WAMQI #12 - Assessment and Management of Horticultural Stormwater Discharges

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Executive Summary

Field studies of stormwater pond dynamics in response to storm events at horticultural operations were carried out to determine the critical points at which farmers must manage their collection ponds to protect the environment. For most horticultural greenhouse operations, stormwater ponds essentially collect rainwater from the greenhouse roofs, and may collect subsurface drainage water from adjacent land or the greenhouse production facility. Continuous as well as strategic monitoring was carried out at three floriculture greenhouse sites over the 2014 season, collecting information on volumes, overflows, meteorological data, and composition of pond water and stormwater overflows. This project is the first phase in developing Best Management Practices for producers to size, design, and monitor their stormwater management systems to adapt to changes in size, intensity, frequency, and variability of growing season storm events predicted by current climate change models. The development of a coherent management and sampling strategy is of value to farmers, who are looking at whether their ponds are designed and operating properly, and are seeking to comply with environmental ministry requirements.

Key conclusions:

- Properly sized and designed stormwater ponds rarely overflow, particularly if used as a water source for irrigation.
- The ratio of roof:pond area can be used as a guide to determine likelihood of overflows in response to storm events.
- Keep stormwater clean – avoid having other inputs into the pond. By doing so,
    - pond design can be simple – and so will sampling and monitoring, and
    - water quality will be optimal, and will generally meet provincial preliminary targets for greenhouse stormwater.
- There are no concerns with when/how to sample if the pond is properly designed and captures only stormwater; there is minimal difference in composition of the overflows with time
- Simple overflow sample collection bottles (e.g. Nalgene first flush or ping-pong samplers) could be used to collect pond overflows.
- If monitoring is required by the provincial environment ministry, a basic EC/pH meter is sufficient to follow EC levels (and to estimate water quality) in the outflow and the pond.
- The use of risers or adjustable outlets to temporarily increase the pond capacity if precipitation exceeds design specs in a given year would be an appropriate BMP to hold extra water for future use or release when appropriate if some settling was required.

Based on the results from 2014, it is not necessary to size irrigation ponds for 100-year storm events. It is possible to manage greenhouse roof stormwater by collecting stormwater only, and basing

the size of the pond on a ratio relative to the area of impermeable surfaces (greenhouse roof size, etc.), and accounting for the estimated water draws for irrigation purposes.

Introduction

Discharges (overflows) from stormwater collection ponds to the environment require approval from the Ontario Ministry of Environment & Climate Change (MOECC) in Ontario, and many ponds overflow at some time during the year in response to storm events and/or spring runoff. MOECC is asking farmers to manage and sample their stormwater, but is unable to provide support to farmers in the form of tools or protocols. Horticulture ponds are typically used for irrigation purposes, may have a mix of source waters, and have varying volumes of water depending on the time of year and production cycle. The management of these ponds, then, can be an important tool in reducing impacts on the environment. If the ponds collect nutrients or agricultural process water, then storm events create the risk of this nutrient-enriched water overflowing and discharging to surface water, directly or indirectly. Further, stormwater itself may contain significant contaminants, including sediments (influencing total phosphorus levels) if the storm water being captured is runoff from surrounding agricultural lands, or salts from road runoff. The challenges for farmers lie in a) understanding the contaminant profile of the water flowing into and out of the pond over the course of a storm event, and b) building capacity for their ponds to properly handle these flows, particularly as climate change scientists predict increased storm severity and changing weather patterns.

While the MOECC has made tangible (albeit temporary) progress in moderating the regulation of stormwater discharges for agriculture, the sampling protocols to determine when and how to sample discharges to evaluate the risk posed by the operation still need clarification. There are many unknowns. Will improperly timed sampling result in over or under-estimating contamination? Farmers complying with alternative regulatory options need guidelines for submitting an Operations & Maintenance manual for their stormwater facility, which may be complicated given the fact that many storm water/irrigation ponds are unique in their design. If needed, can a farmer capture the ‘most contaminated’ portion of a storm event (including any residual process water), and discharge the excess stormwater that poses the least environmental risk? In this way, severe storms (which may become more frequent based on some climate change scenarios) can be managed to have the least detrimental impact on surrounding water bodies. In order to accomplish this type of stormwater management, farmers must be able to predict flows and content of their discharges relative to reservoir capacity.

Objectives:

- Collection of field data regarding volume, flow, and water depth (using staff gauges) of floriculture greenhouse irrigation ponds over storm events of varying intensities and duration,
- Collection of automated/progressive samples to determine composition of stormwater overflows throughout the storm event (from point of overflow to cessation of overflow),
- Evaluation of testing for electrical conductivity (EC) and pH as comparative measures of water quality, relative to full characterization of the water performed at selected intervals,
- Comparison of calculated nutrient loads (if measurable) based on grab samples versus automated sampling systems versus EC/pH continuous monitoring,
- Application of these findings to develop tools to aid producers in collection and reporting of results to MOECC, and
- The knowledge gained on the most appropriate sampling methodologies will be used in a subsequent study that includes modelling stormwater event management and stormwater pond design and sizing. Other factors such as the daily crop water usage per unit area will be incorporated into these models.

Materials & Methods

Site Selection and Characterization

A desktop review of sites was initially conducted, from which a subset of sites were visited to assess suitability for the study. Records were kept of all the sites examined and information was tabulated, such as pond size, greenhouse roof area, lining material, and typical occurrences of overflows. Finally, three greenhouse/outdoor production operations with process water from irrigation entering their ponds were selected, considering access to inlet and outlet pipes, variety of inputs, availability of flow meters and general pond construction (e.g. clay lined). For each of the selected sites, detailed site evaluation and characterization was performed, including a description of the stormwater collection area and area characteristics, pond construction and sizing, potential water sources, location of inlet and outlet pipes, presence of aerators, etc.

Over the course of the study, pond levels were measured; a) using a staff gauge inserted into the near-shore area, and b) with HOBO water level loggers (0-4m range). Manual readings were recorded at each site visit, and logged measurements were stored and downloaded at the end of the season.

Monitoring Methodology

Selected sites were visited weekly throughout the season, and regular communication occurred with the farmer co-operators to verify initiation of rainfall events where overflows were likely. During regular visits, pond level and recent rainfall amounts were recorded on a site-specific checklist, and equipment was cleaned and maintained as required. Following the initiation of a storm event, daily visits of the site took place until overflows ceased.

Both manual and automated progressive collections of overflow samples were conducted in this study. Grab sampling was performed daily during storm events with a Nasco swing-sampler, using clean sample bottles. Autosamplers were used to collect samples over the course of each storm. Hach-Sigma SD900 24-bottle composite sampler or ISCO 3700 24-bottle autosamplers (Figure 1) fitted with 1000mL polyethylene bottles were set up at each site from May-June and again from September-October or November. Sample bottles were cleaned out after each round of samples with reverse osmosis-treated water. The programs were set up to provide one sample of approximately 900mL every 2 hours; two samples were combined so that there was sufficient volume for sample analysis (e.g. bottle 1&2, 3&4, and so on).

