Mink Farm Wastewater Management

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A Major Qualifying Project produced for Stantec, and submitted to the facility of Worcester Polytechnic Institute in partial fulfillment of the requirements for the degree of Bachelor of Science. Advised by Fred Hart and Suzanne LePage.

Abstract:

The Major Qualifying Project was completed for Stantec Consulting Ltd. It considered a mink farm in Nova Scotia. The mink farm has been producing an outflow of impacted stormwater that does not meet the Nova Scotia Department of Agriculture Fur Industry Regulations. The farm also has a seagull pest problem. Methods of treating the impacted stormwater and deterring seagulls were both researched. A wastewater facility and seagull pest control methods were both developed. These designs were then presented to Stantec.

Acknowledgements:

The author would like to thank the following people for their involvement in the completion of the project. First, I would like to thank Professor Hart and Professor LePage for their guidance starting at the preparation of the project and continuing through the completion of it. The project, also, could not have been completed without the support of Stantec Consulting Ltd. In particular I would like to thank Maylia Parker, Krysta Montreuil, and Vijay Sundaram for their knowledge and aid throughout the MQP.

Capstone Design

The Accreditation Board for Engineering and Technology (ABET) requires that all accredited engineering programs include a capstone design experience. At Worcester Polytechnic Institute, this requirement is met through the Major Qualifying Project (MQP). This project, in particular, focused on the following real-world constraints.

- Economic – For design implementation to be feasible, the design must meet the client's financial constraints. Thus, the during the design stage, price estimates were calculated, including cost of construction, daily operation costs, and maintenance.
- Constructability – As the space available on the property is limited, and construction cannot limit the farm's operation, any design for the stormwater facility would have to be compact. Therefore, research focused on compact reactor designs. Furthermore, the farm does not have electricity available at the area where the outflow occurs.
- Environmental – The goal of the project is to reduce contaminants to legal levels, with the intent of making the effluent safe for the environment.
- Ethical – The project was sponsored by Stantec and regarded a private business in Nova Scotia. There was no conflict of interest presented by the project. The treatment of seagulls represents a moral dilemma. Despite widely being thought of as pests, seagulls are a federally protected species. Steps were taken to ensure that any measures taken to deter seagulls were ethically sound.
- Political – This project was designed to meet the requirements of the Nova Scotia Department of Agriculture with regards to surface water discharge. All seagull deterrents were designed to be compliant with the federal laws protecting gulls.

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1. Introduction

The project concerned a mink farm that Stantec has been working with for over a year. The farm has come under public scrutiny over the past several years due environmental and animal rights activists' disapproval of mink farming; regulators responded to complaints of highly turbid effluent leaving the farm. The contaminant levels, in the water leaving the site, do not meet the Nova Scotia Department of Agriculture Fur Industry Regulations (Regulations). It is Stantec's objective to bring the contaminant levels in the effluent into compliance with the Regulations. Furthermore, the farmer has expressed desire to remove seagulls from his property that have been proven to be a nuisance and are also impacting storm water quality.

1.1 Existing Conditions at the Mink Farm

The project site is a 60-acre mink farm. Each year, over 100,000 mink are raised and slaughtered. Traditional mink farms employ open-air structures, consisting of a roof to shelter the animals from the rain, while allowing fresh air to circulate through the cages. Due to this set-up, waste produced by the minks falls to the ground, and is exposed to surface runoff from rain events.

Figure 1: Traditional mink Farming Structure. Notice the cages hanging out over the ground. Photo taken by Stantec.

Stormwater runoff leaves the site through a culvert, and discharges to a small stream. The outflow from the farm, when first tested on August 28th, 2012, contained concentrations of phosphorus, ammonia, E. coli, and total suspended solids well above the Regulations

A large number of seagulls also roost on the property. According to the owner of the farm, they are '5th and 6th generation' seagulls. The seagulls create several issues. First of all, they are a nuisance. Seagulls are loud, and in those sorts of numbers create a lot of waste. Seagull droppings contain very high levels of ammonia. This serves to further impact the stormwater runoff, including otherwise unimpacted runoff collected in roof rain gutters. In addition, the acidic nature of seagull guano is damaging to site infrastructure.

Figure 2: Seagulls at the Site. Photo taken by Stantec.

1.2 Remediation Processes in Place before Stantec's Involvement

Before the involvement of Stantec, several steps towards remediation were constructed. First, to regulate and treat surface water runoff, three retention ponds were put into place. Pond 1 is an approximately 12-foot deep pond, designed for sedimentation. Pond 2 is a shallow pond, approximately 2-feet deep, designed to enhance biological degradation through exposure to air and sunlight. Pond 3 is a constructed wetland, designed to enhance settling, control impacted stormwater, and precipitate nutrient removal though vegetation, and bacterial breakdown. These three ponds are connected sequentially, as shown in Figure 3. Flow is controlled through the use of boards with flow holes that can be raised or lowered.

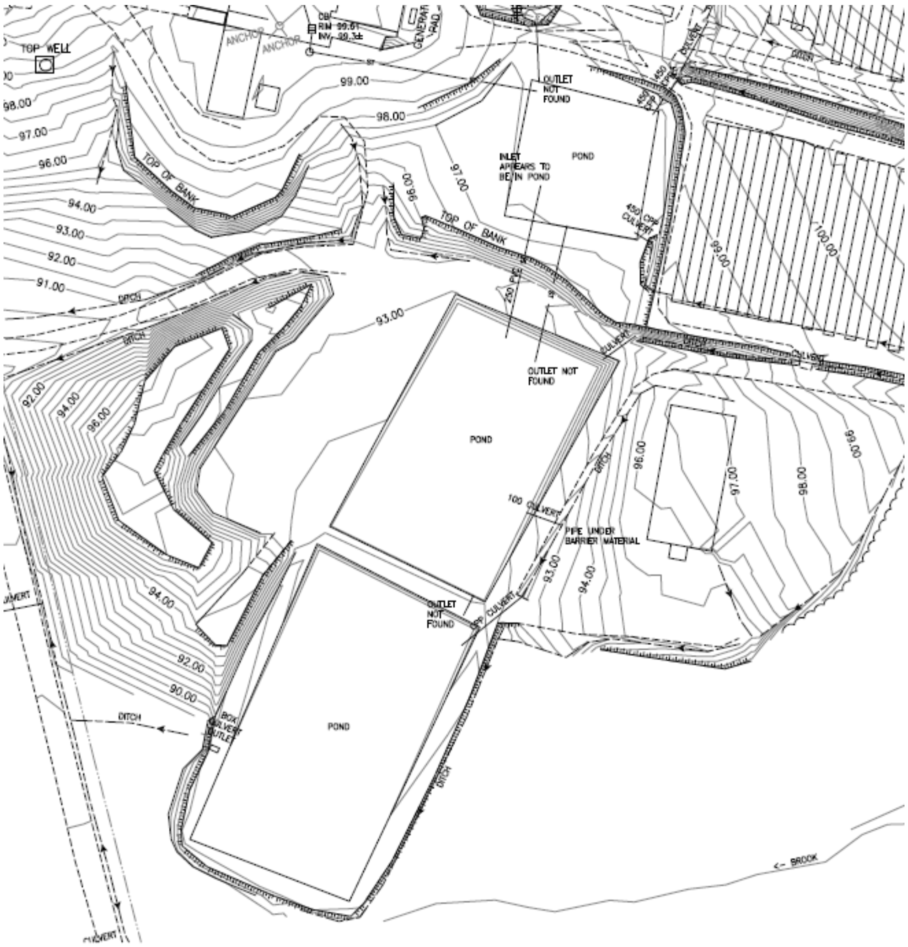

Figure 3: Schematic of the Three Ponds: GIS by Stantec

In addition, a large, covered manure storage building with a level concrete base was built to store manure after it is removed from the barns, which is done on an approximate three-week rotation. The farmer also contracted with Phoslock™ to trial its phosphorus-binding properties, but this proved ineffective.

Removing seagulls from the farm has been a significant challenge for the farmer. The farmer has employed different types of noise dispersal methods: firing gunshots into the air, setting off firecrackers, and playing the sounds of predatory birds through speakers. Each method has resulted primarily in the movement of the seagulls from one part of the farm to another, rather than the removal of them from the site, or the seagulls leave the site temporarily only to return. The farmer is now interested in some sort of physical means to deter seagulls.

1.3 Remediation Steps Taken by Stantec

So far, Stantec has taken several steps to improve water quality leaving the site. They established basic objectives for improving water quality: 1) keep clean water clean; 2) minimize the amount of mink waste exposed to runoff; 3) keep eroded mink waste and residues on-site; 4) avoid steep slopes and promote grass growth, and 5) use filtration with capture media that have an affinity for the chemicals of concern.

To these ends, the following steps were taken. First, they surveyed the site and produced a topographical map. The site survey was used to complete a hydrological study to assess stormwater flow under different flow condition. Analysis of stormwater flow at the site resulted in the following recommended changes:

1) Removal of two areas of the mink-rearing structures, which had been built on the steepest gradients resulting in difficult stormwater management; these were replaced in a more manageable area.

2) Installation of roof extensions and rain gutters to limit the amount of water contacting the manure and separate this water from impacted water. The hydrological study suggested that approximately half of the site stormwater could be collected via rain gutters. The clean water would be piped underground to a clean water pond.

3) Improvement of ditching and grading to divert the water away from the structures. Stantec also added gravel berms in-between the ponds as an emergency measure to filter out suspended solids and biological contaminants.

4) Implementation of a sedimentation and erosion control plan, including long-term vegetation management, to limit sediment-laden water from exiting the site.

5) Finally, to use the excess nutrients in the ponds, hybrid willows were planted on the banks of the retention ponds and on the berms of the constructed wetlands, as well as within ditches and around the manure storage building. The hybrid willows were bred specifically to grow quickly (several feet per year) and the nutrient ratios found in the pond are ideal for promoting their growth. In addition to passively removing nutrient-laden water from the site, the willows can be irrigated with water from the retention ponds.

1.4 Project Goals

The steps taken by Stantec to date have improved water quality leaving the site. The phosphorus concentrations, however, remain a concern. Although, the concentration has dropped from 95.00 milligrams per liter (mg/L) to 7.40 mg/L in the time that Stantec has been involved, this is still several magnitudes higher than the 0.02 mg/L concentration specified in the Regulations. Furthermore, the seagulls remain a nuisance, as well as a source of ammonia. The seagulls are a particular concern because they impact otherwise cleans water from the mink shed roofs. With this in mind, the goals of this Major Qualifying Project (MQP) are as follows:

1. Research methods on phosphorus removal as well as pest control for seagulls.
2. Compare several alternative options for both issues.
3. Evaluate options with regards to the constraints mentioned in the Capstone Design Statement.
4. Produce a recommendation for which method is best-suited for the farm based on real-world constraints.

2. Background

2.1 Phosphorus Removal

2.1.1 Eutrophication

Phosphorus is an essential nutrient for plant and animal growth, and is typically the limiting nutrient in most bodies of water. When introduced in large quantities, phosphorus can cause eutrophication, the bloom in plant life in water bodies that leads to a decrease in dissolved oxygen. The process begins with the introduction of an excess level of phosphorus. This results in a bloom of blue-green algae, which usually is limited by the amount of phosphorus in the water. When the algae die, it sinks to the bottom of the water body where it decays. The bacteria that decompose the algae consume dissolved oxygen. Eventually, this can result in dead zones where there is simply not enough dissolved oxygen to support aquatic life.[i]

2.1.2 Unit Processes for the Removal of Phosphorus

2.1.2.1 Stormwater Management/Hybrid Willows

As noted above, the first step that Stantec took after compiling their list of tasks was to survey the property. After the surveying, a hydrological assessment was complete, in order to produce a stormwater management plan, including the removal of structures and digging of ditches. Plans for further stormwater management were produced, as well. The first task was lessening the overall amount of surface runoff. To do so, clean rain water will be collected by adding gutters to the remaining structures and newly built structures on more moderate slopes. These gutters will lead to new underground piping that diverts water into a clean-water retention pond. This water can be reintroduced to dilute water that passes through the existing stormwater retention ponds.

