Control of Deicing Chemicals at Airports Using Subterranean Aerated Gravel Beds

Design Challenge: Airport Environmental Interactions (Making snow and ice removal more environmentally friendly)

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Table of Contents

List of Figures

List of Tables

Abbreviations

ACRP- Airport Cooperative Research Program
BOD- Biochemical Oxygen Demand
BUF- Buffalo Niagara International Airport
CDPHE- Colorado Department of Public Health and Safety
DIA- Denver International Airport
DO- Dissolved Oxygen
ELGs- United States Environmental Protection Agency's Effluent Limitation Guidelines
EPA- United States Environmental Protection Agency
HDPE- High-Density Polyethylene
GFIA- Gerald R. Ford International Airport
GRV- Glycol Recovery Vehicle
MCDA- Multi-Criteria Decision Matrix
NDPES- National Pollutant Discharge Elimination System
NEPA- National Environmental Policy Act
RCRA- Resource Conservation and Recovery Act
SWMP- Stormwater Management Plan
WADS- West Airfield Diversion System

Executive Summary

Denver International Airport (DIA) has been recognized repeatedly for their environmental accomplishments and would like to continue its leadership in environmental stewardship. Additionally, DIA is expecting to receive a new stormwater permit in the next year that quantifies biochemical oxygen demand (BOD) limits and monitoring requirements. Thus, DIA contracted IIB Consulting ("IIB") to work on BOD capture and reduction.

Deicing chemicals are the primary source of elevated BOD levels in stormwater runoff. This report details four alternatives for the control of deicing chemicals at DIA: additional ponds, mobile collection units, an expanded drain system, and subterranean aerated gravel beds. To compare these alternatives, IIB worked with DIA Environmental Services to develop a weighted multi-criteria decision matrix that examines economic, environmental, and social/logistical factors.

After analyzing each alternative, IIB suggests that DIA implement aerated gravel beds. This recommendation will also require an additional pond to capture water from large storm events and prevent overflow of the beds. The system will be $2.4 million in capital costs and will reduce BOD released from DIA by treating runoff at the area of greatest concern. The aerated gravel beds and the additional pond will be constructed in an area of the airport with little traffic, which will ensure that construction does not interfere with airport operations. Furthermore, both the aerated gravel beds and the additional pond can be constructed in less than one year over the summer months, making it feasible for DIA to have infrastructure in place before deicing operations commence in the winter months. Although this report details a solution pertinent to DIA, subterranean aerated gravel beds have proven to work in airports across the world.

1.0 Problem Statement and Background

Airports around the world maintain tight flight schedules despite winter conditions by using deicing fluids to deice and anti-ice planes. Typically, airplanes are deiced to melt any ice that formed on the plane before being anti-iced to prevent ice formation before and during takeoff. Runways must also be deiced to ensure safe takeoffs and landings. Deicing and anti-icing are vital practices used at airports to keep airline passengers safe; however, these chemicals can have negative impacts on human health and the environment when they enter surrounding waterways.

IIB partnered with Denver International Airport (DIA) Environmental Services to develop an engineered solution for preventing deicing chemicals from entering the clean stormwater system, and in turn, the waterways surrounding the airport. Airside stormwater runoff at DIA has measurable concentrations of two deicing chemicals: propylene glycol and potassium acetate. Propylene glycol is used in aircraft deicing fluids and anti-icing fluids, while potassium acetate is used in pavement deicers.

Aircraft deicing fluid can be categorized further. During icy conditions, airplanes are sprayed with Type I deicer, which consists of 50% propylene glycol and removes the ice and snow from airplanes. These planes are usually also sprayed with Type IV anti-icer, which is 100% propylene glycol and prevents the formation of more ice on the plane during takeoff. Type IV anti-icer is sprayed at designated deicing pads [1].

DIA's clean stormwater system releases into Third Creek which flows into Barr Lake (a Colorado State Park), impacting aquatic life by decreasing the dissolved oxygen (DO) concentration in surface waters [2]. There are clear signs of pollution from stormwater runoff at some locations on site (Figure 1.1).

Figure 1.1. Possibly polluted runoff on the edge of the Whiskey Alpha deicing pad.

DIA currently has technologies in place to capture some of the fugitive glycol leaving DIA in stormwater runoff. One of these technologies is an onsite glycol recovery facility where glycol is recycled and sold for use in industrial products. To be sent to this facility, runoff must have a propylene glycol concentration greater than 1% by volume. Thus runoff for this facility can only be collected from certain areas at the airport, particularly from the eight deicing pads at DIA (Figure 1.2). Since this system is effective at recovering glycol and is profitable for DIA, IIB did not consider any alternatives that would affect operations of this facility. Instead, the project's focus was primarily on treating dilute runoff containing propylene glycol and potassium acetate.

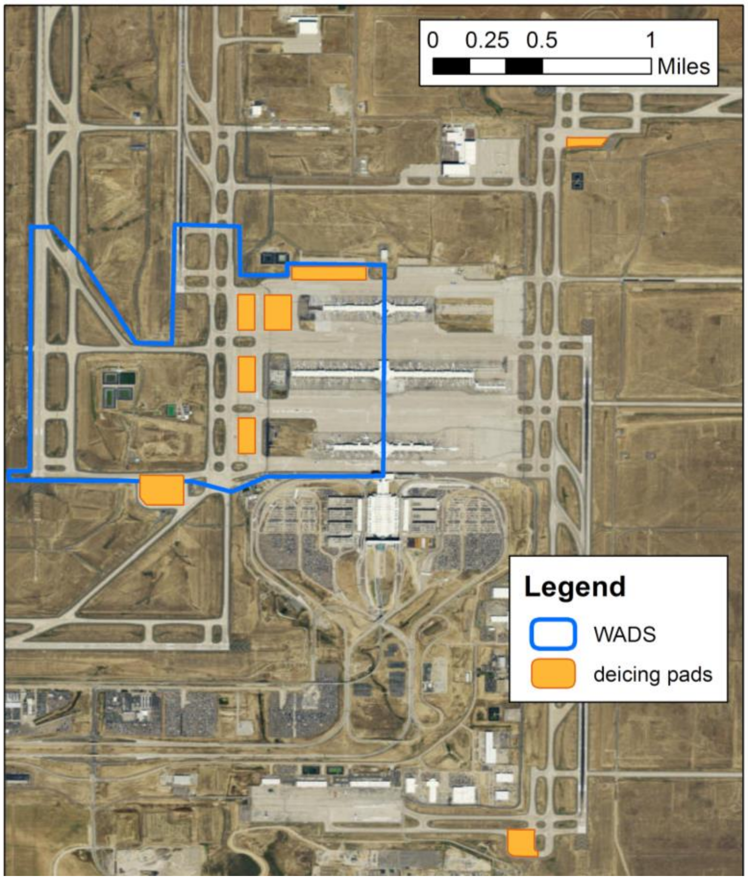

Figure 1.2. Map of the West Airfield Diversion System and deicing pads at DIA.

