AERATED GRAVEL BEDS FOR DE-ICING WASTE TREATMENT

FAA Design Competition for Universities 2011-2012

Topic III: Airport Environmental Interactions

Section D: Stormwater Management

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April 26, 2012

Course: CVEN 4434 – Environmental Engineering Design

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1. Executive Summary

Algae blooms, fish kills, and hypoxic waters are all types of detrimental effects that unregulated stormwater discharge can have on the environments surrounding our nation's airports. With the United States Environmental Protection Agency (EPA) currently proposing stricter regulations on effluent stormwater quality, thinking ahead and constructing viable onsite treatment and sampling plans could ease the financial burden of compliance and improve the economic outlook for the airport industry. Engineering affordable, efficient, and effective stormwater treatment has been successful at some airports which may also employ effluent sampling regimes that accurately model the quality of stormwater flowing into the environment. Our aim was to find a design that could better prepare the Ted Stevens Anchorage International Airport for the EPA's progressive stormwater quality regulations.

Three possible solutions for stormwater treatment were examined as alternatives to direct discharge: aerated gravel beds, constructed wetlands, and infiltration ponds. Two solutions for automated sampling—time- and flow-interval sampling—were also examined. Safety, construction/maintenance costs, and effluent quality were key factors used to evaluate design alternatives.

Based on a weighted decision matrix, the best option is the use of an aerated gravel bed to lower both the biological oxygen demand and total suspended solid load in the effluent stormwater. This design achieves an effective and affordable system to comply with the deicing program at the Ted Stevens International Airport in Anchorage Alaska, and the FAA environmental stewardship goals. This alternative also has the advantage of general suitability over a wider range of airports around the country.

2. Introduction

New guidelines have been proposed by the U.S. Environmental Protection Agency to regulate stormwater discharge from the nation's airports. Preliminary research for improvements to stormwater management included the collection of background information on five different airports in the United States which have de-icing operations. The primary focus of this assessment was to determine alternative sampling methods for effluent stormwater and to discover a feasible de-icing waste (DIW) treatment method as an alternative to direct discharge at applicable airports in the northern United States. Envirodynamics Consulting focused on two automatic water-sampling methods to replace manual methods for sampling and three stormwater treatment methods. The two sampling alternatives are time-interval sampling and flow-interval sampling. The considered stormwater treatment methods are: aerated gravel beds, constructed wetlands, and the use of infiltration ponds.

This document provides background information on current stormwater management practices, potential issues and applicable regulations. A review of our most important literary sources is provided along with insight to our team's problem solving approach. General and FAA specific safety considerations that were taken into account are outlined in the document. This report includes an evaluation of our alternatives based on a set of constraints, cost considerations, and weighted criteria that enabled the Envirodynamics Consulting team to determine that an aerated gravel bed system was the most suitable design with applicability across a variety of airports. The alternative will be designed for Ted Stevens Anchorage International Airport specifically because it serves as a prime example of a facility that would benefit from DIW treatment. This design is detailed with design specifications, drawings and more detailed cost estimation.

3. Background

3.1. A National Perspective

Traditional stormwater management has focused on guiding stormwater flow to drains that ultimately lead offsite efficiently. Stormwater can cause environmental damage such as flooding, erosion, increased turbidity, and waterway contamination. Deicing operations have the potential to cause fish kills, algae blooms, and contamination to surface or ground waters (EPA, 2009). Federal regulation of stormwater containing DIW has been proposed but is still pending; therefore airports around the country have various approaches to managing their effluent. This report examines five U.S. airports which are summarized in Table 1 below.

Table 1: Airport summary

Airport	Avg. Annual Rain Fall (in.)	Avg. Annual Snowfall (in.)	Amount of Deicing Fluid Used (gal)	Airport Area (Acres)	DIW Fate
Denver International, CO	15.81 (NOAA, 2012)	57.5 (NOAA, 2012)	1,043,138 (EPA, 2009)	34000 (Denver.com, 2012)	Greater than 1% concentration is recycled. Concentrations less than 1% are sent to Metro treatment plant.
Seattle Tacoma, WA	36.2 (seattle.gov, 2012).	11.4 (NOAA, 2008)	112,631 PG Type I 14,982 PG Type IV 27,799 EG TypeI 2.052 EG Type IV (EPA, 2009)	2,500 (city-data.com, 2008)	Sent to Midway Sanitary Sewer District or King County South Treatment Plant if there is high loading of BOD
Buffalo Niagara, NY	37.7 (NOAA, 2012)	93.6 (NOAA, 2008)	259,289 PG Type I 25,365 PG Type IV (EPA, 2009)	Almost 1,000 (Buffalo Niagra Int. Airport)	Aerated gravel bed used for biodegradation.
Boston Logan, MA	42.53 (NOAA, 2012)	42.2 (NOAA, 2012)	1,687,000 Type I 184,000 Type IV (EPA, 2009)	2400 (Vanasse Hangen Brustlyn Inc., 2011)	End of pipe oil water separators. Other waste Sent to local treatment plant.
Ted Stevens, AK	20.4 (NOAA, 2012)	86.1 (NOAA, 2012)	420,000 EG Type I (EPA, 2009)	4,837 (Ted Stevens Anchorage Internatuional Airport)	Allowed to flow into surrounding bodies of water. Contaminated snow is pushed into specific areas for biodegradation.

3.1.1. Denver International Airport

At Denver International Airport (DIA) in Colorado, stormwater containing more than 1% propylene glycol is recycled while the rest is mixed in retention ponds and sent to the Metro Wastewater Treatment plant in North Denver. Approximately 70% of the propylene glycol used is recovered from the stormwater runoff. If it is discharged off-site then it is sampled to ensure proper contaminant levels aren't significantly higher than those expected under best management practices. (Denver International Airport, 2011)

DIA's stormwater management system may serve as a leading example but stormwater management techniques vary from airport to airport across the country. The largest determining factor that affects how each airport can handle its stormwater includes space constraints and the regional climate.

3.1.2. Seattle-Tacoma International Airport

Seattle-Tacoma International Airport in Washington, colloquially known as SeaTac, is located in a region where heavy precipitation takes place almost year round (seattle.gov, 2012). SeaTac currently employs a similar stormwater management system to that of DIA in which runoff that comes from heavy industrial activity areas is separated from the runoff that comes from areas where contamination is less likely to occur. The industrial runoff is treated onsite at a small treatment plant and then discharged directly into Puget Sound. When concentrations of BOD in the runoff exceed 61 mg/L during de-icing season, it is pretreated onsite and then sent to a local wastewater treatment plant for further treatment. Runoff that is not collected from industrial areas is tested for contaminants and sent off-site to three separate streams (Port of Seattle, 2009).

3.1.3. Buffalo-Niagara International Airport

Buffalo-Niagara International Airport (BNIA), in Cheektowaga, NY, has invested in onsite treatment of DIW. While located on a small property in a high-density area, the airport was able to construct three aerated gravel beds that treat the runoff before discharging into Ellicott Creek, a tributary to Niagara River. Aerobic biological breakdown of glycol based DIW and other contaminants occur in the beds thus preventing strain on the environment from BOD. While the aerated gravel bed system was originally designed to handle a loading of 4,500 kg/d of BOD, the system has experienced up to 20,000 kg/d with removal efficiencies still above 90% (Liner).

3.1.4. Logan International Airport

Much like SeaTac and Buffalo-Niagara, Logan International Airport, in Boston, MA, is very space constrained with Boston Harbor bordering the airport property on three of its sides. This space constraint gives the airport very little opportunity to improve their stormwater management system. To help ensure proper discharge the north and west effluent discharge points have end-of-pipe treatment that collects and removes oil, grease and any other floating debris. What is not discharged is sent to the municipal local treatment plant (Vanasse Hangen Brustlyn Inc., 2011).

3.1.5. Ted Stevens International Airport

Unlike other airports previously mentioned that utilize onsite treatment, the Ted Stevens Anchorage International Airport in Alaska discharges much of their stormwater without treatment. In an attempt to limit the impact on surrounding water bodies, a comprehensive Stormwater Pollution Prevention Program with numerous best management practices (BMPs) has been implemented. In order to reduce BOD loads to the environment from deicing waste the airport uses low flow nozzles on the sprayer vehicles, which in turn also saves the airport money on glycol. (Ted Stevens Anchorage International Airport, 2002)

The anchorage airport currently practices snow separation where airside snow mixed with DIW and non-airside snow are disposed of in separate designated areas. Airside snow dumps have areas where natural biological treatment can occur prior to entering the storm water drainage system. A new airside snow dump, which utilizes the Postmark Bog as a biofilter, was opened during the 2010-2011 winter season. (Ted Stevens Anchorage International Airport, 2002).

3.2. Current Conditions and Issues

3.2.1. De-icing waste discharge

The main contaminant associated with stormwater runoff is DIW. It is primarily comprised of propylene or ethylene glycol, which are alcohol-based organic compounds (Gallagher, 1998). At some airports, such as DIA, stormwater with high concentrations of DIW is captured separately and then sent to a recycling facility. Other airports may not have the space for large holding ponds and recycling facilities, so they are forced to find alternative management practices for the majority of their DIW waste. The permit conditions for many airports allow for direct discharge of DIW in the conditions that capacity is met according to engineering BMPs.

The natural biodegradation of glycol has a very high oxygen demand, and once introduced to natural surface waters, can reduce dissolved oxygen to levels that can threaten the ecosystem. The potential for oxygen consumption is measured and reported as biochemical oxygen demand. Original ethylene glycol based aircraft de-icing fluid would degrade quickly in the natural environment however it is being phased out for propylene glycol-based ADF because of toxicity concerns with ethylene glycol. Propylene glycol is much less toxic to aquatic organisms; however the degradation is a much longer process and therefore has a greater dissolved oxygen (DO) demand in the natural environment (Gallagher, 1998). A reduction of this BOD by some form of pre-treatment or retention prior to discharge can improve stream quality significantly.

