Vegetable and Fruit Washwater Treatment Manual

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Disclaimer

This document is intended for informational purposes only. This document is not intended to provide engineering, legal or other advice. Producers are advised to consult their own professional engineer or legal counsel to determine the best course of action or legal requirements applicable to their individual operation. The manual is intended to explain the principles of washwater treatment and how they relate to vegetable and fruit processing operations. The operator is responsible for understanding the legislated and regulatory requirements for their operation. Although the manual has been carefully written, the authors and the Government of Ontario do not accept any legal responsibility for the content or any consequences, including direct or indirect liability arriving from its use. While some vendors/products may be identifiable, it does not represent an endorsement of any technology or product.

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Preface

In 2013, the Holland Marsh Growers' Association (HMGA) applied to the Lake Simcoe/South-eastern Georgian Bay Clean-Up Fund (LSGBCUF), administered by Environment and Climate Change Canada, to receive financial support to help growers operating vegetable washing facilities test and select washwater treatment technologies.

HMGA began a four year project (February 2014 – March 2017) focusing on:

- The characterization of root and leafy green vegetable washwaters using laboratory testing.
- Determining water treatment targets for horticultural washwaters.
- Identifying technologies for testing and implementation.

Based on the test results and knowledge gathered, facilities gained confidence in their washwater treatment investments resulting in improvements to water quality.

A component of the project focused on knowledge and technology transfer. A project website (www.hmgawater.ca) was established which contains factsheets, articles, pictures and a blog highlighting the project results and lessons learned. This manual is a compilation of the information developed through the project. While the project was mostly centered on washwater from root vegetables, there is sufficient information to benefit the broader Ontario horticulture and food processing industries.

Organizations and companies involved in the project:

- Agriculture and Agri-Food Canada
- Bishop Water Technologies
- Econse
- Environment and Climate Change Canada
- Farm & Food Care
- Flowers Canada (Ontario)
- Gro-Pak Farms
- Holland Marsh Growers' Association
- Lake Simcoe Region Conservation Authority
- McMaster University
- Newterra
- Nottawasaga Valley Conservation Authority
- Ontario Fruit and Vegetable Growers' Association
- Ontario Ministry of Agriculture, Food and Rural Affairs
- Ontario Ministry of the Environment and Climate Change
- ProMinent Fluid Controls
- SRG Soil Research Group
- University of Guelph
- University of Guelph Muck Crop Research Station
- University of Waterloo
- University of Windsor
- Voltea
- Western University

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The Holland Marsh Growers' Association thanks the following individuals for their hard work and dedication over the past 4 years to help make this project possible.

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Katie Gibb, Sara Goudet, Tim Horlings, Ann Huber, Bruce Kelly, Evan Mott, Dan Sopuch and Janine West

Photo Credits: OMAFRA and HMGA Water Project staff. Thank you to the grower cooperators for providing permission to use images from their operations.

Glossary

Biochemical Oxygen Demand (BOD) — is the amount of oxygen needed to break down the organic material in a sample.

Carbonaceous Biochemical Oxygen Demand (CBOD) — is the measurement of the amount of oxygen used to breakdown the carbon portion of organic matter. This is the form of BOD commonly used in the case studies in this manual, using the 5 day analytical method, $CBOD_{5.}$

Debris — is the larger undesired material in washwater such as sticks, rocks and culls.

Dissolved Oxygen (DO) — is a measure of the amount of gaseous oxygen which is dissolved in water.

Electrical Conductivity (EC) — is a measure of the ability for a sample to conduct electricity.

Nutrients — (e.g., nitrogen and phosphorus) are necessary for plant growth but can negatively impact water quality if released to the environment.

Organic Matter — is a measure of the organic material (from soil, plants and animals) in a sample.

Oxidation/Reduction Potential — is a measure of the reactivity of a sample.

pH — is a measure of the acidity or alkalinity of a sample.

PLC — is a programmable logic controller used to monitor and operate washwater treatment equipment/systems.

Total Kjeldhal Nitrogen (TKN) — is a combination of both organic nitrogen and ammonium/ammonia.

Total Phosphorus (TP) — is the sum of all forms of phosphorus.

Total Dissolved Solids (TDS) — is the portion of solids that will travel through a filter.

Total Suspended Solids (TSS) — is the portion of total solids which can be caught by a filter.

Total solids — is a measure of the solid material in a sample.

Turbidity — is a measure of the cloudiness or haziness of a fluid. It is normally measured by Nephelometric Turbidity Units (NTU).

Washwater — is water that has been used to wash, flume or cool produce. It may contain soil, plant material and other debris.

1. Introduction

Packing vegetables and fruits uses water to move, cool and wash the produce. This water must be managed in a way that promotes environmental stewardship and ensures compliance with food safety and environmental regulations.

This manual provides vegetable and fruit packers with a strategy to select and manage washwater treatment equipment based on a water management plan. It also shows why good washwater management on the farm or at the packing facility is important.

Washwater is water that has been used to wash produce. It may contain soil, plant material and other debris. These contribute to suspended solids and dissolved nutrient loads in the washwater. High levels of solids, nutrients and organic matter can impair the quality of ground water and surface water in and around a farm or packing facility. It is important to manage washwater so that it will not impact nearby water supplies and the quality and shelf life of the produce.

Vegetables and fruits are washed in packing facilities across Ontario. The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) estimates there are up to 2,000 growers in Ontario who may wash produce on the farm. Each facility is unique for the following reasons:

- size of facility
- type of produce being packed
- type of processing (e.g., peeling, cutting or further processing)
- washing techniques
- washwater volumes and flow rates
- on-site water storage capacity
- number of days washing occurs
- season during which the washing occurs
- water source or water quality available

There are many options to manage the washwater generated by a facility. These options include:

- land application (irrigation or spreading on crop land)
- treatment and reuse within the facility
- on-site treatment and discharge
- haulage to a nearby waste water treatment facility

2. General Guidance

2.1 Introduction

This chapter examines how water is used in facilities, defines applicable water quality parameters and introduces the design process and potential washwater management strategies.

2.2 Overview of the Design Process

Developing a washwater management strategy can be complex. This section explains how to create a washwater management strategy for individual facilities. The steps are shown in Figure 2.1.

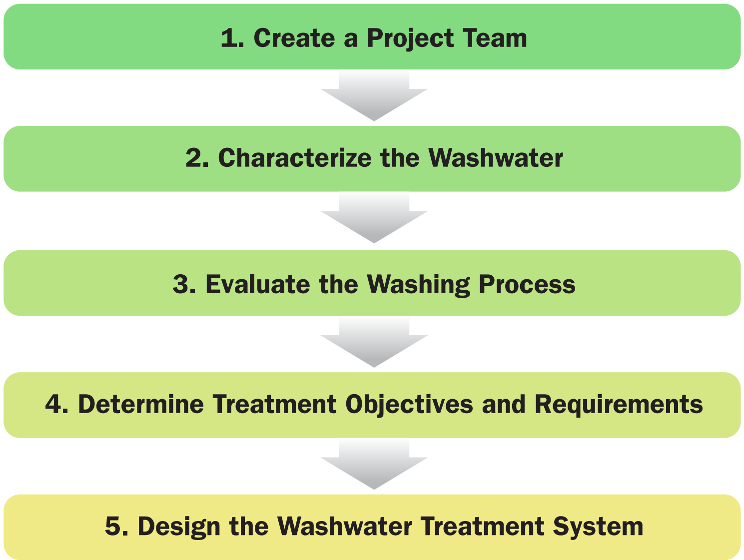


Figure 2.1. The design process for developing a washwater management strategy.

Step 1: Create a Project Team

Create a project team that will plan, assess and implement the washwater management plan. Select a central person or leader who is involved in each step. The daunting task of collecting information and making decisions gets manageable with a consistent team in place. Key members of this team could include:

- a project lead
- financial controller
- the system operator
- the person operating the wash lines
- a consultant (if applicable)

Step 2: Characterize the Washwater

It is necessary to fully understand the characteristics of the washwater to be treated. The collection of water volume data should include:

- flow rates
- total daily volume
- maximum and minimum flow rates
- number of hours/day, days/week and weeks/year of the washing season

There are some water characteristics that need to be measured. These measurements should be conducted on the input and output water:

- water clarity
  - total suspended solids (TSS)
  - total dissolved solids (TDS)
  - turbidity
- nutrient concentration
- organic matter concentration
- dissolved oxygen content
- pH
- microbiological levels (e.g., *E. coli)*
- other parameters as required

Knowing these characteristics will help the project team select the right equipment.

Take an inventory of the treatment system components already in place (e.g., settling tanks). Evaluate the performance of the existing equipment before and after the treatment process. Knowing how well the existing process works helps the project team decide what can stay in place and possibly save money.

Further information can be found in Chapter 4. Flow Monitoring and Chapter 5. Washwater Sampling and Analysis.

Step 3: Evaluate the Washing Process

There may be places within the washing process where water use or loadings can be reduced. Examples include:

- removing more soil using dry methods before washing (e.g., finger tables)
- reusing washwater from the final rinse to an earlier washing step (Chapter 3. Reducing Water Use)

Optimize the washing process by measuring the flow of washwater using in-line meters. Measuring the flow can help to identify:

- the cost of water and rate of use
- the need for standard operating procedures
- the size of treatment technologies needed

The volume of water used may influence the size of treatment equipment needed. Reducing the amount of water used or reducing the loading will potentially simplify the treatment equipment needed and lower equipment costs.

Step 4: Determine Treatment Objectives and Requirements

Decide on the end point of the washwater (e.g., reuse, irrigation or disposal). This decision will help the project team determine the final water quality requirements, the regulations to be met and the treatment system options. The main options include:

- land application (irrigation or spreading on crop land)
- treatment and reuse within the facility
- treatment and discharge
- hauling to nearby a municipal wastewater treatment facility where applicable

Step 5: Design the Washwater Treatment System

After the information has been collected, treatment objectives determined, washwater characterized and the washing process optimized, the treatment system can be designed. The final design of the system should consider the life cycle of the system (from commissioning to decommissioning) and include budget items such as capital investments, ongoing operational costs, maintenance costs, and new infrastructure and labour requirements. All treatment systems will have expenses in these categories but costs will vary based on the size and complexity of the system.

Consider the availability of labour to operate the system. All systems require some oversight and maintenance, but this will vary. A system that needs minimal oversight may cost more upfront. A person(s) will need to be assigned to complete operating and maintenance tasks.

2.3 Hiring a Consultant

A consultant can be a worthwhile investment in the individual design stages or as an overall project manager. Consultants bring experience, industry contacts and project management expertise to the project. The stages for hiring a consultant are summarized in Figure 2.2

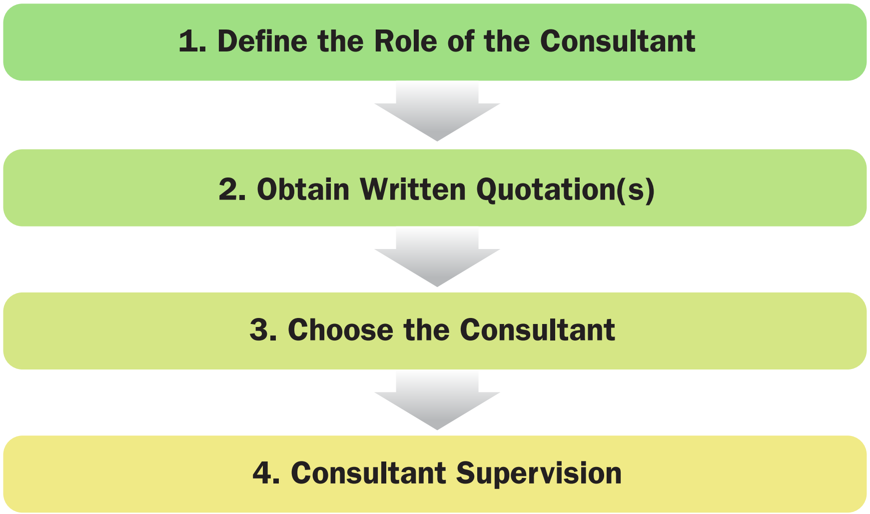


Figure 2.2. The stages for hiring a consultant.

Stage 1: Define the Role of the Consultant

The scope of work for the consultant varies with the needs of the facility. For example, the consultant could be responsible for any of the following:

- Provide a cost-benefit analysis of proposed technologies.
- Provide technical and project management support.
- Manage and characterize washwater samples.
- Find ways to reduce water use and loadings.
- Develop equipment specifications, terms and conditions documents.
- Prepare documents and manage procurement process to the point of making a purchase order to a supplier.
- Manage the entire project from preparation of equipment specifications to acceptance of installed equipment.
- Advise and prepare regulatory approvals and permits.
- Help commission the project through start-up, train the operators and provide ongoing compliance support.

It is a good practice to document the scope of work before hiring the consultant to provide a clear statement of the consultant's responsibilities.

Stage 2: Obtain Written Quotation(s)

A quote is more than just asking for someone's help to fix a problem. Get written quotations from several consultants that include these specifications:

- Identify the problem to be resolved.
- List the consultant's responsibilities and accountabilities.
- Cost for consulting service (usually provided in terms of $ per hour).
- Cost for travel and expenses (e.g., car mileage, meals, accommodation, etc.).
- Invoicing period and method of payment (e.g., how often the consultant can submit invoices for payment).
- Consultant qualifications, experience and references.
- Meeting and reporting schedule (the consultant should provide project status reports to the purchaser on a regular basis).
- A schedule for completing the project including milestones which could be shown in a Gantt chart (Figure 2.3).
- Proof of insurance and coverage level.

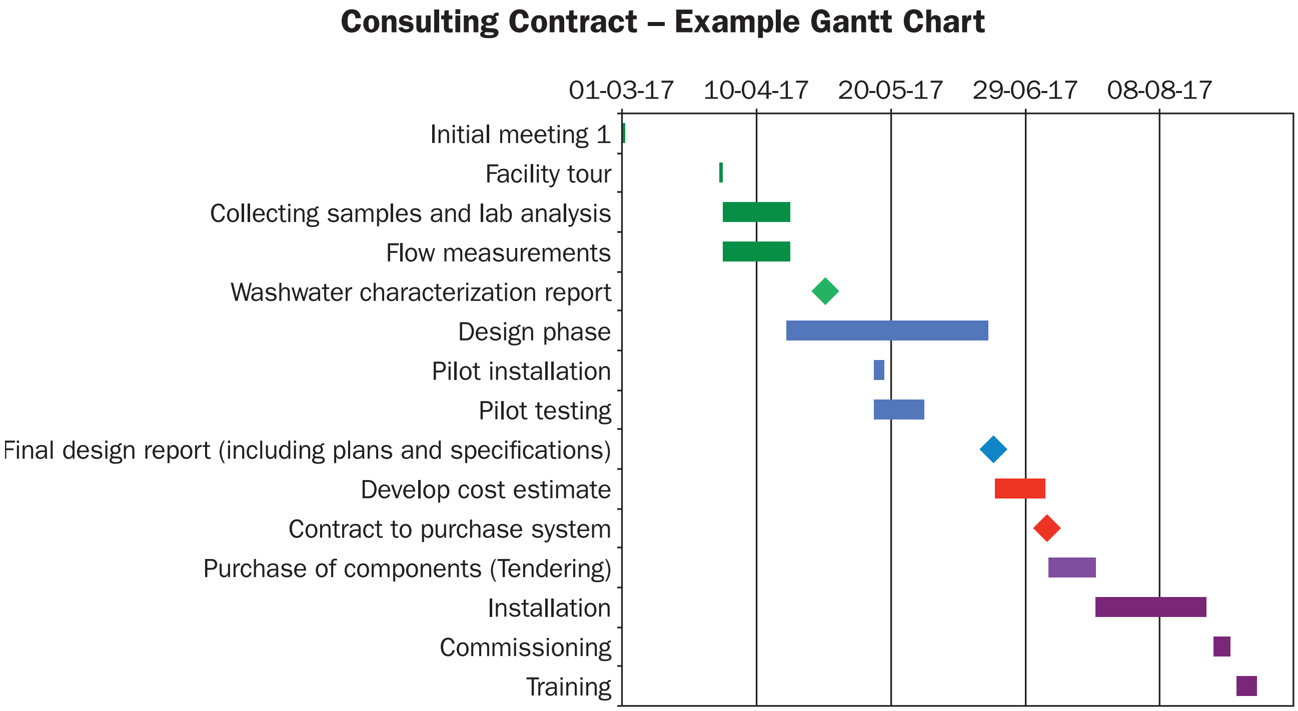


Figure 2.3. An example of a schedule (e.g., Gantt chart) that a consultant can provide to manage the project.

Stage 3: Choose the Consultant

Choose a consultant that best fits the project and do not make that decision based on cost alone. Verify a consultant's qualifications and contact the references provided. Hiring a consultant with direct experience in washwater treatment improves the likelihood for a successful project.

Stage 4: Consultant Supervision

The project team must stay engaged with the consultant throughout the project. Monitor the project status, progress and problems that arise. Keep a record of all communications with the consultant, particularly important decisions or changes.

The contract signed with the consultant will define when regular status reports and review meetings occur. Key project decisions such as which treatment equipment to purchase, approval of payment milestones and final equipment acceptance should remain the responsibility of the project team and not the consultant. Each invoice from the consultant should be accompanied by a report on billable hours and expenses.

2.4 Overview of Washing Vegetables and Fruits

2.4.1 Washing Crops

Vegetables and fruits that are washed after harvest can be sorted into three groups based on their potential washwater loading.

1. Root crops grown in soil carry the heaviest solid load for a washing process (e.g., carrots or turnips).
2. Crops grown on the ground will have a smaller solid load. This is often dust moved by wind or soil splashed upwards by rain. They include:
   - crops grown just above the ground (e.g., peppers, tomatoes, cole crops, leafy greens or melons)
   - small bulbs or roots below ground and harvested with their tops above (e.g., leeks or bunched radishes)
3. Tree/vine crops (e.g., apples, peaches) contribute the least amount of solids during washing and add stems, leaves, dust and fuzz to the washwater.

Nutrients are contributed to the washwater through:

- the soil
- broken produce parts
- juice (starch and sugars) from produce

2.4.2 Washing Processes

There are several wash processes that can be combined to wash vegetables and fruits. Water from the initial wash removes the heaviest loads. The quality and quantity of washwater depends on the complexity of the washing process and the produce being washed.

Dump Tanks

Dump tanks create a soft landing for emptying crates of produce and provide an initial wash (Figure 2.4). When used, they are usually the first step in the washing process. Produce is loaded through conveyor, tipped, dumped or submerged (Figures 2.5 and 2.6). The tank can be aerated to help remove solids from the produce before further processing. Accumulated solids can be removed from the bottom of the tank.

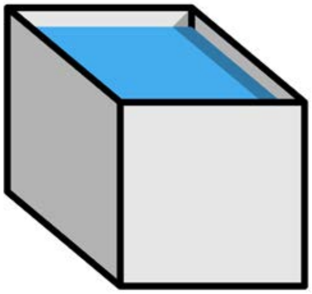


Figure 2.4. Diagram of a dump tank.

Figure 2.5. Potatoes in a dump tank.

Figure 2.6. Carrots in a dump tank.

Fluming

Flumes move product from one place to another place using water (Figure 2.7) and provide a gentle way to move produce and provide a passive wash (Figure 2.8). Flumes can be located at any stage of the washing process.

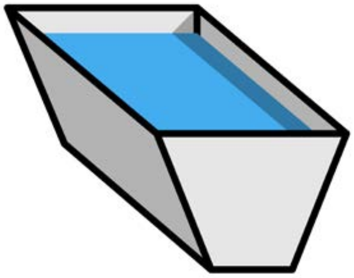


Figure 2.7. Diagram of a flume.

Figure 2.8. Apples in a flume.

Hydro-coolers

Hydro-coolers are used to cool produce (e.g., spray bars, dunk tanks) and need a cold water source or a chiller to cool the water. Hydro-coolers also remove some solids and debris from the produce.

Rinses

A common method of washing uses nozzles in a spray bar to rinse produce (Figures 2.9 and 2.10.), and can be used for all crop types. The amount of loading this contributes to the water depends on the amount of solids on the produce. Pay particular attention to pressure and the rate of flow needed to achieve the level of solids removal desired from the produce. If the pressure is too high, sensitive produce can be injured by the water stream and reduce the value, shelf life and appearance of the produce. Juice (sugars and starch) and produce parts from such injuries contribute nutrients to the washwater.

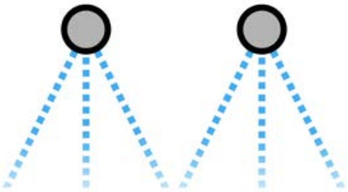


Figure 2.9. Diagram of spray bar.

Figure 2.10. Washing carrots using a spray bar.

Source: Farm & Food Care Ontario (www.farmfoodcareon.org).

Barrel Washers and Polishers

Barrel washers and polishers (Figure 2.11) use a combination of spray bars and rotating drums to rinse soil off the produce (Figure 2.12). Polishers have a series of individual brushers or rollers that rotate in the opposite direction of the barrel, adding additional cleaning capabilities by rubbing the surfaces clean (Figure 2.13). Polishers can also be used to peel certain types of produce. These methods of washing are primarily used for root vegetables. The solid and nutrient load of the exiting water is high due to increased levels of soil and peels in the washwater. Barrel polishers can be used as a waterless step prior to washing when produce is dry.

Figure 2.11. Diagram of a barrel washer and polisher.

Figure 2.12. Interior of a barrel washer.

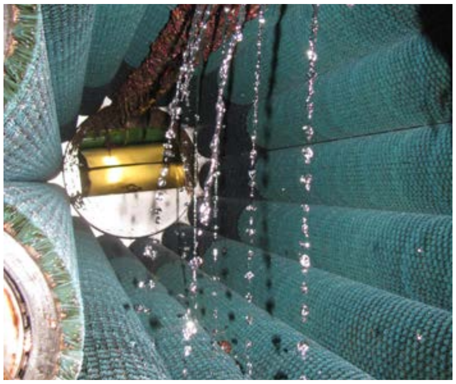


Figure 2.13. Interior of a polisher.

Final Rinses

A final overhead rinse with potable water (Figure 2.14) may be used to meet food safety regulations or as a completion step after a non-washing process (e.g., slicing or peeling). There is typically very little solid or nutrient loading added to the water from this step.

Figure 2.14. Potatoes receiving a final rinse.

2.5 Water Quality for Vegetable and Fruit Production

Steps that use water include primary wash, secondary wash and final rinse applications. Depending on the water's intended use, different water quality standards are required.

Primary Wash

Untreated or non-potable water may only be used for washing where it is followed by a final rinse with potable water. Test the water for *E. coli* and total coliforms a minimum of twice per year; once prior to the season and again mid-season. Test water at both the source and the point of delivery.

Secondary Wash

Water is used for activities such as washing, fluming, rinsing, misting, making ice, cooling, cleaning of equipment, polishing, cutting and hand washing. The best practice is to use potable water.

Final Rinse Water

Final rinse water must meet potable standards (*Canadian Agricultural Products Act, 1985*, Fresh Fruit and Vegetable Regulations C.R.C., c285). Potable water requires a total coliform count of 0 CFU/100 mL and an *E. coli* count of 0 CFU/100 mL. Where water is used for other applications (e.g., drinking water) additional requirements must be followed (*Safe Drinking Water Act, 2002*, O. Reg. 169/03: Ontario Drinking Water Quality Standards).

Aesthetic objectives (e.g., sulphur water) should also be met to limit the impact on visual appearance or taste of the produce (T*echnical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines*, www.ontla.on.ca/library/repository/mon/14000/263450.pdf).

If potable water is stored in a tank, clean the tank to ensure the water remains potable while in storage. For more information, see the OMAFRA publication, *Foods of Plant Origin – Cleaning and Sanitation Guidebook,* www.omafra.gov.on.ca/english/food/inspection/fruitveg/sanitation_guide/cs-guidebook.htm

DID YOU KNOW?

Irrigation water should have less than 1,000 CFU total coliforms/100 mL and less than 100 CFU E. *coli*/100 mL of water. Test the water a minimum of twice per year — once prior to the season and again mid-season. Test water at both the source and the point of delivery to get a better idea of water quality and trends. If following a food safety program (e.g., CanadaGAP, www.canadagap.ca), understand the water testing requirements, as they may be different than what is identified here. The quality of pre-harvest water could greatly impact the product and resulting washwater quality. Be sure to adhere to all relevant use guidelines.

2.6 Water Quality Parameters

Always monitor water quality parameters for environmental and food safety purposes. Parameters include water clarity, nutrient content, organic matter, dissolved oxygen, pH and microbiological levels.

Water Clarity

Total suspended solids (TSS), total dissolved solids (TDS) and turbidity are all measures of water clarity. TSS is a measure of the concentration of solids (mg/L) captured on a filter. Smaller particles that pass through the filter are considered dissolved solids and are quantified as TDS (mg/L).

Turbidity is another way to quantify water clarity, measured in Nephelometric Turbidity Units (NTU). Examples of solutions with different turbidity measures are shown in Figure 2.15.

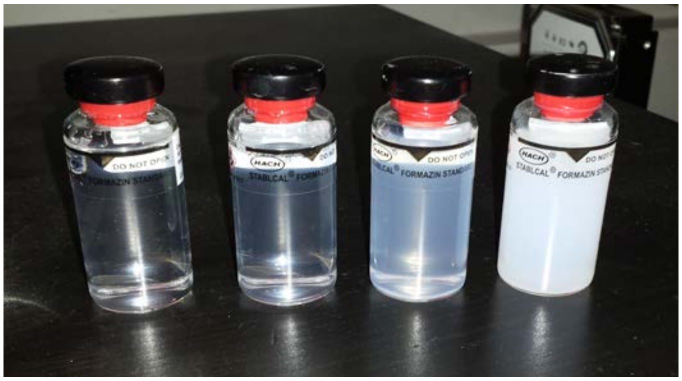


Figure 2.15. An example of solutions with varying turbidity (from left to right 10 NTU, 20 NTU, 100 NTU and 800 NTU).

Produce washwater may contain high TSS and have high turbidity. The main component of the solid load is the soil that is washed from the produce. Suspended solids are considered problematic in washwater because they reduce water clarity, clog plumbing and irrigation lines, and interfere with disinfection technologies. If directly discharged to surface water, washwater with high solids and turbidity could add sediment to aquatic systems. The solids can also contain other parameters, such as nutrients (e.g., nitrogen and phosphorus) and organic matter, and they provide attachment sites for pathogens.

Nutrients

Nitrogen (N) in washwater is found in a number of forms including nitrate (NO_3-), ammonium/ammonia (NH_4+/NH_3) and organic nitrogen, and is measured in mg/L. Total Kjeldahl Nitrogen (TKN) is a combination of both organic N and ammonium/ammonia.

Nitrate levels in produce washwater are often quite low and not usually an issue. Both ammonium/ammonia and organic N levels can be high and may require treatment before discharge to the environment. Ammonia can be extremely toxic to many different aquatic species and therefore discharge levels are regulated. Organic N, found in vegetative material, is often bound to organic material and not immediately free to react. However, as these larger organic molecules breakdown, the N is released and can adversely affect the water.

Phosphorus (P) in washwater can be in the form of phosphate (ortho-phosphate, PO_4^{3-}), particulate P and dissolved P. Total phosphorus (TP) is the sum of all forms of phosphorus and is the form most used when assessing water quality.

All forms of phosphorus can be found in agricultural washwater at moderate levels. TP is regulated and considered an important pollutant. Excess phosphorus introduced to a water body can cause eutrophication events that lead to algal blooms. Eutrophication occurs when excess algae dies and decomposes. Oxygen in the system is depleted, leading to the death of fish and other aquatic organisms. Some algal blooms generate toxic compounds that can negatively impact human and livestock health.

Organic Matter

The amount of organic matter (OM) in washwater is determined by measuring the amount of oxygen consumed during the breakdown of the organic matter. This is reported as biochemical oxygen demand (BOD) in mg/L.

The measurement of the amount of oxygen used to breakdown the carbon portion of organic matter is called carbonaceous biochemical oxygen demand (CBOD) — the most frequently used form of BOD in this manual.

Produce washwater often has high oxygen demands due to its large OM loads. Excess OM in a water body causes the rapid loss of oxygen due to its consumption as OM breaks down, and can also cause the clogging of pipes and reductions in the efficiency of disinfection systems.

Dissolved Oxygen

Dissolved oxygen (DO) is the concentration of oxygen in water, reported in mg/L. Aquatic organisms (e.g., fish) require sufficient DO in the water to live. Healthy bodies of water generally have DO levels ranging from 7–10 mg/L.

Produce washwater can be high in OM and the natural breakdown of organic matter in water consumes the oxygen. If the DO in the washwater is low, there may still be OM in the washwater that can result in a high BOD when discharged to a water body. When interpreting DO data, remember that DO is also affected by temperature, water depth, water flow velocity and the biological components of the system.

Microbiological Levels

Pathogens are microorganisms that can cause disease in humans, animals and plants. Analyzing water samples for all possible microorganisms is not cost effective or technologically possible, so agricultural washwater samples are analyzed for the presence of total coliforms and *E. coli.* If total coliforms or *E. coli* in a water sample exceeds maximum levels, further and more effective water treatment is needed.

Pathogens (e.g., human and plant) in agricultural washwater are an important concern for food safety, plant health and environmental compliance. Pathogen levels in water used for washing produce are a significant concern and disinfection technologies are often required to ensure potable water standards are met for final rinse water. Some plant pathogens can be spread onto crops from the washwater through irrigation and land application. Monitor pathogen levels in discharged washwaters as there is a potential for environmental contamination that can compromise the quality of shared water resources.

2.7 End Points

There are several places where washwater can be used or discharged, after being generated and treated, by a washing facility.

2.7.1 Land Application

Washwater can be applied on land by irrigation, spreading by tanker or using a vegetative filter strip system. Applications should be matched to crop water needs, crop nutrient needs and soil water holding capacity. Vegetative filter strip systems use water flowing over a designed slope, where the flow rate matches the soil water holding capacity. These options are only applicable where sufficient and appropriate land is available. Adequate storage may be required to balance washwater production with land application timing. Consult with OMAFRA (e.g., *Nutrient Management Act, 2002*) and the local Ministry of the Environment and Climate Change (MOECC) office (e.g., Environmental Compliance Approval) about required approvals. Ensure proper permits and approvals are in place before constructing storage and applying washwater.

2.7.2 Reuse in Facility

Used washwater can be collected and treated and reused within the washing facility. The stage where the washwater is reused dictates the treatment required. Reuse options can range from reusing water in the early washing stages to treating the water to potable standards and reusing for final rinse. Extensively reusing water could reduce or eliminate all washwater discharge to the environment.

2.7.3 Subsurface Discharge

Washwater discharged below the soil surface usually occurs through a weeping bed. This washwater may require pre-treatment prior to discharge into the weeping bed. Consult the local MOECC office for the requirements of an Environmental Compliance Approval (ECA) and speak with other authorities (e.g., municipality, conservation authority, public health) about required approvals. Ensure proper permits and approvals are in place before discharge or starting construction.

2.7.4 Surface Water Discharge

Subject to required approvals under applicable regulations (e.g., Environmental Compliance Approval), washwater may be released into surface water. Consult the local MOECC office about required approvals. This washwater likely requires treatment prior to discharge, and proper permits and approvals must be in place before discharging can occur.

2.7.5 Municipal Wastewater Treatment Facility

Washwater may be piped or trucked to a municipal wastewater treatment facility. Contact the municipality to see if this option is available. Characterization of the washwater is necessary and approval is given on a case-by-case basis. The municipal sewer use bylaw defines the quantity and quality of washwater that can be accepted and associated fees. Municipalities may require some pre-treatment before the washwater can be accepted by the wastewater treatment facility and/or surcharges may apply.

If trucking washwater, consider signing a long-term contract with a licenced hauler as they have the required approvals to haul and discharge at the treatment facility.

2.8 Approvals

There are often mandatory approvals required to remove water from, or discharge water into, the environment. This section outlines requirements for Permits to Take Water (PTTW), Land Application under the *Nutrient Management Act, 2002*, and Environmental Compliance Approvals (ECA). In addition, Environmental Orders requiring abatement plans and assimilative capacity studies are addressed.

2.8.1 Abatement Plans

An abatement plan may be used by the MOECC as an interim measure while an ECA is being developed and approved. This is similar to a preventive measures order, where circumstances warrant. An abatement plan may be required after an Environmental Officer has completed an inspection of the facility. The plan is the roadmap for how the facility responds to the issues identified during the inspection.

The plan must address all MOECC concerns and likely includes:

- The volume of wastewater generated per day.
- The proposed treatment system or treatment improvements.
- A timeline for when the steps will be completed.
- Detailed sketches to outline the facility's washwater treatment process with discharge points to the environment clearly identified.
- A description of how past discharges have been monitored.
- Any available data on the quantity and quality of past discharges.
- A schedule for sampling and analysis of washwater.

An abatement plan is a binding legal document, and the steps and timelines identified in the document must be implemented. Maintain records to demonstrate implementation of the plan to the MOECC.

2.8.2 Permit to Take Water

A Permit to Take Water (PTTW) from the MOECC is required for withdrawals greater than 50,000 L/day of water, whether from surface or ground water. This includes water taken from lakes, ponds, rivers, ditches and wells even if those sources are constructed or entirely on the facility's property. The total daily taking limit is cumulative across all water sources on the property. Exemptions exist for takings more than 50,000 L/day for direct watering (without storing) of livestock and poultry, watering of home gardens and lawns, and fire-fighting purposes or if the water is supplied by someone who already has a valid PTTW (e.g., water from a municipal system).

Once a permit is issued, daily volumes taken must be measured, recorded daily and reported annually. Additional terms and conditions may be part of the permit.

Information on the permit and application process can be found at ontario.ca/environment-and-energy/permits-take-water as required by the *Ontario Water Resources Act, 1990.*

Summary of Approval Requirements

Table 2–1 is a summary of the options and associated approvals for washwater.

