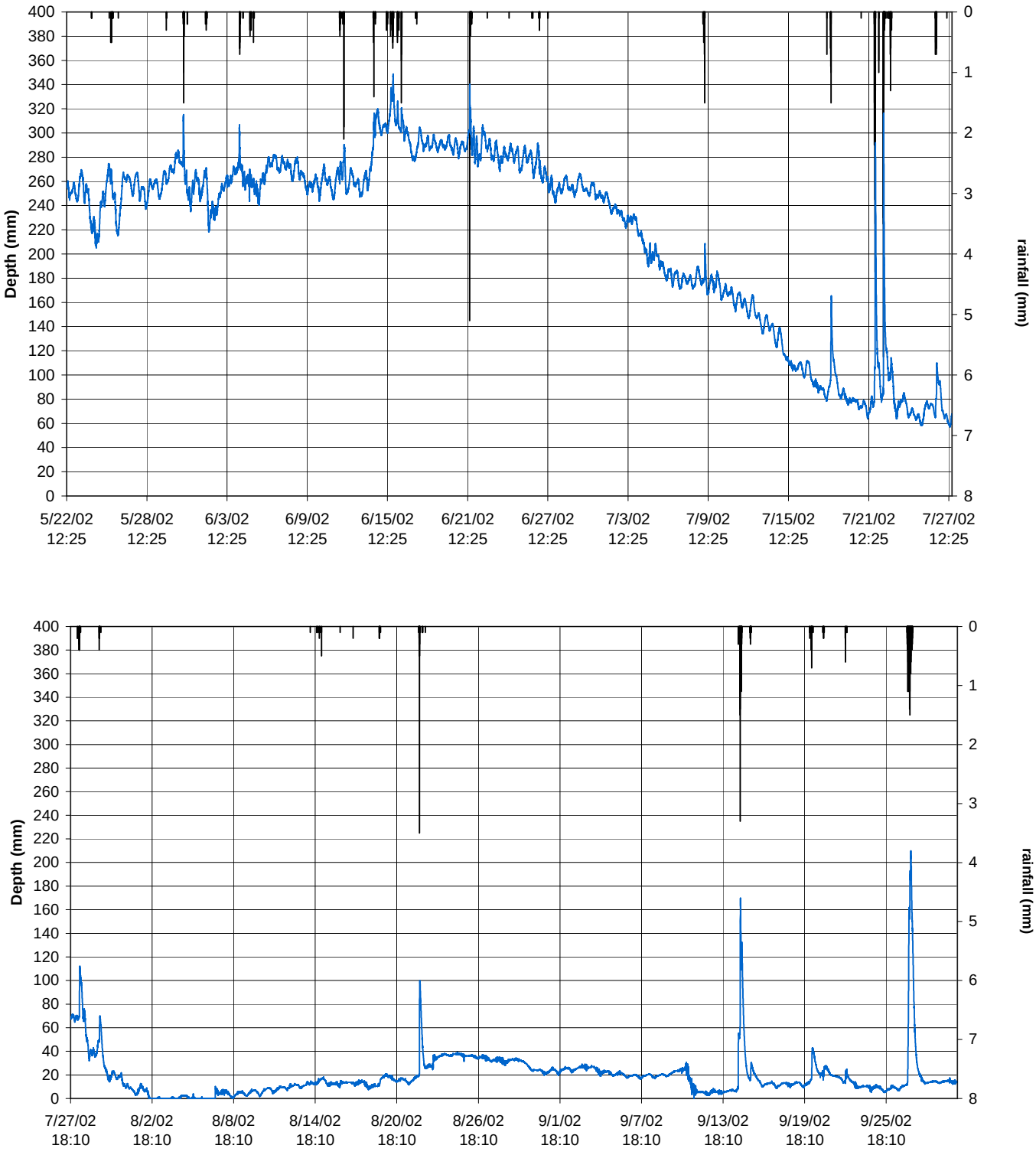
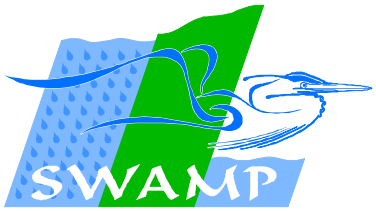


Figure C3: Water level fluctuations in cells 1 to 3 during the 2002 monitoring season. Note that the water elevations and flows are presented relative to an arbitrary dry-weather baseline.



APPENDIX D

Mass-based Analyisis of Two Rain Events

Mass-based Analysis for two Rain Events

Method

Time series plots of suspended solids mass required estimation of outflows. To generate this estimate, continuous pond water level data were used in a standard weir equation of the form:

$$Q = KCH^{1.5} \quad \text{.....equation 1}$$

where Q = flow rate
H = head
C = coefficient (calibrated)
K = constant dependent on units

The coefficient (C) was adjusted such that the measured inflow volume provided a reasonable match with calculated outflow volumes (eqn 1) for a range of events. This approach assumes that (i) the duration of flow is equivalent to the time required for water levels to return to the pre-event water level and (ii) inflow and outflow volumes during rain events are the same. The equation, thus, provides a means of proportioning measured inflow volumes over the known duration of outflow. This estimation approach, while crude in nature, is reasonable given that the information of interest primarily relates to the shape and timing of mass curves, rather than the exact magnitude of peaks.

The two back-to-back events on July 21st and July 22nd were selected for illustration of mass transfer of suspended soilds during storms (Figure D1). These storms were selected because: (i) the events were large events (> 20 mm) that occurred within less than 24 hours of each other; (ii) discrete TSS results were available at a number of stations; and (iii) outflows were not affected by lake water inflow (*i.e.* lake water level was below the lip of the weir). Total outflow volumes calculated using equation 1 for these two events was 12,730 and 12,522 m^3, which compares favourably to measured influent volumes for the same events of 12,338 and 12,603 m^3, respectively.

Since the cell 5 outlet channel was blocked, all flows were assumed to exit through the cell 3 outlet, including water pumped into cell 4. For simplicity, the incremental volumes (at 5 minute intervals) passing the cell 1/2 and cell 2/3 boundaries are assumed to be equal to the incremental volumes exiting cell 3, discounting the volume of water pumped out of cell 1 into cell 4. The volume of water transferred from the lake into cell 3 did not need to be included because the pump was not operating during these events.

Discussion

Some general observations from the mass pollutograph analysis for the two July events include the following:

- Peak inflows are reduced by approximately 72%

- Detention times, calculated as the time delay between hydrograph centroids, was 68 minutes for the July 21st event and only 24 minutes for the July 22nd event

- The volume of water and mass of solids transferred into cell 4 is less than 10% of the total volume of water and mass of suspended solids entering the facility over the course of a rain event.

- The peak of the mass curve at the inlet and cell 1 roughly correspond with peak flows at these two stations. The cell 2 and cell 3 mass peaks occur after peak flow and do not always correspond with peak TSS concentrations at the same station (see cell 3 on July 22, 2002). Mass peaks become progressively smaller as the influent water passes from the inlet to cells 1, 2 and 3.

- The graphs depict a sediment plume traveling quickly through cells 1 and 2 and slowing as it enters cell 3, but eventually discharging through the cell 3 outlet. During both events, the time delay between the inlet and cell 1 mass peaks is 15-20 minutes. Another 20 minutes passes before the cell 2 mass peak is observed. The cell 3 concentration peaks occur roughly one hour and a half after the cell 2 peaks, but the mass peak during the second event occurs roughly at the same time as the cell 2 peak, indicating that while the plume does reach the outlet, the loading impact on the lake is relatively minor.

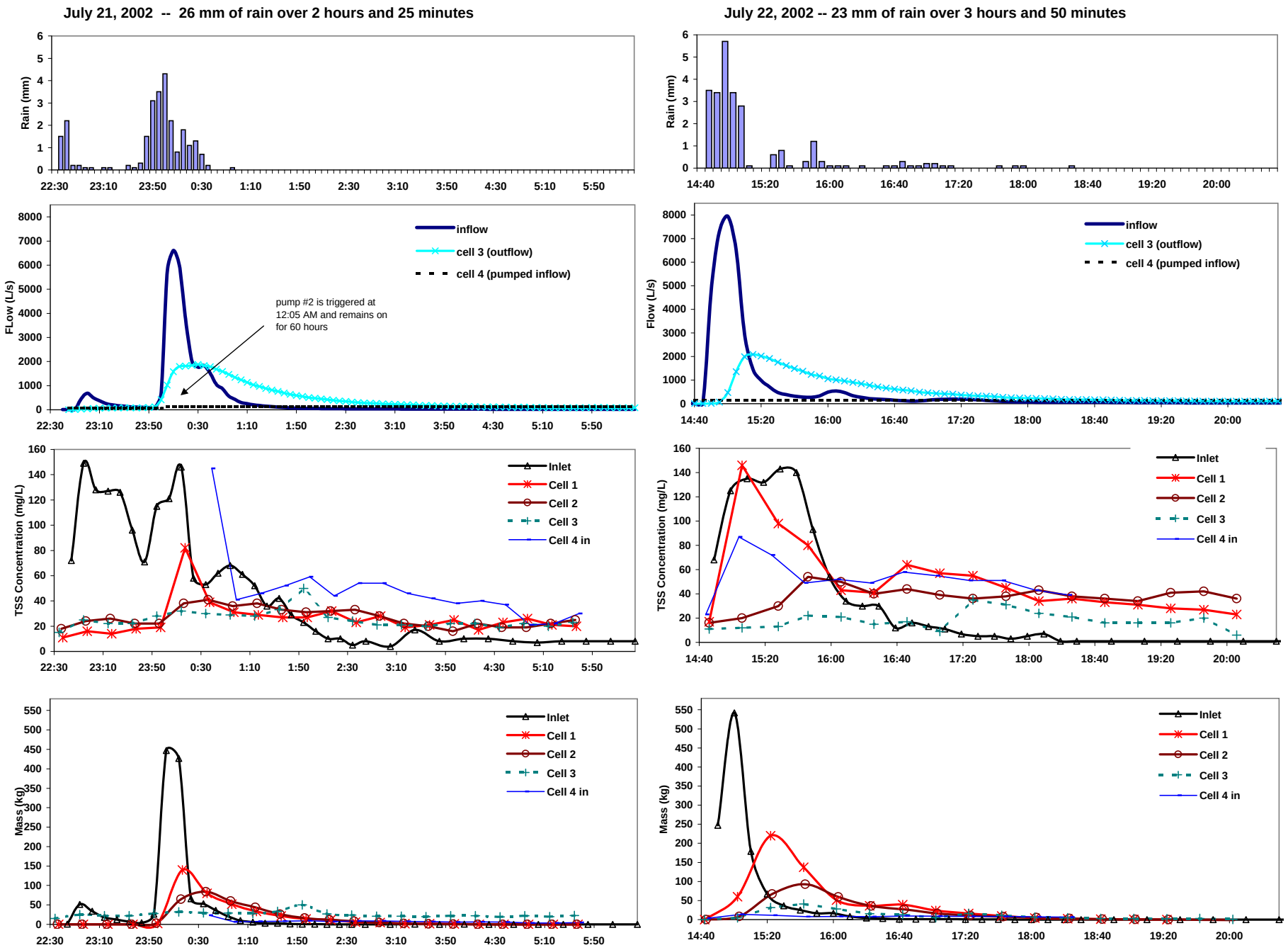
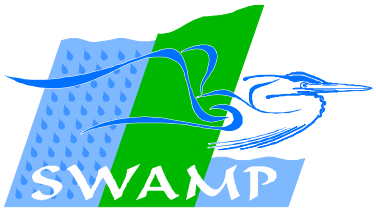
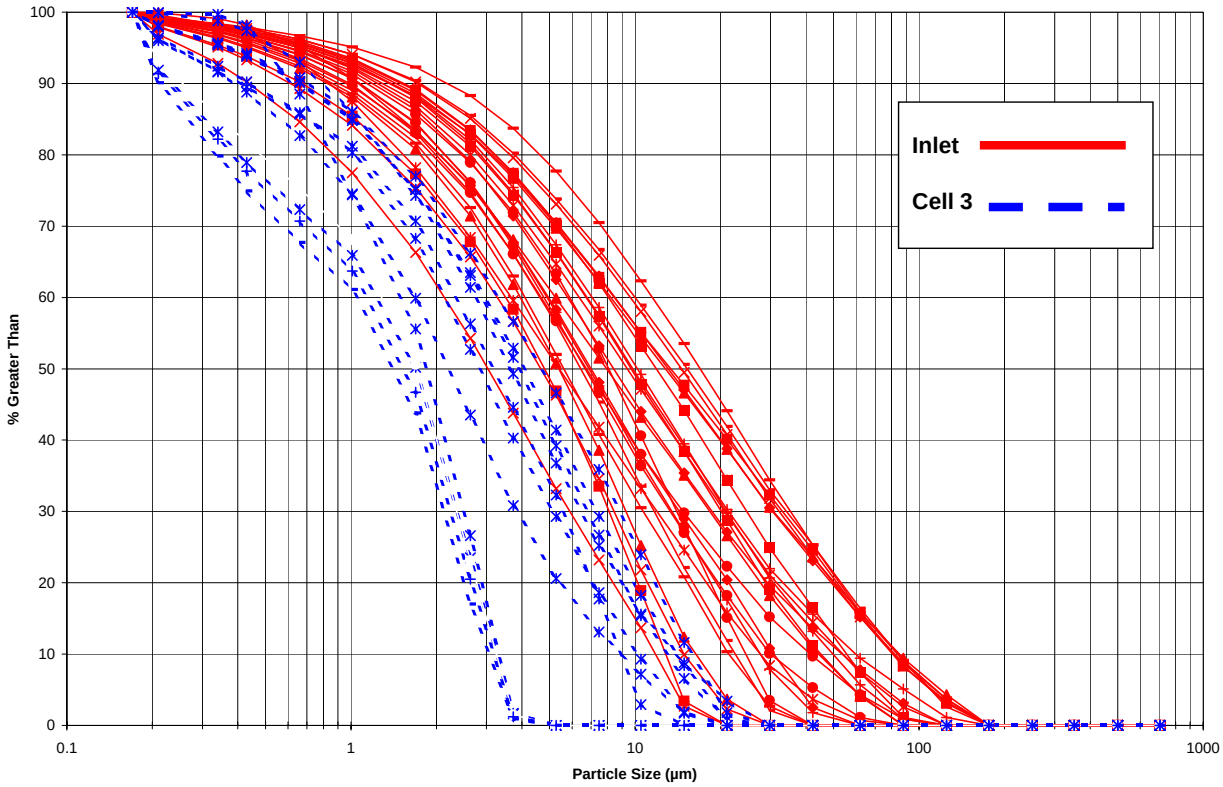


Figure D1 **:** Hydrographs, hyetographs and pollutographs for the back-to-back events on July 21 and July 22, 2002.