Another technology in place at DIA is the West Airfield Diversion System (WADS), shown in Figure 1.2. This system passively collects dilute runoff that contains less than 1% by volume propylene glycol and cannot be sent to DIA's glycol recovery facility. The WADS diverts a portion of this dilute runoff (38% in the winter; 7% in the summer) to retention ponds, where it is stored before being discharged to Metro Wastewater Reclamation District's ("Metro") Robert W. Hite Treatment Facility [3]. The undiverted runoff, which contains propylene glycol and potassium acetate, enters the clean stormwater system and thus the waterways surrounding DIA. This results in elevated biochemical oxygen demand (BOD) at onsite sampling points (Figure 1.3) [4]. BOD is the measure of oxygen available to aquatic life, and elevated BOD levels cause negative impacts on streams and lakes. As shown in Figure 1.3, sampling location D has the highest average concentration of BOD at the site. Therefore, the area surrounding sampling location D was targeted for an engineered solution to maximize the reduction of BOD concentrations at DIA overall.

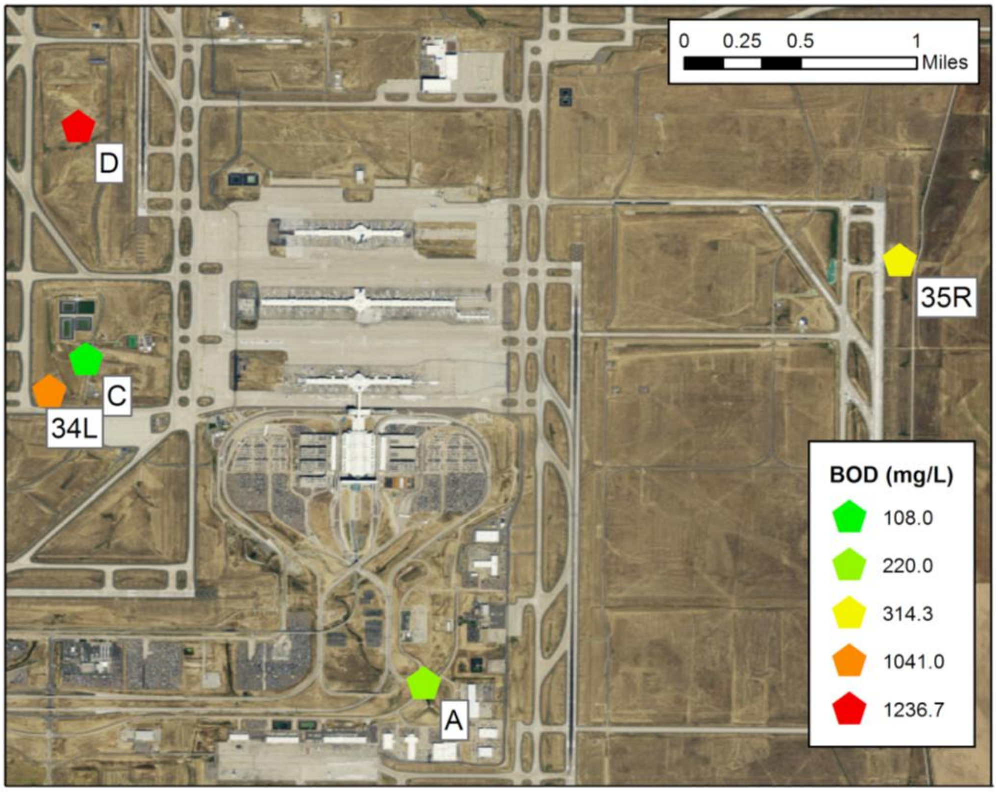

Figure 1.3. Map of DIA showing sampling locations and average BOD levels based on data provided by DIA.

The types of deicing fluids used along with sources and destinations of deicing waste at DIA are summarized in Figure 1.4. Existing operations and infrastructure are not adequate to prevent dilute deicing waste from entering state waters. Therefore, IIB has proposed solutions that will specifically address dilute deicing waste at DIA.

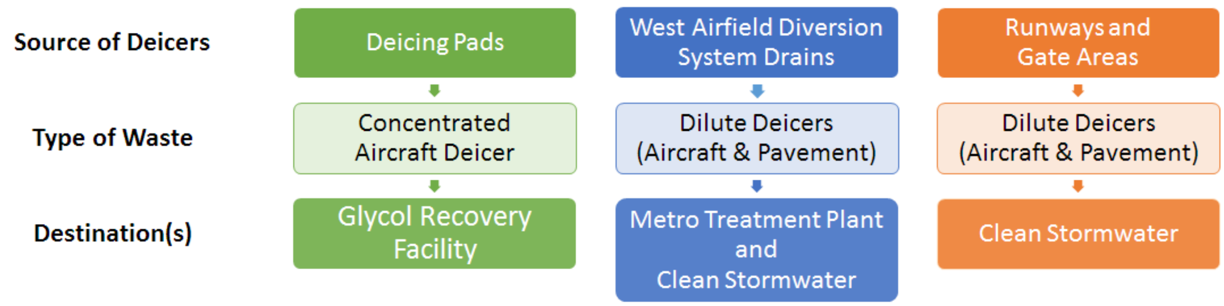

Figure 1.4. Sources and destinations of deicing chemicals at Denver International Airport.

DIA has been recognized across the United States for their environmental accomplishments and sustainable initiatives. DIA is a Gold Member in the Colorado Department of Public Health and Environment (CDPHE) Environmental Leadership Program and was the first airport to be recognized by the U.S. Environmental Protection Agency (EPA) in their Environmental Performance Track Program [5]. Given DIA's environmental awards, one priority of this project was helping to make sure DIA could maintain their environmentally sustainable reputation. In order to lead airports across the nation in environmental stewardship, capturing or diverting deicing waste from state waters draining from the airport is critical.

Moreover, DIA expects to be receiving a new stormwater permit in the next year that will likely require stricter monitoring of propylene glycol and potassium acetate. This stormwater permit is also expected to include quantified effluent limits for BOD and other constituents contained in runoff from the site. Therefore, DIA requires a design to complement existing technologies in order to capture fugitive deicing chemicals.