Table 2–1. Washwater management options

Washwater Destination	Applicable Approvals
Land application (e.g., spreading, irrigation, vegetated filter strip)	ECA or Non-Agricultural Source Material plan (NASM) or Nutrient Management Strategy/Plan (NMS/P)
No discharge (complete recycling)	No washwater discharge approval (i.e., ECA) required but consider food safety requirements
Ground water (e.g., weeping bed, septic system)	If >10,000 L/day: requires ECA If <10,000 L/day: local approval in compliance with the Ontario Building Code, 2012
Surface water	ECA
Municipal sewer	Operating authority and municipal approval

2.8.3 Land Application

Washwater may be land applied under an approved ECA (issued by MOECC), NMS/P or NASM plan (issued by OMAFRA). The application must constitute beneficial use and meet the prescribed requirements as outlined in the regulations. Washwater storage is often required as land application may not be possible during wet or frozen conditions. Land application may be limited by the:

- soil texture
- weather (e.g., saturated, frozen or snow covered)
- crop uptake
- topography
- proximity to surface and ground water
- proximity to neighbours
- depth to bedrock
- nutrient content of washwater (e.g., beneficial use)
- proximity to wells and source water protection areas

OMAFRA's nutrient management resources are found at www.omafra.gov.on.ca/english/ag

2.8.4 Regulatory Process for Discharge Approval

Under the *Ontario Water Resources Act, 1990* (OWRA), agricultural washing operations discharging to ground or surface water are required to obtain an ECA from the MOECC. Steps to obtain an ECA may include an abatement plan, assimilative capacity study and discussion with local MOECC representatives.

2.8.5 Environmental Compliance Approval

An Environmental Compliance Approval (ECA) is a requirement under the OWRA. It is a legal agreement between the MOECC and an operation that sets out specific conditions including:

- approved treatment equipment and technology
- operational conditions
- discharge limits (volume and quality)
- monitoring and reporting requirements
- any other requirements

The ECA process requires pre-consultation with local government and MOECC staff. Once final approval has been received from MOECC, construction and operation can begin. It is recommended to hire a consultant to assist with the regulatory process.

The MOECC ECA resources are found at ontario.ca/environment-and-energy/environmental-approvals.

2.8.6 Discharging to Surface and Ground Water

Washwater can be discharged to surface or ground water under an ECA. The discharge limits to surface water (e.g., lakes or streams) are determined by MOECC. The goal of these limits is to ensure the quality of the receiving water body does not deteriorate due to washwater discharge. MOECC often requires additional studies (e.g., assimilative capacity) to determine discharge limits. The costs of these studies are the responsibility of the operator or facility.

Discharging to ground water can occur through:

- a locally approved weeping bed (<10,000 L/day) in compliance with the Ontario Building Code, 2012
- an ECA approved weeping bed (>10,000 L/day)

DID YOU KNOW? Assimilative capacity refers to the ability of a water body to receive treated washwater without comprising its overall quality. These studies are used to model the ecological impact of discharges from sewage treatment plants, stormwater runoff and agricultural washwater into a watershed. The watershed can be as small as the local creek or as large as an entire lake or river system. These studies build on previous work in the watershed and are often done in partnership with local conservation authorities.

DID YOU KNOW? Regulations require that sample analysis be conducted by an approved method or certified laboratory. Verify that the laboratory selected is acceptable to the receiver of the sample data.

2.8.7 Environmental Officer Inspections

An MOECC Environmental Officer has the authority to inspect agricultural washing operations to ensure compliance with various environmental laws including:

- *Environmental Protection Act, 1990*
- *Ontario Water Resources Act, 1990*
- *Nutrient Management Act, 2002*
- *Pesticides Act, 1990*

An operation found to be non-compliant must take steps to correct the situation. MOECC issues a report that summarizes the results of the inspection and any required actions. In some cases a Provincial Officer's Order may be issued. Response to the order may include submitting an abatement plan or obtaining approvals.

2.9 Commonly Asked Questions

Environmental requirements are complex and many misconceptions exist. Here is a list of commonly asked questions.

Will mixing stormwater with washwater dilute the contaminants in the washwater and make it easier to meet discharge limits?

Answer: No. Stormwater is managed differently from washwater and the two streams must be kept separate. Even though the concentrations are lower, the total loading of contaminants is the same and may have an impact on the receiving water body. Adding stormwater to the washwater requires a larger treatment system which is more expensive to purchase and operate.

Should washwater be used as a fertilizer because of the dissolved nutrients?

Answer: Not necessarily. The concentration of dissolved nutrients in washwater can be very low. Washwater may be used to supplement water demand needs of crops but additional fertilizer inputs may be required to meet nutrient needs of crops.

Is washwater full of nutrients because it has a high TSS concentration?

Answer: No. The high TSS in root vegetable washwater is based on soil particles remaining in solution and is not an indication that it is a suitable fertilizer. To determine the nutrient value of washwater, allow the soil to settle and resample. Washwaters with low nutrient concentrations may not meet the nutrient needs of the crop and additional fertilizer may be required.

Is it possible to avoid getting an ECA by irrigating with washwater instead of discharging it to surface water?

Answer: No. When land applying washwater (including irrigation), an approved ECA or an approval under the *Nutrient Management Act, 2002* is required.

Should washwater be treated before irrigating?

Answer: Yes. Some treatment may be required before washwater can be irrigated. The solids contained in the washwater can clog pumps, pipes, sprinklers or emitters. Food safety and plant pathogens in the washwater should be considered before irrigation.

Can washwater be irrigated at any rate?

Answer: No. The amount of washwater that can be used by a growing crop is typically one inch of water per week, assuming no rainfall. Storage will be required for periods when there is high rainfall.

Can irrigation occur year-round?

Answer: No. It is unacceptable to apply washwater to saturated, frozen or snow covered land. Irrigation is limited to times of the year when crops are growing. Storage or another disposal method will be required over the winter months.

Does a washwater pond require a liner?

Answer: Yes. A liner is usually required to avoid ground water entering the pond or washwater leaving the pond. A liner may be constructed of clay, geo-membrane or concrete. To meet operational and regulatory requirements, use a consultant to help select a liner. Settling ponds require regular cleaning to remove settled soil.

Can washwater be released into a natural area (wooded/grassy) where the plants will use it?

Answer: No. Washwater cannot be released into a natural area without an ECA, and in many cases treatment may be required. Constructed wetlands and vegetative filter strips are examples of systems designed to treat washwaters. They require an ECA even though they are located on your property. These systems have significant limitations in the winter.

Does a washwater treatment system need supervision?

Answer: Yes. Some systems are operated manually while others have some degree of automation. However, all systems require someone to monitor and operate the washwater treatment system to prevent treatment failure.

3. Reducing Water Use

3.1 Introduction

There are ways to reduce the washwater treatment requirements during the washing process. Two best practices include reducing the amount of material (e.g., soil) from entering the water and reducing the amount of water used for washing. This is accomplished by:

- Adding a dry soil removal step at harvest and/or at the washing facility prior to adding water to the process.
- Minimizing the amount of water used during the washing process.
- Using water for more than one washing process (e.g., recycling).

3.2 Dry Soil and Vegetative Material Removal

Using dry soil and vegetative material removal systems can significantly reduce the size and cost of the washwater treatment equipment after the washing process.

Soil contributes suspended solids and associated nutrients such as nitrogen and phosphorus to the washwater of a facility. Removing as much soil as possible from the produce before it comes in contact with water reduces the amount of soil that needs to be separated from the washwater during treatment. Some nutrients tied to the soil particles will also be removed. Vegetative matter such as leaves, stems, roots or culls can clog treatment equipment and are best removed early in the process.

Before vegetables and fruits come into contact with water, a portion of the soil and vegetative material they carry can be removed using waterless techniques in the field during harvest and at the packing facility.

There are several dry removal options available prior to washing, including finger tables (soil removal), hedgehogs (vegetation removal) and compressed air (soil and vegetation). In general, any movement or tumbling of vegetables may remove loose material from the produce. Equipment designed specifically for this purpose is most effective, but physical removal technologies have the potential to damage the produce.

Any soil removal done in the field will have varied success based on the weather. When the soil is dry, it is easier to remove. If harvesting occurs in wetter weather, the soil tends to stick to the produce surface and be more difficult to remove. This also applies in washing facilities if the produce is stored in damp conditions. Some soil particles can always be removed under most conditions.

3.2.1 Finger Tables

A finger table uses rollers, comprised of rubber stars, to jostle and gently bounce the produce to remove some of the loose soil. Finger tables are open at the bottom and the soil is collected in a bin underneath. The soil can be returned to the field or composted, depending on the facility's preference.

Finger tables can be installed at the beginning of the washing process as they can transport the produce from bins or hoppers, and can also be used on harvesters in the field. Finger tables are installed in-line with the conveyors that carry the produce to the storage wagon.

Finger tables are also used to change the direction of the product flow as shown in Figure 3.1. The number and size of rollers can be customized to fit onto most harvesters and in any washing facility. If the rollers or fingers become clogged with soil aggregates, scrappers (Figure 3.2) are installed on the underside to clear the blockages. This is a bigger problem in the field than in a washing facility due to potentially wet conditions when harvesting.

Figure 3.1. A finger table removes soil and changes direction of the produce by 90°.

Figure 3.2. Scrappers installed to clean a finger table.

3.2.2 Hedgehogs

Hedgehogs (Figure 3.3) can be installed in the same location as finger tables in washing facilities, but their function is to remove loose vegetative matter from the produce. Hedgehogs have an inclined rubber belt with a series of knobs spread across the belt. The produce is brought by a belt conveyor into the inclined belt of a hedgehog, and the produce falls down to a flume or conveyor that transports them to the washing process. Some of the vegetative matter is captured by the rubber knobs on the belt and brought over the top of the conveyor to a bin for disposal.

Figure 3.3. A hedgehog installed in a carrot washing facility.

3.2.3 Compressed Air

Compressed air can help remove loose debris from produce. Nozzles placed above an open conveyor belt or finger table blow soil or vegetative matter off the produce, and can be used as an additional step with other removal techniques. When using compressed air, keep the compressor close to the nozzles to reduce pressure loss in hoses. Compressed air is typically more expensive than hedgehogs and finger tables.

3.3 Ontario Research

Soil and debris removal research on carrots grown in the Holland Marsh was conducted by OMAFRA in 2015. The carrots were harvested later in the season in damp weather and carried a medium amount of soil.

The research looked at soil removal using a finger table. The results indicate that dry soil removal can reduce the suspended solids in the washwater by 23%–46% and total phosphorus by 26%–54% depending on factors such as length of finger table (1–5 m), rotational speed, angle of incline and use of compressed air compared to as harvested carrots. The results also showed carrots subjected to these techniques required less water to wash the them to a clean state with the percent reduction in water use ranged from 19%–44%.

Source: *Soil Removal and Turbidity Monitoring for Carrot Washing,* 65th Annual Muck Vegetable Growers Conference, April 12, 2016, Bradford, ON. www.hmgawater.ca

Example of Impacts on Soil Removal in a Washwater Treatment Facility

Based on the results of the 2015 OMAFRA research into soil removal, it is possible to calculate the potential soil and phosphorus loading reductions. For example, a washing facility processes 240,000 kg of carrots in a typical 12-hour day. Without a soil removal system, the average daily loading of washwater is 150 kg of solids and 0.5 kg of phosphorus. Installing a soil removal system capable of removing 25% of both solids and phosphorus would result in 37.5 kg less solids and 0.125 kg less phosphorus that would have to be removed from the washwater.

3.4 Water Use Efficiency

Minimizing water use is an important step before implementing any washwater treatment process. But ensure a sufficient amount of water is used to adequately wash the produce. The size or hydraulic capacity of any washwater treatment system must be large enough to handle the volume and flow rate of washwater being generated by the facility. A higher water usage requires larger treatment equipment, and results in increased capital and operating costs. Determine the size of the treatment system to handle peak volume and flow rates of washwater.

To minimize the amount of washwater generated, measure the volume and flow rate of water being used at each step in the process. Information on flow monitoring is found in Chapter 4. Flow Monitoring.

Water reuse and recycling are good options to reduce the overall water used during washing, and reduce the required size of the washwater treatment system. Water used during the final rinse step is usually collected and reused at an earlier washing step such as initial rinsing or fluming. It is possible to collect the washwater generated and treat it for a variety of uses in the facility.

Test the quality of the collected washwater to determine its suitability for subsequent uses. If the collected washwater is to be used in pre-harvest applications (e.g., irrigation, equipment washing) then treatment may be minimal. If it will be recycled within post-harvest uses (e.g., produce washing) then treatment may be necessary, and different water use guidelines must be followed (e.g., CanadaGAP www.canadagap.ca). The water used for final rinses needs to meet potable water standards. Treatment could include reducing solids, removing nutrients, organic matter and disinfecting the water.

Some washing facilities bring in previously washed produce for packaging and it may be necessary to rinse it prior to packaging. To minimize water use, move the produce through the packing line using conveyors to bypass any unnecessary processes that use water.

3.5 Case Study

The HMGA Water Project completed an on-farm trial of carrot harvesters and wash lines to show the impact of soil removal equipment on the amount of water necessary to wash carrots (Figure 3.4). Soil removal techniques remove the soil from produce through dry methods, reducing the water needed (Figure 3.5) to achieve clean carrots (Figure 3.6). Combining soil removal techniques (e.g., on a harvester, in the field, in the wash facility prior to the wash line) can further decrease the amount of water required to wash produce.

A facility washing produce with differing soil levels should adjust the water use according to the dirtiness. For example, washing carrots with no soil removal with the same amount of water as those using a finger table results in an unnecessarily high and inefficient water use.

Figure 3.4. Harvested carrots (no soil removal and unwashed).

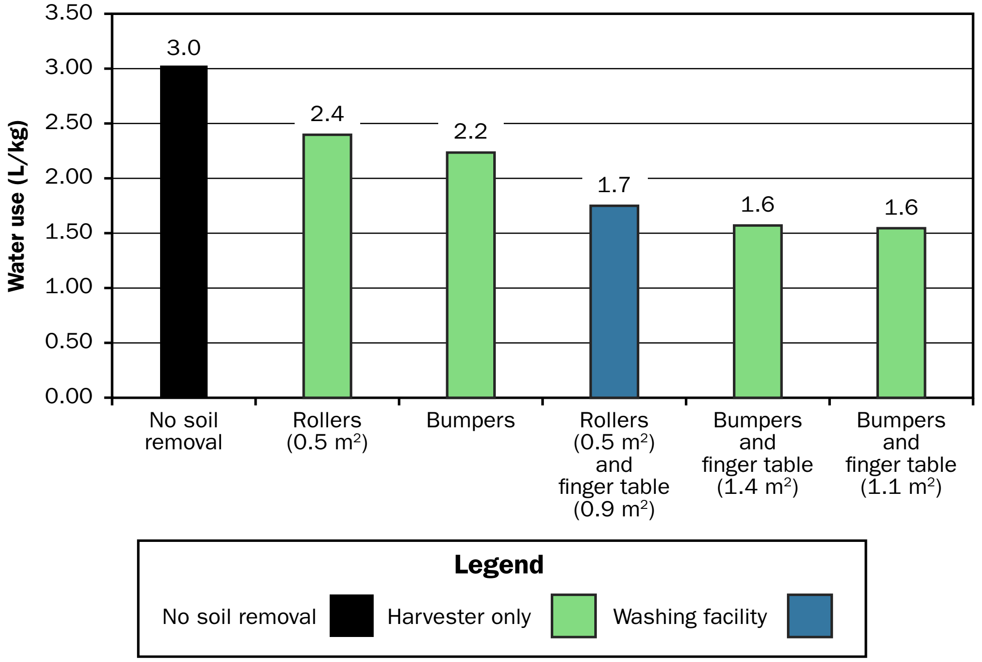


Figure 3.5. Water use for carrots after different dry soil removal techniques.

Figure 3.6. Previously washed carrots.

4. Flow Monitoring

4.1 Introduction

Every facility generating washwater needs to know how much water is being used at each stage of the washing process. This information allows an operator to understand how much water is being used and the resulting washwater requiring treatment. The data can also identify opportunities to reduce use through water saving techniques or recycling. Calculating water use efficiency (e.g., L of water/kg of produce washed) varies with produce type and amount of soil on the produce.

Flow monitoring is an important step for regulatory compliance. Keep accurate water use information to support a Permit to Take Water (PTTW) application and required annual reporting of daily use. Washwater discharge volumes are important for Environmental Compliance Approval (ECA) applications and the required monitoring. Tracking water usage is also important for facilities taking water from and/or discharging to a municipal system for billing purposes.

4.2 Where to Monitor

Monitor volume and flow rates where water enters and exits the facility. Install a flow meter to measure the total amount of water that is entering the facility to account for all water uses (e.g., produce washing, equipment cleaning). Note that water is also used for non-washing purposes (e.g., washrooms) and will not go into the washwater treatment system.

Monitor how much washwater is generated by the washing process to properly size the washwater treatment system. If there are other intermittent water sources (e.g., rain water, seasonal outdoor washing) entering the treatment system, monitor these flow rates/volumes as well.

DID YOU KNOW? Rain and stormwater is managed differently from washwater and it is important to keep these two streams separate. Adding stormwater to the washwater requires a larger treatment system that is more expensive to purchase and operate.

Installing additional flow meters on the water lines supplies key processes (called sub-metering) to understand how much water is used throughout the facility. Some key processes to measure are the water used for initial rinse, final wash and recycling lines. It is also possible to measure the amount of washwater being generated from these key locations by monitoring the outflow pipes.

4.3 How to Monitor

There are several methods to measure the rate and flow of water at a washing facility that includes installing flow meters, tracking the run time and output of pumps, estimating based on rated equipment water use and using the bucket test.

Flow monitoring should be done on an ongoing basis. If it is not possible to install permanent flow meters, monitor for a period of time that represents regular washing activities. This may require an entire season to ensure information is collected for all crops that are processed at the facility.

4.4 Flow Meters

Flow meters measure water supplied or washwater generated by a process or facility. There is a wide array of flow meters available that differ in complexity and function. All meters provide the total volume of water and some measure the instantaneous flow rate. Some units can be connected to a data logger or computer while others require manual reading and recording of the data.

Selecting the appropriate flow meter depends on the:

- desired flow parameters (e.g., instantaneous flow, volume, reporting frequency)
- location (e.g., end of pipe, in-line pipe)
- permanent or temporary installation
- operating environment (e.g., inside/outside, dry/wet environment)
- anticipated flow rates (e.g., high flow, low flow)
- clarity of the water (e.g., dirty vs. clear)
- required accuracy
- budget

The two most common types of flow meters are displacement and velocity meters — each make use of different technologies.

Displacement meters measure the volume of water required to move a piston or disc. They have a built-in strainer to protect the measuring element from debris that could damage the meter.

Velocity-type meters measure the speed of the water travelling through the meter and convert it into flow rate and volume.

Magnetic flow meters are a velocity-type water meter that uses electromagnetic properties to determine the water velocity. They use the physics principle of Faraday's Law of Induction to measure the velocity and require a supply of electricity to the electromagnets. They are able to measure flow in dirtier water without damaging the measuring element.

Ultrasonic water meters send ultrasonic sound waves through the water to determine its velocity. To ensure accuracy, most ultrasonic water meters also measure the water temperature since water density changes with temperature. They may either be of flow-through or "clamp-on" design. Clamp-on meters are used for larger diameters pipes where the sensors are mounted to the exterior of the pipes for pressurized flow (potable water) or mounted inside of the interior of the pipe for gravity flow (washwater discharge). Some washwater meters use a combination of the ultrasonic method to determine the velocity of the water combined with a pressure transducer to measure the depth of water flow to calculate the cross-sectional area of the flow.

Various flow meters are described below in Table 4–1.

Table 4–1. Types of flow meters

Type of Flow Meter	Positive Displacement	Turbine	Magnetic	Ultrasonic
Description	Measures the volume of water required to move a piston or disc	Measures the number of rotations	Uses electromagnetic properties to determine the water velocity	Sends ultrasonic sound waves through the water to determine its velocity
Meter type	Displacement	Velocity	Velocity	Velocity
Accuracy	Very accurate at low to medium flow rates	Very accurate at medium to high flow rates, poor at low flow rates	Moderately accurate	Accurate
Recommended uses	Potable water, reasonably clear washwater	Potable water, reasonably clear washwater	Potable water and washwater	Potable water and washwater
Power requirements	None	None	Yes	Yes
Cost	Low	Medium	High	Medium-High
Meter location on pipe	In pipe	In pipe	In and on pipe	In, on and end of pipe
Recommended flow rates (L/min)	Up to 300 L/min	Up to 10,000 L/min	Up to 10,000 L/min	Depends on pipe and meter size
Pipe sizes	12–50 mm (0.5–2 in.)	75–250 mm (3–10 in.)	100–900 mm (4–36 in.)	>150 mm (>6 in.)
Meter moving parts	Yes	Yes	No	No
Maintenance	Low	High	Low	Medium
Examples	Oscillating piston, nutating disc meters	Turbine meters	Magnetic	Ultrasonic

4.5 Alternatives to Flow Meters

Tracking the run time and output of pumps. The volume of water pumped can be estimated by multiplying the pumping rate and pump run times. For example, a pump operates continuously at a rate of 500 L/hr over a 10-hour washing day. The volume of water pumped is 5,000 L/day (500 L/hr x 10 hr/day).

Estimating based on rated equipment water use. Some washing equipment is rated to use a set amount of water, which can be used to estimate the water use. For example, a polisher uses 2,200 L/hr of water over an 8-hour washing day. The volume of water used is 17,600 L (2,200 L/hr x 8 hr/day).

The bucket test. Complete a bucket test at the outflow pipe of a facility or individual piece of equipment. The water is collected in a container and the volume of water is measured over a set period of time. For example, if 10.8 L is collected over 2 minutes, then the average flow rate over the collection period is 5.4 L/min (10.8 L ÷ 2 min). Repeat the bucket test many times throughout a day of washing and over a representative period throughout the washing season to determine the range and average flow of washwater generated by the facility.

4.6 Case Study

A vegetable operation needed to know the volume of water flowing out of the facility. Flow meters were introduced by the HMGA Water Project to determine washwater flow volumes and rates generated by processing carrots and other root vegetables.

Equipment

Ultrasonic flow meters with pressure transducers were selected for this operation for their reliability, ease of use and ability to determine flow in a variety of conditions, including water with high solids. The flow meters used included the Hach Flow-Tote 3 AV sensor (Figure 4.1) that communicate via a cable to the Hach FL900AV meter (Figure 4.2). The sensor has three electrodes designed to prevent the build-up of debris on the sensor. Pipe bands, ranging from 200–350 mm (8–14 in.) (Figure 4.3) were used to secure the sensor inside the discharge pipe (Figure 4.4).

Figure 4.1. Hach Flow-Tote 3 AV sensor with three protruding electrodes.

Figure 4.2. Hach FL900AV meter and Hach Flow-Tote 3 AV sensor.

Figure 4.3. Sensor installed on pipe band.

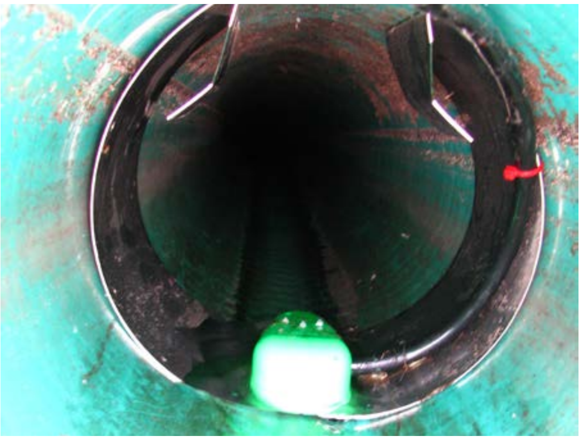


Figure 4.4. Band and sensor placed in the discharge pipe.

The sensor measures velocity and depth of water the meter uses to calculate flow rate and volume. The data is stored for several days until it is downloaded to a computer. The Hach FL900AV meter is powered by four 6V lantern batteries.

Installation and Use

An appropriate band is chosen based on the pipe diameter that, in this case, must be greater than 200 mm (8 in.) to ensure water does not flow beneath the sensor. The sensor is attached to the band using screws and the cable from the sensor is attached to the back of the band using zip-ties with ends snipped in order to have minimal effect on the flow. The sensor and band are then placed into the outlet pipe as far as possible from the outlet to minimize influence from outlet turbulence and measure at a point of streamlined flow. The sensor can operate between -18°C–60°C. Finally, the sensor is connected to the meter and placed in a safe location.

The meter is initiated at installation by connecting to a computer and entering the relevant start up information such as:

- pipe diameter
- current water level
- measurement frequency
- output parameters (e.g., level, velocity, flow rate, volume)

Data collected from the facility (Figure 4.5) shows the instantaneous and daily average flow rates over a 1-week collection period.

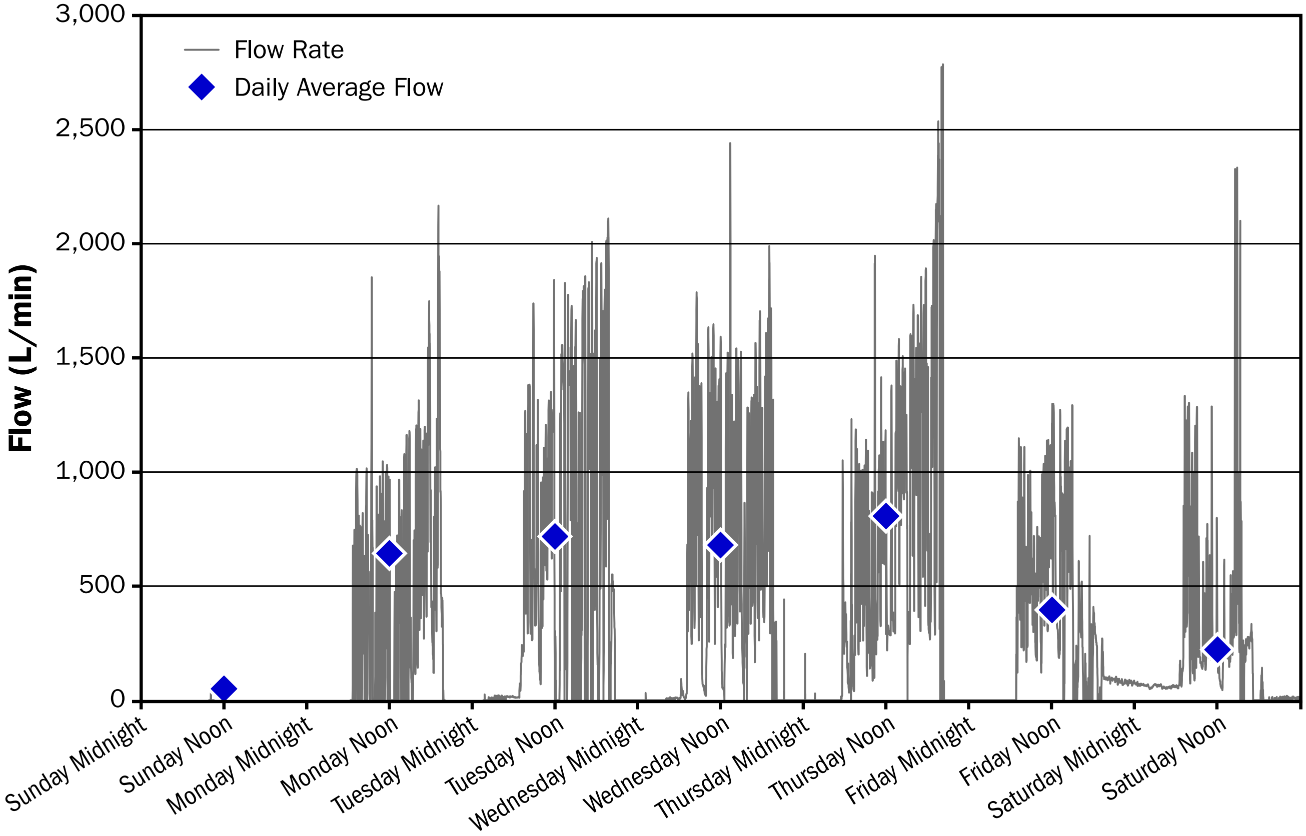


Figure 4.5. Data collected by a flow meter.

5. Washwater Sampling and Analysis

5.1 Introduction

Washwater quality, in a washing facility, is characterized by collecting and analyzing samples for water quality parameters. The sample results are used to evaluate treatment options, assess treatment system performance and meet regulatory requirements.

5.2 Sample Location

Select the appropriate sampling location(s) based on the reason for sampling as shown in Table 5–1.

Table 5–1. Sampling goal and suggested locations

Reason for Sampling	Sample Location
Evaluate treatment options.	fresh water supply washwater after each washing process (e.g., outflow from a barrel washer) recycled water (if using) washwater leaving the facility that needs to be managed
Assess the effectiveness of individual treatment technologies.	before and after each treatment technology
Meet regulatory requirements.	at the discharge location into the environment or municipal sewer system[1]

[1] The exact requirements will be specified in the ECA or municipal sewer-use bylaw.

Choose sample locations that can be consistently sampled into the future (e.g., winter access, permanency) and avoid hazardous locations (e.g., confined spaces). Install and label sample ports to allow for ease in taking samples (e.g., plumbing between two technologies, tanks).

5.3 Sample Frequency

When characterizing washwater, take samples at various times to show an overall profile of the water. Collect several samples at the various locations over the course of one day of washing for each crop and periodically through a week, month or washing season. This will create a data set of minimum, maximum and average values for each of the water quality parameters for each produce type.

It is important to verify the effectiveness of the treatment process. Take samples after installation is complete to show how well the equipment is functioning. If it is not operating at the desired performance level, complete an optimization process (Chapter 11. Optimization). Collect samples prior to the installation of new equipment or operational modifications, and follow the installation or changes with another round of sampling. Comparing the differences will determine the effectiveness of the process changes.

Regulatory documents such as an ECA or bylaws clearly state the required locations, frequency of sampling and the water quality parameters to be tested.

5.4 Who Can Sample

Washwater samples are often collected by:

- trained facility staff
- consulting company staff
- contractor
- professional sampling company

There are some situations that require someone with specialized training to complete sampling in hazardous situations (e.g., confined spaces, when hazardous gases are present). For more information on confined space see the document, *Confined Spaces Guideline*, Ontario Ministry of Labour, ontario.ca/mol

5.5 Types of Analysis

Samples taken for regulatory compliance (e.g., ECA or bylaw) will require an accredited lab to complete the analysis. Use labs certified by the Canadian Association for Laboratory Accreditation Inc. (CALA), www.cala.ca.

Samples for operational purposes can be tested by accredited laboratories or portable field meters. Hand-held field meters can measure various parameters such as:

- pH
- electrical conductivity
- oxidation/reduction potential (ORP)
- temperature
- dissolved oxygen
- turbidity
- total dissolved solids (TDS)

Be sure to periodically check the calibration of the field meter against a sample analysis provided by an accredited laboratory.

Table 5–2 includes suggested water quality parameters that are analyzed to characterize the washwater and assist with determining the required treatment. Parameters identified with an “x” are critical for analysis based on the stated purpose. If testing for regulatory requirements, check the facilities’ ECA to confirm testing requirements before selecting the analytical tests.

Table 5–2. Water quality parameters

Parameters	**Typical ECA Requirements**	**Typical Land Application Requirements**	**Treatment Evaluation**	**Operational Requirements**
Solids				
Total Solids	—	x	—	—
Total Suspended Solids (TSS)	x	—	x	x
Total Dissolved Solids (TDS)	—	—	—	—
Turbidity	—	—	—	x
Nutrients				
Total Phosphorus (TP)	x	x	x	x
Dissolved Phosphorus	—	—	—	—
Total Kjeldahl Nitrogen (TKN)	x	x	—	—
Ammonium/Ammonia	x	x	—	—
Nitrate/Nitrite	—	x	x	x
Potassium	—	—	—	—
Chloride	x	—	—	—
Micronutrients	—	—	—	—
Other				
Regulated Metals	—	x	—	—
Biological Oxygen Demand (BOD)	x	—	x	x
Dissolved Oxygen (DO)	—	—	—	x
Oxidation Reduction Potential (ORP)	—	—	—	x
pH	x	—	x	x
Temperature	—	—	—	x
Electrical Conductivity (EC)	—	—	—	x
E.coli and Total Coliforms	—	—	—	x
Total Organic Matter	—	—	—	—
Total Organic Carbon	—	—	—	—
Particle Size Analysis	—	—	x	—

5.6 How to Sample

To develop consistent and standardized techniques in Ontario, the provincial government provides a sampling protocol document, *Protocol for the Sampling and Analysis of Industrial/Municipal Wastewater,* ontario.ca/document/protocol-sampling-and-analysis-industrialmunicipal-wastewater.

There are two types of samples — discrete and composite. A discrete sample is a single sample taken from a single location at one point in time (called a "grab" sample). A composite sample is collected by combining multiple samples from the same location, separated by time intervals (e.g., 12 samples collected over 6 hours at one point in the treatment process) or several locations into one bottle (e.g., multiple spray bars). Discrete samples provide data from a single point in time, and composite samples provide average data spread over a longer time period.

5.7 Sampling Equipment

There are various types of equipment used for sampling.

Collection bottles are used to take a sample and then transfer it to a sample bottle or field meter.

Sample bottles are required when sending a sample for analysis to a laboratory. The laboratory provides the required sample bottles based on the parameters being tested. Use a permanent marker to label the sample bottles.

A sampling pole (Figure 5.1) allows the user to obtain a sample without the risk of falling into a water body, such as a settling pond or stream, and has a collection bottle attached to an extendable pole. Sampling poles can be purchased or constructed.

Buckets (Figure 5.2) are used to ensure a uniform water sample when a larger volume is required to fill multiple sample bottles for laboratory analysis. Use buckets to collect water from diffuse sources (e.g., spray bars) or create a composite sample.

Coolers and **ice packs** are used to keep samples cool during transport to the laboratory/facility. Samples for microbial and nitrogen analysis must be kept cool at all times.

Auto-samplers or **composite samplers** (Figure 5.3) are used to collect samples at set times without the operator being present. The unit is set to draw a pre-determined sample volume at specific intervals, for example 500 mL every 30 minutes. Auto-samplers create a composite sample and/or a series of discrete samples.

Figure 5.1. Using a sampling pole to collect washwater.

Figure 5.2. Using a bucket to combine samples.

Figure 5.3. An auto-sampler.

5.8 Sampling Process

Pre-Wash

Prior to sampling, wash the collection bottle, bucket and sampling pole using phosphate-free detergent to prevent contamination from site to site and promote the integrity of the representative sample.

Sample Collection

Rinse the collection container three times with the washwater that will be sampled (Figure 5.4). Use the water from the collection container to rinse the sample bottles three times. Do not rinse the bottles containing preservatives (e.g., those used for microorganism analysis such as *E. coli*). Fill the sample bottles to the neck of the bottle (Figures 5.5 and 5.6) or identified fill line, making sure not to overfill — especially the bottles containing preservative.

