Innovative water conservation, recycling, and quality improvement measures in floriculture greenhouse production

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Executive Summary

Floricultural greenhouses are excellent examples of conservative water users, and most recirculate their nutrient rich feed water. However, other waters are generated in the greenhouse were not previously characterized in terms of quality and quantity. This study aimed to identify and characterize those different waters by sampling at 10 different operations in Ontario for a 1.5-year period. Flow meters were also installed to capture volume information. This project has led to identification of Best Management Practices (BMPs) for this sector that may also be applied to the vegetable greenhouse sector.

There was considerable variability in the results primarily due to wide variety of crops grown and the different production systems (subirrigation vs. overhead irrigation; soil vs. container grown, etc.). Further, the limited number of replicates (only one or two samples per water type on some dates) prevents widespread conclusions about the possibilities of either commonalities or range of variance for specific water types. However, some water streams were very consistent in terms of water quality/composition (e.g. boiler flue condensate), and this information may be useful to both farmers wanting to reuse these waters in their operations as well as regulators looking for opportunities to streamline the regulatory process. Other water types varied considerably (e.g. table wash, boiler blowdown) depending on type of operation, time of year, crop grown, and products used (e.g. for sanitation or boiler maintenance). In these cases, further study of composition and flows at additional sites would clarify the contribution of these water types and how to manage their reuse or disposal.

The installation of flow meters and access sampling ports (pepcocks) allowed for ongoing monitoring of flow, and availability of water types for sampling. For the farmer, are no additional costs to continue monitoring flows at the project sites – providing data that will be of value for re-use and treatment option determinations (where applicable). The cost of installing flow meters typically ranged around $2500, depending on the presence of suitable piping. The higher quality 'magmeter' style (remote sensing) was found to be superior to the standard (and cheaper) paddle-wheel/in-line style of meter, so is recommended for future installations. Access sampling ports are very reasonably priced (under $200), and are useful when there are challenging pipe connections or no existing 'simple' ways to obtain water samples. The substantial costs of this project were more related to the isolation of specific water types (which could involve installation of catch basins or other features that cost upwards of $10,000), labour for sampling, and the water sample analyses.

Through the project, examples of best management practices (BMPs) were identified at all farmer co-operator sites. These BMPs were recorded, and selected ones were highlighted in short You-Tube videos to assist in knowledge transfer activities with other farmers. The critical take home message from this project was the wide variety in farming systems at these greenhouses, meaning that there are no 'silver-bullet' solutions for all greenhouse floriculture growers. Research beyond this preliminary study is required to fully determine the range of compositions and flows for the key water types generated in these farms, and establish a suite of BMPs suitable for management. However, some commonalities were found and are highlighted in the recommendations.

Purpose

The purpose of this project was to collect data (samples and volume) from representative greenhouse floriculture operations and observe best management practices (BMP) used by these flower greenhouse operations that will lead to decreased nutrient discharges into local surface water and ultimately the Great Lakes. This water-based project focused on production, water/nutrient recycling and process controls.

Greenhouse floriculture operations generate several different types or streams of waste process water, with many having a low-nutrient content (planting line, tray/crate wash, cut flower pails, floor wash, subsurface drainage tile water, etc.). The scope of the project includes analysis of the risks and potential risk mitigation strategies of managing floriculture process water and stormwater.

Objectives

1. Determine the environmental risk of different sources of flower greenhouse process water and selected discharges through characterization studies of these different sources within different greenhouse operations (e.g. nutrient feedwater/leachate, warehouse wastewater, stormwater and subsurface drainage tile for nutrients and potentially other parameters.

2. Identify environmentally responsible options where possible, that will encourage recycling and reuse of 'waste' water from floriculture operations

Background

The Ontario Great Lakes Strategy was released in December 2012. The Strategy is Ontario's first road map to guide Ontario's future actions to protect the Great Lakes. Ontario's vision is one of healthy Great Lakes for a stronger Ontario – Great Lakes that are drinkable, swimmable and fishable. To achieve this vision, the Province is seeking to protect and restore the ecological health of the Great Lakes and the St. Lawrence River Basin. In recent years there have been occurrences of rotting masses of algae on shorelines, resurgence of massive blooms of potentially toxic blue green algae in western Lake Erie, and occurrences of an expanded hypoxic zone (low oxygen level) in the Central Basin. Sampling and testing of greenhouse nutrient feedwater discharges in Southern Ontario have demonstrated that greenhouse operations may contribute to overall nutrient loading in the Great Lakes. The floriculture greenhouse sector is dedicated to decreasing nutrient inputs to the environment and advance agricultural best management practices.

There are over 240 large commercial floriculture greenhouse operations in Ontario, of which 80% are located in the Niagara Peninsula. These greenhouses are situated in watersheds that lead to two of the Great Lakes: Lake Erie and Lake Ontario. Greenhouse floriculture is a very diverse sector, consisting of many open production systems including soil-grown cut flowers and seasonal bedding plant growers, to flowering potted plant growers utilizing recirculating sub-irrigation technology, and substrate-grown cut flowers using recirculation. A comprehensive Environmental Strategy has been developed by government agencies and the greenhouse agricultural sector to assist greenhouse farmers find practical solutions to reducing nutrients in discharges, comply with provincial requirements, and promote water and nutrient conservation and reuse practices.

Floriculture greenhouse operations, in general, have lower nutrient-containing process water than the greenhouse vegetable sector. Greenhouse floriculture operations produce process water from a variety of sources in addition to irrigation feed water and sub-surface drainage systems located under the plant production facility that may include propagation mist water (where young plants are rooted), planting line water, tray/crate wash water, water from cut flower pails, and concrete floor washing; waste water sources not all necessarily occurring at the same location. A key water resource available to producers in the floral greenhouse and nursery sectors is their stormwater/recycling/irrigation ponds to capture and store rainwater and subsurface drainage water for irrigation purposes often required by local municipalities. These different waters are classified as ‘sewage’ under the OWRA, but none of the process waters have been fully (well) characterized. This project aims to characterize waste water from typical greenhouse floriculture operations representing the different production systems and develop options for management of floriculture process water as part of the overall program that will initially reduce, but with the long-term goal of eliminating, nutrient discharges from greenhouses to surface waters that drain into the Great Lakes. Information on the risks of discharge based on this characterization project would dovetail into the ministry’s current risk-based approach to compliance and inspection that targets impacted watersheds for enhanced compliance attention. The data will allow a better understanding of the impact from various floriculture greenhouse sizes and types.

The floriculture greenhouse sector will gain critical information from this project for the responsible management of stormwater and process water from flower greenhouse operations. Flowers Canada (Ontario) Inc. is in the unique position of understanding floricultural greenhouse operations and having their trust to encourage adoption of industry developed best management practices (BMP). FCO is also involved in research that supports data collection and solution-oriented projects to improve environmental performance. Additional funding from the sector and other agencies was leveraged to stimulate the broader implementation of innovative greenhouse practices in flower greenhouse production for water and nutrient recycling and process controls to reduce nutrient discharges to the Great Lakes.

Description of Water Types

Source Water

Water from storm events cannot infiltrate impermeable surfaces and needs to drain away in a controlled manner to prevent erosion. Roof water off the greenhouses represents an incredibly clean and consistent water supply for floriculture greenhouse growers, and is a responsible way to capture water while preventing erosion. Most groundwater and surface water sources are not suitable for irrigation purposes (for either low volume drip or subirrigation methods). Many (over 90%, FCO records) greenhouse farms collect their roof water in a cistern, pond, above-ground water tank (silo) or a combination thereof for irrigation of their crops. Growers in the Niagara Region are required by regional bylaws to capture rainwater for irrigation purposes as a condition of building or expanding an operation.

Loading Dock Water

Water from parking lots and/or loading docks is considered surface runoff (Figure 1), and although it is stormwater, it is often considered ‘dirty’ and higher risk than roof water due to the possibility of suspended solids from the ground, road salt contamination, and hydrocarbon leaks from vehicles (e.g. hydraulic fluid, oils, gasoline, diesel).

Figure 1. Loading dock (left), with the sump pit (right)

Glazing Shading Material (typically referred to as Whitewash) Removal

Whitewash is a slightly opaque compound applied to greenhouse roofs during the April-August growing season to reduce solar radiation (Figure 2). Excess light passing through the greenhouse glazing can cause heat build-up and scorching of leaves. Whitewash is available from a number of different suppliers, and usually contains calcium carbonate as the light-filtering agent (e.g. ReduSol, ReduHeat, Koolray). Some time after mid-August, farmers will begin to remove the whitewash to allow more light to their crops as the day length shortens and the light intensity decreases. There are a number of different options for removing the whitewash, including mechanical scrubbing, allowing the material to wear off naturally (often sped up with the first frost), or application of a chemical remover solution to breakdown the coating. Typically, a solution of oxalic acid or tetrasodium glutamate diacetate, sodium dodeclybenzenes sulfonate, and sodium cumenesulphonate is applied to disintegrate the whitewash coating (e.g. ReduClean, Strip-It, Green Clean Acid Cleaner, Glass Cleaning Crystals). The whitewash remover is usually applied prior to an anticipated rain event. Rain effectively washes the remover solution and dissolved whitewash off the roof into the greenhouse's freshwater storage, where it becomes highly diluted.