APPENDIX E

Individual Event Particle Size Distributions



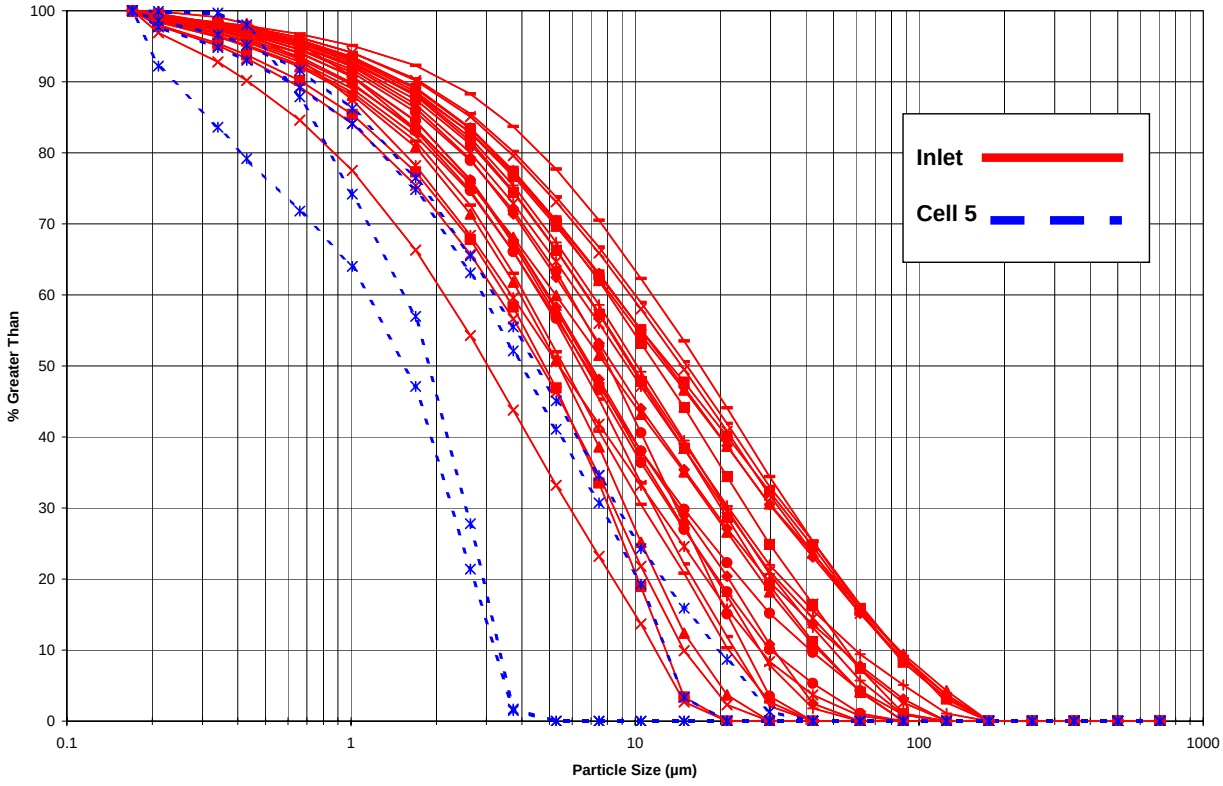
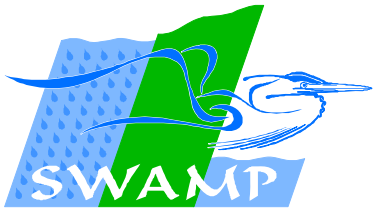


***Figure E1*:** Cumulative wet weather particle size distributions at the inlet and cell 3 (upper graph) and at the inlet and cell 5 (lower graph)



APPENDIX F

Water Quality Summary Statistics

Table F1: Wet weather water quality summary statistics -- Inlet (2000 monitoring season)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	FLOW WEIGHTED MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	20	2.5	100	25	2460	76.75	89.62	139.00	218.95	534.36	-15.24	453.14		
Chemistry	Dissolved Solids (mg/L)	20	10	100	96	514	214	240.59	249.49	262.60	116.44	211.57	313.63		
	Total Solids (mg/L)	20	10	100	210	2900	334	375.28	389.03	481.80	580.64	227.33	736.27		
	Solvents Extractable (mg/L)	19	1	95	1	12	5	4.75	6.14	5.51	2.76	4.26	6.75		
	Conductivity (uS/cm)	20	1	100	149	790	330	370.81	384.45	404.50	179.03	326.04	482.96		
	pH	20	0.1	100	7.3	7.88	7.64	7.64	7.65	7.64	0.15	7.58	7.71		
	Alkalinity (mg/L CaCO3)	20	2.5	100	43	124	70.25	75.25	74.80	78.10	22.56	68.21	87.99		
	Turbidity (FTU)	20	0.01	100	14.7	2000	36.25	43.00	62.01	142.73	439.09	-49.71	335.16		
	BOD (mg/L)	7	0.2	100	5	13.8	7.4	7.96	8.64	8.46	3.25	6.05	10.86		
	Chloride (mg/L)	20	0.2	100	13.8	155	49.5	53.91	61.09	63.49	38.33	46.69	80.29	250.0	0
	Carbon (DOC) (mg/L)	20	0.1	100	3.2	16.3	7.1	7.14	7.31	7.89	3.82	6.21	9.57		
	Carbon (DIC) (mg/L)	20	0.2	100	10.8	30.6	17.7	18.54	18.35	19.24	5.54	16.81	21.67		
	Silicon (mg/L)	20	0.02	100	0.48	2.66	1.24	1.28	1.26	1.38	0.56	1.14	1.62		
Metals	Aluminum (ug/L)	20	11	100	121	1570	419	450.30	598.12	555.20	387.02	385.59	724.81		
	Arsenic (ug/L)	20	1	0	0.5	1	0.5	0.55	0.51	0.58	0.18	0.49	0.66	0.1	100
	Barium (ug/L)	20	0.2	100	19.9	156	28.15	34.71	36.30	39.86	29.51	26.92	52.79		
	Beryllium (ug/L)	20	0.2	5	0.01	0.246	0.0362	0.04	0.06	0.06	0.06	0.03	0.08	1100	0
	Cadmium (ug/L)	20	0.6	5	0.3	1.23	0.3	0.32	0.31	0.35	0.21	0.26	0.44	0.5	5
	Calcium (ug/L)	20	5	100	22500	204000	36350	41061.03	41721.31	47755.00	38784.99	30757.04	64752.96		
	Chromium (ug/L)	20	1.4	95	0.7	7.83	2.87	2.92	3.22	3.27	1.58	2.58	3.96		
	Cobalt (ug/L)	20	1.3	35	0.65	5.4	0.65	0.96	1.05	1.20	1.12	0.71	1.70	0.9	35
	Copper (ug/L)	20	1.6	100	2.5	50.5	19.35	19.50	21.82	22.16	10.38	17.61	26.71	5	95
	Iron (ug/L)	20	0.8	100	256	3690	668	747.16	991.58	952.15	812.86	595.91	1308.39	300	90
	Lead (ug/L)	20	10	45	5	62.1	5	9.43	14.47	13.26	13.73	7.24	19.28	5	45
	Magnesium (ug/L)	20	8	100	2390	11300	4720	5050.90	5321.37	5486.00	2414.14	4427.98	6544.02		
	Manganese (ug/L)	20	0.2	100	34	849	93.25	108.23	156.97	159.50	185.37	78.26	240.74		
	Mercury (ug/L)	20	0.02	30	0.01	0.09	0.01	0.02	0.03	0.02	0.03	0.01	0.04	0.2	0
	Molybdenum (ug/L)	20	1.6	15	0.8	51.6	0.8	1.09	2.03	3.48	11.33	-1.49	8.45	40	5
	Nickel (ug/L)	20	1.3	95	0.65	8.3	2.25	2.72	2.76	3.24	2.00	2.36	4.11	25	0
	Selenium (ug/L)	20	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00				
	Strontium (ug/L)	20	0.1	100	57	398	116.5	119.20	122.59	132.51	74.85	99.70	165.31		
	Titanium (ug/L)	20	0.5	95	0.25	21.6	7.79	6.75	8.70	8.23	4.25	6.37	10.10		
	Vanadium (ug/L)	20	1.5	90	0.75	8.9	2.565	2.62	3.05	3.02	1.78	2.25	3.80	6	5
	Zinc (ug/L)	20	0.6	100	5.72	223	62.8	66.47	79.64	79.76	46.43	59.41	100.11	20	95
Nutrients	Nitrogen (NH3+NH4) (mg/L)	20	0.002	100	0.032	0.376	0.154	0.14	0.15	0.17	0.10	0.13	0.21		
	Nitrogen (NO2) (mg/L)	20	0.001	100	0.015	0.5	0.1385	0.12	0.14	0.15	0.10	0.10	0.19		
	Nitrogen (NO2+NO3) (mg/L)	20	0.005	100	0.085	2.24	1.09	0.88	1.17	1.14	0.63	0.87	1.42		
	Phosphate (mg/L)	20	0.005	90	0.002	0.37	0.0605	0.05	0.06	0.08	0.08	0.04	0.11		
	Total Phosphorus (mg/L)	20	0.002	100	0.004	2.11	0.307	0.28	0.39	0.45	0.46	0.25	0.65	0.03	95
	TKN Nitrogen (mg/L)	20	0.02	100	0.3	4.82	1.69	1.58	1.93	1.91	1.12	1.42	2.41		
Bacteria	*Escherichia coli (c/100mL)*	7	4		7600	46000	20000	19691.99	21184.89	22942.86	13392.39	13021.82	32863.90	100	100
	Fecal streptococcus (c/100mL)	7	4		4800	43000	30000	19559.12	12324.16	25800.00	15722.60	14152.75	37447.25		
	Pseudomonas aeruginosa (c/100mL)	7	4		150	5300	2100	1367.11	1129.89	2141.43	1702.75	880.04	3402.82		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	2	20	100	28	32	30	29.93	30.29	30.00	2.83	26.08	33.92		
Pesticides	Pentachlorophenol (ng/L)	0	10	0	0	0	0	0.00	0.00	0.00	0.00			500	0
	Dicamba (ng/L)	11	50	100	52	240	84	92.25	126.30	107.27	65.01	68.85	145.69	200000	0
	2,4 -D (ng/L)	17	100	100	160	3500	770	928.38	1420.68	1440.00	1236.41	852.26	2027.74	4000	0
PAH	Fluoranthene (ug/L)	3	0.4	0	0.4	1	0.6	0.62	0.73	0.67	0.31	0.32	1.01		
	Pyrene (ug/L)	3	0.4	33	0.2	0.8	0.4	0.40	0.53	0.47	0.31	0.12	0.81		
	Chrysene (ug/L)	2	0.3	50	0.2	0.4	0.3	0.28	0.28	0.30	0.14	0.10	0.50		

Table F2: Wet weather water quality summary statistics -- cell 1 outlet (2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	FLOW WEIGHTED MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	36	2.5	100	4.5	51.9	14.25	14.55	20.26	17.82	12.54	13.73	21.92		
Chemistry	Dissolved Solids (mg/L)	36	10	100	124	493	235	235.06	221.82	250.42	92.97	220.05	280.79		
	Total Solids (mg/L)	36	10	100	146	504	255.5	254.63	242.02	268.19	91.06	238.45	297.94		
	Solvents Extractable (mg/L)	10	1	60	0.5	2.5	1.15	1.03	1.15	1.18	0.64	0.78	1.58		
	Conductivity (uS/cm)	12	1	100	209	759	299.5	318.58	281.75	339.75	148.05	255.98	423.52		
	pH	2	0.1	100	7.74	8.56	8.15	8.14	8.25	8.15	0.58	7.35	8.95		
	Alkalinity (mg/L CaCO3)	12	2.5	100	59	164	79	84.95	76.94	88.96	30.69	71.60	106.32		
	Turbidity (FTU)	36	0.01	100	4.26	33.3	11.2	11.37	14.49	13.11	7.23	10.75	15.47		
	BOD (mg/L)	2	0.2	100	2.8	3.2	3	2.99	2.99	3.00	0.28	2.61	3.39		
	Chloride (mg/L)	11	0.2	100	19.2	198	29.8	35.01	34.82	45.62	51.11	15.42	75.82	250.0	0
	Carbon (DOC) (mg/L)	11	0.1	100	2.2	4.7	3.4	3.23	3.13	3.32	0.79	2.85	3.78		
	Carbon (DIC) (mg/L)	11	0.2	100	14	25.6	18.6	18.51	17.24	18.84	3.71	16.64	21.03		
	Silicon (mg/L)	11	0.02	100	0.16	0.68	0.56	0.47	0.50	0.50	0.15	0.41	0.59		
Metals	Aluminum (ug/L)	10	11	100	51.2	440	155	156.16	201.95	182.52	111.02	113.71	251.33		
	Arsenic (ug/L)	10	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00			0.1	100
	Barium (ug/L)	10	0.2	100	17.4	28.5	23.05	22.33	21.37	22.64	3.89	20.23	25.05		
	Beryllium (ug/L)	10	0.2	0	0.1	0.1	0.1	0.10	0.10	0.10	0.00	0.10	0.10	1100	0
	Cadmium (ug/L)	10	0.6	0	0.3	0.3	0.3	0.30	0.30	0.30	0.00	0.30	0.30	0.5	0
	Calcium (ug/L)	10	5	100	23500	40600	30500	30364.29	28398.95	30800.00	5513.62	27382.69	34217.31		
	Chromium (ug/L)	10	1.4	60	0.7	2.8	1.845	1.35	1.53	1.54	0.77	1.06	2.02		
	Cobalt (ug/L)	10	1.3	0	0.65	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0
	Copper (ug/L)	10	1.6	100	5.09	15.8	7.935	8.29	9.38	8.72	3.18	6.75	10.69	5	100
	Iron (ug/L)	10	0.8	100	145	762	274	311.04	382.67	350.90	188.40	234.13	467.67	300	40
	Lead (ug/L)	10	10	0	5	5	5	5.00	5.00	5.00	0.00			5	0
	Magnesium (ug/L)	10	8	100	3380	8730	5745	5410.48	4919.23	5610.00	1595.65	4621.02	6598.98		
	Manganese (ug/L)	10	0.2	100	23	87.7	36.7	36.72	46.56	40.01	19.40	27.98	52.04		
	Mercury (ug/L)	10	0.02	10	0.02	0.05	0.02	0.02	0.03	0.02	0.01	0.02	0.03	0.2	0
	Molybdenum (ug/L)	10	1.6	0	0.8	0.8	0.8	0.80	0.80	0.80	0.00	0.80	0.80	40	0
	Nickel (ug/L)	10	1.3	30	0.65	3.44	0.65	1.05	1.36	1.33	1.06	0.67	1.99	25	0
	Selenium (ug/L)	10	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00				
	Strontium (ug/L)	10	0.1	100	87.8	169	120	117.65	108.08	120.49	27.89	103.21	137.77		
	Titanium (ug/L)	10	0.5	100	1.74	8.44	4.88	4.58	5.18	4.94	1.87	3.78	6.10		
	Vanadium (ug/L)	10	1.5	10	0.75	1.67	0.75	0.81	0.94	0.84	0.29	0.66	1.02	6	0
	Zinc (ug/L)	10	0.6	100	8.71	38.8	22.9	19.36	23.79	21.56	9.65	15.58	27.54	20	60
Nutrients	Nitrogen (NH3+NH4) (mg/L)	12	0.002	100	0.022	0.156	0.092	0.09	0.11	0.10	0.04	0.08	0.12		
	Nitrogen (NO2) (mg/L)	12	0.001	100	0.032	0.244	0.044	0.06	0.05	0.07	0.06	0.03	0.10		
	Nitrogen (NO2+NO3) (mg/L)	12	0.005	100	0.506	1.1	0.653	0.69	0.65	0.71	0.17	0.61	0.80		
	Phosphate (mg/L)	12	0.005	100	0.006	0.0865	0.02525	0.02	0.02	0.03	0.02	0.01	0.04		
	Total Phosphorus (mg/L)	13	0.002	100	0.048	0.18	0.096	0.10	0.12	0.10	0.04	0.08	0.13	0.03	100
	TKN Nitrogen (mg/L)	13	0.02	100	0.5	1.53	0.76	0.78	0.86	0.82	0.28	0.67	0.97		
Bacteria	*Escherichia coli (c/100mL)*		4											100	
	Fecal streptococcus (c/100mL)		4												
	Pseudomonas aeruginosa (c/100mL)		4												
Herbicides and	2,4,6 -trichlorophenol (ng/L)	8	20	0	20	20	20	20.00	20.00	20.00					
Pesticides	Pentachlorophenol (ng/L)	8	10	13	10	17	10	10.69	10.78	10.88	2.47	9.16	12.59	500	0
	Dicamba (ng/L)	8	50	13	50	88	50	53.66	64.61	54.75	13.44	45.44	64.06	200000	0
	2,4 -D (ng/L)	8	100	50	100	1000	130	174.61	479.00	255.00	308.87	40.97	469.03	4000	0
PAH	Fluoranthene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Pyrene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Chrysene (ug/L)	2	0.3	0	0.15	0.15	0.15	0.15	0.15	0.15	0.00				