Figure 5.4. Sampling procedures include triple rinsing the collection container.

Figure 5.5. Pouring from the collection container into the sample bottle.

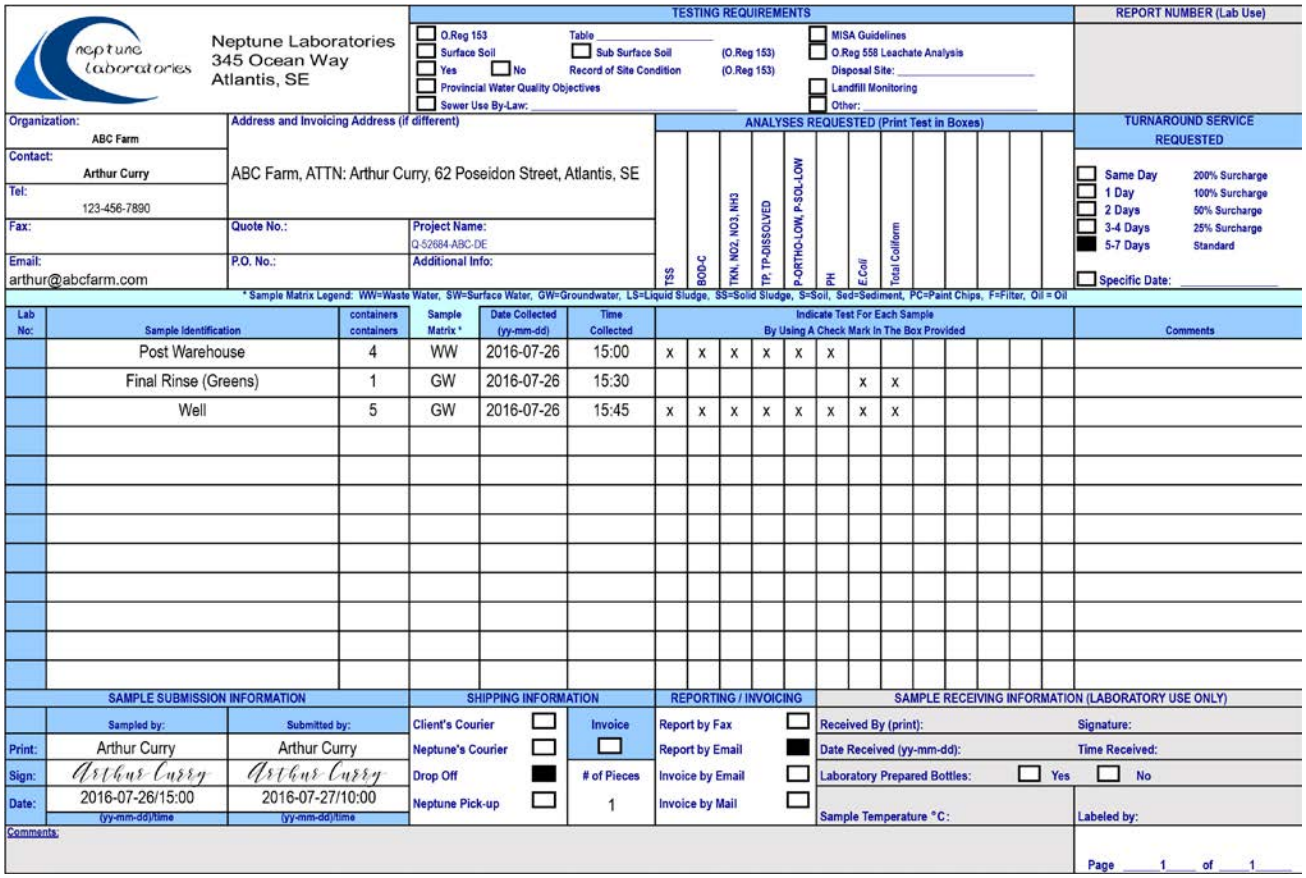
Figure 5.6. Pouring into the sample bottle containing the preservative.

If bottles are not supplied containing a preservative, the sampler must follow the sample preservation techniques for the parameters as specified by the accredited laboratory.

Place the samples in a cooler and keep them cold (ideally <4°C) but not frozen for transport to the laboratory. Keeping the samples cold prevents further chemical reactions or biological activity from taking place. A completed Chain of Custody (COC) form goes with the samples to the laboratory. The form:

- Is provided by the laboratory.
- Provides account and contact information.
- Summarizes the requested analysis.
- Tracks the samples movements from delivery to the lab and throughout the analysis.
- Prevents tampering of the sample by identifying who has custody of the sample at any point in time.

One sample location may require multiple sample bottles be filled to complete the analysis. All bottles are labeled the same and the information found on those bottles is copied onto the Chain of Custody form. An example COC form is shown in Figure 5.7.



Neptune Laboratories
345 Ocean Way
Atlantis, SE

TESTING REQUIREMENTS

☐ O.Reg 153 Table ______________
☐ Surface Soil ☐ Sub Surface Soil (O.Reg 153)
☐ Yes ☐ No Record of Site Condition (O.Reg 153)
☐ Provincial Water Quality Objectives
☐ Sewer Use By-Law: ______________
☐ MISA Guidelines
☐ O.Reg 558 Leachate Analysis
Disposal Site: ______________
☐ Landfill Monitoring
☐ Other: ______________

REPORT NUMBER (Lab Use)

Organization: ABC Farm
Contact: Arthur Curry
Tel: 123-456-7890
Fax:
Email: arthur@abcfarm.com
Address and Invoicing Address (if different): ABC Farm, ATTN: Arthur Curry, 62 Poseidon Street, Atlantis, SE
Quote No.:
P.O. No.:
Project Name: Q-52684-ABC-DE
Additional Info:

TURNAROUND SERVICE REQUESTED

☐ Same Day 200% Surcharge
☐ 1 Day 100% Surcharge
☐ 2 Days 50% Surcharge
☐ 3-4 Days 25% Surcharge
■ 5-7 Days Standard
☐ Specific Date: ______________

* Sample Matrix Legend: WW=Waste Water, SW=Surface Water, GW=Groundwater, LS=Liquid Sludge, SS=Solid Sludge, S=Soil, Sed=Sediment, PC=Paint Chips, F=Filter, Oil = Oil

Lab No:	Sample Identification	containers containers	Sample Matrix *	Date Collected (yy-mm-dd)	Time Collected	ANALYSES REQUESTED (Print Test in Boxes) Indicate Test For Each Sample By Using A Check Mark In The Box Provided TSS	BOD-C	TKN, NO2, NO3, NH3	TP, TP-DISSOLVED	P-ORTHO-LOW, P-SOL-LOW	PH	E.Coli	Total Coliform						Comments
	Post Warehouse	4	WW	2016-07-26	15:00	x	x	x	x	x	x								
	Final Rinse (Greens)	1	GW	2016-07-26	15:30							x	x						
	Well	5	GW	2016-07-26	15:45	x	x	x	x	x	x	x	x						

SAMPLE SUBMISSION INFORMATION

	Sampled by:	Submitted by:
Print:	Arthur Curry	Arthur Curry
Sign:	Arthur Curry	Arthur Curry
Date:	2016-07-26/15:00 (yy-mm-dd)/time	2016-07-27/10:00 (yy-mm-dd)/time

SHIPPING INFORMATION

Client's Courier ☐
Neptune's Courier ☐
Drop Off ■
Neptune Pick-up ☐
Invoice ☐
# of Pieces 1

REPORTING / INVOICING

Report by Fax ☐
Report by Email ■
Invoice by Email ☐
Invoice by Mail ☐

SAMPLE RECEIVING INFORMATION (LABORATORY USE ONLY)

Received By (print): Signature:
Date Received (yy-mm-dd): Time Received:
Laboratory Prepared Bottles: ☐ Yes ☐ No
Sample Temperature °C: Labeled by:

Comments:

Page 1 of 1

Figure 5.7. An example of a Chain of Custody (COC) form.

5.9 Selecting a Laboratory

There are several factors to consider when selecting a laboratory to analyze samples.

Accreditation

Laboratory accreditation is the most important criteria in the selection process. The accreditation required is outlined by the organizations that request the sample results. For example, MOECC requires water samples be analysed by a Canadian Association for Laboratory Accreditation Inc. (CALA) certified lab. There is a list of CALA accredited labs at www.caladirectory.ca. Note that some laboratories may be accredited for the analysis of some parameters and not for others.

Location

Samples can be dropped off at the laboratory, at a drop-off location or couriered. Dealing with a local laboratory may reduce sample transportation costs and time. Consider hours of operation for sample drop-off and courier. Some companies may have multiple sample drop-off locations.

Cost

The cost of analyzing samples is based on the parameters tested and the number of samples. When requesting a quote, choose a standard set of parameters to be evaluated. Additional parameters can be added later for an extra fee. For an accurate quote, estimate the number of samples to be tested on an annual basis.

5.10 Submitting Laboratory Samples

There are a number of steps to follow when submitting samples to a laboratory.

The laboratory provides sample bottles based on the parameters selected (Figure 5.8). The sample bottles have labels to be filled in with the date, time and sample ID. Use a permanent marker or pen (with ink that will not run if it gets wet when the bottle is being filled) to fill out the label. Some laboratories may pre-label some sections such as the parameters and account number.

Some of the testing parameters are time sensitive and must be received and analyzed by the lab within a certain period of time. For example, *E. coli* and coliform tests must be completed within 48 hours to obtain accurate results. Ensure the samples are received by the laboratory within 24 hours of sampling. When selecting the parameters for testing, ask if any are time-sensitive. In general, collect time-sensitive samples on Monday to Wednesday since some laboratories are not able to process samples over the weekend.

Keep samples cool during transport to the laboratory. Laboratories may not supply coolers and ice packs.

Contact the laboratory if there are any issues or concerns with the sample/results.

Figure 5.8. A set of labeled sample bottles.

Source: Australian Laboratory Services (ALS), Waterloo, Ontario, www.alsglobal.com

5.11 Typical Washwater Parameters

The washwater generated at facilities washing similar crop types may have similar characteristics. Table 5–3 provides a summary of the sample results for a variety of washing facilities, collected during the HMGA Water Project. The results are reported as the 25th percentile, average and 75th percentile. This method avoids reporting extreme data (e.g., removes errors caused during sampling or extreme weather events). This data cannot replace the site-specific characterization required before selecting a treatment system.

Table 5–3. Sample results from a variety of agricultural washwaters

Crop Type	**TSS (mg/L)**			**TP (mg/L)**			**TKN (mg/L)**			**CBOD$_5$ (mg/L)**		
	25th	**Avg.**	**75th**	**25th**	**Avg.**	**75th**	**25th**	**Avg.**	**75th**	**25th**	**Avg.**	**75th**
Leafy Greens	35	185	340	0.3	1	1.4	1.7	2.7	2.9	6	20	27
Potato	630	22,031	21,500	14	29	48	49	162	249	134	6,033	4,490
Roof/Rain Water	2.8	3.6	4.4	0.07	0.08	0.09	1.0	1.2	1.4	2.2	3.6	4.5
Root Vegetables	188	1,074	1,040	1.1	4.6	6.2	3	24	33	32	261	450

5.12 Case Study

A root vegetable washing facility characterized its washwater by sampling as it exited the washing facility. These samples were analysed by an accredited laboratory. The root vegetable facility sampled at the following frequencies:

- intensive — six times over 3 days
- long term — monthly samples taken from October–March

The intensive sampling period demonstrated the variation in water quality that occurred over a single day and series of days. The long-term sampling period showed the variability over the washing season (Figure 5.9). Table 5–4 provides the averages, maximums, minimums and ranges of the samples.

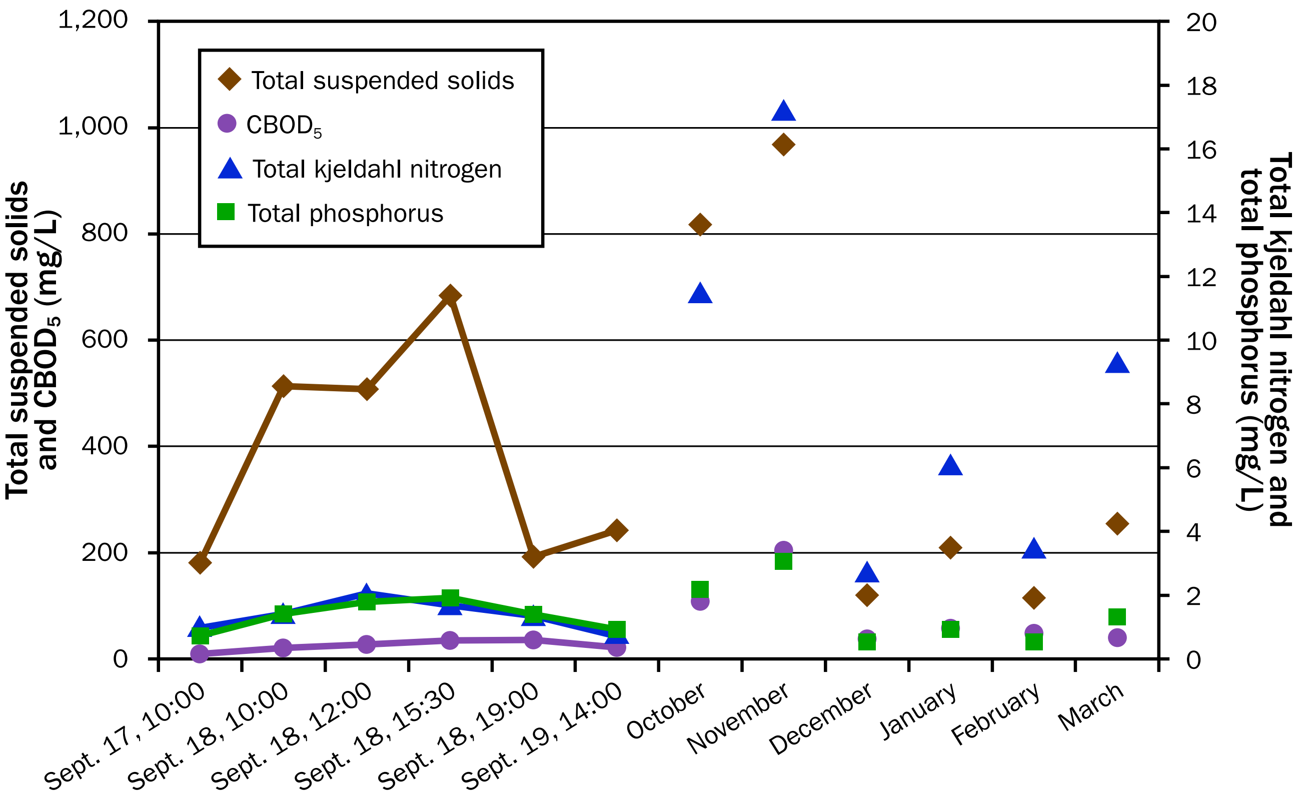


Figure 5.9. Sample results from a root vegetable washing facility.

Table 5–4. Sample results from a root vegetable washing facility

Parameter	**TSS (mg/L)**	**TKN (mg/L)**	**TP (mg/L)**	**CBOD$_5$ (mg/L)**
Average	400	4.9	1.4	54
Maximum	968	17.3	3.0	204
Minimum	114	0.7	0.5	9
Range	854	16.6	2.5	195

Based on the results shown in Table 5–4, parameters fluctuate throughout the day and over the entire washing season. This facility will need to invest in a treatment system to manage the variation of the washwater and treat to a level that is acceptable for the required end point.

6. Pre-Design Considerations

6.1 Introduction

Designing a washwater treatment system is a complex process with many stages including equipment selection, procurement and installation. There are several factors to consider — cost, treatment objectives, potential specialized infrastructure and additional labour requirements. Understand what resources are already installed or available and what resources are needed to limit changes later in the process. A Pre-Design Considerations Worksheet (Table 6–1.) is provided at the end of this chapter to assist with understanding the financial and physical resources that are available at the facility, and helps identify the overall objectives for the washwater treatment equipment.

A well designed washwater treatment system can have positive impacts on the operation including:

- compliance with regulatory requirements
- improved environmental performance
- improved facility efficiencies (e.g., labour, water)
- increased social responsibility
- increase product marketability

6.2 Costs

Washwater treatment is a very expensive investment. The cost of the system is directly related to the scale of the operation and treatment objectives. When washing is occurring on a daily year-round basis and produces large quantities of washwater, a more extensive and expensive treatment system is needed to handle its complexity and will not be solved with a simple solution (e.g., an inexpensive, small earthen settling pond). But an operation that washes only a couple hours a week during the summer months may be able to manage and treat the washwater with a simpler system and a smaller financial investment.

The initial capital costs to design, purchase and install a washwater treatment system include costs for equipment, infrastructure changes, consultants and engineered drawings. Once the system is installed, there are ongoing costs for operation and maintenance. There are cost trade-offs between systems with a high capital cost and those with lower capital costs but higher operational costs.

6.3 Treatment Objectives

When designing a system, always determine the treatment goals. This section of the checklist outlines the level of treatment the system must meet. There are several potential end points for the treated water including:

- discharge into the environment
- land application
- trucked or piped to a municipal wastewater treatment facility
- reused within the washing processes for initial rinses
- treated to potable water standards and reused for final rinses

The volume and flow rate of the water produced by the washing process determines the size and cost of the washwater treatment system. Consider the impact of any equipment changes or future expansions to the washing process before investigating washwater treatment options.

6.4 Site Infrastructure

Existing infrastructure may be incorporated into the new treatment system if possible. Record the details of the existing infrastructure such as pipes, tanks, filters, ponds and electrical services (e.g., size, location, and other specifications). Depending upon the requirements of the new equipment, additional infrastructure may be required. Check with the municipality to confirm whether a building permit is required for the planned project.

When installing new equipment, consider the following:

- labour
- electrical servicing (e.g., voltage, frequency, phase)
- plumbing capacity (e.g., connection points for washwater treatment system to production equipment piping)
- yard piping
- compressed air supply
- space requirements
- floor load capacity (i.e., an engineered review of how much load can safely be applied to the floor)
- storage tanks
- weather proof housing (e.g., heated)
- computer control and instrumentation (e.g., internet, programmable logic controllers (PLC))
- impact on production process
- waste management
- installation site access

All systems require generated waste to be managed on an ongoing basis. Consider the waste stream produced prior to purchasing or installing equipment. Create a plan to deal with the waste in parallel with the system installation, not afterwards. For example, solids collect in the bottom of a settling tank and require removal, storage and disposal (e.g., composting). Filters need backwashing and the backwash water requires disposal (e.g., land application) or further treatment.

6.5 Labour Requirements

After installing the treatment system, an ongoing labour commitment is required for operation, cleaning, maintenance and repairs. The technologies selected determine the amount of time, level of skills and training for staff to operate the equipment. Some systems require manual start-up and operation each day, and other systems are controlled using PLCs. All systems need some level of supervision for operation.

Assign at least two people to learn and operate the system. Larger, more complex systems may have larger staffing requirements. In some cases, the operation of the washwater treatment is done by contracting to a washwater management company. It is important to have a staff member within the facility who understands the system.

6.6 Pre-Design Considerations Worksheet

Use the Pre-Design Considerations Worksheet (Table 6–1) to summarize the financial and physical resources available at the facility before designing the new system, and identify the overall objectives for the washwater treatment equipment.

Table 6–1. Pre-design considerations worksheet

Costs	
Available capital	
Funds available for ongoing costs	
Treatment Objectives	
Treated water is destined for what end point?	
Water quality target for end point?	
Is potable water required?	
Flows (min/max; batch/continuous)	
Seasonality (year-round or seasonal washing)	
Site Infrastructure	
Existing treatment technologies	
Electricity servicing	
Plumbing infrastructure	
Computer network	
Indoor/outdoor space	
Footprint available?	
Soil texture	
Waste handling strategy complete?	
Labour Requirements	
Estimation of man-hours available for operation.	
Estimation of man-hours available for cleaning and maintenance.	
Automated or manually operated system?	
Automated or manually monitored system?	
Washwater managed by facility staff or by washwater management company?	

Note: Completed examples of this worksheet are found in Chapter 10. Building a Washwater Treatment System.

7. Design Considerations

7.1 Introduction

Washwater treatment stages typically follow a stepwise order (Figure 7.1). The required steps depend on the quality of the water to be treated and the desired endpoint. For example, if no solids are present in the washwater, the initial stages can be skipped. The general washwater parameters and stages are described in the following section.

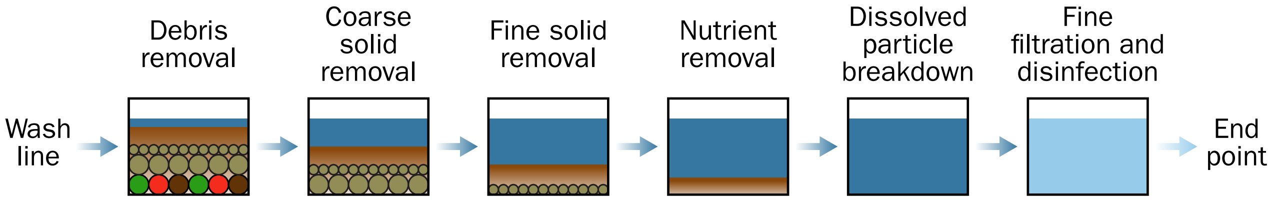


Figure 7.1. Washwater treatment process.

7.2 General Parameter Definitions

Debris — large pieces of vegetative matter (e.g., tops, leaves, roots or culls)

Coarse solids — sand, silty soils and soil aggregates that are large in both size and density

Fine solids — clay, muck soils and soil particles

Nutrients — dissolved nutrients such as nitrogen and phosphorus

Dissolved materials — dissolved materials such as BOD and dissolved nutrients

7.3 Definition of Stages

1. **Debris removal** involves very coarse filtration and/or pulverizing large pieces into smaller ones.
2. **Coarse solid removal** includes medium to coarse filtration or settling.
3. **Fine removal** includes fine filtration and/or chemical-assisted removal.
4. **Nutrient removal** is a biological process or ion removal.
5. **Dissolved material removal** increases dissolved oxygen content and reduces biological oxygen demand.
6. **Fine filtration and disinfection** is the stage of treatment most likely used to create potable water and includes fine filtration, disinfection and potentially pH adjustment.

7.4 Key Data to Collect

Certain basic information must be gathered about the facility before designing the treatment system and includes the following information.

Flow Rate

How much water does the facility use during a washing season? This includes peak flow rate, average daily water use and maximum daily water use. How to measure the facility's water use is covered in Chapter 5. Flow Monitoring.

Operational Run Time

How often does washing happen and for how long? This is an estimate of how much the system runs over a year, and includes hours per day, days per week and weeks per year.

Design treatment systems for the maximum possible flow rates and run time. It is better to oversize the treatment system to provide a factor of safety.An undersized system may be ineffective and fail.

Soil Particle Size and Specific Gravity

Understand the size and specific gravity (density) of any soil that enters the washwater. Soil particles range in size — sand is larger than silt which is larger than clay (Table 7–1). Muck soils are normally the size of clay particles but some muck soil particles can be as large as silt.

Specific gravity is a measure of the density of a substance or particle relative to water, which has a specific gravity of 1. Any particle with a specific gravity greater than 1 will settle whereas any particle with a specific gravity less than 1 will float.

Table 7–1. Size ranges and specific gravity for different soil types

Soil Type	Size (microns)	Specific Gravity
Sand	50–2,000	2.64–2.68[a]
Silt	2–50	2.68–2.72[a]
Clay	<2	2.44–2.92[a]
Peat	0–40,000	1.26–1.90[a]
Muck	<74[b]	1.002[c]

Note: 1 mm = 1,000 microns

[a] Source: Ou, C.-Y. (2006). Deep Excavation: Theory and Practice (p. 8). London, UK: CRC Press. Venkatramaiah, C. (2006). *Geotechnical Engineering* (3rd ed., p. 32). New Delhi, India: New Age International.

[b] Source: Fratta, D. O., Puppala, A. J., & Muhunthan, B. (2010). GeoFlorida (2010). *Advances in Analysis, Modeling & Design* (p. 2753). N.p.: ASCE Publications.

[c] Source: AMEC, Project Number: TR1114005. *Report for Wastewater Management Assessment of Vegetable Production Site Nine (9) with on Farm Processing.* Holland Marsh Growers' Association, Newmarket, Ontario (2014).

This data can be used to determine which treatment technologies may be useful in removing soil from the washwater. Some water treatment systems are negatively impacted by the presence and type of soil in washwater including:

- sedimentation (i.e., particles with a specific gravity close to 1 (e.g., muck soils) are difficult to settle)
- filtration (i.e., particles smaller than the membranes openings will not be removed)
- disinfection (i.e., particles will interfere with disinfection and reduce effectiveness)

There are two ways to identify the soil particle size and density.

1. The mason jar soil test will quickly identify the percentage of sand, silt and clay.
    - Add water and a scoop of the soil into a transparent and colourless jar. Shake it thoroughly to mix the soil and water, and let it stand.

- The sand will settle to the bottom first (approximately 1 minute), followed by the silt (a few hours) and finally the clay will fall out of suspension (a full day). The fine organic matter particles are the last to sink and the large organic particles will just stay afloat (Figure 7.2).
- Use a ruler to measure the layers once they have settled and calculate the percentage of sand, silt and clay. The size range of the particles for sand, silt and clay are found in Table 7–1.

2. A laboratory soil particle size analysis measures the size range of the soil particles within a sample. It is reported in percentages to determine what size is most common.

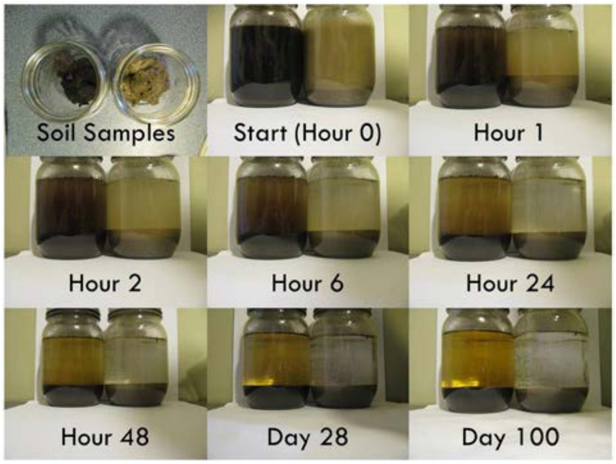


Figure 7.2. Jars with soil particles at various stages of settling.

Water Sampling

It is important to understand the quality of the washwater and this is not an optional step. The data is used in determining which treatment technologies may be useful for treating the washwater and determining the required equipment size. Common parameters are found in Chapter 5. Sampling.

7.5 Sizing the System

To size the system, consider the hydraulic loading, washwater mass loading and the required water quality to meet the targets of the selected endpoints.

Hydraulic Loading

Hydraulic loading is the rate water enters a treatment system and is measured as the total volume of water in a given time period (e.g., 100,000 L/day, 50 L/min). Size the treatment system to match the total daily and instantaneous flow rates generated by the washing operation. Any efforts to reduce and/or optimize (e.g., recycle) water use should be done before identifying the flow rates used to size the washwater treatment system.

Most washwater treatment equipment works best when the flow rates are reasonably constant. If there are large variations in flow rate, install holding tanks to balance any fluctuations and provide a more consistent flow to the treatment equipment. Size the equipment to handle the maximum flow rate unless balancing tanks are installed to regulate the flow evenly.

Washwater Mass Loading

Washwater mass loading is the total amount of material (e.g., solids, phosphorus, BOD) entering the treatment system over a specified time period, and is calculated by multiplying the concentration times the flow rate (e.g., 10 kg solids/day). Size the treatment system to match the mass loading rates for the targeted parameters generated by the washing operation. Different treatment technologies may have maximum mass loading rates. Any efforts to reduce and/or optimize (e.g., recycle) water use and mass loading (e.g., dry soil removal) should be done before determining the loading that will be used to size the washwater treatment system.

Waste Mass Loading

Waste mass loading is the total amount of material (e.g., solids, water) separated from the treated water stream. Most treatment systems produce some form of waste stream that needs to be managed. Develop a plan to manage the anticipated quantity of waste prior to installing the washwater treatment technology.

The waste mass loading will be less than the washwater mass loading based on the efficiency (e.g., 80%) of the treatment system. For example, if the washwater mass loading of solids is 10 kg/day and the treatment efficiency is 80%, then the waste mass loading of solids is 8 kg/day.

Factor of Safety

Be conservative in sizing the system to remove more material than may be required to provide a factor of safety when sizing the system to accommodate unanticipated larger loads.

Mass Loading Calculations

The following examples show how to calculate mass loading for a washing facility.

Example #1

The concentration of total phosphorus in a representative sample (e.g., composite) is 18.73 mg/L and the flow meter measures a total washwater volume of 119,865 L of water during a full day of production. Calculate the washwater mass loading for total phosphorus on a daily basis.

Solution: The daily mass loading of total phosphorus is calculated by multiplying the flow rate (L/day) by the concentration of phosphorus (mg/L). The mass loading of total phosphorus is calculated at 2.25 kg (119,865 L/day x 18.73 mg/L /1,000,000 mg/kg) for that day of washing.

Example #2

A vegetable washing facility generates washwater with the following characteristics:

- average flow rate (Q) – 300 L/min
- length of washing day (WD) – 10 hr/day
- number of washing days (WS) – 260 days/yr
- average total phosphorus concentration (TP) – 0.4 mg TP/L (lab analysis of washwater samples)

Estimate the total amount of water used (hydraulic loading) and the mass loading of total phosphorus over a 1-year period.

Solution:

Calculate the water used (hydraulic loading).

Total water flow = Q × WD × WS
= 300 L/min × 60 min/hr × 10 hrs/day × 260 days/yr
= 46,800,000 L/yr

Solution:

Calculate the mass loading of total phosphorus over a one year period.

Mass loading of total phosphorus = total water flow × TP
= 46,800,000 L/yr × 0.4 mg TP /L
= 18,720,000 mg TP/yr

Convert to kilograms

Mass loading of total phosphorus = 18,720,000 mg TP/yr × 1 kg/1,000,000 mg
= 18,720,000 mg TP/yr ÷ 1,000,000
= 18.72 kg TP/yr

Example #3

A facility washes vegetables 5 days/week year-round. Their flow rate is 190,000 L/day and an extensive sampling program has shown their average total suspended solids (TSS) concentration is 870 mg/L. The treatment system is designed to remove 90% of the solids in the washwater. The operator wants to create a plan to handle and dispose of the solids generated by the treatment system in 1 year.

Calculate the amount of solids to be managed on an annual basis.

1. Calculate yearly flow

- Operational run time – 5 days/week, 52 weeks/yr
- Daily flow – 190,000 L/day

Days washing = 5 days/week × 52 weeks/yr
= 260 days/yr

Yearly flow = 260 days/yr × 190,000 L/day
= 49,400,000 L/yr

2. Calculate solids produced

- Yearly flow – 49,400,000 L/yr
- TSS – 870 mg TSS/L

Solids waste = 49,400,000 L/yr × 870 mg TSS/L
= 42,978,000,000 mg TSS

3. Convert mg to kg

1 kg = 1,000,000 mg

Solids waste = 42,978,000,000 mg TSS × 1kg/1,000,000 mg
= 42,978 kg TSS

4. Apply treatment performance

- Assume the treatment system reduces the total suspended solid loading by 90%.

Total suspended solid waste = 42,978 kg TSS/yr
Removal = 90%

Actual waste = 42,978 kg TSS/yr × 90%

= 38,680 kg TSS/yr

Solution: Over 1 year this operation needs to manage 38,680 kg of total suspended solids.

7.6 Selecting Technologies

Reading Figure 7.3 from left to right, determine which particular washwater parameters need to be addressed and select the corresponding technologies for evaluation.

Based on the technologies selected (Figure 7.3), complete the Technology Evaluation Worksheet (Table 7–2) for each technology chosen. Compare the technology worksheets to each other and to the Pre-Design Considerations Worksheet (Table 6–1, Chapter 6. Pre-Design Considerations). There are four categories in the worksheet to consider: treatment costs, functionality, site requirements and labour requirements.

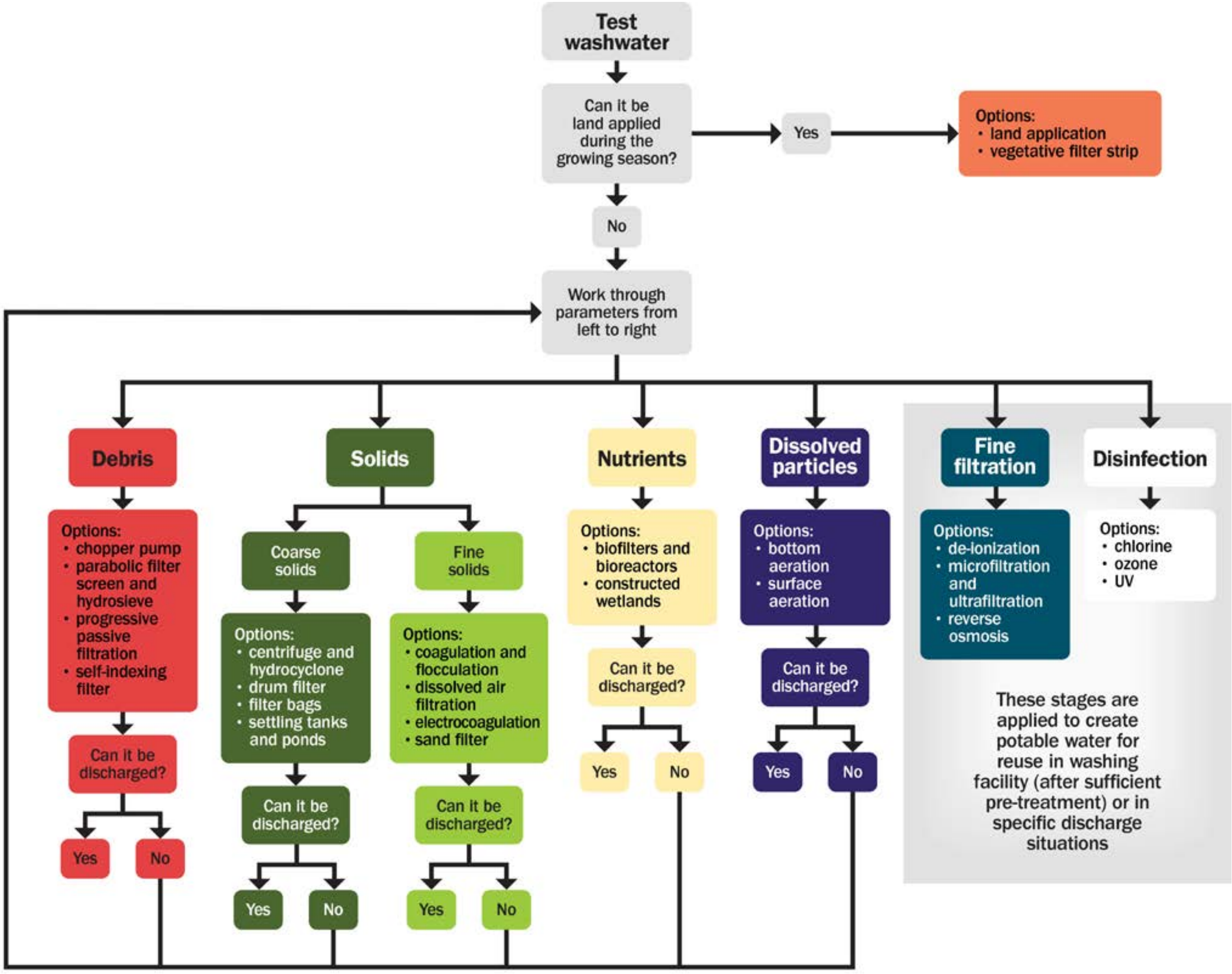


Figure 7.3. Flow chart for treatment technology selection.