After analysis of several alternatives, IIB has developed a preliminary design of a solution for DIA to implement for controlling deicing chemicals. Although IIB worked directly with DIA, this versatile solution could be easily implemented at any airport that routinely uses deicing chemicals to maintain airport operations in the winter months.

2.0 Summary of Literature Review

Regulations

DIA must adhere to environmental regulations in the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA), and other Airport Cooperative Research Program (ACRP) policies. DIA currently manages its on-site stormwater in compliance with a National Pollutant Discharge Elimination System (NPDES) permit (No. COS-000008), which was first issued in 2001 to ensure compliance with the Clean Water Act [3]. The permit requires that DIA develop and implement a stormwater management plan (SWMP) that includes best management practices and sampling protocols. DIA's SWMP has been in place since March 2010. The SWMP requires that only propylene glycol deicing products be used on planes and that only potassium acetate, potassium formate, sodium acetate, and sodium formate be used on paved surfaces; however, DIA currently only uses potassium acetate to deice pavement [4]. Within the next year, the airport expects to receive a new NPDES permit, which will likely require a revision of the SWMP to include new monitoring requirements and management practices for reducing discharge of deicing waste into state waters [4].

DIA is classified as a "Heavy Industrial Facility," meaning that the airport uses more than 1,000 gallons of deicing agent per year [3]. Although DIA has an extensive wastewater catchment system, some polluted runoff still enters clean stormwater channels that lead to natural waterways such as Third Creek and Barr Lake.

Management of pavement deicers and spent aircraft deicing fluid must also comply with the following series of rules and regulations established by DIA: Part 40 (Conduct of Tenants Using the Airport); Part 180 (Environmental Management); and Part 190 (Aircraft Deicing Regulations) [6, 7, 8]. The selected alternative(s) must also comply with DIA's Environmental

Guidelines ES-301-1.06: Aircraft Deicing and ES-301-4.06: Pavement Deicing [9, 10], and must not violate contracts with tenants, contractors, and operators involved in deicing at DIA [3].

Alternatives

Additional Ponds

The current storage ponds at DIA fall in the confines of the WADS and hold runoff before it can be sent to Metro's Robert W. Hite Treatment Facility for treatment [4]. The current ponds capture a percentage of the runoff, but some is still released into creeks on the property, affecting water quality and aquatic life in surrounding waterways [3]. Adding more ponds would increase water storage capacity so that a greater volume of runoff could be captured and eventually sent to Metro without increasing current pumping rates.

Mobile Collection Units

Mobile collection units vacuum snowmelt for transportation to temporary storage tanks or to for discharge to Metro through the WADS ponds. These vehicles come in two forms: glycol recovery vehicles (GRV) produced by Vactor, and larger commercial vacuum trucks like those produced by Imperial Industries [12]. DIA currently only uses one glycol recovery vehicle [4], but multiple mobile collection units are in use at Gerald R. Ford International Airport (GFIA) in Grand Rapids, Michigan, to collect spent aircraft deicing fluid [13]. This has proven to be effective at GFIA.

Expanded Drain System

The WADS does not encompass the Whiskey Alpha deicing pad area, meaning that the snowmelt contaminated with both propylene glycol from aircraft deicing fluid and potassium acetate from pavement deicers is not captured [3]. An expanded drain system at this location would include concrete walls with trench drains along the west side of the deicing pad. The captured snowmelt could then be sent to the current retention ponds used for the WADS and eventually to Metro. The goal of this expanded drain system would be to capture BOD and prevent it from ending up in surrounding creeks.

Subterranean Aerated Gravel Beds

Subterranean aerated gravel beds are a form of biological water treatment and can be used to treat water contaminated with deicing and anti-icing chemicals [11]. This technology is low-risk and offers a good form of onsite treatment despite harsh winter conditions and large snow dumps at airports [11]. The technology makes use of microbes in the beds that eat contaminants and prevent them from spreading into surrounding waterways.

Buffalo Niagara International Airport (BUF) was one of the first airports to experiment with subterranean aerated gravel beds [14]. These beds came about because of more stringent regulations in BUF's stormwater permit, similar to what DIA will be facing in the next year [15]. Full-scale testing for this project began in 2009, and the aerated gravel beds are still operating today [14]. The main contaminants of concern at BUF are propylene glycol and ethylene glycol, similar contaminants to those being monitored at DIA. The design successfully meets the requirements in the New York Stormwater Permit of 30mg/L BOD [15], and today the aerated gravel beds can handle BOD loadings up to five times the original design because of the increased number of microbes over time [14].

Subterranean aerated gravel beds have also proven to work well at other airports in cold regions across the world. These airports include Long Island MacArthur Airport, London Heathrow, and Edmonton International Airport [16]. However, this design concept has not been incorporated in many airports, giving IIB a unique opportunity to expand this design to DIA, and eventually to other airports located in cold regions of the world.

3.0 Problem Solving Approach to Design Challenge

IIB structured its approach to the design challenge by defining several distinct project phases: the proposal, the alternatives assessment, and the development of a preliminary design. In the proposal phase, IIB identified a number of alternatives as potential solutions to the problem. In the alternatives assessment phase, a subset of these alternatives were selected for in-depth research and a comparative evaluation. Finally, in the preliminary design phase, IIB further analyzed the preferred alternative—subterranean aerated gravel beds—to develop design parameters and a detailed cost assessment.

The proposal phase consisted of a site visit to DIA, interviews with airport personnel, an initial literature review, and preparation of the proposal document. During this phase, several alternatives (engineered wetlands, anaerobic and aerobic water treatment, infrared deicing, expanded drain systems, additional ponds, mobile collection units, and ozonation) were identified as potential methods for reducing deicing chemicals in stormwater runoff based on knowledge of (1) existing infrastructure and operations at DIA, (2) opportunities for modifying DIA’s infrastructure and operations, and (3) management practices and engineered solutions implemented at other airports.

Prior to the alternatives assessment, a few proposed alternatives were eliminated from further consideration. Aerobic and anaerobic water treatment, infrared deicing, and ozonation were deemed infeasible due to significant logistical and economic obstacles to implementation. The remaining alternatives were then refined and researched further. For example, the engineered wetlands model was revised to an aerated gravel beds model, and IIB identified specifications of the proposed mobile collection units.

At this stage, the alternatives were subjected to a multi-criteria decision analysis (MCDA), which included design criteria grouped under economic, environmental, and social/logistical categories. The alternatives were assigned a score from 1 to 5 based on how effectively they addressed each criterion, 1 being least effective and 5 being most effective. The scoring for each criterion then yielded an overall weighted score for each alternative (Table 3.1).