Table F3: Wet weather water quality summary statistics -- cell 2 outlet (2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	FLOW WEIGHTED MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	32	2.5	100	4	38.1	10.25	10.44	12.86	12.33	7.93	9.58	15.08		
Chemistry	Dissolved Solids (mg/L)	32	10	100	156	496	230	250.58	243.99	262.88	88.32	232.28	293.47		
	Total Solids (mg/L)	32	10	100	164	505	240	262.90	257.09	275.38	90.51	244.01	306.74		
	Solvents Extractable (mg/L)	11	1	36	0.5	2	0.5	0.77	0.88	0.88	0.51	0.58	1.18		
	Conductivity (uS/cm)	13	1	100	242	763	305	331.67	315.43	347.92	134.82	274.63	421.21		
	pH	13	0.1	100	7.87	8.58	8.03	8.05	8.07	8.06	0.18	7.96	8.16		
	Alkalinity (mg/L CaCO3)	13	2.5	100	68	194	88.5	92.38	96.43	96.27	33.44	78.09	114.45		
	Turbidity (FTU)	32	0.01	100	3.56	20.8	8.2	8.73	10.48	9.80	4.87	8.11	11.48		
	BOD (mg/L)	3	0.2	100	2	2.4	2	2.13	2.10	2.13	0.23	1.87	2.39		
	Chloride (mg/L)	12	0.2	100	23.4	201	30.6	35.23	36.19	44.55	49.41	16.59	72.51	250.0	0.00
	Carbon (DOC) (mg/L)	12	0.1	100	2.1	3.9	2.7	2.73	2.75	2.78	0.51	2.49	3.06		
	Carbon (DIC) (mg/L)	12	0.2	100	16	25.2	20.6	20.03	19.40	20.20	2.73	18.66	21.74		
	Silicon (mg/L)	12	0.02	92	0.02	0.7	0.52	0.39	0.49	0.48	0.18	0.38	0.58		
Metals	Aluminum (ug/L)	11	11	100	46.4	269	92.2	95.38	115.70	107.20	61.39	70.92	143.48		
	Arsenic (ug/L)	11	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00			0.1	100.00
	Barium (ug/L)	11	0.2	100	18	24.9	22.1	21.93	21.61	22.03	2.13	20.77	23.29		
	Beryllium (ug/L)	11	0.2	0	0.0161	0.1	0.1	0.08	0.08	0.09	0.03	0.08	0.11	1100	0.00
	Cadmium (ug/L)	11	0.6	0	0.0483	0.3	0.3	0.25	0.25	0.28	0.08	0.23	0.32	0.5	0.00
	Calcium (ug/L)	11	5	100	26800	39500	33900	33096.05	32195.18	33245.45	3275.47	31309.81	35181.10		
	Chromium (ug/L)	11	1.4	18	0.7	1.59	0.7	0.80	0.87	0.85	0.33	0.65	1.04		
	Cobalt (ug/L)	11	1.3	0	0.65	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0.00
	Copper (ug/L)	11	1.6	100	3.15	9.78	5.56	5.52	5.95	5.78	1.86	4.69	6.88	5	72.73
	Iron (ug/L)	11	0.8	100	118	437	160	192.85	221.49	207.45	93.08	152.45	262.46	300	18.18
	Lead (ug/L)	11	10	0	3.76	5	5	4.87	4.78	4.89	0.37	4.67	5.11	5	0.00
	Magnesium (ug/L)	11	8	100	4440	8740	6050	6331.38	6127.23	6417.27	1104.17	5764.76	7069.78		
	Manganese (ug/L)	11	0.2	100	18.8	43.7	24.4	25.11	28.48	25.88	7.18	21.64	30.13		
	Mercury (ug/L)	11	0.02	0	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.2	0.00
	Molybdenum (ug/L)	11	1.6	36	0.585	4.93	0.8	1.22	1.52	1.60	1.42	0.76	2.44	40	0.00
	Nickel (ug/L)	11	1.3	100	0.65	4.66	0.65	1.03	1.23	1.34	1.26	0.60	2.09	25	0.00
	Selenium (ug/L)	11	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00				
	Strontium (ug/L)	11	0.1	100	106	167	138	134.51	130.29	135.45	16.72	125.57	145.34		
	Titanium (ug/L)	11	0.5	100	1.62	7.7	3.33	3.22	3.62	3.51	1.64	2.55	4.48		
	Vanadium (ug/L)	11	1.5	0	0.75	1.19	0.75	0.78	0.83	0.79	0.13	0.71	0.87	6	0.00
	Zinc (ug/L)	11	0.6	100	3.28	18.1	12.2	9.58	11.66	10.76	4.68	8.00	13.53	20	0.00
Nutrients	Nitrogen (NH3+NH4) (mg/L)	13	0.002	100	0.074	0.426	0.124	0.13	0.14	0.15	0.09	0.10	0.20		
	Nitrogen (NO2) (mg/L)	13	0.001	100	0.031	0.302	0.037	0.05	0.05	0.06	0.07	0.02	0.10		
	Nitrogen (NO2+NO3) (mg/L)	13	0.005	100	0.322	0.722	0.603	0.55	0.56	0.57	0.14	0.49	0.64		
	Phosphate (mg/L)	13	0.005	85	0.0025	0.022	0.018	0.01	0.01	0.01	0.01	0.01	0.02		
	Total Phosphorus (mg/L)	14	0.002	100	0.034	0.18	0.058	0.06	0.08	0.07	0.04	0.05	0.09	0.03	100.00
	TKN Nitrogen (mg/L)	14	0.02	100	0.48	1.71	0.6	0.67	0.77	0.73	0.35	0.54	0.91		
Bacteria	*Escherichia coli (c/100mL)*	3	4	100	120	18000	840	1219.68	7254.22	6320.00	10121.58	-5133.44	17773.44	100	100.00
	Fecal streptococcus (c/100mL)	3	4	100	20	11000	2100	773.06	5060.95	4373.33	5832.34	-2226.45	10973.12		
	Pseudomonas aeruginosa (c/100mL)	3	4	100	12	240	80	61.30	126.67	110.67	117.05	-21.79	243.12		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	9	20	0	20	20	20	20.00	21.43	20.00	0.00				
Pesticides	Pentachlorophenol (ng/L)	9	10	0	10	10	10	10.00	10.72	10.00	0.00			500	0.00
	Dicamba (ng/L)	9	50	11	50	180	50	57.65	97.35	64.44	43.33	36.13	92.76	200000	0.00
	2,4 -D (ng/L)	9	100	44	100	500	100	144.33	266.07	171.11	131.29	85.34	256.88	4000	0.00
PAH	Fluoranthene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Pyrene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Chrysene (ug/L)	2	0.3	0	0.15	0.2	0.175	0.17	0.19	0.18	0.04	0.13	0.22		

Table F4: Wet weather water quality summary statistics -- cell 4 inlet (2000, 2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	38	2.5	100	5.9	104	19.25	18.82	23.52	18.70	17.57	29.46		
Chemistry	Dissolved Solids (mg/L)	38	10	100	140	459	232	243.38	253.24	73.74	229.79	276.68		
	Total Solids (mg/L)	38	10	100	172	480	256	267.46	276.87	74.77	253.09	300.64		
	Solvents Extractable (mg/L)	36	1	64	0.25	4	1.35	1.15	1.41	0.85	1.13	1.69		
	Conductivity (uS/cm)	38	1	100	214	706	356	370.68	386.05	114.41	349.68	422.43		
	pH	38	0.1	100	7.59	8.45	7.975	7.97	7.97	0.16	7.92	8.02		
	Alkalinity (mg/L CaCO3)	38	2.5	100	62	188	88.25	87.32	89.49	22.18	82.44	96.55		
	Turbidity (FTU)	38	0.01	100	5.23	76.4	12.6	13.44	15.83	12.09	11.99	19.68		
	BOD (mg/L)	11	0.2	100	1.4	7.4	3.6	3.40	3.84	1.92	2.70	4.97		
	Chloride (mg/L)	38	0.2	100	20.4	188	42.8	48.14	56.93	37.73	44.94	68.93	250.0	0
	Carbon (DOC) (mg/L)	38	0.1	100	2.1	8.1	3.4	3.57	3.75	1.29	3.34	4.16		
	Carbon (DIC) (mg/L)	38	0.2	100	13.6	28.8	20.9	20.30	20.66	3.82	19.44	21.87		
	Silicon (mg/L)	38	0.02	100	0.16	1.38	0.59	0.55	0.61	0.27	0.53	0.70		
Metals	Aluminum (ug/L)	38	11	100	50.5	586	117.5	135.98	159.38	107.52	125.20	193.57		
	Arsenic (ug/L)	39	1	0	0.5	1	0.5	0.52	0.53	0.11	0.49	0.56	0.1	100
	Barium (ug/L)	38	0.2	100	19.9	42.6	27.15	27.58	28.21	6.18	26.25	30.17		
	Beryllium (ug/L)	38	0.2	0	0.00487	0.1	0.1	0.04	0.06	0.04	0.05	0.08	1100	0
	Cadmium (ug/L)	38	0.6	5	0.0261	0.918	0.3	0.28	0.32	0.16	0.27	0.37	0.5	5
	Calcium (ug/L)	38	5	100	22900	52200	34500	34744.45	35423.68	7094.40	33168.03	37679.34		
	Chromium (ug/L)	38	1.4	34	0.102	3.05	0.7	0.92	1.10	0.70	0.88	1.32		
	Cobalt (ug/L)	38	1.3	0	0.121	1.11	0.65	0.59	0.61	0.15	0.56	0.66	0.9	3
	Copper (ug/L)	38	1.6	100	2.11	40	6.96	6.67	7.74	5.97	5.84	9.64	5	74
	Iron (ug/L)	38	0.8	100	135	950	307.5	309.19	340.11	167.57	286.83	393.38	300	53
	Lead (ug/L)	38	10	3	0.258	11.6	5	4.49	4.85	1.48	4.38	5.32	5	5
	Magnesium (ug/L)	38	8	100	1070	9770	6415	6175.31	6522.37	1805.93	5948.18	7096.56		
	Manganese (ug/L)	38	0.2	100	20.6	143	55.05	52.77	58.42	26.39	50.03	66.81		
	Mercury (ug/L)	26	0.02	0	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.2	0
	Molybdenum (ug/L)	38	1.6	29	0.333	9.78	0.8	1.12	1.57	1.84	0.99	2.16	40	0
	Nickel (ug/L)	38	1.3	55	0.65	8.14	1.35	1.15	1.40	1.25	1.00	1.79	25	0
	Selenium (ug/L)	38	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	38	0.1	100	88.6	218	148.5	142.12	145.23	30.12	135.66	154.81		
	Titanium (ug/L)	38	0.5	100	1.97	12	3.85	4.11	4.44	1.97	3.81	5.06		
	Vanadium (ug/L)	38	1.5	13	0.45	2.4	0.75	0.88	0.94	0.43	0.81	1.08	6	0
	Zinc (ug/L)	38	0.6	100	3.36	34.4	17.8	15.57	17.75	8.33	15.11	20.40	20	42
Nutrients	Nitrogen (NH3+NH4) (mg/L)	38	0.002	100	0.005	0.364	0.116	0.09	0.12	0.08	0.10	0.15		
	Nitrogen (NO2) (mg/L)	38	0.001	100	0.009	0.321	0.0475	0.06	0.08	0.07	0.06	0.10		
	Nitrogen (NO2+NO3) (mg/L)	38	0.005	100	0.182	1.46	0.645	0.60	0.68	0.32	0.58	0.78		
	Phosphate (mg/L)	38	0.005	97	0.0025	0.0669	0.02	0.02	0.03	0.02	0.02	0.03		
	Total Phosphorus (mg/L)	38	0.002	100	0.04	0.26	0.1096	0.10	0.12	0.06	0.10	0.14	0.03	100
	TKN Nitrogen (mg/L)	38	0.02	100	0.44	1.63	0.82	0.83	0.88	0.31	0.78	0.97		
Bacteria	*Escherichia coli (c/100mL)*	7	4	100	76	30000	2300	2342.57	8775.14	11575.07	200.37	17349.92	100	86
	Fecal streptococcus (c/100mL)	7	4	100	640	19000	2800	2654.38	5382.86	6802.91	343.29	10422.43		
	Pseudomonas aeruginosa (c/100mL)	7	4	86	2	520	92	53.73	184.00	205.55	31.73	336.27		
Herbicides an	2,4,6 -trichlorophenol (ng/L)	24	20	4	20	26	20	20.22	20.25	1.22	19.76	20.74		
Pesticides	Pentachlorophenol (ng/L)	24	10	17	10	20	10	10.80	11.04	2.76	9.94	12.15	500	0
	Dicamba (ng/L)	26	50	42	50	770	50	80.57	119.69	155.11	60.07	179.32	200000	0
	2,4 -D (ng/L)	32	100	78	100	4100	295	356.32	688.13	990.66	344.88	1031.37	4000	3
PAH	Fluoranthene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.00				
	Pyrene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.00				
	Chrysene (ug/L)	2	0.3	0	0.15	0.15	0.15	0.15	0.15	0.00				

Table F5: Wet weather water quality summary statistics -- cell 4 outlet (2000, 2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	38	2.5	100	3	35.5	9.75	9.57	10.78	6.18	8.82	12.75		
Chemistry	Dissolved Solids (mg/L)	38	10	100	184	500	245	259.93	268.21	72.53	245.15	291.27		
	Total Solids (mg/L)	38	10	100	194	512	254	270.99	279.16	73.11	255.91	302.40		
	Solvents Extractable (mg/L)	38	1	26	0.25	3	0.5	0.66	0.82	0.62	0.62	1.01		
	Conductivity (uS/cm)	38	1	100	285	769	377.5	400.03	412.76	111.54	377.30	448.23		
	pH	38	0.1	100	7.91	8.32	8.1	8.10	8.10	0.10	8.06	8.13		
	Alkalinity (mg/L CaCO3)	38	2.5	100	79	108	96.75	95.04	95.39	8.17	92.79	97.99		
	Turbidity (FTU)	38	0.01	100	2.93	25	8.24	8.62	9.46	4.30	8.09	10.83		
	BOD (mg/L)	12	0.2	100	1	3.6	2.6	2.14	2.37	1.03	1.78	2.95		
	Chloride (mg/L)	38	0.2	100	25.8	158	42.6	49.42	56.44	32.91	45.97	66.90	250.0	0
	Carbon (DOC) (mg/L)	38	0.1	100	0.67	8	3	2.96	3.15	1.24	2.76	3.54		
	Carbon (DIC) (mg/L)	38	0.2	100	18.2	33.2	22.35	22.51	22.66	2.71	21.80	23.52		
	Silicon (mg/L)	38	0.02	100	0.18	94	0.52	0.54	2.98	15.17	-1.85	7.80		
Metals	Aluminum (ug/L)	38	11	100	23.7	212	71.95	71.29	80.71	43.60	66.85	94.57		
	Arsenic (ug/L)	38	1	0	0.5	1	0.5	0.51	0.51	0.08	0.49	0.54	0.1	100
	Barium (ug/L)	38	0.2	100	21.4	40	26.95	27.91	28.28	4.73	26.78	29.78		
	Beryllium (ug/L)	38	0.2	0	0.00789	0.1	0.1	0.05	0.07	0.04	0.06	0.09	1100	0
	Cadmium (ug/L)	38	0.6	5	0.282	9.39	0.3	0.35	0.56	1.47	0.10	1.03	0.5	8
	Calcium (ug/L)	38	5	100	27100	42700	37300	36870.27	37084.21	3943.08	35830.52	38337.90		
	Chromium (ug/L)	38	1.4	5	0.14	5.05	0.7	0.70	0.81	0.73	0.57	1.04		
	Cobalt (ug/L)	38	1.3	3	0.0768	1.4	0.65	0.61	0.65	0.20	0.59	0.71	0.9	5
	Copper (ug/L)	38	1.6	84	0.8	81.3	3.735	3.60	6.31	12.81	2.24	10.39	5	34
	Iron (ug/L)	38	0.8	100	72.9	549	182.5	188.00	210.90	111.05	175.59	246.21	300	13
	Lead (ug/L)	38	10	3	0.39	38.2	5	4.66	5.62	5.55	3.85	7.38	5	5
	Magnesium (ug/L)	38	8	100	5580	9730	7750	7591.51	7673.16	1111.04	7319.91	8026.41		
	Manganese (ug/L)	38	0.2	100	14.1	93.3	31.9	35.39	39.01	18.30	33.19	44.83		
	Mercury (ug/L)	28	0.02	4	0.01	0.24	0.02	0.02	0.03	0.04	0.01	0.04	0.2	4
	Molybdenum (ug/L)	38	1.6	37	0.8	8.53	0.8	1.34	1.85	1.80	1.28	2.42	40	0
	Nickel (ug/L)	38	1.3	29	0.54	32	0.65	1.04	2.60	6.56	0.51	4.68	25	5
	Selenium (ug/L)	38	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	38	0.1	100	127	195	165.5	160.56	161.63	18.59	155.72	167.54		
	Titanium (ug/L)	38	0.5	97	0.25	10	2.88	2.56	3.09	1.90	2.48	3.69		
	Vanadium (ug/L)	38	1.5	3	0.218	2.48	0.75	0.76	0.80	0.30	0.70	0.89	6	0
	Zinc (ug/L)	38	0.6	100	0.656	244	6.04	5.69	12.00	38.72	-0.31	24.31	20	3
Nutrients	Nitrogen (NH3+NH4) (mg/L)	38	0.002	95	0.002	0.281	0.136	0.10	0.13	0.07	0.11	0.16		
	Nitrogen (NO2) (mg/L)	38	0.001	100	0.005	0.305	0.0315	0.04	0.05	0.06	0.03	0.07		
	Nitrogen (NO2+NO3) (mg/L)	38	0.005	100	0.047	1.14	0.3955	0.34	0.43	0.27	0.35	0.51		
	Phosphate (mg/L)	38	0.005	71	0.0025	0.0517	0.01025	0.01	0.01	0.01	0.01	0.02		
	Total Phosphorus (mg/L)	38	0.002	100	0.032	0.146	0.056	0.07	0.07	0.03	0.06	0.08	0.03	100
	TKN Nitrogen (mg/L)	38	0.02	100	0.44	1.44	0.68	0.72	0.75	0.23	0.67	0.82		
Bacteria	*Escherichia coli (c/100mL)*	8	4	100	20	17000	330	274.79	2430.25	5899.74	-1657.98	6518.48	100	63
	Fecal streptococcus (c/100mL)	8	4	100	40	9600	300	273.40	1409.25	3313.72	-887.00	3705.50		
	Pseudomonas aeruginosa (c/100mL)	8	4	50	2	1400	6	12.02	186.00	490.74	-154.06	526.06		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	24	20	4	20	24	20	20.15	20.17	0.82	19.84	20.49		
Pesticides	Pentachlorophenol (ng/L)	23	10	0	10	10	10	10.00	10.00	0.00			500	0
	Dicamba (ng/L)	23	50	22	50	2400	50	73.95	180.17	489.58	-19.91	380.25	200000	0
	2,4 -D (ng/L)	28	100	64	100	24000	190	275.61	1282.86	4515.60	-389.71	2955.43	4000	4
PAH	Fluoranthene (ug/L)	4	0.4	0	0.2	0.2	0.2	0.20	0.20	0.00				
	Pyrene (ug/L)	4	0.4	0	0.2	0.2	0.2	0.20	0.20	0.00				
	Chrysene (ug/L)	4	0.3	0	0.15	0.15	0.15	0.15	0.15	0.00				