The impacted stormwater will continue to run into the three ponds, where the hybrid willows will take up the water and nutrients, including the excess phosphorus. The willows are specifically bred to grow rapidly, using large amounts of water and nutrients. Leaf fall is not considered a concern, because the bulk of the phosphorus is stored in the woody matter (trunk and branches.)[ii]

2.1.2.2 Chemical Removal of Phosphorus

The chemical removal of phosphorus is accomplished through precipitation. Precipitation is the process by which solids are formed within a solution caused by the reaction of two or more ions. Precipitation of phosphorus is initiated through the introduction of multivalent metal ions.[iii] These ions react with the dissolved phosphorus to form insoluble phosphates. The insoluble phosphates are left to settle, and the resulting sludge is removed.

2.1.2.2.1 Precipitation with Calcium

Calcium in the form of lime [$Ca(OH)_2$] is introduced to the impacted water. The lime reacts with the alkalinity in the water to form calcium carbonate [$CaCO_3$]. This causes the pH of the water to rise. As the pH increases, excess calcium ions begin to attach to phosphate ions to form insoluble hydroxylapatine.

$$10Ca^{2+} + 6PO_4^{3-} + 2OH^- \leftrightarrow Ca_{10}(PO_4)_6(OH)_2$$ [iv]

The amount of lime needed depends on the alkalinity of the water. Usually the amount of lime needed ranges from 1.4 to 1.5 times the total alkalinity.[v] This reaction with lime also creates an outflow with a high pH; as a result, a pH-lowering process, such as recarbonation may be necessary.

2.1.2.2.2 Precipitation with Iron and Aluminum

Both processes have simple, similar reactions.

Aluminum reaction:

$$Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4\ nH^{+}$$ [vi]

Iron Reaction:

$$Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4\ nH^{+}$$ [vii]

Theoretically, one mole of iron or aluminum will be enough to precipitate one mole of phosphate; however, this is not usually the case, as a multitude of other factors impact the required dosage of alum or ferrous salts, including, but not limited to, alkalinity, trace elements and ligands found in the wastewater.[viii] Therefore, the chemical equations are generally not used and testing is used, instead, to determine the correct dosage. For this project, an assumption was made that it will take a 3:2 molar ratio to precipitate the phosphates.

2.1.2.2.3 Struvite

Struvite, or magnesium ammonia phosphate [$NH_4MgPO_4 \cdot 6H_2O$], is a sparingly soluble mineral which can be formed with a 1:1:1 molar ratio between magnesium ammonia and phosphate. Struvite is a known method for storing phosphorus for later use as fertilizer.[ix] To create Struvite, a pH around 9.0 is necessary.[x] Struvite creation is also harsh on wastewater-treatment facilities as it can clog pipes and pumps.

2.1.2.3 Biological Removal of Phosphorus

Biological phosphorus removal works by encouraging the growth of phosphate-accumulating organisms (PAOs), which are subjected to anaerobic conditions, then to aerobic conditions.[xi] Under the anaerobic conditions, the organisms break polyphosphate bonds, resulting in phosphates (PO_4). When conditions are made aerobic, the PAOs ingest the phosphate, removing it from the water. The PAOs are themselves removed from the water for a more thorough cleaning.[xii]

Anaerobic Process:

PAOs + Polyphosphates + glycogen + VFA =

PAOs + stored biopolymers + CO_2 + H_2O + PO_4

Aerobic Process

PAOs + stored biopolymers + PO_4 =

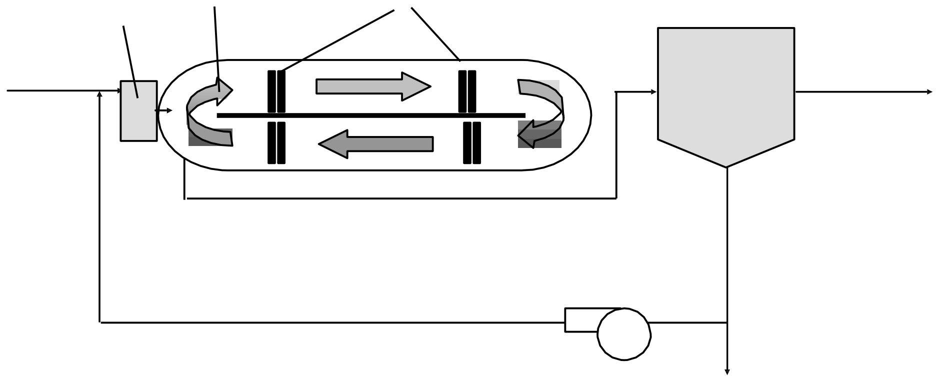

Figure 4: Phosphorus Removal with Small Anaerobic Chamber, and Large Aerating Chamber.

PAOs + stored

polyphosphates + glycogen + CO_2 +H_2O

2.1.3 Reactors for Phosphorus Removal

2.1.3.1 Batch Reactor

In a batch reactor, flow neither enters nor leaves during mixing. Flow enters, is treated, discharged and the process is repeated.

Sequencing batch reactor is a process where two batch reactors are run simultaneously, with one filling while the other is reacting.[xiii] Typically, they are used to treat wastewater in a biological manner.

2.1.3.2 Complete Mix Reactor

A complete mix reactor runs on the assumption that mixing happens instantaneously and uniformly throughout the reactor. Fluid particles leave the reactor in terms of their population, i.e. solid particles are removed at a different rate than clean water.

2.1.3.3 Plug Flow Reactor

In a plug flow reactor, fluid particles enter and exit with little to no longitudinal mixing. There is a constant flow entering a constant flow exiting.

Figure 5: Static Inline Plug Flow Reactor. Source http://www.stamixco-usa.com/products/plug-flow-reactors/default.html

2.2 Seagull Control

2.2.1 Seagull Issues

Seagulls are a fish-eating, ground-nesting bird. Due to their status as a fish eating bird, they are federally protected under Canadian law.[xiv] This makes nuisance control difficult, as they cannot be harmed. The seagulls present a nuisance for several reasons. First, seagulls are loud, and in the number found on the farm, they are extremely aggravating. Furthermore, seagull guana is another source of nutrients and bacteria at the site. Since it is Stantec's intent to put gutters on the structures to collect rain water and store it in a clean water retention pond, the seagull waste presents a real problem; it is a source of nutrients, particularly ammonia, in the "clean water". Lastly, seagulls are rather destructive. They can peck through many sorts of building materials, and the acidic nature of their guano can also damage infrastructure, such as the textile roof of the manure storage building.

2.2.2 Seagull Control Methods

2.2.2.1 Noise

There are two ways that noise can be employed to control seagulls. Studies have shown that the sound of predatory birds or seagulls in distress can scare away gulls, but, usually, after a day or two, the seagulls grow accustomed to the noise and return. The other method is simpler; intermittent loud noises can temporarily scare away the birds. This could manifest itself in gunshots, or firecrackers; however, this method may not result in the seagulls leaving the property, but rather moving a different part of the property or leaving the property temporarily, only to return.

2.2.2.2 Physical Methods

Seagulls have webbed feet that are ill-suited for grasping branches and the like. Therefore, a wire-mesh covering over the roofs may discourage the seagulls from perching. The netting should have a 3-5 centimeter mesh.[xv] Alternatively, simple wiring, referred to as lines, may be enough to discourage gulls. Gulls will typically be deterred by 125 centimeter spacing.[xvi] This distance, however, is recommended for the protection of ponds. For buildings, the line spacing will likely need to be closer. There are also spikes that can be installed on top of buildings. They are generally made of metal and do not allow the birds to land. Spikes are a more expensive method.

2.2.2.3 Fake Eggs

One British company has reported success replacing seagull eggs with plastic replicas. The seagulls cannot tell the difference, and attempt to raise the plastic egg. The theory is that the seagulls will not lay new eggs if there is a fake egg in their nest. There are not many case studies available for this method.

2.2.2.4 Electricity

There are several options for putting electric strips on rooftops. They shock the gulls and any other bird that lands on the roof of the building. They are rather expensive, need electricity, and could be considered cruel.

3. Methodology

The goals of this project were to develop a water treatment facility as a comparison to the stormwater management and hybrid willows plan that Stantec has begun to implement, as well as research and develop methods of pest control for seagulls. The following steps were taken to reach these goals.

3.1 Phosphorus Removal

There are two main variables that must be determined before either a biological or chemical unit process can be designed: flow rate and contaminant concentration. Flow rate can be determined for this project through the rational method. The rational method is an equation that calculated the peak surface runoff, in cubic feet per second (cfs) of a storm of a certain return period. The rational method calculates the total runoff from a storm based on intensity, contributing area, and the runoff coefficient of the surface where the rainfalls, as such:

$$Q=ciA$$

Where Q is peak rate of runoff (cfs), c is the runoff coefficient; i represents the rainfall intensity (in/hr) and A is the contributing area (acres).

First, the rainfall intensity from a design storm is determined. This is accomplished through referring to a region's intensity-duration-frequency (IDF) curve. An IDF curve charts rainfall intensity against rainfall duration.[xvii] The lines on the chart represent probability. Next, the area of the site is determined; after consulting with members of Stantec, the contributing area was determined to be 49 acres. The next variable is the runoff coefficient. This varies depending on land use of the site. The runoff coefficient is based on soil type, land use and the gradient of the slope.[xviii]

To determine the contaminant levels, water quality testing must be done. Stantec has tested the water for the last year and a half, and their data was used. The data was evaluated, and the year was broken up into seasons based on concentration differences. This allows for different concentrations to be planned for. The year wilwasl likely be broken up into three seasons. The first season is the rearing season. This is when the farm has minks, but not full grown and not in the largest number. The next season is peak; this is when the farm has the largest number of minks, before they are slaughtered. The last season is winter, when there are no mink on the farm and phosphorus concentrations are very low. The seasons was determined through the examination of data produced by Stantec during their testing.

3.1.1 Chemical Removal of Phosphorus

Besides flow rate and contaminant levels, several other factors must be considered when designing for chemical removal of phosphorus. This is due to the different factors that impact each metal used for precipitation. After the determination of which metal to add, settling time was determined.

3.1.1.1 Precipitation with Lime

Lime dosage is dependent on alkalinity in the wastewater, as such:

$$Ca(HCO_3)_2 + Ca(OH)_2 \leftrightarrow CaCO_3 + 2H_2O$$

Stantec has done some alkalinity sampling, which can be used. Economic constraints are important with lime as well, as lime raises the pH of the effluent meaning that a recarbonation chamber must be constructed, adding construction costs as well as daily operating costs.

3.1.1.2 Precipitation with Iron and Aluminum

3.1.1.2.1 Iron

The typical concentration of ferrous solution must be researched. Due to iron forming iron hydroxide at certain pH values- reaction shown below-the pH value must be determined.

$$2FeCl_3 + 3Ca(HCO_3)_2 \leftrightarrow 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

The operating regions for iron precipitation occur in a pH range of 7-9.[xix] If iron is chosen, then the settling time of iron phosphate must be calculated.

3.1.1.2.2 Alum

The typical concentration of alum solution must be researched. Furthermore, since the pH of the effluent affects the efficacy of precipitation, with a pH value around 6.8 producing the highest levels of solid $AlPO_4$, and other values producing larger amounts of aluminum hydroxide, the pH of the wastewater must be determined.[xx] Because the mixing of alum and phosphate is assumed to be instantaneous and uniform, a short rapid mix time will be used, followed by a longer slow mix time for flocculation.