Figure 1 – Autosamplers used in the research study, showing interior sample collection basket, the control panel, and the setup at the greenhouse.

First flush sampling was achieved with Nalgene Stormwater (ping-pong) samplers (Figure 2). The samplers were mounted on posts in the water, with the top of the bottle set at the level where the pond would just start to overflow. As the pond water level rose to reach the lip of the bottle, the ‘first’ flush of water would enter the bottle through an opening in the lid. As the bottle filled up, the ping-pong would float, eventually closing off the opening in the lid so that the sample bottle would not continue to fill if the level of the pond continued to rise.

Figure 2 – Nalgene first flush (ping-pong) samplers used in the research study, placed in a swale that lead to one of the ponds, and in a pond mounted on a post.

Chemical analysis of selected grab samples and automatically collected samples was performed within 48 hours of collection by ALS Environmental (Waterloo, Ontario). Analysis included a full suite of parameters including: nitrate, ammonia, phosphorus, total suspended solids, conductivity, pH, etc. For sample results less than the detection limit, the number 0.0001 was used so that the sample result could be incorporated into averages and other analyses. The chemical composition data was used to develop correlation curves with turbidity and conductivity (EC) monitoring data. Continuous monitoring during the test periods was achieved with YSI 6600 sondes (Figure 3) fitted with optical turbidity and DO probes, as well as temperature, conductivity and pH sensors. Sondes were used to obtain continuous characterization of the overflow water quality over the course of the storm events. While continuous electrical conductivity (EC) measurements do not provide the details of composition (e.g. road salts versus nutrient components), the goal is to find practical tools for estimating the overall fluctuations in water quality with time, and determine if these simpler tools can be used to predict periods during a storm where the water may be of deteriorated quality.

Figure 3 – Sensor and staff gauge setup in the ponds, where the sonde and water level meter are mounted in a floating 'mat'. Sometimes getting the setup complete involved getting right in!

Meteorological Sensors

Meteorological data (temperature, precipitation) were collected throughout the test periods. Calibration of the reservoir model in the subsequent study depends on reliable data collected in this project. Precipitation was tracked at each site during the test periods with a 16,000 event HOBO pendent event logger with a tipping bucket rain gauge. In addition, a rain gauge was positioned adjacent to the tipping buckets for a second measure of rainfall (Figure 4).

Figure 4 – Tipping bucket (left) and rain gauge (right).

Results & Discussion

Site Selection:

Over 40 sites were considered for this project, based on preliminary information such as, a) did they have a pond, b) was it lined, c) did their pond experience overflows and d) would they be willing to be participants in the project (Table 1). Note that the survey did not include determination of the cistern capacity at each farm, or the use/capacity of cisterns prior to storage in an irrigation or stormwater pond, though this would be a necessary consideration for future design development studies.

Table 1: Summary of farm sites considered for the current study.

Parameter	Count	Percent
Number farms surveyed	65	-
Number farms with irrigation ponds	43	66%
Number of farms using only cistern/municipal water	22	34%
Number of irrigation ponds that are lined	29	67%
Number of irrigation ponds known to overflow	20	47%
Range of GH roof:pond area ratios	0.25 to 59	-

Out of a dozen sites visited, nine were not selected since ability to sample or install monitoring equipment was not feasible. In the end three sites were chosen (two in the spring, and an additional one in the fall), with the details of the ponds listed in Table 2. A fourth site was selected later in the season as a potential research site, but there were no overflows from their pond through the fall so only the initial pond water quality data collected for this site is presented here. Descriptions of the three sites are as follows:

Greenhouse Cooperator Site 1 - Site 1 pond was excavated into clay subsoils with no dyke or fill sections evident, and has inputs from subsurface drainage from a 6-acre adjacent horticultural field production, excess greenhouse nutrient feedwater (i.e. nutrient solution), and overflows from their cistern (roof water) (Figure 5). The cistern is the primary collection point for roof water. The pond overflows via a pipe to a catch basin, where other field and production water mixes with the pond overflow, before draining to the north. Overflows are largely triggered by subsurface drainage flows from the adjacent fields, which often last for several weeks after large rainfall events (Figure 5). The pond has a significant freeboard above its spill level (nearly 1.5m), and did not overtop the banks during a severe localized rainfall event (>100mm). The pond has steep side slopes and is not aerated, which contributes to poorer pond water quality. The drawing down of the pond for field irrigation purposes permits the replenishment of the pond with fresh water. The pond water is rarely used for irrigation of the greenhouse crops, as there is generally sufficient cistern storage.

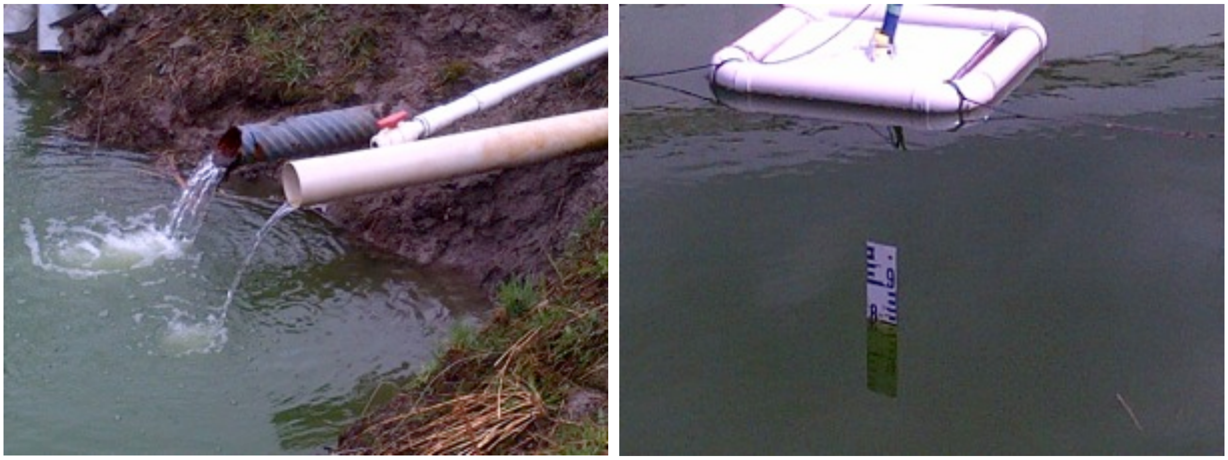


Figure 5. Site 1 tile water inflow from adjacent outdoor field and roof water from 2 production zones; Staff gauge, indicating pond height approximately 0.7m above outflow pipe.