Table F6: Wet weather water quality summary statistics -- cell 3 oulet (2000, 2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	FLOW WEIGHTED MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	53	2.5	100	3.3	67	11	11.22	18.83	13.09	9.54	10.52	15.66		
Chemistry	Dissolved Solids (mg/L)	53	10	100	160	486	232	252.93	256.91	263.04	80.12	241.47	284.61		
	Total Solids (mg/L)	53	10	100	170	495	244	266.17	275.47	276.02	80.55	254.33	297.70		
	Solvents Extractable (mg/L)	50	1	36	0.25	4	0.95	0.83	1.17	1.04	0.77	0.83	1.25		
	Conductivity (uS/cm)	52	1	100	247	748	362.5	391.00	396.98	406.58	123.45	373.02	440.13		
	pH	52	0.1	100	7.41	8.56	8.065	8.05	8.01	8.05	0.18	8.01	8.10		
	Alkalinity (mg/L CaCO3)	52	2.5	100	53.5	217	97.45	97.74	96.67	99.35	20.57	93.75	104.94		
	Turbidity (FTU)	53	0.01	100	2.01	58.4	8.15	8.81	14.80	10.53	8.70	8.19	12.87		
	BOD (mg/L)	12	0.2	100	1.2	4.4	2.7	2.37	2.86	2.57	1.02	1.99	3.14		
	Chloride (mg/L)	52	0.2	100	23.8	212	38.5	46.85	53.80	56.48	41.94	45.08	67.88	250.0	0
	Carbon (DOC) (mg/L)	52	0.1	100	2	8.2	2.85	3.16	3.33	3.34	1.31	2.99	3.70		
	Carbon (DIC) (mg/L)	52	0.2	100	18	31.2	22.8	23.02	22.91	23.18	2.81	22.41	23.94		
	Silicon (mg/L)	52	0.02	98	0.02	1.08	0.46	0.42	0.53	0.52	0.29	0.44	0.60		
Metals	Aluminum (ug/L)	52	11	98	7.14	736	84.6	80.92	130.08	103.56	106.65	74.57	132.55		
	Arsenic (ug/L)	52	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00			5	0
	Barium (ug/L)	52	0.2	100	20.1	39.9	26.4	27.95	28.47	28.46	5.68	26.92	30.01		
	Beryllium (ug/L)	52	0.2	0	0.000697	0.1	0.1	0.03	0.05	0.06	0.04	0.05	0.07	1100	0
	Cadmium (ug/L)	52	0.6	6	0.043	0.875	0.3	0.31	0.37	0.33	0.13	0.30	0.37	0.5	10
	Calcium (ug/L)	52	5	100	29700	50200	37000	37811.63	37752.75	38105.77	4891.67	36776.22	39435.31		
	Chromium (ug/L)	52	1.4	6	0.0733	3.01	0.7	0.64	0.79	0.74	0.44	0.62	0.86		
	Cobalt (ug/L)	52	1.3	2	0.331	5.36	0.65	0.65	1.02	0.72	0.66	0.54	0.90	0.9	2
	Copper (ug/L)	52	1.6	94	0.8	52.3	3.95	4.13	5.21	5.95	8.03	3.76	8.13	5	37
	Iron (ug/L)	52	0.8	100	2.76	1450	192	188.83	270.10	234.40	197.08	180.83	287.97	300	17
	Lead (ug/L)	52	10	2	0.14	15.7	5	4.66	5.19	5.03	1.72	4.56	5.50	5	4
	Magnesium (ug/L)	52	8	100	5160	11900	7880	7731.97	7553.51	7828.65	1245.19	7490.21	8167.09		
	Manganese (ug/L)	52	0.2	98	0.134	206	33.25	33.85	56.05	45.62	35.26	36.04	55.21		
	Mercury (ug/L)	37	0.02	3	0.01	0.2	0.02	0.02	0.02	0.02	0.03	0.01	0.03	0.2	0
	Molybdenum (ug/L)	52	1.6	27	0.223	10.1	0.8	1.11	1.14	1.53	1.81	1.04	2.02	40	0
	Nickel (ug/L)	52	1.3	35	0.0531	3.84	0.65	0.89	1.09	1.11	0.81	0.89	1.33	25	0
	Selenium (ug/L)	52	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00				
	Strontium (ug/L)	52	0.1	100	121	237	165	161.74	158.68	162.98	20.59	157.38	168.58		
	Titanium (ug/L)	52	0.5	98	0.25	13.4	3.095	2.84	3.85	3.43	2.23	2.82	4.03		
	Vanadium (ug/L)	52	1.5	2	0.164	3.08	0.75	0.69	0.79	0.75	0.37	0.65	0.85	6	0
	Zinc (ug/L)	52	0.6	100	2.23	106	5.855	6.74	11.68	9.10	14.26	5.23	12.98	20	2
Nutrients	Nitrogen (NH3+NH4) (mg/L)	52	0.002	98	0.001	0.506	0.123	0.09	0.15	0.13	0.09	0.11	0.15		
	Nitrogen (NO2) (mg/L)	52	0.001	100	0.003	0.528	0.035	0.04	0.07	0.05	0.08	0.03	0.07		
	Nitrogen (NO2+NO3) (mg/L)	52	0.005	100	0.121	1.16	0.448	0.41	0.47	0.47	0.24	0.41	0.54		
	Phosphate (mg/L)	52	0.005	69	0.00025	0.039	0.0085	0.01	0.01	0.01	0.01	0.01	0.01		
	Total Phosphorus (mg/L)	52	0.002	100	0.028	0.156	0.052	0.06	0.08	0.07	0.03	0.06	0.07	0.03	98
	TKN Nitrogen (mg/L)	52	0.02	100	0.4	1.76	0.63	0.68	0.77	0.72	0.27	0.64	0.79		
Bacteria	*Escherichia coli (c/100mL)*	11	4	100	10	9000	240	278.96	4199.13	1730.73	2795.66	78.63	3382.83	100	64
	Fecal streptococcus (c/100mL)	11	4	91	4	5700	500	234.57	3147.57	1298.00	1851.51	203.85	2392.15		
	Pseudomonas aeruginosa (c/100mL)	11	4	64	2	290	28	20.50	106.13	70.55	94.14	14.92	126.18		
Herbicides an	2,4,6 -trichlorophenol (ng/L)	30	20	7	20	48	20	20.82	20.56	21.20	5.27	19.31	23.09		
Pesticides	Pentachlorophenol (ng/L)	30	10	7	10	19	10	10.36	11.20	10.47	1.85	9.80	11.13	500	0
	Dicamba (ng/L)	30	50	13	50	340	50	58.40	67.60	68.07	59.22	46.88	89.26	200000	0
	2,4 -D (ng/L)	38	100	58	100	2300	140	207.57	199.67	367.11	513.93	203.70	530.51	4000	0
PAH	Fluoranthene (ug/L)	4	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Pyrene (ug/L)	4	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Chrysene (ug/L)	4	0.3	0	0.15	0.15	0.15	0.15	0.15	0.15	0.00				

Table F7: Wet weather water quality summary statistics -- cell 5 (2000, 2001 and 2002 monitoring seasons)

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	FLOW WEIGHTED MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	38	2.5	100	6	37	13.5	13.80	17.85	14.83	6.06	12.90	16.75		
Chemistry	Dissolved Solids (mg/L)	38	10	100	190	506	236	255.96	272.00	264.16	73.96	240.64	287.67		
	Total Solids (mg/L)	38	10	100	202	528	250	270.97	290.15	279.11	75.52	255.10	303.12		
	Solvents Extractable (mg/L)	36	1	39	0.25	2	0.5	0.76	1.04	0.89	0.52	0.72	1.07		
	Conductivity (uS/cm)	37	1	100	292	779	364	396.56	421.81	409.22	114.20	372.42	446.01		
	pH	37	0.1	100	7.9	8.45	8.11	8.10	8.10	8.10	0.11	8.06	8.13		
	Alkalinity (mg/L CaCO3)	37	2.5	100	84	110	98	96.78	95.01	97.04	7.25	94.71	99.38		
	Turbidity (FTU)	37	0.01	100	5.79	31.8	12.6	12.36	15.41	13.10	4.79	11.56	14.65		
	BOD (mg/L)	5	0.2	100	0.4	4	3.4	2.15	3.06	2.76	1.49	1.45	4.07		
	Chloride (mg/L)	37	0.2	100	28.2	165	38.8	47.63	60.09	54.81	34.75	43.61	66.00	250.0	0
	Carbon (DOC) (mg/L)	37	0.1	100	2.3	7.8	3	3.11	3.48	3.25	1.20	2.86	3.64		
	Carbon (DIC) (mg/L)	37	0.2	100	18.8	25.6	22.6	22.50	22.23	22.57	1.77	22.00	23.14		
	Silicon (mg/L)	37	0.02	100	0.16	1.08	0.52	0.45	0.53	0.51	0.24	0.43	0.59		
Metals	Aluminum (ug/L)	38	11	100	46.5	297	97.3	94.79	129.90	103.85	50.73	87.72	119.98		
	Arsenic (ug/L)	37	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00			5	0
	Barium (ug/L)	38	0.2	100	21.3	41.1	27.85	28.26	30.06	28.61	4.63	27.14	30.08		
	Beryllium (ug/L)	38	0.2	0	0.00923	0.1	0.1	0.06	0.07	0.08	0.04	0.07	0.09	1100	0
	Cadmium (ug/L)	38	0.6	3	0.227	0.685	0.3	0.31	0.32	0.32	0.08	0.29	0.34	0.5	5
	Calcium (ug/L)	38	5	100	29200	45900	37650	37716.14	37480.78	37871.05	3439.12	36777.59	38964.51		
	Chromium (ug/L)	38	1.4	0	0.322	1.24	0.7	0.69	0.74	0.70	0.11	0.66	0.73		
	Cobalt (ug/L)	38	1.3	0	0.469	0.975	0.65	0.65	0.68	0.65	0.06	0.63	0.67	0.9	3
	Copper (ug/L)	38	1.6	92	0.8	67	3.175	3.44	9.77	5.36	10.45	2.03	8.68	5	24
	Iron (ug/L)	38	0.8	100	114	711	235.5	233.65	304.30	252.58	114.25	216.25	288.90	300	21
	Lead (ug/L)	38	10	5	5	14.6	5	5.24	5.68	5.39	1.76	4.83	5.95	5	5
	Magnesium (ug/L)	38	8	100	5550	9980	7720	7576.75	7675.01	7666.84	1177.63	7292.42	8041.27		
	Manganese (ug/L)	38	0.2	100	22.2	82.7	31.9	35.83	43.72	38.29	15.56	33.35	43.24		
	Mercury (ug/L)	27	0.02	0	0.01	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.2	0
	Molybdenum (ug/L)	38	1.6	26	0.8	9.56	0.8	1.17	1.76	1.70	2.11	1.03	2.37	40	0
	Nickel (ug/L)	38	1.3	26	0.65	8.22	0.65	0.92	1.01	1.22	1.39	0.77	1.66	25	0
	Selenium (ug/L)	37	1	0	0.5	0.5	0.5	0.50	0.50	0.50	0.00				
	Strontium (ug/L)	38	0.1	100	125	198	163.5	160.68	162.05	161.76	18.79	155.79	167.74		
	Titanium (ug/L)	38	0.5	100	1.28	11.6	4.55	4.04	5.63	4.54	2.27	3.81	5.26		
	Vanadium (ug/L)	38	1.5	0	0.557	1.4	0.75	0.76	0.82	0.77	0.12	0.73	0.81	6	0
	Zinc (ug/L)	38	0.6	97	0.3	15.5	5.11	4.91	6.35	5.61	2.82	4.71	6.50	20	0
Nutrients	Nitrogen (NH3+NH4) (mg/L)	37	0.002	97	0.002	0.237	0.15	0.11	0.13	0.14	0.06	0.12	0.16		
	Nitrogen (NO2) (mg/L)	37	0.001	100	0.002	0.22	0.032	0.03	0.04	0.04	0.04	0.03	0.05		
	Nitrogen (NO2+NO3) (mg/L)	37	0.005	100	0.008	1.28	0.371	0.30	0.37	0.42	0.28	0.33	0.51		
	Phosphate (mg/L)	37	0.005	62	0.002	0.0388	0.008	0.01	0.01	0.01	0.01	0.01	0.01		
	Total Phosphorus (mg/L)	37	0.002	100	0.028	0.129	0.06	0.07	0.08	0.07	0.02	0.06	0.07	0.03	97
	TKN Nitrogen (mg/L)	37	0.02	100	0.48	2.16	0.7	0.74	0.80	0.77	0.29	0.68	0.87		
Bacteria	*Escherichia coli (c/100mL)*	7	4	100	8	650	60	73.52	345.43	209.71	291.32	-6.09	425.52	100	29
	Fecal streptococcus (c/100mL)	7	4	100	12	500	60	65.52	194.59	134.57	178.46	2.37	266.77		
	Pseudomonas aeruginosa (c/100mL)	7	4	14	2	300	4	6.08	62.91	45.71	112.13	-37.35	128.78		
Herbicides an	2,4,6 -trichlorophenol (ng/L)	26	20	4	20	28	20	20.26	20.16	20.31	1.57	19.70	20.91		
Pesticides	Pentachlorophenol (ng/L)	25	10	4	10	170	10	11.20	13.11	16.40	32.00	3.86	28.94	500	0
	Dicamba (ng/L)	25	50	20	50	910	50	66.32	88.87	102.64	176.50	33.45	171.83	200000	0
	2,4 -D (ng/L)	29	100	38	100	9700	100	185.03	532.37	595.17	1796.13	-58.54	1248.88	4000	3
PAH	Fluoranthene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Pyrene (ug/L)	2	0.4	0	0.2	0.2	0.2	0.20	0.20	0.20	0.00				
	Chrysene (ug/L)	2	0.3	0	0.15	0.15	0.15	0.15	0.15	0.15	0.00				

Table F8: Dry weather water quality statistics - inlet

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	28	2.5	46	1.25	64	2.5	3.23	6.58	12.25	2.04	11.12		
Chemistry	Dissolved Solids (mg/L)	28	10	100	272	7300	913	1046.01	1391.36	1483.62	841.83	1940.89		
	Total Solids (mg/L)	28	10	100	280	7320	918	1054.05	1397.43	1484.22	847.67	1947.18		
	Solvents Extractable (mg/L)	27	1	41	0.25	12	1	0.93	1.49	2.24	0.64	2.33		
	Conductivity (uS/cm)	28	1	100	637	12500	1505	1716.19	2295.68	2555.02	1349.30	3242.05		
	pH	28	0.1	100	7.85	8.45	8.25	8.21	8.21	0.14	8.16	8.27		
	Alkalinity (mg/L CaCO3)	28	2.5	100	118	294	219.5	211.34	215.93	43.66	199.76	232.10		
	Turbidity (FTU)	28	0.01	100	0.92	143	2.06	3.21	9.51	26.94	-0.47	19.49		
	BOD (mg/L)	19	0.2	89	0.2	8.6	2.2	1.69	2.52	2.21	1.52	3.51		
	Chloride (mg/L)	28	0.2	100	102	4480	315	387.98	647.61	974.02	286.83	1008.38	250.0	71
	Carbon (DOC) (mg/L)	28	0.1	100	1.3	11	3.5	3.71	4.01	1.85	3.33	4.70		
	Carbon (DIC) (mg/L)	28	0.2	100	26.8	71	51.4	49.24	50.42	10.69	46.46	54.38		
	Silicon (mg/L)	28	0.02	100	2.08	5.22	4.02	3.86	3.95	0.78	3.66	4.23		
Metals	Aluminum (ug/L)	28	11	100	23.4	936	64.05	76.41	114.92	172.82	50.91	178.93		
	Arsenic (ug/L)	28	1	0	0.5	0.5	0.5	0.50	0.50	0.00			5	0
	Barium (ug/L)	28	0.2	100	29.9	94.3	57.95	57.93	59.68	14.53	54.30	65.06		
	Beryllium (ug/L)	28	0.2	0	0.01	0.1	0.1	0.05	0.07	0.04	0.06	0.09	1100	0
	Cadmium (ug/L)	28	0.6	14	0.3	1.1	0.3	0.36	0.39	0.22	0.31	0.47	0.5	14
	Calcium (ug/L)	28	5	100	50000	154000	112500	104576.94	108342.86	27317.24	98224.60	118461.12		
	Chromium (ug/L)	28	1.4	25	0.7	11.4	0.7	0.98	1.39	2.06	0.62	2.15		
	Cobalt (ug/L)	28	1.3	4	0.65	1.43	0.65	0.67	0.68	0.15	0.62	0.73	0.9	4
	Copper (ug/L)	28	1.6	100	2.65	75	8.87	8.51	11.65	13.85	6.52	16.78	5	79
	Iron (ug/L)	28	0.8	100	48.8	4740	100.55	131.63	313.44	879.45	-12.31	639.18	300	14
	Lead (ug/L)	28	10	4	5	61	5	5.47	7.00	10.58	3.08	10.92	5	4
	Magnesium (ug/L)	28	8	100	7500	21900	16650	16124.69	16446.43	3023.67	15326.47	17566.39		
	Manganese (ug/L)	28	0.2	100	4.35	215	18.6	24.20	42.97	48.17	25.13	60.81		
	Mercury (ug/L)	28	0.02	4	0.01	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.2	0
	Molybdenum (ug/L)	28	1.6	46	0.8	145	0.8	2.46	11.51	28.91	0.81	22.22	40	11
	Nickel (ug/L)	28	1.3	36	0.65	6.5	0.65	1.00	1.29	1.24	0.83	1.75	25	0
	Selenium (ug/L)	28	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	28	0.1	100	185	739	347	359.14	374.29	115.22	331.61	416.96		
	Titanium (ug/L)	28	0.5	43	0.25	8.17	0.25	0.71	1.64	2.21	0.82	2.46		
	Vanadium (ug/L)	28	1.5	4	0.75	5.68	0.75	0.81	0.93	0.93	0.58	1.27	6	0
	Zinc (ug/L)	28	0.6	100	4.5	390	16.3	19.68	36.05	71.79	9.46	62.64	20	43
Nutrients	Nitrogen (NH3+NH4) (mg/L)	28	0.002	93	0.001	0.402	0.109	0.07	0.12	0.09	0.09	0.15		
	Nitrogen (NO2) (mg/L)	28	0.001	100	0.01	0.38	0.0635	0.07	0.08	0.07	0.06	0.11		
	Nitrogen (NO2+NO3) (mg/L)	28	0.005	100	0.231	3.54	2.725	2.42	2.61	0.71	2.34	2.87		
	Phosphate (mg/L)	28	0.005	96	0.005	0.19	0.076	0.07	0.08	0.05	0.07	0.10		
	Total Phosphorus (mg/L)	28	0.002	100	0.064	0.372	0.127	0.13	0.15	0.08	0.12	0.18	0.03	100
	TKN Nitrogen (mg/L)	28	0.02	100	0.062	6.16	0.64	0.80	1.12	1.24	0.66	1.58		
Bacteria	*Escherichia coli (c/100mL)*	22	4	100	180	8200	1400	1492.13	2322.73	2228.52	1391.50	3253.95	100	100
	Fecal streptococcus (c/100mL)	22	4	100	120	27000	2050	2061.86	4364.55	6471.11	1660.49	7068.60		
	Pseudomonas aeruginosa (c/100mL)	22	4	100	12	1600	70	83.08	227.18	438.05	44.14	410.23		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	19	20	11	20	36	20	21.00	21.26	4.01	19.46	23.07		
Pesticides	Pentachlorophenol (ng/L)	18	10	11	10	640	10	13.53	46.44	148.26	-22.05	114.93	500	6
	Dicamba (ng/L)	18	50	33	50	270	50	65.38	76.11	56.50	50.01	102.21	200000	0
	2,4 -D (ng/L)	18	100	39	100	1800	100	224.56	443.89	574.61	178.44	709.34	4000	0
PAH	none detected													