3.1.1.3 Struvite

Struvite production must be researched. There is one company, Ostara, that designs struvite-producing wastewater facilities; their designs will be researched.[xxi] Furthermore, struvite is more likely to precipitate at a pH of around 9.0, so the pH of the wastewater must be determined.[xxii] The reaction for struvite is as follows.

$$Mg^{2+} + NH_4^+ + H_nPO_4^{3-n} + 6H_2O \leftrightarrow MgNH_4PO_4 \cdot 6H_2O + nH^+$$ [xxiii]

3.1.1.4 Sludge Creation

The amount of sludge produced must be determined. This can be done through simple stoichiometry. The amount of moles of the created precipitate can be determined, and then the dry weight can be determined. After this, a specific gravity and moisture content can be assumed, and a total sludge volume was calculated.[xxiv]

3.1.2 Biological Treatment

Flow rate and contaminant concentrations of phosphorus again must be determined. Furthermore, ammonia levels must be determined. The amount of nitrates in the wastewater flow will reduce the efficiency of the biological removal process.[xxv] Thus, the ammonia will have to be reduced during the phosphorus removal process as well.

In addition to contaminant levels, biological and chemical oxygen demands need to be known.

The problem with biological removal of phosphorus is the lack of flow during the winter. Despite precipitation totals staying steady, precipitation during the winter falls primarily as snow, and does not provide runoff. In fact, during winter testing of flow from the site, there is often none to be detected. This is a major problem in any biological treatment facility, as the organisms in the sludge need to be kept alive. Another issue with biological treatment is the need to keep the temperature in the reactors steady. Under 20° C, biological treatment is severely impacted.[xxvi]

3.1.3 Reactors for Phosphorus Removal

3.1.3.1 Batch Reactors

Batch reactors operate after filling completely. After filling, the reaction occurs, and the clean water is decanted, and sludge can be removed. In a biological treatment facility, anaerobic time, aerobic time, anoxic time and settling times must all be calculated. In a chemical treatment facility, mixing and settling times must be calculated.

3.1.3.2 Complete Mix Reactor

A complete mix reactor assumes instantaneous and uniform mixing. This occurs in the chemical removal of phosphorus. A reactor of this sort will have to be sized for the flow passing through. This means that it must be long enough and tall enough so that it can handle the flow coming through, while providing enough time for particles to settle.

3.1.3.3 Plug Flow Reactor

This sort of reactor has water continuously running through. Water and particles enter and exit at the same rate. This sort of reactor will be used if there is a non-instantaneous reaction that needs to occur.

3.1.3 Decision Making Process

The constraints identified are inconsistent flow, inconsistent contaminant concentrations, small available space, and small available budget. Based on this, the decision-making process is detailed below in Figure 6.

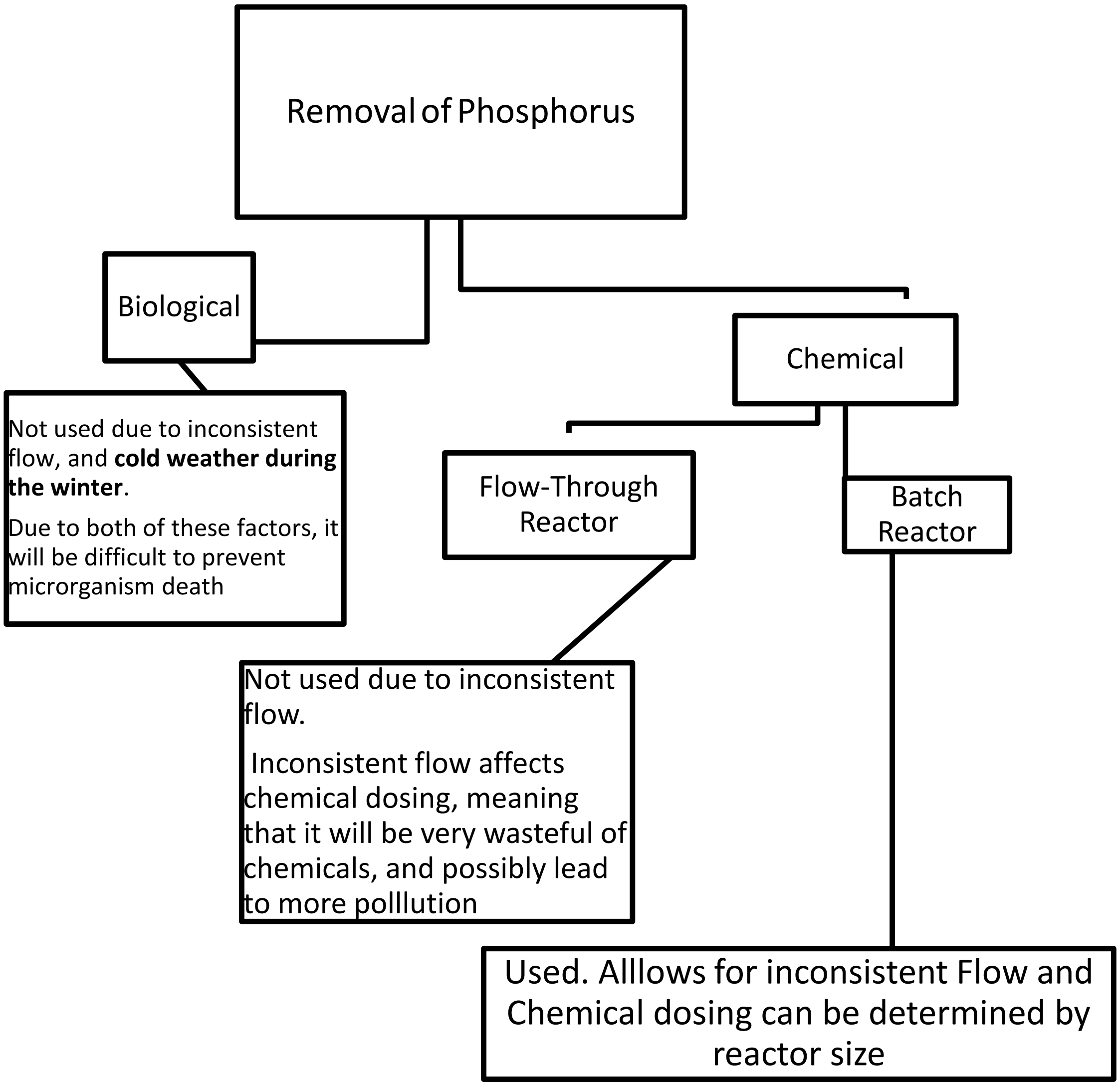

Figure 6: Decision Tree

3.1.4 Cost Analysis for Phosphorus Removal

Cost analysis was done with Costworks software. Costworks is the computer program used by Stantec to estimate costs of projects. First the location of the project is entered, and then the dimensions of the reactor is entered, as well as the length of piping needed. After this, the program gives a cost estimate. The cost estimates include the cost of the materials, the labor, and the transportation costs of the materials.[xxvii] This was done to provide a simple cost estimate.

The chemical cost was determined through stoichiometry. First, a seller of ferric chloride solution was found. Then, the cost per liter was determined. Finally, the cost per reaction was determined.

The operating costs were determined by first researching the average salary of a wastewater technician in Nova Scotia, and then calculating the energy required to run the facility. The energy costs were estimated employing the energy equation for mxing:

$$P = N_P \rho \eta D^3$$ [xxviii]

Where P is power in watts, N_P is the unitless power number of the turbine determined by the type of turbine used, η is the revolutions per second, ρ is density in kg/m and D is diameter in meters.

3.2 Seagull Control Methods

It was determined early that it made most sense to try a physical method of seagull pest control on the newly constructed manure storage building. This building has a soft textile roof that is very susceptible to the acidic nature of seagull guano. By installing pest control on this building, the efficacy of that method can be determined, with the other buildings at the site acting as controls.

First, a literature review was conducted. This was done to determine what sorts of pest control methods are available. Then, the research turned to comparing the methods. The selected method must be able to deter a large, established population of seagulls.

Second, cost estimates for methods ruled effective enough were prepared. These were done by researching companies that sell the materials for pest control and observing trends.

3.2.1 Noise

The area that the farmer wants to keep clear of seagulls must be determined. After this, it can be determined whether or not noise is feasible. Furthermore, sounds that can scare away seagulls must be found. Predators must be identified so that their calls can be used. Additionally, companies that work in seagull pest control will be researched, to look at the prices that typically go along with this method of seagull control

3.2.2 Physical Methods

The three physical methods that were researched were nets, lines and spikes.

3.2.2.1 Nets

Nets are designed to keep birds of all sizes of off various structures. They, however, are rarely used for the tops of buildings. In the literature search, it was found that they were more often employed either covering ponds, or scaffolding underneath open air buildings.

3.2.2.2 Lines

Lines are wires that run the length of a building, designed to discourage perching. They are generally the least expensive physical method of seagull pest control. When used to deter seagulls from landing in ponds, they are generally placed 125 cm apart from each other. On a roof, however, they may need to be placed closer together. This method is also generally not used for large, established populations.

3.2.2. Spikes

Bird control spikes are devices consisting of thin metal rods. They are often used in urban environments. They reduce the area available for birds to perch or land. They are considered humane, as they do not harm the birds. They are also considered one of the most effective methods of bird control.

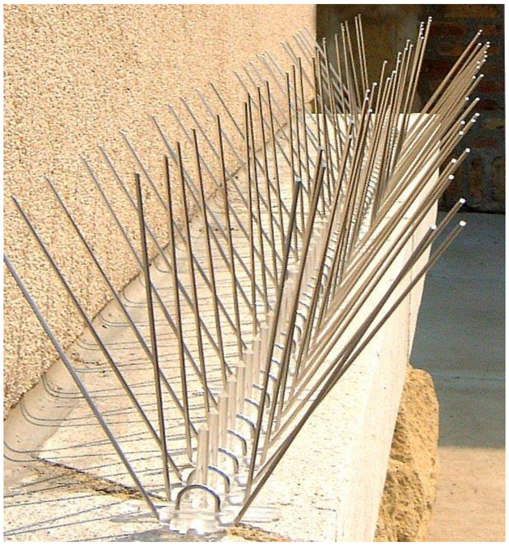

Figure 7: Bird Control Spikes. Source: http://www.birdxcanada.com/roost/bird_spikes_steel.html

3.2.3 Fake Eggs

The efficacy of this method was researched. Due to there are no case studies besides the one company that offers this service, it was dismissed. Furthermore, the legality of removing seagull eggs from the nests in Nova Scotia was determined. Seagulls are a federally protected species in Canada and they are illegal to kill.

3.2.4 Electricity

First, the legality of electric devices for seagull pest control in Nova Scotia will be determined. This will be accomplished through contacting federal environmental agencies. Again, seagulls are a federally protected species in Canada and they are illegal to kill. If such devices are legal, the price of electric devices will be determined.

4. Results and Recommendations:

4.1 Phosphorus Removal

4.1.1 Determination of Flow Rate

The first step is the determination of flow rate. The water that will be treated is impacted stormwater. Therefore, there will not be a uniform daily flow rate, but rather a great range of possible flow rates. The wastewater facility should be able to handle the worst-case scenarios. To determine the total runoff from such a storm, the rational method may be employed. The rational method calculates the total runoff from a storm based on intensity, area of the property, and the runoff coefficient of the surface where the rainfalls, as such:

$$Q=ciA$$

Where Q is peak rate of runoff (cfs), c is the runoff coefficient; i represents the rainfall intensity (in/hr) and A is the contributing area (acres).

Rainfall intensity for storms of varying return periods can be found using an IDF curve such as the one shown below.