Greenhouse Cooperator Site 2 – Site 2 pond has two sections, with a slight berm between the two parts (north and south) that was submerged in the spring when water levels were high, or after very heavy rains. The pond was excavated into clay soils, with a dyke section typically less than 1.0 m in height at the north and east sides. Side slopes are typically flatter than 2:1 and there are relatively few areas where erosion was evident (either in the original pond at the south end, or the newer pond section at the north end). It receives only roof water directly from the greenhouse. The pond is the primary source of irrigation water for the greenhouse crops. The pond only overflows in the spring and with large rain events only when the pond is nearly full prior to the event (Figure 6). A weir was constructed to facilitate monitoring activities (Figure 6).

Figure 6 - Site 2 pond outlet and constructed weir during an overflow event

Greenhouse Cooperator Site 3 – Site 3 pond was also excavated into the clay subsoils with no sections of dyke. There is a grassed-over soil pile along the west side of the pond. The pond is shallow and takes the overflow from the cistern when the cistern is full. The cistern receives only collected roof water, and is the primary source of irrigation water for the greenhouse. If the cistern is low, pond water will be pumped into the cistern. There is a small swale on the west side of the pond that allows only minimal surface runoff water to enter the pond. The pond overflows in the spring and with large rain events (assuming the pond is nearly full prior to the event). Because of its shallow nature, the pond bottom is mainly covered in submersed rooted macrophytes (Figure 7). The pond outlet is controlled by an engineered overflow pipe outlet shown in Figure 7.

Figure 7 - Site 3 pond and overflow outlet showing sample intake tubing for autosampler

The dimensions of the three ponds and corresponding greenhouse roof areas are presented in Table 2. Roof to pond area ratios were calculated for each site, based on the total greenhouse roof area that collected rainwater to the storage facility, and the approximate surface area of the pond when full. Pond and roof surface areas were calculated from measurements obtained using the measuring tool on Google Maps. This enabled a degree of predictability for if and when a pond was likely to overflow, based on the current pond height the predicted rainfall and the roof to pond ratio. For example, at a roof to pond area ratio of 10:1, a 10mm rainfall would be expected to raise the pond level by about 10cm. This is, of course, only a rough approximation and does not take into account water used for irrigation that day, changing pond surface area as affected by slope, the loss of water not going directly into the pond, or other factors. Site 2, with a low roof:pond surface area ratio, only overflowed in the early spring of 2014, and during the July 27th rainfall (approximately 45 mm). By the end of 2014, the Site 2 pond was again close to overflowing. Site 3, with a moderate ratio of 11.8, overflowed several times in the fall. Site 1 on the other hand, had a much higher roof to pond surface area (25.7) but a large portion of the roofwater was directed to a cistern, and while the greenhouse discharges were limited to cistern overflows and small volumes of excess nutrient solution, the pond also received water from field tiles from an adjacent 6 acre field. Consequently, the pond overflowed regularly throughout the season.

Table 2: Specific characterization of the three co-operator farm ponds and capture areas.

Site	Pond Section	Length (m)	Width (m)	Area (m^2)	Depth (m)	End slope	Side slope	Vol (m^3)	Vol (Imp g)	Roof Area (m^2)	Roof to Pond Area Ratio
Site 1		35	16	560	2.85	1.3:1	1.4:1	1085	239,000	14,400	25.7
Site 2	South	60	22	1320	2.45	3:1	2.75:1	2025	535,000	-	-
	North	65	27	1755	2.55	3:1	2.75:1	2985	657,000	-	-
	Total	-	-	3075	-	-	-	5010	1,192,000	16,250	5.3
Site 3		48	12	576	2.5 est.	2:1	2:1	775	170,000	6,775	11.8

Water Quality:

The chemistry for all three sites was determined for both grab and automated samples by ALS Environmental (Waterloo, ON). The results for average (mean) concentrations for all water quality parameters, standard deviations, MOECC targets and detection limits are presented in Table 3. As can be seen for Site 1's pond, which receives some greenhouse nutrient solutions as well as tile water from an adjacent field, has nutrient concentrations that often meet or exceed the targets. This represents an undesirable scenario where high nutrient solutions impact the water quality of stormwater ponds that can then overflow. Sites 2, 3 and 4 ponds, which receive only roof runoff, have much better water quality generally far below the MOECC maximum target limits.

Table 3: Average (mean) and Standard Deviations for water quality parameters at all test sites, Ontario Ministry of the Environment and Climate Change (MOECC) preliminary stormwater targets, and analytical detection limits.

Parameters	Units	Site 1 (N=17)		Site 2 (N=13)		Site 3 (N=30)		Site 4 (N=1)	MOECC Target (PPM)	Detection Limit (PPM)
		Avg	STDEV	Avg	STDEV	Avg	STDEV			
Conductivity	µS/cm	395.7	49.44	216.00	8.57	83.50	12.87	122.00	-	3
pH	-	8.5	0.48	8.03	0.14	7.90	0.15	8.64	6.5-8.5	0.1
Total Suspended Solids	ppm	29.0	17.00	13.00	12.00	5.00	2.00	21.50	30	2
Total Dissolved Solids	ppm	291.0	75.00	143.00	7.00	57.00	8.00	68.00	-	20
Nitrate-N (NO3-N)	ppm	17.0	25.00	1.00	1.00	1.00	0.00	0.10	10	0.1
Ammonia, Total (as N)	ppm	2.0	1.00	0.10	0.00	1.00	0.00	0.10	1	0.05
Phosphorus (P)-Total	ppm	0.76	0.21	0.01	0.03	0.01	0.02	0.00	0.5	0.05
Potassium (K)-	ppm	22.54	29.26	1.48	0.67	0.00	0.00	3.00	10	1
Calcium (Ca)	ppm	54.84	18.55	30.12	4.16	13.13	1.92	19.50	-	0.5
Magnesium (Mg)	ppm	13.37	5.82	6.27	1.10	2.02	0.55	1.44	-	0.5
Sodium (Na)	ppm	9.54	7.20	2.82	0.22	0.10	0.28	0.82	-	0.5
Chloride (Cl)	ppm	11.0	10.00	1.00	1.00	1.00	1.00	0.10	200	2
Sulphate (SO4)	ppm	41.0	22.00	36.00	2.00	1.00	1.00	3.40	200	2
Hardness (as CaCO3)	ppm	186.0	54.00	105.00	7.00	39.00	10.00	54.60	-	-
Alkalinity, Total (as CaCO3)	ppm	129.0	26.00	60.00	3.00	43.00	7.00	58.00	-	10
Aluminum (Al)	ppm	0.64	0.46	0.64	0.39	0.22	0.09	0.27	-	0.01
Copper (Cu)	ppm	0.04	0.09	0.00	0.00	0.00	0.00	0.02	0.05	0.001
Iron (Fe)	ppm	0.75	0.46	0.63	0.49	0.25	0.11	0.45	1.5	0.05
Manganese (Mn)	ppm	0.07	0.07	0.01	0.01	0.04	0.04	0.18	0.2	0.001
Molybdenum (Mo)	ppm	0.02	0.04	0.00	0.01	0.00	0.00	0.00	0.05	0.0005
Zinc (Zn)	ppm	0.20	0.37	0.04	0.01	0.01	0.01	0.02	0.1	0.003
Boron (B)	ppm	0.04	0.04	0.00	0.01	0.01	0.00	0.02	0.5	0.01
Silicon (Si)	ppm	3.64	0.71	0.27	0.77	1.26	0.34	0.00	-	1