Table 3.1. Multi-criteria decision matrix used to select the preferred alternative.

		Criteria Score			
Criteria	**Criteria Weight**	*Additional Ponds*	*Expanded Drain System*	*Mobile Collection Units*	*Aerated Gravel Beds*
Economic					
Capital Costs	0.132	1	5	1	3
Operations Personnel	0.066	4	5	1	4
Recurring Energy Costs	0.132	5	4	1	3
Environmental					
BOD Reduction	0.33	2	1	4	5
Social/Logistical					
Spatial Requirements	0.0825	3	5	2	3
Maintenance Requirements	0.0825	5	5	2	3
Adaptability	0.0825	4	2	3	3
Feasibility	0.0825	5	3	2	5
	Weighted Score	**3.10**	**3.10**	**2.40**	**3.86**

The preferred alternative, which scored higher across virtually all of the design criteria, was the subterranean aerated gravel beds. For the preliminary design of the gravel beds, IIB identified a location for implementation of the beds and proposed design specifications along with the expected flow rate of runoff for winter storm events. IIB also developed a detailed cost estimate for implementation of the beds at DIA using *WinEst Pro* based on construction and operation of the beds. More information about the cost estimate can be found in Section 8.0.

4.0 Design Alternatives

This section contains information about the four alternatives that were compared in detail to come up with a recommended solution for DIA. The general description and final score from the decision matrix is included for each alternative.

4.1 Additional Ponds

DIA currently has retention ponds that hold water as part of the WADS collection system. Water within the WADS either flows to the retention ponds or to the clean stormwater system. The valves that determine how much water is diverted to the ponds are open 38% in the winter and 7% in the summer [4]. After being held in retention ponds, the water is sent to Metro for treatment. Occasionally, DIA experiences flows from large storms that exceed the storage capacity of the existing ponds and the contaminated water is released to the clean stormwater system.

Increasing the capacity of the airport's system of ponds would create additional storage for contaminated water so more of it could be sent to Metro rather than running off into Third Creek. IIB identified an area on the airside of DIA to build a new retention pond containing two cells, each with a storage capacity of 7.5 million gallons (Figure 4.1). This would increase DIA's water storage capacity by 15 million gallons and the WADS retention pond capacity by 50%, resulting in a 12% capture of overall BOD. Additional ponds scored 3.10 out of 5 on the multi-criteria decision matrix, which is attributable to low scores for BOD reduction and capital costs. However, this alternative received the highest possible score for recurring energy costs, maintenance requirements, and feasibility.

4.2 Mobile Collection Units

Under DIA's snow management plan, snow is plowed from runways and deicing pads to the sides of paved areas. Once pushed into these grassy areas, the snow melts into the clean stormwater system. Snow is also melted on paved areas by snow melting equipment, and the resulting snowmelt is discharged directly into the clean stormwater system (Figure 4.1). The goal of deploying mobile collection units is to intercept the melted runoff that is potentially contaminated with propylene glycol and/or potassium acetate. This interception requires that snow be melted at new strategic locations (i.e., not over clean stormwater drains). Once collected, snowmelt could be transported to retention ponds, drains serving the WADS, or temporary storage tanks. Finally, snowmelt would be combined with the sanitary sewer and discharged to Metro for treatment, along with the rest of the contents of the WADS ponds.

Assuming that 50% of snowmelt can reasonably be collected by vacuum trucks, approximately 640 cubic feet of snow must be vacuumed per minute for a typical storm event. Based on the 4,000-gallon capacity of the proposed vacuum truck model and the time required to periodically offload collected snowmelt, 13 vacuum trucks would be required [12]. Implementing this mobile collection fleet would result in a 21% decrease in BOD released. This alternative scored 2.40 out of 5.00 on the multi-criteria decision matrix, receiving low scores for all of the economic criteria including capital costs, operations personnel, and recurring energy costs and no perfect scores in any category.

4.3 Expanded Drain System

Currently, snow is pushed to the edge of deicing pads to melt and prevent interference with airport operations during snow events [5]. The WADS does not encompass the Whiskey Alpha deicing pad area, meaning that the snowmelt removed from the pad is not captured. This snow is contaminated with concentrated propylene glycol and potassium acetate due to aircraft and pavement deicing fluid respectively.

As previously mentioned, IIB proposed building drains with concrete walls on the west edge of the Whiskey Alpha deicing pad (Figure 4.1). The concrete walls would go behind the trench drains to prevent snowmelt from escaping. The captured snowmelt would be sent to the current retention ponds used for the WADS system so that it could eventually be sent to Metro. The addition of an expanded drain system would result in an overall BOD diversion of 10%. This alternative scored 3.10 out of 5.00 on the multi-criteria decision matrix, scoring particularly low for BOD reduction and particularly high for capital costs, operational costs, spatial requirements, and maintenance requirements.

4.4 Subterranean Aerated Gravel Beds

Aerated gravel beds are designed to harness the biological function of microbial respiration to biodegrade potassium acetate and propylene glycol. IIB based the preliminary design of aerated gravel beds on beds designed by Mark Liner, PE, that are currently in operation at BUF in Buffalo, New York [14]. Microbes are grown on 1 ½ inch-diameter gravel that is contained in trenches (“beds”) that are dug into the ground [17]. Contaminated stormwater is pumped to the top of the beds from Third Creek near sampling location D and allowed to trickle down through the beds, giving the microbes time to digest the contaminants (Figure 4.1). Each bed has an influent distribution chamber which takes the incoming stormwater and distributes it among the beds. As the water moves horizontally through the beds, oxygen is introduced into the system by aeration orifices in GeoFlow aeration tubing that runs along the entire length of the bed [18]. Once the water reaches the end of the beds, it is collected and released back to Third Creek. Aeration of the beds provides oxygen for microbial respiration and ensures that the beds will not turn anoxic and kill off the microbial communities. The subterranean quality of the beds will keep them warm enough to prevent the microbes from freezing in the winter.

This alternative was selected as the preferred alternative with a score of 3.86 out of 5.00 on the MCDA. This alternative received scores of 5 on BOD reduction and feasibility and did not receive a score lower than 3 in any category. A detailed technical description of the preliminary design can be found in Section 6.0.

