Implementing Airside Bioswales for Stormwater Management at the Airport

(January 2023 - April 2023)

Design Challenge: Airport Environmental Interactions: *New tools for stormwater management methods, water use, and dealing with negative impacts of standing water.*

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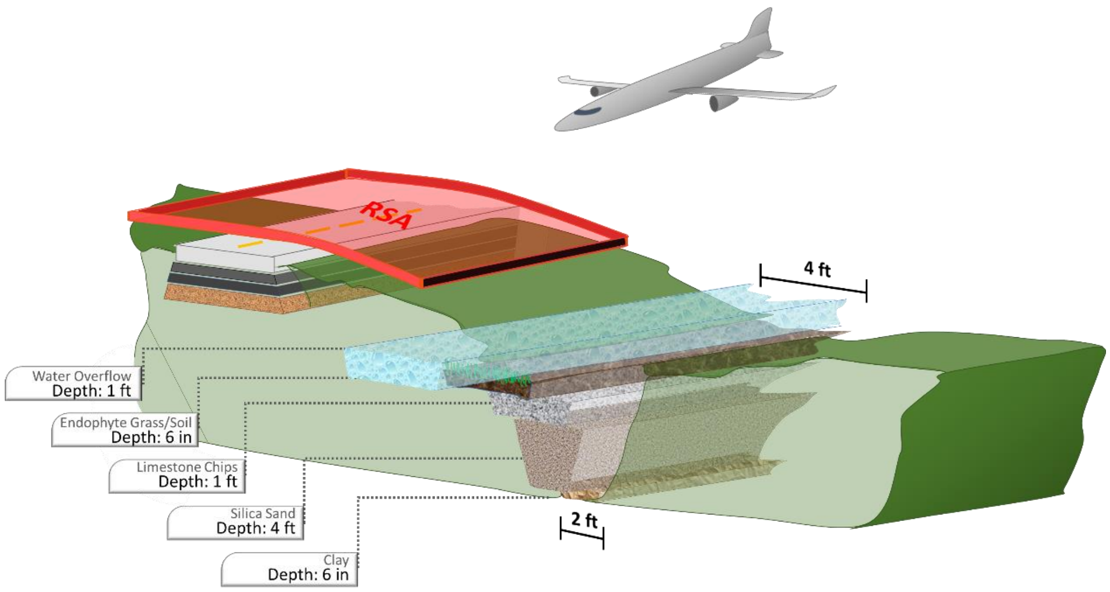

Executive Summary

This design aims to tackle the **Airport Cooperative Research Program Airport Environmental Interaction Challenge D**: *new tools and approaches to stormwater management methods, water use at airports, and dealing with negative impacts of standing water* by innovating a new method for airport stormwater management and pretreatment. Airports have high amounts of impervious surfaces which can cause excess runoff during storm events. Chemicals used in aviation can be hazardous to the environment. Federal and state governments regulate water and chemical levels due to the abundance of water combined with potentially high levels of pollutants.

The design is an airside bioswale that employs methods for storing and pretreating stormwater through phytoremediation, soil biodegradation, and multi-layered filtration. The team interviewed experts from the agricultural, civil engineering, and aviation industries to better understand the problem and create a more informed design. The team collected real airport data to run an Arena® model to simulate the amount of water that the design can manage. Additionally, the team built a one-third physical model to corroborate the system's water absorption, filtration, and biodegradation capacity.

Benefit-cost analysis was conducted based on two scenarios: retrofitting or new build/expansion of stormwater treatment facilities on the airport property. The benefit-cost ratios were 1.06 and 9.18, respectively, over a ten-year period. Furthermore, the proposed system addresses six of the seventeen United Nations Sustainable Development Goals. An EONS analysis proved the sustainability of the design.

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Background and Problem Statement

The problem addressed by this proposal is the environmental damage and financial expenditures caused by stormwater and its pollutants. Accordingly, this design tackles the **Airport Cooperative Research Program Airport Environmental Interaction Challenge D**: *new tools and approaches to stormwater management methods, water use at airports, and dealing with negative impacts of standing water* (Transportation Research Board, 2023) by innovating a new pre-treatment method for airport stormwater runoff.

Fundamentally, the large impervious surfaces and outsize use of toxic chemicals at airports pose two significant stormwater threats to downstream watersheds: 1) severe erosion and 2) toxicity. Impervious surfaces, such as buildings, roads, and runways, are increasing in the United States (Gaffield, 2003) and as such, their stormwater discharge causes increased erosion along riparian areas (Shi et al., 2016). Compared to their organic counterparts, impervious surfaces collect drastically more pathogens, metals, sediment, and chemical pollutants and rapidly transmit them downstream (Gaffield, 2003). Airports are rife with pollutants such as anti-icing and deicing chemicals, corrosion inhibitors, additives, and other elements from unpainted metal surfaces such as zinc and copper (Shi et al., 2016). The airport's "landside" drainage areas, such as roads and rooftops, are particularly dangerous with acute toxicity recorded in runoff samples from three such areas of the Seattle-Tacoma airport in 2002 (Tobiason, 2002).

In addition to erosion and toxic pollution, pooling of stormwater also creates a public safety problem at airports, as it provides habitat for species of insects and animals undesirable at airports. From a public health perspective, pooling stormwater increases breeding areas for mosquitos, which are vectors for a variety of infectious diseases (Gaffield, 2003). Though mosquitos alone are cause for some concern, poor management of stormwater can also become a wildlife attractant. Stormwater-produced habitats create potential hazards for aviation (International Civil Aviation Organization [ICAO], n.d.) with the cost of bird strikes to global aviation reaching $2 billion dollars in 2019 alone (Pennell, 2019). Proactive investments in stormwater management are a boon for community health, a saving for airport operations, and a great risk-reduction for flight safety.