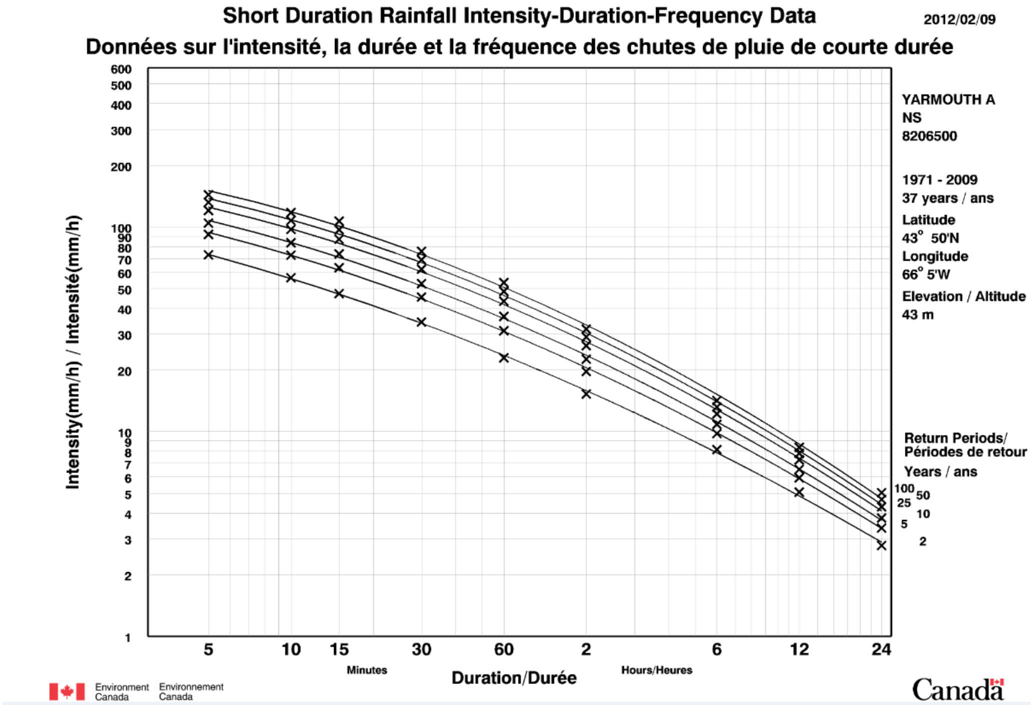

Figure 8: IDF Curve for Yarmouth, Nova Scotia

Using the IDF curve, a five year storm for the area lasting for one hour would have a rainfall total of 40 millimeters, or 1.57 inches.[xxix] This 5-year design storm was selected after consulting with members of Stantec. The contributing area of the farm, which leads runoff to the ponds, measures 49 acres, with most runoff from the site entering the retention ponds. The runoff coefficient depends on soil type, land use and slope. The soil at the farm was identified by Stantec as silty sand with gravel. After consulting with engineers working at the site, the runoff coefficient was assumed to be 0.95, indicating very little infiltration.[xxx] Furthermore, 45% of the runoff is assumed to be retained in the lagoons, further lessening the peak flow

$$Q = (0.95)(1.57 \text{ inches/hr})(49 \text{ acres})(0.45)$$

Based on this, the peak flow from a five-year storm would be 32.88 cfs, or 0.9 cubic meters per second.

Using data supplied by Stantec, the peak flow was given as 1244.16 m^3/day. This number was determined by looking at weekly rainfall from the period which Stantec had been working at the site, selecting the highest total, and determining the total runoff from that information.[xxxi] This number was used for the design of the reactors.

4.1.2 Determination of Concentrations

The concentration at the site is highly variable. Thus, the concentration will be determined by season. As seen in Figure 8, in 2013 the peak months were from August to November.

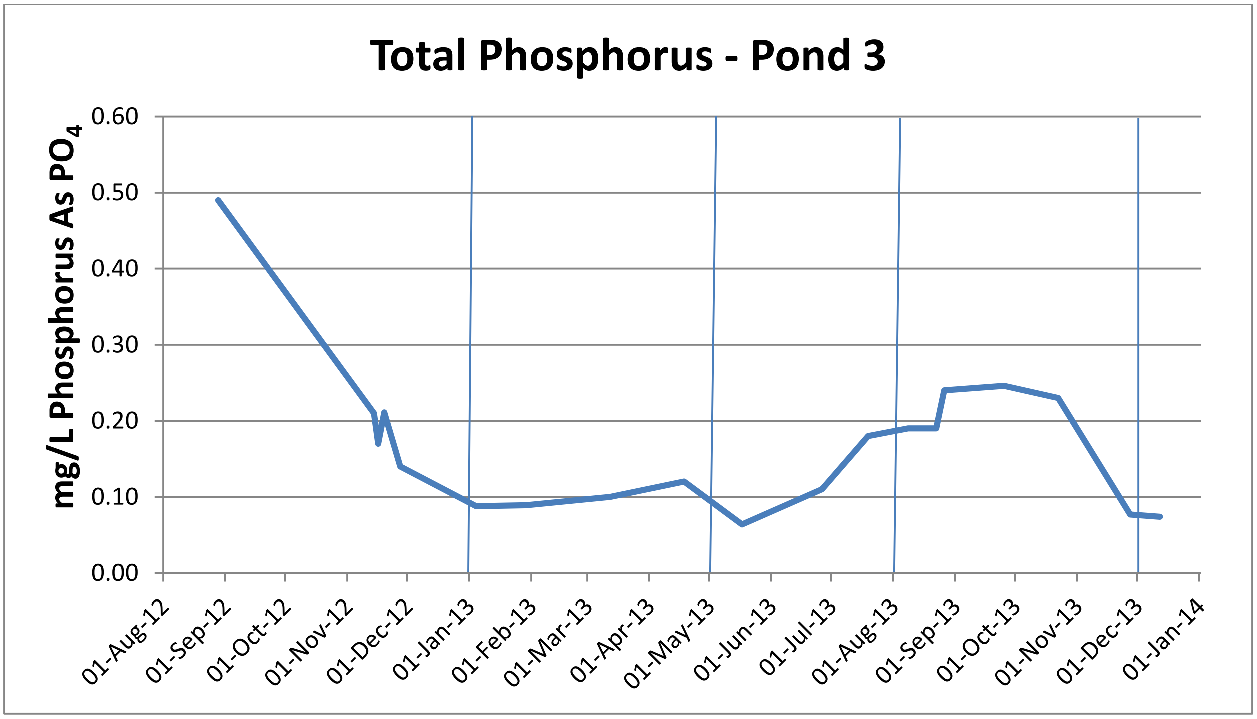

Figure 9: Phosphorus Concentration in mg/L by Month; Seasons Indicated by the Lines: Chart Produced by Stantec

During these months, the average phosphorus concentration in the water leaving Pond 3 measured 21.92 mg/L. This will represent one season. From December to April, the average was 8.56 mg/L. This will represent another season. The third season is from May to July. In this range, the average phosphorus concentration measured 13.67 mg/L. These three averages represent the concentrations that will be planned for.

4.1.2 Phosphorus Removal Design

4.1.2.1 Selection of Chemical

As stated above, the four chemicals used for chemical precipitation are iron, alum, lime, and magnesium ammonia phosphate, called struvite.

Struvite is an exciting prospect. The cost of running the treatment facility could possibly be offset by selling the struvite as fertilizer. However, after a literary review, the process may not be efficient for this particular site. In lab tests, the struvite process was only able to remove 91% of phosphorus, which is not enough for this site.[xxxii] Furthermore, the wastewater facilities that employ the struvite process all handle much larger quantities of water, than is available at the mink farm.[xxxiii] All of the case studies available on Ostara's website point to treatment facilities that handle wastewater from entire regions. The amount of wastewater produced at the farm is much smaller than any struvite recovery facilities are designed to handle. Struvite plants need to be very large because struvite recovery is expensive.[xxxiv] If there is an insufficient concentration of phosphorus coming into the plant then it is not profitable to produce struvite. After consulting with Vijay Sundaram, a wastewater engineer who has worked with struvite before, it was determined that there is just not enough water coming through the mink farm to make struvite recovery possible.[xxxv] Furthermore, struvite is very destructive; struvite will cake onto reactors and pumps, and will increase maintenance and operating costs. For these reasons, struvite recovery was not selected.

The second precipitate to be considered is lime. Lime usage at the site is unfitting for several reasons. First, precipitation with lime produces a larger amount of sludge, which requires disposal compared to other metal salts. In addition, as stated above, addition of lime raises the pH of wastewater. Because of this, recarbronation is necessary. The construction of an extra chamber is neither cost nor space effective. Like struvite, most wastewater facilities that employ lime for phosphorus removal are very large. At a large wastewater facility, lime recovery can be used to lower chemical costs. However, to recover lime, a thermal regeneration facility is needed, which converts calcium carbonate to lime by heating the sludge to 980° C.[xxxvi] This also produces the carbon dioxide needed to lower the pH back to less basic levels. This is unfeasible for such a small system. Furthermore, precipitation of phosphorus using lime will only occur past a pH value of 10.[xxxvii] This pH level does not meet the Regulations. Therefore, lime will not be used.

Iron and aluminum are the next metals to be considered. For these, the main concern is the pH of the water. Both of these metals will react with hydroxide ions and precipitate out of the wastewater at certain pH values. With alum, the operating values occur in a pH range from about 5-7.[xxxviii] With iron, the operating values occur within a pH range from about 7-9.[xxxix] Furthermore, studies have shown that the maximum removal rate of phosphorus with iron occurred at a pH of 8.[xl] The pH value in the effluent has been tested 5 times since Stantec has been involved at the project site. The average of these five tests is a pH value of 8.10. This means that iron is more suitable for phosphorus removal at this site.

4.1.2.3 Reactor Selection

The three reactors researched were batch reactors, plug flow reactors and complete mix reactors. Plug flow reactors will not be needed as the mixing is instantaneous and uniform. A complete mix reactor would manifest itself at this site as a sedimentation tank, or a clarifier. The issue with either of these tanks is that there is highly inconsistent flow, ranging from large flows during storms and virtually no flow during dry weather and during the winter. Therefore, the reactor that will be used is a batch reactor. Two batch reactors are proposed. While running, one reactor will fill up with wastewater, and then the ferrous solution will be added. The iron phosphate will be allowed to settle, and most of the water will be decanted. As this happens, the second batch reactor will be running in parallel, meaning that it will be filling up as the other is reacting, settling and decanting. The remaining sludge, consisting of iron phosphate and solid waste, will be pumped onto drying beds, where it can then be disposed, as shown in figure 10.