Treatment Costs

When considering the cost of a treatment technology, look at both the capital, ongoing operation and maintenance costs. Capital costs can include design, procurement, installation and start-up costs. Operational and maintenance costs can include labour, electricity, coagulants and flocculants, replacement filters, disinfection chemicals, UV bulbs and servicing the equipment.

Functionality

In general, water treatment systems have multiple treatment steps that progressively improve water quality. Each step targets different parameters such as solids, organic material, nutrients or pathogens to provide complete treatment. Depending on the required water quality of the final output (e.g., based on assimilative capacity, Chapter 3. Reducing Water Use), the number of treatment steps will vary. If water is reused and not discharged, the standards of treatment are higher to meet food safety guidelines.

Some technologies have limitations such as:

- temperature (e.g., reaction rates that depend on temperature or potential freezing in the winter)
- volume and flow (i.e., systems must be able to handle the minimum and maximum flow rates and not just the average flow)
    - continuous uniform flow rates (e.g., required by biological systems)
    - batch or intermittent flow rates

Also consider whether the technology has a proven track record for treating similar washwaters and in similar environments (e.g., wet, corrosive, debris).

Site Requirements

The site must provide the specific requirements of the treatment system. Determine the additional site infrastructure requirements for each technology (e.g., electrical, plumbing, space requirements, weather proof housing and waste management). If the new technology is integrated into an existing treatment system, ensure pre-treatment requirements are met. Understand how the waste by-products that each technology generates will be managed.

Labour Requirements

Determine how much staff time and effort is required to operate, monitor, clean, maintain and repair the treatment equipment. Some technologies require specialized training to be managed effectively.

7.7 Technology Evaluation Worksheet

Use the Technology Evaluation Worksheet (Table 7–2) for each technology chosen.

Table 7–2. Technology evaluation worksheet

Treatment Cost (Estimate)	
Capital cost	
Operating cost	
Functionality	
Targeted water quality parameters (e.g., solids, organics, nutrients, etc.)	
Treatment process stage (e.g., pre-treatment, final discharge or potable water)	
Flow capacity (min/max/average; batch/continuous)	
Temperature (e.g., year-round, seasonal or indoor)	
Proven technology under similar conditions?	
Site Requirements	
Technical requirements (e.g., electricity, plumbing, etc.)	
Pre-treatment requirements	
Indoor/outdoor (e.g., placement of equipment)	
Footprint/land area required	
Is the soil suitable for the technology? (e.g., land application, earthen ponds)	
Waste by-products	
Labour Requirements	
Trained operator required?	
Manual operation or automated equipment?	
Constant supervision required (e.g., on-call)?	
Estimate of man-hours for operation and monitoring.	
Estimate of man-hours for cleaning, maintenance and repair.	

8. Treatment Technologies

8.1 Introduction

This chapter describes the treatment technology options and provides examples using case studies. Technologies are grouped and presented in the same order as those in Figure 7.3 Flow Chart for Treatment Technology Selection (Chapter 7. Design Considerations).

8.2 Land Application

Land application is a method to manage washwater by using it for irrigation or spreading on agricultural land for crop production (Figure 8.1). It can also be used as a method of managing the solid by-products of a washwater treatment process. Land application must be done in a way that protects soil quality, surface and ground water quality, and reduces odour impacts on neighbours. There are economic benefits to land applying washwater or solids as they can be a source of irrigation water, nutrients or organic matter. In most cases, this benefit is minor compared to the cost of the application. But compared to treatment, land application may be one of the least costly disposal methods.

Figure 8.1. Land application of water through an irrigation system.

Description

To determine the suitability for land application, test both the washwater (i.e., liquid or solid streams) and the crop land soil. This testing determines an appropriate application rate. Balance nutrient content in the washwater with crop removal. To avoid runoff, applications are limited by wet conditions and the volume of water that can be used by the crop. The first step to develop a land application plan is to sample the washwater during the washing season (Table 8–1).

Table 8–1. Parameters for washwater and soil sampling

Test	Washwater	Solids	Soil
Macro nutrients (e.g., nitrogen, phosphorus, potassium) Micro nutrients (e.g., sodium, magnesium, boron, manganese, iron, zinc, copper, sulfur)	x	x	x
Regulated metals* (e.g., arsenic, cadmium, cobalt, chromium, copper, lead, mercury, molybdenum, nickel, selenium, zinc)	x	x	x
Microorganisms (e.g., total coliforms, *E. coli,* plant pathogens)	x	x	—
Standard wastewater characteristics (e.g., BOD, pH, TSS, chlorine, E.C. % dry matter)	x	—	—
Standard solids characteristics (e.g., pH, % dry matter)	—	x	—
% organic matter**	—	—	x

*Regulated metals are not common in fruit and vegetable washwater.

**Soils >80% organic matter (e.g., muck soils) cannot have agriculture source material added under the *Nutrient Management Act, 2002*.

Considerations

The quality of the washwater is critical for determining suitability and land application rates. Ensure washwater has been properly characterized since washwater quality can dramatically change during the production cycle.

Washwater storage is required to hold washwater for periods of time (e.g., hours, days, months) between its generation and application. This may be required when the soil is saturated and when volumes generated exceed crop water demands. Washwater storage may need to be engineered and located in compliance with regulatory requirements. Occasional removal of accumulated solids may be necessary from the washwater storage.

Filtration maybe required before putting it into an irrigation system to avoid plugging of sprinklers and emitters. Screen, disc or sand filters may be recommended by the irrigation equipment supplier.

Do not apply washwater to frozen or snow covered fields. Facilities that wash through the winter must have sufficient washwater storage (e.g., lined pond or tanks) for the winter months.

Plant pathogens, which may be present in washwater, can be transferred to the field where it is being land applied. Mitigate the risk of solids by correctly composting them before land application.

Consider food safety guidelines before using washwater to irrigate produce (Section 2.5. Water Quality for Vegetable and Fruit Production). Irrigation water quality standards for pathogens are total coliforms (1,000 CFU/100 mL water) and E. coli (100 CFU/100 mL water) as set by Environment Canada. See the document, *Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses*, Environment Canada, 2002, http://ceqg-rcqe.ccme.ca/en/index.html. Keeping water test records are good agriculture practices and an important part of an on-farm food safety program. For more information on irrigation standards, see the OMAFRA factsheet, *Improving On-farm Food Safety through Good Irrigation Practices*; Order 10-037, ontario.ca/omafra. For more information about sampling irrigation water, view OMAFRA's YouTube video, *Irrigation Water Sampling – Sampling Irrigation Systems*.

Mitigate the food safety risks of washwater irrigated crops by applying it:

- to crops that will not be eaten raw (e.g., corn, wine grapes)
- to non-food crops (e.g., trees, sod, flowers)
- through an irrigation method that ensures washwater does not come in contact with the edible portion of the crop (e.g., drip)
- post-harvest (i.e., for nutrient benefit for subsequant crop)
- after treatment

Costs

Capital costs include solid waste handling equipment (if applicable), land application equipment, pumps and piping infrastructure, washwater storage and regulatory approval process.

Ongoing costs include labour, fuel, equipment maintenance and lab analysis. Land application requires labour dedicated to spreading the material (i.e., driving a tractor) or operating an irrigation system, and may be substantial where washwater volumes are high and fields are far from the washing facility. Table 8–2 summarizes the capital and operational costs for land application.

Land application of washwater is a low-cost solution if there is available land nearby and sufficient washwater storage.

Table 8–2. Capital and operational costs for land application

Capital Costs	Operational Costs
Solid waste handling equipment (e.g., storage bins, front end loader)	Labour
Land application equipment (e.g., manure spreader) or field irrigation equipment	Equipment maintenance
Pumps and piping	Fuel/electricity
Washwater storage (e.g., design, construction)	Washwater sample analysis
Regulatory approval process	

Case Study

A 2012 OMAFRA fruit and vegetable characterization project evaluated the option of land application of washwater. A scenario was developed based on a mid-sized root vegetable washing facility that washes and packs year-round. The objectives were to evaluate the:

- Amount of land required for managing the washwater (volume, nutrients).
- Amount of winter storage required.
- Agronomic nutrient value of washwater for land application.
- Regulated metal levels in washwater.
- Food safety suitability of land applying washwater to an edible crop.

Volume of washwater available for land application

In the case study, the amount of washwater generated was 20 m^3/day for a 5-day washing week totalling 100 m^3 or 100,000 L/week and annually generating 5,200 m^3. The facility had pre-existing irrigation lines and planned to irrigate all of the washwater annually generated (5,200 m^3) in 10 applications from May to September at a depth of 12.7 mm (0.5 in.) each week. This equates to 127 m^3/ha/application.

$$\frac{\mathbf{5{,}200\ m^3}}{\mathbf{10\ applications \times 127\ \dfrac{m^3}{ha \times application}}} = \mathbf{4.1\ ha}$$

The facility would need 4.1 ha (10.1 acre) to apply all the annual washwater generated.

Winter storage required

Due to field conditions between September and April, the facility needs 240 days of storage or approximately 3,400 m^3. The facility designed a 3,500 m^3 rectangle storage that was 8 m deep x 15 m wide x 30 m long. The storage is designed with a cover to avoid rainfall, a 1 m freeboard and impermeable to ground water.

Agronomic removal nutrient value

The case study looked at how the washwater could be managed through land application. The nutrient value of the washwater for irrigation onto a fresh market spinach crop was determined by collecting samples of washwater to be land applied and completing a water nutrient lab analysis. Results (Table 8–3) show the average nutrients in the washwater. The OMAFRA nutrient recommendation to produce a 4.5 tonne/ha spinach yield would require 110 kg N/ha, 180 kg P_2O_5/ha and 230 K_2O/ha. If additional nutrients are not available in the soil, fertilizer applications would be required.

Table 8–3. Average nutrients in washwater to be land applied (case study)

Nutrient	Washwater Lab Analysis (mg/L)	Washwater Nutrient Supplied (kg/ha)	Remaining Nutrients Required for 4.5 t/ha Spinach Crop (kg/ha)
N*	2	3	107
P_2O_5	35	44	136
K_2O	121	154	76

NOTE: These results do not consider soil test background values.

*measured as nitrate in the washwater

Regulated metal limits

The washwater was evaluated for regulated metals and the results show it was below defined limits (in most cases not detectable).

Food safety suitability

Microbiological analysis showed that washwater was not suitable for irrigation on a fresh market edible crop (e.g., spinach) without pre-treatment to reduce microbial risk. The facility could consider land applying onto a crop that is not sold as a fresh market (e.g., root vegetables, field grain crops). The washwater met four of the five objectives for land application to a fresh market edible crop (Table 8–4).

Table 8–4. Summary of suitability of washwater for land application

Objectives	Outcome
Match volume of washwater for irrigation supply to the available land.	✓
Determine the amount of storage required.	✓
Match agronomic nutrient value of the washwater to crop production.	✓
Meet regulated metal levels.	✓
Food safety suitability of the washwater (applied as irrigation water) onto a fresh market edible crop.	X

8.3 Vegetative Filter Strip System

A Vegetative Filter Strip System (VFSS) distributes washwater to an infiltration area designed and planted in vegetation. Through the process of water infiltration, nutrients are absorbed and solids are collected from the washwater. A VFSS is engineered to be a zero-discharge treatment as all the water and what it carries is taken up within the area.

Description

The design of the VFSS infiltration area is dependent upon the amount of washwater to be treated, soil texture, slope and vegetation. The amount of washwater to be treated is related to the amount of water that can be evapotranspired by the infiltration area. The required size of the infiltration area is also directly related to the soils' saturated hydraulic conductivity. In general, a finer soil texture (e.g., clay vs. sand) has a lower saturated hydraulic conductivity with slower infiltration rates, resulting in a larger infiltration area.

A distribution pipe system (i.e., perforated pipe) evenly spreads the washwater across the entire width of the VFSS.

VFSS slopes range between 2%–12%; steeper slopes require an infiltration area with greater length. There must be no slope across the width of the VFSS infiltration area.

Plant a dense population of grasses and legumes to remove different nutrients from the washwater. Select perennial species according to the climate, tolerance to flooding, long growing season, large root masses, tolerance to salt and low maintenance requirements. Maintain grasses by mowing and reseeding as needed.

For further detailed information on VFSS, see OMAFRA's publication, *Vegetated Filter Strip System Design Manual*, Pub 826, ontario.ca/omafra.

DID YOU KNOW? VFSS are different from vegetative buffer strips and can easily be confused with each other. Vegetative buffer strips are generally placed adjacent and parallel to surface waters. They may feature somewhat uneven terrain to reduce surface flow and collect sediments, and include a variety of vegetation such as trees, bushes and grasses. Buffer strips allow water to pass through, but VFSS is designed as a zero-discharge system.

Considerations

Evaluate if a VFSS meets the facility's needs and the site characteristics.

- A VFSS operates best in the growing season (e.g., summer, fall) when the vegetation is growing quickly. It is not a year-round system.
- Depending on the soil type, the footprint of the required VFSS may need to be larger than expected.
- Dams or ditches can be used to divert upslope runoff away from the VFSS infiltration area.
- There are minimum separation distance requirements for a VFSS from ground water, bedrock, wells, surface water, flood plains, tile drained land and buried refuse to protect water quality.
- Limit traffic over the area to reduce compaction and prevent developing concentrated flow paths.
- Grazing livestock is not permitted on the VFSS area.
- An existing woodlot is not suitable for an infiltration area.
- VFSS for washwater are regulated through an Environmental Compliance Approval process under the *Ontario Water Resources Act, 1990.*
- The *Ontario Water Resources Act, 1990,* requires that a VFSS is designed by a qualified professional (e.g., a professional engineer).

Cost

The cost of a VFSS depends on the size of the infiltration area and the amount of work necessary to grade and seed the area. Table 8–5 summarizes the capital and operational costs.

Table 8–5. Capital and operational costs for a VFSS

Capital Costs	Operational Costs
Professional design	Maintenance (e.g., mowing, baling)
Permits	Reseeding
Grading	Land out of production
Pumps and piping	Fuel/electricity
Seeds	

8.4 Debris Removal

Debris removal eliminates of large pieces (e.g., culled produce, stones, leaves and stems) from the washwater to increase the efficacy of various downstream treatment technologies by preventing clogging and reducing loading. Four options for debris removal are chopper pumps, parabolic screen filters and hydrosieves, progressive passive filtration and self-indexing filters. In a multi-stage treatment system, debris removal is usually the first stage in the treatment process.

8.4.1 Chopper Pumps

A chopper pump can replace a regular pump within an existing plumbing system. Chopper pumps reduce the size of debris which, in some cases, allows them to be removed more easily by other debris removal steps. They are recommended in situations where large vegetable/fruit pieces enter the washwater stream. Chopper pumps have a cutting system that can break up debris into smaller pieces, reducing clogging in downstream treatment steps. Chopper pumps do not remove debris and do not replace debris removal techniques.

8.4.2 Parabolic Screen Filters and Hydrosieves

A parabolic screen filter and hydrosieve remove debris through a curved screen (Figure 8.2) and a process called the Coanda effect (Figure 8.3). It can be either an enclosed or open system and sized according to the facility's hydraulic loading (L/sec). Parabolic screen filters and hydrosieves operate by the same principle with larger, open units commonly called hydrosieves.

Figure 8.2. A hydrosieve removing carrot debris from washwater.

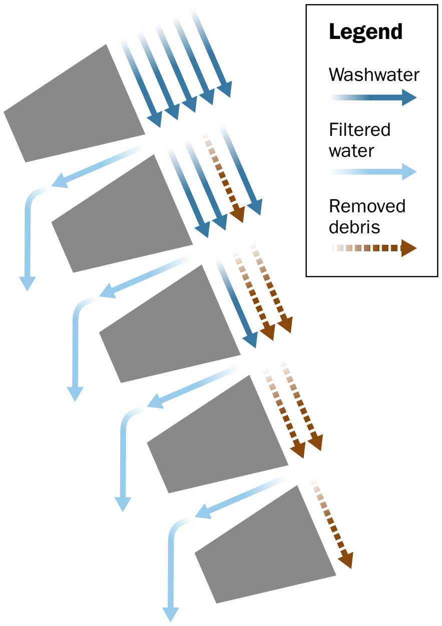


Figure 8.3. The Coanda effect.

DID YOU KNOW? The Coanda effect is the process of flowing water wrapping around the surface of the sieve, which then separates the water from the debris. Water wraps around the surface of the wire that makes up the screen, while the solids continue down the screen (Figure 8.3).

Description

Parabolic screen filters and hydrosieves are designed to remove debris, aggregated soils and vegetable/fruit pieces, but do not remove finer solids.

In Figure 8.4 washwater enters the unit through the inlet (A). The water rises until it overflows (B) onto the parabolic screen filter made from wedge wire. An additional horizontal plate (Figure 8.5) can be added to slow the water and force it down onto the screen. Due to the Coanda effect, the shape of the screen allows the water to fall through the length of the screen while debris remains on the screen's surface (C). The size of debris separated is dependent on the screen size. Debris captured by the filter is removed through a trough. Augers can be added to pull the debris out as required (D). Separated water flows (E) to the outlet (F). For enclosed units, if debris has plugged the screen, the washwater overflows and joins the clarified water leaving the system, bypassing the filtering effect of the screen (G). This bypass continues until the screen is manually cleaned.

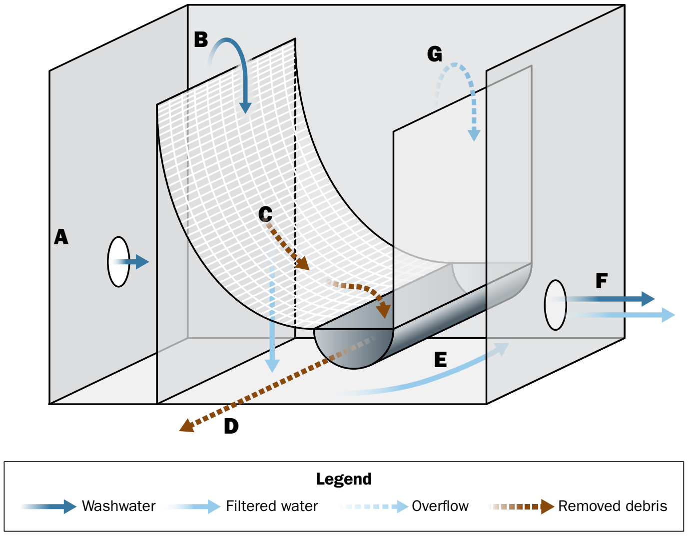


Figure 8.4. Diagram of a parabolic screen filter.

Figure 8.5. A parabolic screen filter fitted with a metal plate to direct the water down onto the screen.

Considerations

Evaluate if a parabolic screen filter or hydrosieve meets the facility's needs:

- A parabolic screen filter requires a "fall"' for the screen to function properly so it must be placed in an area where there is vertical space.
- Place it in an area that allows for visual monitoring for performance.
- The screen requires regular cleaning so it does not become clogged. The frequency of cleaning is based on the flow rate and solid load.
- The debris collected off the screen needs to be managed.

Work with a supplier to size the sieve and get the right curvature of the screen. If after installation the water is not flowing along the surface of the screen, but instead falling over it, add a plate to direct the water flow back down onto the screen (Figure 8.5).

A pump may be required to move the washwater up to the top of the screen as the system operates by gravitational flow. Add a chopper pump if there are a large number of solids pumped.

Cost

The capital cost of the unit depends on its size, determined by the hydraulic loading (flow rate) and screen size. Operational and maintenance costs are minimal since the screens have a long life expectancy. Table 8–6 summarizes the capital and operational costs.

Table 8–6. Capital and operational costs for a parabolic screen filter or hydrosieve

Capital Costs	Operational Costs
Parabolic screen filter or hydrosieve	Maintenance (e.g., cleaning)
Pumps and piping	Debris management (e.g., compost, animal feed)
Auger System	Electricity for pumping

Case Study

The operational performance of a parabolic screen filter is difficult to quantify as it is intended for the removal of coarser solids. However a visual inspection confirms its effectiveness at removing coarse solids, as shown in Figure 8.6.

Figure 8.6. Coarse solids collected by a parabolic screen filter.

The HMGA Water Project results showed that a parabolic screen filter (200 microns) reduced total suspended solids in the recirculated water of a greenhouse by 71% (low load situation). The ability to remove suspended solids is an added benefit on top of the unit's main purpose of removing large solids.

8.4.3 Progressive Passive Filtration

A progressive passive filter is a series of screens with increasingly smaller openings (microns) that trap solids as water flows through the unit (Figure 8.7). It is designed to be a gravity-fed process and is best suited for low water volumes (e.g., washing 2 hr/day with low flow rates) or low solid loading. Undesirable overflow may occur when filters are not cleaned frequently.

Description

The screens are installed on an angle within the tank and the water level gradually climbs as the screens become clogged. Clear the screens before they become fully clogged by removing the screens and rinsing off the solids. Depending on the settling capability of the solids being filtered, the tank holding the screens may also need to be rinsed.

This type of filter is targeted to a range of solids as the screen's opening sizes can be customized based on the particle size distribution of the washwater solids. Removing the solids will reduce the associated nutrient content but further treatment may be required to focus on dissolved nutrients.

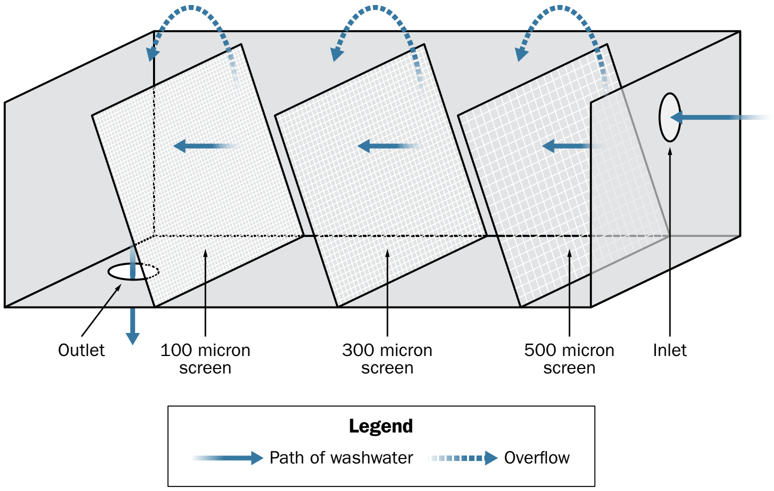


Figure 8.7. Diagram of a progressive passive filter.

Considerations

This system is intended for washing facilities with low solid loads and flow rates. High solid loads require more frequent cleaning. If the screens are clogged by high solids, water flows over the top of one screen and enter the next chamber. The system will easily handle changes in the flow rate as long as the higher flow rates don't overflow the filters.

Size the filter unit for the maximum flow or restrict the flow to the filter's capacity. The number and opening sizes of screens selected are based on the type of solids to be removed. The final screen should have openings no larger than 100 microns to ensure no large solids pass through and settle in the pipes.

Cost

The capital cost of the unit depends on its size, and is determined by the hydraulic loading (flow rate) and the number of screens and screen sizes required. It may be less expensive if custom screens can be installed into an existing water holding tank.

Operational costs are minimal since the screens have a long life expectancy. Maintenance consists of washing off and disposing built-up solids. Table 8–7 summarizes the capital and operational costs.

Table 8–7. Capital and operational costs for a progressive passive filter system

Capital Costs	Operational Costs
Custom built screens	Maintenance (e.g., cleaning, repairs, replacing parts)
Build a new holding tank or modify an existing holding tank	Debris management (e.g., hauling, handling and disposal of compost, animal feed)

Case Study

A small leafy greens washing facility generated washwater 3 hr/day, 5 days/week for 18 weeks with the following characteristics:

- TSS 530 mg/L
- TP 0.5 mg/L
- TKN 4.9 mg/L
- $CBOD_5$ 12 mg/L

The facility installed a progressive passive filter system to remove solids from the washwater (Figure 8.8). The system used four screens with openings measuring: 1000, 500, 300 and 100 microns. Together the screens decreased the solids (TSS) by 91% and the associated TP by 31%, TKN by 29% and $CBOD_5$ by 54%.

The filtered water was reused as an initial rinse in the washing system and did not clog the initial rinse nozzles, which was a main concern. Once washing was complete, the water was applied to the neighbouring field as irrigation water.

When a screen is clogged and needs cleaning:

- Stop the water flow, remove the screen(s) and clean.
- Replace the screen(s) with a spare screen to allow continuous washing and treatment of washwater.
- Clean the screens in place (e.g., squeegee, shop vac) which may or may not be possible with continuous washing and treatment of washwater.

In this case study, the operator removed the final clogged screen (100 micron) while the system was in full operation. As a result, the solids (<300 micron) were passing through the filter system which could collect in the hoses or plug the spray nozzles.

Figure 8.8. Inside view of a progressive passive filter.

8.4.4 Self-Indexing Filter

A self-indexing filter uses a paper or cloth media to separate solids from water. The pore size of the media can range in size from <10–200 microns.

Description

The unit works by feeding a filter media off a roll and laying it on a mesh support that forms a trough (Figure 8.9). Washwater is distributed across the width of the roll and is evenly released onto the media. Washwater flows down the media and settles into the base of the trough where the solids in the water are captured by the filter and the water falls through into a collection tray. The solids eventually clog the filter media and cause the water level to rise. Once a pre-set level is reached, the media is indexed and a predetermined amount of new media is automatically fed off the roll to replace the clogged media in the trough. The removed solids are trapped within and on the filter media and stay with it as it is rolled out of the unit. The soiled media is usually sent to landfill. Some cloth media may be reused once the solids are removed. These are commonly used in greenhouse applications.

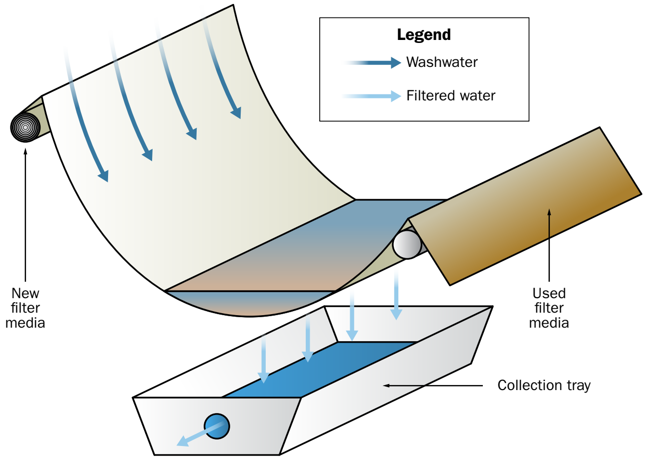


Figure 8.9. Diagram of a self-indexing filter.

Considerations

The system easily handles changes in the flow rate and automatically uses more filter media as necessary depending on the flow rate and solid loading. The system is automated and can be run with minimal operator input.

Cost

The capital cost of the unit depend on its size, and is determined by the hydraulic loading (flow rate) and the solids loading. This system is a proven technology for removing solids and readily available from multiple suppliers.

Labour and maintenance costs are minimal since the system is automated. Operational costs include the disposal of the media and solids. Table 8–8 summarizes the capital and operational costs.

Table 8–8. Capital and operational costs for a self-indexing filter

Capital Costs	Operational Costs
Self-Indexing filter system	Disposal of solids and media (e.g., landfill)
Pumps and piping	Electricity for pumping

Case Study

A greenhouse facility uses a self-indexing filter to manage their recirculated water. As shown in Figure 8.10, the media captured a substantial volume of solids.

Conclusion

Debris removal is a recommended step to ensure treatment systems are not clogged by large pieces of vegetative matter. Chopper pumps are sometimes recommended upstream of other debris removal systems to avoid plugging where large vegetable/fruit pieces are present in the washwater. The selection of a debris removal system will depend upon the facility's flow rate, solids loading and operational constraints (e.g., regular screen cleaning).

Figure 8.10. Solids collected by the paper of a self-indexing filter.

8.5 Solids Removal

Solid removal technologies remove coarse and fine solids (e.g., soil and small organic material) from water after the large debris have been taken out.

An important aspect of solid removal is disposal of the collected waste. Depending on the source and contents of the removed solid load, different disposal options are available such as land application, disposal at a landfill and composting. Additional regulatory requirements may impact the disposal method selected. The disposal of solids is an ongoing cost.

Impact of Solids Characteristics on Treatment

The size and density of the solids in the washwater limits treatment technology options. Particles with low specific gravity (low density) are difficult to settle, and technologies that use gravitational and centrifugal forces to remove the soil may be impractical without the use of coagulation. Particles with larger specific gravity (i.e. greater than water) settle out more quickly.

Larger sized particles (e.g., TSS) can be trapped by a filter, but small sized particles (e.g., TDS) flow through a filter as they are too small to be trapped by the openings.

8.5.1 Centrifuges and Hydrocyclones

Centrifuges and hydrocyclones are two water treatment technologies that use centrifugal force to separate substances, with different densities, from suspension. In washwater treatment they are often used to separate solids from water. In both systems, washwater spins around inside a container which separates solids from water.

Description

Centrifugal force occurs when an object is rotating in a circular motion. The rotation of the object causes outward movement from the centre of a circle, similar to swinging a ball attached to a string in a circular motion around a central pivot point. When washwater containing solids with different densities is rotated at high enough speeds the denser solids are pushed outwards from the centre of the circle the same way the ball attached to the string does. In this way, the solids can be separated from washwater (Figure 8.11). The removal efficiency of dense particles found in washwater is much higher than that of lighter particles.

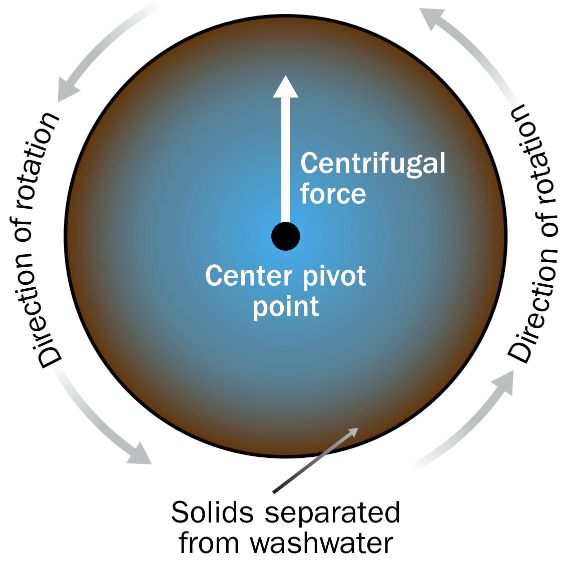


Figure 8.11. Centrifugal force.

For hydrocyclones, the centrifugal force is applied passively and there are no mechanical components except for the pump that feeds the system. The incoming washwater is pumped into a chamber that has grooves on the interior surface to force the water to rotate in the desired circular motion. As the washwater spins around the chamber, solids are separated and captured and clarified water flows out of the top of the unit (Figure 8.12). Some hydrocyclone systems contain multiple hydrocyclones in parallel within one treatment system (Figure 8.13).

For centrifuges, the centrifugal force is applied by a motor rotating the entire chamber that contains the washwater. These systems are able to apply larger forces to the washwater compared to a hydrocyclone, resulting in higher solid separation. Similar to hydrocyclones, the washwater spins around the chamber, solids are separated and captured, and clarified water flows out of the unit.

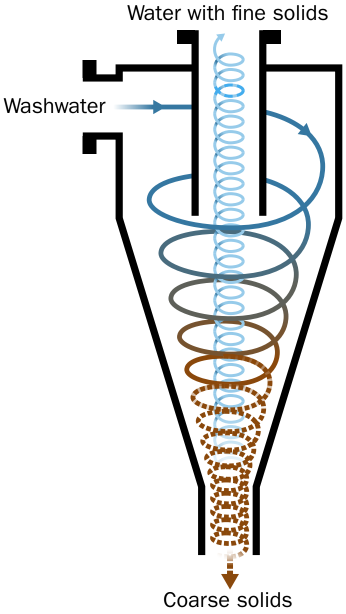


Figure 8.12. Diagram of a hydrocyclone and the process by which it separates solids from liquids.

Figure 8.13. Inside view of the 16 hydrocyclones of a multi-cyclone unit.

Considerations

These technologies only target larger and denser solids. Muck and clay soils with small particle size and low densities are very difficult to remove by centrifugal force. Centrifuges and hydrocyclones have relatively small footprints compared to other technologies and are an option where space is limited.

Cost

The capital cost of a centrifuge or hydrocyclone depends on its size, and is determined by the hydraulic loading (flow rate) and the solids loading. These systems are proven for removing sand and grit and are readily available from suppliers.

Hydrocyclones are less expensive as a capital cost than centrifuges due to their less complex design. A small hydrocyclone can cost a couple hundred dollars. Centrifuges are able to treat more concentrated wastewaters and this is reflected in the cost. A unit designed to treat 100,000–150,000 L/day can cost approximately $100,000.