The last problem area for airports posed by stormwater is regulatory. Airports manage dissonance between operational guidance priorities from the Federal Aviation Administration (FAA) and environmental priorities from the Environmental Protection Agency (EPA) (Shi et al., 2017). Advisory Circular AC 150/5320-5D requires airports to remove stormwater quickly and efficiently from their facilities (FAA, 2013). However, this conflicts with EPA regulations to eliminate pollutants from such runoff per the 1977 Clean Water Act (Clean Water Act, 1997). These dual mandates create a regulatory dilemma, as airports must find a balance between removing stormwater rapidly and ensuring its full treatment before downstream release.

Unmitigated stormwater at airports poses significant environmental, operational, and regulatory challenges. This proposal assesses the combined effect of landscaping and greenspace management to reduce unmitigated stormwater risks at airports, with particular emphasis on environmental contamination. This approach contributes to the field by applying practical methods in novel combinations to optimize stormwater management. The resulting design provides informed options for aviation leaders seeking to employ new, regionally appropriate designs to address the harms of unmitigated stormwater.

Summary of Literature Review

This literature review is organized into Hydrology and Ecology, Stormwater Treatment, Topographical Filtration, Regulations, and existing ACRP Efforts.

Hydrology and Ecology

The water cycle is a macro process encompassing all locations in the natural travel of water. A major component of hydrology is soil makeup, which determines the rate of absorption, how much water the soil can hold, and what nutrients can exist in the water. The three basic components of soil are clay, loam, and sand, which can all hold and absorb different amounts of water at different rates. Clay can hold the most water, but it absorbs it more slowly than loam and sand. Sand can absorb water the most quickly, but it does not hold as much as clay or loam (University of California, n.d.).

Another major component of the water cycle is plant choice. Different plants need different amounts of water to survive, and they can change the properties of the soil to absorb and hold the appropriate amount of water. In addition to changing soil properties, water is absorbed by plants and can be evaporated and transpired into the air or used to build new plant cells.

Runoff can carry ambient pollutants downstream, posing a threat to aquatic ecosystems and drinking water. Plane deicer runs off airplanes and onto the pavement where it stays until carried off with runoff to permeable surfaces along the apron (Corsi, 2009). Propylene glycol, a common deicer, reacts with dissolved oxygen in water to effectively asphyxiate organisms that rely on the same dissolved oxygen (Udaykumar, 2020).

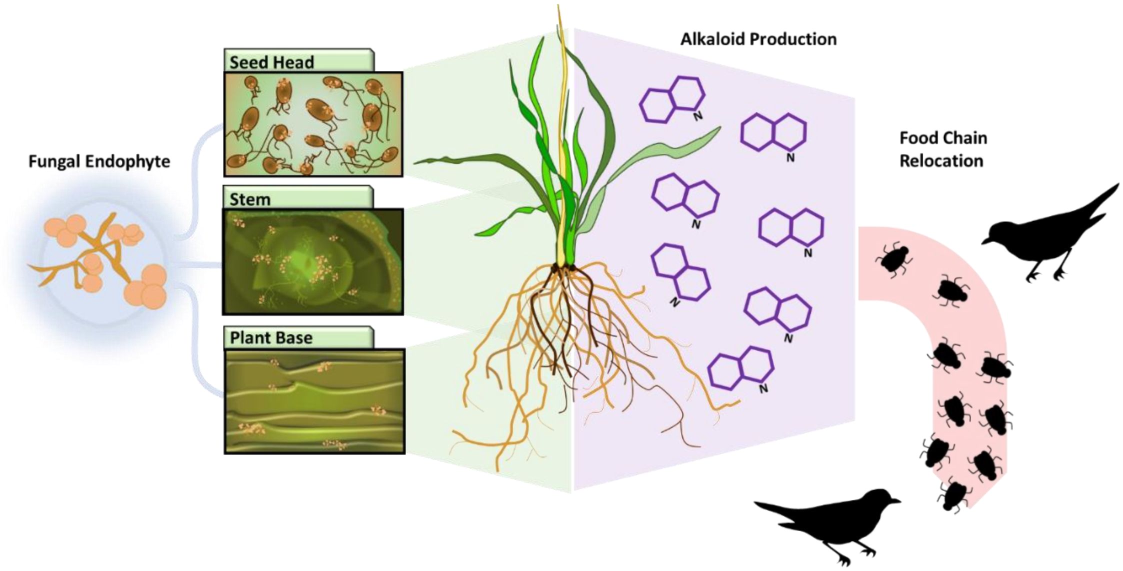
There are many plants that can filter water and maintain soil integrity; some of the best plants for this have deep root systems and can withstand drought. Current airport ecosystems have various grass types that are kept short; this keeps the roots short (Biswell & Weaver, 1933) and reduces filtration and absorption of runoff (Suelee et al., 2017). As mentioned previously, during evapotranspiration, water evaporates from plant surfaces and leaves behind pollution; this process is called phytoremediation (Indiana Public Media, 2007). When nutrients or chemicals enter a plant, they do not leave until decomposition, making plants an excellent short-term pollutant storage option.