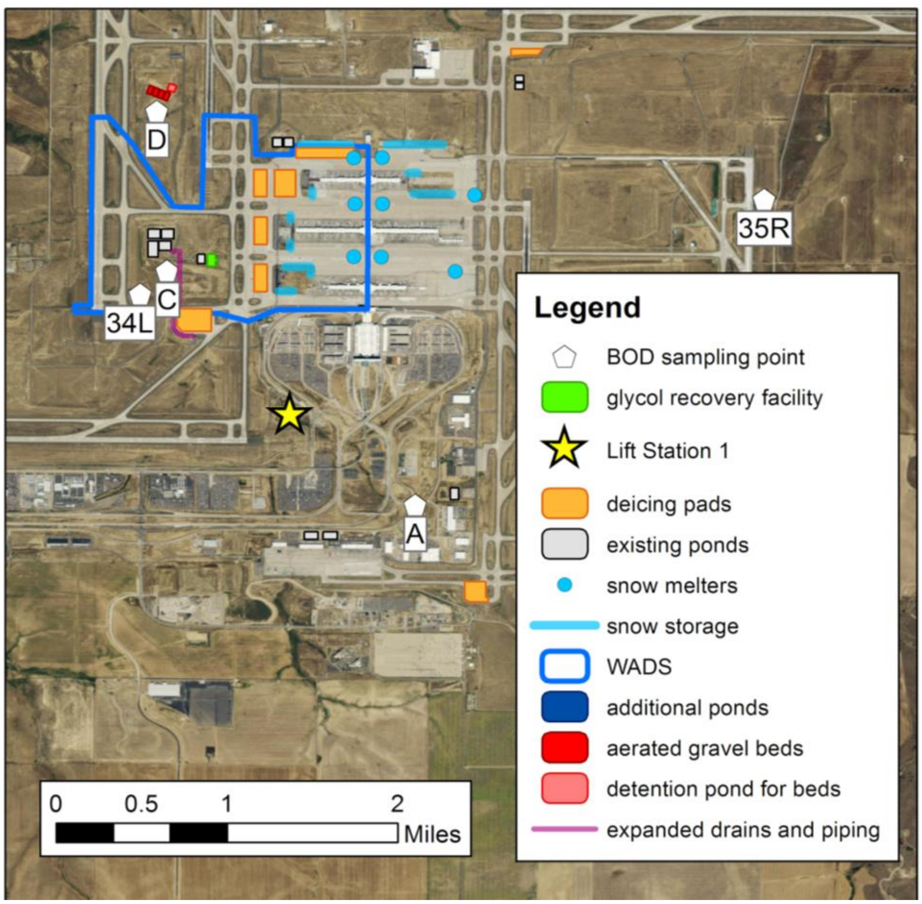

Figure 4.1. Map of deicing infrastructure at DIA and locations of proposed alternatives.

5.0 Safety Risk Assessment

Implementing aerated gravel beds at DIA will require some logistical accommodations, including very limited interference in airport operations from construction activities. However, compared to the other proposed alternatives, this interference is minimal. Implementation of the preferred alternative will not result in any increased risk to airline passengers or airport personnel. The beds will have a substantial physical footprint on the site, but the large area required is located away from aircraft and other airside vehicles, so construction will have a minimal impact on normal airport operations. Moreover, regular maintenance of the beds will not significantly increase airside traffic. In addition, the subterranean nature of the beds—unlike engineered wetlands at the surface—will not attract wildlife that might pose a risk to airside operations. Furthermore, the detention pond will provide influent for the aerated gravel beds which will decrease very high flow rates in the box culvert at sampling location D. This may reduce the risk to personnel conducting water sampling or other activities at the culvert in the aftermath of a storm event (Figure 1.3).

The SWMP and DIA's stormwater permit were developed and approved in order to control the release of deicing chemicals while ensuring that aircraft and pavement are adequately deiced and anti-iced during winter storm events. IIB reviewed these two documents in-depth to ensure that the preliminary design will not violate the requirements established in either document. By extension, implementation of the aerated gravel beds will not interfere with the safety provisions already in place at DIA.

6.0 Technical Description

The alternatives assessment conducted by IIB concluded that implementing aerated gravel beds at DIA would be the most feasible and cost effective way to reduce the amount of deicing waste in stormwater draining to Third Creek. Accordingly, IIB prepared a preliminary design of the beds based on designs developed for BUF by Mark Liner, PE [14]. The dimensions of the preliminary design were scaled from these reference designs in order to address the BOD concentrations and flow rates associated with winter storm events and deicing operations at DIA, as well as the amount of airside space available at the site.

IIB proposes that the subterranean aerated gravel beds will be constructed near sampling location D, since this sampling location has the highest average BOD level compared to other locations at the site (Figure 1.3). Based on available space near this sampling location, four beds will be placed in parallel, and each bed will be 80 meters in length, 40 meters in width, and 1 meter in depth. A photo of the box culvert where stormwater is sampled and runoff flows to Third Creek is shown in Figure 6.1.

Figure 6.1. Box culvert at DIA receiving stormwater runoff from the west side of the airfield.

The BOD loading rate and the flow rate of runoff entering Third Creek through sampling location D was estimated based on average rates of stormwater discharge sent to the Metro treatment plant from 1999 to 2009, since this discharge constitutes a known fraction (38%) of runoff from the WADS. These data were provided by Kim Ohlson, an environmental public health analyst and IIB's main point of contact at DIA. IIB then estimated an upper limit for the mass flow rate of BOD in runoff from winter storm events by applying the average BOD concentration at sampling location D to the expected flow from one of the approximately five winter storms that occur each year, assuming that such flow takes place over a two-day period [19, 20]. This BOD concentration is likely an overestimation, given that sampling probably occurred during periods of relatively low flow and not immediately after winter storm events, when deicing waste would be diluted by high flows of runoff. Based on the desired residence time (about 6.1 days for the beds at BUF), the flow through the beds must be regulated at 2,115 m^3/d. At this flow rate, the operational load for the beds will be 2,373 kilograms of BOD per hectare per day, which is equivalent to the oxygen demand of 1,213 kilograms of propylene glycol per hectare per day. This loading is significantly lower than the upper limit for the beds at BUF, which is about 20,000 kg/d, or 8,600 kg/d-ha [14]. Key design parameters for the aerated gravel beds are summarized in Table 6.1.

Table 6.1. Final design parameters for aerated gravel beds.