Operational costs include the disposal of solids and energy consumption (e.g., centrifuge). Table 8–9 summarizes the capital and operational costs.

Table 8–9. Capital and operational costs for a centrifuge and hydrocyclones

Capital Costs	Operational Costs
Centrifuge or hydrocyclone (including pump)	Management of solids (e.g., collection, handling, disposal)
Plumbing	Energy costs

Case Study

The HMGA Water Project evaluated the treatment efficiency of a hydrocyclone for treating vegetable washwater. Several tests were completed using muck, clay and sandy soils. Each sample was prepared by mixing a predetermined amount of soil and water together. The initial cloudiness of the water was measured using a turbidity meter. Each sample was run through a hydrocyclone and retested with the turbidity meter and the depth of solids removed was measured.

Figure 8.14. A hydrocyclone showing heavier mineral soil at bottom and cloudy water above.

The results showed that the hydrocyclone was effective for the removal of larger and heavier mineral soil particles, but was unable to remove the smaller and lighter muck soil from solution. The washwater remained cloudy following treatment by the hydrocyclone showing the need for additional treatment (Figure 8.14). If space is limited, hydrocyclones may be a viable alternative to settling systems for the removal of larger soil particles.

8.5.2 Drum Filters

A drum filter uses a horizontal rotating screened drum to filter solids out of washwater, and is best suited for removing coarse solids early in a treatment system. Drum filters produce two different streams — filtered water and a concentrated liquid waste stream.

Description

Install drum filters as a gravity-fed system or feed with a pump. The water enters the drum and flows by gravity through the rotating screen (Figure 8.15) to the outlet. As the screen becomes clogged with solids, the water level rises within the drum. At a specified level a motor rotates the drum so that the clogged portion of the screen is over a collection tray. A spray bar outside the drum sprays recycled water, collected from under the drum, through the screen and the solids are removed by falling into the collection tray (Figures 8.16 and 8.17). The liquid waste stream exits through the waste outlet. Different screen sizes are used depending on the size of the solids in the washwater. The percentage of solids in the waste stream is dependent on the washwater's initial concentration and operation efficiency of the drum filter.

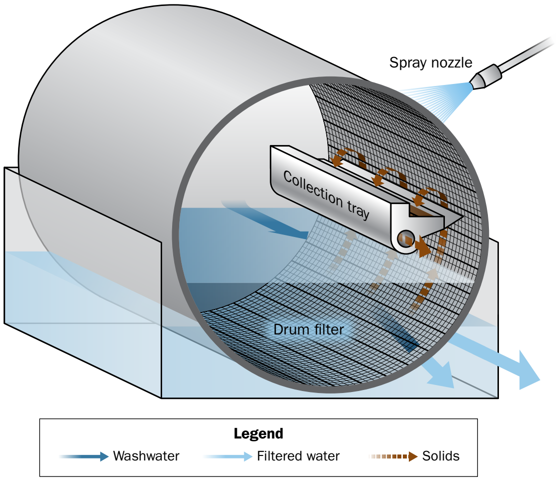


Figure 8.15. Diagram of a drum filter.

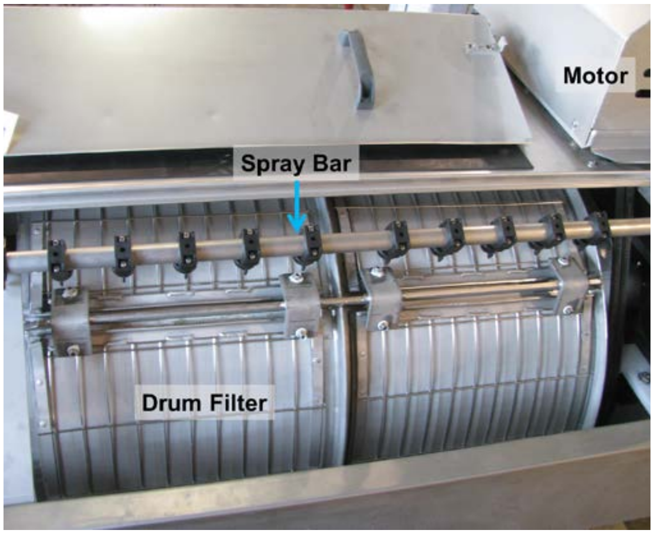


Figure 8.16. Spray bar located on the exterior of the drum.

Figure 8.17. Interior of a drum filter.

Figure 8.18. Solids trapped by the screen are left behind after being drained.

The spray cycle is controlled by a programmable logic controller (PLC) that initiates drum rotation and sprayer operation when the water level sensor is tripped (Figure 8.18). The PLC ensures the drum filter operates only when there is water flow in the system. Changing the frequency and duration of the spray cycle keeps the drum screen clean but affects the water content and volume of the liquid waste stream.

The screen size of a drum filter is dependent on the size and characteristics of the particles to be filtered. The required dimensions of the drum are based on the solid and hydraulic loading rate (a higher load requires a larger drum). Size the drum considering both loading rates since a heavier solid load decreases the maximum flow rate that a specific drum filter can treat.

Considerations

A drum filter is a system that can be integrated into an existing system with minimal modifications due to its small footprint. The screen sizes available for drum filters are not suitable for fine solids. The liquid waste stream can be dewatered to further concentrate it and decrease the volume, making it easier to handle.

Cost

The capital cost of a drum filter is directly related to the water flow and solid load as these two factors determine the required size. Where gravity flow is not feasible, it may be necessary to use pumps to deliver the washwater to the unit.

The ongoing cost of the drum filter operation is the small amount of electricity needed to power the drum rotation and manage the liquid waste stream. The lifespan of a drum filter is approximately 10 years or more. Table 8–10 summarizes the capital and operational costs.

Table 8–10. Capital and operational costs for a drum filter

Capital Costs	Operational Costs
Drum filter	Electricity for pumping and drum operation
Pumps and piping	Liquid waste stream management

Case Study

A drum filter was installed in a root vegetable washing facility and the spray cycle duration was shortened from the factory setting to a 5 second duration. The TSS removal efficiency increased from 46% (factory setting) to 71% (optimized setting) by shortening the spray cycle. This also resulted in a waste stream with a higher amount of solids (Figure 8.19).

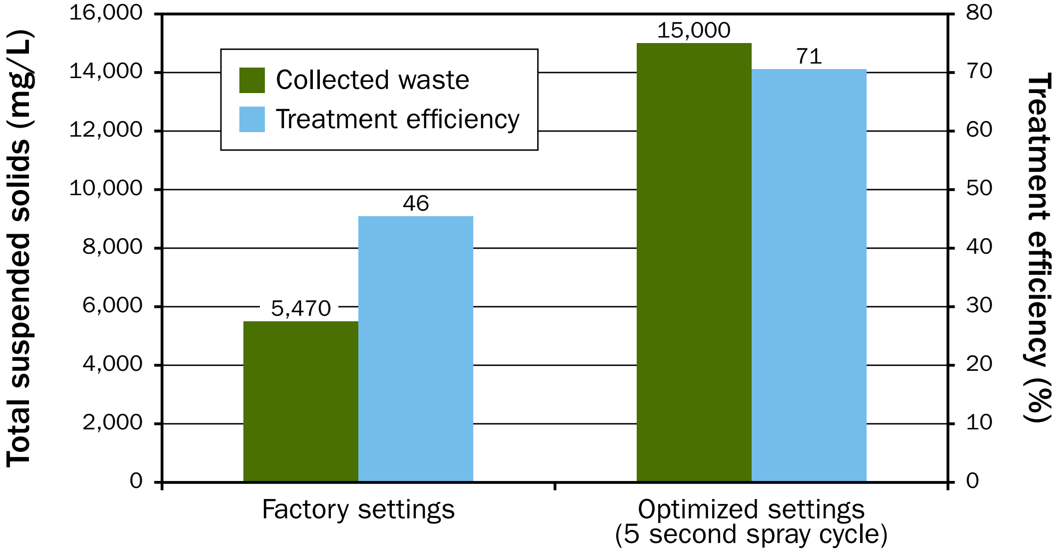


Figure 8.19. Optimized spray cycle for a drum filter.

8.5.3 Filter Bags

Filter bags are cloth bags that separate solids from washwater. The washwater is pumped into the filter bag, the solids are trapped and treated water is allowed to exit through the pores in the fabric. Filter bags are an effective way to dewater the solids coming from the washwater.

Description

Filter bags can be made out of several different types of fabrics using a variety of fibres (Figures 8.20 and 8.21). Woven fabrics are created by interlacing threads together. The fabric has consistently sized openings that depend on the tightness of the lacing and thickness of the thread. Non-woven fabrics are made by compressing fibres together to produce a mesh. Unlike woven fabrics that have one or two layers of threads, non-woven fabrics have multiple layers and the pore spaces are disjointed and not consistent throughout the fabric. Pore spaces, on average, are smaller in non-woven fabrics than in woven fabrics due to the overlapping nature of the fibres. The system becomes more efficient the longer it is used as the pores begin to plug as the retained solids trap the finer solids.

Figure 8.20. Non-woven filter bag fabric.

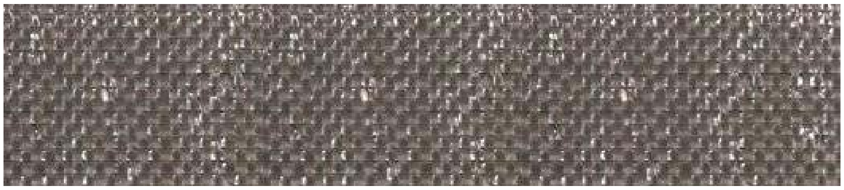


Figure 8.21. Woven filter bag fabric.

Bags are sewn out of fabric and can be produced in different sizes and configurations. Large bags are commonly used only once and are filled, dewatered and cut open to remove the solids for disposal. Smaller bags can be configured into a reusable system by adding an opening to empty out the solids (Figure 8.22). The cord is untied, solids released and the fabric is bundled together and retied.

To capture solids smaller than the fabric's pore size, coagulants may be required (Section 8.4.7). These are added using a dosing system prior to the washwater entering the bag and cause small particles to bind together to form larger solids which can be captured. If a coagulant is used, ensure sufficient mixing and time to bind the particles together before entering the bag (e.g., long enough piping or storage tank).

Figure 8.22. The bottom opening of a reusable filter bag.

Considerations

A tank, pond or reservoir may be necessary to even out the flow being received by the filter bags. Size the pumping system to provide a consistent flow rate of washwater to the filter bags. Work with the bag manufacturer to determine if a coagulant is necessary and the appropriate type and dosage.

During filling, do not allow the filter bags to freeze to ensure consistent performance. If the bags are filled during the winter, place them inside a structure to keep them warm. Two filter bags can be used in parallel during the filling, and by switching between the two they can be completely filled. Once filled, leave the bags to dewater. The longer the bags sit, the easier the solids are to handle.

If the solids are kept in the filter bag for a long enough period of time, and composting guidelines are followed, the removed solids may be used as compost (*Ontario Compost Quality Standards* and the *Guideline for the Production of Compost in Ontario*, ontario.ca).

Filter bags need to accommodate the entire volume of washwater including both the liquids and the solids. As the liquids seep out of the bag, more space becomes available for further filling. Determine the size and number of bags required based on the hydraulic and mass loading of the washwater, and the length of time available/required for dewatering (Figure 8.23). Reusable smaller filter bags are more suitable for small washing facilities, but the large disposable bags are better for bigger washing facilities.

Figure 8.23. A large disposable filter bag (Geotube®).

Cost

The capital costs for a filter bag system includes balancing tanks/reservoirs, pumping infrastructure, a dosing system (if required), a structure to house the bag(s) (if necessary) and the filter bags. A smaller, reusable filter bag has similar costs and does not require as large a footprint (i.e., easier to place indoors).

Ongoing costs include coagulants (if used), replacement bags and electricity for pumping. If the system is large enough, it may need a trained person to operate, maintain and repair the components. Table 8–11 summarizes the capital and operational costs for filter bags.

Table 8–11. Capital and operational costs for a filter bag

Capital Costs	Operational Costs
Balancing tanks/reservoirs	Coagulants
Pumps and piping	Replacement filter bags
Dosing system	Electricity for pumping
Filter bags	Staff training
Indoor housing	Disposal of solids

Case Study

Several types of filter bags were installed at root vegetable washing facilities. The characteristics for the bags tested are provided in Table 8–12.

Table 8–12. Characteristics of the different filter bags tested

Type of Water	Filter Bag Type	Fabric Style	Pore size (micron)	Coagulant Added
Highly dilute carrot washwater	Filter Bag	Non-woven	212	No
Carrot washwater	Geotube	Woven	40	Yes
Carrot washwater	Hanging Geotube	Woven	40	No
Carrot washwater		Woven	40	Yes

Figure 8.24 shows the total suspended solids concentrations (before and after the bags) for all filter bags. Where the TSS of the incoming water was high, the filter bags were very effective in removing TSS. The addition of coagulants significantly improved the performance of the woven fabric and reduced the TSS concentration to below the facility's treatment goal of 25 mg/L.

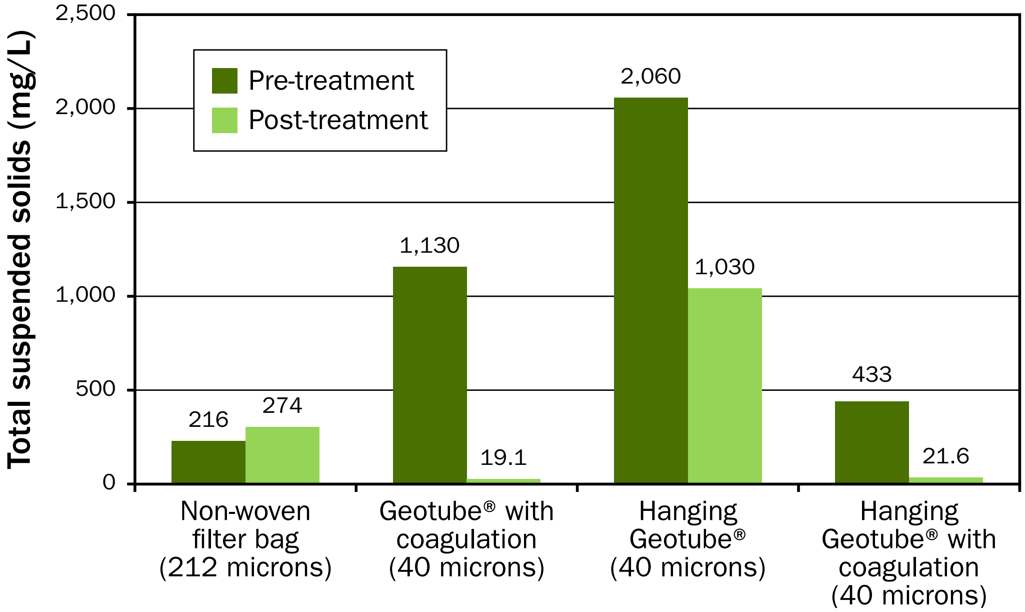


Figure 8.24. Change in total suspended solids concentrations for different filter bags.

In addition to reducing the TSS, the associated nutrients are reduced by the filter bags (Table 8–13). The unanticipated increase in TSS at the site with highly dilute carrot washwater may be a result of the low TSS in the incoming water, larger pore size (212 microns) in the selected filter bag and the pre- and post-treatment samples having relatively similar concentrations.

Table 8–13. Average percent reduction of TSS, TP and TKN in evaluated filter bag systems

Type of Water	Coagulant added	Solids % Reduction	P % Reduction	N % Reduction
Highly dilute carrot washwater	No	-27	8	11
Carrot washwater	Yes	91	42	69
Carrot washwater	No	50	34	61
Carrot washwater	Yes	89	72	68

8.5.4 Settling Tanks

The process of sedimentation removes suspended particles from water by gravity. Water enters tanks or ponds allowing the particles to settle over time. As the particles settled out, the treated water exits the tanks leaving a build-up of solids at the bottom. The required settling time is based on the size and specific gravity of the particles with larger, heavier particles requiring less time to settle out. This treatment system is suggested for sand and silt, since the finer particles of clay and muck require additional time making this system impractical. Settling tanks are best used after the debris removal process.

Description

Settling tanks are concrete structures or clay-lined ponds with different shapes and varying depths (Figure 8.25). The treated water exits at the far end of the tank over a weir or through a pipe at the top of the tank. The amount of time water spends in the tank is called the hydraulic retention time (HRT). The treatment efficiency of settling tanks is dependent on the particle size distribution of the solids, the flow dynamics within the tank and the HRT.

Figure 8.25. An example of a clay-lined settling pond.

Particle size is important. Different sized particles settle out at different rates depending on their shape, weight and density (Table 8–14). Larger, denser particles sink quickly but smaller, less dense particles require more time to settle. Sand and silt particles take seconds to minutes to settle. Clay particles can take days to weeks, but muck particles may not settle unless given months to do so as the majority of particles are smaller than 5 microns with densities similar to water. Use coagulation and flocculation upstream of settling tanks to enhance the settling process. This process adds costs for additional equipment and ongoing operational costs, and increases the amount of solids that settle out and may require a larger tank.

Table 8–14. Size ranges and specific gravity for different soil types

Soil Type	Size (microns)	Specific Gravity
Sand	50–2,000	2.64–2.68[a]
Silt	2–50	2.68–2.72[a]
Clay	<2	2.44–2.92[a]
Peat	0–40,000	1.26–1.90[a]
Muck	<74[b]	1.002[c]

NOTE: 1 mm = 1,000 microns

[a] Source: Ou, C.-Y. (2006). Deep Excavation: Theory and Practice (p. 8). London, UK: CRC Press. Venkatramaiah, C. (2006). Geotechnical Engineering (3rd ed., p. 32). New Delhi, India: New Age International.

[b] Source: Fratta, D. O., Puppala, A. J., & Muhunthan, B. (2010). GeoFlorida (2010). *Advances in Analysis, Modeling & Design* (p. 2753). N.p.: ASCE Publications.

[c] Source: AMEC, Project Number: TR1114005. Report for Wastewater Management Assessment of Vegetable Production Site Nine (9) with on Farm Processing. Holland Marsh Growers' Association, Newmarket, Ontario (2014).

The size of the particle and the rate it settles helps determine the HRT required for adequate settlement. The HRT can be estimated using a mason jar soil test by collecting a water sample in a jar and leaving the solids to settle (Chapter 7, Section 7.4).

The volume and rate washwater passes through the settling tanks are important factors in designing settling ponds and tanks to ensure water flows slowly through the system and allows adequate time for solids to settle out. Add certain design features (e.g., baffles, weirs and plate/tube settlers) to settling tanks to enhance the settling rate in the system.

Settling tanks require additional depth allow solids to accumulate at the bottom of the tank (Figure 8.26). Ensure the tank is deep enough to have both settling and accumulated solid zones. Remove accumulated solids frequently so ongoing settling is not impeded.

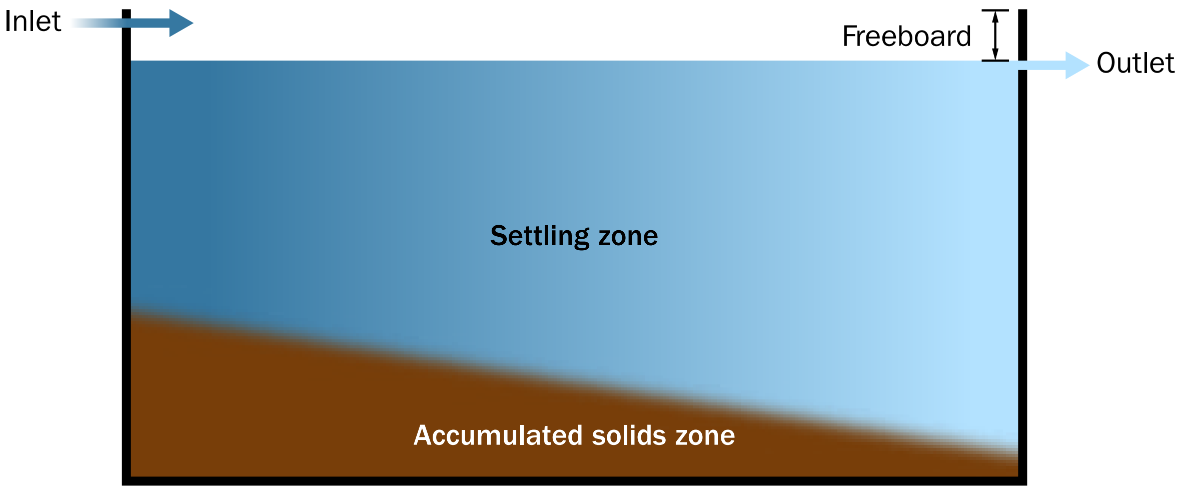


Figure 8.26. Settling tank with settling and accumulated solids zones.

Ensure the design of a settling tank is completed by a qualified professional to determine the required configuration, including surface area and depth.

Settling systems are often made of multiple tanks connected by weirs. Tanks in series (Figure 8.27) allows for more efficient settling by giving the larger particles an opportunity to settle out in the first tanks, leaving the later tanks for the removal of smaller particles. Tanks running in parallel give the option to have one tank emptied and solids removed while the other tanks remain operational.

Figure 8.27. An example of a concrete settling tank with three cells in series.

Considerations

Routinely remove the solids from the settling tanks. The frequency depends on the size and design of the tank, and the amount of solids in the washwater (e.g., an undersized tank needs to be cleaned out more frequently). Develop a plan to manage and dispose of the accumulated solids.

The tanks are usually large structures located outdoors and therefore they are affected by the environment.

- Precipitation collects in tanks that are uncovered. Size the tank to account for this additional inconsistent volume of water.
- The freezing of tanks in the winter months negatively impacts their ability to function. Freezing is more likely if the flow into the tanks is intermittent.
- Keep wildlife (e.g., geese) away from the tanks to reduce possible contamination.

Remove the solids from the tanks shortly after the washing season is over or there is an extended break in production. When washing lines are not operating and little to no water enters a settling tank, the tank stagnates. Any remaining solids and nutrients continue to be a food source to the bacteria present. The solids and nutrients in the tank are converted into other compounds that release stored nitrogen and phosphorus into the water column. The tank may become anaerobic (i.e., lacking oxygen) resulting in poor water quality and releasing a bad odour. In the summer months, warm temperatures accelerate this process and the heat encourages bacterial activity. Aerating tanks encourages more desirable bacteria (e.g., aerobic) to colonize the water and avoid stagnation.

If stagnation cannot be avoided, dispose of the stagnant water from the settling tank separately (e.g., land application, haul to a wastewater treatment plant) prior to resuming washing. Stagnant water contains higher concentrations of nutrients that will not comply with the discharge limits. If washing resumes without emptying stagnant water from the tank, an environmental impact can occur.

Cost

The capital costs for a settling tank depends on the size and materials for construction (e.g., concrete, synthetic liner or a clay lined system). Capital costs may also include a pumping infrastructure, balancing tanks/reservoirs and a dosing system.

Ongoing costs include removal and management of the settled solids, coagulants (if used) and electricity for pumping. Table 8–15 summarizes the capital and operational costs for a settling tank.

Table 8–15. Capital and operational costs for a settling tank

Capital Costs	Operational Costs
Professional design	Disposal of solids
Settling tanks	Coagulation
Pumps and piping	Electricity for pumping
Dosing system	

Case Study #1

An OMAFRA Washwater Characterization Study and HMGA Water Project (2012) measured particle size distribution for six root vegetable washwaters on mineral and muck soils. The results showed that for muck soils an average of 87% of the particles were 5 microns or less in size and for mineral soils 20% of the particles were 5 microns or less in size. Two thirds (66%) of the mineral particles were between 5–20 microns. Muck soil particles have a specific gravity close to water (assumed 1.002), so they float, and particles need more time to settle than mineral soils. Settling times vary substantially with temperature. Table 8–16 shows the settling velocity and time to settle for muck vs. mineral soils of different particle sizes calculated using Stokes' Law.

Table 8–16. Settling velocity and time required to settle soil 0.3 m deep at 20°C

	Muck Soil				Mineral Soil			
Specific Gravity	1.002[a]				2.6			
Particle Size (microns)	Settling Velocity (m/hr)	Time to Settle 0.3 m		Percent of Particles	Settling Velocity (m/hr)	Time to Settle 0.3 m		Percent of Particles
1	4.1×10^{-6}	8.5	years	87%	3.4×10^{-3}	3.9	days	20%
5	$\mathbf{1.0 \times 10^{-4}}$	**120**	**days**	**13%**	$\mathbf{8.2 \times 10^{-2}}$	**3.7**	**hours**	**80%**
13	7.0×10^{-4}	18	days		5.6×10^{-1}	33	minutes	
20	1.7×10^{-3}	7.7	days		1.3 x 100	14	minutes	

[a] AMEC, Project Number: TR1114005. Report for Wastewater Management Assessment of Vegetable Production Site Nine (9) with on Farm Processing. Holland Marsh Growers'Association, Newmarket, Ontario (2014).

As seen in the 5 micron row (Table 8–15), the majority (87%) of the muck soil particles take more than 120 days to settle 0.3 m. The majority (80%) of the mineral soil particles take less than 3.7 hours to settle 0.3 m.

Case Study #2

The HMGA Water Project evaluated several existing settling tank systems including concrete tanks and clay-lined ponds. There were four systems including two 1-cell systems, one 2-cell system and one 3-cell system with no coagulation. Samples were taken over a period of two years at the inlet and outlet of each system to evaluate their performance. The values in Table 8–17 are average % reductions for solids, phosphorus and nitrogen.

Table 8–17. Average percent reduction for evaluated settling systems

Facility Type	System Configuration	% Reduction in TSS	% Reduction in TP	% Reduction in TKN
Celery, broccoli greens	1-cell	56	23	37
Root vegetables	2-cell	30	4	Negligible
Root vegetables, potatoes	3-cell	73	32	14
Average	—	55	21	13

Solids can be effectively removed with settling tanks as demonstrated by the evaluation results. In a settling tank, nutrient reduction is expected to be limited and is predominantly related to the reduction of solids (TSS). Coagulation and flocculation improves the functioning of these systems.

Multiple cell systems are expected to have better reductions in TSS and associated nutrients than single cell systems. The results in Table 8–16 demonstrate that a professional design of settling tanks is more important than adding multiple cells. The evaluated 2-cell system was undersized for the volume of washwater treated resulting in less solid and nutrient removal than the 1-cell systems. With more appropriate design (e.g., larger tanks size), it is expected that the 2-cell system would perform better at removing solids.

8.5.5 Coagulation and Flocculation

Coagulation and flocculation are used in conjunction with other technologies to enhance solid removal efficiencies.

Description

Particles in washwater can be charged and repel each other unless the charges are neutralized. Coagulation neutralizes these charges. Flocculation is the process in which neutralized coagulated particles come together through gentle mixing. If necessary, additional chemicals called flocculant aids are added to encourage this process. It is essential to provide sufficient time for flocculation to occur (e.g., between mixing and solids removal).

Coagulants are added to a water stream using a dosing system (Figure 8.28). The system injects the chemicals into the washwater using metering pumps. The chemicals are mixed by either static (e.g., in-line mixer, baffled pipe) or dynamic mixers (e.g., propeller or paddle mixer). Dosing systems controls can be simple or complex (e.g., a set rate or a fluctuating rate based on feedback from washwater flow and quality monitoring).

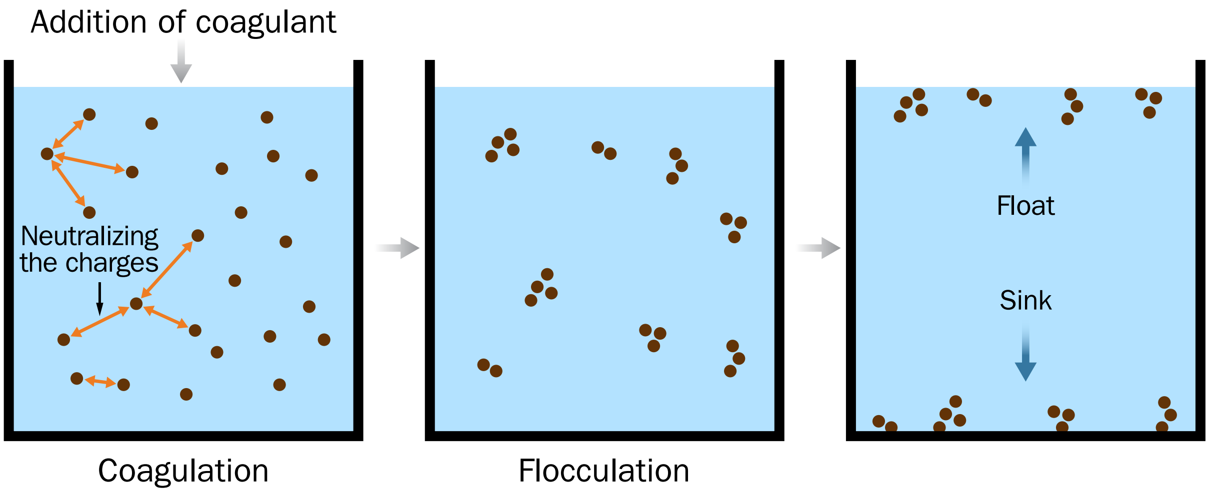


Figure 8.28. The process of coagulation and flocculation.

The type and dose of coagulants chosen are based on the chemistry of the washwater and the size of the particles to be removed. Most coagulants work best within a specified pH range and pH adjustments may be necessary. The choice of coagulant type affects the amount of solid waste produced and how it is managed (e.g., alum produces a lot of waste with potential heavy metal limits). On-site testing is crucial to determine the correct type and dose of coagulant for the facility.

Once the flocculation process is complete, the larger particles (known as "flocs") can be removed from the washwater. The process either causes solids to sink or float, and affects the choice of technology for the removal of the flocs. If the flocs sink, some treatment options are settling tanks or filter systems. If the flocs float, some treatment options are skimmers, Dissolved Air Flotation (DAF) and filter systems.

Considerations

The fate of the water after treatment is an important factor when selecting the appropriate coagulants. If the water is reused in packing or processing, the coagulants and flocculants must adhere to food safety guidelines. If the water is discharged to the environment, the chemicals cannot cause harm to the environment. If the removed solids are to be land applied, ensure the chemicals will not harm the environment or negatively impact the productivity of the land.

Cost

The capital costs for coagulation and flocculation systems include the chemical storage tank(s), dosing system, piping, mixing equipment and tank (if required). Ongoing costs include purchasing the coagulant and flocculent chemicals, and maintenance and electricity for dosing and mixing systems. Table 8–18 summarizes the capital and operational costs for coagulation and flocculation.

Table 8–18. Capital and operational costs for coagulation and flocculation

Capital Costs	Operational Costs
Chemical storage tanks	Coagulant and flocculant aid
Dosing system	Maintenance
Pumps and piping	Electricity for pumping and mixing
Mixing equipment and tank	
Floc removal system (e.g., filtration, settling, DAF unit)	Disposal of solids

If inexpensive coagulants such as alum and iron chloride are used, they may need to be applied at high rates to be effective. Polymerized coagulants could be effective at lower doses, but may be more expensive on a volume of coagulant basis.

Automated dosing systems, which can have higher capital costs, add the required amount of coagulant and flocculant. An automated system reduces treatment inefficiencies and prevents excessive use of chemicals. These systems may result in lower operational costs in the long term.

Case Study

The HMGA Water Project tested vertical hanging Geotubes, with and without coagulation and flocculation, on root vegetable washwater. Figure 8.29 shows the treatment efficiency as a percent reduction of solids and associated nutrients in the washwater. The results demonstrate that the percent reduction of solids, phosphorus and nitrogen in the washwater was greater with the addition of coagulant, compared to no coagulant.

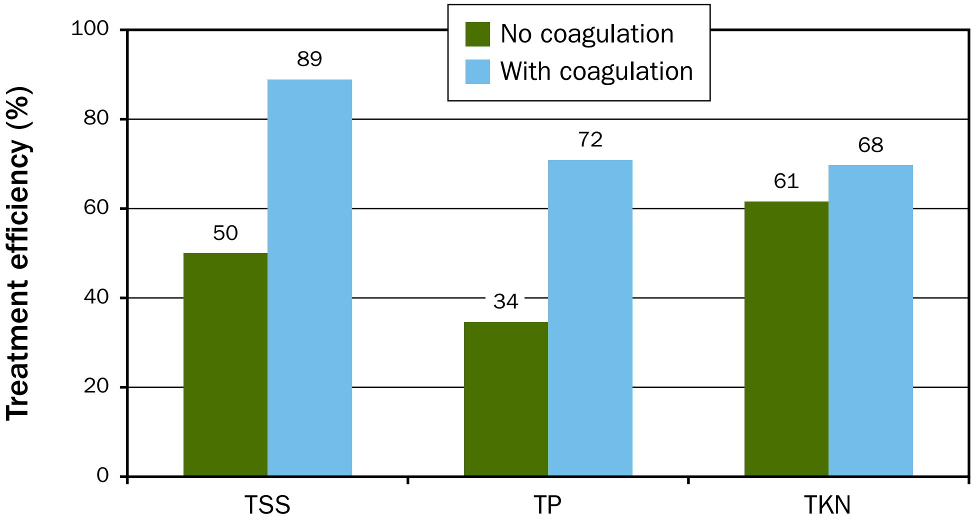


Figure 8.29. Percent reduction in total suspended solids (TSS) and associated nutrients, phosphorus (TP) and Kjeldahl nitrogen (TKN), in a hanging vertical Geotube (with and without the addition of coagulants).

8.5.6 Dissolved Air Flotation

Dissolved Air Flotation (DAF) is a method of removing fine solids from washwater by floating them with pressurized air and then removing them using skimmers.

Description

Pressurized air is injected into washwater. Once in the DAF tank, the dissolved air is no longer pressurized and forms tiny bubbles. These bubbles attach to the fine solids and rise to the surface where they are skimmed off. Treated water exits through the bottom of the tank (Figure 8.30).

Some washwaters contain solids that are too fine to be caught by the rising bubbles. In these cases, coagulation and flocculation can be used to aggregate the solids into larger clusters before the air is added to the process. This takes place in a preceding tank or piping system.