The concentrations over time of the key parameters nitrate-N (NO_3-N), ammonia-N (NH_4+N), total P (TP), total suspended solids (TSS), electrical conductivity (EC), and pH for the three sites are graphed in Figures 8-10. The corresponding MOECC targets and detection limits are presented in each graph. At Site 1 targets are exceeded only for TP and TSS, whereas at Sites 2 and 3 there are very low nutrient or contaminant loadings in the overflows, with very few changes over time (TSS at Site 2, and NH_4+N at Site 3 are exceptions). The figures also illustrate that, for Sites 1 & 3, the grab samples are very similar in composition to the samples obtained with the autosampler (data unavailable for Site 2).

Ammonia levels are somewhat higher at Site 3 than at Site 2, likely because of the shallow nature of the pond and submerged rooted macrophytes (Figure 11) which, when decomposing, likely release NH_4+N. Site 2 pond, on the other hand, had somewhat higher levels of TSS, likely representing a higher level of suspended clays from the pond bottom (Figure 6). The TSS is not associated with high nutrients.

Likewise, the pH appears high at all 3 sites relative to the MOECC target but the critical factor is that the alkalinity is relatively low at all of the sites. This means there is very little buffer capacity present and so the impact of the pH on the environment is negligible.

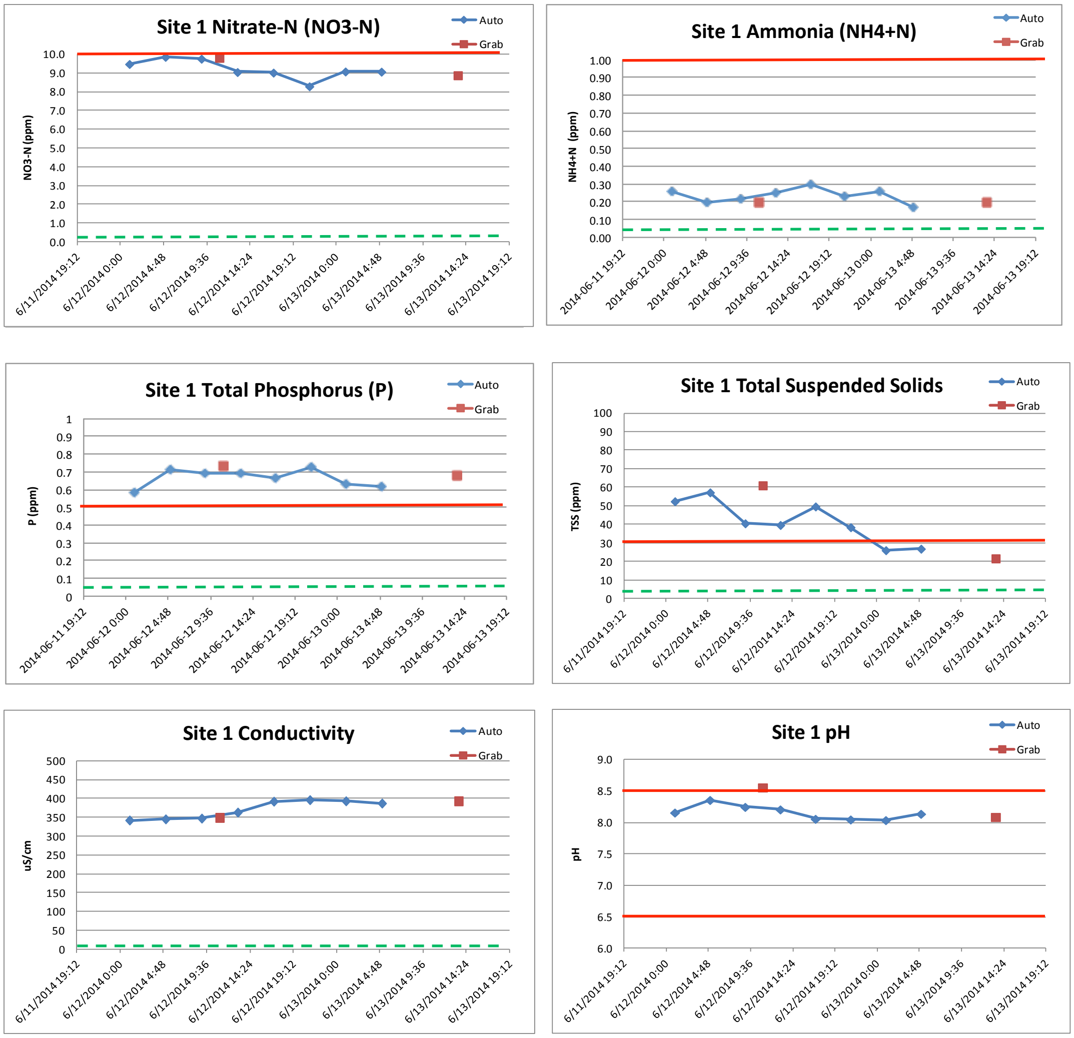
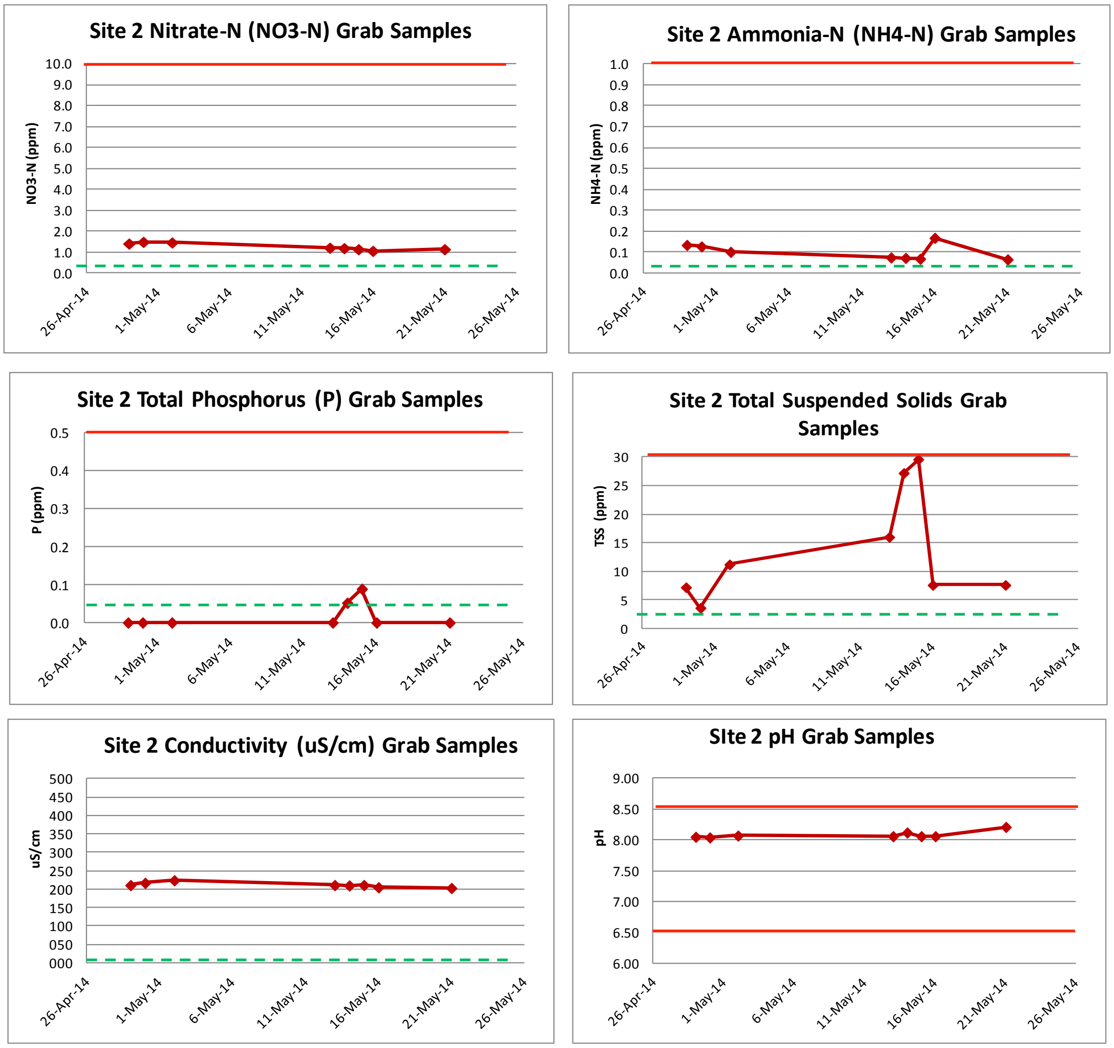