Design Component	Value
Number of beds	4
Length of each bed	80 m
Width of each bed	40 m
Depth of each bed	1 m
Flow rate through beds	2,115 m^3/d
Residence time per bed	6.1 d
Average influent concentration (BOD)	1,236.7 mg/L
Average influent concentration (propylene glycol)	734 mg/L
Operational load (BOD)	2,373 kg/ha-d
Operational load (propylene glycol)	1,213 kg/ha-d

In order to supply the beds with a steady flow of runoff, IIB proposes that a detention pond (60 meters in length, 60 meters in width, and 5 meters in depth) be constructed upstream of the beds. This detention pond will receive runoff passing through sampling location D by diverting flow from the existing pipe (Figure 6.2). The size of the pond must be adequate to safely receive a portion of the total flow, which will be approximately 22 million gallons for a single 48-hour winter storm resulting in two inches of snowfall [19, 20]. IIB proposes collection of about 20% of the total flow for a single storm event. Therefore, the volume of the pond must be approximately 5 million gallons. This volume has been overestimated by 25% in order to introduce a factor of safety; a larger volume will decreasing the likelihood that the pond will overflow or that diversion to the pond will be severely restricted during larger storms. IIB anticipates that collecting runoff in the detention pond will allow operation of the beds to continue into the summer months when drought conditions may limit the volume and frequency of flow at sampling location D.

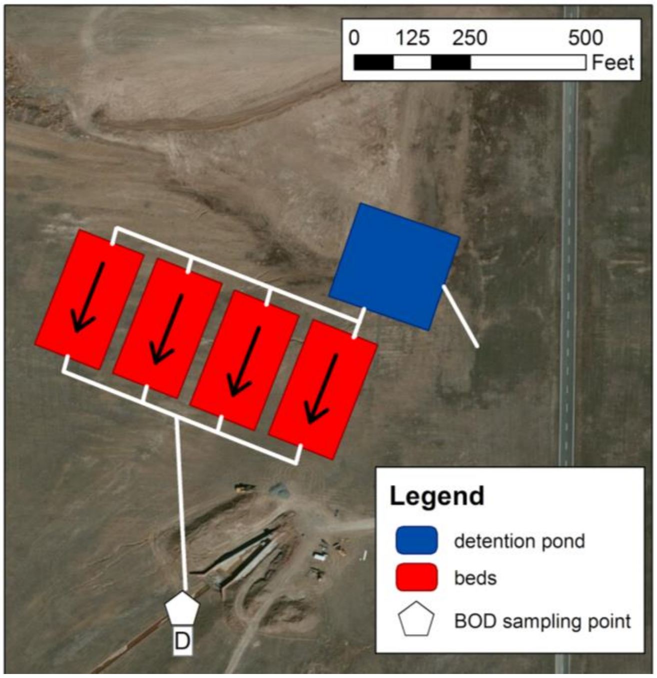

Figure 6.2. Plan view of proposed layout for subterranean aerated gravel beds and corresponding detention pond near sampling location D.

A schematic for the aerated gravel bed system is provided in Figure 6.3. From the detention pond, a pump system will move runoff from the bottom of the pond to the beds, where an influent distribution chamber can distribute the flow at the entrance to each of the four beds. Each bed will be filled with 1.5 inch diameter screened and washed gravel where Aerobacter and Pseudomonas bacteria can grow on the gravel surface [14]. Aerobacter and Pseudomonas bacteria have been shown to effectively degrade potassium acetate and propylene glycol as well as other organic contaminants [21]. The beds will be lined with 60 mm high-density polyethylene (HDPE) liners, which prevent leaching of contaminants into the surrounding soil [14]. GeoFlow aeration tubing will run lengthwise along the base of the beds [18]. A 3-horsepower air blower will provide aeration for each bed: the addition of oxygen from the aeration tubes will maintain a beneficial environment for the bacteria to grow as well as ensuring that the bed environment will not become anoxic. The beds will be one meter in depth, and an overlying layer of peat mulch will be four inches in thickness in order to provide adequate insulation for the system [14]. This insulation is critical for keeping the beds above freezing so the bacteria will stay alive in the winter. If the bacteria were to freeze, it would severely damage the effectiveness of the beds. Once the water has moved horizontally through the substrate to the end of the beds, an effluent collection pipe captures clean water and diverts it back into Third Creek due to the pull of gravity.

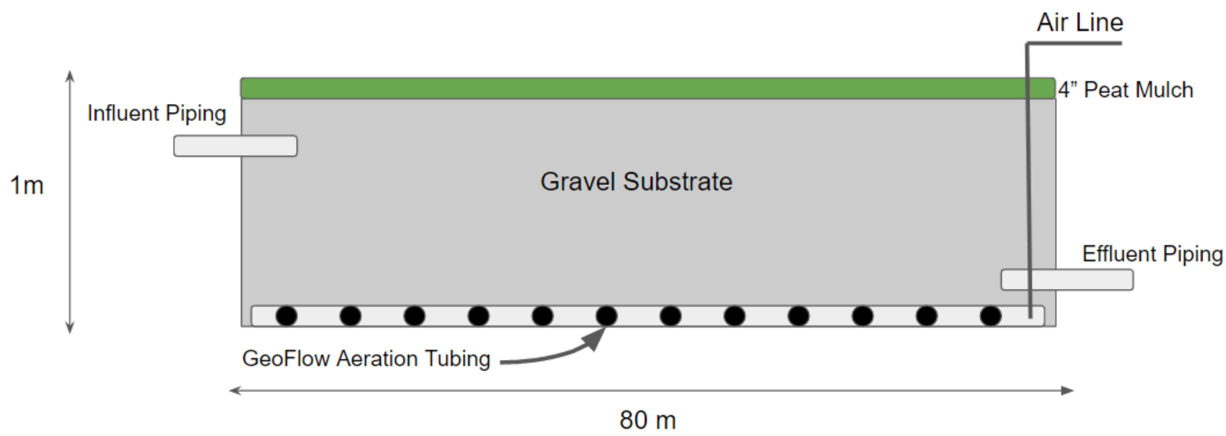

Figure 6.3. Schematic of a subterranean aerated gravel bed (adapted from Nivala et al. 2013) [22].

7.0 Interactions with Airport Operators and Experts

IIB Consulting met with several stakeholders and experts to collect information and arrive at the final proposed design. Throughout the design process, IIB maintained frequent correspondence with employees of DIA's Environmental Services Department, including Kim Ohlson, Keith Pass, and Craig Schillinger. At the beginning of the project, DIA employees arranged a site visit and acquainted IIB with the existing systems and challenges regarding the airport's deicing practices. IIB saw first-hand the complex deicing system that is in place, the existing snow removal equipment, and the current set of other deicing technologies at the airport. The site visit, along with other DIA employee interviews and a detailed literature review, allowed IIB to identify areas of intervention at DIA.

After gathering initial information, IIB reached out to the main contracting company for deicing operations at DIA, Swissport, and spoke with Tom Fahdenbruch, the co-founder and partial owner. This conversation provided insights about the extensive measures taken to keep planes and runways operational during storm events. Through this interaction, IIB learned more about current deicing operations at DIA, particularly on deicing pads.