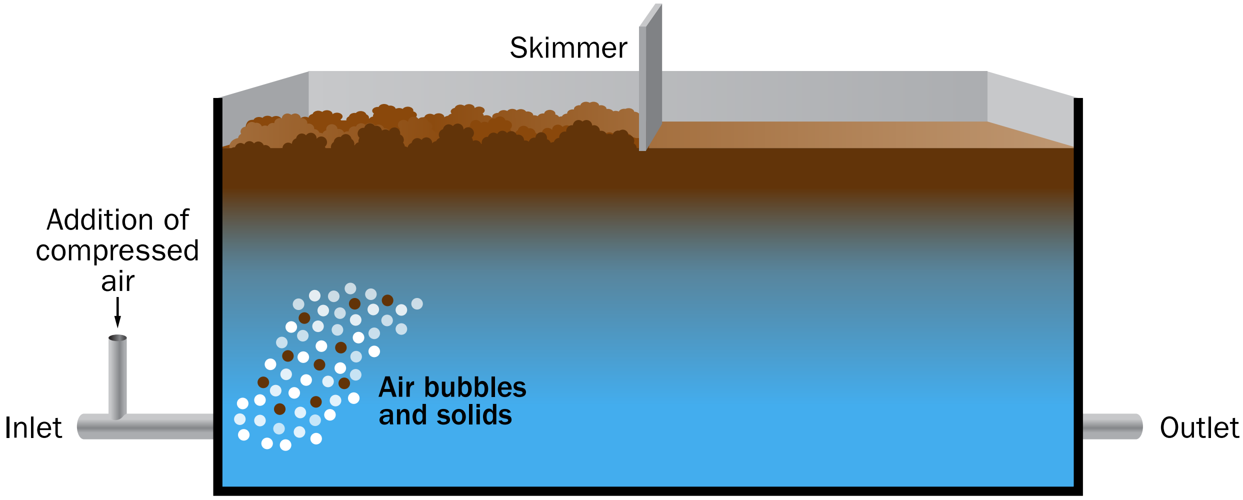


Figure 8.30. Diagram of a dissolved air flotation (DAF) unit.

Considerations

DAF systems have a smaller footprint than a settling system and are installed indoors to avoid freezing. The location of the coagulation and/or flocculation systems must ensure there is sufficient time to aggregate the solids.

Cost

The capital costs for DAF systems include the DAF unit (i.e., tanks, pumps, control panels, skimmers) and possibly a coagulation and flocculation system. Ongoing costs include purchasing the coagulant and flocculent chemicals (if applicable), maintenance and electricity. Table 8–19 summarizes the capital and operational costs for a DAF system.

Table 8–19. Capital and operational costs for DAF

Capital Costs	Operational Costs
DAF Unit	Disposal of solids
Pumps and piping	Maintenance
Coagulation and flocculation system (if required)	Electricity for pumping, air compressor and skimmer
	Coagulant and flocculant aid

8.5.7 Electrocoagulation

Electrocoagulation is a method of coagulation and flocculation that applies an electrical charge (as opposed to chemicals) to aggregate solids by changing the charge on the particles' surfaces.

Description

Electrocoagulation is used in conjunction with other technologies to enhance solid removal efficiencies. Fine solids need to be aggregated together to make them large enough to be efficiently separated from water. Electrocoagulation uses electricity to complete this process.

The washwater enters the electrocoagulation unit where an electrical field is applied using charged metal surfaces called anodes and cathodes. Applying the charge to the water allows the solids to come together to form a stable floc. Some of the floc rises to the surface, while others sink to the bottom with treated water in the middle. The floc is skimmed from the surface and removed from the bottom.

Considerations

The electrocoagulation unit may be small, but the supporting equipment (i.e., pre-reaction holding tank, floc removal tank) may require a substantial indoor footprint. Install pre-reaction holding tanks to ensure a constant incoming washwater flow rate. A PLC operates the unit and must be placed in a dry and clean location. The sacrificial anodes must be replaced on a regular basis.

Some advantages of electrocoagulation over chemical coagulation are:

- The waste stream is free of any added chemicals that impacts disposal options.
- The process is less dependent on the washwater's pH or composition.

An electrocoagulation system should have a dedicated electrical circuit due to high power consumption, in some cases, three-phase power may be required.

Electrocoagulation units have been piloted in Ontario for leafy green washing operations and for washwater in the Holland Marsh.

Cost

Capital costs include the electrocoagulation unit, pumping and piping infrastructure, and a system to handle the waste stream. Ongoing costs include electricity, sacrificial anode replacements, waste handling and maintenance. Table 8–20 summarizes the capital and operational costs for electrocoagulation.

Table 8–20. Capital and operational costs for an electrocoagulation unit

Capital Costs	Operational Costs
Electrocoagulation unit	Electricity
Pre-reaction holding tank	Disposal of solids
Pumps and piping	Maintenance
Upgrade electrical supply (if necessary)	

8.5.8 Sand Filters

Sand filters remove fine solids from washwater using a filter bed of sand granules as the water flows through the unit.

Description

Sand filters remove solids from washwater in two ways:

- straining them out
- attaching to the sand granules

The filter bed contains pores (e.g., space between the sand granules) that allows water to pass through the unit. Solids that are larger than the pores are trapped in the filter bed. Sand granules have a charge and oppositely charged solids in the washwater attach and become trapped.

The pores within a sand filter clogs as water is treated and solids are trapped. To remove the trapped solids, pump a small portion of the treated water backwards through the sand filter (called backwashing). Backwash water has a high concentration of solids and requires disposal. The frequency of backwashing for a sand filter is dependent on the amount of solids in the washwater that gets trapped in the filter.

The types of sand or media used in sand filters are based on the characteristics of the washwater.

Considerations

Sand filter operation may benefit from coarse solids removal earlier in the process as high solid loads cause frequent backwashing.

Multiple sand filters can be operated in parallel to allow one filter to be backwashed while the others continue to filter the washwater. Sand filters can be used in series with different sizes of sand or an alternate media to remove smaller and smaller solids. As an alternative, use a multi-media filter which has multiple sized media in the same filter.

Manage the backwash from sand filters by:

- removing the backwash from the site by an approved hauler
- land applying
- introducing to a composting system
- dewatering (e.g., filter bag, screw press)

Cost

Capital costs include the sand filter unit, pumping and piping infrastructure and a system to handle the waste stream. Ongoing costs will include electricity, sand or alternate media replacement, waste handling and maintenance. Table 8–21 summarizes the capital and operational costs for sand filters.

Table 8–21. Capital and operational costs for sand filters

Capital Costs	Operational Costs
Sand filter unit	Electricity for pumping
Pumps and piping	Disposal of backwash
Tanks for backwashing (optional)	Maintenance
	Sand or alternate media replacement

8.6 Nutrient Reduction

Once coarse and fine solids have been removed from the washwater, the water may appear clear but dissolved nutrients and dissolved solids remain. High nutrient concentrations have detrimental effects on the environment and require treatment prior to discharge.

8.6.1 Biofilters and Bioreactors

Biofilters and bioreactors are a type of washwater treatment that use biological activity as water passes through biologically active surfaces, and target dissolved nutrients such as phosphorus and nitrogen. Solids should be removed before using a biofilter or bioreactor.

Description

Biofilters and bioreactors provide an environment for communities of microorganisms, that consume organic matter and transform or trap nutrients present in the washwater, to thrive. They are designed to provide places where beneficial microorganisms are encouraged to grow and proliferate. These microorganisms require:

- An appropriate surface to attach and grow on.
- Food (organic matter) and nutrients.
- Appropriate temperature, pH, and dissolved oxygen levels.

There are many different types of materials that can be used in biofilters and bioreactors. Examples include inert materials such as sand, gravel, rock, or man-made materials such as plastic and glass structures, or organic material including woodchips, coconut material, crustacean shells and compost (Figures 8.31, 8.32 and 8.33).

Figure 8.31. Lava rock media in a biofilter.

Figure 8.32. Woodchip media in a biofilter.

Figure 8.33. Synthetic cording (a man-made material) in a BioCord®.

The material selected is based on a number of factors including amount and type of surface area available for the microorganisms. Some washwater may not have sufficient food and/or nutrients for the microorganisms. This can be provided through the selection of the appropriate material or added directly to the washwater. For example, woodchips can provide carbon for washwaters with limited organic matter.

The oxygen levels in a biofilter and bioreactor can be controlled to produce the ideal environment for different types of microorganisms depending on the washwater characteristics. The treatment system is designed to be anaerobic/anoxic (i.e., no or low oxygen levels) or aerobic (i.e., high oxygen levels) depending on the treatment objectives. High nutrients levels are better treated with anaerobic/anoxic microorganisms, but high organic matter (e.g., high BOD) is better treated with aerobic microorganisms.

Types of Biofilters and Bioreactors

The following are examples of common biofilters and bioreactors that can be used to treat vegetable washwater.

Woodchip biofilters are simple systems that require a tank or lined pit to hold the woodchips. These filters are designed to remove nutrients from washwater under low oxygen conditions. The microorganisms require a carbon source for food which is provided by the woodchips. Water levels are maintained in the biofilter to ensure the woodchips remain saturated and oxygen levels are kept low.

BioCords are bioreactors that contain synthetic cords with large surface areas. A BioCord system is submerged in a washwater lined pond or tank. It is an aerobic process and may require the addition of oxygen to the washwater (Aeration, Section 8.7.1) to enhance biological activity. The bacteria that grow on BioCords are able to break down organic material and trap nutrients.

Membrane bioreactors (MBR) are membranes with biological activity that remove solids and nutrients from washwater (Membrane, Section 8.8.2). The water flows through the membranes and removes solids similar to a filter process. The microorganisms live on the membrane surface and breakdown the organic material and trap nutrients.

Moving bed bioreactors consist of objects (usually spherical in shape) with a high surface area circulating throughout a holding tank. Bottom aeration moves the objects throughout the holding tank for even distribution and circulation of the washwater. Microorganisms grow on the objects and break down organic matter and trap nutrients.

Considerations

The microorganisms in biofilters and bioreactors are living creatures and are affected by their environment. Air and water temperature, water chemistry (e.g., pH, presence of sanitizers or toxicity) and a consistent amount of incoming organic matter (food) all impact the health of a biological system. The addition of chemicals may be required to adjust pH. Low temperatures can decrease the biological activity of a system but with proper design, biofilters can be used year-round (e.g., insulation, sufficient agitation). There is an initial period required for the establishment of desirable colonies.

While reducing dissolved nutrients and BOD, some bioreactors may generate additional solids if the biofilm detaches from the media. An additional solid removal step (e.g., settling tank) may be necessary to remove these solids after bioreactors.

To reduce the frequency of backwashing and replacement of media (e.g., woodchips), remove as much suspended solids as possible prior to the biofilter to avoid clogging the media. Biofilters or bioreactors can be used as a final polishing step prior to discharge or reuse. A disinfection step may be required if the water is to be reused.

Cost

The capital cost of biofilters and bioreactors are highly variable and dependent on the washwater characteristics, flow rate and the type of biofilter or bioreactor. The capital costs include the materials to grow microorganisms, a lined pond, tank or pit to hold the material, an aerator, chemical dosing system and pump(s).

Ongoing costs include backwash disposal, maintenance, biofilter/bioreactor material replacement, pH adjustment chemicals and electricity. Table 8–22 summarizes the capital and operational costs for biofilters and bioreactors.

Table 8–22. Capital and operational costs for biofilters and bioreactors

Capital Costs	Operational Costs
Lined pond, tank or pit	Disposal of backwash
Biofilter/bioreactor material	Maintenance
Aerator	Biofilter/bioreactor material replacement
A chemical dosing system	pH adjustment chemicals
Pumps and piping	Electricity for pumping
Insulated structure (for winter use)	

Case Study #1

As part of the HMGA Water project, a greenhouse evaluated a lava rock bioreactor to reduce the nutrients in their recirculation water (Table 8–23).

Table 8–23. Percent reduction of various parameters by a lava rock bioreactor

Parameter	% Reduction
Ammonia	30
Nitrate	-18
Dissolved P	27
TP	26
$CBOD_5$	BDL

BDL = Below detectable limit

The results of the test show that ammonia and phosphorus (both total and dissolved) can be reduced using a lava rock bioreactor. The increase in nitrate may be associated with the transformation of nitrogen compounds (e.g., nitrite) into nitrate within the biofilter. This type of transformation is common within biological systems and must be considered in the design phase. At this site there was no detectable CBOD in the greenhouse water either before or after the bioreactor.

Case Study #2

An OMAFRA research project evaluated the effectiveness of a woodchip biofilter to reduce the nutrients in root vegetable washwater. The washwater entering the biofilter had low solid levels as a solid removal system was in installed ahead of it. Table 8–24 shows the percent reduction of various parameters for the woodchip biofilter.

Table 8–24. Percent reduction of various parameters by a woodchip biofilter

Parameter	% Reduction[1]
Nitrate	53
TP	16

[1] Choudhury, T., Robertson, W. D., & Finnigan, D. S. (2016, March 21). Suspended Sediment and *Phosphorus Removal in a Woodchip Filter System Treating Agricultural Washwater*. Journal of Environmental Quality, 45(3), 796-802.

The results of the research show that nitrate can be significantly reduced through the biological activity in a lava rock biofilter. The total phosphorus was also slightly reduced.

Case Study #3

As part of the HMGA Water project, a root vegetable washer evaluated the potential to establish microbiological communities using the BioCord system. The test was started in October when microbiological communities can be more difficult to establish because of cooler temperatures. Fifty-five days after installation, a visual inspection of the BioCord confirmed that microbiological colonies were forming on the surfaces of the units (Figure 8.34).

Figure 8.34. Bacteria growth on a BioCord after 55 days of treating washwater.

8.6.2 Constructed Wetlands

Constructed wetlands are engineered systems designed to replicate the beneficial physical, chemical and biological processes that occur in natural wetlands. They target dissolved nutrients such as phosphorus and nitrogen. Solids should be removed before using a constructed wetland.

Figure 8.35. A constructed wetland.

Description

A constructed wetland is a defined area that contains a mixture of sand, gravel and organic material. They are designed based on flow rate, washwater characteristics and treatment objectives. They provide an environment for microorganisms and hardy wetland plants to break down organic matter, filter out solids and trap nutrients (Figure 8.35).

Considerations

Constructed wetlands are often composed of multiple cells (e.g., 3–4) in sequence through which the washwater can flow horizontally or vertically. Depending on the treatment objectives, different cells are designed for anaerobic or aerobic conditions. Pumping may be required between cells unless the system is designed for a complete gravity flow. The size of the cells is determined by the holding time and the flow rate.

Design cells so that nutrient uptake is done by both plant growth and microbiological activity in the summer months. For systems that operate year-round, the design relies on microbiological activity in the cells as opposed to the plants. Cold conditions reduce the effectiveness of the biological activity. Determine the size of the cells based on the most limiting factors (e.g., winter conditions).

Water flow during the summer months is applied on or at the top of the constructed wetland and travels in a downward direction. To prevent water from freezing in colder temperatures, water is pumped into the bottom of a cell it travels in an upwards direction. The flow direction is controlled by a valve located in each cell. Under cold temperatures, the microbiological activity decreases and reduces the rate of nutrient removal from the washwater.

Phosphorus accumulates in the media and the media becomes saturated with phosphorus, eventually requiring replacement. To extend the life of the media, harvest biomass (containing phosphorus) from the wetland on a regular basis.

Cost

The capital cost of a constructed wetland is dependent on the washwater characteristics, flow rate and the configuration. The capital costs include design, construction and pumping equipment. The cells may be open concrete tanks or lined pits.

Ongoing costs include maintenance (e.g., removal excess vegetation, replanting, removal and replacement of phosphorus saturated media) and electricity if needed for pumping. Table 8–25 summarizes the capital and operational costs for a constructed wetland.

Table 8–25. Capital and operational costs for a constructed wetland

Capital Costs	Operational Costs
Design (e.g., engineering)	Maintenance (e.g., removal of excess vegetation, replanting, replacement of media)
Construction (e.g., fill material, plants)	Electricity for pumping
Concrete tank or lined pit	Land out of production
Pumps and piping	

8.7 Dissolved Materials Removal

Once debris, solids and associated nutrients have been removed from the washwater, the water may appear clear but dissolved materials remain. High concentrations of various dissolved materials (e.g., BOD) can have detrimental effects on the environment and require further treatment prior to discharge.

8.7.1 Aeration

Description

Aeration is a process that adds air to washwater within a tank or pond. The use of aeration during washwater treatment increases the amount of dissolved oxygen (DO) in the water. The additional oxygen creates an aerobic environment that encourages aerobic microbial activity to decompose dissolved materials more efficiently than anaerobic microbes. Aeration reduces BOD and can also promote the mixing of washwater to enhance coagulation and flocculation or filtering systems. Locate aeration equipment either on the water surface or on the bottom of a tank.

When choosing between bottom or surface aeration, there are several factors to consider:

- tank depth and surface area (e.g., ability to deliver oxygen throughout the tank)
- electrical capacity at the site
- summer and winter conditions
- issue of re-suspending settled solids

Bottom Aeration

Description

Bottom aeration is known by several different names including diffused aeration, lakebed aeration, and destratification systems. There are three components to a bottom aerator:

1. diffuser (e.g., perforated tubing or porous stone)
2. weighted air hose
3. compressor (located on the surface)

A compressor, which requires a power supply, provides compressed air through the air hose to the diffuser (Figure 8.36). Bubbles are released from the diffuser that range in size from fine (1–3 mm) to coarse (5–12 mm). Aerators that produce smaller bubbles are more efficient at increasing dissolved oxygen in the washwater due to the ratio of surface area to volume and the slower speed at which they rise. As the bubbles rise, they circulate the water from below causing a surface disturbance (Figure 8.37). Bottom aerators provide air uniformly throughout the water column (vertical). A diffuser releases air to a specific section of the tank and multiple diffusers are used to cover greater areas of the tank.

Figure 8.36. Bottom aeration diffuser.

Figure 8.37. Surface disturbance by a diffuser.

The efficiency of a bottom aeration system increases with greater tank depth. Their use is not recommended for ponds or tanks less than 2.5–3 m deep. When used in shallow tanks, more diffusers are necessary (compared to a deep tank) to ensure there are no non-aerated areas (Figures 8.38, 8.39 and 8.40).

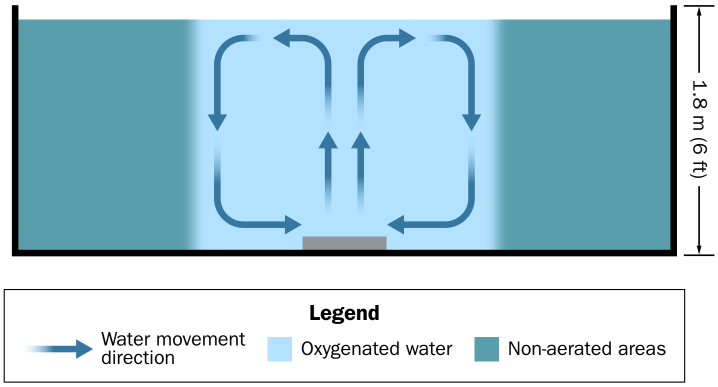


Figure 8.38. A shallow tank with a bottom aerator showing large non-aerated areas.

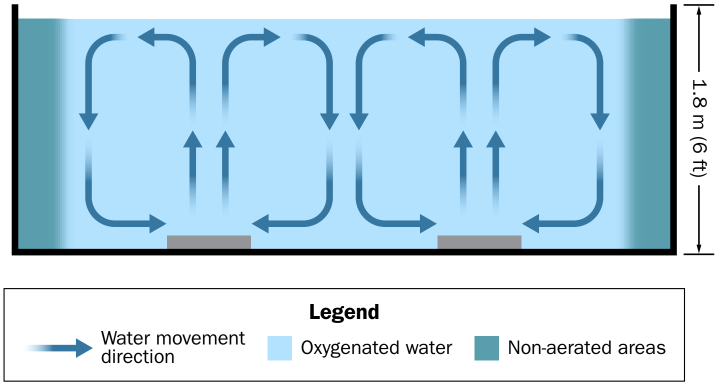


Figure 8.39. A shallow tank with two bottom aerators showing small non-aerated areas.

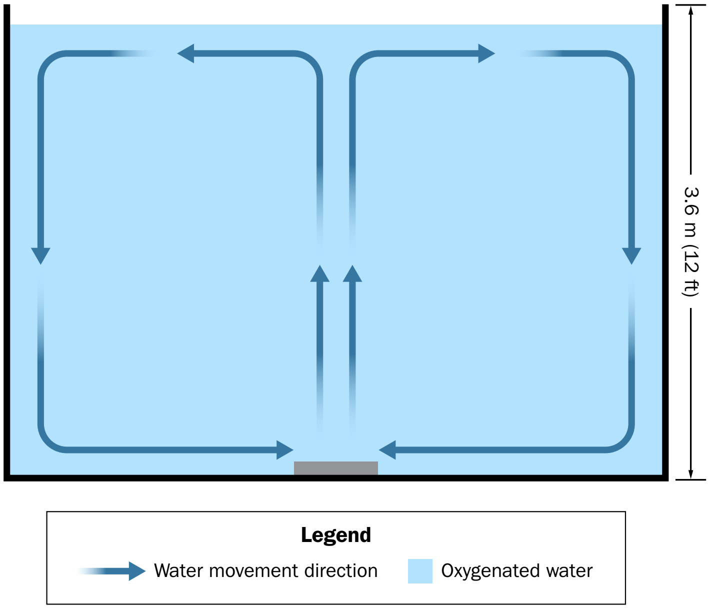


Figure 8.40. A deep tank with a bottom aerator showing no non-aerated areas.

Cost

A bottom aeration system will have capital costs for diffusers, air compressors, hoses, and associated costs for installation and design (e.g., sizing and number of diffusers). Bottom aeration can be installed into existing tanks or new ones are purchased.

Ongoing costs include maintenance and electricity to run the compressor. Table 8–26 summarizes the capital and operational costs for a bottom aerator.

Table 8–26. Capital and operational costs for a bottom aerator

Capital Costs	Operational Costs
Design	Maintenance
Diffusers	Electricity
Air compressors	
Hoses	
Installation	

Surface Aeration

Surface aeration can occur actively (e.g., pumped) or passively (e.g., riffles, weirs).

Description

Active surface aeration systems consist of a float and a water pump. The aerator floats on the surface of the tank or pond and pumps the water into the air (e.g., a fountain) (Figures 8.41, 8.42 and 8.43). The disturbance caused by the water movement allows for gas venting and oxygen transfer into the water.

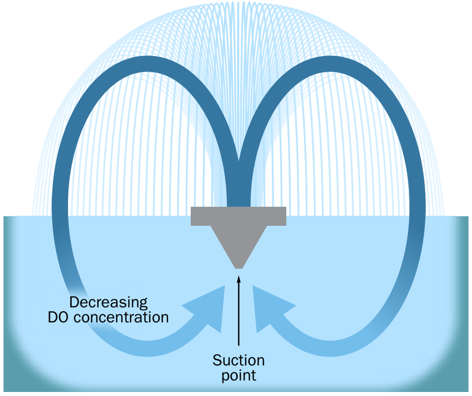


Figure 8.41. Surface aerator showing water movement and dissolved oxygen concentration.

Figure 8.42. An installed surface aeration system.

Figure 8.43. Surface aeration in operation.

Surface aerators function best in tanks or ponds with depths not exceeding 2.5–3 m deep. There is an uneven distribution of oxygen through the water column (vertical) when using these aerators due to the water only being drawn from the surface. The highest concentration of oxygen is in the pumped water and it is lowest farthest from the suction point, leaving non-aerated areas. Surface aeration, as opposed to bottom aeration, may not disturb residual sediment at the bottom of the tank.

Cost

A surface aeration system has capital costs for design, aerators and electrical capacity. Surface aeration can be installed into existing tanks.

Ongoing costs include maintenance and electricity to run the aerator. Note that the electricity demand of a surface aerator is higher than for a bottom aerator. Table 8–27 summarizes the capital and operational costs for a surface aerator.

Table 8–27. Capital and operational costs for a surface aerator

Capital Costs	Operational Costs
Aerator	Maintenance
Electrical capacity	Electricity to run the aerator
Design	

Riffles and Weirs

Description

Riffles consist of an uneven surface formed when water flows over coarse substrates (e.g., rocks) just below the water surface and/or by reducing the width of water pathways. The combination of the irregular surface and water movement creates a turbulent flow with higher velocity that aerates the water as it flows.

Riffles can be naturally occurring or constructed. They are built during stream reconstruction using rocks and boulders, and their effect can be mimicked in washwater treatment systems using shaped concrete (Figure 8.44).

Weirs are a waterfall structure where air is introduced through turbulence where falling water meets the surface water (Figure 8.45). This is another system that can occur naturally or be constructed.

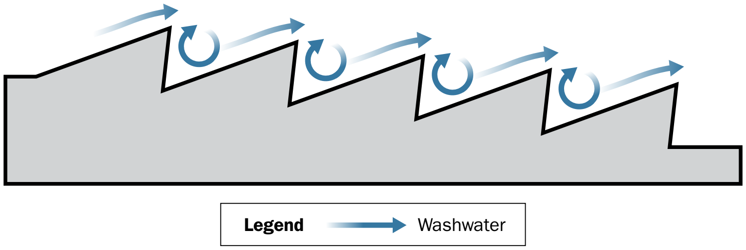


Figure 8.44. Water movement over a riffle.

Place riffles and weirs between two tanks or ponds, rather than using piping. These types of aeration are passive systems that don't require electricity and require little maintenance. The disadvantage of a riffle is the amount of oxygen transferred to the washwater is limited and is dependent upon the length and design of the riffle.

Cost

There are minimal capital costs associated with riffles and weirs as they require limited maintenance and no ongoing costs. The main costs are designing and constructing the structures. Cleaning may be necessary depending on the quality of water travelling through or over them. Table 8–28 summarizes the capital and operational costs for a riffle or weir.

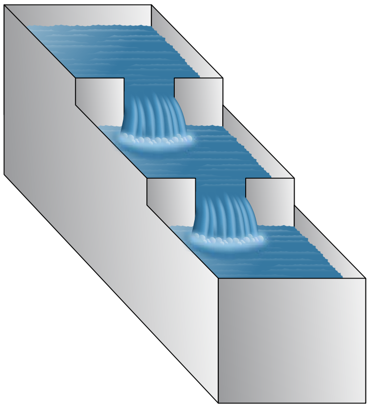


Figure 8.45. Water flowing over a weir.

Table 8–28. Capital and operational costs for a riffle or weir

Capital Costs	Operational Costs
Construction	Limited maintenance (e.g., cleaning)
Design	

Case Study #1

The HMGA Water Project evaluated two surface aerators (B) in the third tank of a three-tank system at a root vegetable washing facility (Figure 8.46). Pre-aeration (A) and post-aeration (C) samples for water quality parameters were taken at the tank's inlet and outlet.

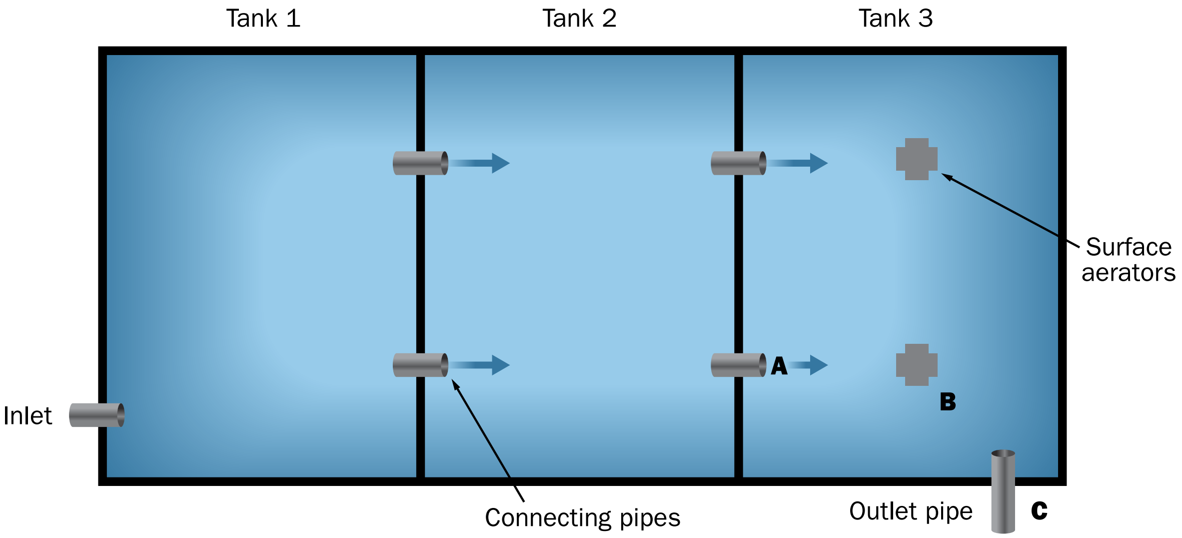


Figure 8.46. Plan view of surface aerators installed in a three-tank system.

The dissolved oxygen increased between the inlet to tank 3 and the outlet, as a result of the aeration (Table 8–29). The impact of active surface aeration had a positive effect on water quality parameters.

Table 8–29. Dissolved oxygen content pre-aerator, at aerator and at the outlet

Parameter	Pre-Aerator (A) (mg/L)	At-Aerator (B) (mg/L)	Outlet (C) (mg/L)	% Change
DO	0.1	1.9	2.3	+2210
NH_3-N	1.7	—	0.16	-91
TP	2.4	—	2.1	-13
$CBOD_5$	225	—	40	-82

Figure 8.47. Fountain-style aerator.

Case Study #2

Testing was carried out at another root vegetable washing facility with a 1-cell tank with two fountain-style aerators (Figure 8.47). Water quality samples were taken at the inlet to the tank and at the outlet. The surface aeration resulted in a decrease of TKN (40%), TP (45%), $CBOD_5$ (47%) and TSS (56%).

8.8 Fine Filtration

After the removal of debris, majority of solids and associated nutrients, fine filtration is the final step to remove any remaining dissolved solids and nutrients. This stage is necessary to create potable water and may be used in certain discharge situations (e.g., discharging into a sensitive waterbody).

8.8.1 Capacitive Deionization

Description

Capacitive deionization (CapDI) is a process where very small charged particles (i.e., ions) are removed from washwater. Washwater flows through a unit containing negatively and positively charged electrodes. Dissolved ions (e.g., phosphorus) are attracted to the oppositely charged electrode where they are held, while treated washwater flows out of the unit (Figure 8.48). The collected ions are released by reversing the charge of the electrodes during a backwash cycle. The resulting backwash water is directed to a managed waste stream. Design systems to target different ions depending on the chemistry of the washwater.

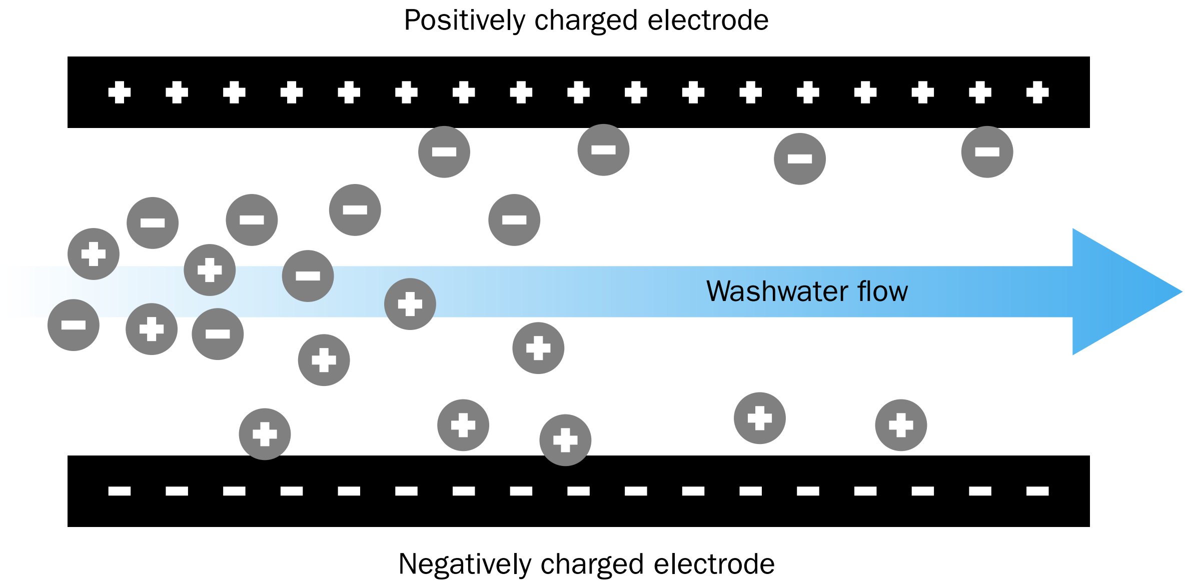


Figure 8.48. Capacitive deionization process.

Considerations

CapDI systems are complex units and require specialized training (e.g., computer-based control systems) to operate. Place the units indoors to prevent freezing and damaging the parts. A sufficient electrical capacity is required to operate the unit. Check with the manufacturer to determine system requirements.

Options to manage the backwash include:

- removing the backwash from the site by an approved hauler
- land applying
- transform into a fertilizer product (e.g., approved through the Canadian Food Inspection Agency)

Cost

Capital costs include the CapDI unit (can be expensive), piping infrastructure, internet infrastructure, electrical infrastructure and a system to handle the waste stream. The unit operates using a computer (i.e., PLC unit). Ongoing costs include electricity, waste handling, monitoring, operator costs and maintenance. Table 8–30 summarizes the capital and operational costs for a CapDI unit.

Table 8–30. Capital and operational costs for a capacitive deionization unit

Capital Costs	Operational Costs
CapDI unit	Electricity
Pumping and piping	Waste handling
Computer control infrastructure	Monitoring
Electrical infrastructure	Operator costs
Waste stream handling system	Maintenance

Case Study

The HMGA Water Project evaluated a CapDI unit at a root vegetable washing facility after solid removal when water appeared clear. Two tests were conducted at different settings, to remove 50% (setting 1) or 90% (setting 2) of the ions from the incoming washwater. Water quality samples were taken at the inlet, outlet and of the backwash at both settings.

Research shows the system reduced the total dissolved solids (TDS), total phosphorus (TP) and ammonia at settings 1 and 2 (Figure 8.49). Other forms of nitrogen and neutrally-charged molecules were not removed by this system and passed through into the effluent. The backwash cycle removed the captured ions and produced a concentrated stream of solids and nutrients.