Figure 2. Applying whitewash

Recirculated Feed Water

The nutrient-rich water applied to crops can be applied either overhead, through low volume emitters (e.g. drippers), or through the bottom of the pots. The latter, termed subirrigation, is becoming more popular, and now represents over >75% of growing systems in floriculture flowering potted greenhouses in Ontario. The nutrient solution can be applied to the bottom of the pots in troughs, Dutch trays or ebb-and-flow tables or concrete floors. The nutrient solution is wicked up by the growing media in the pot via capillary action until the media approaches its moisture holding capacity. The use of flood tables and floors meant a great amount of volume was now required to uniformly water the crop resulting in it being impractical to 'throw away' this solution and continually apply freshly prepared fertilizer solution to the crops. To achieve efficiency, the water is recirculated - collected as it comes off the troughs or flood tables/floors (Figure 3) and returned to a central tank where it can be blended into to the next round of outgoing feed/fertigation water. Total water use has decreased by more than 50% compared to drip irrigation or overhead irrigation. Because in sub-irrigation what goes into the pot stays in the pot, nutrients/salts and other 'limiters' observed in recirculating vegetable greenhouse waters are less of an issue. In addition because crop cycles of floricultural plants are reasonably short (e.g. 10-20 weeks) disease issues are of lesser concern.

Figure 3. Under bench return tanks for recirculated nutrient feed water

Subsurface Drains

Subsurface drains (previously called tile drains when clay tiles were used) are usually installed 30- 60 cm below grade, with a header pipe that connects the individual lines within each greenhouse bay. Subsurface drainage is installed to manage groundwater and wet ground that can occur in greenhouses. In a floriculture greenhouse the drains can collect leachate dripping from plants grown on, over or in the soil if the volume is sufficient to infiltrate the ground and reach the drains. The leachate can travel through soil or gravel to the perforated drains and can be carried to central pits for pumping out to a return tank for reuse.

Boiler Discharges

Greenhouses are generally heated by boilers that generate steam, which is then forced through a piping system where the steam condenses, or by hot water boilers that circulate hot water through a piping system. A small volume of solution in a steam boiler needs to be 'bled off' to remove the sediment/scale that builds up at the bottom of the boiler as fresh make-up water is added to replenish water loss in the piping system. Steam boilers are blown down on a regular basis (usually 1x/day) but could be less frequent depending on time of year, temperature difference and frequency of use of the boiler, with up to 20L bled off each time. For example in-ground cut flower growers only use their steam boiler for pasteurizing their soil beds between crops if using hot water as their heating system (Figure 4). The use of oxygen scavengers is critical in boilers, to prevent corrosion of the system. These chemicals are of interest in the steam boilers, that require blowing down, compared to the closed system of a hot water boiler (no discharge required).

There are four main water treatment chemical options (Ian Findlay, personal communication) for steam boilers:

1. Molybdate-based: Molybdate is the oxidized form of molybdenum ($MoO_4^{=}$), and the solution should not go into septic beds or sewer systems. This is the best chemical component for maintaining boilers and preventing corrosion.
2. Sodium-sulphite based: food grade, only about 30% efficiency in boilers so needs a lot of attention to maintain the right chemistry. Often need to 'overfeed' on the rates but this leads to salt (EC) buildup in the system. Waste can go to the sewer or septic system without harm.
3. DM (tree-bark extract): Also safe (eco-friendly) but has relatively poor efficiency for boiler maintenance. Waste can go to the sewer or septic system without harm.
4. Hydrazine: This is a hazardous chemical, but the levels used in boilers are extremely low. Further, this chemical is known (CERI 2007, USDH&HS 1997) to degrade completely within seconds of contact with soil and thus poses no risk to the environment. Note that this compound is not degraded as quickly in water (1-2 hours) so waste should not be put directly into a watercourse.

Figure 4. Steam boilers (left), with the blowdown access port (right)

Boilers powered by natural gas may have a flue-condensing unit to improve heating efficiency of the boiler and reduce the amount of natural gas utilized through the heat extraction process. The condensate is discharged from the system, leaving a water type that must be addressed through recirculation or disposal (Figure 5). The chemical makeup in the flue condensate is thought to be quite consistent, while steam boiler blowdown water (boiler blowdown) can be quite variable, depending on the chemical regimen used to prevent corrosion/pitting and for oxygen scavenging. Hot water boilers do not require a blowdown process, as it is a closed system.

Figure 5. Boiler flue condensate collection, with sump pits and flow meters

Planting Line/Floor Drain Water

There are three main types of water that are often plumbed into floor drains in a greenhouse: planting line water (Figure 6), table wash water, and cut flower pail water (Figure 9). The small amount of water that drains from equipment or vehicles or stormwater that comes into the greenhouse can not really be separated from the other water sources entering floor drains, and represent a very small portion of the total waste generated. Therefore, this study focussed on planting line, table wash and cut flower bucket water.

Figure 6. Planting line and the undertray to collect the water, and a floor drain

Table Wash Water

Sanitation is particularly important in production systems with continued reuse of containers and benches used for growing. Table wash water for flood tables, Dutch trays/containers and carts (Figure 7) is generated when these objects are washed and sanitized prior to reuse. After a crop is grown there is plant/media debris/algae and small amounts of residual fertilizer remaining on the tables. The tables are first pressure washed, and sometimes sanitized.

Figure 7. Dutch growing trays/containers, and table/tray washing

Cut Flower Pail Water

In cut flower operations, flowers are cut and placed into pails of water which may contain a hydrating and/or cut flower preservative (Chrysal (NL) and Floralife (USA) being the two key manufacturers), or an oxidizing compound (e.g. chlorite or chlorate) at least until shipping. Other common additives include antimicrobial agents, flower food or compounds that minimize ethylene production (to prevent early senescence of the cut flowers). The cut flower pail water is dumped weekly or after each use into floor drains before the pail is washed and water is treated with fresh preservative and re-used (Figure 8).

Figure 8. Collected cut flower pail water

Filter Backwash

Filters used in the greenhouse screen out the particles that can clog irrigation lines, especially if low-volume drippers (tape, spaghetti, etc.) are used. Depending on the system, some filters have an automatic backwash feature that reverses the flow of water through the filter to clean the screens or discs so the filter can continue to function. The reverse flow water is usually diverted so that it does not directly re-enter the source tank or pond (Figure 9). If the nutrient feed water is filtered before going out to the crop there may be very high levels of nutrients in the filter backwash, or, if the filter is only filtering fresh source water, there will be no nutrients in the backwash. Depending on how the filters function, there should be very little water volume and only a collection of solids, including biofilm, peat fibres, and other suspended particles.

Figure 9. Filter near fertilizer feed tanks.

Methodology

Site selection

Floriculture greenhouse operations were chosen based on past history as project collaborators, operational practices that are common to Ontario greenhouses, and the feasibility of separating and characterizing various water types. All sites are in or have completed an abatement process to meet the requirements of the *Ontario Water Resources Act*. Initially, four farms were identified as potential research sites, but the list was expanded to ten (10) sites to ensure at least two farms with similar waste streams were included. A significant effort was made to find three farms with the same waste stream (e.g. boiler blowdown) to improve the characterization aspect of the study. Some sites had only one waste stream being characterized at their farm. While the first four sites were confirmed by April 2014, the remaining six sites were not finalized with an isolation/installation plan until July 2014.

Installation process

Each site was evaluated on how to best separate and monitor their individual water types. If the water streams were mixed, plumbing/re-routing was necessary to isolate each water stream (e.g. often floor wash water, bucket water, planting line water may all go to one line). This often required installation of new piping and/or diversion of existing pipes. Once the different waters were identified and separated, collection systems and flow measurements were designed for each site with the assistance of Zwart Systems (Beamsville, ON). In some cases, catch basins (concrete basins) with sump pumps were installed to collect and funnel each waste stream to record the flow/volume data. At the cut flower farms, the bucket water was not easily monitored with flow meters and pumps; it was more practical to collect the used bucket water in a tank and record how often the tank was emptied. For boiler blowdown water, the design of the system and the temperature of the water made it difficult to collect and pipe in plastic lines immediately after the boiler, so a variety of solutions were created to allow sample collection and volume measurements. Specific examples of isolation, collection, and flow meters are detailed in the Results & Discussion section.

Figure 10. Collecting samples of table wash/floor water that have been captured and recirculated.