Throughout the entire design process, IIB consulted with its faculty advisor at the University of Colorado Boulder, Christopher Corwin, PhD, PE. IIB utilized Dr. Corwin's expertise in water resources engineering to gain valuable insights into every step of the design process.

8.0 Immediate Impacts

IIB has identified and addressed two main immediate impacts to DIA following implementation of the aerated gravel bed system: capital costs and airport activity disruption.

8.1 Capital Costs

The upfront cost of implementing the aerated gravel beds and detention pond is $2.4 million. The estimated costs of the materials and processes required for implementation are summarized in Table 8.1, and the assumptions used to compute each estimate are stated in Table 8.2. Given that the beds can be operated in all months of the year and will likely have a long operational life, the capital costs associated with their implementation are relatively small compared to the benefit of reducing high BOD concentrations from the west side of the airfield.

Table 8.1. Material and construction costs for subterranean aerated gravel beds and detention pond.

MATERIAL OR PROCESS	UNIT COST	CITATION	QUANTITY	COST ($)
Beds				
Washed gravel (1.5")	$12.96/ton		23,704	$307,205
Peat mulch	$123/yd^3	(1)	1,701	$209,219
60 mil HDPE liner	$1.84/ft^2	(2)	148,111	$258,265
GeoFlow Aeration Tubing	$0.79/ft	(3)	8,399	$6,635
Air blower	$2750/blower	(4)	1	$2,750
HDPE infiltration chamber pipe	$58.88/ft	(5)	166	$9,774
Water pump	$2762/pump	(6)	2	$5,524
Excavation	$2234.5/day		60	$134,070
Construction labor	$580/week/ employee		200	$116,000
Material unload labor	$25/hr		56	$1,400
Soil disposal	$22/yd^3		16,742	$368,319
Seeding	$200/acre	(7)	3.16	$633
Pond				
Concrete pavement 9" thick	$46.87/yd2		1,912	$89,632
60 mil HDPE liner	$1.84/ft2		17,211	$31,669
Excavation	$2234.5/day		60	$134,070
Soil disposal	$22/yd3		24,308	$534,770
Concrete prep with crew	$1226.5/day		30	$36,795
Concrete machinery	$845/month		5	$4,225
Construction labor	$580/week/ employee		200	$116,000
Material unload labor	$25/hr		56	$1,400
TOTAL				**$2,382,644**

(1) Mr. Mulch [23] (2) XR Geomembranes [24] (3) Geo Flow [18] (4) SeaGate Filters [25] (5) ADS Piping [26] (6) First Out Rescue Equipment [27] (7) Massachusetts Nonpoint Source Pollution Management [28]; All other values calculated in WinEst.

Table 8.2. Assumptions used to compute capital costs for subterranean aerated gravel beds and detention pond.

MATERIAL OR PROCESS	ASSUMPTIONS
Beds	
Washed gravel (1.5")	● The density of gravel is 1.85 tons/m^3 [24]
Peat mulch	● Compressed Canadian sphagnum peat moss
60 mil HDPE liner	● Lines total inner surface (base and 4 sides) of each bed
GeoFlow Aeration Tubing	● 8 rows of tubing along the length of each bed
Air blower	● Overall flow rate of air for beds is 25,600 m^3/hr ● Pump capacity must equal or exceed 0.11 hp to ensure adequate aeration
HDPE infiltration chamber pipe	● Infiltration pipe connects ponds to beds
Water pump	● Overall flow rate for beds is 23,275 gal/hr ● Pump capacity must equal or exceed 1.61 hp to pump water from base of pond to top of beds
Excavation	● Excavation will require 60 days to complete
Construction labor	● Construction will require the labor of 10 workers for 5 months (20 weeks)
Material unload labor	● Material unloading will require approximately 7 full days
Soil disposal	● 16,742 yd^3 of soil must be removed
Seeding	● Using the lowest cost estimate from the US EPA
Pond	
Concrete pavement 9" thick	● Covers total inner surface of pond (base and four sides)
60 mil HDPE liner	● Covers total inner surface of pond (base and four sides)
Excavation	● Excavation will require 60 days to complete
Soil disposal	● 24,308 yd^3 of soil must be removed
Concrete prep with crew	● Concrete preparation will require 30 days
Concrete machinery	● Georgia Buggy, truck mixer, trailer pump
Construction labor	● Construction will require the labor of 10 workers for 5 months (20 weeks)
Material unload labor	● Material unloading will require approximately 7 full days

[29] Engineering ToolBox

8.2 Airport Activity

IIB anticipates minimal construction impacts on DIA operations. The estimated construction time is five months. Construction would take place during the summer months when deicing operations are not occurring so DIA could be prepared for the coming winter. The chosen location is far enough from runways and terminals that it will not impact flights. The access roads around the construction site might be more congested, but this will have little impact on daily airport operations.

9.0 Future Impacts

IIB has identified and addressed numerous long-term economic and logistical considerations for its design. Forward-thinking is vital for the project's sustainability, so IIB spent many hours researching each area.

9.1 Recurring Costs

Long-term economic considerations include maintenance costs and personnel costs. As the beds are used, it is safe to assume they will require occasional maintenance. The microbes may die if the beds are not adequately saturated, and the beds will have to be reseeded. However, this risk is reduced by the presence of a detention pond upstream of the beds, so only a significant period of drought would cause microbial death. The pumps or piping might need repairs or replacement as they near the ends of their functional lifetimes. When considering the 20-year lifecycle of the beds, all of these possibilities become practical considerations.

Personnel costs will certainly be a long-term, recurring cost needed to maintain the aerated gravel beds throughout their lifecycle. Personnel will need to conduct periodic sampling of discharged water to ensure the aerated gravel beds are meeting the target removal. In events of flood or drought, DIA personnel will have to regulate the flow into the detention ponds and through the beds to keep the microbes alive. Another recurring cost to consider is the energy to run the pump and the blower. Along with personnel, this is a guaranteed recurring cost.

However, operation and maintenance costs are small in comparison to the capital costs. Accordingly, IIB gave more weight to capital costs when determining the economic feasibility of the design.

9.2 Variable Flows and Runoff Events

Aerated gravel beds are able to handle variable flow rates and influent BOD concentrations, so the beds are well-suited to handle future changes in hydrologic processes at DIA. The beds could also be useful for cleaning up runoff of organic contaminants after occasional events such as jet fuel spills. Since the beds are subterranean, temperature will not affect the efficiency of treatment. This is important because deicing and anti-icing agents are used at airports when temperatures are below freezing and the microbes must still stay alive.