Figure 8 – Key parameters of Site 1 overflows over time, comparing grab samples with samples obtained with an autosampler. MOECC targets are marked in red lines (—) and analytical detection limits are marked in green hatched lines (-----)



Site 2 Nitrate-N (NO3-N) Grab Samples

Site 2 Ammonia-N (NH4-N) Grab Samples

Site 2 Total Phosphorus (P) Grab Samples

Site 2 Total Suspended Solids Grab Samples

Site 2 Conductivity (uS/cm) Grab Samples

SIte 2 pH Grab Samples

Figure 9 – Key parameters of Site 2 grab sample taken at outflow. MOECC targets are marked in red lines (——) and analytical detection limits are marked in green hatched lines (-----). During the test period there were no autosampler samples to compare with grab samples.

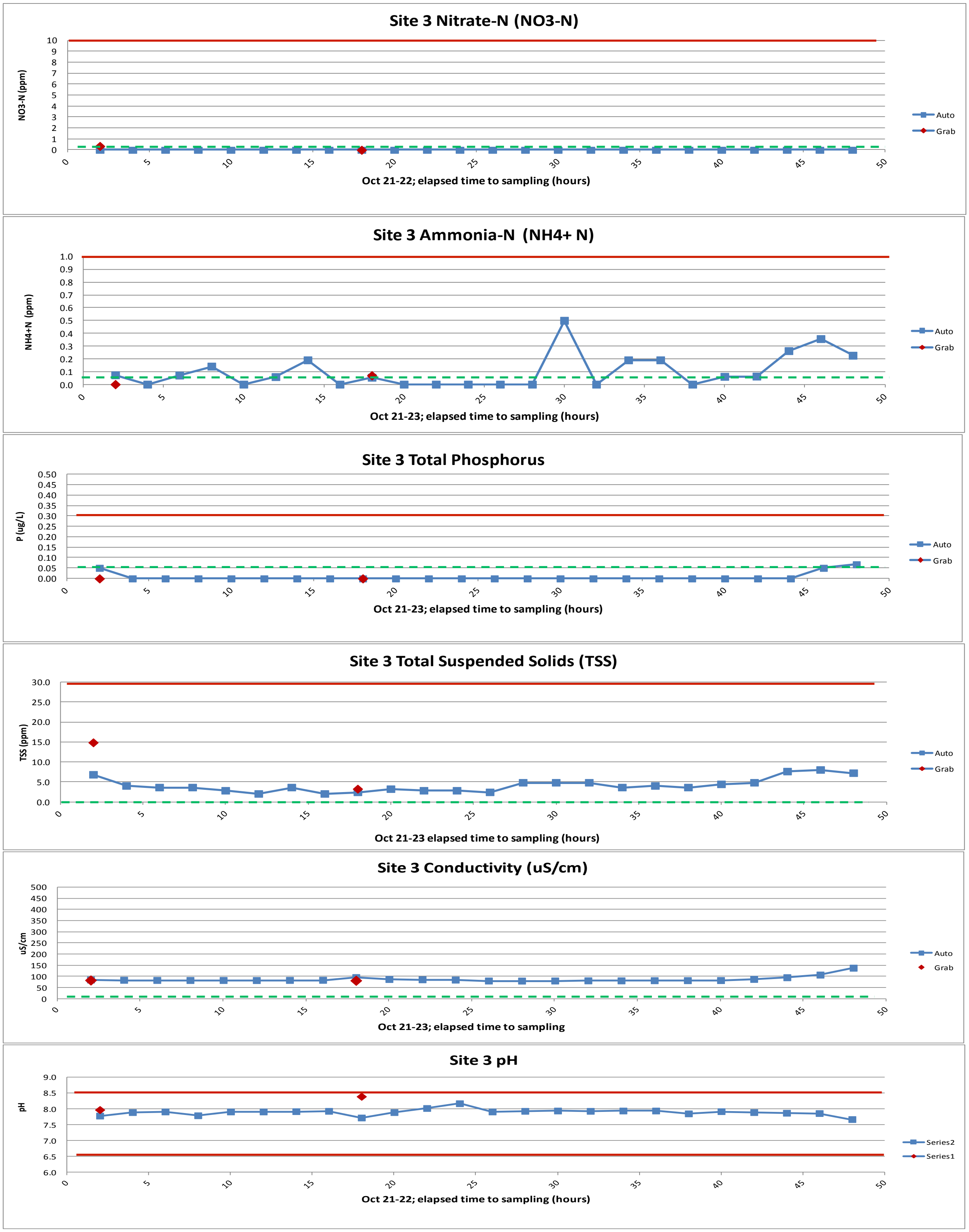


Figure 10 – Key parameters of Site 3 overflows over time, comparing grab samples with samples obtained with an autosampler. MOECC targets are marked in red lines (—) and analytical detection limits are marked in green hatched lines (-----)

Figure 11. Site 3 pond illustrating its shallow nature and presence of submerged rooted macrophytes.