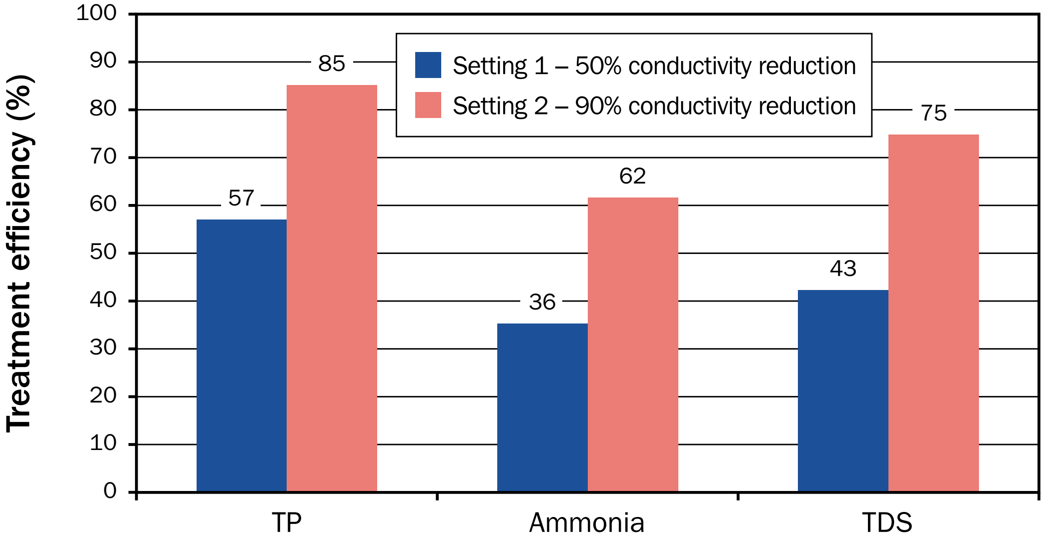


Figure 8.49. Percent reduction in total phosphorus (TP), ammonia and total dissolved solids (TDS) at two settings (50% and 90% reduction in conductivity) by a CapDI unit.

8.8.2 Membrane Filtration

Description

Membrane filters are very small sieves that separate particles (as small as molecules and elements) by their physical properties and electrical charge. Developments in material science have advanced the manufacture of membranes with very accurate and precise pore sizes (Table 8–31) allowing for the filtration of specific charged particles (e.g., nitrate and phosphorus). The pore size of the selected filter type ranges from 10 to less than 0.001 microns. For context, a human hair has a width of 100 microns.

Table 8–31. Pore size of membrane technologies

Filter Type	Pore Size (micron)	Examples
Microfiltration (MF)	0.1–10	bacteria, oil emulsions
Ultrafiltration (UF)	0.01–0.1	proteins, viruses
Nanofiltration (NF)	0.001–0.01	phosphorus, nitrate
Reverse Osmosis (RO)	<0.001	metals, chloride

Note: 1mm = 1,000 microns

Membrane filters are typically pressure fed cartridge systems. As the pore size gets smaller, higher pressures are required to push the water through the filter. As an alternative to higher pressures, smaller particles are often separated by their electrical charge rather than their physical properties (i.e., size). Reverse osmosis (RO) is the most expensive process to operate (i.e., high electrical costs) due to its very small pore size and high pressure required. After water passes through a RO unit it is essentially pure or potable water.

Considerations

Membranes are often used for specific target particles. It is important that larger physical particles do not clog the membrane. Pre-treatment is a necessary step if there are larger particle sizes to prevent constant membrane fouling and backwashing. If the washwater contains carbonates (e.g., hard water) pre-treatment may include acid injection. Membranes may be used in sequence (e.g., stacking) with smaller and smaller pore sizes to ensure the particle sizes being removed are matched to each membrane step. These systems generate a constant reject line of water that must be managed.

Membrane systems need regular backwashing to prevent fouling by solids. Water is pumped back through the membrane to remove the solids and this backwash water is directed to a managed waste stream. These systems have automatic backwash cycles and some training is required to properly operate them.

Washwater with insufficient pre-treatment may cause the membrane to require cleaning or replacement sooner than necessary. Membranes are usually cleaned many times before they are replaced. Some are cleaned *in-situ*, others are removed and cleaned in a cleaning chamber, and some are sent away for cleaning. Common cleaners are acids or bases, depending on the type of membrane and deposits. Determine the need for membrane cleaning by monitoring the pressure drop across the membrane. Membrane technology is rapidly developing with reduced fouling of the membranes and lower volumes of wastewater. Replace the membranes as required, based on the amount of solids in the washwater and the amount of cleaning.

Avoid physically damaging the membranes with chemicals, excessive pressure or temperature shock. Keep the membranes indoors and do not allow them to freeze (including during storage). Before storing membranes, fill them with a recommended solution to avoid drying out and prevent biological fouling.

Cost

Capital costs include the membrane filtration unit (which can be expensive), pumping and piping infrastructure, and a system to handle the waste stream. They are often computerized to control the backwashing process.

Ongoing costs include electricity for pumping (e.g., high pressure), membrane replacement, waste handling, monitoring, operator costs and maintenance. Table 8–32 summarizes the capital and operational costs for a membrane filtration unit.

Table 8–32. Capital and operational costs for a membrane filtration unit

Capital Costs	Operational Costs
Membrane filtration unit	Electricity for pumping and membrane operation
Pumping and piping	Membrane replacement
Waste stream handling system	Waste handling
	Operator costs
	Maintenance
	Monitoring

Case Study

The HMGA Water Project evaluated an ultrafiltration (UF) membrane filtration unit at a root vegetable washing facility. Water quality samples were taken at the inlet and outlet of the membrane filtration unit.

The results show that the UF unit was able to significantly reduce total suspended solids (TSS). The levels of total Kjeldahl nitrogen (TKN) and total phosphorus (TP) were also reduced (Figure 8.50).

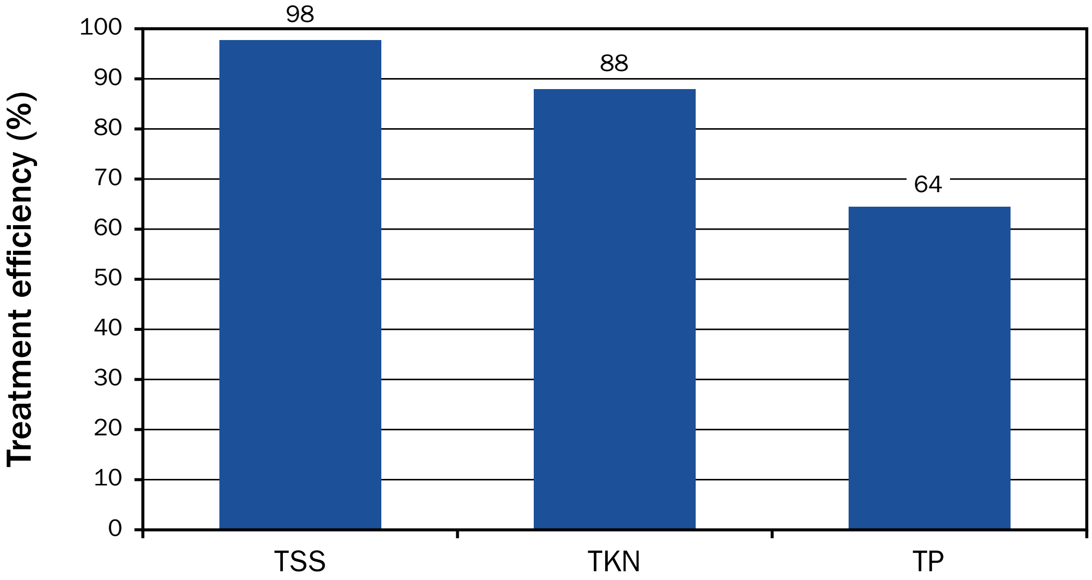


Figure 8.50. Percent reduction of total suspended solids (TSS), total phosphorus (TP) and total Kjeldahl nitrogen (TKN) by an ultrafiltration unit.

8.9 Disinfection

Disinfection kills or deactivates microorganisms (e.g., *E. coli*) and viruses that are present in the washwater to an acceptable level. This step is necessary if treatment objectives include producing potable water. Example technologies include chlorine, ozone and ultraviolet systems.

The presence of organic matter (e.g., plant material and juices, microbes, soil) impacts the effectiveness of disinfection technologies, and consumes chlorine and ozone, hides the microorganism from the disinfectant and absorbs UV. Remove any organic matter before the disinfection step.

Disinfection is often the final step in a washwater treatment system, but some systems include a disinfection step at the start to reduce the presence of spoilage organisms in the water. Final disinfection steps must be placed after any biological treatment steps so disinfection does not kill the beneficial microorganisms required for biological treatments (e.g., biofilters). Disinfection does not remove all microorganisms and viruses from the product, but can kill, deactivate or reduce those present in the water.

8.9.1 Chlorine

Description

Chlorine dosing is a widely used disinfection technique. When added to water, chlorine forms compounds that act as oxidizing agents to kill or deactivate microorganisms and viruses. A metering pump and chlorine storage tank are used to supply chlorine to the washwater to be treated. Alternatively, use a mixing tank to treat the washwater with chlorine in batches. Free chlorine — the chlorine that remains after interacting with the organic matter — continues to disinfect the water

Considerations

Chlorine is less effective when organic matter is present because organic matter deactivates the chlorine. Where the organic matter levels in the washwater are highly variable, organic matter removal (prior to the disinfection step) is necessary or the chlorine dosing levels will need frequent adjustments.

The chlorine dose is based on the source water quality and flow rate. Monitor chlorine concentrations by taking water samples and analyzing to ensure that chlorine dose is adequate, but not excessive. This may be done with a continuous analyzer installed at the facility. Chlorine can be measured as total chlorine and free chlorine. Free chlorine is used to determine if the chlorine dose is adequate for its intended use and purpose. Too much chlorine is undesirable (e.g., impact on produce colour, off gassing from the wash tank or water bodies that may receive the discharge water) and the chlorine concentrations may need to be reduced.

Chlorine needs sufficient contact time with the washwater to kill or deactivate the microorganisms or viruses, and this can be accomplished in a tank or a sufficient length of pipe.

Cost

Capital costs include the design, dosing pump, chlorine storage tank, reaction tank or pipe.

Ongoing costs include chlorine, monitoring and maintenance. Table 8–33 summarizes the capital and operational costs for chlorine disinfection.

Table 8–33. Capital and operational costs for chlorine disinfection

Capital Costs	Operational Costs
Design	Chlorine
Dosing pump	Monitoring
Chlorine storage tank	Maintenance
Reaction tank or pipe	

8.9.2 Ozone

Description

Ozone is a molecule made up of three oxygen atoms that can effectively oxidize microorganisms and viruses causing them to be inactive. Ozone is created by passing filtered air through an electrical field to produce gaseous ozone. The ozone gas is fed into a reaction tank where it reacts with the microorganisms and viruses.

Considerations

In the presence of organic matter, ozone is rendered less effective. Where the organic matter levels in the washwater are highly variable, remove organic matter before the disinfection step or the ozone dosing levels will need frequent adjustments.

The ozone dosing rate is based on the source water quality and flow rate. Monitor ozone concentrations to ensure the ozone dose is adequate, but not excessive. Excessive ozone in washwater is a serious health and safety concern (e.g., displaces breathable oxygen) in the washing facility as the water releases the excess ozone as a gas. For safety reasons, an ozone system must have an air handling and ozone destruction unit.

Ozone is often used instead of chlorine to avoid potential by-products resulting from the chlorination process. The cost of treating washwater with ozone is normally higher than chlorination as the ozone generation requires specialized equipment. Check with the manufacturer to determine electrical and operational specific requirements.

Cost

Capital costs include the ozone treatment unit and the supporting infrastructure.

Ongoing costs include electricity, monitoring and maintenance. Table 8–34 summarizes the capital and operational costs for ozone disinfection.

Table 8–34. Capital and operational costs for ozone disinfection

Capital Costs	Operational Costs
Ozone treatment unit	Electricity for pumping and ozone generation
Pumping and piping	Monitoring
Air handling system or ozone destruction unit	Maintenance

8.9.3 Ultraviolet Disinfection

Description

Ultraviolet (UV) disinfection inactivates microorganisms and viruses in water by having them pass by a single or series of light bulbs emitting ultraviolet light. The UV rays penetrate the microorganisms and viruses and deactivate them. Unlike chlorine, UV only disinfects water as it passes through the UV unit and there is no residual disinfection.

Considerations

The size and number of UV lights is dependent on the quality and flow rate of the washwater. The turbidity (i.e., the ability for light to be transmitted through the washwater) greatly impacts the ability for UV lights to deactivate microorganisms and viruses. Organic matter and particulate will also absorb the UV light and shield the microorganisms and viruses from being deactivated by the light (Figures 8.51 and 8.52).

If disinfection is required beyond the point of treatment (e.g., prolonged storage), a secondary disinfectant may be added (e.g., chlorine).

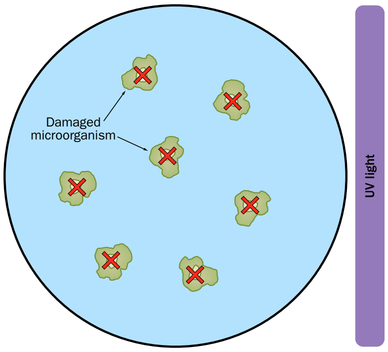


Figure 8.51. UV disinfection system with no organic matter or particulate.

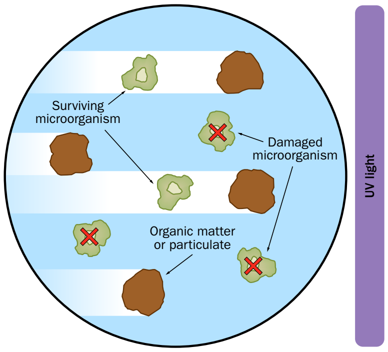


Figure 8.52. UV disinfection system with organic matter, particulate and surviving microorganisms.

Cost

Capital costs include the UV lamps and piping.

Ongoing costs include electricity, bulb replacement, monitoring and maintenance. Table 8–35 summarizes the capital and operational costs for ultraviolet disinfection.

Table 8–35. Capital and operational costs for ultraviolet disinfection

Capital Costs	Operational Costs
UV lamps	Electricity
Pumping (if necessary) and piping	Monitoring
	Maintenance (e.g., lamp cleaning)
	Bulb replacement

9. Purchasing Capital Equipment

9.1 Introduction

The purchase of new treatment equipment for any washing facility is an important part of operations. Be involved and actively manage the purchasing process to control cost and reduce risk. Hiring a consultant to manage some aspects of the process may be a good investment.

There are 10 steps to purchasing treatment equipment (Figure 9.1).

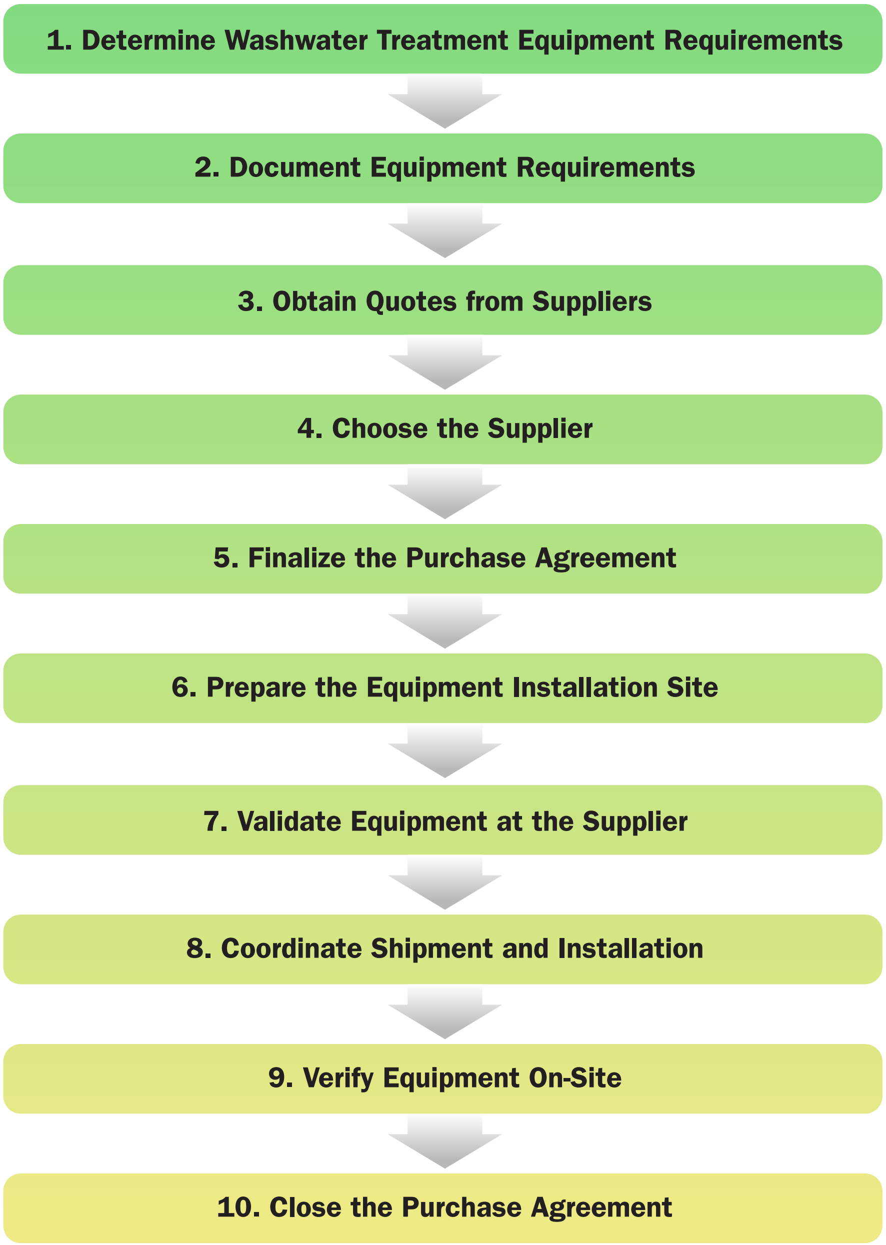


Figure 9.1. Steps to purchasing capital equipment.

9.2 Purchasing Treatment Equipment

Step 1: Determine Washwater Treatment Equipment Requirements

The first step is to determine the hydraulic and mass loading entering the treatment system, and the required equipment performance to meet endpoint use (Chapters 5–8). This is important information for the equipment suppliers to use to design the washwater treatment equipment.

Determine if sufficient infrastructure is available (Pre-Design Considerations Worksheet, Table 6–1 and Technology Evaluation Worksheet, Table 7–2) to ensure the washwater treatment equipment can be installed at the planned location.

Step 2: Document Equipment Requirements

Develop an equipment specification using all the equipment performance requirements determined in Step 1. Include a statement on the water quality after treatment in the specification.

The purchase of treatment equipment is a negotiation process with the supplier. Include negotiable items in the Terms and Conditions section of the purchase agreement. These are not related specifically to equipment performance and include the following items.

- Delivery schedule — Delivery of the equipment is dependent on when the equipment must be commissioned and functioning, taking into account the time required to install and ensure the equipment operates as required.
- Equipment performance verification — Describe how the equipment will be tested to confirm that it meets the performance requirements. Ensure the supplier includes the costs (e.g., laboratory, on-site technician) associated with testing in the equipment price.
- Payment — Include a payment schedule. Final payment is only made after equipment performance has been verified. The following is an example of a payment schedule:
  - 20% payment with placement of purchase order
  - 20% payment when equipment ready to ship
  - 40% payment when equipment condition and performance is confirmed after installation
  - 20% 30 days after equipment acceptance on-site, receipt of the system manual, completion of all training and equipment verification
- Shipping — Decide who is responsible for preparing equipment for shipment, shipping and associated costs (e.g., packing, trucking, border crossing fees). A few options are:
  - Ex Works — The purchaser is responsible for loading the equipment onto a truck at the supplier's location, shipping to the installation site and unloading.
  - Free On Board (FOB) — The supplier loads the equipment onto a truck supplied by the purchaser. The purchaser is responsible for unloading the equipment at the installation site.
- Installation by supplier — The supplier is responsible for all aspects of equipment shipment and installation.
- Installation — Determine who is responsible for equipment installation and the tools required for installation (e.g., crane service, backhoe, millwrighting, electrical connection, plumbing, water, and inspections).
- Warranty — Understand the equipment warranty period, terms conditions.
- Manual and training requirements — Ensure a detailed system operation and maintenance manual is delivered before final payment. Finalize the training schedule before installation of the equipment.
- Penalties — Negotiate a monetary penalty for late equipment delivery and for not meeting treatment objectives.

Step 3: Obtain Quotes from Suppliers

The completed equipment specification is sent to potential equipment suppliers with a quotation submission deadline. It should take less than 3 weeks for a supplier to prepare a quotation. If possible get three quotes, which may not be for the same technology but meet the treatment objectives.

The quotation document from the supplier must provide sufficient information for the washing facility to evaluate the:

- proposed washwater treatment technology
- system purchase and installation costs
- operational and maintenance costs
- treatment objectives will be met
- waste output characteristics
- delivery timing

Step 4: Choose the Supplier

Carefully review the quotations received to confirm whether they fulfill all the requirements listed in the equipment specification. Often the quotes do not meet all the specifications so the purchaser needs to determine which option is both the lowest cost and lowest risk. Note that the lowest quotation price may not actually be the best option, when all the other details in the equipment specification are taken into account. Annual operation and maintenance costs can amount to a significant cost and can vary greatly between different treatment technologies. Consider the required infrastructure changes when evaluating quotes as some equipment may need more work to fit into the system than others.

Consider the company's reputation when choosing a supplier and whether they are able to deliver what they have committed to in their quote. The facility should request the equipment suppliers to provide references for similar projects. The quotations received almost always include the supplier's terms and conditions — read these as they may be different from those included in the facilities' equipment specification. Negotiate with the supplier to achieve mutually acceptable terms and conditions.

Sometimes it is possible to conduct a pilot project to confirm the efficacy of the proposed washwater treatment technology before making a large investment in the technology. There may be costs associated with a pilot project but it is considered a good investment.

Step 5: Finalize the Purchase Agreement

Document any changes to the final purchase agreement to minimize risk to the facility, and finalize the purchase agreement.

1. Inform the successful supplier by issuing them a Purchase Order (PO) document (Appendix A). The PO document must specifically reference the final equipment specification.

2. Include a receipt of Purchase Order Acknowledgement form (Appendix B) the supplier must sign to confirm they have received the PO and agree to comply with all the conditions in the equipment specification.

3. Require an invoice from the supplier for the initial deposit payment. This invoice is only paid once the signed receipt of Purchase Order Acknowledgement has been received from the supplier.

This process results in a document trail that confirms all the expectations, terms and conditions associated with the purchase agreement. These documents are very important if there is a disagreement which may result in a legal conflict.

Step 6: Prepare the Equipment Installation Site

Work with the supplier to understand the site specifications for the equipment ordered. While the equipment manufacturing process is underway, prepare the facility for the installation by:

- Obtaining a building permit (if required).
- Installing equipment foundation (e.g., concrete and steel).
- Building structures to protect equipment.
- Relocating and modifying surrounding equipment.
- Installing services (e.g., electrical, compressed air and plumbing).
- Preparing for equipment access to site.
- Obtaining quotes for all services required to install equipment (e.g., crane, millwright, electrician, plumber).

Step 7: Validate Equipment at the Supplier

If possible, travel to the supplier to view the equipment and verify its performance prior to shipment. It is easier for the supplier to fix equipment problems and make adjustments at their location rather than the installation site. If it is not possible to confirm the system performance, view the equipment to confirm workmanship, completeness, configuration, footprint and details such as lifting locations to simplify the installation process prior to shipment. There is usually a payment milestone associated with equipment validation and shipment.

Step 8: Coordinate Shipment and Installation

A thorough job in preparing the equipment installation site (Step 6) significantly reduces the effort of this step. The purchaser needs to supervise this process quite closely as unanticipated problems can arise. As an alternative, the consultant contracted to manage the capital equipment purchase process can coordinate the shipment, installation and validation activities on behalf of the facility.

Step 9: Verify Equipment On-Site

Carefully examine the condition of the installed equipment in comparison to the equipment specification. Conduct all performance verification tests outlined in the specification including water quality. The equipment must pass all these tests. Refer to the purchase agreement terms and conditions if the washwater treatment equipment supplied does not meet the required treatment objectives. A significant payment milestone is the successful completion of this step.

Step 10: Close the Purchase Agreement

This step involves the completion of all outstanding project details. Ensure the supplier provides the operating manuals, spare parts lists, warranty information and conducts training as required by the purchase agreement before making the final payment. The equipment warranty period begins at the completion of this process step.

10. Building a Washwater Treatment System

10.1 Introduction

This chapter presents four examples of facilities of varying size and washing different produce types. Each example includes background information on the facility, objectives for the treatment system, design considerations and a treatment strategy. The examples include a:

- small scale leafy greens washer
- medium scale apple washer
- large scale vegetable washer
- facility treating washwater to potable standards

10.2 Small Scale — Leafy Greens Washer

Background

A small scale leafy greens grower for a local farmers' market is looking to improve their washing system. The washing system is used 1 day/week for a few hours from June until early October. The existing system (Figure 10.1) consists of overhead spray bars that rinse the vegetables as they travel along a conveyor belt. Washwater is collected in a holding tank and filtered with a coarse screen (1000 micron) and then discharged.

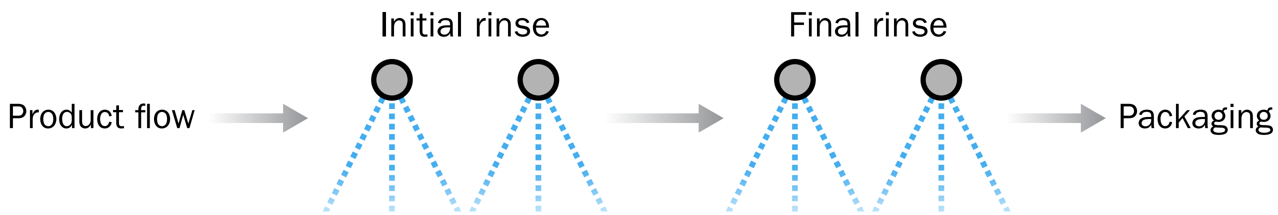


Figure 10.1. Existing washing system for small scale leafy greens facility.

Objectives

The facility would like to:

- Treat the washwater for reuse for an initial wash only.
- Eliminate or reduce the need to discharge washwater.
- Find a low-cost solution.

The facility completed the Pre-Design Considerations Worksheet (Table 6–1.) that summarizes the financial and physical resources available (Table 10–1).

Table 10–1. Pre-design considerations worksheet for a small scale leafy greens facility

Costs	
Available capital	$10,000
Funds available for ongoing costs	$1,000/yr
Treatment Objectives	
Treated water is destined for what end point?	Reuse
Water quality target for end point	Clear of solids
Is potable water required?	No (well provides potable water)
Flows (min/max; batch/continuous)	Batch: 4,500 L/day 1day/week
Seasonality (year-round or seasonal washing)	Seasonal — summer/fall
Site Infrastructure	
Existing treatment technologies	Holding tank with coarse filtration
Electricity servicing	Minimal from nearby building
Plumbing infrastructure	Existing piping for water delivery
Computer network	No
Indoor/outdoor space	Outdoor
Footprint available?	3 m x 6 m
Soil texture	Loam
Waste handling strategy complete?	No
Labour Requirements	
Estimation of man-hours available for operation	1–2 hr/day when washing
Estimation of man-hours available for cleaning and maintenance	1 hour/week
Automated or manually operated system?	Manual
Automated or manually monitored system?	Manual
Washwater managed by facility staff or by washwater management company?	Facility staff

Washwater Characteristics

Six washwater samples were taken in total with three samples taken over 1 day of washing and one sample taken on three other washing days. Samples were collected from the inlet of the existing holding tank. The average results for these samples are:

- 332 mg/L TSS
- 1.49 mg/L TP
- 3.56 mg/L TKN

A flow meter installed on the well recorded an average water use of 4,500 L/day (1 day/week).

Treatment Objectives

The treatment objectives for the facility include debris removal (e.g., pieces of vegetation) and removal of large solids (e.g., greater than 100 microns) including soil aggregates to avoid solids settling in pipes and plugging spray nozzles.

Treatment Strategy

The facility will modify the washing system so that the initial wash performed by the first spray bar is fed with treated water from the holding tank. The second spray bar will continue to apply potable water supplied by the well. Potable water will only be used by the second spray bar which will reduce the overall water use.

The washwater collected under both spray bars will be piped into the existing holding tank. The original 1,000 micron screen will serve as the debris removal system. A new progressive passive filter system (500, 300 and 100 microns) will be installed after the 1,000 micron screen (Figure 10.2). The screens are removable to allow for cleaning. The water is pumped back into the first spray bar for the initial washing.

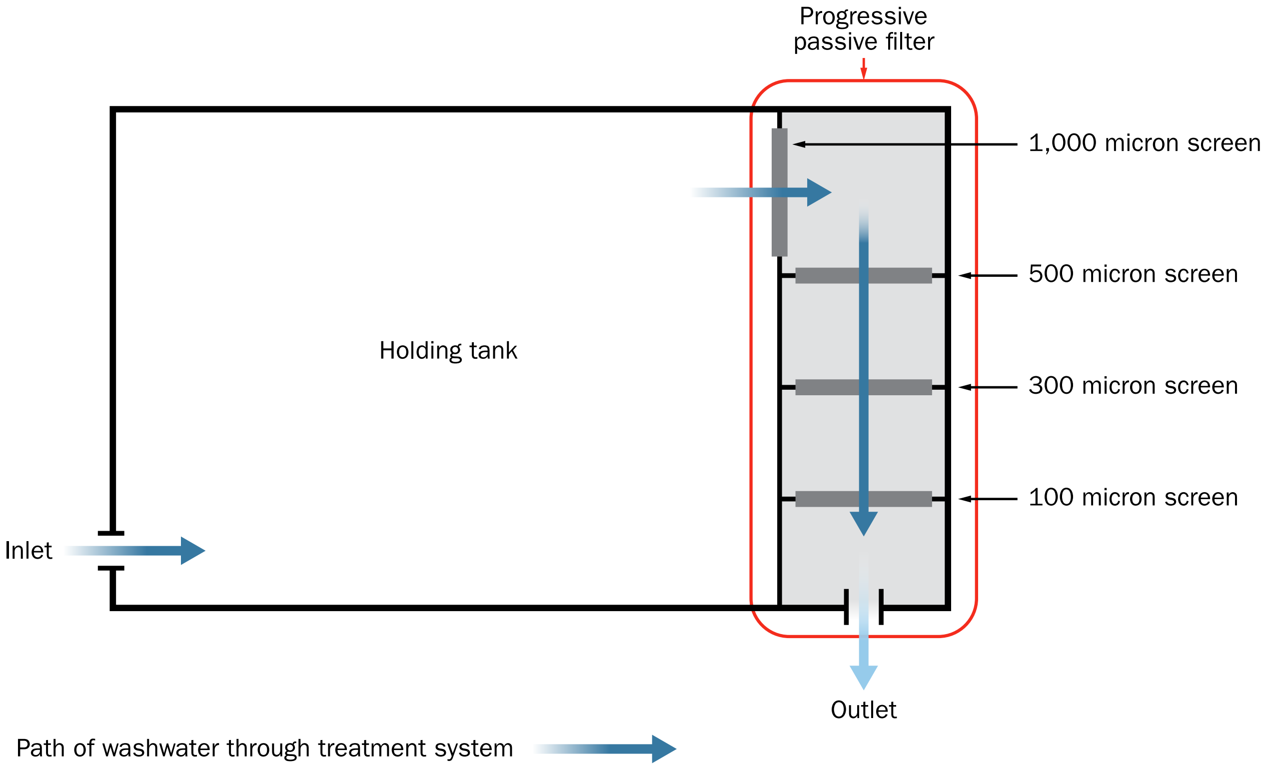


Figure 10.2. Proposed washwater treatment system for a small scale leafy greens washer.

Once the daily produce washing is complete, the remaining washwater will be used to water the facility's greenhouse plants or field crops. In this case, the facility will be land applying the washwater under an approved ECA. The solids removed from the holding tank and cleaned from the filters will be composted. In the fall, the solids will be land applied and worked into the soil.

10.3 Medium Scale — Apple Washer

Background

A medium scale facility washes and packs apples for 8 hr/day, 5 days/week and 10–11 months/yr. They are looking at reducing their overall water use. The apples are brought from storage and moved to the sorting table using water. They are dropped from the sorting table into separate flumes according to their size and grade. After grading, they are put back into storage where they wait to be packed. The packing line uses water to move the apples and wash them (Figure 10.3). All the water is treated with chlorine to maintain potable water for food safety requirements. The discharged washwater is currently untreated.

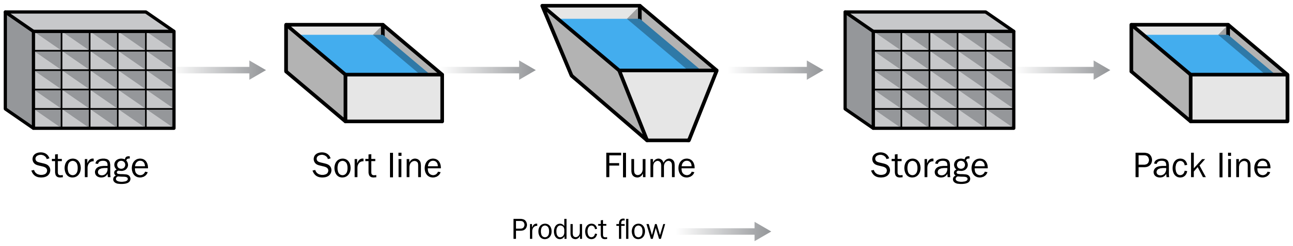


Figure 10.3. Flow of apples through a medium scale apple packing facility.

Objectives

The facility would like to:

- reduce overall water use
- eliminate or reduce the need to discharge washwater

The facility completed the Pre-Design Considerations Worksheet (Table 6–1.) that summarizes the financial and physical resources available (Table 10–2).