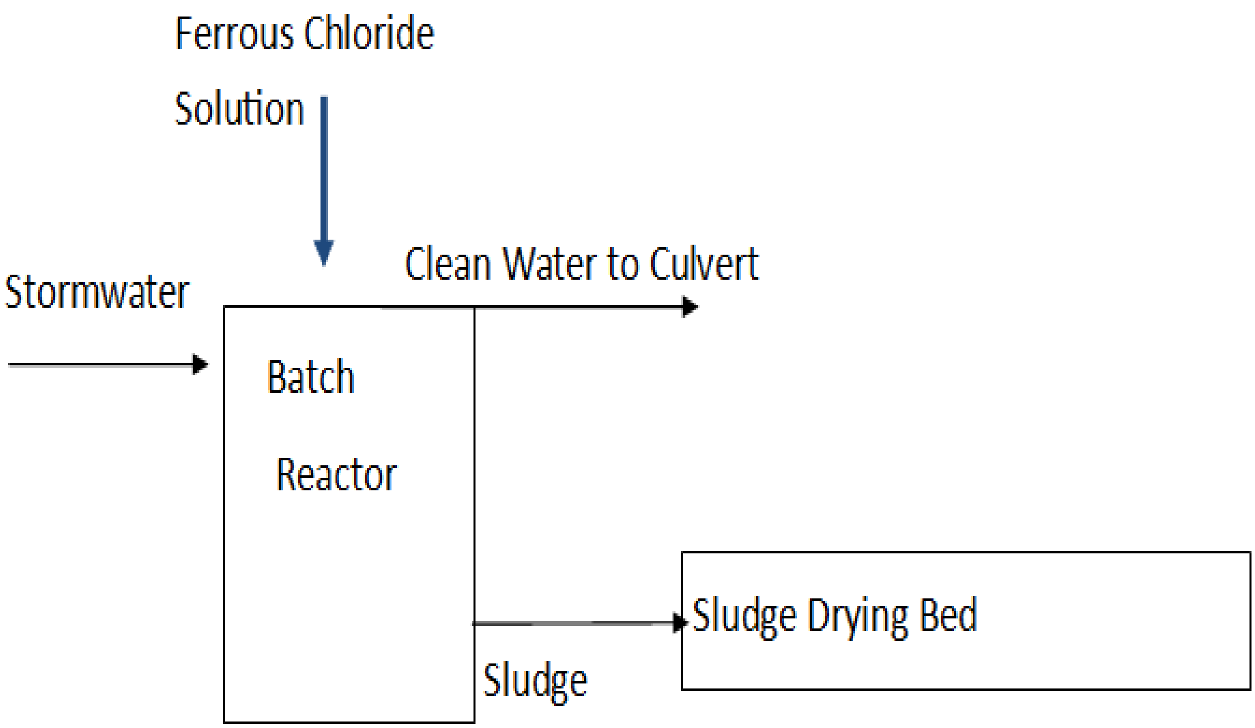

Figure 10: Process Flow Chart for One Reactor

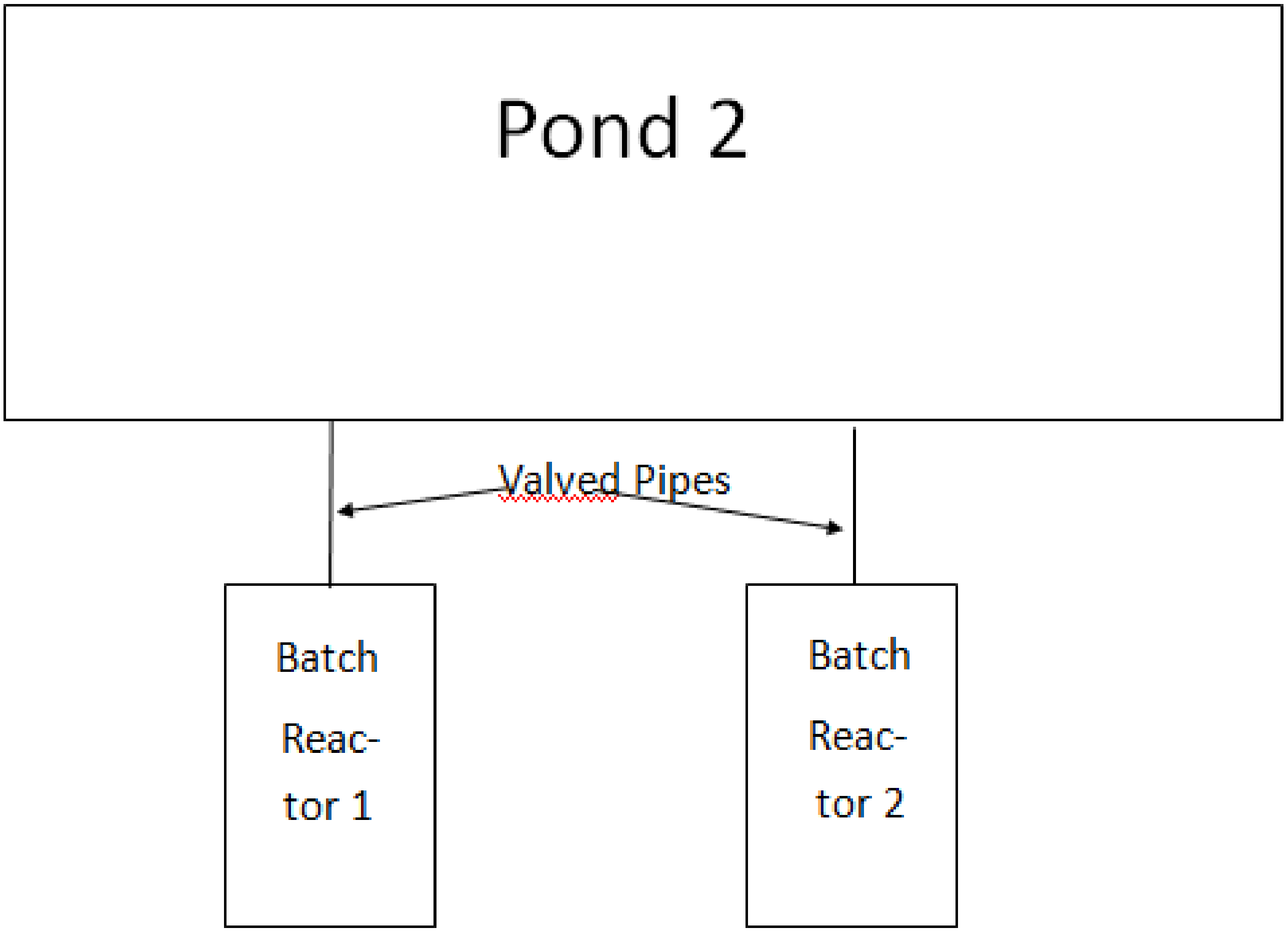

Figure 11: Diagram of the Two Reactors Running in Parallel, With Water Flowing From Pond 2 to the Reactors

4.1.2.3 Reactor Sizing

With the peak 24-hour flow rate determined, the batch reactors can be sized. This design proposes two batch reactors, as shown in Figure 11. On a day with peak 5 year flow, 1244.14 m^3 will flow through the culvert. Both of the reactors operating will be able to handle 3.85 hours of peak flow. This means that both reactors should be able to hold 200.88 m^3. However, additional volume must be included for chemical additions and contingency. If both reactors have a height of 5 meters, than the area needs to be 40.17 m^2. If the chambers are cylindrical, then the diameter will need to be 7.15 meters.

Table 1: Dimensions of Reactors

Dimension	Unit	Value
Height	Meters	5
Diameter	Meters	7.2
Volume	Cubic Meters	203.575
Flow Rate	Cubic Meters per Day	1244.14
Hydraulic Resonance Time	Hours	2.5

4.1.2.3 Iron Dosing

Iron is added to wastewater in the form of ferrous chloride ($FeCl_3$). Ferric chloride is shipped in a solution that consists of 42% $FeCl_3$ by weight, and has a density of 1.5 kg/L.[xli] According to studies; a Fe/P ratio of 2.25 removes the most phosphorus in an efficient manner.[xlii] To calculate the appropriate dosing, first the total weight of ferric chloride must be determined. (Equations extrapolated from equations in Wastewater Engineering: Treatment and Reuses, Pg.503)

1. Determination of weight of iron available per liter of ferric chloride solution
   a. The weight of ferric chloride per liter is:
      i. $FeCl_3$/L = (0.42)(1.5 kg/L) = 0.63 kg/L
   b. The weight of ferric chloride per liter is:
      i. Molecular weight of ferric chloride = 162.2[xliii]
      ii. Molecular weight of iron = 55.84
      iii. Iron/L = (0.63 kg/L)(55.84/162.2) = 0.217 kg/L
2. Determination of weight of iron required per unit weight of P
   a. Theoretical dosage = 1.0 mole Fe per 1.0 mole P

b. Iron required:

    i. (1.0 kg)(molecular weight iron / molecular weight phosphorus)

    ii. (1.0 kg)(55.84/30.97) = 1.8 kg Fe/kg P

3. Determination of amount of ferric chloride solution required per kg P.

    a. Ferric Chloride dose = 2.25(1.8 kg Fe/1.0 kg P)(L $FeCl_3$ solution/0.217 kg) = 18.66 L ferric chloride solution per kg phosphorus

4. Determination of quantity of ferrous solution needed per reaction:

    a. Phosphorus concentration = 21.92 mg/L at peak season.

        i. Ferrous solution = ((200.83 m^3/d)(21.92 g/m^3)(18.66 L ferrous solution/kg phosphorus))/(10^3 g/kg) = 82.14 L/Reaction.

    b. Phosphorus concentration = 13.67 mg/L at midseason

        i. Ferrous solution = ((200.83 m^3/d)(13.67 g/m^3)(18.66 L ferrous solution/kg phosphorus))/(10^3 g/kg) = 51.23 L/Reaction.

    c. Phosphorus content = 8.56 mg/L at lowest season

        i. Ferrous solution = ((200.83 m^3/d)(8.56 g/m^3)(18.66 L ferrous solution/kg phosphorus))/(10^3 g/kg) = 32.08 L/Reaction.

The iron sulfate will be added via pump.

4.1.2.4 Chemical Mixing

Since mixing is assumed to be instantaneous, a short rapid mix time is necessary. This should be followed by a slow mix time for flocculation. There will be rapid mixing for 60 seconds at 200 revolutions per minute (r/min) and slow mixing for 15 minutes at 50 r/min for flocculation.[xliv] These values were determined through a literature review

4.1.3.4 Settling Time

The settling time will be assumed after installation to be 2 hours.[xlv] This cursory settling time was determined through a literature review and it is recommended that this time be determined with full scale testing.

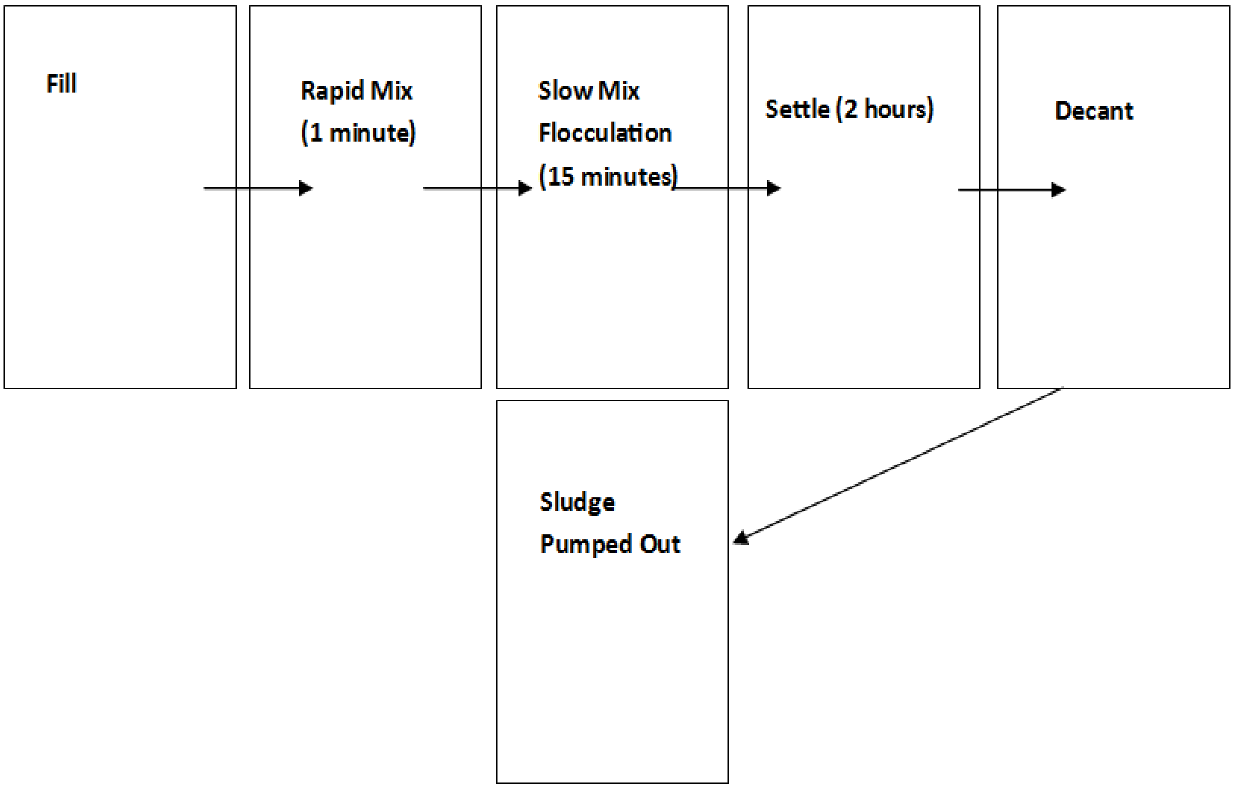

Figure 12: Batch Reactor Process

4.*1.2.5 Drying Beds*

The precipitation process will produce sludge. The sludge in question is mainly iron phosphate. To calculate sludge volume, stoichiometry must be used. As stated earlier, iron precipitates phosphorus as such:

$$Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$$

At peak season, a reactor handles water with a phosphorus concentration of 21.92 g/m^3. Phosphorus has a molar mass of 30.97 grams per mole. This means that there is 0.71 moles per m^3. If the tank is filled to its full volume of 203.6 m^3, then there will be 144.10 moles of phosphorus. Using the above equation, this means that after reacting, there will be 144.10 moles of iron phosphate. Iron phosphate has a molar mass of 150.816 grams. Therefore, the total mass of the sludge produced by this reaction will be 21.73 kilograms, at peak season. This, however, only refers to the dry sludge that requires disposal. To estimate the total volume of sludge, the moisture content must be assumed and specific gravity must be assumed.[xlvi] These values will be assumed to be 92.5% and 1.07 respectively.[xlvii]

The volume sludge (V_s) = (21.73 kg sludge/reaction)/(1.07)(1000kg/m^3)(0.075) = 0.27 m^3

This means that after each reaction, 270 L will be removed as sludge, and will require drying.