Comparison of methods of measuring water quality (EC versus nutrients):

Electrical Conductivity (EC) represents the total concentration of dissolved salts in a solution, and hence should reflect the level of nutrients and dissolved contaminants in water. It is, in fact, the most common means by which growers routinely monitor the strength of their irrigation solutions. To answer whether or not routine use of EC could be used to meaningfully monitor the quality of the much more dilute pond water, we have made two comparisons:

1. EC probe from Sonde and EC from laboratory analysis: for all sites the results are quite similar (see below, Figure 12).
2. 2. EC compared with NO3-N, TP, NH4+N, for all samples taken for laboratory analysis (Figure 13)

Figure 12 shows clearly that the EC as measured by laboratory analysis and EC as measured by the in-situ probe (Sonde) at the same time as samples were taken are very similar. Any very minor differences likely reflect the specific differences in sample location, with the sonde measurements being further out in the pond, and the grab samples taken near the pond outlet.

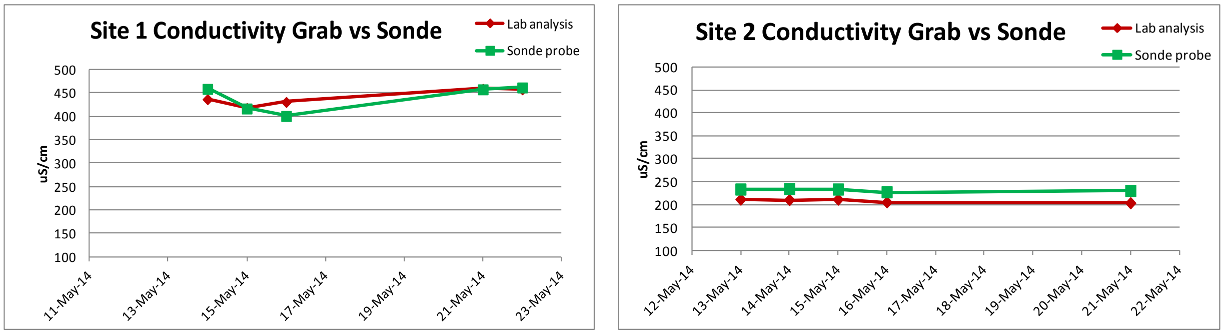


Figure 12– Conductivity compared between laboratory measurements of EC in samples taken by grab and the data logged by the EXO Sonde for conductivity.

Figure 13 illustrates a comparison of ECs (laboratory measurements) with key nutrients NO3-N, TP and NH4-+N for all sites and samples. Reasonably good correlations were demonstrated between EC and NO3-N and TP; the correlation with NH4+N was poorer. NH4+N is a volatile compound in a pond system, particularly in systems with decomposable organic sources (Sites 1, 3); it also represents a very small fraction of the total dissolved salts in the water. Dissolved NO3-N and TP, on the other hand, are not volatile; NO3-N in particular represents a higher fraction of the total dissolved salts in the system. Therefore, they are more closely represented by EC, and furthermore, nitrate is generally of greater concern than ammonia in greenhouse production systems where ponds are impacted by nutrient solutions (See Figure 9).

Hence, EC appears to be a reasonable indicator for growers to use to monitor changes in water quality in pond overflows. Since baseline pond water chemistry can be different from pond to pond, it would be prudent for growers to compare the chemistry of a number of samples to determine at what EC point there might be concern regarding overflow quality for their pond. In the case of the 4 ponds studied here, it appears that around 300μS/cm would be the point of concern. Correlations between should be checked for each operation since the water chemistry contributing to EC will be site specific.

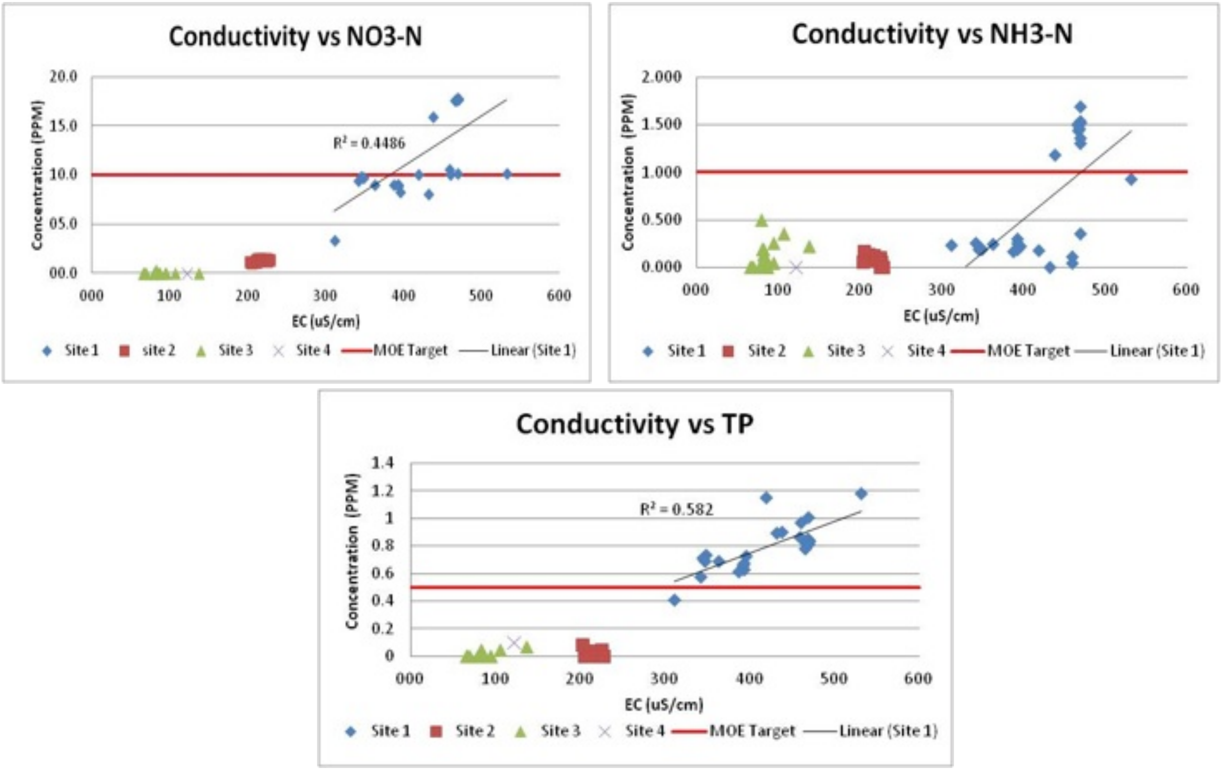


Figure 13 – Conductivity analysed in water samples from all three sites compared to key nutrients.