Table F9: Dry weather water quality statistics - Cell 4 inlet

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	10	2.5	100	6	19	11.25	11.66	12.30	4.16	9.72	14.88		
Chemistry	Dissolved Solids (mg/L)	10	10	100	184	274	226	223.46	224.80	25.89	208.75	240.85		
	Total Solids (mg/L)	10	10	100	196	284	239	235.76	237.00	25.51	221.19	252.81		
	Solvents Extractable (mg/L)	10	1	30	0.25	1.6	0.5	0.68	0.81	0.49	0.50	1.11		
	Conductivity (uS/cm)	10	1	100	284	421	348.5	343.91	345.90	39.12	321.65	370.15		
	pH	10	0.1	100	7.85	8.39	8.105	8.11	8.11	0.15	8.02	8.21		
	Alkalinity (mg/L CaCO3)	10	2.5	100	86	108	98.25	95.87	96.15	7.71	91.37	100.93		
	Turbidity (FTU)	10	0.01	100	4.77	14.8	9.955	9.20	9.73	3.18	7.76	11.70		
	BOD (mg/L)	7	0.2	100	2.2	4.8	2.8	3.07	3.17	0.91	2.50	3.84		
	Chloride (mg/L)	10	0.2	100	28.8	53.6	36.6	36.76	37.36	7.37	32.79	41.93	250.0	0
	Carbon (DOC) (mg/L)	10	0.1	100	2.2	3.5	3	2.91	2.95	0.47	2.66	3.24		
	Carbon (DIC) (mg/L)	10	0.2	100	19.6	25.2	22.3	22.19	22.26	1.89	21.09	23.43		
	Silicon (mg/L)	10	0.02	100	0.24	0.8	0.38	0.40	0.44	0.19	0.32	0.55		
Metals	Aluminum (ug/L)	10	11	100	39.1	156	77.5	74.99	81.08	34.65	59.61	102.55		
	Arsenic (ug/L)	10	1	0	0.5	0.5	0.5	0.50	0.50	0.00			0.1	100
	Barium (ug/L)	10	0.2	100	23	30	26.4	26.26	26.37	2.49	24.83	27.91		
	Beryllium (ug/L)	10	0.2	0	0.01	0.1	0.1	0.07	0.08	0.04	0.06	0.11	1100	0
	Cadmium (ug/L)	10	0.6	0	0.3	0.3	0.3	0.30	0.30	0.00	0.30	0.30	0.5	0
	Calcium (ug/L)	10	5	100	30300	41400	36900	36486.68	36640.00	3471.54	34488.36	38791.64		
	Chromium (ug/L)	10	1.4	0	0.7	0.7	0.7	0.70	0.70	0.00				
	Cobalt (ug/L)	10	1.3	0	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0
	Copper (ug/L)	10	1.6	60	0.8	5.71	1.74	1.68	2.14	1.61	1.14	3.13	5	10
	Iron (ug/L)	10	0.8	100	115	381	182.5	207.24	221.30	85.43	168.35	274.25	300	10
	Lead (ug/L)	10	10	0	5	5	5	5.00	5.00	0.00			5	0
	Magnesium (ug/L)	10	8	100	5240	9190	7790	7256.09	7399.00	1477.07	6483.52	8314.48		
	Manganese (ug/L)	10	0.2	100	27.2	71.9	37.5	37.99	39.77	13.79	31.22	48.32		
	Mercury (ug/L)	10	0.02	0	0.01	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.2	0
	Molybdenum (ug/L)	10	1.6	30	0.8	4.98	0.8	1.27	1.64	1.43	0.75	2.52	40	0
	Nickel (ug/L)	10	1.3	30	0.65	3.71	0.65	0.91	1.11	0.97	0.51	1.71	25	0
	Selenium (ug/L)	10	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	10	0.1	100	124	182	162	153.68	155.10	21.66	141.68	168.52		
	Titanium (ug/L)	10	0.5	100	1.2	6.68	2.515	2.71	3.09	1.68	2.05	4.13		
	Vanadium (ug/L)	10	1.5	0	0.75	0.75	0.75	0.75	0.75	0.00			6	0
	Zinc (ug/L)	10	0.6	100	2.69	11.5	5.65	5.38	6.07	3.07	4.17	7.98	20	0
Nutrients	Nitrogen (NH3+NH4) (mg/L)	10	0.002	100	0.036	0.22	0.136	0.10	0.12	0.06	0.08	0.15		
	Nitrogen (NO2) (mg/L)	10	0.001	100	0.018	0.061	0.035	0.03	0.04	0.01	0.03	0.04		
	Nitrogen (NO2+NO3) (mg/L)	10	0.005	100	0.181	0.621	0.3555	0.34	0.36	0.15	0.27	0.45		
	Phosphate (mg/L)	10	0.005	50	0.0025	0.015	0.006	0.01	0.01	0.00	0.00	0.01		
	Total Phosphorus (mg/L)	10	0.002	100	0.034	0.112	0.053	0.06	0.06	0.02	0.05	0.07	0.03	100
	TKN Nitrogen (mg/L)	10	0.02	100	0.48	0.96	0.65	0.66	0.68	0.13	0.59	0.76		
Bacteria	*Escherichia coli (c/100mL)*	8	4	100	20	1800	140	153.98	393.75	606.16	-26.29	813.79	100	63
	Fecal streptococcus (c/100mL)	8	4	100	10	860	50	65.79	221.25	342.86	-16.34	458.84		
	Pseudomonas aeruginosa (c/100mL)	8	4	38	4	30	4	6.29	8.50	8.99	2.27	14.73		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	8	20	0	20	20	20	20.00	20.00	0.00				
Pesticides	Pentachlorophenol (ng/L)	8	10	0	10	10	10	10.00	10.00	0.00			500	0
	Dicamba (ng/L)	8	50	25	50	260	50	62.32	77.00	73.97	25.74	128.26	200000	0
	2,4 -D (ng/L)	10	100	60	100	2000	240	250.53	430.00	578.83	71.24	788.76	4000	0
PAH	none detected													

Table F10: Dry weather water quality statistics - Cell 3 outlet

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	27	2.5	93	1.25	21	8	7.54	9.01	5.23	7.04	10.98		
Chemistry	Dissolved Solids (mg/L)	27	10	100	174	2030	254	409.48	596.44	581.25	377.20	815.69		
	Total Solids (mg/L)	27	10	100	182	2030	266	420.93	605.33	579.87	386.61	824.06		
	Solvents Extractable (mg/L)	26	1	27	0.25	1.5	0.5	0.59	0.71	0.45	0.54	0.88		
	Conductivity (uS/cm)	27	1	100	268	3620	391	660.39	1016.89	1048.79	621.29	1412.49		
	pH	27	0.1	100	7.63	8.48	8.17	8.17	8.17	0.20	8.10	8.25		
	Alkalinity (mg/L CaCO3)	27	2.5	100	82	181	97	108.85	111.28	24.94	101.87	120.69		
	Turbidity (FTU)	26	0.01	100	1.98	33.1	7.125	7.03	9.04	6.96	6.36	11.71		
	BOD (mg/L)	18	0.2	100	1	6.2	2.2	2.48	2.73	1.37	2.10	3.37		
	Chloride (mg/L)	27	0.2	100	22.4	1150	52.8	98.49	240.74	325.39	118.01	363.47	250.0	33
	Carbon (DOC) (mg/L)	27	0.1	100	1.9	4.6	3.4	3.29	3.37	0.70	3.10	3.63		
	Carbon (DIC) (mg/L)	27	0.2	100	18.6	43.2	23.2	25.31	25.92	6.05	23.64	28.20		
	Silicon (mg/L)	27	0.02	100	0.14	2.68	0.7	0.68	0.97	0.77	0.68	1.26		
Metals	Aluminum (ug/L)	27	11	100	19.2	320	64.1	68.26	91.56	80.93	61.04	122.09		
	Arsenic (ug/L)	27	1	0	0.5	0.5	0.5	0.50	0.50	0.00			0.1	100
	Barium (ug/L)	27	0.2	100	21	61.9	26.7	30.73	32.32	11.32	28.05	36.59		
	Beryllium (ug/L)	27	0.2	0	0.01	0.1	0.1	0.05	0.07	0.04	0.05	0.09	1100	0
	Cadmium (ug/L)	27	0.6	0	0.3	0.3	0.3	0.30	0.30	0.00	0.30	0.30	0.5	0
	Calcium (ug/L)	27	5	100	29900	101000	36400	45442.97	48485.19	19227.40	41232.70	55737.67		
	Chromium (ug/L)	27	1.4	19	0.7	2.55	0.7	0.84	0.93	0.51	0.74	1.12		
	Cobalt (ug/L)	27	1.3	0	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0
	Copper (ug/L)	27	1.6	70	0.8	12.8	3.41	2.91	4.39	3.58	3.04	5.74	5	48
	Iron (ug/L)	27	0.8	100	22.2	412	126	141.67	171.24	103.31	132.27	210.21	300	11
	Lead (ug/L)	27	10	4	5	10.6	5	5.14	5.21	1.08	4.80	5.61	5	4
	Magnesium (ug/L)	27	8	100	5870	84600	8130	9782.25	13950.37	19755.26	6498.78	21401.96		
	Manganese (ug/L)	27	0.2	100	3.04	284	44.9	42.38	62.15	62.96	38.40	85.90		
	Mercury (ug/L)	27	0.02	0	0.01	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.2	0
	Molybdenum (ug/L)	27	1.6	56	0.8	4.38	1.69	1.53	1.88	1.23	1.42	2.35	40	0
	Nickel (ug/L)	27	1.3	48	0.65	5.14	0.65	1.09	1.32	0.98	0.95	1.69	25	0
	Selenium (ug/L)	27	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	27	0.1	100	130	379	166	188.67	198.44	70.82	171.73	225.16		
	Titanium (ug/L)	27	0.5	89	0.25	11.7	1.89	1.90	3.15	3.16	1.96	4.35		
	Vanadium (ug/L)	27	1.5	4	0.75	1.52	0.75	0.77	0.78	0.15	0.72	0.83	6	0
	Zinc (ug/L)	27	0.6	100	1.21	57.5	6.17	6.96	11.92	13.27	6.92	16.93	20	19
Nutrients	Nitrogen (NH3+NH4) (mg/L)	27	0.002	93	0.001	0.764	0.128	0.10	0.19	0.18	0.12	0.26		
	Nitrogen (NO2) (mg/L)	27	0.001	100	0.01	0.098	0.037	0.03	0.04	0.02	0.03	0.04		
	Nitrogen (NO2+NO3) (mg/L)	27	0.005	100	0.139	2.89	0.364	0.50	0.75	0.74	0.47	1.03		
	Phosphate (mg/L)	27	0.005	48	0.0025	0.138	0.005	0.01	0.02	0.03	0.01	0.03		
	Total Phosphorus (mg/L)	27	0.002	100	0.008	0.2	0.054	0.06	0.07	0.04	0.05	0.09	0.03	93
	TKN Nitrogen (mg/L)	27	0.02	100	0.28	1.6	0.68	0.74	0.80	0.32	0.68	0.92		
Bacteria	*Escherichia coli (c/100mL)*	21	4	100	10	1000	50	64.02	159.86	256.33	50.22	269.49	100	33
	Fecal streptococcus (c/100mL)	21	4	100	10	4200	50	92.60	462.14	1098.31	-7.60	931.89		
	Pseudomonas aeruginosa (c/100mL)	21	4	29	2	700	4	5.75	39.14	151.53	-25.67	103.95		
Herbicides and	2,4,6 -trichlorophenol (ng/L)	19	20	11	20	36	20	21.15	21.47	4.46	19.47	23.48		
Pesticides	Pentachlorophenol (ng/L)	18	10	22	10	710	10	13.23	49.39	164.87	-26.78	125.55	500	6
	Dicamba (ng/L)	18	50	22	50	1300	50	70.49	139.22	296.90	2.06	276.38	200000	0
	2,4 -D (ng/L)	22	100	59	100	15000	205	262.88	1010.00	3155.27	-308.48	2328.48	4000	5
PAH	none detected													