3.2.2. Sampling

Most permits, in accordance with the National Pollutant Discharge Elimination System, require regular sampling of stormwater runoff as BMP's. Often, sampling must be conducted by hand due to high fluctuations in seasonal flows and the unpredictability of the wet weather events. During the winter and dry seasons many drainage channels are dry, but if a wet weather event exceeds 0.11 inches then wet weather sampling must be conducted. Most of the sampling at DIA is done in the retention and detention ponds during mixing and dilution of the contaminated fluid. Sampling at the discharge points is conducted quarterly at DIA. Other Airports such as Boston Logan International, which is located on Boston harbor, requires monthly sampling for numerous contaminants and water properties (Vanasse Hangen Brustlyn Inc., 2011).

DIA has tried to establish real-time measurements of BOD using cultured microorganisms. This hasn't worked because the organisms can't become acclimated to the high fluctuations in the concentration of propylene glycol. These concentrations fluctuate seasonally and with the unpredictable wet weather events. For DIA there are also very strict requirements for discharging to the local treatment plant. There are ramping limitations which require the flow to the treatment plant be altered slowly as not to overwhelm the treatment plant. The same goes for stopping the flow to the treatment plant. This is because the treatment plant uses the alcohol based DIW coming from DIA to help culture the microbes for treatment. If the flow of DIW stops abruptly the organisms will die and cause problems for the plant such as clogging. Discharge into local streams would have the same effect, providing food for microbes and increasing the stream's heath, as long as the concentrations aren't too high.

3.3. Evaluation of Pertinent Regulations

Airports are required to obtain stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES) which was created by the United States EPA to protect surface waters from the effects of industrial and municipal discharge. The NPDES is currently responsible for issuing permits with required guidelines for such discharge and typically grants this authority to the state level. Traditionally, the NPDES has traded numerical effluent limits for proof of utilization of BMPs and development of a management plan outlining their implementation. In recent years, however, the EPA has begun to address growing concern for the environmental effect associated with direct discharge allowed within a number of currently issued NPDES permits. Since 2009, the EPA has been developing proposed technology based effluent standards to be implemented in the NPDES permit which the EPA Administrator is expected to sign in April 2012. The proposed guidelines, summarized in Table 2, would apply to primary commercial airports with 1,000 or more annual jet departures and 10,000 or more total departures and require the collection of DIW with treatment on-site or at an off-site Publicly Owned Treatment Works (POTW). The standards that would apply to Ted Stevens International and an estimated 218 other airports are classified as Best Available Technology Economically Achievable (BAT). BAT guidelines represent what the EPA has deemed the best economically achievable performance in the treatment of the particular toxic or nonconventional pollutant through case studies and surveys at selected airports including Ted Stevens International. The EPA determines economic feasibility on total costs to the industry and the burden of compliance to the financial conditions of the subcategory (Environmental Protection Agency, 2009). The process for implementation of the new rule is incorporated into the NPDES permits at the time of renewal which is in 2013 for Ted Stevens International Airport (Strassler, 2012).

Table 2: Proposed Airport Deicing Effluent Limitation Guidelines and Standards

Regulatory Level	Technology Basis	Airports ≥ 1,000 Annual Jet Departures and ≥ 10,000 Annual Departures	Airports ≥ 1,000 Annual Jet Departures and ≤ 10,000 Annual Departures
BAT	• 60% or 20% ADF capture • Biological treatment • Pavement deicer product substitution	• Capture 60% of available ADF for airports ≥ 460,000 gals ADF usage or 20% for airports ≤ 460,000 gals ADF usage. • Treat wastewater to meet effluent limit for COD	• Certify use of non-urea based pavement deicers or meet effluent limit for ammonia

Note: Ted Stevens International has >1,000 annual jet departures and >10,000 annual departures and uses < 460,000 gallons ADF (Environmental Protection Agency, 2009).

Table 3: Technology basis (BAT limitations) for the effluent limitation guidelines

Waste stream	Pollutant or Pollutant Property	Daily Maximum	Weekly Average
Aircraft Deicing	COD	271 mg/L	154 mg/L
Airfield Pavement Deicing	Ammonia as Nitrogen	14.7 mg/L	

Note: Values subject to change when finalized rule (Environmental Protection Agency, 2009).

In addition to BMPs and other permit requirements, DIA and similar airports are subject to regular, as well as event specific, sampling requirements. Sampling is desired from effluent containing DIW at a point near to the source in the discharge stream. DIA conducts wet weather monitoring at designated locations chosen to represent discharges from areas of industrial activities. Sampling is required monthly through the year at DIA, and also in the event of a storm (wet weather sampling) amounting to over 0.1 inch within the first 30 minutes of discharge (Denver International Airport, 2011). Some sampling requirements from DIA's permit are shown in Table 4 below. Results of such sampling are reported on a "Discharge Monitoring Report" and cannot violate the permit, but are used rather as a gauge to what BMPs are working at the facility and which need attention. Detection of contamination is the first step towards identifying environmental hazards and the permits are not lenient on the issue of sampling.

Table 4: Wet weather monitoring requirements at four monitoring locations at DIA

Effluent Parameter	Measurement Frequency	Sample Type
Chemical Oxygen Demand mg/L	Once every 2 months	Grab
Dissolved Oxygen mg/L	Once every 2 months	Grab
Oil and Grease mg/L	Once every 2 months	Visual (Grab if sheen is present)
pH	Once every 2 months	Grab
Total Suspended Solids mg/L	Once every 2 months	Grab
Propylene Glycol mg/L	Once every 2 months	Grab
Nitrate plus Nitrite as N, mg/L	Once every 2 months	Grab
Total Kjeldahl Nitrogen (TKN), as N, mg/L	Once every 2 months	Grab

(Denver International Airport, 2011)

4. Relevant Literature

This report's research, assessments, and designs were based on a broad spectrum of reputable sources. This section outlines some of the more important sources and explains how they were used in the context of our project.

DIA Stormwater Management Plan

The Denver International Airport possesses one of the most advanced stormwater management systems in the country. The Storm Water Management Plan provides details for the airport's operations and BPMs concerning industrial runoff. Having reviewed these practices provided the group with valuable resources which demonstrate the components necessary to produce a successful management program. (Denver International Airport, 2011)

Buffalo Niagara Case Study

The case study of the submerged aerated gravel bed system at Buffalo Niagara International Airport proved to be an invaluable resource. Having chosen an aerated gravel bed as our design alternative, we have often referenced this report. At the time of publishing, Buffalo Niagara had constructed a subsurface aerated gravel bed that had been in successful operation for two years.

Buffalo Niagara ranks among the top 20 airports with highest usage of ADF and their new aerated gravel bed has treated loads above 15,000 mg/L of BOD successfully. (Liner)

Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) website contains a guidance manual specific to airport stormwater management practices. The design manual was developed through a collaboration of WSDOT Environmental Services, WSDOT Aviation, and the FAA. It provides advice and guidelines for the design, construction, and maintenance of stormwater facilities in accordance with BMPs for engineering and wild life interactions. With respect to this assessment, the document was primarily used as a reference for BMPs commonly implemented at airports, as well as a guide for concerns and conditions that should be considered when designing control technology in the airport setting.

Environmental Protection Agency

Several documents from the United States Environmental Protection Agency's website provided essential information with respect to particular regulations and BMPs, particularly with constructed wetlands and bio-infiltration basins. The document pertaining to the NPDES provided current laws and requirements of airports with stormwater discharge permits, and gave us information that would provide effluent limitation guidelines for airport deicing operations which would require collection and proper handling of DIW at all airports. (EPA, 2000) (EPA, 2006) (EPA, 1993) (EPA, 2009) (EPA, 2000)

4700 Refrigerated Sampler Installation and Operation Guide

This document is the user manual for the automated sampler suggested for use in our alternative assessment. This document outlined the limitations of the sampler and suggested the best methodology to work around these limitations. It provides detailed installation guidelines which cover physical preparation of the device as well as information on programing the sampler for specific requirements. Operation and maintenance considerations along with a list of parts are also presented.

5. Team's Problem Solving Approach

Our team selected criteria for evaluation of design alternatives based on a comprehensive approach including a wide range of factors. Some factors encompass both categories of design alternatives — direct discharge and automated sampling — while others are specific to one or the other. These factors were influenced by considerations of safely, ecological protection, operation and logistics.

Before approaching any design alternative, we discussed every problem as a team. This allowed team members with extensive knowledge in a specific area — ecology, for example — to contribute their unique perspective. This discussion also allowed for brainstorming on a number of components before they are delegated to specific group members. Our contacts at the Denver International Airport also provided us with valuable information along with the viewpoint of those who actually manage airport stormwater on a day-to-day basis. This gave us a better understanding of airport infrastructure, real-life problem solving approaches and insight into current stormwater sampling practices.

Group members worked independently on their assigned tasks but may approach other group members or outside experts for assistance with specific details. Since all work was later reviewed by another team member, the frame of reference of the reviewer can provide a valuable differentiation in context.

6. Safety Considerations

Envirodynamics Consulting considers safety as an upmost priority. We identified potential hazards, evaluated risks, and explored possible safety measures for all design alternatives considered. The consideration of factors related to safety is evidenced by its inclusion in our weighted decision matrix.

Safety is also a major focus and driver for the policies of the FAA. The FAA plays a crucial role in the provision of all airport operations, giving the United States one of the safest and most complex aviation systems in the world (U.S. Department of Transportation, FAA, 2007). An important step towards the future of aviation safety is the implementation of an integrated Safety Management System (SMS). While developing our designs and procedures, the principle sources on SMS included an Advisory Circular detailing SMS for airport operators (U.S. Department of Transportation, FAA, 2007) and the SMS manual provided by the FAA's Air Traffic Organization. For the alternatives considered, the two main concerns regarding health and safety on our project are avoiding the possibility of bird/aircraft collisions and safe sampling operator techniques.