In managing airport greenspace, the risk of wildlife strikes becomes a paramount consideration. Largely due to FAA Advisory Circular 150/5300-13A which specifies that grass height may not exceed 6 inches within the Runway Safety Area (RSA), most airports enforce that same standard throughout the airside of their grounds. A 1999 study at JFK, NY recorded higher bird populations in an un-mowed section of grass compared to a mowed section thus corroborating the practice of short air-side grass (Barras et al., 2000). Prior to, and following the 1999 study however, numerous studies documented the opposite phenomenon – higher grass areas visited by fewer birds and resulting in fewer bird strikes. A 1980 study on British airfields found that long grass “did not eliminate but heavily reduced” bird populations (Brough, 1980). A 2004 study at Schiphol Airport in Amsterdam reached the same conclusions as the British study (Barenbrug Corporation, 2016) and a more recent, 2013 study at Schiphol reinforced those results (Van Der Meide & Pieterse, 2013). The general interpretation of these mixed findings is that some birds prefer short grass to better spot predators while other birds prefer longer grass due to the higher concentration of sustenance (rodents and insects).

Recent breakthroughs in the incorporation of an endophytic fungus into grass strains makes these areas inhospitable to rodents and insects thus tipping the scales towards long grass policies at airports. Endophytes bond to the grass structure at all levels including the seed head, stem, and plant base (Barenbrug Corporation, 2016). After bonding, the endophytic grass produces a unique Alkaloid which repels insects to encourage relocation of the bird food-chain (Miller, 2015). Other, grass-consuming birds such as Canadian Geese, also reject endophytic grass to such a degree that they will exhibit “learned avoidance behavior” for large areas surrounding an encountered endophyte patch of grass (Pennel & Rolston, 2002). Figure 1 visually represents the endophytic bonding with grass, production of Alkaloids, and relocation of the food-chain.

Figure 1

Endophytic Grass Reduction on Wildlife Strikes



Note: Figure created by team member Paul Knudsen.

Stormwater Treatment

Pollutants can come from many sources including aircraft deicing fluids (ADF), aircraft anti-icing fluids (AAF), pavement deicing/anti-icing products (PAP), and even common materials such as roofs, tires, and brake pads. Deicing of aircraft uses glycol-based solutions to remove ice build-up on aircraft, the chemicals in these solutions cause high biochemical oxygen demand (BOD) and aquatic toxicity (Shi et al., 2017). Quantities of deicing solution used vary based on weather and size of aircraft, requiring as little as 40 L/plane to 15,000 L/plane for large aircraft in bad weather (Sulej et al., 2012).

Literature shows that pollutants can be diluted and treated through on-site biological and physical treatments such as anaerobic fluidized bed reactors, passive facultative treatment systems, aerated gravel beds, membrane filtration, and evaporation (Shi et al., 2017). Aerobic and anaerobic solutions use aeration to produce microorganisms that biodegrade the chemicals, producing harmless end-products, these means can be expensive and/or produce residual biomass (sludge) that must be further treated before disposal (Switzenbaum et al., 2001). Additionally, previous studies show that glycols are degradable in soil (Bausmith and Neufeld, 1999). Bausmith and Neufeld (1999) found ADF to biodegrade when various concentrations of Propylene glycol (PG) were introduced to the soil. Some airports pump their collected wastewater to off-site publicly owned treatment works (POTW) or private recycling facilities, however, these solutions are typically more expensive.

Topographical Filtration

Understanding how water flows greatly impacts the amount of storm and wastewater that can be filtered and collected through environmental means. A case study done on the Dallas Executive Airport analyzes slope, soil quality, hydrology, and land cover to suggest the best management practice for the airport to manage their stormwater (Khoshkar, 2018). The study suggests the Dallas Executive Airport incorporate biofiltration swales to filter runoff using various plants and gravel beds as it leads the excess water to containment basins for further treatment. Biofiltration swale design is broken down by the California Department of Transportation (2012) giving formulas to determine the specifications for the swale that the airport needs, including formulas for water quality flow, water quantity flow, and hydraulic residence time for optimized filtration.

It is important to note that the Title 14 Code of Federal Regulations (CFR) Part 139.307 regulates the slope of the topography around the runways and taxiways (Certification of Airports, 2004) requiring no more than a slope of 2:1 or 27-degree slope. Additional regulations are outlined in Advisory Circular 150/5320-5D Airport Drainage Design (FAA, 2013).

Regulation

Several regulations regulate and guide the management of stormwater at the airport. From the environmental perspective, the Federal Water Pollution Control Act (FWPCA), also known as the Clean Water Act (CWA), requires that an airport must acquire a National Pollutant Discharge Elimination System (NPDES) permit to directly discharge processed wastewater and certain types of stormwaters into the Waters of the United States. (National Academies of Science, Engineering, and Medicine, 2016).

From the operational perspective, Title 14 of Code of Federal Regulation requires each airport to prevent water accumulation within the runway safety areas using gradings or storm sewers. In the case of water accumulation on the movement area or ramp, the airport must collect and report such information in a timely manner to airport users (Certification of Airports, 2013).

The Federal Aviation Administration publishes series Advisory Circulars providing guidance for airport administration and operation, of which AC 150/5320-15A provides guidelines for developing airport Storm Water Pollution Prevention Plan (SWPPP) to reduce pollutants in storm water runoff as far as possible (FAA, 2008).