Water quality and quantity sampling program

Grab samples for each isolated water type were collected biweekly, initiated once the different water types were separated. Flow monitoring equipment was not necessarily installed prior to sampling. The samples were collected in clean bottles (provided by laboratory), kept cool (<10C), and shipped to A&L Laboratories (an accredited laboratory in London, Ontario) within 48 hours of sampling. Biweekly sample collection continued until the end of June 2015. Note that there were some weeks where selected water types were not accessible or available to be sampled. The samples were analyzed for the “Solution Complete” package, which included (but not exclusively): Ammonium/Ammonia-N, Nitrate-N, Total Phosphorus, Potassium, Sulphate, Chloride, pH, EC, Hardness, Zinc, Copper, Manganese, Iron, Molybdenum, and Boron. Analysis of Total Suspended Solids (TSS) was also added to the regular biweekly testing. Regulated heavy metals were tested four times through the sampling season, by preparing split samples and submitting them to SGS Agrifood Laboratories (Lakefield, ON), Whitewash residue in the collection cisterns was collected in the fall of 2014 (depending on the operation’s schedule) and these samples were also submitted to A&L Laboratories for the regular testing (Solution Complete plus TSS). Source water samples from each site were collected at least four times through the sampling season (and up to six times for some sites), and analyzed at A&L Laboratories for the regular testing, as well as for the heavy metals package on one date. Dyes/pesticides were not observed to be in use at the cooperating farms and thus no testing for either was performed.

Figure 11. Isolating water streams in a catch basin (left), and installed flow magmeter (right)

Results & Discussion

Site Details

A total of ten sites were included in the study, having been changed from the original four sites due to complications with installations and separation of water types, as well as the desire to obtain multiple similar types for a better understanding of the variability between water discharges at different operations. All sites were in the Niagara-Hamilton region, and were identified as sites A through J (Table 1). The following is a description of each farm (i.e. site), including production and water types available. Isolation/flow meter installation progress information is discussed separately under each water type.

Table 1. Site Description Summary

Practice \ Site	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Pots on ground/bench	Y	Y		Y	Y	Y		Y	Y	Y
Grown in ground/soil			Y				Y			
Nutrient solution collected with no contact with ground				Y	Y	Y			Y	Y
GNF** collected via drainage system	Y	Y					Y	Y		
GNF infiltrates soil			Y							

*GH = Greenhouse

**GNF = Greenhouse Nutrient Feedwater (i.e. nutrient rich feed solution)

Isolation and Installation Details

While some pipes had convenient points for obtaining samples, others required an access point to be installed. An access port (petcock) was installed at most sample points to allow easier access for the grab sample (Figure 1) at a nominal cost (less than $200). To obtain volume measurements through pipes, flow meters were installed so that flow could be logged continuously. The flow meters were installed downstream from the petcock or sampling port. The cost for flow meters varied by type and ease of installation – electricity is required in addition to an available port on the computer control system panel. The installation process for Site D was completed immediately, before their spring shipping season was fully underway. However, due to the delayed start date for the project, the spring shipping season was the first priority for the remaining cooperators. As a result, there was a significant delay in separating water types for most sites. To further complicate the project, both the parts supplier and control services were occupied with a large emergency: a renovation job at another greenhouse that had experienced a devastating fire in the spring. However, the connection to the computer control systems was not completed in a timely manner due to the unavailability of the contractor, resulting in limited flow data until the spring of 2015. For the boiler blowdown water, two sites collected a sample in a heat resistant container and then transferred a subsample into a pre-labeled sample bottle on the bi-weekly sampling date. At these sites, the average volume of a blowdown was estimated, and each blowdown event is recorded with the date so that volume/flow estimates could be calculated. At the third site, it was possible to pass the blowdown water through a flow meter since there was a storage/cooling tank after the boilers.

Loading Docks

Loading docks already had sump pits or catch basins installed in the ground, and were already isolated from other water types at three out of the four farms selected. The fourth farm required separation of the floor drain water from the loading dock, so a separate catch basin required installation, as well as plumbing re-routing. Magmeter style flow meters were installed at each of the four sites due to the expected amount of particulates in the water. The magmeters have no moving paddle wheel or other parts inside the pipe, and remotely sense the water flow. For situations where particulates can plug or interrupt the flow, magmeters are the preferred option. Installation of magmeters (including parts, installation, electrical and connectivity to the computer control system) generally cost $2500 per meter, depending on the complexity of the piping required, the distance to a computer control panel, and the availability of a ‘port’ on the computer board. The meter itself costs approximately $1500 for a 2” line. Adding a catch basin significantly increases the cost, bring the total cost to over $8,000 for the one site (costs covered in part by the farmer cooperator, and the balance through the grant).

Recirculated feed

Nutrient feed water is recirculated at most of the test sites, so the water was already isolated, and just needed installation of a flow meter on the line returning the water to the fertilizer dosing system. Again, a magmeter was the preferred choice, since return water can contain debris and particles from the potted plants.

Filter backwash

Before fresh water (pond or cistern) or fertilizer rich water is applied to the crops, it is usually pre-filtered to remove any particulates that could plug drip-irrigation lines. A magmeter was the preferred choice since filter backwash water was expected to contain debris and particles. Unfortunately only one site was setup to monitor filter backwash.

Subsurface drains

At the three sites chosen, the subsurface drains were already isolated and a flow meter (magmeter) was only required at one of the sites. The other two sites had flow meters installed for a prior project, although the flow measured was only for a portion of the greenhouse (approximately 1 hectare). In addition to the flow meters, in-line EC loggers were installed to track electrical conductivity (EC) on a continual basis. Two of these units were installed to track these parameters for the subsurface drain water. Each logger costs around $400, but the total installed cost was closer to $1500 per logger, depending on the complexity of the materials required, the distance to a computer control panel, and the availability of a 'port' on the computer board. At a third site (H), the in-line EC logger was installed for the mixed recirculated feed/subsurface drain water as it was not possible to completely separate these water types.

Boiler flue condensate

Boiler flue condensate at all three farms selected was collected in a container to cool first, and then a sump pump was installed to pump the water through a meter. Note that at two farms, the hot water boilers assessed were the secondary (backup) boiler and were not used continuously through the year. At these same farms, the meter installed was a simple brass ¾" water counter style meter (Neptune, costs <$200, measures volume in m^3). At the third farm, a magmeter was installed to measure flow on their primary hot water boiler.

Boiler blowdown

At two sites (C, F), the volume/flow of this stream was calculated based on the volume of each blowdown (estimated at 20L per event) multiplied by the total number of blowdowns per month. A third site (G) installed a magmeter after a collection tank setup, so that the very hot water could cool before passing the meter. At all sites, the boilers are manually blown down.

Planting Line/floor drains

Floor drains required sump pits or catch basins installed in the ground, or a separate pipe to isolate the water from other water types. Sites A, B and C required piping and a magmeter (debris from planting line), and Site J required the installation of a new pit and extensive piping to separate it from the loading dock water.

Table wash

Table wash water was isolated by creating a pit or containment system, with extensive plumbing required at one site. A pump followed by piping and an in-line magmeter allowed for the measurement of flow rates at both sites.

Cut flower pail water

To measure the cut flower pail water (bucket water) volumes, all the water at two of the sites was manually poured into a central water tank (barrel), and the date was recorded each time the tank reached a set point and was drained. Total volumes over a month were estimated. The third site with this water type did not record their water use. The cost of the tank (with basal valve for draining) was nominal, at less than $200 each.

Water Quality & Quantity Sampling Program

Each identified water stream was assessed, considering the different chemical groups (nutrients, metals, other major categories) that could impact environment. The following water types were isolated and were characterized for both composition and volume to determine potential loading and risk. See below for a discussion of the results.

Table 2. Sample Descriptions by Site for Water Sampling Program

Water Type:	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H	Site I	Site J
Loading Dock	✓	✓						✓		✓
Planting line/Floor Drain	✓	✓						✓		✓
Subsurface Drain Water	✓	✓				✓	✓			
Filter Backwash	✓									
Whitewash Residue	✓			✓					✓	
Cut Flower Pail Water			✓		✓		✓			
Recirculated Feed Water	✓	✓		✓				✓		
Table Wash Water		✓		✓						
Boiler Flue Condensate	✓	✓		✓	✓					
Boiler Blowdown Water			✓			✓	✓	✓		
Source Water	✓	✓	✓	✓	✓	✓	✓	✓		✓

Assumptions & Comparisons

There were some general assumptions made throughout the study for missing samples and samples with parameter levels less than the detection limit. If no sample was taken, averages ignored the missing data. The full list of number of replicates is reported (n values) in the individual water type discussions below. For parameters that were analysed but below the laboratory detection limit (BDL), a designated value was assigned (see Table 3). The use of a designated number allowed for conservative estimations of these sample results, and inclusion within the average. Average and median calculations were employed for the water quality and metals data respectively. Minimum and maximum values are presented for water quality data below, in preference over standard deviation, as the true range of variability of the data could be observed visually. Standard deviation calculations were completed where relevant, and are presented within the text of the discussion. For water quality, comparisons were made against the Ministry of Environment and Climate Change's Greenhouse Effluent Preliminary Objectives: Stormwater (MOECC 2013, also detailed in Table 3). As the MOECC stormwater targets represent generally clean water suitable for reuse as irrigation water in the greenhouse, the values (used in some Environmental Compliance Approvals) were used as a guide for generally acceptable, low risk water. The provincial water quality objectives (PWQOs) were not used, as often source water does not even meet these guidelines.