Bird Aircraft Strike Hazards (BASH) are a significant threat to flight safety. Bird strikes usually occur during takeoff and landing, when planes are flying at low altitudes. To reduce the possibility of strikes we will take this problem into account when designing a de-icing waste control system by limiting open water bodies. (U.S. Department of Transportation, FAA, 2012)

When collecting stormwater samples the working personnel must not be in danger at any time. Some of these dangerous situations include adverse weather conditions, slick surfaces, working around stormwater drainage infrastructure, and operating motor vehicles around moving aircraft.

7. Summary of Criteria for Design Alternatives

Our selection of the most suitable design alternative will be based on a number of weighted criteria. These criteria were decided on by members of the Envirodynamics Consulting team based on relevance to design alternatives for both direct discharge and automated sampling. The weighting of these criteria reflects their relative importance and was collectively decided on by the team then amended based on input from the Environmental Services division at Denver International Airport. An overview of the criteria can be found in Table 5.

Present value cost is heavily weighted for alternatives to DIW direct discharge because such projects would come at a significant cost. Client reputation may ride on the performance of the alternative and the aesthetics is important in the airport setting; however, these factors hold little weight in overall selection. Weighting for long-term effectiveness was based on the need for alternatives to adapt to variations in BOD concentrations and loading over the design life. Ease of operation becomes important during maintenance of the alternatives. Safety concerns over bird strikes influenced our weighting for safety and reliability. Ecological impact and effluent discharge quality are closely related and weights are influenced by the pending EPA regulations.

Automated sampling alternatives had a relatively low cost, so that criterion had less weight. For social concerns, client reputation may be at risk if sampling fails, but aesthetics have very little importance with such small systems. Long-term effectiveness is important because effluent conditions could change over the design life due to variations in operations and climate. Since the purpose of sampling is to detect detrimental or hazardous stormwater effluent conditions, reliability is heavily weighted. During operation, Ecological impact and effluent quality are not affected by sampling equipment so they were not considered in the comparison.

Table 5: Brief descriptions of criteria for design alternatives

Criteria	Description	Weight: DIW Direct Discharge	Weight: Automated Sampling
Present value cost	Present value cost represents the combined capital and operation and maintenance (O&M) costs over a 20 year period. The capital cost describes the initial, one-time cost necessary for the project to reach operational status. This includes the cost of materials, equipment, legal consultation, and construction. The O&M costs are sustained throughout the life of the alternative. This may include scheduled maintenance, repairs, and energy requirements.	**45%**	**20%**
Client reputation	Takes into account the public's perception of design alternatives and their sustainability and environmental friendliness. Airports have a reputation to maintain, especially for practices related to sustainability and environmental protection.	**3%**	**2%**
Aesthetics	High aesthetic quality is important for airports servicing millions of passengers each year. Aesthetic considerations will likely need to be considered for DIW direct discharge alternatives as the project may be visible from the terminal, the air or the tarmac.	**2%**	**0%**
Long-term effectiveness	Continued performance of the project within its projected life-span is important. Additionally, it is critical that design alternatives are able to adapt to variations in operating conditions, within reason, over the life of the project.	**8%**	**20%**
Ease of operation	It is important that alternatives avoid overly complicated operation requirements in order to minimize training costs and lower the need for more expensive skilled operators. This includes adaptation to new procedures by current personnel and training for new personnel. Alternatives that require specialized skills will receive deductions under this criterion.	**5%**	**18%**
Reliability and safety	Safe and reliable operation of our design alternatives is critical. Our team has taken the legal, environmental, and social consequences of malfunction, abnormal conditions, and operator error into consideration. We are also concerned with potential safety hazards from wildlife on airport property during both construction and normal operation.	**12%**	**40%**
Ecological impact	Our team has taken into consideration the ecological impacts for both the operation and potential malfunction of our alternatives to DIW direct discharge. During malfunction or failure of the design, we are concerned with the environmental impact of untreated or undertreated stormwater in downstream aquatic and riparian ecosystems.	**10%**	**0%**
Effluent discharge quality	Effluent discharge quality is an important requirement for our alternatives to direct discharge due to pending EPA regulation which will reduce the maximum weekly average chemical oxygen demand concentration to 154 mg/L (Environmental Protection Agency, 2009). This criterion will be based on treatment efficiency of common pollutants, primarily DIW and, to a lesser extent, trace contaminants.	**15%**	**0%**

8. Design Alternatives to DIW Direct Discharge

This report covers three design alternatives to untreated direct discharge of DIW: an aerated gravel bed, a constructed wetland and an infiltration pond. These alternatives are described in more detail below and later compared in a weighted decision matrix. Although our preliminary design will be for the Ted Stevens Anchorage International Airport, we took general applicability into account during our analysis of alternatives. Table 6 below summarizes the major advantages and disadvantages of the direct discharge alternatives. Comparative discussions of each alternative follow with design parameters and cost considerations.

Table 6: Summary of advantages and disadvantages for direct discharge alternatives

Alternative	Advantages	Disadvantages
Aerated Gravel Beds	• Low operational & maintenance cost • High BOD removal efficiency • Subsurface design effective in cold climates	• Large required area • May require detention pond or tanks for pre-storage and flow control
Constructed Wetlands	• No need for detention areas • Capable of handling variable flow rates	• Risk of increased wildlife strikes • Large required area
Infiltration	• Low capital cost • Lower land area requirements	• Large required area • High dependence on site conditions • Risk of increased wildlife strikes

8.1. Aerated Gravel Bed

8.1.1. Description

An aerated gravel bed is a type of subsurface constructed wetland that uses microbes to consume the BOD in the influent waste. This treatment process is currently used to treat stormwater at Buffalo-Niagara International Airport. The influent DIW flows downward through 1-2 meters of gravel where it is then pumped out of the bed. The bottom of the bed is covered with an impermeable 60-mil polyethylene membrane to prevent groundwater contamination. Along the bottom, there is an aeration system that pumps air through perforated PVC pipes up through the gravel in order to provide oxygen for aerobic biodegradation of the waste. The BOD removal rate is largely affected by the amount of aeration. The combination of the BOD in the waste and the aeration that occurs encourages microbial growth on the gravel. These microbes consume the BOD as the stormwater travels through the gravel. The subsurface design allows temperature buffering by the surrounding soil which helps stabilize BOD removal efficiency since efficiency of microbial processes general slow at lower temperatures. Propylene and ethylene glycol do not contain nitrogen, phosphorus, or other nutrients, which results in lower BOD removal efficiencies. This issue can be bypassed by adding a nutrient-addition system to the bed system.

Figure 1: Construction of aerated gravel beds at Buffalo-Niagara International Airport

Each gravel bed requires a large amount of space because the influent flows downward through the gravel and not laterally. The four aerated gravel beds located at Buffalo-Niagara International Airport are 4,640 m^2 each with depths of 1.5 m and are shown in Figure 1. The bed system typically handles 1.2 MGD, which results in a residence time of roughly 6.1 days. However, flow can be varied as the system depends on BOD loading instead of flow rate. While a very effective and efficient method of BOD removal, aerated gravel beds would be impractical for airports with limited space.

The aerated gravel beds at Buffalo-Niagara International Airport were originally designed to handle 200 g $BOD/m^2 \cdot d$. During the first winter season after the beds were constructed, polysaccharide slime formed on the gravel due to lack of nutrients including phosphorus and nitrogen. The addition of 0.085 kg nitrogen and 0.017 kg phosphorus per kg of biomass, in addition to various micronutrients, can resolve the issue of nutrient deficiency (Liner). The following season, a nutrient-addition system was added which increased the load that the bed could handle to 20,000 kg/d, with an average BOD removal efficiency of 98.3%. Figure 2 shows the calculated BOD removal efficiency of the aerated gravel beds at Buffalo-Niagara with varying influent BOD concentrations. Because of the success of the aerated gravel beds at Buffalo-Niagara, similar treatment methods are being implemented at Heathrow Airport in London and at an airport facility in Edmonton, Alberta (Liner).

To be implemented, a large site needs to be identified that is nearby the existing stormwater infrastructure. A site that is uphill of the stormwater collection areas would be impractical due to the cost of pumping the stormwater uphill to be treated. Aerated gravel beds can be placed in parallel for increased flow capacity, in series for high BOD removal efficiencies, or be standalone treatment practices if neither high flow rate nor high BOD removal efficiencies are required. The implementation of an aerated gravel bed system includes excavation of earth, lining of the beds with the polyethylene membrane, adding the forced bed aeration system and the effluent piping to the beds, adding the gravel to the beds, and adding the infiltration chamber that is used to disperse the wastewater over the gravel. Additionally, pumps may be necessary to pump the wastewater toward or away from the beds.

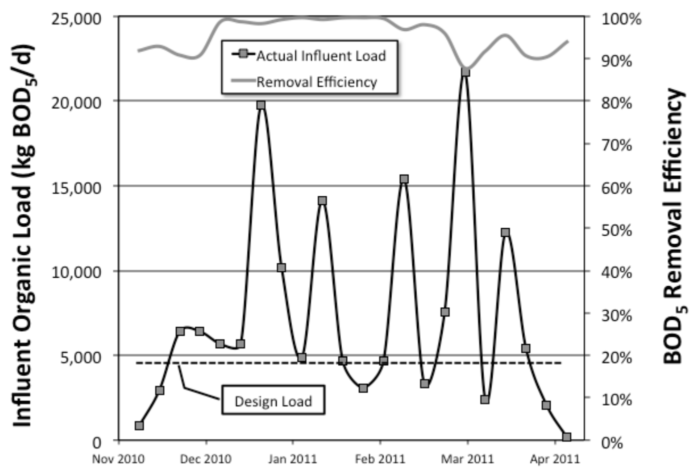

Figure 2: Influent organic load and BOD removal efficiency for aerated gravel beds at BNIA (Liner)

While requiring a very large amount of space, aerated gravel beds have many benefits. The subsurface design of the aerated gravel bed keeps contents from freezing and the microbes from dying in cold climates. Additionally, the subsurface design decreases the chance of wildlife strikes, a key safety concern. Also, the amount of aeration can be throttled for varying levels of BOD loading, which can reduce operation costs when little glycol is being used.