The sludge will need to be removed. The first step for sludge removal is decanting. This refers to the removal of the clean water. This will be accomplished through a cleanwater pump, leading the decanted treated stormwater to a nearby creek. The remaining water and sludge will be removed via a sludge pump.

To facilitate removal, as well as to ease in any maintenance, the bottom of the reactor will be at an incline, as shown in Figure 14.

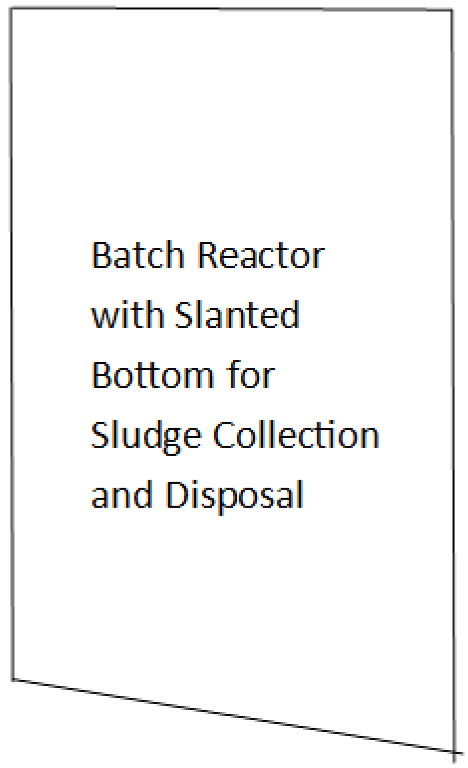

Figure 13: Decant Diagram

4.1.2.4 Cost

4.1.2.4.1 Chemical Cost

One metric ton of ferrous chloride solution costs up to $601.[xlviii] With a density of 1.5 kg/L, there are 666.66 liters in a shipment. At peak season, there is a need for 82.14 liters per reaction. Therefore, it is estimated that each reaction will cost $123.21.

4.1.2.4.2 Construction Cost

The first construction cost to be considered is for the piping leading to the reactors. The water will be piped 100 meters away from the pond to an area with a sufficient grade to allow gravity to fill the tanks.

Costworks 2014 was employed to calculate the cost of constructing the reactors and the piping, as well as the cost of a sludge pump and the necessary piping. Costworks allows for the input of various materials and projects and estimates how much it will cost in certain areas of North America. Employing Costworks, the total estimate was $2,072,955.00. This includes construction costs, materials costs and transportation costs. A chemical pump to add ferric chloride will cost about $8000.[xlix]

Table 2: Pricing

Description	Material	Labor	Total
Piping	$18,900.00	$4,250.00	$23.150.00
Reactors			$2,020,000.00
Sludge Pump	$21,200.00	$5,425.00	$26,625.00
Sludge Piping	$2,200.00	$10,655.00	$3,180.00
Total	$42,300.00	$10,655.00	$2,072,955.00

4.1.2.4.3 Operating Costs

This treatment facility will need at least one dedicated technician, to divert flow during heavy rain, to add chemicals, and to operate the sludge pump. An average salary for a wastewater technician in Canada is $48,000 a year.[l] The labor, however, may not require a full-time professional. The operating that needs to be done manually is as follows: flow diversion, chemical addition, starting the reactors, decanting the reactors and operating the sludge pump. These tasks should be able to be done by anyone currently employed by the farmer. There are also maintenance and electric costs associated with the running of the reactors.

Mixing require power. The power requirement for mixing is modeled by

$$P = N_P \rho \eta D^3$$ [li]

Where P is power input in watts, N_p is the power number for the used turbine (unitless), ρ is density in kg/m^3, η is the revolutions per second (r/s), and D is the diameter of the turbine. The turbine will hang down to the bottom of the batch reactor as show in Figure 15.

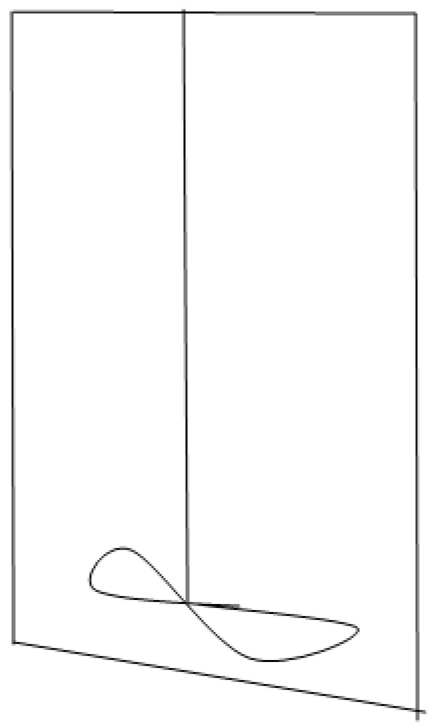

Figure16: Turbine

The turbine needs to be able to provide flash mixing and flocculation. A low shear hydrofoil fulfills both needs.[lii] The power number for such a turbine is 0.30.[liii] During rapid mix, the r/s is 3.33, and during slow mixing the r/s is 0.8333. The density is assumed to be 1000 kg/m^3. The diameter should be a quarter the diameter of the tank, so it will be 1.25 meters.[liv] Thus, the power needed will be as follows.

$$\text{Rapid mix: } P = (0.30)(3.33\ \text{revs/sec})(1000\text{kg/m}^3)(1.25\ \text{m})^3 = 1951.17\ \text{watts}$$

$$\text{Slow mix: } P = (0.30)(0.833\text{r/s})(1000\text{kg/m}^3)(1.25\ \text{m})^3 = 488.08\ \text{watts}$$

The rapid mix cycle lasts for 1 minute and the slow mix cycle runs for 15 minutes. This will be done with a timer. This means that during this time, power must be provided to the facility. Currently, the farm does not have electricity at that area. The client will have to install electricity, meaning additional construction costs.

A kilowatt-hour in Nova Scotia costs $0.14.[lv]

The rapid mix cycle measures:

$$(1.95117 \text{ kW})(1/60 \text{ hr}) = 0.0325 \text{ kWh}$$

The slow mix cycle measures:

$$(0.48808 \text{ kW})(15/60 \text{ hr}) = 0.12202 \text{ kWh}$$

In total, each reaction costs just over 2 cents in energy. The reactors will likely be running around 4 times per day, thus the likely yearly energy cost is around $28.80

There will also be disposal costs. The sludge will need to be brought off site by a professional company for disposal. There are no companies in Nova Scotia currently taking new clients.[lvi]

4.2 Seagull Pest Control

4.2.1 Sizing

While the entire property has been consistently exposed to seagulls, the owner of the farm has made it clear that he would first and foremost like to protect his new manure storage building. This building was very expensive and was built to reduce contaminants entering the stormwater runoff, so it is very important. Furthermore, if a seagull deterrent can be shown to be effective on one building, the owner will have more incentive to install such deterrents on all of his buildings.

The manure storage building is located to the east of Pond 2. The size of this building is 40 m x 20 m.

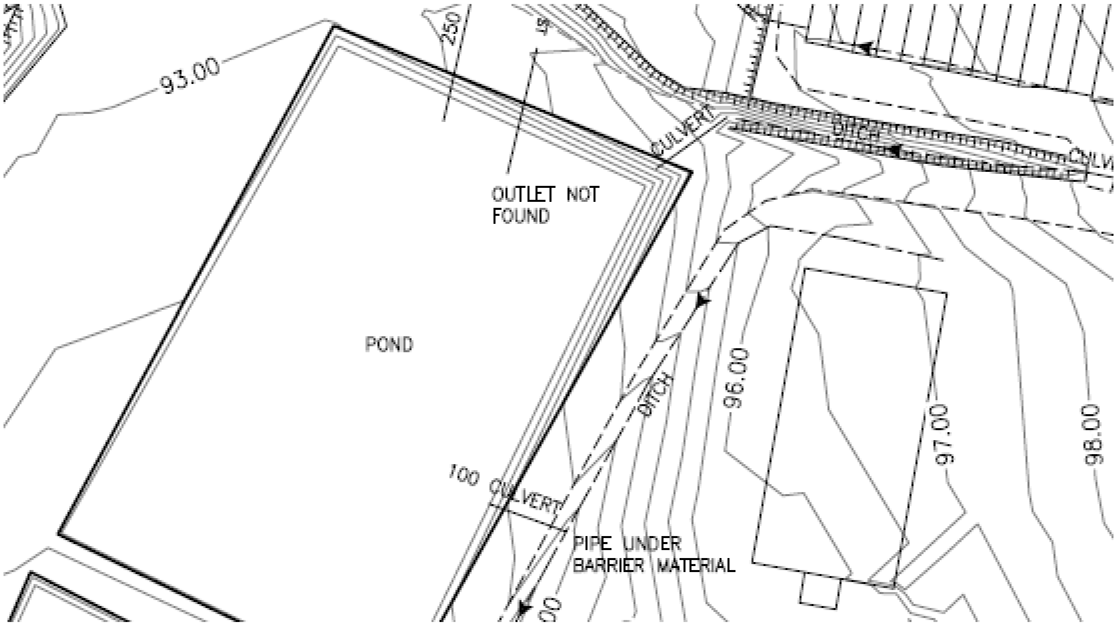

Figure 17: Manure Storage Building Shown in Reference to Pond 2. GIS by Stantec

Figure 18: Manure Storage Building. Photo Taken by Stantec

Based on the shape of the building, as shown in Figure 10, there is not a lot of area for gulls to perch. In fact, it may be possible to apply deterrents along the center of the building. This may represent a cost-effective manner in which to test out the efficacy of various methods of seagull control. If it is effective, it may be applied to other buildings on site.

4.2.2 Comparison of Seagull Deterrents

Ideally, whatever method is selected will deter the seagulls from landing on the manure building. The fake egg method does not meet this goal. In addition, the removal of seagull eggs from their nest is not legal in Canada.[lvii] Therefore, this method will not be considered. For this reason it will not be used. For a method to be considered, it must deter seagulls from landing, be able to handle weather, and be economical. Based on these requirements, nets, spikes, electric strips and wiring will be considered.