Table 3. The MOECC greenhouse effluent preliminary objectives for stormwater (MOECC 2013), data laboratory detection limits, and the assigned value if the result was below the detection limit.

Parameter	MOECC SW Target	Detection Limit (ppm)	Value Assigned if BDL
Adjusted SAR		0.01	0.001
Aluminum		0.1	0.01
Ammonia (NH_3/NH_4-N)	1	0.01	0.001
Bicarbonate		10	1
Boron	0.5	0.02	0.002
Calcium		0.1	0.01
Carbonate		10	1
Chloride	200	1	0.1
Conductivity (mS/cm @25 C)		0.02	0.002
Copper	0.05	0.02	0.002
Hardness		1	0.1
Iron	1.5	0.1	0.01
Magnesium		0.1	0.01
Manganese	0.2	0.02	0.002
Molybdenum	0.05	0.02	0.002
Nitrate-N	10	1	0.1
pH	6.5-8.5	0.01	0.001
Total Phosphorus	0.5	0.1	0.01
Potassium	10	0.1	0.01
Silicon	0.5	0.1	0.01
Sodium		0.1	0.01
Sulphur	200	0.1	0.01
Total Alkalinity		10	1
Total Dissolved Solids		10	1
Total Suspended Solids	30	10	1
Zinc	0.1	0.02	0.002

Source Water

Only source water sources derived from roof water were included in the analysis. Groundwater was occasionally used at one site to supplement their rainwater, but the water quality was very different from stormwater collected in cisterns or lined collection ponds. This water type was generally consistent, with occasional peaks of nitrogen (both ammonia/ammonium and nitrate), copper, molybdenum, potassium and zinc. Total phosphorus levels exceeded 0.5ppm at least one time over the course of the study at 8 out of the 9 sites. As source water was not collected every sampling date, n values ranged from 1-9, but usually n=9.

Loading Dock water

Samples from the catch basin or sump pit of up to three different loading docks (collecting both actual loading dock and some parking lot water) were collected. Daily and monthly precipitation data (Figures 12 and 14 below) can be compared to loading dock water composition, with significant rain events (>60 mm/month) occurring in April and July of 2014, and April, June, September and October of 2015. Interestingly, the 110mm rainfall event on July 27-28 2014 did not result in a noticeable change in any parameter measured. However, the total suspended solids (TSS) were the most variable during the months of high rainfall. The nature of this water type is that collection of particulates from the ground surface is common. It was expected that if residual water sat in the sump pit (i.e. below the pump action line), then evaporation over time could result in exaggerated levels of salts or other components. The only time salts (measured as electrical conductivity) really peaked was in the spring of 2015, just as the temperatures were fluctuating around the freezing point. Extra application of road salt influenced the results particularly at one site. The range of variability between sites and throughout the season is quite large, and additional sampling would be required to understand the variability. Flow data (Figures 13 & 15) indicate more flow in the spring, particularly at Site A (with year-round data available), despite the rainfall amounts (Fig 12,14). Monthly peak flows observed in March, April, and June of 2015. April and June 2015 did have >60mm precipitation, but peak flows were not observed at other peak precipitation periods.

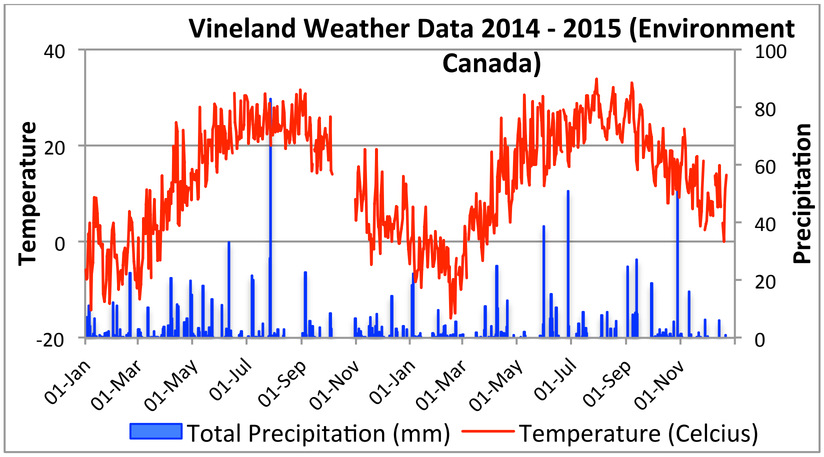

Figure 12. Weather data from Environment Canada's website for Vineland Station.

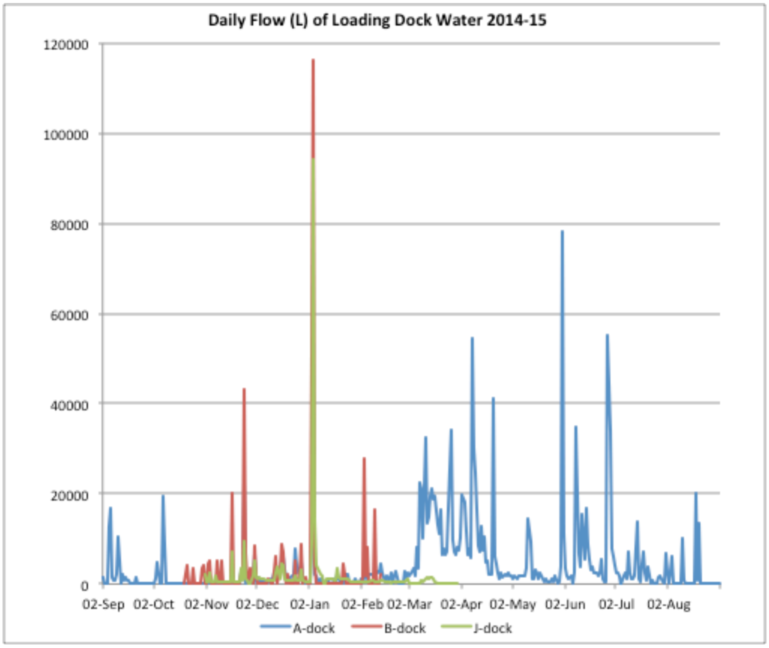

Figure 13. Daily flow data for loading docks.

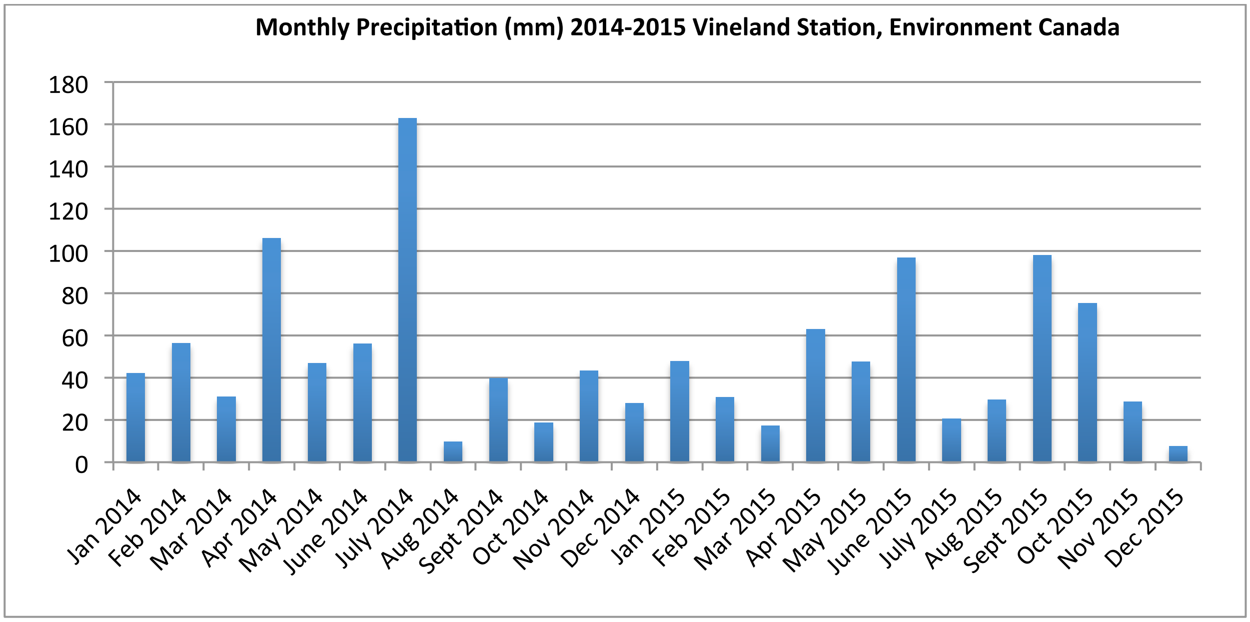

Figure 14. Calculated monthly precipitation from Environment Canada's website for Vineland Station.