8.1.2. Evaluation

The aerated gravel bed treatment method is a low cost, effective option for the removal of BOD from stormwater runoff. The Buffalo-Niagara aerated gravel bed was originally designed to handle 4,500 kg/d of BOD or 1.2 MGD of stormwater runoff while 280,000 gallons of glycol are used annually (Liner). At Ted Stevens Anchorage International Airport, 420,000 gallons of glycol are used annually (EPA, 2009). Using the amount of glycol sprayed annually at each airport and the flow rate design specification of the Buffalo-Niagara aerated gravel bed system, a flow rate of 2.0 MGD and the ability to handle a load of 5,300 kg/d was decided to be an adequate design specification for an aerated gravel bed system at Ted Stevens Anchorage. While these specifications are adequate for Ted Stevens International and the airport's current situation, Envirodynamics Consulting recommends designing the treatment system to meet the predicted doubling of air travel in the next 20 years this flexibility is important (U.S. Department of Transportation, FAA, 2012). Precise specifications and reasoning for the final design can be found in the design section.

The aerated gravel bed system is an environmental success considering it results in high quality effluent and almost no negative ecological impact. Additionally, the aerated gravel bed is effective and requires little training to operate. Due to the possibility of nutrient-limitation, the reliability of the aerated gravel bed is not as good as the infiltration system.

8.2. Constructed Wetlands

8.2.1. Description

A design alternative common to stormwater systems is an engineered (or constructed) wetland. The wetland can achieve contaminant removal from stormwater by utilizing microbial breakdown during retention, plant uptake, settling, and adsorption (Metropolitan Council , 2011). An engineered wetland is similar to a natural wetland in that it supports vegetation and maintains a permanent pool, but uses the natural processes it provides to degrade and collect pollutants. Engineered wetlands achieve high removal efficiencies for particulates as well dissolved matter and significantly reduce BOD. Space requirements are demanding, and careful design considerations and adjustments must be made to sustain vegetation as well as to maintain a permanent pool. However, if the airport conditions accommodate these limitations, constructed wetlands can provide very efficient pollutant removal and act as a buffer for stormwater system overflow in extreme storm events.

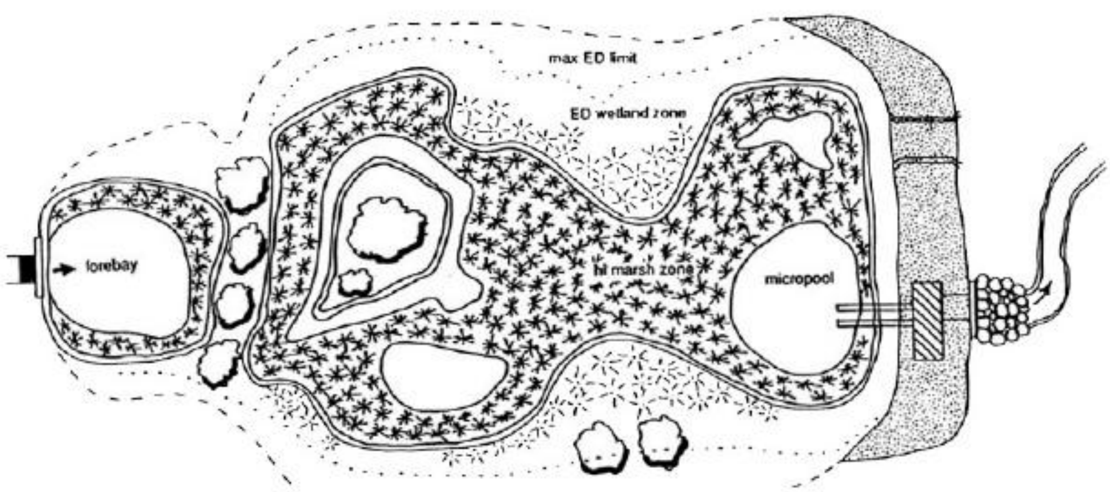

Figure 3: Schematic of engineered wetland (Schueler, 1992)

Engineered wetlands are typically designed to be one of four different types based on the dimensions and components that optimize the operation for a given geography: shallow marsh systems, pond systems, extended detention (ED), and submerged gravel wetlands. These variations are similar in appearance but are characterized by the volume of deep pools, high marshes, low marshes and additional detention capacity (EPA, 2006). In general, the wetland consists of at least one pond component in conjunction with shallow marsh components. At the inlet would be a wet pond (forebay) used to reduce velocity coming in, as well as provide some settling of particulates. The forebay would flow to a shallow marsh where additional treatment would take place (particularly for soluble components) by the presence of biological degradation as well as adsorption to soil and vegetation. Each wetland would include a forebay (near the inlet to the wetland) containing at least 10% of the wetland's treatment volume, a buffer area surrounding the marsh (if necessary for aesthetics), above ground berms to act as baffles for controlling flow, a micropool before the outlet containing another 10% of the total volume, and an embankment of sorts for ease of access during maintenance (Metropolitan Council , 2011).

8.2.2. Evaluation

Space concerns, which are common at airports, can prove to be a critical downfall of a wetland system. Typically, the required wetland surface area to operate with maximum efficiency and at optimum flow conditions is about 10% of the area of its watershed (EPA, 2006). The total volume that such an implementation at an airport would require would depend on the collection area of the watershed, as well as capacity to handle peak flow conditions during major storms.

As is the case with any control solution exhibiting open water, engineered wetlands can be a major attraction for wildlife (especially waterfowl). This factor raises questions concerning bird or animal related strikes by aircraft. Safety is a first priority at airports and the degree to which the implementation of a wetland sacrifices safety for effective treatment cannot be taken lightly. However, the environmental services department at DIA informed Envirodynamics Consulting that bird strikes are not a problem currently at DIA, despite the presence of retention/detention ponds in their stormwater management system. Also, in areas such as Anchorage, AK where migratory birds are present, the proximity to the ocean could make deterring birds from the ponds to alternate surface water sources a manageable process. However, if strikes become a concern then the wetland could be retrofitted with floating balls to deter birds from landing on the water surface.

With respect to effectiveness, engineered wetlands are excellent. They are among the most effective stormwater management practices used today at removing pollutants (EPA, 2006). In particular, removal of nitrate is very effective. However, factors effecting performance of the wetland have to do with appropriate maintenance, vegetation selection (certain types can be maintained in particular climates), and soil selection. Table 7 below shows some typical pollutant removal rates of wetlands given by the EPA from the winter of 2000.

Table 7: Typical Pollutant Removal Rates of Wetlands (%)

Pollutant	Stormwater Treatment Practice Design Variation			
	Shallow Marsh	Extended Detention Wetland	Pond/Wetland System	Submerged Gravel Wetland
Total suspended solids	83±51	69	71±35	83
Total phosphorus	43±40	39	56±35	64
Total Nitrogen	26±49	56	19±29	19
Nitrate/nitrite (NO_x)	73±49	35	40±68	81
Metals	36-85	(80)-63	0-57	21-83
Bacteria	76	NA	NA	78

(EPA, 2006)

Although maintenance for an engineered wetland is typically considered low-to-medium, there are regular activities that must be administered to ensure efficient operation. Surface coverage by vegetation that offers at least 50% surface area coverage by the second growing season is required as a 2-year maintenance procedure (planting and monitoring). In addition, a semi-annual inspection/removal of invasive plant species, annual inspection for damage and hydrocarbon buildup, and sediment removal from forebay which is needed every 5-7 years (EPA, 2006). The design life of a wetland is virtually limitless. However, removal of sediment from marsh (typically needed every 20-50 years) is a very tricky process to avoid significant damage to the developed vegetation and soil.

The cold climates that are present at airports requiring deicing can compromise the effectiveness of an engineered wetland. Freezing temperatures may cause problems with vegetation, and microbial activity. Besides temperature effects, the freezing of the surface of the wetland, can cause runoff to "skate" over the surface and escape treatment (EPA, 2006). Design to allow for continuous flow through the wetland can attempt to prevent freezing. Another cold weather downfall of constructed wetlands is the potential for warming of water retained. The water that is unnaturally retained in the permanent pool can obtain warming from the sun, which when discharged, can pose a threat to the cold water species and processes in the natural receiving water body. Alternative designs to wetlands, such as an aerated gravel bed (one of the proposed alternatives) avoid these cold weather effects by directing processes to the subsurface and can potentially be a better option in cold weather climates.

8.3. Infiltration

8.3.1. Description

Given suitable conditions, direct infiltration into the ground can serve as a practical airport stormwater management practice. Natural biodegradation of glycol-based deicing solutions is effective over a range of temperatures and at varying concentration levels (Klecka, Carpenter, & Landenberger, 1993). Breakdown of such contaminants through infiltration prevents BOD related risks to riparian/aquatic ecosystems that can occur under direct discharge conditions. Construction of infiltration ponds allows for direct infiltration into soil as well as temporary storage capacity. Ponds are typically lined with sand or a fabric filter to prevent sediment buildup on the soil surface. Collected or diverted stormwater may need to be pre-settled in advance if sediment load is an issue. To further prevent clogging of soil pores, plants and grasses should be planted in and around the area of infiltration. These should be selected based on site conditions and wildlife deterrence characteristics. Flow capacity will be limited by surface area so an outlet control structure is necessary to manage excess flow during extreme precipitation events. Infiltration ponds must be located outside of critical airport areas to avoid interference with regular airport operation during pond maintenance (Washington State Department of Transportation, 2008).