ACRP Existing Efforts

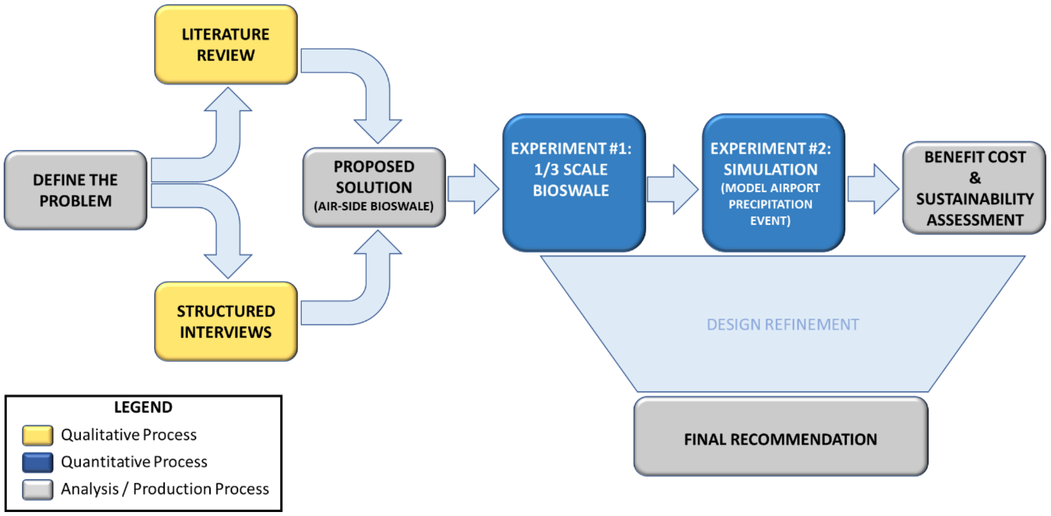
ACRP Report 174 provides step-by-step instructions on how to develop a sustainable Green Stormwater Infrastructure (GSI) at an airport, including detailed information required to be considered, assessment matrixes, and possible solutions considering local environmental and geographical characteristics. Bioswales are vegetated channels providing treatment and retention for stormwater. They are especially suitable in long-distance linear format landforms. (National Academies of Sciences, Engineering, and Medicine [NASEM], 2017b). A holistic review of existing applications of GSIs is also provided as examples to prove the effectiveness and implementation of GSI designs (NASEM, 2017a). ACRP Report 99 contains complete information and guidelines, from regulation level to practical implementation level, for treating airport stormwater containing deicers. It suggests that the economy of scale theory also applies to reduce the treatment and storage costs (NASEM, 2013).

Problem Solving Approach

This study employed a mixed-methods design, which encompassed qualitative and quantitative components. The qualitative segment entailed a systematic literature review and structured interviews conducted with industry experts. The quantitative steps comprised two experiments, one utilizing a physical model of the bioswale concept and the other using a computer-simulated airport undergoing a high precipitation event. The design team analyzed the results of each of these processes to develop the design concept, validate its merits, and refine the final recommendation. **Figure 2** provides a visualization of this problem-solving approach.

Figure 2

Mixed-Method Problem Solving Approach



Note: Figure created by team member Paul Knudsen.

Problem Formulation and Questions

An initial literature review enabled the design team to codify a problem statement for Challenge D. Fundamentally, the problem addressed by this study is the environmental and financial consequences of stormwater storage and pollution at airports, which cause erosion, toxicity, safety hazards, and regulatory conflicts. To focus the subsequent literature review, design, and validation processes, the group settled on two fundamental questions:

1. How effective is biofiltration, landscaping, and greenspace management in mitigating the environmental damage caused by stormwater runoff at airports?
2. What are the most cost-effective strategies for airports to balance FAA guidance on the quick removal of stormwater with EPA regulations requiring extensive treatment?

Concept Formulation – Literature Review and Structured Interviews

To address these questions with a validated design solution, the group first embarked on a comprehensive literature review of hydrology and ecology, regulations, and greening approaches pertaining to stormwater and airports to include a variety of case studies. Additionally, the group reached out to industry experts in the airport, government, and commercial sectors to gather stormwater and environmental data, and to extract themes that could be applied to the design. These themes included wildlife management, biofiltration, plant selection, soil composition, and the qualities of absorption, infiltration, and filtration.

Proposed Solution

The combination of the literature review and structured interviews guided the study towards an airside bioswale design capable of storing and pre-treating large volumes of water to reduce or remove follow-on treatment costs. Incorporating wildlife-repelling endophytic grass and a structural overflow channel to prevent pooling, the design concept addressed the greatest concerns expressed by industry experts and literature. Firmly grounded in existing expertise and academic literature, the study next turned to validating its design through experimentation.

Experimentation

Validating the design involved two experiments - one simulated and one physical. The simulation modeled multiple precipitation events in a one-year period. It recorded the volume of water absorbed by the design and the length of time needed to be absorbed. The physical experiment then validated the capability of the bioswale design to store and treat this volume of stormwater. Employing a one third scale model, the study recorded holding capacity, drainage time, and treatment efficacy for two common airport pollutants: zinc and propylene glycol. Results indicated sufficient holding capacity and sufficient efficacy to preclude follow-on treatment.

Benefit Cost, Sustainability, and Refined Design

The study concluded by refining the design and incorporating results into the benefit-cost and sustainability analysis. Minimal design refinements focused on adjusting the dimensions of the proposed bioswale to increase the margin of error for high precipitation holding capacity. The benefit-cost analysis analyzed options for both retrofitting an existing airport or executing a new-build/expansion; both options produced positive ratios. Finally, the practical experience gained from experimentation and interviews aided the sustainability analysis which generated overwhelmingly positive outcomes for implementing the design.