Table 10–2. Pre-design considerations worksheet for a medium scale apple packing facility

Costs	
Available capital	$50,000
Funds available ongoing costs	$1,000/yr
Treatment Objectives	
Treated water is destined for what end point?	Reuse
Water quality target for end point.	Clarified and free of solids
Is potable water required?	Yes, treatment system is existing
Flows (min/max; batch/continuous)	Batch: 20,000 L
Seasonality (year-round or seasonal washing)	10–11 months/yr
Site Infrastructure	
Existing treatment technologies	Chlorine disinfection to maintain potability
Electricity servicing	Adequate electrical capacity
Plumbing infrastructure	No
Computer network	Yes, system operating pack line
Indoor/outdoor space	Both
Footprint available?	9 m x 3 m inside, unlimited outside
Soil texture	N/A
Waste handling strategy complete?	No
Labour Requirements	
Estimation of man-hours available for operation.	1–2 hr/day
Estimation of man-hours available for cleaning and maintenance.	1–2 hr/week
Automated or manually operated system?	There is a desire for the system to run in background during regular operations
Automated or manually monitored system?	Automated
Washwater managed by facility staff or by washwater management company?	Facility staff

Washwater Characteristics

The washwater quality varies at different stages in the packing process. Sorting water is the first water to come into contact with the apples and is the dirtiest. The flume water is the cleanest as the majority of the washing of the apples is done during sorting. The packing line washwater has varying water quality as soil or particles can be picked up during storage.

The sorting and packing lines each use 20,000 L and the flume uses 40,000 L to operate. There is an estimated water loss of 5% (4,000 L) over a week that requires replacement. The sort line water is replaced three times each week, the packing line water is replaced twice per week and the flume water is slowly replaced over a period of 1 month. The average water use is calculated as 114,000 L/week.

Treatment Objectives

The treatment objectives for the facility include debris removal (e.g., culled apples, leaves and stems) and removal of solids to ensure the disinfection system works efficiently.

Treatment Strategy

To eliminate the discharge of washwater, the facility will need to treat water and store it for later use (Figure 10.4). A coarse filtration system is used to remove culls, leaves and stems. A balancing tank is used after coarse filtration to ensure a consistent flow rate into the sand filters. The sand filter system is comprised of multiple units running in parallel. The water is treated and stored in a water holding tank until it is needed. When the water is needed, it will pass through a UV system to provide initial sanitation prior to the chlorine disinfection system.

The backwash from the sand filters will be pumped into a filter bag to collect the solids. The filtered backwash water will be discharged to a septic system (for septic tanks <10,000 L/day check with the municipality, for septic tanks >10,000 L/day check with MOECC). The solids will be composted within the bag and then disposed through land application once the bag is full.

The flow of the water in the facility follows a two-day cycle. On day 1, the water in the packing line is not changed. The water in the sorting line is pumped into the treatment system and is refilled with treated water from the treated water holding tank (treated the day before). On day 2, the water in the sorting line is not changed. The water in the packing line is pumped into the treatment system and is refilled with treated water from the treated water holding tank (treated on day 1).

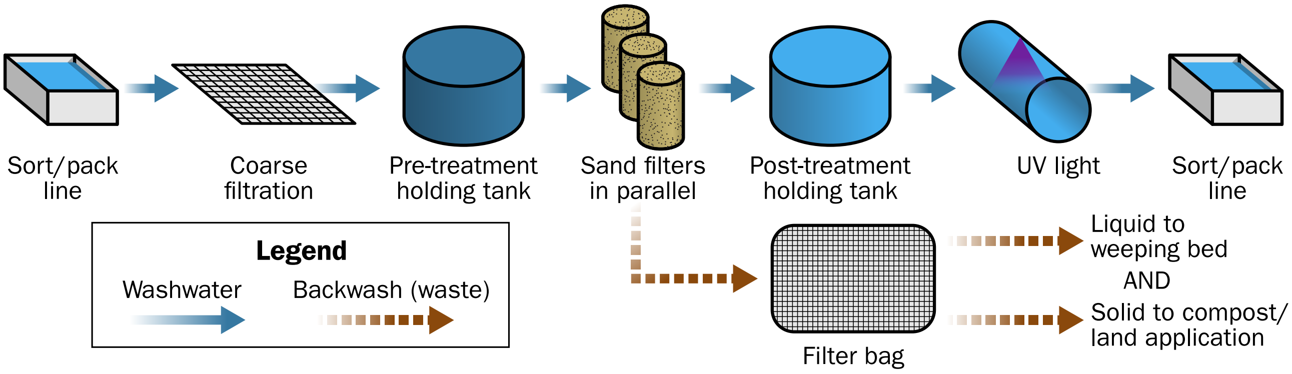


Figure 10.4. Proposed washwater treatment system for a medium scale apple packing facility.

The flume water does not require regular treatment and is not included in this process. Water will be lost from the system through evaporation, splashing and removal during treatment due to backwashing the system and waste removal. It will be replaced by siphoning water out of the flume and putting it into the sorting and packing lines as required. Potable water is added to the flume, as required, to replace the water losses.

The facility will be able to reduce its water use significantly by switching to a recycled water system.

10.4 Large Scale — Vegetable Washer

Background

A large washing facility washes a wide selection of root and bunched vegetables and leafy greens destined for both fresh consumption and the food service trade (e.g., restaurants). It is a year-round operation that imports produce to fill the gap when local supply is unavailable. They need to install a washwater treatment system to meet regulatory objectives. They also plan to market their improved environmental performance using a sustainability marketing program.

The existing washing system has three separate wash lines (Figure 10.5). The first line washes root vegetables (primarily from crates and pallets) using a dump tank followed by a barrel washer and then a final spray bar using potable water. The second line washes root vegetables (primarily from trailers or storage) using a flume followed by a barrel washer and then a final spray bar using potable water. The third line washes leafy greens and bunched vegetables (e.g., radishes, green onions) using an initial spray bar followed by a final spray bar using potable water. The facility measured its water use at various points in the washing system. The amount of water used by each process is outlined in Table 10–3.

Before designing and installing a washwater treatment system, the facility recycled washwater in the washing system to reduce the amount of water used.

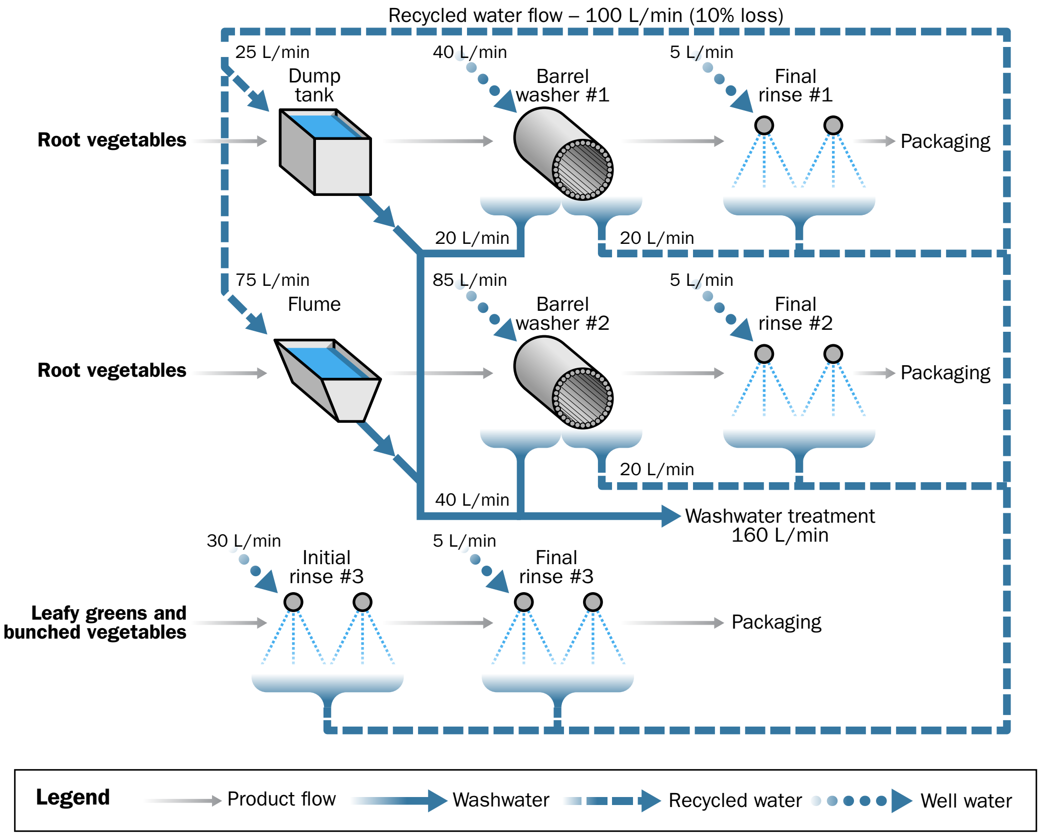


Figure 10.5. Existing washing system for a large-scale vegetable washing facility.

The less dirty washwater was collected from the initial rinse (third line), all final rinses and the back halves of the barrel washers and reused in the dump tank (25 L/min) and flume (75 L/min). Prior to reuse, this washwater should receive treatment to remove debris. The water collected below the front halves of the barrel washers and the spent water from the dump tank and flume will be directed to the washwater treatment system.

To design the washwater treatment system, the flows exiting each stage were estimated assuming water loss to the washing process (e.g., 10%). Additional wastewater from this facility will result from cleaning the washing equipment and facility. With the current configuration, the amount of washwater to be reused following debris removal is 100 L/min. The amount of washwater requiring treatment prior to discharge is approximately 160 L/min.

Table 10–3. Process stage descriptions, water source and water usage

Process Stage	Description	Water Source	Water Usage
Dump Tank	Tank receives dumped root vegetables; provides initial wash.	Recycled	25 L/min
Barrel Washer #1	Polishing unit provides washing and scrubbing to root vegetables. Front half of barrel washer water is sent directly to waste treatment.	Well	40 L/min
Final Rinse #1	Provides final potable rinse (5 nozzles at 1 L/min).	Well	5 L/min
Flume	Moves root vegetables from unloading area to barrel washer; provides initial wash.	Recycled	75 L/min
Barrel Washer #2	Polishing unit provides washing and scrubbing to root vegetables. Front half of barrel washer water is sent directly to waste treatment.	Well	85 L/min
Final Rinse #2	Provides final potable rinse (5 nozzles at 1 L/min).	Well	5 L/min
Initial Rinse	Spray bars (3 sets of 5 nozzles at 2 L/min) provide initial rinses to bunched vegetables and leafy greens.	Well	30 L/min
Final Rinse #3	Provides final potable rinse (5 nozzles at 1 L/min).	Well	5 L/min

Objectives

The facility would like to:

- Treat washwater with different characteristics from multiple crops:
    - Debris removal for reuse.
    - Meet regulatory discharge requirements.
- Market improved environmental performance using a sustainability marketing program.
- Design the washwater treatment system to allow for future growth.

The facility completed the Pre-design Considerations Worksheet (Table 6–1.) that summarizes the financial and physical resources available (Table 10–4.).

Table 10–4. Pre-design considerations worksheet for a large scale vegetable washing facility

Costs	
Available capital	$500,000 +
Funds available for ongoing costs	$15,000–$25,000/yr
Treatment Objectives	
Treated water is destined for what end point?	Reuse Discharge
Water quality target for end point	Removal of debris Meet discharge requirements
Is potable water required?	Yes, provided by well
Flows (min/max; batch/continuous)	Continuous flow, maximum flow is 160 L/min
Seasonality (year-round or seasonal washing)	10–12 months/yr
Site Infrastructure	
Existing treatment technologies	Settling pond/tank
Electrical servicing	Yes, but limited by building capacity
Plumbing infrastructure	250 mm (10 in.) pipe to settling pond
Computer network	No
Indoor/outdoor space	Only outdoor space
Footprint available?	60 m x 60 m
Soil texture	Loam
Waste handling strategy complete?	No
Labour Requirements	
Estimation of man-hours available for operation	2 hr/day
Estimation of man-hours available for cleaning and maintenance	1 hr/day
Automated or manually operated system?	Automated
Automated or manually monitored system?	Manual
Washwater managed by facility staff or washwater management company?	Facility staff

Washwater Characteristics

Sampling was conducted over a washing season at the pipe exiting the building, to characterize the combined washwater during the washing of multiple produce types. Table 10–5 shows the average and maximum concentrations for various parameters which will be used by technology suppliers to size the washwater treatment equipment.

Table 10–5. Washwater concentrations at end of pipe

Parameters	Average (mg/L)	Maximum (mg/L)
TSS	890	1300
TKN	21	35
TP	4.9	5.3
$CBOD_5$	220	300
NO^3	BDL	BDL

BDL = below detectable limits.

Note: The flow rate of washwater to be treated is 160 L/min.

Treatment Objectives

The treatment objectives for the facility include:

- debris removal (e.g., pieces of roots and tops)
- solid removal (e.g., soil and vegetable pieces)
- nutrient removal (e.g., phosphorus)
- reducing dissolved particles (e.g., increase dissolved oxygen through aeration)

Treatment Strategy

It was determined the washwater being recycled to the flume and dump tank required debris removal. A hydrosieve (with a 100-micron screen) will be installed to remove debris (e.g., roots, leaves, soil aggregates) to ensure pipes and pumps don't clog.

To meet regulatory discharge requirements, the washwater treatment system will consist of equipment to remove debris, solids, nutrients and dissolved material (Figure 10.6). The debris removal will be completed using a chopper pump and a hydrosieve with a 100-micron screen. Solids and associated nutrient removal will be completed with the addition of coagulants followed by a filter bag. Nutrients remaining in the washwater after the solid removal stage will be removed (e.g., phosphorus) using a deionization system. The deionization process will produce a waste stream resulting from backwashing the unit. The backwash water will be pumped back into the filter bag.

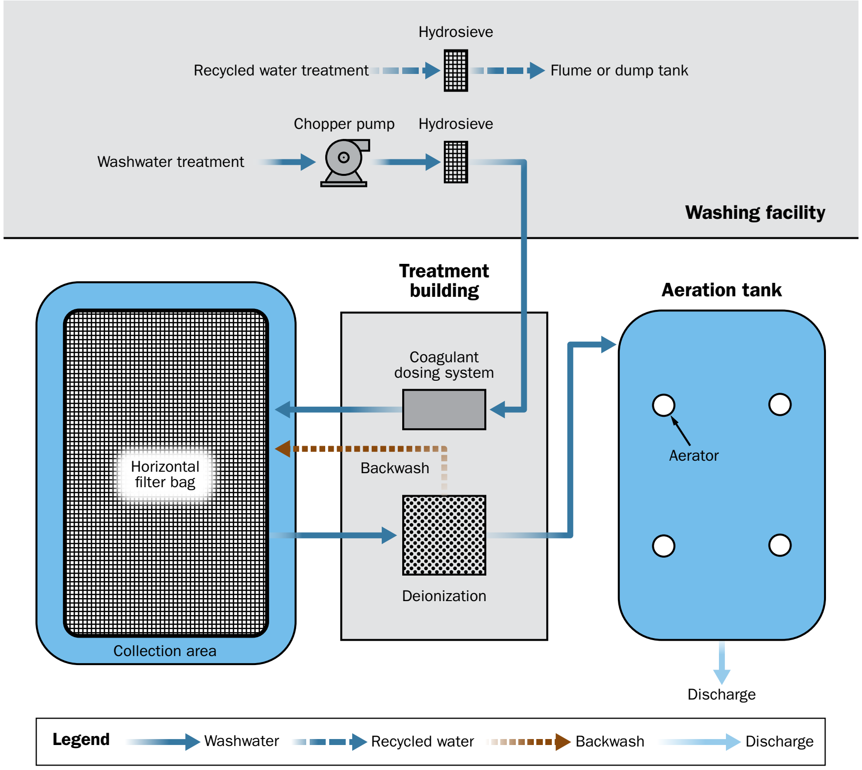


Figure 10.6. Proposed washwater treatment system for a large scale vegetable washing facility.

The final step in this washwater treatment process is reducing dissolved material through aeration. Aerators will be installed in the existing settling pond and the water will be discharged to surface water (under an Environmental Compliance Approval from the MOECC).

The chopper pump and hydrosieves will be installed inside the washing facility building. Another building will be constructed next to the existing settling tank to house the coagulant and flocculant aid dosing system and the deionization unit. An additional electricity line is needed to supply power to the building's equipment and aeration units installed in the existing settling pond.

The waste handling strategy will consist of:

- Daily removal and composting of debris and built up solids from the two hydrosieves.
- Pumping the backwash water from the deionization unit into the filter bag.
- Composting solids from the filter bag (once full).

The system will be automated using PLCs to control the coagulant dosing system and deionization unit, but will require oversight by an operator to ensure the units are functioning properly and efficiently.

10.5 Treating Washwater to Potable Standards

Background

A produce washing facility has decided to eliminate the washwater discharge by completely recycling all their water. They already have a washwater treatment system that meets regulatory requirements for discharging to the environment.

Objectives

The facility would like to:

- Eliminate discharge of all washwater to the environment.
- Treat a portion of collected washwater to potable standards for use at any stage in the washing process.

The facility completed the Pre-design Considerations Worksheet (Table 6–1.) that summarizes the financial and physical resources available (Table10–6).

Table 10–6. Pre-design considerations worksheet for treating washwater to potable standards

Costs	
Available capital	$300,000
Funds available for on-going costs	$50,000
Treatment Objectives	
Treated water is destined for what end point?	Final rinse water
Water quality target for end point?	Potable standards
Is potable water required?	Yes
Flows (min/max; batch/continuous)	Continuous 65,000 L/day, consistent flow rate due to prior treatment
Seasonality (year-round or seasonal washing)	10–12 months/yr
Site Infrastructure	
Existing treatment technologies	Existing treatment meets regulatory discharge requirements
Electrical servicing	Yes
Plumbing infrastructure	Yes
Computer network	Available
Indoor/outdoor space	Indoor
Footprint available?	9 m x 15 m
Soil texture	N/A
Waste handling strategy complete?	Yes
Labour Requirements	
Estimation of man-hours available for operation	Dedicated half-time employee
Estimation of man-hours available for cleaning and maintenance	Dedicated half-time employee
Automated or manually operated system?	Automated with supervision
Automated or manually monitored system?	Automated with supervision
Washwater managed by facility staff or by washwater management company?	Facility staff

Washwater Characteristics

The washwater currently being discharged meets regulatory requirements for release into the environment.

Treatment Objectives

The treatment objective for the facility is to treat a portion of their washwater to potable standards.

Treatment Strategy

Fine filtration is required to remove the remaining fine solids from the washwater. A sand filter will remove the larger particles and a membrane filter will remove the smaller particles. Fine filtration must occur before disinfection, as solids and organic matter in the water will interfere with the disinfection system.

Disinfection will be achieved with a UV system designed to inactivate bacteria, protozoa and viruses, followed by chlorination for a residual disinfectant so the water remains potable. A metering pump will add chlorine to the water.

Due to the complexity of the treatment system, the facility will employ a part-time employee to oversee the operation of the treatment system.

11. Optimization

11.1 Introduction

Technologies require some adjustments after installation to ensure they function at maximum efficiency. Optimize each technology separately starting with the first treatment stage and progress through each stage (e.g., debris removal through to nutrient removal). Once each piece of equipment has been optimized, test the entire system to ensure all technologies work together efficiently.

11.2 Optimization Process

There are several steps to follow when optimizing a technology or system (Figure 11.1).

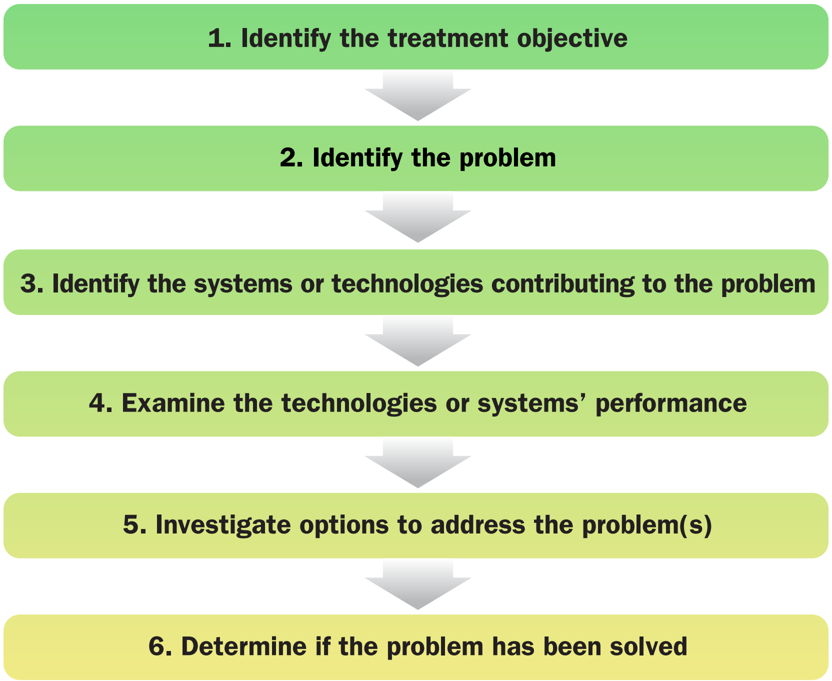


Figure 11.1. Optimization steps.

Step 1: Identify the treatment objective

Determine the desired performance for each treatment stage or equipment. It can be broad (e.g., visual debris removal) or specific (e.g., TSS removal meets the expected performance).

Step 2: Identify the problem

Problems may become apparent when conducting water quality sampling and monitoring water and electricity use. For example, there is excessive water use, high electricity demand, variable water quality and the discharge limit is exceeded.

Step 3: Identify the systems or technologies contributing to the problem

Conduct a walk-through of the entire system including water source, washing equipment and washwater treatment equipment to identify which treatment stage(s) are contributing to the problem. For example, when solid removal is the problem, focus on systems that remove solids (e.g., hydrosieve) and not systems that target other parameters (e.g., biofilter). If excessive nutrients are the problem, optimize the solids removal equipment first since it will have a positive impact on nutrient removal. Test the impact of optimizing the solids removal equipment on nutrient removal prior to optimizing nutrient removal systems.

Step 4: Examine the technologies or systems' performance

Determine treatment efficiency by comparing the water quality of the incoming and outgoing water. Compare the treatment efficiency to the supplier's specifications. When the treatment efficiency is not meeting the specification, evaluate if:

- The water quality and/or flow rate entering the treatment system is different than in the equipment specification.
- The equipment worked better when first installed and is losing efficiency over time.
- The washing facility capacity changed since installation (e.g., adding a product or a change in load demand, installing an additional wash line).
- There are any other deficiencies (e.g., pump malfunction).

Step 5: Investigate options to address the problem(s)

There is a progression of options to address the problem:

- Use in-house maintenance staff for immediate trouble shooting and repair.
- Contact the technology supplier to assess their equipment and repair/modify.
- Hire a consultant to evaluate the entire system and make recommendations.

Step 6: Determine if the problem has been solved

After changes to the system have been made, allow the system to operate for a few days. Re-evaluate the technologies or systems' performance (Step 4) to determine if the problem has been solved. If not, repeat Steps 3–5 until satisfied.

11.3 Case Study #1

Objective

Ensure the solid removal system is functioning efficiently.

Problem

The solid waste stream was not concentrated enough.

Technology Evaluated

Drum filter

Examination and Investigation

A drum filter installed at a root vegetable washing facility was treating washwater as expected. However, after installation the output of the waste collection tray contained excessive amounts of water. It required optimization to increase the solids concentration in the waste stream to decrease the volume produced for easier management. The drum filter is automated to rotate and spray on a regular schedule. The purpose of the optimization process is to find the spray duration that produces the most concentrated waste stream.

Figure 11.2. Amount of solids in the waste for different spray cycle durations (left to right) 25 seconds, 20 seconds, 15 seconds, 10 seconds and 5 seconds.

Changing the spray duration impacted the total spray cycle (e.g., spray duration plus time between sprays), amount of waste produced for each spray cycle, waste output and amount of solids in the waste (measured by depth of solids in a collection jar, Figure 11.2). Table 11–1 shows the results from the optimization process.

Table 11–1. Drum filter optimization results

Spray Duration (second)	Total Spray Cycle (second)	Waste Output per Spray (L)	Waste Output (L/min)	Depth of Solids (cm)
25	150	9.5	3.8	2.3
20	140	7.6	3.2	2.4
15	120	5.7	2.8	2.6
10	45	3.8	5.0	2.5
5	23	0.9	2.5	2.6

Based on the results of the optimization (Table 11–1), the spray cycle durations of 5 and 15 seconds had the highest amount of solids in the waste stream. The 5-second spray cycle duration had the lowest overall waste output (L/min) with the highest solids concentration.

Evaluate Success

Prior to optimizing the spray cycle duration, the drum filter removed 46% of the total suspended solids. Following optimization, using the 5-second spray cycle duration, the drum filter removed 71% of the TSS. The solids removal efficiency of the drum filter was increased by optimizing the spray cycle duration.

11.4 Case Study #2

Objective

Ensure the washwater treatment system is functioning effectively.

Problem

The dissolved oxygen (DO) concentration at the discharge point is too low.

Technology Evaluated

Bottom aerator units in the third cell of a 3-cell settling tank.

Examination and Investigation

A 3-cell treatment system is installed at a root vegetable washing facility. The primary goal of the first two cells is to remove suspended solids by settling, and then the clear water at the surface enters the third cell. The third cell provided additional time for biological nutrient removal but did not include an aeration system. The water leaving the third cell was not meeting the regulatory target for dissolved oxygen. To raise the dissolved oxygen concentration, three bottom aerators were installed in the third cell on sampling day 6 (Figure 11.3). The aerators pump air to the bottom of the tank (cell), release it through the diffusers and oxygen dissolves into the water as the air rises (Figure 11.4).

Figure 11.3. A bottom aerator diffuser.

Figure 11.4. Air bubbles rising to the surface of the cell.

The DO (Figure 11.5) and total suspended solids (TSS) (Figure 11.6) were monitored before and after the installation of bottom aeration. Samples were taken as water entered and exited the third cell.

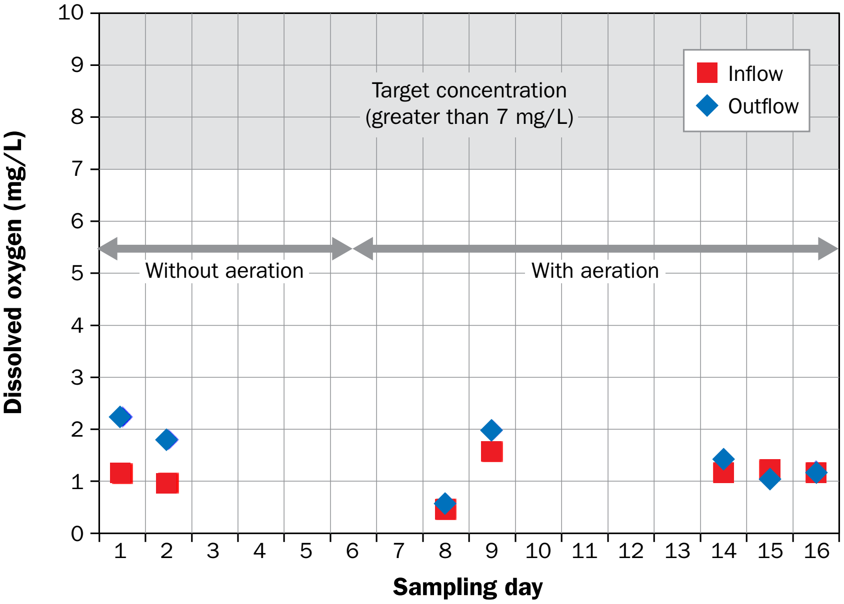


Figure 11.5. DO concentration in a settling tank with and without aeration.

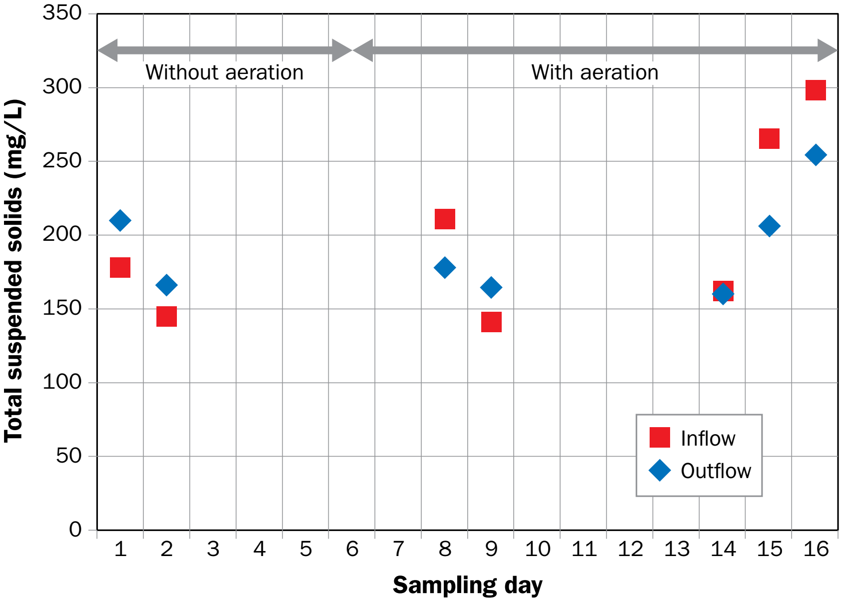


Figure 11.6. TSS in a settling tank with and without aeration.

In this case, the bottom aerators did not effectively increase the DO in the water leaving the third cell. The TSS remained high as the air bubbles surfacing from the aerator interrupted the settling process by keeping the particles in suspension.

Evaluate Success

Based on the low DO concentration leaving the third tank, the number and capacity of the aerators installed was not sufficient for the size of the third cell. The first two cells were also not adequately removing the solids before the water entered the third cell. The recommendation is to optimize the solid removal stage (e.g., cells one and two) before addressing the DO concentration leaving the third cell. Once the solids removal system is operating efficiently, re-evaluate the use of aerators.

12. Post Installation

12.1 Operation and Maintenance of a Washwater Treatment System

After installing a washwater treatment system, consider these best practices for the operation and maintenance of the system.

Water Treatment System Operation Team

Identify facility staff that will be responsible and accountable for the operation and maintenance of the washwater treatment system. Ensure there is more than one operator fully trained on all aspects of the system to guarantee coverage when one person is away.

Make sure facility staff are adequately trained to operate each piece of equipment and have full access to all system manuals, spare parts lists and service contacts. General water treatment operator training may be an asset.

The system operators need to understand how a change in the washing facility process (e.g., volume and quality) impacts the washwater treatment system. If a piece of treatment equipment is not performing as expected, it might be a change in the washing process rather than a problem with the washwater treatment system. Understanding both the washing process and washwater treatment system will assist with finding a solution.

Spare Parts and Tools Inventory

Maintain an inventory of the spare parts recommended by the equipment supplier. Some specialized tools may be required for maintenance and repairs.

Preventative Maintenance Schedule

Conduct the recommended maintenance as scheduled in the system operation and maintenance manual (Chapter 9) or from the equipment manual provided by the manufacturer.

Local Specialized Support

Develop a group of local contractors (e.g., electricians, plumbers) that can become familiar with the system to provide specialized support when problems occur that are outside the capability of the facility washwater treatment operator(s).

System Monitoring, Testing and Alarms

Install monitoring equipment and conduct the required sampling to confirm the washwater treatment system is operating effectively. Document and retain all test results in a format for easy evaluation of the equipment's performance. Test alarms regularly to ensure they are functioning properly.

Contingency Plans

Minor breakdowns of the washwater treatment equipment may result in interruptions to the washing process. Major breakdowns may cause all washing to cease. In these cases, implement contingency plans to allow washing to resume quickly. Ensure a contingency plan(s) is in place prior to system operation. Options may include off-site haulage or storing the washwater temporarily until the equipment is fixed. These plans are a requirement of ECA applications.

Spills may have an impact on food safety and the environment. Develop a contingency plan to address how to handle a spill, document when it occurred and the method used to resolve it. A spill must be reported to the Ministry of the Environment and Climate Change's Spills Action Centre, 1-800-268-6060.

12.2 Record Keeping

Records are kept to fulfill regulatory requirements and track day-to-day operations.

Training Records

Maintain records for both internal and external training. Records may be needed to comply with food safety requirements, liability purposes, insurance and environmental regulations.

Water Quality Results

Maintain records of all water quality results (e.g., laboratory reports) whether they are for operational or regulatory purposes including:

- confirm equipment efficiency/optimization
- food safety compliance
- environmental compliance

Operations and Maintenance

Use a logbook or calendar to document maintenance work, repairs, adjustments to equipment and frequency of operational processes. Examples may include:

- removing accumulated solids
- membrane or filter replacement
- chemical usage (e.g., how much coagulant is used on a daily/weekly basis)
- changes to chemical type and dosing
- frequency of backwashing
- UV light cleaning and replacement
- scheduled maintenance outlined in operation and maintenance manual
- types, cost and frequency of repairs
- other items specific to the washwater treatment system

12.3 Evaluate System Performance

Evaluate system performance using water quality results, operation and maintenance records, equipment down time and visual inspections. Where the system is not treating the water to the required water quality objectives, identify if this relates to system design or operation and maintenance. If frequency of repair is higher than expected, increase the frequency of scheduled maintenance or modify the equipment or system. Investigate to find the reason why the system is not performing adequately (i.e., when a filter requires more frequent backwashes than expected, the system may need to include additional filters).

Evaluate the system performance on a regular basis (e.g., annual). Assessing the treatment process may uncover opportunities to increase efficiency or reduce inputs. Consistent, documented reviews create historical data which is useful to make informed choices about changes to the system, upgrades and potential additions.

Appendix A

PURCHASE ORDER

Purchase Order #	Purchase Order Issue Date

PURCHASER
Name Company Name Address Phone Email

VENDOR
Name Company Name Address Phone Email

Item	Part #	Description	Qty	Unit Price	Amount
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
				Total Net	

Notes
This purchase order refers to the following related documents:
1. Equipment Specification (identify document number and date).
2. Vendor Quotation (identify document number and date).
3. Buyers Standard Terms and Conditions.

Payment Terms:	Per Buyers Standard Terms and Conditions
Ship Via:	

Signature:	
Date:	

Appendix B

Purchase Order Acknowledgement

Date:

Buyer's Name:

Buyer's Address:

Dear Sir / Madam,

This is to confirm that we are in receipt of your Purchase Order # ________ for the purchase of ______________________________. We acknowledge that the functional requirements and terms & conditions provided by the Buyer are applicable to this order.

Regards,

Seller's Name

Seller's Company

Seller's Address

ontario.ca/omafra