Figure 4: Infiltration basin cross-section (Stormwater PA, 2006)

8.3.2. Evaluation

Suitability for infiltration pond systems is extremely site dependent. Airports with moderate to severe space limitations will likely need to look at other alternatives. The site under consideration must have an infiltration rate, which varies with soil type, of at least 1.0 in/hr to be considered for an infiltration pond. Standing water can present a safety hazard if waterfowl are attracted, but deterrence measures can be taken including structural considerations. Additionally, in-depth analysis of effects on groundwater quality may be necessary in areas where groundwater pollution may be an issue or if a high water table could impede infiltration. However, given suitable soil and space requirements, infiltration ponds are a lower cost alternative to wetlands and subsurface installations. Ted Stevens International has soil with infiltration rates exceeding 1.0 in/hr but its high groundwater table could prove troublesome (United States Department of Agriculture, 2001).

9. Design Alternatives for Automated Sampling

The goal of our automated sampling alternatives was to develop a strategy that achieved an appropriate balance between limitations of budget, equipment, and personnel work time; while accurately characterizing storm water quality, volume of flow, and contaminant concentrations.

The principal challenge facing an operator implementing BMP monitoring programs is accounting for both the temporal and spatial variability of stormwater flows and pollutant concentrations at an airport. Typically, only points of effluent discharge need to be sampled and analyzed; DIA, for example, has four bi-monthly sampling locations (Denver International Airport, 2011). Stormwater quality at a given location varies greatly both between storms and even during a single storm event, and thus a small number of samples are not likely to provide a representative indication of stormwater quality at a given site or the effect of a given BMP. Therefore, collection of numerous samples is generally needed in order to accurately characterize stormwater quality at a site and BMP efficiency (Urban Stormwater BMP Performance Monitoring, 2002).

Sampling will either occur at pre-defined time intervals or at specific flow intervals. With either alternative, all samples will be automatically taken as grab samples which is a single sample taken at a specific time or over as short a period as feasible. For best results, this will incorporate discrete sampling which is a technique where multiple grab samples taken over a given time and treated as independent samples with respect to time. Discrete sampling has the advantage of being able to measure pollutant variation within a storm (R. D. Harmel, Automated Storm Water Sampling on Small Watersheds, 2003).

Samples will be stored inside the sampler, waiting to be transported to and analyzed in a laboratory for contaminants such as glycol based DIW. It is recommended that sampling locations are placed where runoff from impervious surfaces can be collected before mixing with natural stream water. Temperature, pH, conductivity, and dissolved oxygen (DO) are recommended to be continuously measured at each sampling location in-situ attached to a data logger.

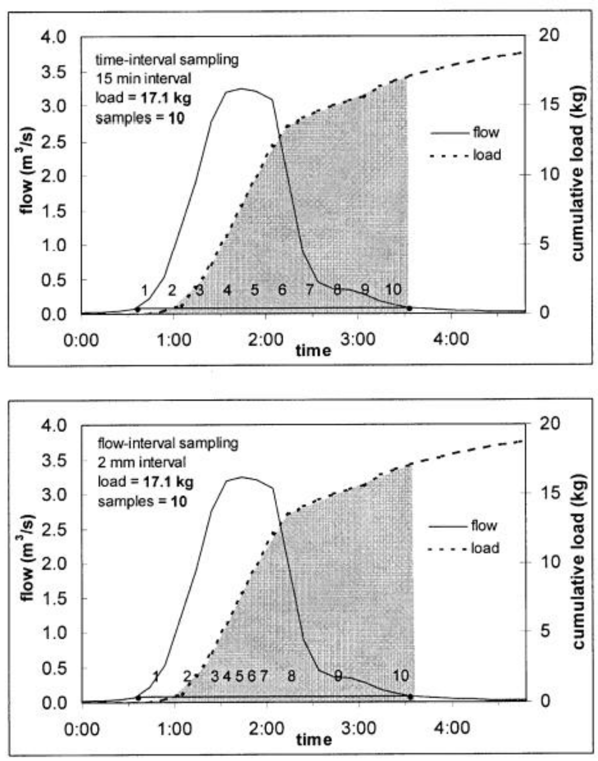

Figure 5: Sample comparison of sampling intervals for time- and flow-interval sampling (R. D. Harmel, 2003)

9.1. Time-Interval Sampling

Time-interval grab sampling is appealing because it is accurate at small time intervals and it is more dependable than flow-interval sampling since it does not require a flow trigger to sample. With this type of sampling it is difficult to choose a proper sampling time interval that will accurately represent storm water characteristics. Although a specific flow is not needed to trigger sampling, it still must be accurately measured to calculate contaminate concerntation. Discrete collection is recommended to be used with this technique (R. D. Harmel, Automated Storm Water Sampling on Small Watersheds, 2003).

9.2. Flow-Interval Sampling

Flow-interval grab sampling can more accurately measure storm loads because samples can be taken automatically at different points on a storm discharge hydrograph. With this sampling technique it is relatively easy to choose a proper flow interval, and if the system is working correctly the first flush will be captured and characterized. Flow-interval sampling is obviously flow dependent, so if the flow measurement equipment fails, the sampling will too. Because of this disadvantage, a flow control structure such as a weir is strongly recommended. Flow-interval sampling has the advantage of being able to measure variations within a given storm. Discrete collection is also recommended to be used with this technique (R. D. Harmel, Automated Storm Water Sampling on Small Watersheds, 2003).

9.3. Evaluation

Table 8 below was used to compare the advantages and disadvantages of sampling options and techniques. A comparison of the possible differences in sampling intervals between time- and flow-interval sampling was shown in Figure 5.

Table 8: Sampling decision table

Time- or Flow-Interval Sampling	
Time-Interval Sampling	**Flow-Interval Sampling**
Advantages • Accurate at small time intervals • Dependable (less likely to fail) • Flow measurement not required to take samples Disadvantages • Difficult to choose proper time interval • Flow measurement needed to measure loads	Advantages • More accurate measurement of storm loads • Relatively easy to choose proper flow interval Disadvantages • Flow measurement required to take samples • Flow control structure recommended • Sampling will fail if flow measurement fails
Discrete or Composite Sampling	
Discrete Sampling	**Composite Sampling**
Advantages • Reduced sampling error • Capture within storm variability Disadvantages • Decreased sampling duration/magnitude • Increased sample numbers	Advantages • Increased sampling duration/magnitude • Decreased sample numbers Disadvantages • Can increase sampling error • Limited information on within storm variability

(R. D. Harmel, 2003)

Time-interval sampling is less complicated and more dependent that flow-interval sampling. Despite the dependence of time-interval sampling, it lacks contaminant concentration characterization that is needed for an airport.

Since flow-interval grab sampling has the ability to more accurately measure storm loads than time-interval sampling it will most likely be utilized. With this sampling technique the first flush of an impermeable surface can be captured and characterized. Special setup period testing and occasional system checks will need to be performed to ensure proper operation of this more complicated sampling option.

It is recommended that a pilot installation of one sampling unit be installed to ensure proper operation before other units are installed at other airport discharge locations.

9.4. Equipment

Figure 6: The all-weather, semi-permanent, ISCO 4700 (130cm × 72cm × 84cm) (John Morris Scientific)

Teledyne ISCO is a reputable company that manufactures a variety of automated sampling equipment. The recommended product to use with either time- or flow-interval sampling is the 4700 sequential refrigerated sampler. The refrigerator component has the ability to keep samples as low as 4 degrees Celsius. This ensures that microbial activity is limited so accurate contaminant concentrations can be measured days after the sample is grabbed. Once the sample bottles are full they are transported to a water chemistry lab, where a mass spectrophotometer is used to measure the reflection and transmission of light waves passing through the sample. (National Institute of Standards and Technology, 2011) These values are used to calculate COD and correlate to the BOD.

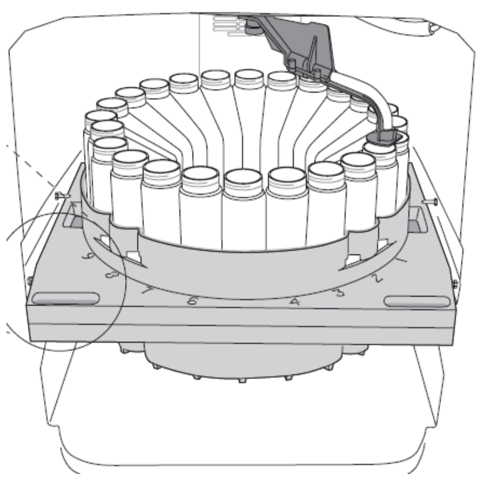

Figure 7: The bottle configuration within the ISCO 4700 (Teledyne Isco, Inc., 2008)

What is most appealing about the ISCO 4700 is the operating range of -20 degrees Fahrenheit to 120 degrees Fahrenheit. This device is also equipped with a liquid presence detector which automatically changes pump suction levels to compensate for changes in stream head height. The pumps are capable of moving water at a velocity of 0.9 m/s under 0.9 meters of head or 0.67 m/s under 7.6 meters of head. The maximum lifting height of the pumps is 8meters. Sample collection is through 9mm tubing placed directly into the stream and is directed to bottles with various sizing options available depending on sampling frequency and collection volume needs (Teledyne Isco, Inc., 2008).

10. Decision Matrix

Table 9: Decision matrix

	Direct Discharge				Automated Sampling		
Alternative	**Weight**	**Aerated Gravel Bed**	**Constructed Wetland**	**Infiltration**	**Weight**	**Time-interval**	**Flow-interval**
Cost	**0.45**	**5**	**8**	**6**	**0.20**	**10**	**10**
Social	**0.05**				**0.02**		
Client reputation	0.03	10	9	7	0.02	4	5
Aesthetics	0.02	8	7	6	0.00		
Technical	**0.25**				**0.78**		
Effectiveness	0.08	10	8	7	0.20	6	7
Ease of operation	0.05	9	5	6	0.18	6	5
Reliability/fail-safe	0.12	8	5	5	0.40	7	4
Environmental	**0.25**				**0.00**		
Ecologic impact	0.10	10	8	6	0.00		
Effluent quality	0.15	10	7	6	0.00		
TOTAL (Out of 10)	1.00	**7.42**	**7.35**	**5.99**	1.00	**7.16**	**6.00**

11. Final Design

11.1. Aerated Gravel Bed System

A design load of 5,300 kg BOD/d was calculated by averaging the annual glycol use (420,000 gal/yr) over the four peak months of deicing activity (November to March). This will sufficiently treat glycol throughout the year with exceptional removal efficiencies averaging about 90%.