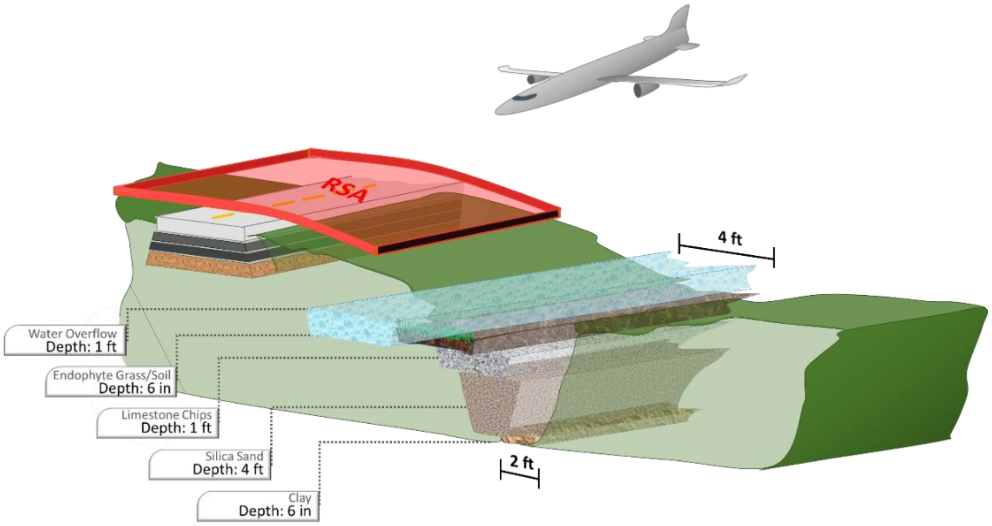
Technical Description

Technical Description Overview

The design created can be seen in Figure 3 which hypothesizes the implementation of bioswales at airports to direct water toward detention ponds or drainage points. The design filters and removes pollutants through three methods, phytoremediation, biodegradation, and general filtration. The design is ideally located outside of the runway safety area (RSA) with a 3% grade or a 0.12 slope leading to a slight drop-off into the bioswale, which would be four feet wide and six feet deep with walls angled inwards resulting in a two-foot width at the base.

Figure 3

Cross-Section View of Airside Bioswale Design



Note: Stormwater grading angle in RSA exaggerated due to compressed scale of the figure. Figure created by team member Paul Knudsen.

The top layer is a foot of soil where biodegradation takes place. According to Bausmith and Neufeld (1999), a 10% deicer fluid-to-water mixture (14,032 mg of solution/kg of soil (14,032 pollutants per million)) takes 21 days to biodegrade the glycol to natural levels. Furthermore, after the initial application of glycol, the bacteria degrade the solution fast, bringing the length of time down from 21 days to 13 days upon reapplication, at a 10% glycol-water mixture. Soil biodegradation specifically targets the propylene glycol found in a majority of deicing fluids (Bausmith and Neufeld, 1999).

On the surface are plants that employ phytoremediation to remove pollutants from the stormwater runoff. Anderson and Coats (1997) conclude that soil with vegetation allows for nearly three times as much biodegradation as soil with no vegetation in it. The bottom three layers are for general filtration of the water, one foot of gravel, four feet of sand, and a final six inches of semi-impermeable hard clay which additionally serves as a semipermeable guide for any water that falls through the layers above. The gravel layer will be composed of limestone gravel. The sand layer will use silica sand. Finally, the clay base layer is intended to guide the stormwater to the water catchment area while filtering at a slower rate over time than the materials above it.