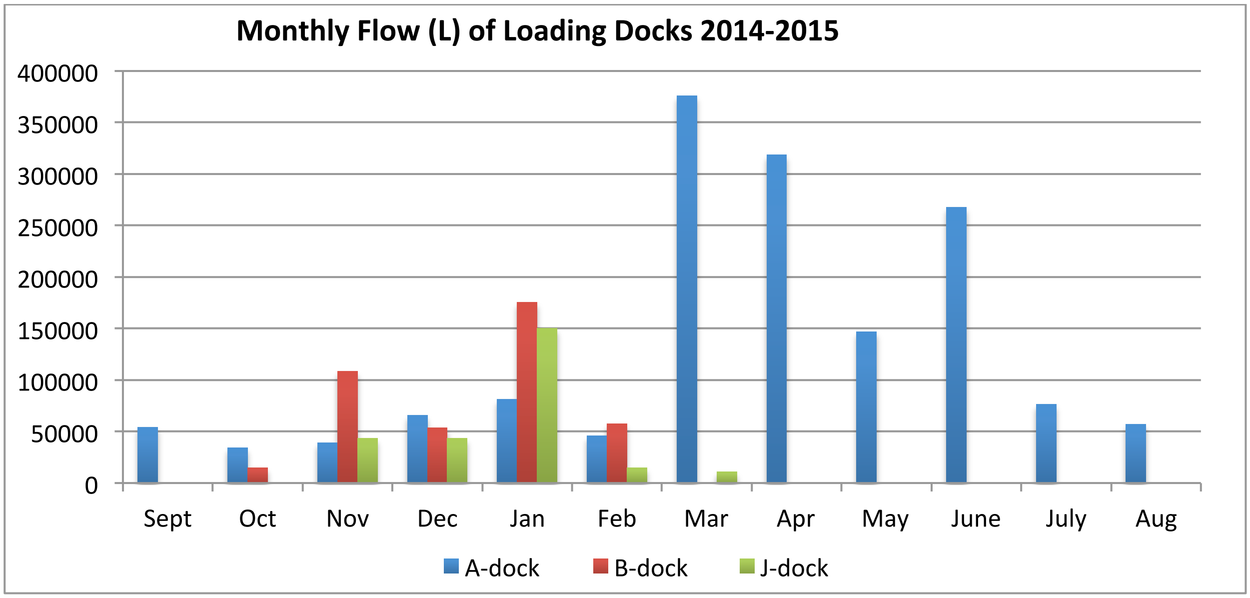

Figure 15. Monthly loading dock flows, September 2014 to August 2015.

Whitewash

Five (5) whitewash samples were requested at the end of August through mid-September, specifically from growers that indicated they would use whitewash remover. The samples were taken from their cistern, following the first rain event (greater than 5mm) after whitewash remover application. Results suggest that the water in the cistern after the remover is applied is actually cleaner than the normal roof water, with the exceptions of only slightly higher levels for bicarbonate, calcium, sodium, TSS and zinc. These results suggest that the removal of whitewash with the use of an accelerating agent does not negatively impact the quality of the water. Plant Products is a supplier of whitewash remover, and states in their online literature (referencing observations in The Netherlands) that there are no environmentally harmful ingredients in these products. This suggests that other jurisdictions with significant greenhouse industries view whitewash remover/cleaner as a low risk water type.

Recirculated Feed

At four sites, the recirculated nutrient feedwater (i.e. fertigation water) was sampled bi-weekly. Macronutrient and micronutrient levels were similar to that of feed solution for the plants. There is significant variability in some of the parameters tested (e.g. manganese, potassium, sodium, zinc). The limited data available, combined with the extreme variability of crops throughout the seasons at each farm means that it is complicated to make general observations regarding nutrient levels expected. Therefore, the nutrient feed solution and the recirculated feed were tested at three farms, taking the outbound and return water samples within an hour of each other. In this way, the change in solution from feed to return could be examined. Since the feeds were quite different from farm to farm, it was more practical to take the difference of the values before and after irrigation, and then average the differences. Positive values for the average percent change meant that the value of that parameter increased in the return water compared to the outbound feed solution. Most elements were relatively unchanged, since the three farms practice subirrigation. Solution passing around and through the media in the lower parts of the pots can increase total suspended solids levels.

Filter backwash

While filter backwash was to be isolated at three farms, it was only tracked at one farm, making it difficult to consider trends from the limited data (data not shown). It was expected that suspended solids would be present in the filter backwash, along with nutrient levels similar to nutrient feed solutions. It may have been more interesting to characterize sand filter backwash (not necessarily nutrient-rich), particularly at sites that filter their pond water before using in irrigation.

Subsurface Drain

Data from two farms in another study (OMAFRA-FCO transfer project 2012-2014) was combined with an additional two sites in the current study to provide information on the quality and quantity of subsurface drain water. There were production systems studied: one of the farms grows plants in the soil, while the other three grow potted plants on benches/troughs or on the ground. For the drains at the soil-grown crop farm, nutrient levels were similar to nutrient feed solution, with the exception of phosphorus, which was lower than the feed concentration (adsorbed by soil particles). For the flow rates, one potted plant grower's flow meter did not work at all, so no flow data was collected. The other three sites comprised of one in-soil grower (G) and two potted plant growers (A and F). While the in-soil grower flows (Figure 16) remained fairly consistent, and corresponded with irrigation, the potted growers' flows fluctuated widely, and upon close examination of weather data, peaks aligned themselves with significant rainfall events. For example, in July of 2014 Site F experienced a serious rainfall, with over 160,000L flowing through their subsurface drains. In contrast, when there was no rainfall, but irrigation events occurred, there were no flows detected in the drains. The same pattern followed for the other potted plant grower, who appeared to be equally vulnerable to rainfall events (Sept 2014, May and July 2015). Where there is in-soil production, it is possible to collect leachate through subsurface drains, and recirculate it. The retention time in the soil may not be sufficient for soil microflora to sanitise the leachate solution reaching the drains, so a study of disease pathogens, particularly root pathogens, may be valuable when considering recirculation options.

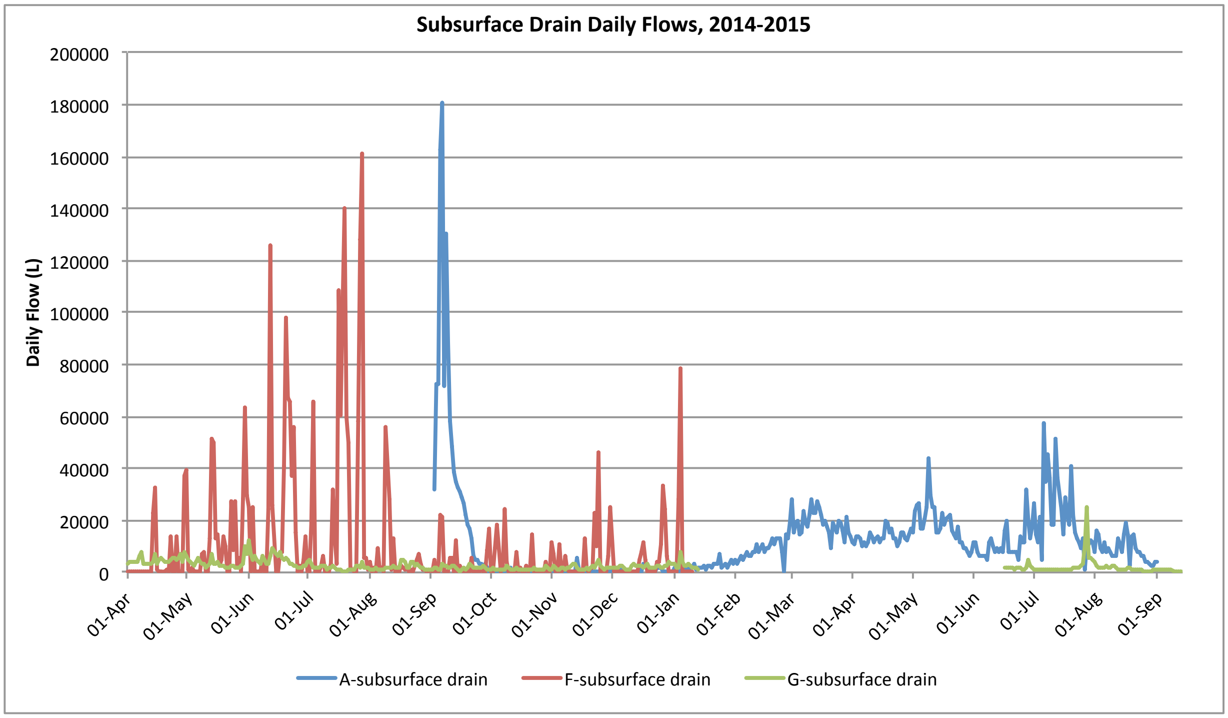

Figure 16. Daily flows of subsurface drains at three sites.