4.2.2.1 Nets

They are not generally used for covering the tops of buildings as is needed in this case.

4.2.2.2 Bird Control Spikes

A single strip down the center of the manure storage facility may be an effective enough deterrent, and a test for whether or not to apply on more buildings on the site. The length that the spikes will be applied to measures 40 meters, or 131 feet. The cost for 100 feet of spikes is $239; the cost of 24 feet is $90 and the cost of 8 feet is $30.[lviii] In total the cost for a single strip of spikes would be $359.

4.2.2.3 Lines

This method is cheaper than bird spikes, however, it is most effective when there it is either installed immediately after a building is constructed, or installed in an area where there are not a lot of seagulls. Because of the large established community of seagulls, this method is unlikely to be effective. Thus, it should not be used.

4.2.2.4 Electricity

The legality of electricity for pest control is still an unknown. After contacting Environment Canada, and other federal services, a definitive answer could not be found. Electricity is not typically used to cover entire building tops. Electric strips are typically applies to ledges around buildings, in areas where seagulls perch.[lix] On the manure storage facility, one electric strip running the length of the building, down the middle, may be enough of a deterrent. The price per 50 feet of electric strip is $205.00.[lx] The length needed measures 40 meters, or 131 feet. Thus, the cost for the strip alone is $615.00. The strips need power. There are solar-power batteries available for this purpose. They cost $199.00.[lxi] So in total the cost would be $814.

Table 3: Comparison of Pest Control Methods

Method	Pros	Cons	Decision
Nets	• Birds cannot get through • Very effective	• Expensive • Not intended for large areas	Not likely a good fit for the farm
Spikes	• Very effective • Birds cannot roost • Durable	• Somewhat expensive	Might be a good fit for the farm
Lines	• Inexpensive • May prevent birds from landing	• Ineffective in areas with an established population • Ineffective against a large amount of birds	Not likely a good fit for the farm
Electricity	• Very effective • Shocks birds, scaring them away	• Most expensive • Requires electricity • May not be as resistant to weather events as other methods	Might be a good fit for the farm
Fake Eggs	• Inexpensive	• No case studies available • Removal of eggs illegal in Canada	Not a good fit for the farm

5. Conclusions

5.1 Phosphorus Removal

The phosphorus treatment facility would theoretically work. However, the costs of construction, labor and chemicals makes it prohibitively expensive. Furthermore, there is no current way to dispose of the sludge produced by a chemical treatment plant. The best course of action is to continue with stormwater management. Minimizing time that manure is on the ground, combined with minimizing surface runoff from storm events is a less-expensive way to lower contaminant levels.

5.2 Seagull Control

The spikes should be put in place. They represent a highly-effective and cost efficient manner of seagull pest control. If they are effective enough at keeping seagulls off of the manure storage facility, then they should be put in place along other structures at the mink farm. If they are found to be ineffective, then they should be combined with some sort of noise-producing apparatus. The noise should be either the sound of a seagull in distress, or the sound of a predatory bird. Even more effective would be the cycling between these two sounds every few days, as that would give the seagulls less time to adjust.

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WASTEWATER TREATMENT FACILITY FOR AN AGRICULTURAL CLIENT

Appendix A: Project Proposal

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Contents

Introduction

Intensive animal farming, commonly known as factory farming, is a modern, industrialized form of livestock production that confines a large number of animals (i.e., "high stocking density") in order to produce the highest product output (e.g., meat, milk, eggs) at the lowest overhead cost. While factory farming provides the potential for enormous profit, its practice raises serious environmental issues. For example, confining a large number of animals produces vast quantities of solid waste containing nutrients detrimental to the environment.

This project will propose a wastewater treatment system that will remove these nutrients. The first step will be to identify the chemical composition of these nutrients, their concentrations, and wastewater flow rates. After these parameters have been identified, a suitable treatment approach will be proposed, and a preliminary system design will be created.

Final deliverables for this project will include a treatment process design, a presentation at the Stantec office, and a poster summarizing the project.

BACKGROUND

This section describes the proposed processes for removing contaminants from the influent.

Removal of Nutrients

If not properly reduced by a wastewater treatment facility, nutrients, like nitrogen and phosphorus, can cause eutrophication in local water bodies. This can result in a dense overgrowth of algae that consumes oxygen, blocks light from reaching lower depths, and degrades aesthetic qualities. Both nitrogen and phosphorus can be removed from wastewater by either biological or chemical methods. A selection will be made when more information about the wastewater is available.

Biological Removal of Nitrogen

The biological method of removing nitrogen from an influent consists of a two-step process using nitrification and denitrification.

During nitrification, ammonia (NH_3) is converted to nitrites (NO_2) which are then converted to nitrates (NO_3).[lxii] The processes are illustrated as follows:

$$NH_3 + O_2 + \text{Nitrosomonas} = NO_2$$

$$NO_2 + O_2 + \text{Nitrobacter} = NO_3$$

Nitrification is fast and keeps nitrite levels to a minimum.[lxiii] This is accomplished by using two nitrifying bacteria, nitrosomonas and nitrobacter. Both of these bacteria strands require oxygen, so the water being treated must undergo aeration before they are introduced.

After the water has spent enough time in the aeration chamber with the nitrifying bacteria, (this is known as "hydraulic retention time"), denitrifying can begin. Here, the nitrates are converted into nitrogen (N_2). The process is illustrated as follows:

$$\text{Heterotrophic Bacteria} + \text{Carbon} + NO_3 = N_2 + O_2$$

Denitrifying requires organics as well as heterotrophic bacteria. Heterotrophic bacteria obtain the O_2 needed to break down their food through the O_2 naturally dissolved in a water body; however, if the water is kept anaerobic, the bacteria are forced to break down nitrates entering the activated sludge.[lxiv] If this occurs, nitrification and denitrification must take place in different chambers. The bacteria use the O_2 stripped from the nitrates to break down carbon, their food source; therefore, it is important to keep a consistent amount of carbon sources in the anaerobic-activated sludge chamber. This can be done by supplying solid waste from the farming system into the sludge chamber.

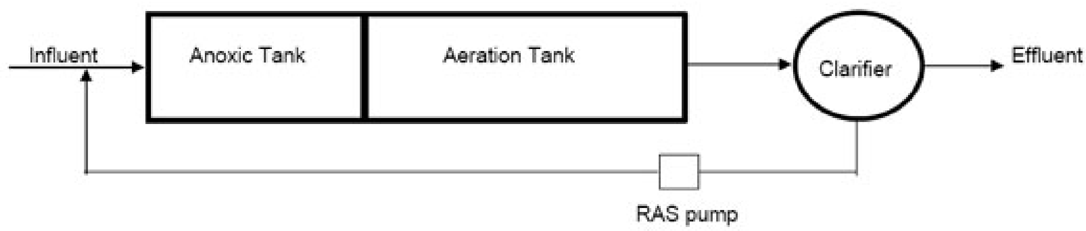

Figure 12: Two chamber reactor for nitrification/denitrification

There are many chamber designs for the nitrification/denitrification process. They will be considered when more information is available.

Chemical Removal of Nitrogen

A purely chemical approach to remove nitrogen is called nitrate ion exchange. In this process, wastewater is passed through a resin bed containing strong base anion (SBA) exchange resins.[lxv] Conventional resins, however, exhibit more selectivity for sulfates than nitrates, so nitrate-selective resins must be used. Nitrate anions are exchanged for chloride or bicarbonate ions.[lxvi] Once the resins' exchange capacity is reached, the resin bed can be regenerated by adding brine. After passing through the resin, the nitrate bonds with a cation and is filtered from the water.

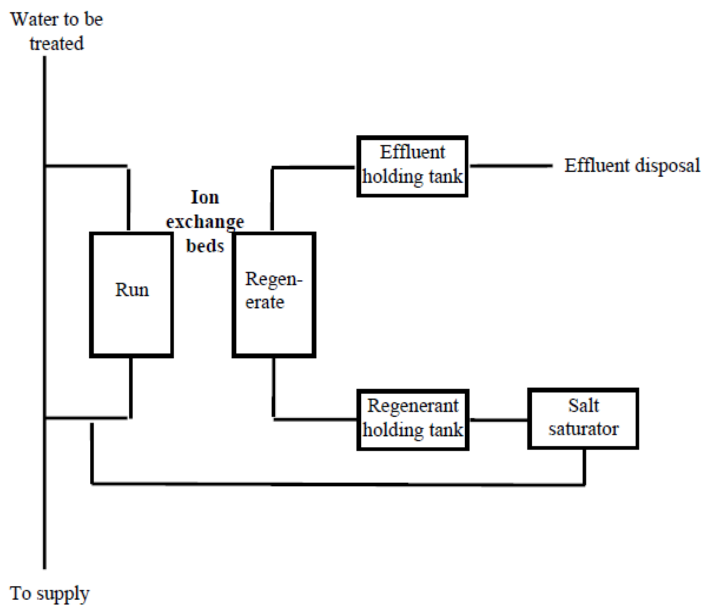

Figure 13: Reactor for Ion Exchange of Nitrates

Biological Removal of Phosphorus

Biological phosphorus removal works by encouraging the growth of phosphate-accumulating organisms (PAOs), which are subjected to anaerobic conditions, then to aerobic conditions.[lxvii] Under the anaerobic conditions, the organisms break polyphosphate bonds, resulting in phosphates (PO_4). When conditions are made aerobic, the PAOs ingest the phosphate, removing it from the water. The PAOs are themselves removed from the water for a more thorough cleaning.[lxviii]

Anaerobic Process:

PAOs + Polyphosphates + glycogen + VFA =

PAOs + stored biopolymers + CO_2 + H_2O + PO_4

Aerobic Process

$$PAOs + stored\ biopolymers + PO_4 =$$

$$PAOs + stored\ polyphosphates + glycogen + CO_2 + H_2O$$

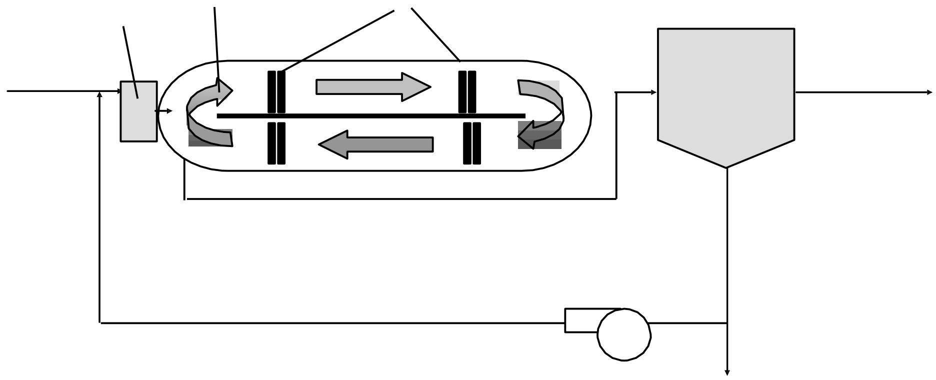

Figure 14: Phosphorus Removal with Small Anaerobic Chamber, and Large Aerating Chamber.

This process, like nitrogen, has both anaerobic and aerobic stages, and likely will be handled in similar reactors.

Chemical Removal of Phosphorus

The chemical removal of phosphorus is a four-part process.

1. Hydroxide is introduced.
2. The hydroxide separates the phosphorous into phosphate ions.
3. The phosphate ions are exchanged with less harmful anions like sulfate or chloride. The final result is aluminum phosphates or iron phosphates, which are solid.
4. The new phosphates are removed by filtration.