Prediction of pond overflows

Sensors were installed in each pond to continuously monitor changes in pond height; changes were recorded every 15 minutes. Since the pond height would be affected by water taking for irrigation, the flow data for Sites 2 & 3 are illustrated in Figure 14. The depth sensors do not measure absolute pond height, but rather changes in the depth above the sensor. Changes in pond height and the corresponding recorded precipitation events (daily accumulations plotted at midnight) are illustrated for Sites 1-3 in Figure 15.

It can be clearly seen that the height of the water in the ponds respond directly to water taking and rainfall events, and for the ponds at Sites 2 and 3 the response is proportional to the magnitude of the event. At Site 1, water was taken from the pond to fill the cistern twice in June, and again in the first and third week of August. From the graphs, Site 2 pond level increases about 10 cm in response to a 20 mm rainfall, or a ratio of about 5:1 which corresponds well with the estimated roof to pond surface area ratio of 5.3. At Site 3, a pond level rise of about 35 cm results from a 25 mm event, or a ratio of about 14, similar to the estimated 11.8 roof to pond surface area ratio. As previously discussed, while these estimates are not precise, they do provide a logical "rule of thumb" for growers to predict when ponds might overflow, if the ponds receive only roof water. If roof water is directed into a cistern first, and the excess directed to a pond, the cistern free volume must be taken into account, and the relationship is less direct; additional sources such as field tiles adds further complexity. When we overlay the water taking (Figure 14) to the pond height changes, we can see for Site 3 that as the water-taking decreased the pond height responded fairly well to precipitation events, and the pond levels gradually increased through the fall. Due to the small size of the cistern, water taking to fill the cistern may not have had as large of an impact on pond height as may be seen at other sites. At Site 2, water-taking fluctuated significantly through the fall, with higher amounts taken out of the pond in September. Actual area in production increased through September as a result of cropping changes, keeping the pond height low. The correlation for Site 2, between precipitation and the pond height is not as apparent. With the large pond area relative to roof area, the response in pond height is lessened. For Site 1 there is a direct response in pond height to precipitation event, but the response ratio varied from about 15 to 40; the roof to pond surface area was estimated at 25.5.

Precise models for predicting pond overflows based on information on input volumes (precipitation, unused irrigation water, drainage water from other sources), storage volume (ponds and cisterns), daily water use (measured or predicted based on crop and solar radiation) and evaporation could be developed and incorporated into the growers computer system, but this is beyond the scope of the current project.

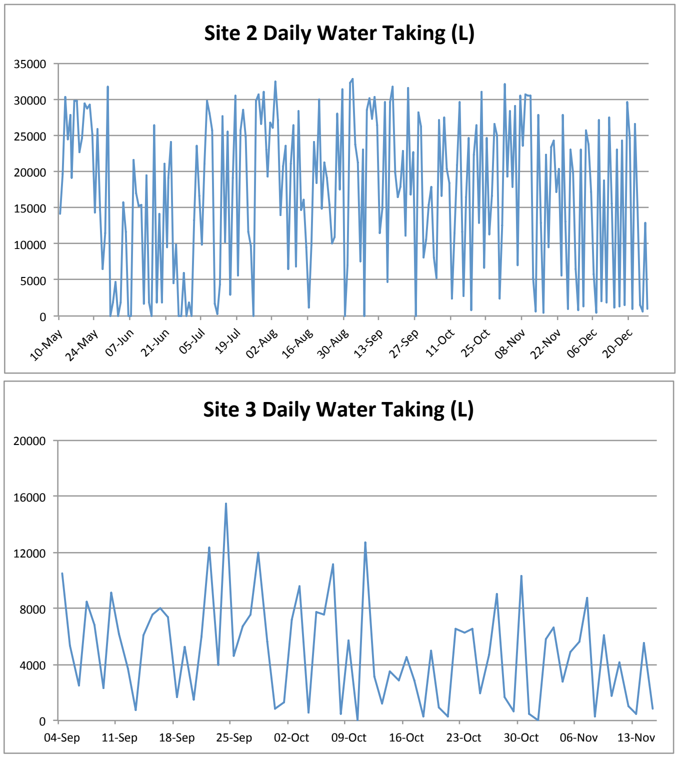


Figure 14 – Water taking at Sites 2 & 3, for the appropriate sampling periods. The data was taken from flow meters fitted on the intake pipes, and downloaded to their computer control systems. This type of data was not available for Site 1.