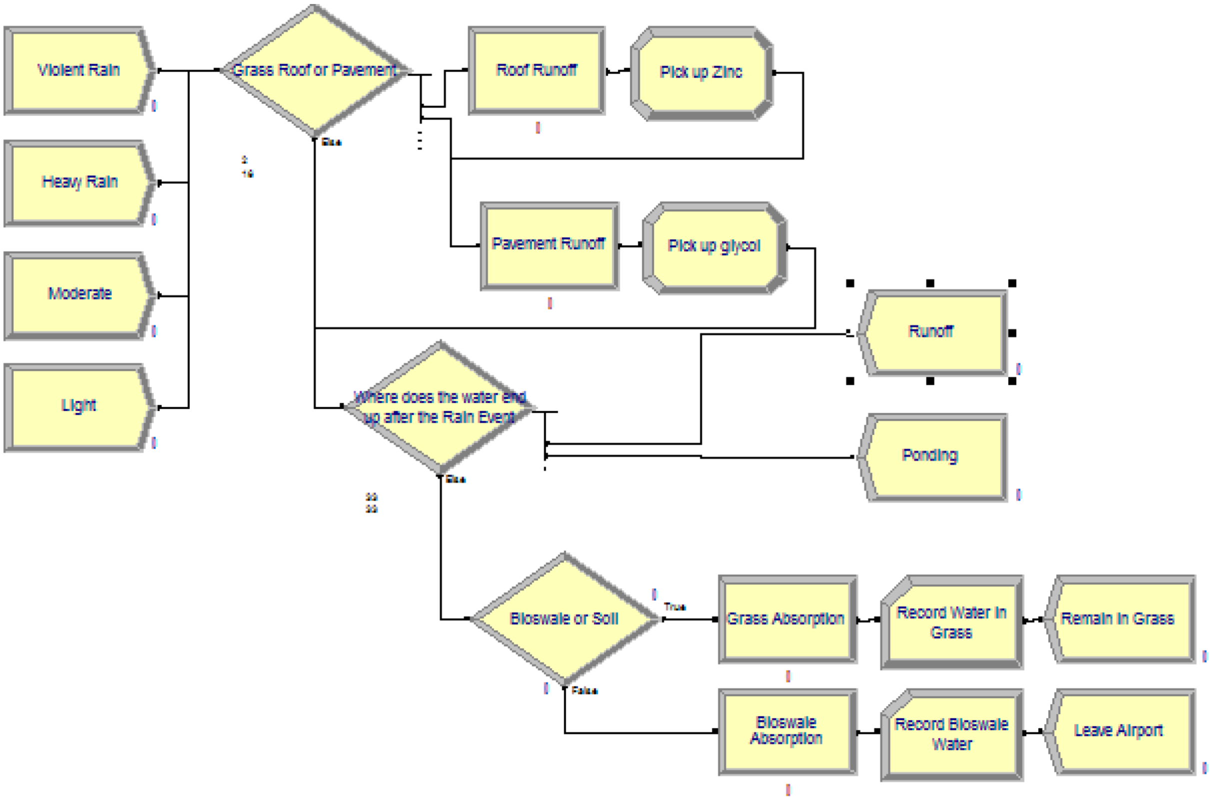
Arena® Model Technical Description

The group used Arena® Simulation to model the water cycle with pollutants at an airport to determine the difference in absorption rate when a small fraction of the grassy area is replaced with the new bioswale design. The purpose of this simulation is to find if the addition of sandy soil removes water from the airport more quickly than loamy clay soil. Sandy soil absorbs 2 inches of water every hour whereas clay and loam soil absorbs 0.25-0.5 inches of water per hour (Harmich Water and Wastewater Department, n.d.). This is significant because Midwestern soil is primarily made up of clay and loam on the surface and under the surface, it becomes loamier (Mancl, 2016). Increasing the amount of soil at the airport with gravel and sand below the surface increases the absorption rate for the airport.

Figure 4 is the final Arena® model for this project. The system is limited to airport property within the fence line in one year period. The model assumes that water enters the system during one of four rain events and is split between rooftops, pavement, and grass, based on the layout of Indianapolis International Airport. Rain picks up zinc from rooftops and deicer from the pavement. Most of the rain ends up on the grass, where it is absorbed into the soil or bioswale, ponds on top of the soil, or runs off into waterways. This model is limited to fully saturated soil, allowing contaminated water to absorb quickly into the ground. The model prioritizes the bioswale over grass absorption. When the precipitation volume is above the capacity of the bioswale, grass will absorb the excess.

Figure 4

Arena® Model of Airport Water Cycle



Arena® Results

The model was run with a normal bioswale and then the new design. The results indicate that more water was able to flow through the new design over time. Table 1 shows the results of both designs. The results show a shorter queue for the new design than a normal bioswale, which allowed more water to pass through. The absorption time for 100,000 cubic feet of water using loamy clay is 23 minutes (normal design). While only 4 minutes for the same amount to be absorbed in loamy sand (new design).

Table 1

Arena ® Results

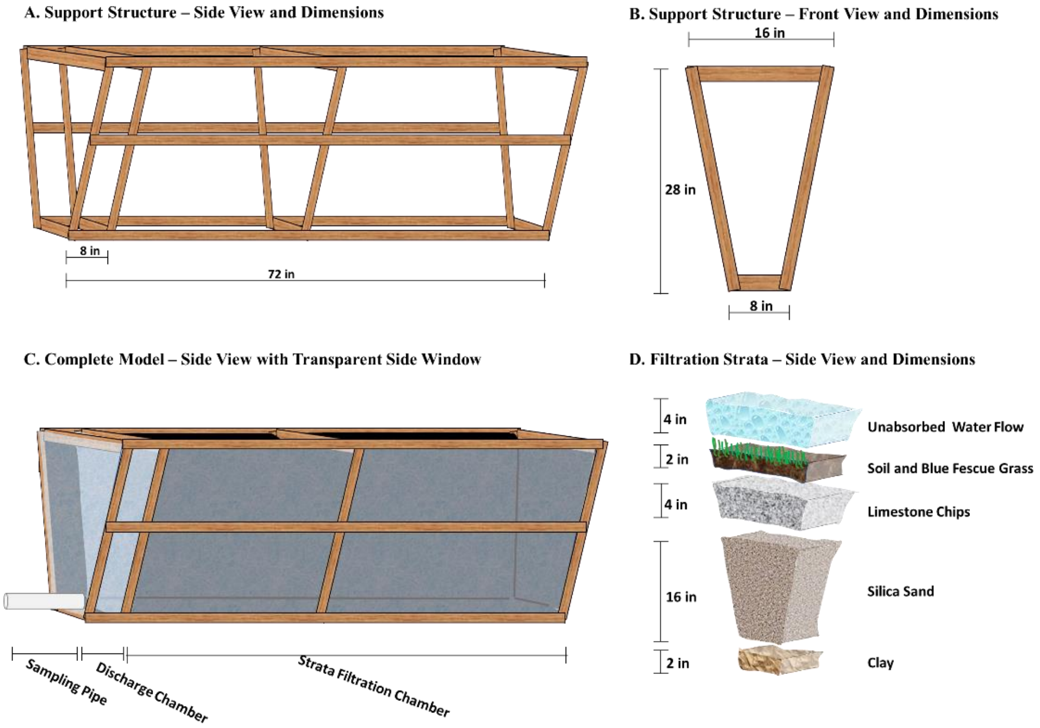
	Average Bioswale Queue Time (Minutes)	Water Into Grass (Cubic Feet/Year)	Water Into Bioswale (Cubic Feet/Year)
Normal Bioswale	18.83	9,300,000	6,800,000
New Bioswale	1.80	8,100,000	8,000,000

Physical Model Technical Description

The bioswale water treatment system incorporates a three-step process consisting of phytoremediation from blue fescue grass, biodegradation from soil, and filtration using a combination of limestone chips, silica sand, and clay. The experiments were conducted using a one-third scale model of the bioswale with dimensions and structure as shown in Figure 5. It was placed with a five-degree slope, which is shown in Figure 6. The purpose of the experiment was twofold: 1) estimate carrying capacity of the bioswale system as a volume of water and 2) estimate treatment capacity given a particular volume of water contaminated with zinc and glycol. These results were then extrapolated to estimate the carrying and treatment capacity of the larger bioswale proposed in the design.