Table F11: Dry weather water quality statistics - cell 5 outlet

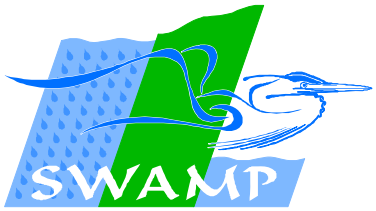
Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE
General	Suspended Solids (mg/L)	23	2.5	100	5	58.5	11	13.06	15.93	13.40	10.46	21.41		
Chemistry	Dissolved Solids (mg/L)	23	10	100	174	1940	294	427.47	612.96	575.69	377.68	848.23		
	Total Solids (mg/L)	23	10	100	184	1950	308	448.81	629.22	572.83	395.11	863.32		
	Solvents Extractable (mg/L)	23	1	35	0.25	1.6	0.5	0.76	0.88	0.46	0.69	1.06		
	Conductivity (uS/cm)	23	1	100	268	3460	453	724.20	1090.00	1042.62	663.90	1516.10		
	pH	23	0.1	100	7.62	8.52	8.17	8.14	8.15	0.18	8.07	8.22		
	Alkalinity (mg/L CaCO3)	23	2.5	100	68	164	107	111.09	113.63	24.64	103.56	123.70		
	Turbidity (FTU)	23	0.01	100	4.54	28	11.5	11.72	13.05	6.29	10.48	15.62		
	BOD (mg/L)	16	0.2	100	1.4	5.2	3	2.89	3.04	0.97	2.56	3.51		
	Chloride (mg/L)	23	0.2	100	21.2	976	56.8	108.04	259.27	322.09	127.64	390.90	250.0	39
	Carbon (DOC) (mg/L)	23	0.1	100	1.9	4.3	3.4	3.28	3.34	0.64	3.08	3.61		
	Carbon (DIC) (mg/L)	23	0.2	100	15.4	39	24.6	25.38	26.09	6.31	23.51	28.66		
	Silicon (mg/L)	23	0.02	100	0.16	2.08	0.6	0.68	0.92	0.67	0.65	1.20		
Metals	Aluminum (ug/L)	23	11	100	39.9	270	102	104.78	121.30	70.01	92.69	149.92		
	Arsenic (ug/L)	23	1	0	0.5	0.5	0.5	0.50	0.50	0.00			0.1	100
	Barium (ug/L)	23	0.2	100	21.1	62.9	31.1	33.72	35.47	12.27	30.46	40.49		
	Beryllium (ug/L)	23	0.2	0	0.01	0.1	0.1	0.06	0.08	0.04	0.07	0.10	1100	0
	Cadmium (ug/L)	23	0.6	4	0.3	0.621	0.3	0.31	0.31	0.07	0.29	0.34	0.5	4
	Calcium (ug/L)	23	5	100	30200	89900	42300	47893.38	50291.30	16809.65	43421.52	57161.09		
	Chromium (ug/L)	23	1.4	22	0.7	3.89	0.7	0.89	1.04	0.77	0.73	1.36		
	Cobalt (ug/L)	23	1.3	0	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0
	Copper (ug/L)	23	1.6	78	0.8	12.5	2.82	3.00	4.35	3.57	2.89	5.81	5	39
	Iron (ug/L)	23	0.8	100	101	639	216	228.47	250.43	123.22	200.08	300.79	300	22
	Lead (ug/L)	23	10	0	5	5	5	5.00	5.00	0.00			5	0
	Magnesium (ug/L)	23	8	100	5180	14100	8640	8434.70	8685.65	2196.14	7788.13	9583.17		
	Manganese (ug/L)	23	0.2	100	23.6	433	49.5	55.92	81.90	99.59	41.20	122.60		
	Mercury (ug/L)	23	0.02	0	0.01	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.2	0
	Molybdenum (ug/L)	23	1.6	52	0.8	4.91	1.65	1.49	1.83	1.21	1.34	2.32	40	0
	Nickel (ug/L)	23	1.3	39	0.65	2.62	0.65	1.04	1.25	0.79	0.93	1.58	25	0
	Selenium (ug/L)	23	1	0	0.5	0.5	0.5	0.50	0.50	0.00				
	Strontium (ug/L)	23	0.1	100	121	353	181	192.62	200.91	63.07	175.14	226.69		
	Titanium (ug/L)	23	0.5	100	0.664	10.6	3.97	3.89	4.72	2.84	3.56	5.88		
	Vanadium (ug/L)	23	1.5	0	0.75	0.75	0.75	0.75	0.75	0.00			6	0
	Zinc (ug/L)	23	0.6	100	1.41	44.6	7.58	7.52	11.18	10.61	6.84	15.52	20	13
Nutrients	Nitrogen (NH3+NH4) (mg/L)	23	0.002	96	0.002	0.856	0.098	0.09	0.18	0.20	0.09	0.26		
	Nitrogen (NO2) (mg/L)	23	0.001	100	0.018	0.091	0.034	0.04	0.04	0.02	0.03	0.04		
	Nitrogen (NO2+NO3) (mg/L)	23	0.005	100	0.059	2.69	0.437	0.43	0.69	0.66	0.42	0.96		
	Phosphate (mg/L)	23	0.005	43	0.001	0.1	0.0025	0.01	0.02	0.03	0.01	0.03		
	Total Phosphorus (mg/L)	23	0.002	100	0.04	0.192	0.06	0.08	0.09	0.05	0.07	0.11	0.03	100
	TKN Nitrogen (mg/L)	23	0.02	100	0.56	1.72	0.72	0.84	0.89	0.34	0.75	1.02		
Bacteria	*Escherichia coli (c/100mL)*	18	4	100	10	290	70	74.38	103.89	78.23	67.75	140.03	100	39
	Fecal streptococcus (c/100mL)	18	4	100	9	1700	25	56.87	273.28	505.55	39.73	506.83		
	Pseudomonas aeruginosa (c/100mL)	18	4	17	2	16	4	4.21	4.89	3.38	3.33	6.45		
Herbicides an	2,4,6 -trichlorophenol (ng/L)	19	20	5	20	36	20	20.63	20.84	3.67	19.19	22.49		
Pesticides	Pentachlorophenol (ng/L)	18	10	17	10	25	10	10.78	11.11	3.60	9.45	12.77	500	0
	Dicamba (ng/L)	18	50	39	50	830	50	71.85	124.22	207.59	28.32	220.12	200000	0
	2,4 -D (ng/L)	23	100	53	5	58.5	11	13.06	15.93	13.40	-11.81	2025.50	4000	11
PAH	none detected													

Table F12: Dry weather water quality statistics - Lake Ontario

Category	Parameter	N	RMDL	%>DL	MIN	MAX	MEDIAN	GEOMETRIC MEAN	ARITHMETIC MEAN	SD	95%CI -LL	95%CI -UL	GUIDELINE	% > GUIDELINE	#>DL	#>GUIDELINE
General	Suspended Solids (mg/L)	14	2.5	29	1.25	24	1.25	2.68	5.84	8.29	1.50	10.18			4	
Chemistry	Dissolved Solids (mg/L)	14	10	100	180	204	192	192.47	192.57	6.49	189.17	195.97			14	
	Total Solids (mg/L)	14	10	100	180	220	196	197.82	198.14	11.83	191.95	204.34			14	
	Solvents Extractable (mg/L)	14	1	21	0.25	8.5	0.5	0.62	1.15	2.15	0.02	2.27			3	
	Conductivity (uS/cm)	14	1	100	276	315	296	295.84	296.00	10.11	290.71	301.29			14	
	pH	14	0.1	100	8.11	8.66	8.325	8.35	8.36	0.17	8.26	8.45			14	
	Alkalinity (mg/L CaCO3)	14	2.5	100	86	95	92	91.97	92.00	2.24	90.83	93.17			14	
	Turbidity (FTU)	14	0.01	100	0.24	13.9	0.775	1.41	3.65	4.87	1.09	6.20			14	
	BOD (mg/L)	10	0.2	100	0.4	2.4	0.7	0.73	0.86	0.60	0.49	1.23			10	
	Chloride (mg/L)	14	0.2	100	21	53.2	21.8	23.24	24.06	8.41	19.65	28.46	250.0	0	14	0
	Carbon (DOC) (mg/L)	14	0.1	100	1.8	3.3	1.9	2.04	2.06	0.39	1.86	2.27			14	
	Carbon (DIC) (mg/L)	14	0.2	100	19	28	21.6	21.52	21.60	2.06	20.52	22.68			14	
	Silicon (mg/L)	14	0.02	100	0.04	0.98	0.13	0.13	0.23	0.26	0.09	0.36			14	
Metals	Aluminum (ug/L)	14	11	71	5.5	82.1	19.1	19.29	30.79	28.98	15.61	45.97			10	
	Arsenic (ug/L)	14	1	0	0.5	0.5	0.5	0.50	0.50	0.00			0.1	100	0	14
	Barium (ug/L)	14	0.2	100	0.23	26.6	21.35	15.58	20.10	6.02	16.94	23.25			14	
	Beryllium (ug/L)	14	0.2	0	0.01	0.1	0.1	0.04	0.06	0.05	0.04	0.09	1100	0	0	0
	Cadmium (ug/L)	14	0.6	0	0.3	0.3	0.3	0.30	0.30	0.00	0.30	0.30	0.5	0	0	0
	Calcium (ug/L)	14	5	100	27400	35800	33500	32754.50	32835.71	2333.57	31613.34	34058.09			14	
	Chromium (ug/L)	14	1.4	14	0.7	2.36	0.7	0.80	0.87	0.47	0.62	1.12			2	
	Cobalt (ug/L)	14	1.3	0	0.65	0.65	0.65	0.65	0.65	0.00			0.9	0	0	0
	Copper (ug/L)	14	1.6	36	0.8	7.3	0.8	1.43	2.14	2.27	0.95	3.33	5	14	5	2
	Iron (ug/L)	14	0.8	100	5.29	170	29.6	28.55	53.71	59.00	22.81	84.62	300	0	14	0
	Lead (ug/L)	14	10	7	5	11.3	5	5.30	5.45	1.68	4.57	6.33	5	7	1	1
	Magnesium (ug/L)	14	8	100	7290	8850	8455	8369.35	8380.00	429.85	8154.84	8605.16			14	
	Manganese (ug/L)	14	0.2	100	0.737	11.3	2.315	2.90	4.14	3.87	2.12	6.17			14	
	Mercury (ug/L)	14	0.02	0	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.2	0	0	0
	Molybdenum (ug/L)	14	1.6	7	0.8	1.74	0.8	0.85	0.87	0.25	0.74	1.00	40	0	1	0
	Nickel (ug/L)	14	1.3	21	0.65	11.4	0.65	0.91	1.57	2.86	0.07	3.07	25	0	3	0
	Selenium (ug/L)	14	1	0	0.5	0.5	0.5	0.50	0.50	0.00					0	
	Strontium (ug/L)	14	0.1	100	140	171	160.5	159.43	159.64	8.45	155.21	164.07			14	
	Titanium (ug/L)	14	0.5	43	0.25	4.35	0.25	0.60	1.23	1.52	0.44	2.02			6	
	Vanadium (ug/L)	14	1.5	0	0.75	0.75	0.75	0.75	0.75	0.00			6	0	0	0
	Zinc (ug/L)	14	0.6	79	0.3	22.5	1.0285	1.37	3.20	5.79	0.17	6.23	20	7	11	1
Nutrients	Nitrogen (NH3+NH4) (mg/L)	14	0.002	86	0.002	0.168	0.03	0.02	0.05	0.05	0.02	0.08			12	
	Nitrogen (NO2) (mg/L)	14	0.001	100	0.004	0.028	0.0115	0.01	0.01	0.01	0.01	0.02			14	
	Nitrogen (NO2+NO3) (mg/L)	14	0.005	100	0.226	0.556	0.362	0.33	0.34	0.09	0.29	0.39			14	
	Phosphate (mg/L)	14	0.005	7	0.001	0.006	0.0025	0.00	0.00	0.00	0.00	0.00			1	
	Total Phosphorus (mg/L)	14	0.002	100	0.008	0.056	0.012	0.01	0.02	0.01	0.01	0.02	0.03	7	14	1
	TKN Nitrogen (mg/L)	14	0.02	100	0.2	0.4	0.27	0.28	0.29	0.06	0.25	0.32			14	
Bacteria	*Escherichia coli (c/100mL)*	10	4	100	8	880	42	55.42	193.60	284.15	17.49	369.71	100	40	10	4
	Fecal streptococcus (c/100mL)	10	4	70	4	560	40	28.39	93.00	168.79	-11.61	197.61			7	
	Pseudomonas aeruginosa (c/100mL)	10	4	10	2	50	4	3.90	7.80	14.86	-1.41	17.01			1	
Herbicides and	2,4,6 -trichlorophenol (ng/L)	9	20	11	20	26	20	20.59	20.67	2.00	19.36	21.97			1	
Pesticides	Pentachlorophenol (ng/L)	8	10	0	10	10	10	10.00	10.00	0.00			500	0	0	0
	Dicamba (ng/L)	8	50	0	50	50	50	50.00	50.00	0.00			200000	0	0	0
	2,4 -D (ng/L)	8	100	13	100	280	100	113.74	122.50	63.64	78.40	166.60	4000	0	1	0

Table F13: Analytical Detection Limits and PWQOs for Pesticides/Herbicides and PAHs

Polynuclear Aromatic Hydrocarbons	**Reporting Method Detection Limit (μg/L)**	**PWQO Limit (μg/L)**
Napthalene	1.6	7.0
2-methylnaphthalene	2.2	2.0
1-methylnaphthalene	3.2	2.0
2-chloronaphthalene	1.8	0.2
Acenaphthylene	1.4	--
Fluorene	1.7	0.2
Phenanthrene	0.4	0.03
Anthracene	1.2	0.0008
Fluoranthene	0.4	0.0008
Pyrene	0.4	--
Benzo(a)anthracene	0.5	0.0004
Chrysene	0.3	0.0001
Benzo(b)fluoranthene	0.7	--
Benzo(k)fluoranthene	0.7	0.0002
Benzo(a)pyrene	0.6	--
Dibenzo(a,h)anthracene	1.3	0.002
Benzo(g,h,i)perylene	0.7	0.00002
1-chloronaphthalene	2.5	0.1
Perylene	1.5	0.00007
Indole	1.9	--
5-nitroacenaphthene	4.3	--
Biphenyl	0.6	0.2
Herbicides and Pesticides		
2,4-dichlorophenol	2.0	0.2
2,4,6-trichlorophenol	0.02	18.0
2,4,5-trichlorophenol	0.1	18.0
2,3,4-trichlorophenol	0.1	18.0
2,3,4,5-tetrachlorophenol	0.02	1.0
2,3,4,6-tetrachlorophenol	0.02	1.0
Pentachlorophenol	0.01	0.5
Silvex	0.02	--
Bromoxynil	0.05	--
Picloram	0.1	--
Dicamba	0.05	200.0
2,4-D-propionic acid	0.1	--
2,4-D	0.1	4.0
2,4,5-T	0.05	--
2,4-DB	0.2	--
Dinoseb	0.02	--
Diclofop-methyl	0.1	--



APPENDIX G

Water Temperature Data

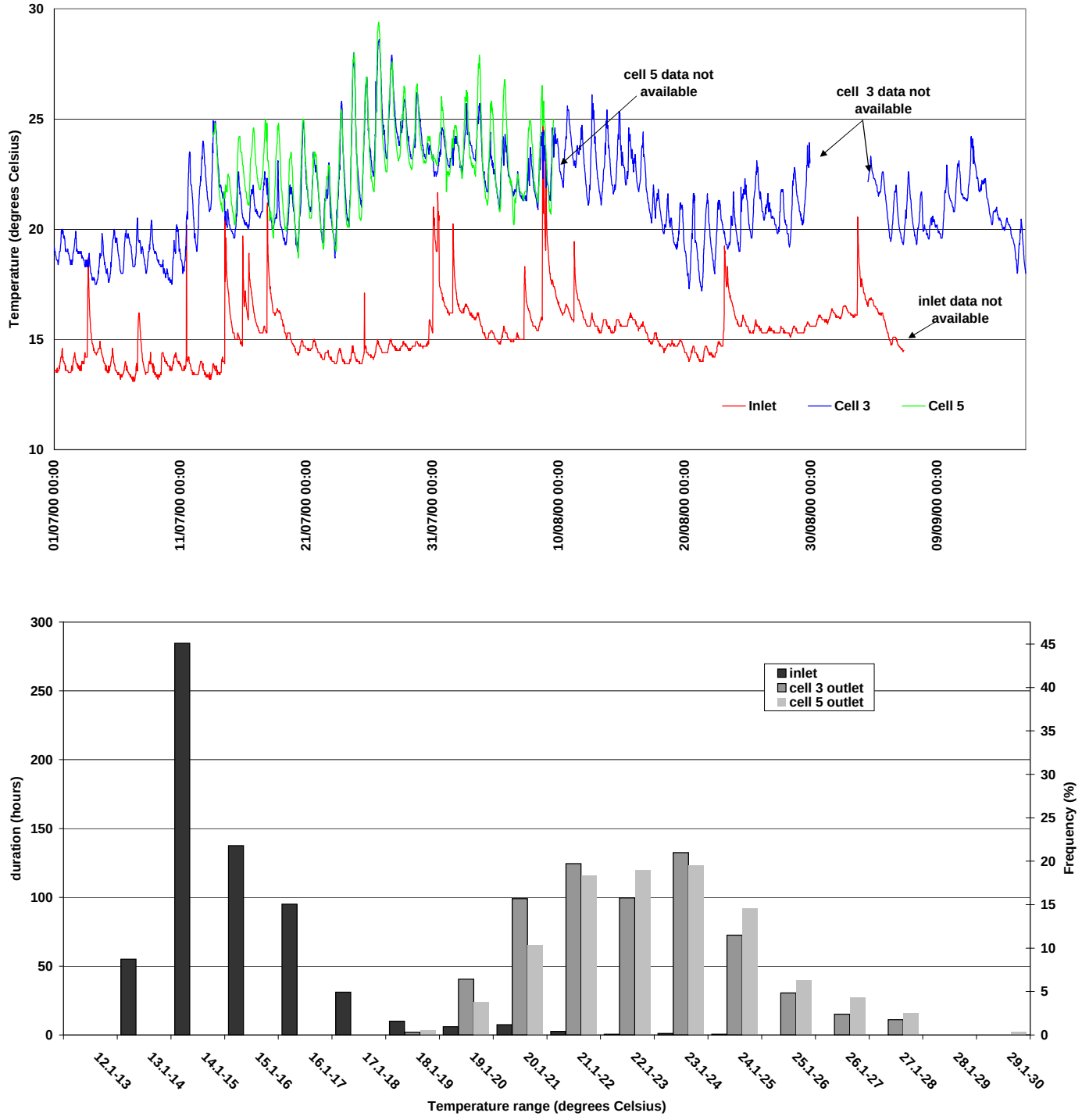


Figure G1 **:** Temperature fluctuations (upper graph: July 1 to September 16, 2000), durations and frequencies (lower graph: July 13 to Aug 9, 2000).