First Reaction:

$$H_3PO_4 + nOH = PO_4^{3-} + nH_2O$$

Second Reactions:

$$Al_2(SO_4)_3 = 2Al^{3+} + 3(SO_4^{2-})$$

$$Al^{3+} + PO_4^{3-} = AlPO_4$$

Or

$$FeCl_3 = Fe^{3+} + 3Cl^-$$

$$Fe^{3+} + PO_4^{3-} = FePO_4$$

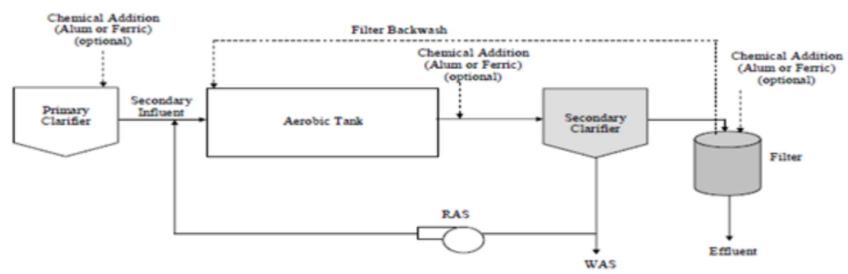

Figure 15: Process for Ion Exchange

METHODS

The scope of the project is to provide a preliminary design of a wastewater-treatment facility for the removal of nutrients from an agricultural source. Likely technologies will include nitrification and denitrification chambers as well as a clarifier and filter for phosphorus removal.

Methodology

A preliminary facility design will be presented. The following steps will be taken to accomplish this goal:

Task 1: Background research into topics applicable to the facility design.

A literature search has been conducted using the WPI library and other references provided by the project advisors. Additional literature will be obtained from outside sources. Stantec is a resource for professional advice and literature. Stantec will also be a source for more local knowledge, such as the legal limits for contaminant concentration of the effluent. Stantec will also be a resource for similar projects whose final results may help in the decision making process.

Task 2: Site Visit & Development of Design Criteria

To determine many of the parameters of the project, the site must be visited. Parameters to be determined include daily flow rate, contaminant concentration, and space available for reactors.

Task 3: Cost and Space Analysis.

The budget for the project and the space available for treatment must be determined. Then, cost estimates for various design alternatives will need to be developed. The cost analysis will include the cost of construction as well as the daily operating costs and likely maintenance costs. The space analysis will determine the amount of room for multichambered reactors, and which processes will fit more efficiently in the space available.

Task 4: Selection of Treatment Processes.

The preliminary evaluations done in tasks 2 and 3 will be utilized to select the most appropriate treatment process (or chain of processes). The selection will be made in consideration of removal efficiency, budget, and available space.

Task 5: Preliminary Design Alternatives.

After the decision making process has been completed, a series of preliminary designs will be created. This will include reports detailing the technology involved, the space required as well as the total volume of the reactor, the daily amount of additives needed, and costs for the construction, running and maintenance of the reactors.

Task 6: Selection of Preferred Design.

Utilizing the constraints detailed in the CAPSTONE DESIGN discussion of this proposal, an objective analysis of each preliminary design alternative will be completed. Based upon the results, a preferred alternative will be selected and refined for presentation.

Task 7: Reporting.

After all decision making and analysis has been completed, a final report will be created. This final report will consist of multiple-draft paper, design details, a formal presentation to Stantec, and a poster detailing the project.

TENTATIVE SCHEDULE

Week 1:

Acclimate to office.

Background research.

Obtain literature.

Look into Stantec resources.

Week 2:

Site Visit.

Identify parameters.

Week 3:

Cost and Space analysis of the various processes.

Begin decision making process

Week 4:

Decide upon which processes to use.

Begin Preliminary design.

Compare ideal facility design with actual constraints.

Determine what is not feasible because of real-world constraints.

Redesign based on real-world constraints.

Week 5:

Redesign.

Work on final presentation

Week 6: Finish final presentation

GANTT CHART

C-Term Gantt Chart

	Week							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Task	Jan. 14- Jan. 16	Jan. 16- Jan. 20	Jan. 23-Jan. 27	Jan. 30- Feb. 3	Feb. 6-Feb. 10	Feb. 13- Fec. 17	Feb. 20- Feb. 24	Feb. 27- Mar. 2
Getting familiar with the office and apartment	■							
Meeting with Stantec Advisors	■	■						
Visit Site		■						
Indentify Problems/Goals		■	■					
Identify Parameters		■	■					
Identify Constraints		■	■	■				
Prelimnary Drafts			■	■	■	■		
Select Best Option					■	■	■	
Final Report and Presentation Preparation and Delivery								■

CAPSTONE DESIGN

Introduction

As part of the Accreditation Board for Engineering and Technology requirement, students seeking a degree in Civil Engineering must complete a Capstone Design Experience. The capstone design must address eight real-world constraints, constructability, economic, environmental, ethical, health and safety, and political. This project will consider all of the previous in the final reports to WPI and to Stantec.

Constructability

The primary concern in reference to constructability involves the space available. The treatment facility will most likely have to process large quantities of water each day. The water will be processed in batch reactors, which depending on the flow, can reach very large sizes.

Economic

There will be costs in constructing and maintaining the wastewater treatment facility. For example, construction will require capital for materials and labor. After construction is complete, various additives may need to be purchased and added to the reactors. Also, the cost of energy required to operate the facility will need to be assessed. Finally, preventative and corrective maintenance will be necessary to keep the facility in good working order and financially viable

Environmental

Although all construction projects have adverse environmental impacts, the ecological benefits of treating wastewater outweigh the impact that the facility itself will have on site, i.e., preventing eutrophication from occurring in, and removing heavy metals from, bodies of water protects both human and animal life.

Ethical

The American Society of Civil Engineers has high ethical standards. Each project must be done to the best of an engineer's ability, and each project must leave behind the smallest environmental impacts possible. This project, concerning the removal of harmful nutrients from the environment, will be led by ethics.

Health and Safety

The wastewater treatment facility will benefit public health by reducing pollutants from local bodies of water.

Political

There are legal restrictions on maximum concentrations of contaminants in an effluent. This project will refer to local legislation to determine what the effluent concentration must be.

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Appendix B: Stoke's Law Discussion

Settling velocity is determined through Stoke's equation. As stated above Stoke's equation determines settling velocity based on the density of the particle, the density of the water, the dynamic viscosity of the water, and the diameter of the particle as such:

$V_s = (g(\rho_p - \rho_w)d_p^2)/18\mu$

The density of iron phosphate is 3056 kg/m^3.[lxix] The density of water is 1000 kg/m^3. The dynamic viscosity of water varies from 1.781E-3 N·S/m^2 at 0° C to 6.53E-4 N·S/m^2 at 40° C depending on the temperature.[lxx] If the floc produced by the iron phosphate measures 0.5 mm, and the wastewater is 0° (hypothetically the coldest it will be while the facility is running, and the longest it will take for the iron phosphate to settle), then the settling velocity will be 0.28 m/s. this means if the chamber is 5 meters tall, then it will take 17 seconds for a particle to settle.

This number, however, does not apply. The use of Stoke's law only applies when the Reynolds number is under 1.[lxxi] The Reynolds number (N_R) of a settling particle is defined as:

$N_R = (V_s d_p \rho_w)/\mu$

At 0° C, the Reynolds number equals 7.86. Since this number is greater than 1, the settling velocity must be calculated in a different way. The settling velocity is calculated using Newton's equation:

$V_s=\sqrt{((4g/3C_d\Phi)((\rho_p - \rho_w)/\rho_w)d_p)}$

Where C_d is the dimensionless drag coefficient defined by:

$C_d = 24/N_R + 3/\sqrt{(N_R)} +0.34.$

And Φ is the shape factor defined as 5 for fractal floc. Using this method, the settling velocity was found to be 0.0077 m/s. In a 5 meter high chamber, it would take 649 seconds for the iron phosphate to settle.

Appendix C: Volume of Concrete

Assume 14” thick concrete:

(14 inches)(0.254meters/inch) = 0.3556 meters

7.2/2 = 3.6 meters. 3.6 meters + 0.3556 meters = 3.9556 meters

Volume of a cylinder = $\pi r^2 h$

Volume concrete = $280.73_{\text{total volume}} - 203.6_{\text{reactor volume}} - 17.48_{\text{volume of the top}} = 59.66\ m^3$ concrete/reactor

($59.66\ m^3$ concrete/reactor)(2 reactors) = $119.31\ m^3$ concrete

Appendix D: Weekly Rainfall

The range of weekly total rain events is shown below.

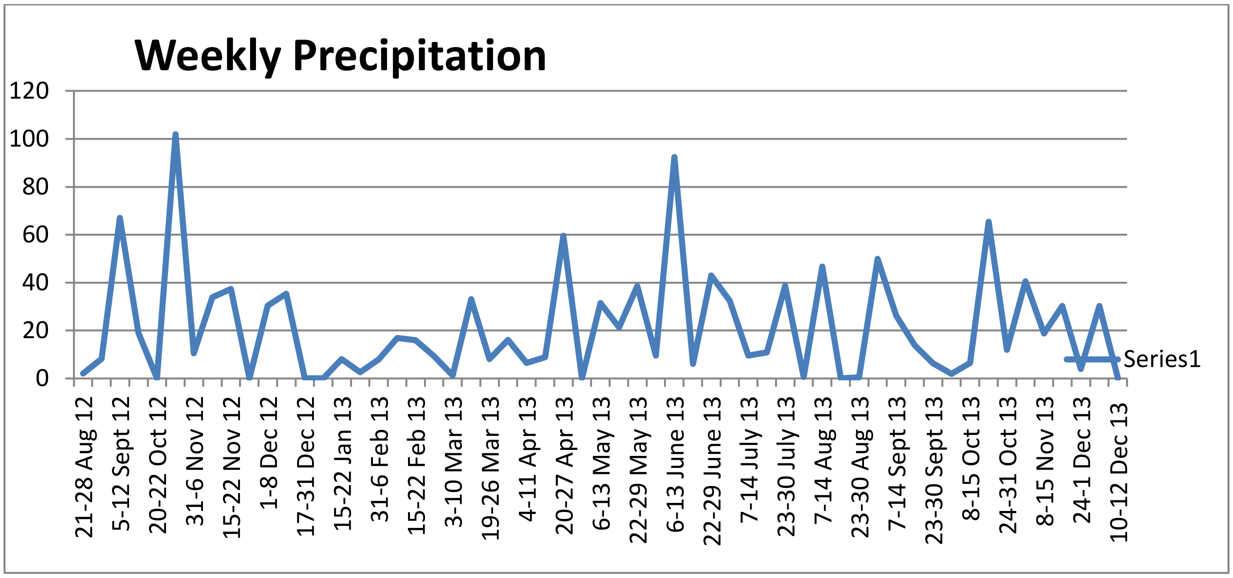

Figure 16: Weekly Precipitation Totals (in millimeters)

The highest total weekly rainfall occurred from October 23rd to the 30th 2012. The total rainfall in this period was 101.9 millimeters of rain. That week, it only rained one day, so this also represents the largest daily rainfall. This value could represent the design storm for the facility.

Appendix E: Costworks 2014 Pricing

Description	Crew	Daily Output	Labor Hours	Unit	Bare Mat.	Bare Labor	Bare Equip.	Bare Total	Total Incl. O&P	Zip Code Prefix	Type	Release
Pneumatic tube system, twin tube,	2 Stpi	15.12	1.058	m	8,900.00	,250.00	$0.00	23,150.00	$27,200.00	C66	Metric	2014
Aboveground water utility storage				Ea.	$0.00	$0.00	$0.00	20,000.00	2,226,000.00	C66	Metric	2014
Pump, general utility, single stage,	Q3	.28	114	Ea.	1,200.00	,425.00	$0.00	26,625.00	$31,500.00	C66	Metric	2014
Pipe, cast iron soil, single hub,	Q2	22.86	1.050	m	2,200.00	$980.00	$0.00	$3,180.00	$3,880.00	C66	Metric	2014
Totals					**$42,300.00**	**655.00**	**$0.00**	**,955.00**	**288,580.00**			

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