Figure 5

Bioswale Physical Model Design



Note: One third scale model of the proposed bioswale incorporating transparent side view, discharge collection chamber, and sample collection spout. Figure created by team member Paul Knudsen.

Figure 6

Bioswale Physical Model in Experiment

Note: Picture was taken during the experiment by team member Taoran Yin.

In the first phase of the physical experiment, the sampling pipe valve was closed, and the system saturated while measuring the water volume required to reach carrying capacity. After saturation, the system was fully drained for 30 minutes, and the time required to drain 75% of the original water volume was recorded. In the second phase of the experiment, a volume of water contaminated with glycol and zinc was applied to the system, with samples taken before and after filtration.

Though zinc pollution is measured in mg/L, the effects of Propylene Glycol (PG) are measured by Biochemical Oxygen Demand (BOD), or the increased oxygen required for organisms to survive in a volume of PG-contaminated water. A key secondary observation during the experiment was visual monitoring of layer integrity (soil, limestone, sand, clay, etc.) to inform an estimate for system longevity.

This experiment contained limitations both in precision and accuracy. The experiment was designed to measure volume and treatment capability, with less precision applied to flowrate. The time readings for flowrate were influenced by the diameter of the 2-inch sampling pipe which was proportionally smaller than a real-world, pipe-to-bioswale ratio. The system was not designed to test different slope angles nor different materials thus future experiments could reveal more optimal angles and composition.

Though the bioswale was drained for 30 minutes prior to the zinc-glycol trial, the layers retained limited clean water which contributed dilution, rather than purely treatment, to our results. In a real stormwater event, rain will fall along the length of the bioswale and introduce greater dilution than that seen in the experiment; thus, the study maintains high validity for its results within the context of stormwater treatment.

Lab Results

As shown in Figure 7, Sample 1 is the unfiltered contaminated water that was poured over the bioswale, and Sample 2 is the water that came out of the bioswale. Sample 1 was created by mixing 0.3L of 90% propylene glycol deicer and 150mg of zinc powder with 15L of water. These amounts were calculated by calculating how much deicer could be on an impermeable surface and what percent of rainwater would pick it up during a rain event, and the maximum amount of zinc allowed in industrial water disposal by the EPA (10mg/1L).

Figure 7

Two Samples Collected from the Physical Model

Note: Picture was taken during the experiment by team member Taoran Yin.

The results of the physical model experiment were positive, indicating that absorption capacity is sufficient to manage a high precipitation event and treatment capacity can remove over 95% of zinc and glycol contamination. Though some of this treatment is attributable to dilution from clean water in the system, even a very conservative estimate of the bioswale's treatment capability indicates efficacy. The full list of measurements and results from this experiment are summarized in Table 2. These experimental results, combined with the Arena® simulation, literature review, and industry interviews, indicate that airside bioswales are highly effective at managing and treating stormwater at airports.

Table 2

Results of One-Third Scale Model Experiment

Measurement	Recording	Units	Notes
Temperature	49	°F	
Angle of Bioswale	5	Degrees	
Drainage Time	2:56	Minutes	Limited by 2-inch pipe flow-rate
Holding Capacity (To soil-grass line)	23.78	Gallons	This indicates the amount of water the bioswale can hold without pooling
Holding Capacity (To overflow line)	43.59	Gallons	This indicates the amount of water the bioswale can hold without flooding the runway
Zinc Concentration (Contaminated Sample)	2,150	Mg/Liter	
Zinc Concentration (Treated Sample)	0.715	Mg/L	
BOD (Contaminated Sample)	1,600	Mg/L	Glycol causes an increase in BOD which asphyxiates living organisms
BOD (Treated Sample)	17	Mg/L	Some of this treatment is attributed to dilution from water in the system rather than treatment
Layer integrity	N/A	N/A	Isolated penetration occurred where lower layers condensed and caused sagging.
Results	**Recording**	**Units**	**Notes**
Absorption Capacity (without pooling)	11.89	Gallons/foot	Full-size bioswale. Calculation: *(23.78 gallons ÷ 6 feet) × 3 = gallons/ft*
Zinc Treatment Capability	99.95	%	Some of this treatment capability is attributed to dilution from existing water in the system.
BOD (Glycol) Treatment Capability	99	%	

Industry Expert Interaction

The team interviewed eight industry experts from six airports, two agriculture research companies, and a civil engineering consultation firm. Industry experts helped the team focus on the areas where the industry currently struggles, common trials on the subject, and direction to resolving problems.

Interviews conducted earlier in the design process helped the team identify some of the more predominant problems and factors faced when dealing with stormwater on an airport. Industry experts highlighted regulatory standards, water pollutants, standing water, and wildlife mitigation as some of the points our study should focus on. Most of the industry experts interviewed emphasized the importance of knowing and conforming to the federal and state regulations for airport design, stormwater management, pollutant levels, and all other related fields.