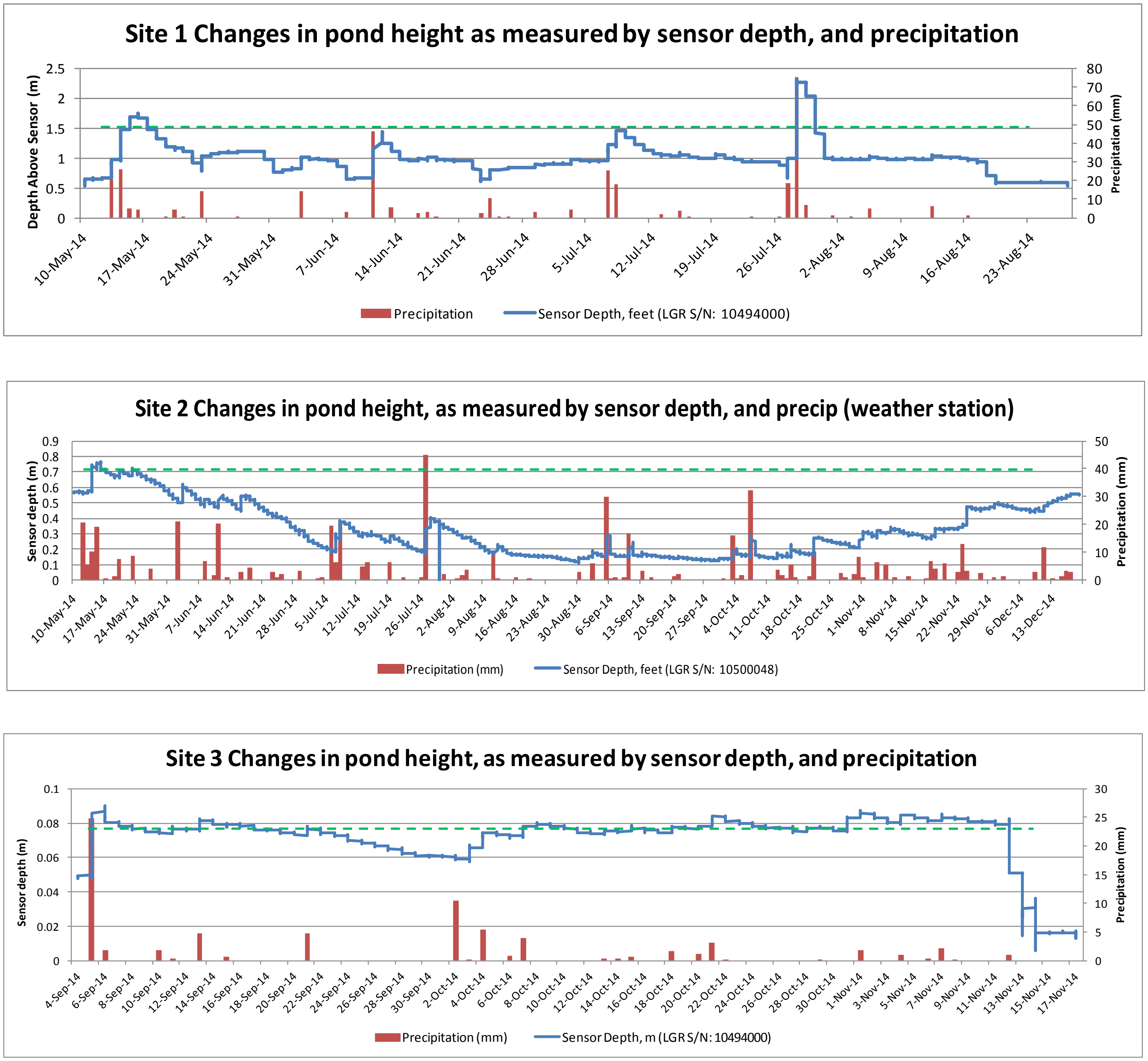


Figure 15 – Changes in pond height as measured by sensor depth, and precipitation data for Sites 1, 2 and 3. Pond overflow marked as hatched green line (- - -). Note differences in scales among the three graphs.

Outcomes/Recommendations

Most ponds sized according to need, so rarely overflow!

Farmers need BMPs and management tools to meet MOECC regulations for stormwater discharges. Currently, these tools are lacking, yet thousands of farmers in Ontario are encouraged (or mandated) to construct retention ponds to manage stormwater. Many, particularly in horticulture, use the collected stormwater for irrigation purposes. Integration of municipal water storage volumes and MOECC stormwater storage capacity need to be in sync as municipalities require growers to manage their stormwater to pre-development levels as part of any new or expanding operation.

During severe storms, however, runoff and agricultural process water (including that from subsurface drainage pipes) may contaminate retention/collection ponds and overflows. If a farmer is able to capture the 'most contaminated' portion of storm events (including any residual recirculation water), and discharge the excess stormwater that poses the least environmental risk, then these severe storms (1 in 10 or 1 in 25 year storm events) can be managed to have the least detrimental impact on infrastructure and surrounding surface water. The use of risers or adjustable outlets to temporarily increase the pond capacity if precipitation exceeds design specs in a given year would also be an appropriate BMP to hold extra water for future use or release when appropriate if some settling was required.

This study showed that ponds designed to collect only roof water have very good water quality, suitable for irrigation purposes, and representing very low environmental risk if they should overflow. Furthermore, the quality of water of any overflows changed very little over the overflow events captured in this study, and grab samples were reflective of the water quality determined by continuous sampling of overflow events. The value of aeration (to prevent stratification), berming, and regular site maintenance (mowing, etc.) are illustrated through this study. Simple first flush (ping pong) samplers could be used to capture the beginning of an overflow event. It should be noted that spring melt events have yet to be evaluated, and destratification, temperature and storm events may impact some parameters more than others (e.g. TSS, ammonia). The situation is different for ponds that are impacted by nutrient inputs from other sources (greenhouse leachate and/or field tile water from adjacent production areas such as orchards), as water quality targets may be exceeded for some parameters (as shown in this study). The justification for the best management principle of "keeping the clean water clean" by separating storm or roof water from other water sources was clearly demonstrated.

Several methods of monitoring water quality were evaluated: laboratory analysis from continuous sampling of overflow events and grab samples from ponds during and between overflow events, and continuous monitoring with probes installed in-situ in the pond. Electrical conductivity (EC) measurements were very consistent between laboratory analysis and in-situ measurements. EC was also shown to be a reasonable measure of water quality that could be used by growers to monitor pond water quality between and during overflow events. It is suggested that, because baseline water chemistry may vary between individual ponds, nutrient levels be compared against EC for several pond water samples to determine the EC at which water quality of overflows would be of concern. Using turbidity as a measure of pond water quality is also not practical, as turbidity can be influenced by surface runoff and adjacent field subsurface drainage. Roof water collected in lined irrigation ponds generally results in low turbidity, and is more desirable for greenhouse production so their low volume drip systems can be maintained without additional filtration.

Each pond responds very differently to precipitation events based on their design. Predicting changes in pond height in response to forecasted rainfall events is simple for ponds that only collect roof runoff water: predicted rainfall X roof to pond area ratio = approximate predicted rise in pond height. For example, a 2.5 cm event would raise the ponds at Site 2 by approximately 13 cm, at Site 3 by 30 cm, and at Site 1 by 64 cm (if Site 1 pond only received only roof water). There will be variations depending on the slope of the pond sides, and any losses in rain reaching the pond. None-the-less, the estimate can serve as a good rule of thumb for predicting when a pond (with a simple design) will overflow, based on the current pond height and the predicted rainfall.

The use of the roof to pond area ratio is less accurate if the greenhouse collects rainfall to the cistern first, and then overflows to the pond. It then depends on the size of the cistern(s) and the level of water in the cistern(s) prior to the rain event, as well as the pond capacity (i.e. the overall total water storage capacity). To further complicate the equation, usage from the pond and/or cistern draws down the level of water in the storage facility and must be incorporated into the overall water balance. Two of the sites (2 and 3) had flow meters for their water taking, so it was possible to determine the daily draws from the pond and cistern (so indirectly, the pond), respectively. However, if there are other inputs such as waters generated from the greenhouse or subsurface drainage (either from the greenhouse or adjacent fields), then it becomes very complicated to estimate pond height changes and overflows as the pond doesn't respond to rainfall in the same way. These variations were observed in this study, particularly at Site 1 where inputs from adjacent field subsurface drainage that came into the pond after the storms were over and the flows continued for days (even though it was no longer raining)!

This study is the first step in securing low-cost practical tools and BMPs that are applicable to not only greenhouse farmers, but also to any farmer that collects process water, including: vegetable wash water and processing sites, irrigation recycling ponds, winery process water collection ponds, outdoor greenhouse/nursery production ponds, water collection ponds created during sweet corn cooling, etc.

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