Using this design load, each individual bed was sized using a known maximum flux rate of 200 g BOD/m^2/d which was experimentally found by Mark Liner, lead designer of the aerated gravel system at Buffalo-Niagara International Airport. Any loading above this flux rate will result in microbial clogging of the beds which causes a large drop in removal efficiencies.

Using this flux rate and the optimal design load, a total surface area of roughly 6.55 acres was calculated. Optimizing for cost, five beds will be constructed with each having a surface area of 1.31 acres with a length-to-width ratio of 1.8. A depth of 1.5 meters is optimal for a longer residence time resulting in greater removal efficiencies. Figure 8 and Figure 9 are CAD drawings of the proposed design and Table 10 provides a summary of the final design parameters for the aerated gravel bed system.

Table 10: Final design specifications

Parameter	Value
Design Load, total	5,300 kg BOD/d
Number of Beds	5 beds
Bed Length, each	98 meters
Bed Width, each	54 meters
Bed Depth	1.5 meters
Bed Surface Area, each	1.31 acres
Total Max Daily Flow Rate	2.0 MGD

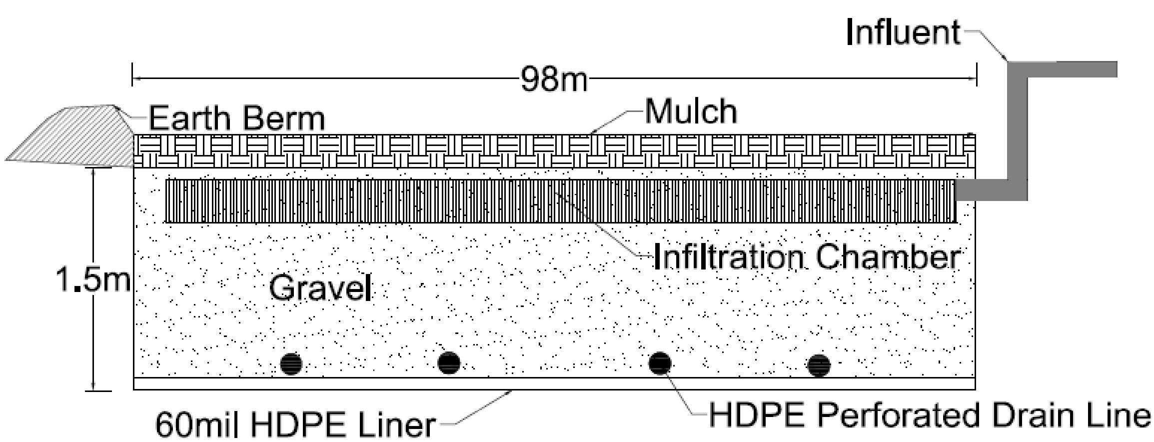

Figure 8: Cross-sectional view of the length of the aerated gravel bed design

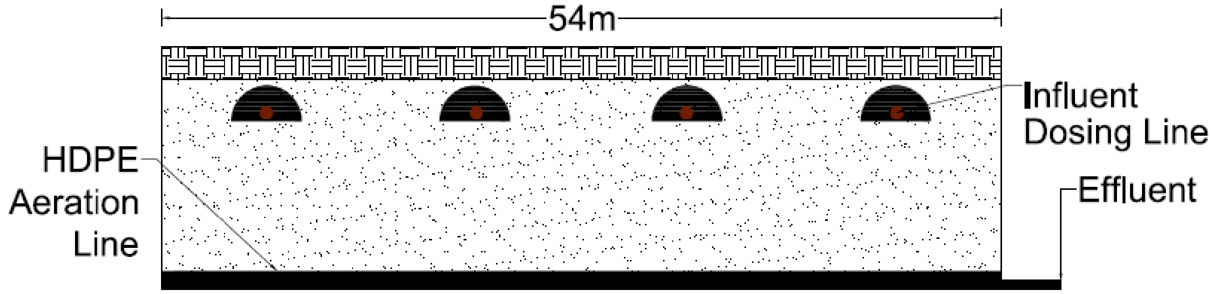

Figure 9: Cross-sectional view of the width of the aerated gravel bed design

While not the limiting constraint of the design, a maximum flow rate of 2.0 MGD will enable the quick evacuation of stormwater in large storm events. An upstream retention pond will be used to dilute the DIW into manageable concentrations for the aerated gravel bed system.

Each bed will have 35 dosing lines and 35 drain lines. The bottoms and sides will be lined with a 60-mil HDPE liner. Each bed will have 120 GeoFlow aeration tubes at the bottom of the bed spanning its length. Required materials are summarized in Table X in the cost section.

The best location for DIW treatment is within the large, grassy area where stormwater drains converge north of De Havilland Avenue and west of Postmark Drive. This location has adequate space and is at a low point within the drainage basin for the area of the airport where the majority of deicing activity occurs.

This design is optimal for wide seasonal variation, too. The subsurface design will insulate the stormwater during the winter season, which keeps it from freezing. In order to prevent the aerated gravel bed from drying out during dry periods during the deicing season, an upstream stormwater storage system is to be built. During the summer months where DIW is minimal but stormwater from snowmelt may be great, the aeration pumps can be switched off and the aerated gravel bed system can be used as retention ponds.

11.1.1. Upstream Retention Pond

In order to handle the flow from the approximately 700 acres of impermeable collection area while maintaining the maximum design load to the gravel bed, a retention pond must precede it. The retention pond was sized with a required ability to retain 0.5 inches of runoff per acre collection area according to a commonly accepted practice (Menery, 1999). In order to reduce the amount of surface area taken up by the pond, a truncated square pyramid shape was selected as seen in figure 1. The side length at the surface was determined to be 120 m; giving a pond surface area of 14400 m^2 (about 3.4 acres). The side length and depth at the pond bottom were 11 m, and 3 m respectively. The 3 m depth leaves a safe distance to the 30 ft deep water table from the pond bottom (U.S Geological Survey, 2012). The truncated pyramid shape with a 15 degree slope allows for easy access for sediment removal. Due to the high propylene glycol content of the water retained, a high density polyethylene (HDPE) liner will be used to line all surfaces in contact with the water.

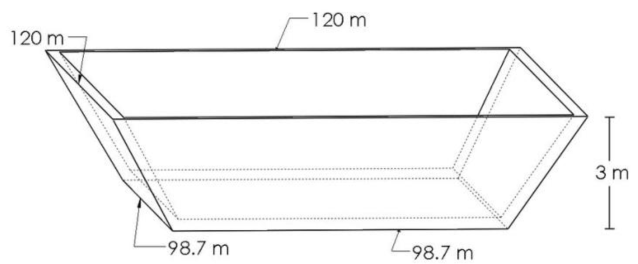

Figure 10. Side view of retention pond. The top would be ground level and interior surfaces lined with HDPE. Not to

The pond will be placed in the lowest topographical area of the collection basin and in a designated area near the gravel bed. In the event that the pond reaches its 9.5 MG capacity, the overflow will be directed to the current stormwater drainage system and directly discharged. However, a precipitation event of this magnitude would likely dilute the BOD concentration to levels above proposed discharge standards. In addition to the retention of water for the gravel bed, the retention pond will provide some settling of suspended particles and possible (depending on residence time) microbial breakdown of dissolved pollutants (Menery, 1999). The retention pond will have 5, 10in. diameter pipes connected to the gravel bed, each with a hand operated gate valve to control flow. The pipes will be installed near the bottom of the pond so the flow can be driven by hydrostatic pressure. If the hydrostatic pressure and topographical gradient to the gravel bed doesn't provide sufficient flow, then a pump may need to be implemented. Also, in the event that the pond becomes an attraction for waterfowl, Bird Balls™ can be placed on the pond surface.

11.1.2. Aeration Pumps

Each bed requires its own aeration pump. The pumps must be large enough to supply enough air to meet the oxygen demand. Aeration pumps were sized using a 10% oxygen transfer efficiency, which means the pumps must supply oxygen by a factor of ten greater than the BOD design load of 5,300 kg/day (Liner). Knowing that 21% of air is comprised of oxygen and that the density of air at atmospheric pressure is 1.225 kg/m3, the air flow rate was calculated to be 5,052 cfm. The aeration pumps are sized by using a 25% safety factor, meaning that the pump must be running at 80% of the maximum power in order to achieve the required flow rate of 5,052 cfm. Knowing the required flow rate and that BNIA uses four separate 250-horsepower pumps for proper aeration, we were able to identify that the best solution for aeration pumps is using five separate 250-horsepower aeration pumps; this is summarized in Table 11.

The recommended aeration pump is the Hoffman 42 Frame centrifugal blower. The flow range for this blower is 100 to 1,548 cfm and the pressure created can also be varied with a range from 0.75 to 15.3 psi at sea level. This is more the enough to overcome the hydraulic pressure under the bed and the friction loses in the tubing and piping during transport of the air. Each blower, including the motor to run it, costs about $30,000 according to the sales representative at Gardner Denver (Gardner Denver Inc., 2009).

Table 11: Final design specifications for the required aeration pumps

Parameter	Value
Required Static Pressure	4-8 psi
Flow Rate	5,052 cfm
Number of Pumps	5
Cost per Pump	$30,000
Pressure at Bottom of Bed	3.13 psi

11.1.3. Discharge Piping

The aerated gravel bed system can be implemented within current infrastructure therefore constructing capture points is not required. Construction of piping will be required though. This piping will connect each aerated gravel bed with the upstream storage system and the dosing pumps. Downstream piping will be constructed for the treated effluent to Lake Hood.