Boiler Flue Condensate

The composition of the flue gas condensate from the (hot water) boilers was fairly consistent and was subsequently not sampled from October 2014 through May 2015 to save on laboratory costs. Any variability generally was due to one site where the flue condensate was collected from a pit in the floor, as opposed to a barrel (e.g. Figure 5). The main parameter of interest is pH, which was commonly around 4, well below a reasonable range for direct use on crops. However, it would be possible to blend this water with fresh water when preparing nutrient feed solution within the greenhouse, as all the other elements were present at minimal levels. Where there are a limited number of sites as seen in this data set, it is worth noting again that any minor variation will appear exaggerated, and can skew the results. It is important to remember this study represents a cursory look at various water types, and a larger number of sites with similar practices would likely provide more consistent data.

Flow data for flue condensate also varied significantly by site (Figure 17). Site B and D samples were taken from 200hp Boilersmith boilers, while Site E had a Cleaver Brooks 150hp hot water boiler. All three boilers were fitted with van Dijk condensers. At Site B, a large amount of condensate was collected and measured through the magmeter. This farm uses their boiler as their primary heat source, and the lower numbers in the summer of 2015 clearly indicate there is minimal flue condensate generated when the boilers are not in use. At Site E, the boiler is also their main boiler, however the flow meter was of a different style (standard brass counter) and plugged regularly. In fact, the meter was replaced in March 2015 due to performance issues. At the third site (D), the flows recorded from their standard brass counter meter were also very low, but likely due to the fact that this boiler is their back-up boiler. Their main hot water boiler is not fitted with a flue, so there is no condensate generated from that boiler.

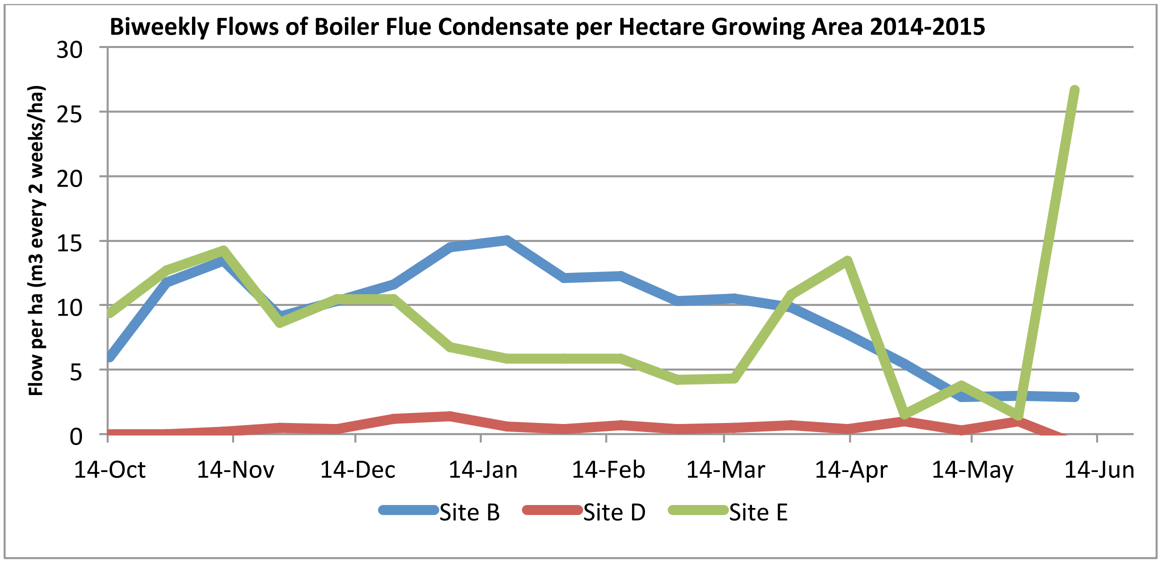

Figure 17. Flow per hectare production of boiler flue condensate at three farms.

Boiler Blowdown

There were distinct differences between the boiler blowdown waters tested. The pH of boiler blowdown water is consistently high (over 9), and the other elements tested were highly variable, including the presence of heavy metals. There were usually 2 sites with the steam boilers running despite the summer months, although there was a total of 4 sites being tracked through most of the sampling season. The growers that have in-ground crops (C and G) use steam year-round for pasteurising the soil, whereas potted plant growers (Sites F and H) use the boilers for heating only. Each boiler is from a different manufacturer, each boiler technician uses a different mix of anti-corrosion agents in the boilers, and the results certainly illustrate the wide variability to be expected in this water type. This variability makes it extremely different to make generalizations of this water type, and thus, to consider ways to re-use this water.

Flow data for the boiler blowdown water was determined by noting the dates of blowdown over the course of a season, and estimating the volume at each event. Typically, the volume released during standard steam boiler maintenance is sufficient to fill a 20-litre pail. In normal operation, the boilers are blown down daily in the wintertime, and alternate days during periods of low use. In some operations, the boilers are shut down completely during the summer months. From Figure 18, it is clear that at Site G the boilers are used throughout the summer, and only to steam sterilize the beds (confirmed by grower). The volume of blowdown is much higher when growers pasteurize their soil because the steam is not returning to the boiler, but rather is being pumped into the soil. Far more water is required to 'top up' the boilers, and that requires the addition of more chemicals as well as an increase in the time that the boilers are blown down. A magmeter was installed in the fall of 2014, but not connected to the computer control system until the summer of 2015. Flow data continues to be collected at this site; year-round data will be available for future years.

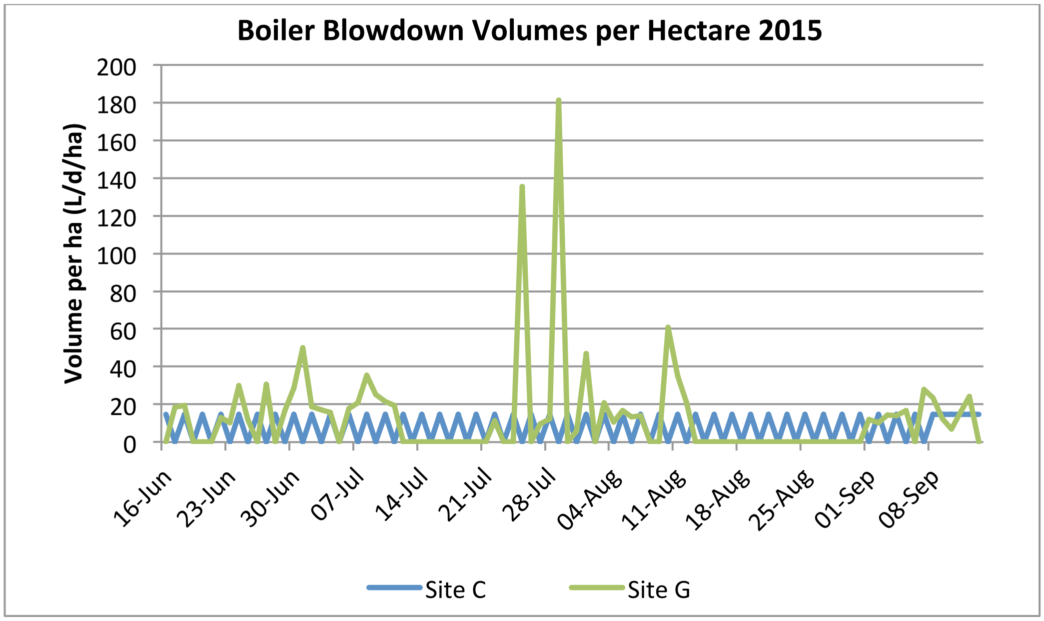

Figure 18. Daily steam boiler blowdown volumes, calculated manually at all but Site G.

Planting Line/Floor Drains

The floor drain water, often containing water from the planting lines, may contain nutrients, since plugs can be planted in pots with or without fertilizer depending on the early needs/requirements of the crop. Elevated levels of nitrogen (ammonia/ammonium and nitrate), total phosphorus, and potassium as well as some micronutrients (e.g. copper and zinc), were detected at the sites with planting lines draining to their floor drains. Planting lines use fresh water for certain crops, but some crops (e.g. Easter lilies) require significant nutrient levels up front. In addition, there may be nominal levels of nutrients in the media (starts out with a low ‘nutrient charge’) that leach out when the plants are initially watered. Floor drain water results (e.g. at Site H) without the impact of planting line water, suggest that there are still sources of nutrients entering the drains. It is possible that finished plants, racked and ready for shipping could be watered in the warehouse (note: this is not very common) and some nutrient solution could leach out of the pots into the floor drains. General trends from these results point to a wide variability of composition of this water type, depending on production cycles and growing practices (crop-based). The water from these drains can be (and is) reused on the farm, as long as the farmer has evaluated the water quality.

Flow meters were installed at four sites, but at one site there was no data collected (Site J). Therefore, only three sites had flow data information (Figure 19). When the flow data at Sites A and B was examined, it followed closely with their planting schedules. Site A does a lot of propagation and cuttings, so there is a lot of activity on their planting line from December through spring, often in 4 day intervals (Mondays-Thursdays), and again in the summer ahead of the poinsettia season. At Site B, the biggest push for planting is in October/November during the potting of Easter lilies but there is fairly continuous potting year-round. In contrast, Site H did not have a planting line draining into their floor drains, and the levels of flow are extremely small throughout the year compared to Sites A and B.