9.3 Biochemical Oxygen Demand Removal

The current sampling regime at DIA is governed by requirements put forth in the SWMP created by DIA and the Colorado Department of Public Health and Environment. As stated in the Stormwater Management Plan, grab samples of Chemical Oxygen Demand (COD) must be taken in October, December, February, and April at five specific locations around DIA property, shown in Figure 1.3 [3].

The Metro Wastewater Permit specifies that a derivation of COD data should be used to determine compliance with set BOD limits; therefore, IIB used COD data multiplied by 0.78 for the environmental BOD analysis [30]. The final BOD concentrations used for the environmental analysis of alternatives were determined by averaging data from 2007 to 2016 at each location and are included in Figure 1.3.

9.4 Commercial Implementation

The aerated gravel bed design by IIB has great commercial potential. Since it is not patented, it can be altered for implementation at any airport attempting to address deicing chemical runoff. Moreover, the design presented can be scaled up or down to meet the needs of any size airport while maintaining high efficiencies assuming the residence time is maintained at about six days.

10.0 Conclusion

IIB is committed to providing DIA with a viable and cost-effective solution to capture and treat fugitive contaminants. These contaminants primarily include propylene glycol and potassium acetate. After completing a written proposal with initial ideas, IIB narrowed the scope and worked diligently to analyze four potential alternatives to ultimately provide DIA with an implementation plan. After completing the alternatives assessment, IIB is confident that subterranean aerated gravel beds will be able to reduce the amount of BOD released initially into Third Creek and ultimately into Barr Lake. Although this alternative does not provide a solution for every drop of water leaving DIA, it will reduce BOD concentrations at the sampling location of greatest concern, which will have a significant impact on reducing overall BOD concentrations in runoff from the airport.

This solution could also be easily implemented in other airports that utilize deicing agents for their runways and aircraft. Subterranean aerated gravel beds have been shown to be a reliable treatment technology for contaminants like propylene glycol and potassium acetate at many other airports, like BUF, and IIB is confident that this design can be similarly effective. Four beds will be placed near Third Creek to collect and treat runoff before the water is released back into the creek. A detention pond will be installed with the gravel beds in order to regulate the flow through the gravel beds. A water pump, aeration tubing, and an air blower will control the environment of the beds to ensure that they remain functional in variable precipitation events and that they prevent microbial death.

IIB's final design for control of deicing chemicals meets all ACRP goals: it focuses specifically on airport environmental interactions and emphasizes the ability of airports to provide vital and interesting engineering jobs. IIB is proud to present an airport solution that will increase the sustainability of activities at DIA, improve water quality in nearby waterways, and ensure that both of these tasks are accomplished without impeding airport operations.

Appendix A: Team Contact Information

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Appendix B: Description of University

The University of Colorado was founded in 1861 and has over 61,000 students spread across four campuses in Boulder, Denver, Colorado Springs, and the Anschutz Medical Campus [31]. The University of Colorado Boulder campus is the main campus, with over 30,000 students and many unique research and learning opportunities. Research funding at the university totals over 800 million annually, attracting internationally recognized scholars [31]. The diverse faculty includes Nobel Peace Prize winners, recipients of MacArthur Fellowships, members of the National Academy of Science, the American Academy of Arts and Sciences, the National Academy of Engineering, and the National Academy of Education [31].

Appendix C: Description of Non-University Partners

DIA

Kim Ohlson was IIB's main point of contact with the Environmental Services Team at DIA. IIB and Ohlson communicated through weekly email, monthly conference calls, and a site visit in early February. Information provided by DIA included water quality monitoring data, site maps, snow management plans and descriptions of operations, hydrology and water quality permits, and descriptions of airport operations. Another member of the Environmental Services Team at DIA, Keith Pass, led the site visit and provided valuable answers to all questions IIB had during the tour.

Swissport

Swissport is an independent deicing company responsible for a majority of deicing operations at DIA [1]. One of the owners of Swissport, Tom Fahdenbruch, scheduled a personal interview with IIB to answer specific questions concerning deicing chemical management and application. Fahdenbruch provided information regarding deicing chemicals used by Swissport, management practices, and deicing fluid regulations. IIB was able to more fully understand deicing operations at DIA, as well as receive feedback on possible management alternatives and feasibility of changes to DIA's daily operations.

Appendix E: Evaluation of Educational Experience

Student Questions

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes, this competition allowed our group to work with a client (DIA) to come up with a design for a real-world problem. In addition to the real world consulting experience this project provided, our team was also able to learn more about working on engineering projects with a team to meet deadlines, something pertinent to any future career.

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

The main challenge in this project was the lack of information provided in the early stages of our design process. Our team realized that communicating and working with a client adds an extra layer of complication, as well as time for communication and exchange of important documents and information. We got to have conversations with other individuals, learn how to make good assumptions, and figure out creative ways to move forward and work on other aspects of the project when we were waiting for data.

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

To develop our hypothesis, our team began with a literature study of the industry, its standards, and solutions that have been considered and implemented at other airports. After completing our research, we reached out to DIA for a tour and a discussion of regulations and possible treatment sites. With all of this information, we were able to move forward and develop a hypothesis for treatment of deicing chemicals at DIA.

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

Yes, participation by the industry was incredibly useful for the advancement of our project. Without being in direct contact with our client, our group would not have had the information necessary for sizing and locational information for our design considerations. Even early on in our project when our group was just considering alternatives, we were able to meet with our clients to gain a deeper understanding of their specific needs and the way the airport is set up. We were also able to understand current practices at DIA to recycle propylene glycol to ensure that our proposed solutions were actually beneficial to the situation.

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?

This project did help us gain skills and knowledge that will be useful for the workforce. Our team learned more about navigating literature, designing within constraints presented by a client, and writing technical reports. Additionally, we learned a lot about working with a team to carry out a design project, something that is very common in the workforce.

Mentor Questions

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

The students used this competition as a vehicle to get an authentic engineering experience in working with an actual client (DIA) on a relevant, current problem. The students developed the project with the client resulting in a proposal, then investigated several alternative solutions to the problem, and finally design the best alternative. The competition provides the opportunity for the students to combine all their undergraduate courses into this “capstone” project while improving their skills in written and oral communication.

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

Yes, very much so.

3. What challenges did the students face or overcome?

Finding cost data applicable to airport work is always a challenge.

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

Yes. The competition provides a vehicle to motivate the students to perform their best and provides an outlet for their hard work.

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

We have had teams win twice in the past three years. A small cash award to the University would be nice to promote participation and cover the overhead of administering the travel for the students.

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