11.1.4. Applicability to Other Airports

The biggest downfall for the aerated gravel bed treatment system is the large space requirements. This means that the system can only be constructed at airports with large, open area. The Ted Stevens Airport in Anchorage has a lot of available space; therefore, the 10.1 acres required to treat the DIW is easy to find and develop. Space constrained airports, such as Logan International Airport or LaGuardia, will likely be need to invest in off-site treatment options such as treating at an existing WWTP or constructing an off-site facility that can effectively treat the DIW before it is discharged into local waterways.

As mentioned before, Ted Stevens uses 420,000 gallons of ADF annually. This amount, while large, does not approach the amount of ADF used at much larger airports. DIA uses roughly 1,000,000 gal/yr while Detroit Metropolitan Wayne County airport uses 2,100,000 gal/yr (EPA, 2009). For airports like these, either very large retention ponds would need to be used to dilute the DIW or alternative treatment methods would be required.

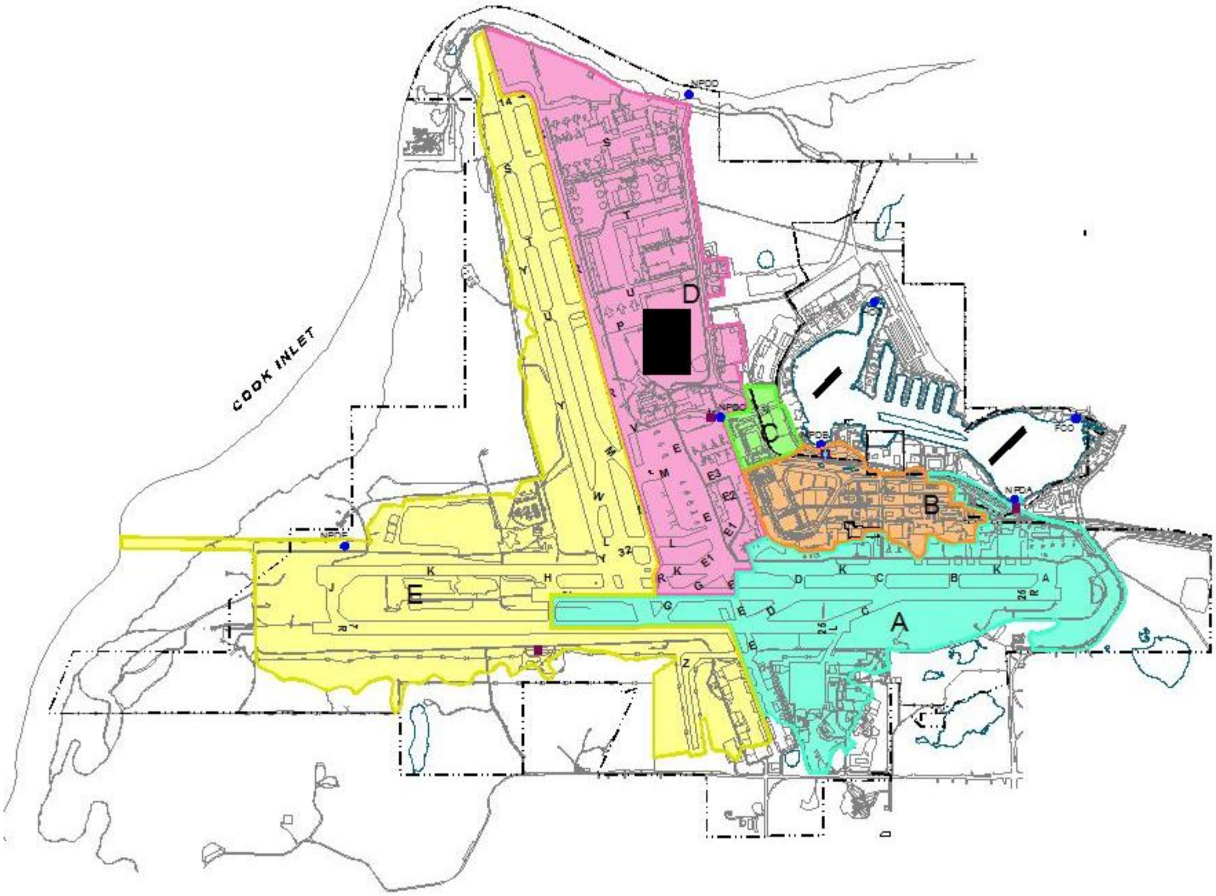

Figure 11: Map of Ted Stevens airport with proposed project location in black

12. Cost Estimate for Aerated Gravel Bed System

The capital cost of an aerated gravel bed comes from site investigation, clearing, excavation and earthwork, liner, media, inlet structures, outlet structures, piping and pumps, engineering and legal fees, and he contractor’s overhead and profit.

Costs were primarily estimated using RSMeans. The aerated gravel bed cost estimations are viewable in, which includes the required materials, their respective required quantities, the cost per unit of each material, and the capital cost of each material. The engineering design cost is 35% of the capital cost of the project (Texas Water Development Board, 2005).

Table 12: Estimated costs for the aerated gravel bed (RSMeans)

Material/Labor	Required Quantity	Unit Installed Cost	Total Cost (2012)
60-mil HDPE liner	34,412 sy	$1.84/sf	$569,863
6” HPDE perforated drain line	18,670 yards	$5.55/lf	$310,856
1” GeoFlow aeration tubing	64,000 yards	$0.79/lf	$151,680
HDPE influent dosing line	18,670 yards	$0.79/lf	$44,248
30” HDPE Infiltration chamber pipe	18,670 yards	$58.88/ lf	$3,297,869
Foam board (2” R8)	2,930 sy	$1.98/sf	$52,213
3/4” Plywood	2,930 sy	$6.58/sf	$173,521
Peat Moss Mulch	878 cy	$129/cy	$113,444
Gravel (15-mm diameter)	52,740 cy	$34.69/cy	$1,829,551
Excavation (labor)	51,915 cy	$4.68/cy	$242,962
Hoffman 42 Frame blower	5 units	$30,000/unit	$150,000
Total Capital Cost Items			$6,936,207
Engineering Design			$2,427,672
Total Capital Cost Items			$9,363,879

Table 13, below, shows the estimated annual operational cost of the Hoffman 42 Frame centrifugal blowers. This operational cost was estimated assuming the blowers are operating at 80% maximum power for 24 hours each day for a total of 150 days in the year. The energy cost used is $0.062252/kWh (Anchorage Municipal Light & Power, 2012).

Table 13: Estimated annual operational cost of the Hoffman 42 Frame blowers

	Energy usage per blower per year	Cost per kWh	Annual operational cost (for 5 blowers)	Present value operational cost over 20-year period
Hoffman 42 Frame blower	3,600 kWh/yr	$0.062252 /kWh	$167,072.00	$3,341,438

The 20-year cost of the upstream retention pond was calculated first using Equation 1 (United State EPA Office of Water, 2006), which calculates the construction and permitting cost (2006 dollars) for a wet pond.

$$C = 24.5V^{0.705} \quad \text{Equation 1}$$

C = Construction and permitting cost (2006 dollars)
V = Volume of pond

The construction and permitting cost totaled $550,109 scaled from 2006 dollars using CPI values (U.S. Dept. of Labor, 2012), which did not include the cost for the five gate valves, the 156,956 square feet of 60-mil HDPE liner, or the 1,200 feet of outlet riser piping. With these costs included the capital is $854,418. The costs of each component were found via RSMeans and costs are representative of the Anchorage, AK area.

In addition to these capital costs, an annual O&M cost was estimated as 5% of the total construction (United State EPA Office of Water, 2006). This takes into account routine maintenance such as clearing sediment from the pond bottom as well as labor costs for routine observation. No major maintenance is expected within a 20-year life (Menery, 1999).

Table 14: Capital and O&M costs over a 20-year period for the designed detention pond

Material/Labor	Required Quantity	Unit Cost	Total Cost (2012)
Gate Valves	5	$690	$3,450
HDPE Liner (60 mil)	156,956 ft^2	$1.84/$ft^2$	$288,799
Outlet riser pipe (10")	1200 ft	$10.05/ft	$12,060
Construction and Permitting	N/A	N/A	$550,109
Engineering Design	N/A	N/A	$299,046
Maintenance	20 years	5% of construction cost	$493,117
		Total cost:	**$1,347,535**

The total capital cost and O&M cost over a 20-year period for the entire project is summarized in Table 15.

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Table 15: Estimated capital and O&M cost over 20-year period for entire project

Project Cost Breakdown	Cost of Item
Aerated gravel bed capital cost	$6,936,207
Aerated gravel bed O&M cost, present value	$3,341,438
Retention pond capital cost	$854,418
Retention pond O&M cost, present value	$493,117
Engineering Design cost	$2,726,718
Total Capital and O&M Cost:	**$14,351,898**

Table 16: Summary of required maintenance for aerated gravel bed system

Summary of Maintenance Requirements
a) Blower maintenance (change oil, filters, and belts)
b) Pump maintenance
c) Dosing lines must be washed once per year using a pressure jetting system
d) Airlines must be acid cleaned once every two years
e) Maintenance of TOC analyzers

13. Conclusion

Envirodynamics Consulting is proud to have completed this portion of the FAA design project. After researching five different airports around the United States that spray deicing fluid and evaluating their respective stormwater treatment systems, we have recommended our design solution. Envirodynamics has determined that the biggest positive environmental impact from one single project can be made at the Ted Stevens International Airport in Anchorage Alaska by installing an aerated gravel bed, since they currently have a somewhat primitive stormwater treatment system.

The environmental, safety, and economic benefits of adopting a modern stormwater treatment system are well-understood. Successfully meeting the FAA's environmental stewardship goals and engineering this design solution will create a symbolic and tangible commitment to the environment from both our design firm, the FAA and the Ted Stevens International Airport.