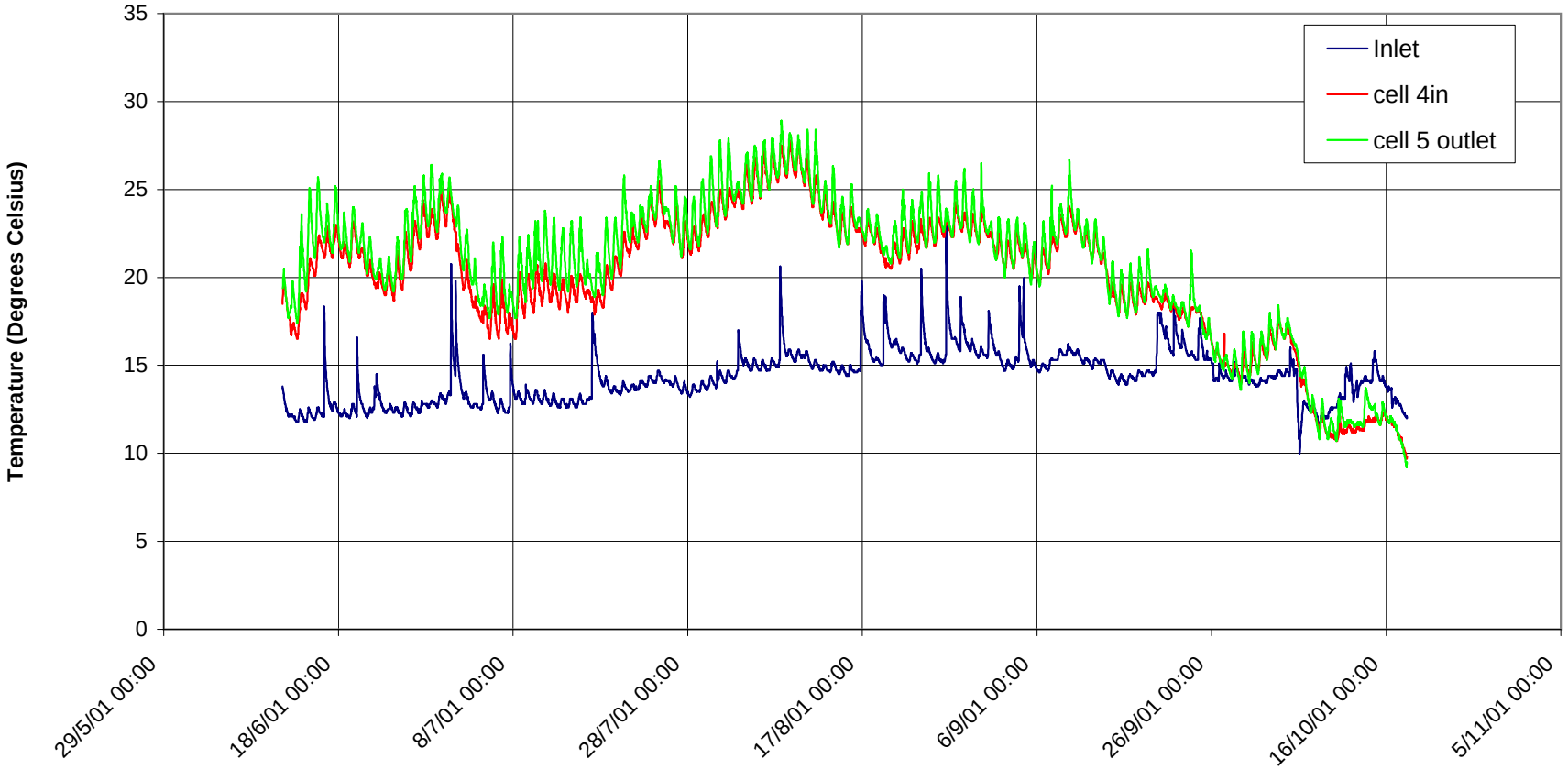


Figure G2: Continuous water temperature data collected from June 11 to October 18, 2001

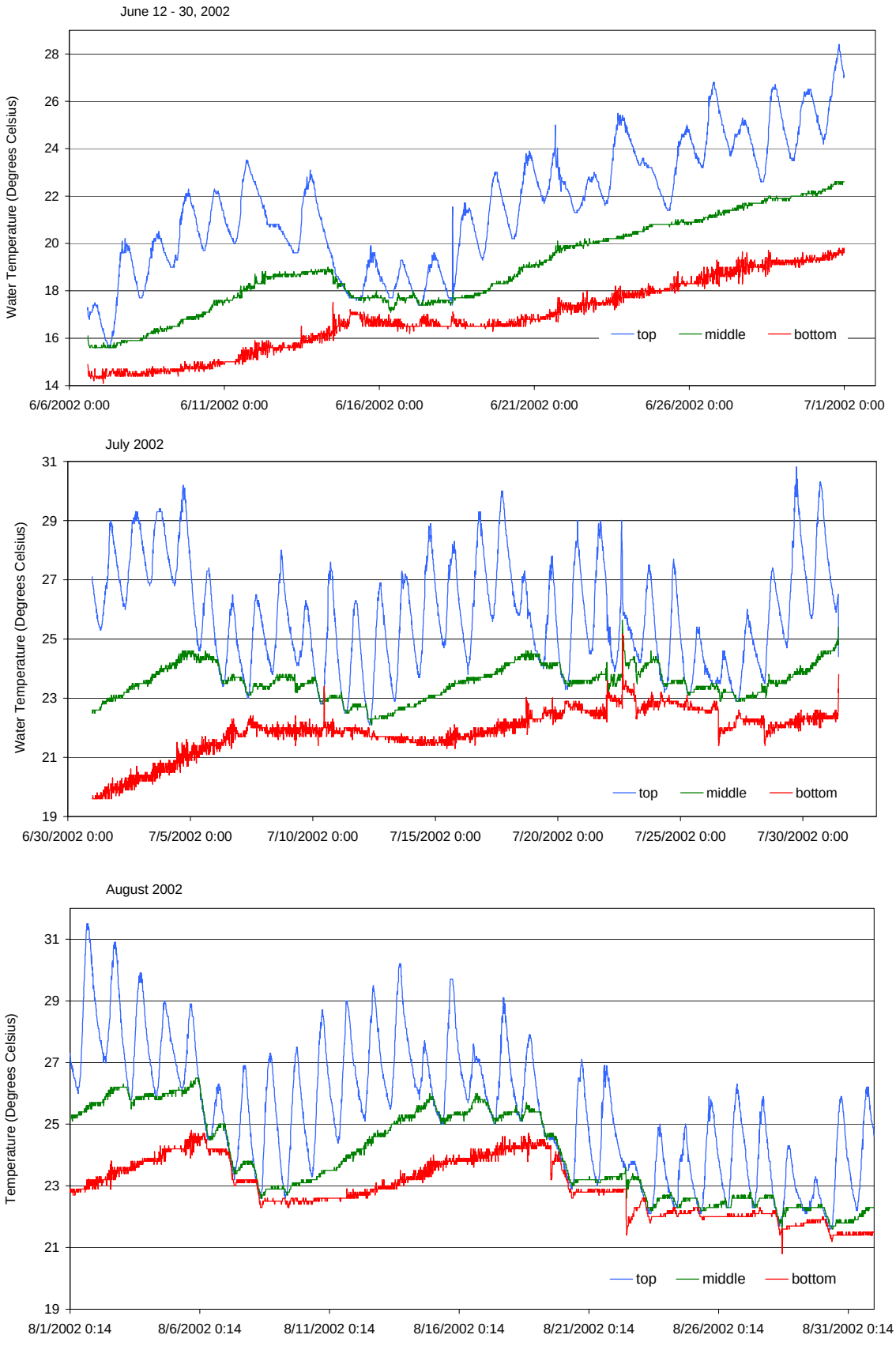
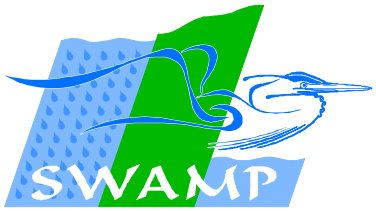


Figure G3: Water temperature measured on the south side of the cell 1-2 curtain at three depths below the water surface (0.5, 1.5 and 2.5 m)



APPENDIX H

Sediment Quality and Particle Size Distributions

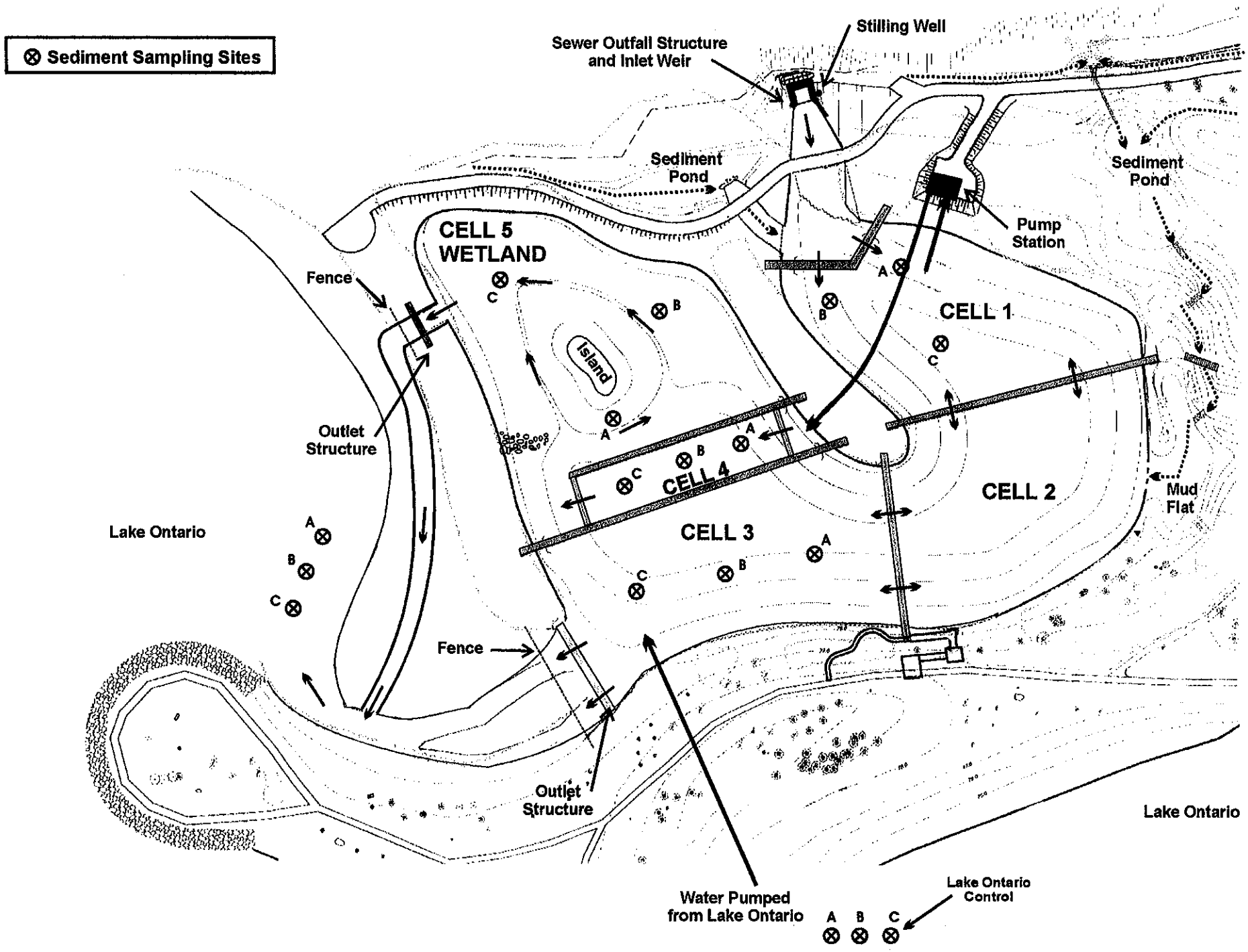


Figure H1: Sediment sampling sites

Table H1: Sediment chemistry data (see Figure H1 for sampling locations)

Group	Variable	Units	Cell 1			Cell 3			Cell 4			Cell 5			Lake Beach			Lake Ontario Control		
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
General Chemistry	Carbon; total organic	mg/g dry	14	34	42	28	25	42	24	23	16	4.0	6.0	6.0	2	2	1	1.0	2.0	3.0
	Solids; total, loss on ign	mg/g dry	27	67	77	56	53	67	53	55	39	7.9	14	9.3	5.6	4.8	8.3	4.8	0.9	6.8
	Solvent extractable	mg/L	2800	10000	13000	6700	6500	4800	48000	5000	3400	320	440	500	100	130	110	200	260	190
Metals	Mercury	ug/g dry	0.03	0.14	0.30	0.05	0.05	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Beryllium	ug/g dry	0.5	0.6	0.5	0.7	0.8	0.5	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Magnesium	ug/g dry	13000	15000	16000	15000	15000	6600	14000	13000	12000	4400	5500	6700	4000	3400	3900	3700	4200	3600
	Aluminum	ug/g dry	11000	15000	10000	18000	20000	6800	18000	18000	13000	4300	4500	5300	3700	3300	3700	2400	2700	2400
	Calcium	ug/g dry	88000	110000	91000	110000	110000	45000	96000	92000	73000	39000	40000	54000	48000	42000	41000	59000	60000	52000
	Vanadium	ug/g dry	33	40	33	46	47	23	45	44	36	16	17	21	19	8	12	18	21	17
	Chromium	ug/g dry	29	43	46	44	43	17	40	40	30	9	10	12	9	6	7	7	8	6
	Manganese	ug/g dry	430	510	420	580	580	220	540	540	430	190	200	260	200	140	170	170	200	180
	Iron	ug/g dry	17000	23000	18000	27000	2800	13000	26000	26000	20000	8300	8700	11000	8700	4600	6100	7800	9000	7200
	Cobalt	ug/g dry	7.3	9.6	7.5	11	11	5.7	11	11	8.7	3.5	4.4	4.4	3.3	2.6	2.9	1.7	3.2	3.2
	Nickel	ug/g dry	18	25	21	29	31	13	27	28	22	8	7.8	10	7	6	6.3	4.9	4.3	4.3
	Copper	ug/g dry	38	70	90	61	62	26	53	51	36	7	8	12	8	4	5	1	2	1
	Zinc	ug/g dry	130	250	320	210	210	79	180	170	120	24	28	35	14	10	12	12	13	14
	Molybdenum	ug/g dry	0.6	0.5	1.1	0.9	0.7	0.5	0.5	0.5	0.6	0.5	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Cadmium	ug/g dry	1	1.3	1.5	1.2	1.7	0.5	1.1	1	1	0.5	0.4	0.2	0.3	0.4	0.5	0.2	0.3	0.4
	Barium	ug/g dry	59	100	76	100	110	36	97	100	70	17	19	22	12	11	12	8	9	8
	Lead	ug/g dry	32	58	69	42	45	20	39	42	28	6	6	11	3	5	5	6	5	5
	Strontium	ug/g dry	140	170	130	170	170	79	150	140	120	70	68	88	85	75	74	86	89	77
	Arsenic	ug/g dry	2.4	4.1	3.4	4.3	4.5	3.8	4.5	4.9	3.4	1.3	1.3	1.5	1.1	0.9	0.9	2.2	1	1.1
	Selenium	ug/g dry	0.2	0.4	0.4	0.4	0.5	0.6	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Titanium	ug/g dry	690	680	560	780	820	470	790	760	680	430	470	480	560	190	320	570	620	580
Nutrients	Nitrogen; total Kjeldahl	mg/g dry	0.8	2.2	2.2	2.1	2	2.6	1.7	1.8	1.3	1	0.4	0.4	0.1	0.2	0.2	0.1	0.2	0.2
	Phosphorus; total	mg/g dry	0.68	0.96	0.8	0.92	0.94	0.64	0.78	0.8	0.76	0.44	0.58	0.52	0.68	0.36	0.4	0.44	0.48	0.54
PCB's and OC Pesticides	PCB; total	ng/g dry	80	40	60	80	60	80	80	40	80	20	40	40	20	20	20	20	20	60
	Hexachlorobenzene	ng/g dry	2	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
	pp-DDE	ng/g dry	7	5.0	5	3.0	4.0	3.0	5.0	3.0	3.0	1	1	1	1	1	1	1	1	1
PAHs	Naphthalene	ng/g dry	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Acenaphthylene	ng/g dry	40	40	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Acenaphthene	ng/g dry	60	20	40	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Flourene	ng/g dry	120	80	100	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Phenanthrene	ng/g dry	2000	1000	1700	260	360	200	200	240	160	20	60	140	20	20	20	20	20	20
	Anthracene	ng/g dry	220	120	180	20	40	40	20	20	20	20	20	20	20	20	20	20	20	20
	Flouranthene	ng/g dry	4400	2400	4000	760	940	440	680	740	480	40	100	200	20	20	20	20	20	20
	Pyrene	ng/g dry	3400	1800	3100	580	740	340	520	560	360	40	100	160	20	20	20	20	20	20
	Benzo(a)anthracene	ng/g dry	1500	640	1200	200	260	160	180	200	140	20	40	80	20	20	20	20	20	20
	Chrysene	ng/g dry	2400	1200	1900	460	520	260	400	420	260	40	60	100	20	20	20	20	20	20
	Benzo(b)fluoranthene	ng/g dry	2900	1500	2400	620	700	260	540	540	360	40	80	100	20	20	20	20	20	20
	Benzo(k)fluoranthene	ng/g dry	1000	500	860	200	240	100	180	180	120	20	20	40	20	20	20	20	20	20
	Benzo(a)pyrene	ng/g dry	1500	800	1400	280	320	160	240	280	160	40	40	80	40	40	40	40	40	40
	Indeno(1,2,3-c,d)pyrene	ng/g dry	1500	840	1400	400	440	120	360	360	200	40	40	80	40	40	40	40	40	40
	Dibenzo(a,h)anthracene	ng/g dry	320	160	280	80	80	40	40	40	40	40	40	40	40	40	40	40	40	40
	Benzo(g,h,i)perylene	ng/g dry	1200	680	1100	320	360	120	280	280	160	40	40	40	40	40	40	40	40	40
	d8-naphthalene	%R	42	41	36	52	47	40	47	44	47	66	57	53	65	73	71	60	58	67
	d10-phenanthrene	%R	95	93	97	98	92	84	92	95	81	100	89	81	110	100	82	110	100	100
	d12-chrysene	%R	77	67	62	64	71	75	70	71	65	87	89	75	83	80	79	81	87	86