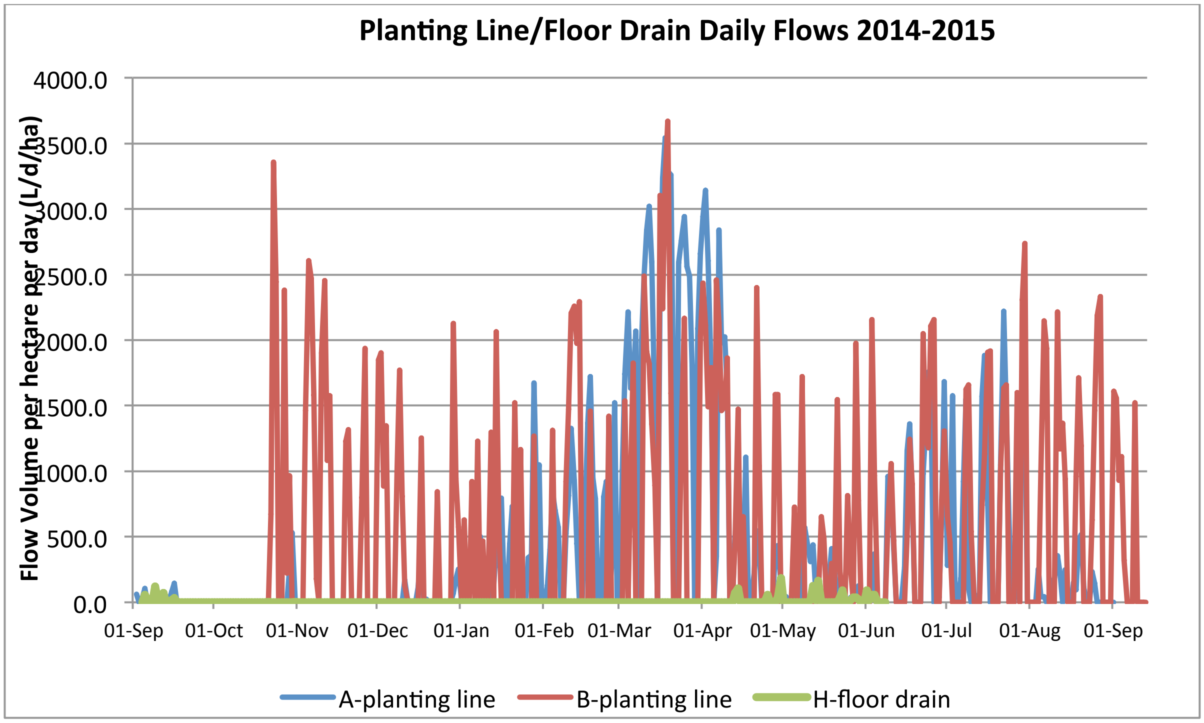

Figure 19. Daily flow volumes for floor drains per hectare growing area, two of which collected planting line water (Sites A and B).

Table Wash water

Note that table wash water was only collected at 2 sites; a third site was not located until the Fall of 2015. The water that comes off the tables during washing is coarsely filtered through a screen, and then fine filtered with a cloth filter before being collected. This practice of filtering is common, as the water can easily be re-used in the operation as long as the debris is removed from the solution. The nutrient content of this water type suggests that there may be residual fertilizer on the media that is being washed off the troughs/tables. At Site B the water from washing tables was combined in a sump pit containing return water until the Fall of 2014, however the nutrient levels after this point were not different in their degree of variability. Crop type may have also played a large factor – at site D Cyclamen were grown, and these plants require very little nutrients. Therefore, there were periods where there was very little nutrient observed in this site’s wash water. However, Easter lilies, kalanchoes and poinsettias require higher levels of nutrients, so residual fertilizer water on the Dutch trays (growing tables) would also show higher levels of the tested parameters. In addition, seasonal variation can impact the amount of nutrients applied – for example, since winter waterings are less frequent, higher concentrations of nutrients may be added to the irrigation water. In the summer, with frequent waterings, much lower rates of fertilizer are used and only fresh water is often used during the heat of the summer to provide cooling for the roots and water to the growing media for losses due to high transpiration rates and because the risk that salts may build up in the growing media.

The volume generated of this water type (i.e. flow, and therefore overall loading) will be an important factor when determining risk of this wastewater on the environment, and what best management practices need to be put in place. Figure 20 illustrates the flows measured at both sites. Note that at Site D, there is a very small amount of floor/planting line water that may contribute to the overall volumes, but it was estimated to be at less than 1% (grower information). The most interesting information gleaned from comparing the two sites is the wide difference in the amount of water used. After discussions with the two farms, it was discovered that Site B uses a fine hose fitted with a pressure washer nozzle (10L/min) while Site B uses pressurized water with a 1.5” hose (75L/min) to remove the plant and media debris from the tables. The difference in cleaning practices is clearly visible in Figure 20, where Site B rarely exceeds 2000 litres on a given day (of intense table cleaning), and Site D regularly washes tables with more than 2000 litres in a day.

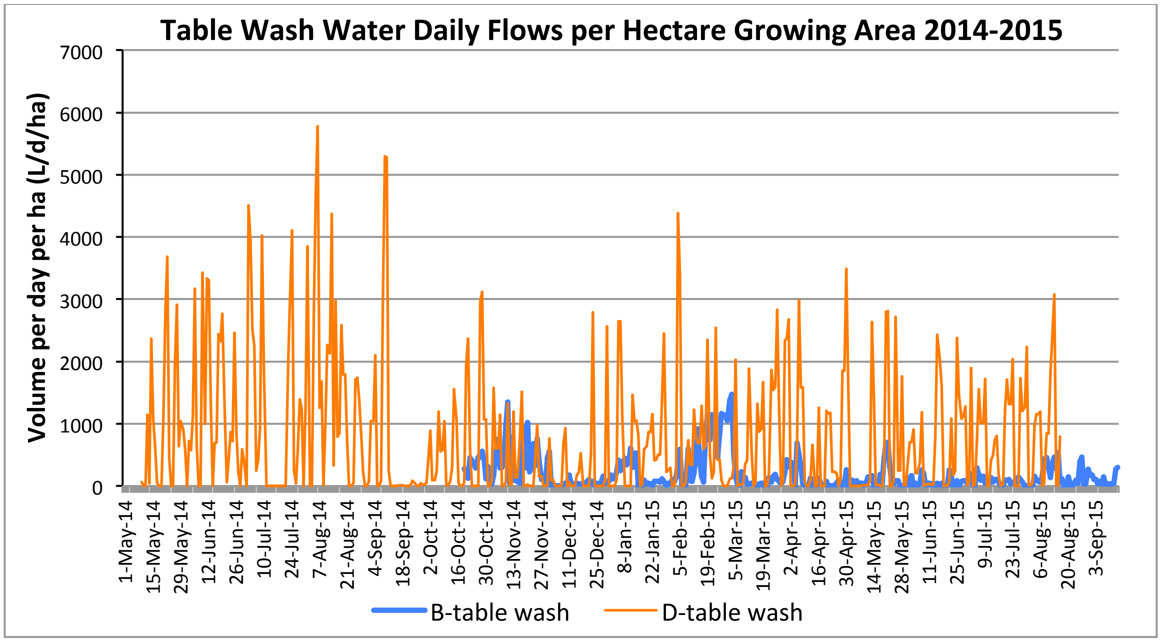

Figure 20. Table wash volumes, measured daily at two sites using magmeters.

Cut flower pail water

Cut flower pail water was sampled at three sites, and the water quality reflects both the preservatives used (if applicable) and the presence of plant material from the cut ends of the flower stalks. Aluminum sulphate or thiosulphate can be present in preservatives, and is likely the main component of the preservative used at one of the three sites tested. One site used no preservative, another Chrysal (both ABV and Clear Professional 1), and the third used both Floralife (Crystal Clear 300) and Chrysal (Clear Professional 2) depending on the crop they were harvesting. Chrysal AVB’s active ingredient is silver nitrate. There are many forms of preservatives used in cut flower production, and the active ingredients vary to improve wetting/hydration, and prevent ethylene production and microbial activity. Aluminum levels in recirculated water need to be considered, since aluminum can influence bloom colour.

Flows were not measured in ‘real time’ using flow meters, however total volumes of cut flower pail water were determined at two sites through a tank collection system, and recording the dates when the tanks were full and subsequently drained. Since Site E’s greenhouse production area is approximately half the size of Site G’s, the volumes were divided by the total production area to compare volumes in terms of harvesting based on similar areas. Site E has year-round production, with peaks during the spring/early summer wedding season. Site G, on the other hand, has very little harvesting during the months that the crop is not flowering. Note that at all three sites, the flowers are harvested by cutting the stems and placing them in pails of water. The flowers are stored in the pails until the time of shipping, where they may be shipped either in the same pails, or dry packed in boxes.