14. Appendices

14.1. Appendix A. Team Contact Info

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14.2. Appendix B. Description of CU/College of Engineering

The College of Engineering and Applied Sciences at the University of Colorado at Boulder (CU) was established in 1893. The undergraduate engineering school is ranked 34th overall and 19th among public universities. Majors include: Aerospace, Mechanical, Chemical, Civil, Electrical, Computing Science, Architectural and Environmental Engineering. (University of Colorado , 2012)

The environmental engineering (EVEN) program at CU is unique because it is a multidisciplinary collaboration from Civil Engineering, Chemical Engineering, Mechanical Engineering, and Aerospace Engineering. There are twenty faculty members from these departments have chosen to affiliate with the growing EVEN program (University of Colorado , 2012). The EVEN B.S. degree is accredited by the Engineering Accreditation Commission (ABET). (Engineering Accreditation Commission , 2012)

Each EVEN student is required to specialize in a degree concentration by taking three classes related to one of the following option classes: air quality, ecology, water resources management and treatment, remediation, chemical processing, and energy. Four members of the Envirodynamics team specialize in the water resources management and treatment option and the fifth is enrolled in the ecology option.

14.3. Appendix C. Non-University Partners

14.3.1. Project partners

Throughout our project research DIA has been our main point of contact and resource for information pertaining to stormwater management. DIA is the leader in airport sustainability and environmental preservation with an innovative stormwater management plan and modern facilities. Although our project is not designed for DIA, they have given us guidance, ideas, and direction to help improve stormwater infrastructure at the Ted Stevens International Airport.

14.3.2. Interactions with airport operators and industry experts

Our main project liaison was Keith Pass of the environmental services department at DIA. He is in charge of stormwater discharge at the airport. He met with the team on two separate occasions. The first time he briefed us on the problems airports face related to stormwater, gave us an overview of DIA's current infrastructure, showed some airport maps, and provided us with some literature to read pertaining to stormwater. On a second visit Mr. Pass checked us through a security clearance and gave us a tour around the airport tarmac. We were able to see a plane being de-iced up close as well as the stormwater detention ponds. In the water quality lab we saw the water testing lab setup as well as the interworking of stormwater system including controls that adjust flow rates between pipes, ponds, and the local treatment plant. Tracy Schilz of the water quality lab answered our questions about what procedures are used to measure basic parameters of the stormwater.

Tracy Mitchell was our point of contact at the Ted Stevens International Airport. She is employed by the Alaska Department of Transportation and works in the environmental services department at Ted Stevens. Mrs. Mitchell first gave us an overview of what currently happens to stormwater at Ted Stevens. Next she provided us with valuable airport maps, showed us where de-icing occurs, and answered questions related to directions of surface water flow. Finally she recommended areas for us to research placing the aerated gravel bed.

Eric Strassler of the Environmental Protection Agency (EPA) was contacted to provide information on the upcoming proposed effluent limitation guidelines and standards. Mr. Strassler answered regulation questions for us specific to the Ted Stevens airport.

Mark Liner, the lead designer at Liner Company was contacted by our group because he designed the aerated gravel be at Buffalo Niagara airport. He provided us with the specifications of Buffalo Niagara's beds, and answered questions for us about sizing out own beds. Mr. Liner also helped us design an annual maintenance plan for our aerated bed system based on the maintenance schedule of his existing beds.

Garret Meal, a civil engineer at Stantec was contacted by our group because he worked on implementing the aerated gravel at Buffalo Niagara airport. Mr. Meal worked with us to design a way to implement the aerated gravel bed treatment system into the existing infrastructure at the Ted Stevens airport. He recommended ways to size the retention pond and air pumps.

Figure 12: Tracy Schilz in the DIA water quality lab

14.5. Appendix E. Evaluation of Educational Growth Attained

The project thus far has provided the team with rewarding, educational, and valuable early career experience. The team agrees that the interacting with industry leaders at DIA has provided the most experience, as well as motivation to peruse professional jobs in the field.

Throughout the final design of the project the team was confronted with various challenges. Tackling a design problem that no one on team had any previous knowledge of was a challenge in and of itself. When we learned that the stormwater treatment system at DIA was literally too good for improvement, we were forced to think outside the box and create a way to broaden the scope of our project without throwing away all of our previous research.

We benefitted indefinitely from establishing formal communication protocols both with industry professionals and within our team. It quickly became communication issues are serious, and that we are fortunate to experience it before entering the workplace. Weekly meetings were setup to discuss progress, and file sharing pathways were utilized that were new to us.

In addition, the team's extensive use of the Microsoft Office Suite, Solid Works, and AutoCAD allowed for a more profound understanding of each of their powerful capabilities in preparation for our entrance to industry.

14.5.1. Student Questions

1. *Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?*

The FAA Design Competition did provide a meaningful learning experience for the entire group. The project was an excellent opportunity because it allowed us to build valuable early career experience such as working in a team and interacting with industry professionals.

2. *What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?*

For team Envirodynamics, tackling a design problem that no one on team had any previous knowledge of was a challenge in and of itself. When we learned that the stormwater treatment system at DIA was literally too good for improvement, we were forced to think outside the box and create a way to broaden the scope of our project without throwing away all of our previous research. To overcome this problem we researched other airports around the country and selected the one that we thought we could make the biggest positive environmental impact at.

3. *Describe the process you or your team used for developing your hypothesis.*

To develop our hypothesis our team first met with Keith Pass of the Environmental Services at DIA. We traded some ideas, and he educated us about environmental concerns of effluent stormwater at airports. Next we “hit the books” so to speak and researched all about airport stormwater and gathered data. Treatment alternatives were evaluated and compared in a decision matrix.

4. *Was participation by industry in the project appropriate, meaningful and useful? Why or why not?*

For our project the participation of DIA was pivotal. Even though we didn't end up designing a project specifically for that airport, they provided a heap of information. Mr. Kieth Pass brought our group out on to the tarmac for us to see the behind the scenes areas of the airport. It felt very appropriate to take an airport tour, and see a stormwater treatment system in person because of all the research we were doing on the subject.

5. *What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?*

The team learned a great deal about possible negative effects of effluent stormwater, ways to treat it, as well as airport interactions. Team members agreed that this project has greatly improved their readiness to enter the workforce. Everyone's extensive use of the Microsoft Office Suite, Solid Works, and AutoCAD allowed for an improved familiarity and a more profound understanding a computers capability. We also benefitted indefinitely from establishing formal communication protocols both with industry professionals and within our team.

14.5.2. Faculty Advisor Questions

l. Describe the value of the educational experience for your student(s) participating in this Competition submission.

The context of environmental issues at airports was novel for all of the students. The opportunity to meet with the folks at Denver International Airport (DIA) provided excellent real-world context and an understanding of needs in the industry. The topic of stormwater issues as related to airports was rather broad and seemed to overlap significantly with de-icing issues.

Since our class had three teams working with DIA, we tried to have each group working on unique topics. This issue made it challenging for the stormwater group to identify an area of need for DIA outside the de-icing topic. This obstacle forced the team to explore stormwater issues at airports more generally. The proposed US EPA stormwater regulations will impact many airports that are not as advanced as DIA, so this context will be more broadly applicable.

2. *Was the learning experience appropriate to the course level or context in which the competition was undertaken?*

The students were all participating in the 4-credit Environmental Engineering Design course, which is the required capstone design course for all students earning a bachelor's degree in Environmental Engineering from the University of Colorado Boulder. The learning experience was unique compared to the other projects in the course, which were defined more precisely from the very beginning of the semester. For example, the AECOM Academic Design Competition defines a specific problem and site conditions for a drinking water or wastewater treatment problem and then asked the students to propose a solution. The nature of the FAA competition gave the students more choice on the direction of their project, but this same flexibility made it more difficult to start the process.

3. *What challenges did the students face and overcome?*

The greatest challenge to the students was the navigation of significant uncertainty surrounding the project throughout the semester. The first challenge was starting the spring semester activities in January prior to meeting with DIA representatives. This made it difficult for the students to get started on their project, particularly since it was difficult to acquire specifics on DIA from traditional references and sources. Therefore, some of the work that the students had completed at the beginning of the semester was not used in the overall project and was not useful to DIA. Next, after the meeting with DIA it was determined that they had few needs for enhanced stormwater capture or treatment, outside of de-icing concerns. Therefore, it was about the middle of the semester and we were still struggling to define a specific problem that the group's design should address. Their new direction was to examine stormwater issues at multiple airports. Then the challenge became finding detailed information about those airports, since there were not contacts identified.

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

I hope to use the competition again. However, we would likely try to find a different local airport partner, since we already worked on key environmental issues with DIA this semester. A site visit was critical to helping the students appreciate the challenges and opportunities at airports, so we would hope to continue to interface with experts at DIA. But since DIA is very advanced in all of its environmental systems, it was difficult to find environmental elements to improve upon. My attempts to find interested partners at other local airports were less successful, so I would need to devote more lead time to cultivate these partnerships in advance of spring semester next year. Using the student design reports from this year as examples of the student work might help entice partners for future years.

A challenge for me as the course instructor was to m (University of Colorado , 2012)erge the learning objectives for the design course and the project requirements for the competition. Traditional projects all have a specific problem and specific client/community identified at the beginning of the semester. Then, the course requires students to simulate a consulting firm and prepare a proposal, followed by an alternatives assessment / feasibility study, and finally complete a design supported with detailed calculations, AutoCAD drawings, etc. The FAA competition guidelines were restrictive in terms of length and not allowing supporting appendices, so this required the students to do "extra" work beyond the FAA competition for the course (but did not allow them to present this information to the FAA), and extra formatting challenges for the competition that were not required for the other students in the design course.

5. Are there changes to the Competition that you would suggest for future years?

The primary recommendation that I would make relates to changes in the formatting and length requirements. Allowing students to submit appendices of supporting calculations would be helpful. The double-spaced text also seemed odd – a shorter page limit with single spaced text might be more effective. Further, environmental engineering designs are typically site-specific, but it is unclear the degree to which the FAA desires general ideas for airports versus more detailed designs for specific individual airports.

14.6. Appendix F. References

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