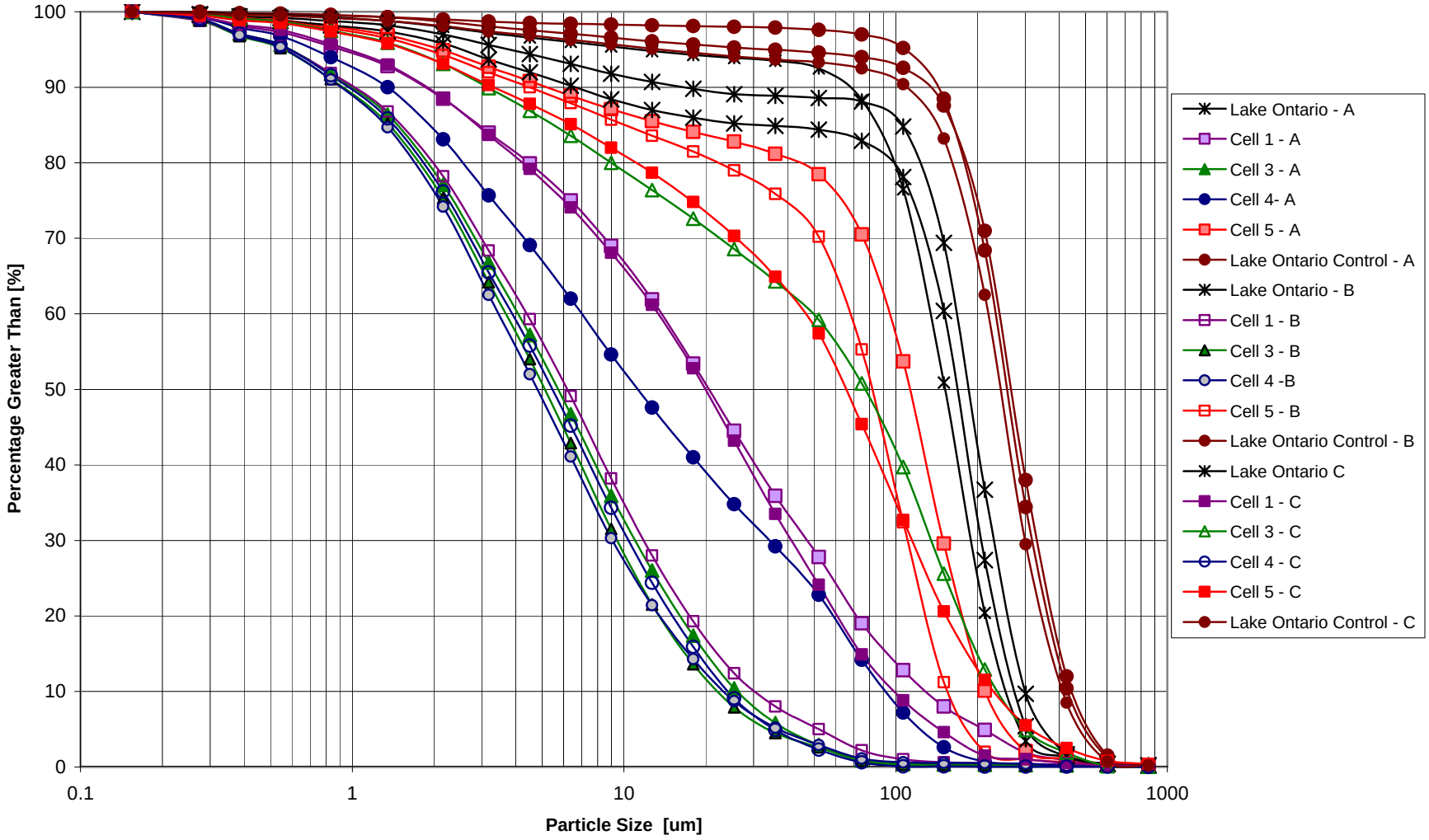
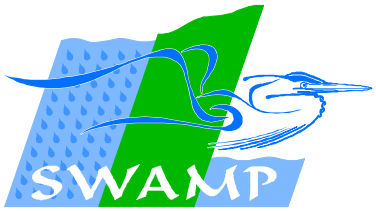


Figure H2: Sediment particle size distributions



APPENDIX I

Removal Efficiencies

(2000 monitoring season)

Table I1 **: Total load (kg) and performance data for events monitored in 2000**

Event		14-Jul-00			17-Jul-00			30-Jul-00			8-Aug-00			23-Aug-00			2-Sep-00			10-Sep-00			14-Sep-00			22-Sep-00			4-Oct-00			27-Oct-00			TOTAL		
Group	**Variable**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**	**In**	**Out**	**% Rem.**
General	TSS	4448.7	560.9	87.4	3410.3	1952.9	42.7	2544.3	446.2	82.5	4089.6	245.9	94.0	1459.9	212.9	85.4	683.7	35.7	94.8	833.8	145.1	82.6	395.1	159.1	59.7	212.5	42.7	79.9	243.8	16.3	93.3	77.0	10.3	86.6	18398.7	3828.0	79.2
Chemistry	Diss.Solids	3017.4	5377.1	-78.2	2798.2	5363.2	-91.7	6835.3	5259.4	23.1	2254.7	3070.2	-36.2	3236.2	2749.5	15.0	540.8	556.1	-2.8	2216.6	2237.7	-1.0	2175.8	2145.0	1.4	1699.8	739.5	56.5	470.0	595.0	-26.6	223.3	320.5	-43.5	25468.0	28413.2	-11.6
	Total Solids	7504.7	5918.7	21.1	6237.7	7287.0	-16.8	9417.6	5686.6	39.6	6332.3	3310.1	47.7	4696.1	2956.3	37.0	1224.5	591.8	51.7	3061.0	2385.4	22.1	2565.8	2298.9	10.4	1913.9	786.3	58.9	715.0	610.0	14.7	299.9	330.9	-10.3	43968.3	32162.0	26.9
	Oil/grease	164.4	38.7	76.5	204.0	116.6	42.9	180.4	23.7	86.8	36.0	12.0	66.7	73.0	12.2	83.3	30.6	0.6	97.9	10.6	2.6	75.0	41.1	20.5	50.0	15.1	1.7	88.6	19.0	2.5	86.8	7.8	0.9	88.0	781.8	232.1	70.3
	BOD										88.7	36.0	59.5	143.6	40.1	72.0	12.8	3.6	72.0	57.0	25.3	55.6				24.8	4.0	83.8	34.5	7.5	78.3				361.3	116.5	67.7
	Chloride	572.5	1056.1	-84.5	402.2	874.4	-117.4	1762.0	1097.4	37.7	427.0	570.9	-33.7	803.0	458.0	43.0	104.6	90.3	13.7	521.4	391.6	24.9	509.0	327.4	35.7	481.8	112.6	76.6	97.0	103.0	-6.2	44.0	61.0	-38.5	5724.6	5142.8	10.2
	Carbon (DOC)	92.8	69.6	25.0	93.3	93.3	0.0	288.6	65.5	77.3	69.6	43.2	37.9	90.0	37.7	58.1	23.7	7.1	69.9	52.8	40.6	23.0	44.1	36.2	18.0	21.7	9.5	56.5	17.3	7.0	59.4	16.9	3.9	76.7	810.8	413.6	49.0
	Carbon (DIC)	297.9	545.4	-83.1	314.8	565.5	-79.6	478.5	454.7	5.0	191.9	278.2	-45.0	214.1	256.1	-19.6	50.0	55.6	-11.2	160.4	216.4	-34.9	143.7	219.1	-52.5	102.4	80.6	21.2	44.0	63.0	-43.2	19.2	30.6	-59.1	2016.9	2765.3	-37.1
Metals	Aluminum	19.7	2.1	89.4	16.0	8.9	44.5	16.2	3.3	79.8	15.8	1.7	89.2	9.0	1.5	83.3	4.0	0.3	93.1	5.5	0.9	83.1	3.3	0.7	78.5	1.2	0.4	69.0	1.2	0.1	90.6	0.7	0.1	88.0	92.5	19.9	78.5
	Arsenic	0.010	0.010	0.0	0.015	0.015	0.0	0.009	0.009	0.0				0.006	0.006	0.0	0.003	0.001	50.0	0.005	0.005	0.0	0.005	0.005	0.0				0.001	0.001	0.0	0.001	0.001	50.0	0.055	0.053	3.3
	Barium	0.90	0.68	25.1	0.68	0.75	-11.2	0.99	0.66	33.0	0.61	0.36	40.9	0.46	0.35	24.2	0.14	0.07	47.8	0.30	0.32	-6.6	0.25	0.27	-11.0	0.15	0.10	35.2	0.07	0.07	3.3	0.04	0.04	0.3	4.60	3.68	19.9
	Beryllium	0.002	0.000	90.0	0.002	0.001	36.9	0.001	0.000	81.5	0.002	0.000	93.2	0.001	0.000	82.2	0.000	0.000	83.0	0.000	0.000	77.7	0.000	0.000	62.8	0.000	0.000	70.5	0.000	0.000	74.0	0.000	0.000	74.2	0.009	0.002	76.7
	Cadmium	0.006	0.017	-191.7	0.009	0.009	0.0	0.006	0.006	0.0	0.004	0.004	0.0	0.004	0.005	-32.1	0.003	0.001	75.6	0.003	0.003	0.0	0.003	0.003	0.0	0.001	0.001	0.0	0.001	0.001	0.0	0.000	0.000	0.0	0.039	0.049	-25.5
	Calcium	864.6	874.3	-1.1	655.8	1011.4	-54.2	1012.0	737.6	27.1	611.6	438.9	28.2	514.6	424.6	17.5	138.3	88.0	36.3	321.9	333.8	-3.7	290.4	319.7	-10.1	216.8	129.4	40.3	81.3	94.5	-16.3	33.4	50.9	-52.3	4740.8	4503.2	5.0
	Chromium	0.07	0.01	80.4	0.08	0.02	75.5	0.08	0.01	83.9	0.07	0.01	87.1	0.04	0.01	76.7	0.02	0.00	91.1	0.02	0.01	68.8	0.04	0.01	80.7	0.01	0.00	70.7	0.01	0.00	78.7	0.01	0.00	86.4	0.44	0.09	80.6
	Cobalt	0.03	0.01	62.6	0.02	0.02	0.0	0.03	0.01	51.9	0.03	0.01	71.1	0.01	0.01	0.0	0.01	0.00	70.0	0.01	0.01	0.0	0.01	0.01	0.0	0.00	0.00	0.0	0.00	0.00	50.8	0.00	0.00	52.9	0.14	0.08	43.0
	Copper	0.56	0.06	88.6	0.46	0.14	69.2	0.73	0.10	86.1	0.29	0.06	80.5	0.39	0.03	92.0	0.13	0.00	96.4	0.18	0.02	88.7	0.14	0.01	92.0	0.08	0.02	79.4	0.05	0.01	79.3	0.04	0.01	82.2	3.06	0.47	84.7
	Iron	28.2	5.8	79.5	17.8	11.3	36.3	40.3	8.6	78.8	21.2	3.4	84.0	17.6	3.4	81.0	9.4	0.7	93.0	9.1	2.1	76.4	5.2	2.0	61.3	2.0	0.8	59.1	1.9	0.3	86.6	1.4	0.2	85.9	154.1	38.5	75.0
	Lead	0.52	0.10	81.3	0.45	0.15	67.3	0.37	0.09	74.2	0.33	0.06	81.8	0.19	0.06	68.2	0.16	0.01	91.9	0.16	0.05	66.0	0.05	0.05	0.0	0.02	0.02	0.0	0.01	0.01	0.0	0.01	0.01	64.8	2.26	0.61	73.0
	Magnesium	99.8	158.6	-58.9	69.7	150.4	-115.9	130.8	130.2	0.5	66.6	80.7	-21.3	74.7	96.6	-29.3	19.4	21.5	-11.2	43.9	79.2	-80.3	38.6	66.3	-71.8	34.5	25.3	26.5	9.5	16.0	-69.0	4.3	7.8	-82.8	591.6	832.6	-40.7
	Manganese	6.4	1.8	72.3	3.3	2.7	18.2	5.6	1.9	65.8	3.0	0.7	77.3	2.5	0.4	82.8	0.6	0.1	78.7	1.1	0.4	61.5	0.6	0.5	12.7	0.2	0.1	42.3	0.3	0.1	71.1	0.2	0.0	73.2	23.8	8.8	62.9
	Mercury	0.001	0.000	85.7	0.000	0.000	0.0	0.002	0.000	87.5	0.000	0.000	75.0	0.000	0.000	0.0	0.000	0.000	75.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	66.7	0.004	0.001	70.7
	Molybdenum	0.015	0.015	0.0	0.023	0.023	0.0	0.015	0.015	0.0	0.010	0.010	0.0	0.010	0.022	-122.8	0.002	0.006	-185.0	0.008	0.011	-29.1	0.008	0.008	0.0	0.173	0.005	97.3	0.002	0.006	-211.3	0.001	0.002	-180.0	0.267	0.123	53.8
	Nickel	0.071	0.013	82.2	0.041	0.019	53.9	0.077	0.012	84.0	0.063	0.016	74.1	0.046	0.008	82.8	0.021	0.002	92.2	0.024	0.007	71.1	0.016	0.007	59.4	0.016	0.004	75.4	0.009	0.002	82.4	0.006	0.002	66.3	0.391	0.091	76.7
	Titanium	0.26	0.04	83.9	0.29	0.17	40.6	0.20	0.15	26.0	0.07	0.04	39.8	0.16	0.07	60.1	0.06	0.01	77.4	0.06	0.03	47.1	0.08	0.02	69.1	0.03	0.02	53.4	0.02	0.00	79.6	0.01	0.00	60.8	1.25	0.56	54.7
	Vanadium	0.08	0.01	82.0	0.08	0.02	73.2	0.07	0.01	80.9	0.07	0.01	87.0	0.04	0.01	75.6	0.02	0.00	91.6	0.03	0.01	71.4	0.03	0.01	70.1	0.00	0.00	0.0	0.01	0.00	69.9	0.00	0.00	76.6	0.43	0.09	78.8
	Zinc	2.71	0.24	91.1	1.88	0.57	69.8	2.35	0.16	93.2	1.31	0.08	93.9	1.29	0.07	94.8	0.57	0.01	97.5	0.58	0.06	89.6	0.45	0.04	90.9	0.20	0.02	90.6	0.15	0.01	94.0	0.11	0.01	93.1	11.60	1.26	89.1
Nutrients	Ammonia	2.5	3.6	-43.8	4.3	6.6	-54.1	2.3	3.8	-62.3	2.5	3.1	-26.0	1.9	1.0	47.5	0.8	0.5	33.3	0.8	0.6	30.6	1.1	1.9	-61.2	0.3	0.5	-68.8	0.9	0.4	52.9	0.4	0.2	37.2	18.0	22.3	-24.2
	Nitrites	3.4	3.3	1.1	3.9	1.9	52.6	3.8	0.8	78.1	2.8	0.5	82.6	0.2	0.2	5.2	0.6	0.2	68.7	1.1	0.2	82.3	1.0	0.3	74.3	0.2	0.1	45.7	0.4	0.1	74.5	0.1	0.0	59.0	17.5	7.6	56.4
	Nitrates	21.7	11.4	47.3	30.9	17.8	42.3	13.6	4.2	69.0	19.7	3.5	82.3	1.0	3.2	-209.4	2.4	0.4	82.8	18.9	1.3	92.9	12.0	1.7	86.2	5.1	1.1	78.1	0.6	0.9	-35.9	0.1	0.4	-239.0	126.0	46.0	63.5
	Phosphate	2.4	0.4	82.4	1.2	1.1	2.5	0.8	0.1	89.4	0.9	0.1	89.5	0.0	0.0	65.6	0.1	0.1	43.6	1.3	0.0	97.9	0.7	0.1	82.0	0.1	0.0	80.6	0.2	0.0	87.6	0.4	0.0	99.7	8.0	2.0	75.1
	TP	12.2	1.9	84.2	7.8	4.5	41.8	9.3	1.7	81.8	6.7	0.9	87.1	4.6	0.7	85.2	2.1	0.3	86.6	4.4	0.8	82.6	2.1	1.1	48.8	0.7	0.2	77.7	1.2	0.1	91.0	1.0	0.1	93.2	52.1	12.2	76.7
	TKN Nitrogen	48.0	19.3	59.7	42.0	26.2	37.5	53.2	16.3	69.3	32.1	10.6	67.2	26.3	8.2	69.0	8.8	2.1	75.6	16.9	6.3	62.5	10.3	9.3	9.0	8.1	2.1	73.6	4.9	1.7	66.3	3.4	1.0	70.7	253.8	103.2	59.3
Bacteria	*E. coli*				495516	262332	47.1				239860	8395	96.5							369425	31665	91.4							115000	25	100.0				1219801	302417	75.2
	F.strep.				169058	166144	1.7				57566	9355	83.8							348315	18999	94.5							105000	25	100.0				679940	194522	71.4
	P. aeruginosa				4372	3498	20.0				5277	1199	77.3							55942	2296	95.9							5250	5	99.9				70841	6998	90.1