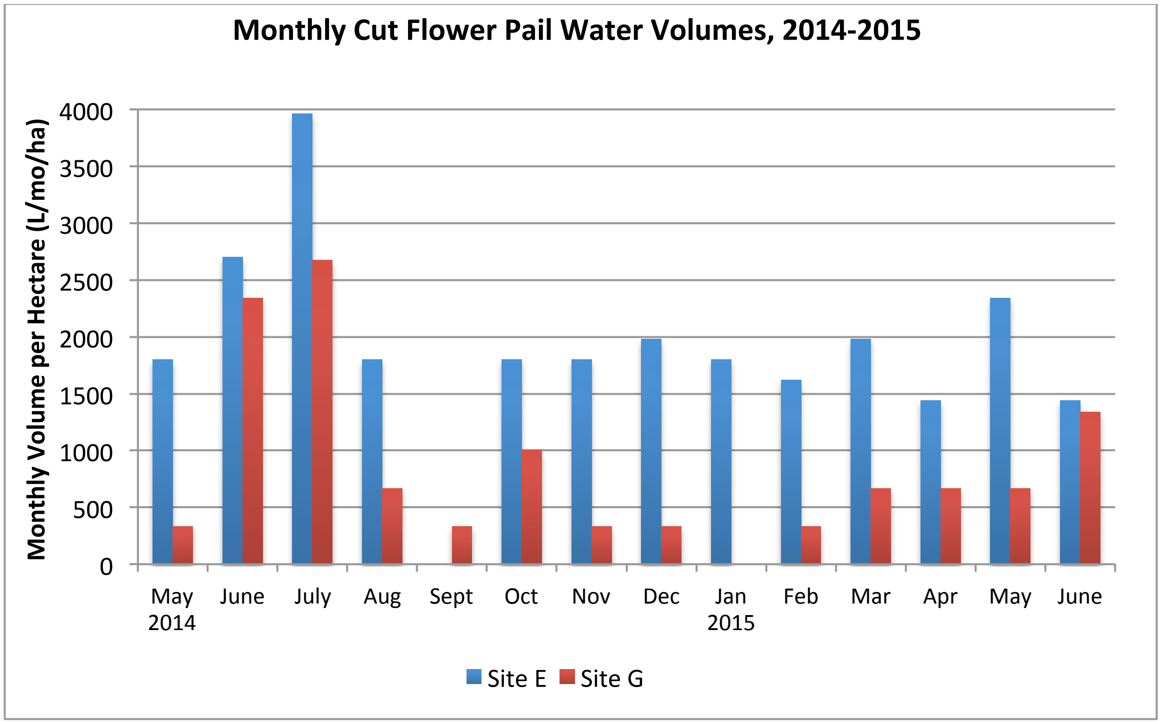

Figure 21. Cut flower pail water volumes from two sites, using calculated volumes based on number of times collection barrels were emptied.

Best Management Practices

With restrictions on water taking, and the need for high quality, consistent water, there is a distinct advantage for farmers to reuse the water they 'generate' through agricultural processes. A significant number of floricultural greenhouses are recirculating many of these potential water types, i.e. collecting the excess water generated through some of the on-farm process, and reusing the water in some part of the operation to avoid waste and conserve water. While this study was a cursory look at the quality and quantity of these potential water streams, there was an opportunity to observe various solutions to collecting and reusing water at all participating farms. Additional Best Management Practices (BMPs) are being catalogued in the floriculture self-assessment and BMP guide (OMAFRA, 2016), which will be available to floriculture farmers by the end of 2016. The following represents examples of the BMPs observed and recommended through the current study.

Nutrient feed solution, planting line water, table wash water, and occasionally subsurface drain water can contain very high levels of nutrients. In these cases, these waters must be recirculated and reused in the greenhouse as a BMP (as observed in this study). For sensitive crops (e.g. *Cyclamen*) it may not be possible to reuse water directly onto these crops, but the water can be used on other crops that are less sensitive or at a later stage in the production cycle as mature plants ready for sales generally do not require water that is pathogen free the way propagated plant material may. Other crops such as *Pelargonium* (Geranium) have restrictions if the owner is shipping the final product to the United States: concerns over *Ralstonia* bacteria contamination have caused a restriction on using recirculated water for this crop by federal agencies. The reuse of nutrient-rich water represents an incredible water savings. When subirrigation systems were initially applied to open systems, the amount of 'waste' nutrient solution was quickly realized to be impractical for both the excessive amount of water use, and the amount of fertilizer that was lost during each fertigation event. Recirculation provided a solution to both of these concerns, for example, the volume of storage required to have enough water on hand to flood floors is significantly reduced if the farm can return the water and use it again in the next greenhouse section. In the case where a farmer is unable to treat and reuse their excess nutrient-rich waters, they must determine a suitable form of disposal, and follow all applicable regulations. It is unlikely that high levels of nutrients could be discharged to the environment, as permits would generally require that the nutrient levels be decreased to meet site-specific, low-level concentrations before discharge.

For low-nutrient content waters, recirculation is also the best BMP. Boiler flue condensate and whitewash removal waters are good examples of waters that are generally safe for crop use when blended appropriately with fresh water (i.e. diluted). Each farm needs to have knowledge of the composition and volume of their low-risk waters so they can collect them (without overflow risk) and reuse them. While the volume of low-risk water can vary by site and practice, recirculation can still represent significant water savings and decreases the need to take more water from the environment.

Specific examples of BMPs and potential risks are highlighted below:

Stormwater – keep separate from other water types, 'keep clean water clean', separate loading dock and parking lot water from roof water and other high quality water sources, test water regularly to know if it changes – even municipal sources can have spikes in salts or micronutrients from time to time.

Loading dock (and parking lot) water – keep on property, try to drain to a dry pond/infiltration area where it can infiltrate the soil and not reach ditches or watercourses; look for opportunities to prevent salts, oils and hydrocarbon contaminants from reaching the drain – e.g. new technologies, chemical filters for overtop of drains.

Whitewash – allow to wear off naturally, or if not possible, then consider investments in shading. Avoid removal processes that could result in high particulates in surface water. Capture and re-use whitewash removal residues, and dispose of legally, or blend into fertilizer solution depending on composition/volume and crop needs.

Nutrient water – recirculate and re-use. If the crop is sensitive, use on older crop or alternative crops. May need to treat for water quality and pathogens depending on crops and export market.

Subsurface drains – capture and re-use, unless primarily used to capture excess groundwater. Sample the water at regular intervals to ensure it is not contaminated with greenhouse-generated water – groundwater drainage may be exempt from discharge regulations under the *Drainage Act*.

Boiler flue condensate - capture and re-use, and blend into fertilizer solution depending on composition/volume and crop needs.

Boiler blowdown – still very difficult to determine BMPs based on the variety of composition and the requirement of the chemicals to be oxygen scavengers. Store, evaporate, or pay for disposal following all applicable regulations.

Floor drains/planting line water - capture and re-use, and blend into fertilizer solution depending on composition/volume and crop needs.

Table wash – possible to do 100% closed loop, i.e. capture and re-use, and blend into fertilizer solution depending on composition/volume and crop needs.

Cut flower pail water - capture and re-use, and/or blend into fertilizer solution depending on composition/volume and crop needs.

General Conclusions

Greenhouse floriculture farmers in Ontario represent some of the most innovative, environmentally responsible farmers in the world. While some growing systems have lent themselves naturally to recirculation (e.g. flood floors), the farmers have strived to incorporate BMPs throughout their farming operations. Recirculation of many water types, including storm and roof water, nutrient feed solutions, wash and planting waters, condensate waters, and subsurface drainage was observed through this project, and commonly throughout the sector. Since high quality water, with consistent properties, is extremely valuable for growing greenhouse floriculture crops, over 90% of all floriculture greenhouse growers in Ontario collect their stormwater and reuse it for irrigation, significantly decreasing the need to take water from surface or groundwater reservoirs.

Characterization of water quality and quantity is possible for farms that wish to implement BMPs at their farms. It may require isolation of water types, or separating out of water streams that carry more risk (e.g. remove boiler blowdown from floor drain water so that the drain water can be reused). Volumes and composition can be determined through flow meter installations and water testing by accredited laboratories. It is possible to use electrical conductivity (EC) as a rough indicator for re-use options, but it is preferable to use EC in combination with knowledge of common plant growth limiter levels (specifically, chloride, sodium and sulphate). Sensitive crops would likely require more robust analyses to be performed. Review of this data in cooperation with a floriculture specialist is critical to ensure that crop quality/health is not compromised.

The data obtained in this report confirms the initial hypotheses and statements from the sector that certain water types are not an environmental risk (e.g. stormwater, whitewash removal, boiler flue condensate), but other waters generated through floriculture greenhouse farming do need to be addressed through BMPs, primarily through recirculation. While this study provided insight into greenhouse floriculture-generated water quality and quantity, it is a preliminary study and caution must be exercised in interpreting results from a one year study with limited replicates and available data. There are numbers and results in this report that have no explanation, and further study at additional sites is strongly advised. It is recommended that future efforts, including additional research and regulatory options, be focussed on the high-risk waters, and waters that do not, as yet, have solutions other than paid disposal.

Acknowledgements

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