Each airport expert interviewed was asked about their Stormwater Pollution Prevention Plan (SWPPP) and treatment facilities. Additionally, the team was invited to tour Indianapolis International Airport's stormwater management system and the $1.5 billion new expansion glycol treatment facility. Many of the experts the team interviewed noted the biochemical oxygen demand (BOD), which is also a vital parameter for glycol concentration in stormwater, is tested, along with other parameters, prior to the release of stormwater into natural waterways or the city's sewage system.

Industry experts emphasized the need for risk management when dealing with environmental factors such as grass and standing water to not attract wildlife. Two grass companies, Grasslanz and Barenburg, endorsed specific endophytic grass strains for air-side use as they do not provide a food source nor habitable environment for most avian wildlife (J. Caradus, personal communication, February 1, 2023) (M. Gould, personal communication, February 2, 2023). Interviews conducted later in the design process were able to give constructive feedback on the design the team created and helped identify and iron out kinks and flaws in the system.

Design Alternatives

Current approaches to stormwater management generally fall into one of three primary categories and new literature into permeable pavements has some limited application to airports. In each of the three main approaches and their associated case studies, the airports incorporate varying levels of the same best practices. Each airport layout incorporates runoff diversion to infiltration channels, swales, or wetlands; directs stormwater to reservoirs and holding basins; and minimizes impervious surfaces (Marsalek, 2009). Most airports do not incorporate bioswales and wetlands within the air-side due to concerns over wildlife strikes with aircraft. A summary of these primary approaches follows with case studies presented for each.

The first approach involves releasing untreated discharge into the local watershed, provided that the runoff consistently meets EPA thresholds. San Diego International Airport in California and Paine Field in Washington are both examples of airports that utilize this approach. The second approach involves treatment of stormwater either on-site or through local municipalities. San Francisco International Airport in California is an example of an airport that maintains its own stormwater treatment facility and regularly treats its runoff. The third approach is a hybrid model where tested runoff below EPA tolerances is discharged into the local watershed and runoff above EPA tolerances is treated on-site or through local municipalities. Indianapolis International Airport in Indiana is an example of this approach and utilizes large reservoirs to first collect stormwater and then route to either their discharge permit or municipal water treatment depending on sampling and EPA thresholds.

One innovative approach for stormwater management growing in popularity are permeable pavement systems (PPS). PPS spans a variety of forms such as concrete blocks, plastic grids, and pervious/porous cement. Existing literature investigating the filtration capacity of various PPS systems for heavy metals and hydrocarbons has yielded promising results however experimentation gaps exist in the areas of biodegradation rates, extreme temperatures, and nutrient removal (Scholz, 2007). In addition, a key limitation of PPS when applied to airports is that this surface is not suitable for heavy usage or frequent traffic, which restricts its application in any air-side operations (Imran, 2013).

There are multiple approaches to managing stormwater runoff in airport operations, with varying levels of success depending on factors such as local conditions and available resources. Permeable pavement systems offer a sustainable drainage system alternative, but their limited use in air-side operations and experimental gaps indicate that the combination of endophyte grasses with bioswales may be a more promising innovation for airside stormwater management.

Safety Risk Assessment

Advisory Circular 150/5200-37A outlines the requirements for a safety management system at an airport. This ensures the “safe operation of aircraft through effective management of safety risk” (FAA, 2023). FAA Order 5200.11A walks through the five steps for safety and risk assessment: describe the facility or system, identify hazards, analyze risks, assess risks, and mitigate the risks (FAA, 2021). This study presents a bioswale utilizing different materials to filter and treat stormwater before reaching the treatment facilities or points of exit. The model presents two main potential risks to safety: the attraction of wildlife and the failure of the model.

Plant selection is important at an airport as it can provide a habitat or food source for animals and birds of all types. Further, the pooling of water at the airport can attract wildlife either providing habitat to ground animals and food to birds. The system may fail if flooding due to abnormally heavy rainfall were to occur, the model may prove to leave excess water standing above ground. Blockages in or erosion of the subterraneous layers may lead to the system failing to treat stormwater or restrict water flow and leave water pooling above ground. Finally, the concentration of stormwater and pollutants in a focused area may lead to the death of the vegetation in the area.

The study uses a risk assessment matrix, pictured in Table 3, to assess the hazards based on the severity and frequency of failure. The risk assessment and mitigation methods can be viewed in Table 4. The associated costs for mitigation actions are considered in the next section.

Table 3

Risk Assessment Matrix and Key

Low Risk	1-4
Medium Risk	5-12
High Risk	13-25

	Minimal (1)	**Minor** (2)	**Major** (3)	**Hazardous** (4)	**Catastrophic** (5)
Frequent (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Moderate (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5

Table 4

Risk Assessment and Mitigation for the Proposed System

Hazard	Severity	Frequency	Risk	Mitigation	Residual Risk
Wildlife Strike	5	4	20	Endophyte grass produces a fungus which repels birds and animals, this report utilizes this grass type	10
Flooding or pooling	4	4	16	The system builds in an additional foot of sloped flow space in the event of a blockage which allows water to flow above ground to the retention pond	8
Blockage	3	4	12	Regular inspections will be suggested to identify maintenance needs in the system	6
Erosion	3	3	9	Layering a liner between the layers of material to prevent mixture and erosion of the materials.	4
Plant Death	1	2	2	Monitor plant health and replant when needed	2

Projected Impacts of Design

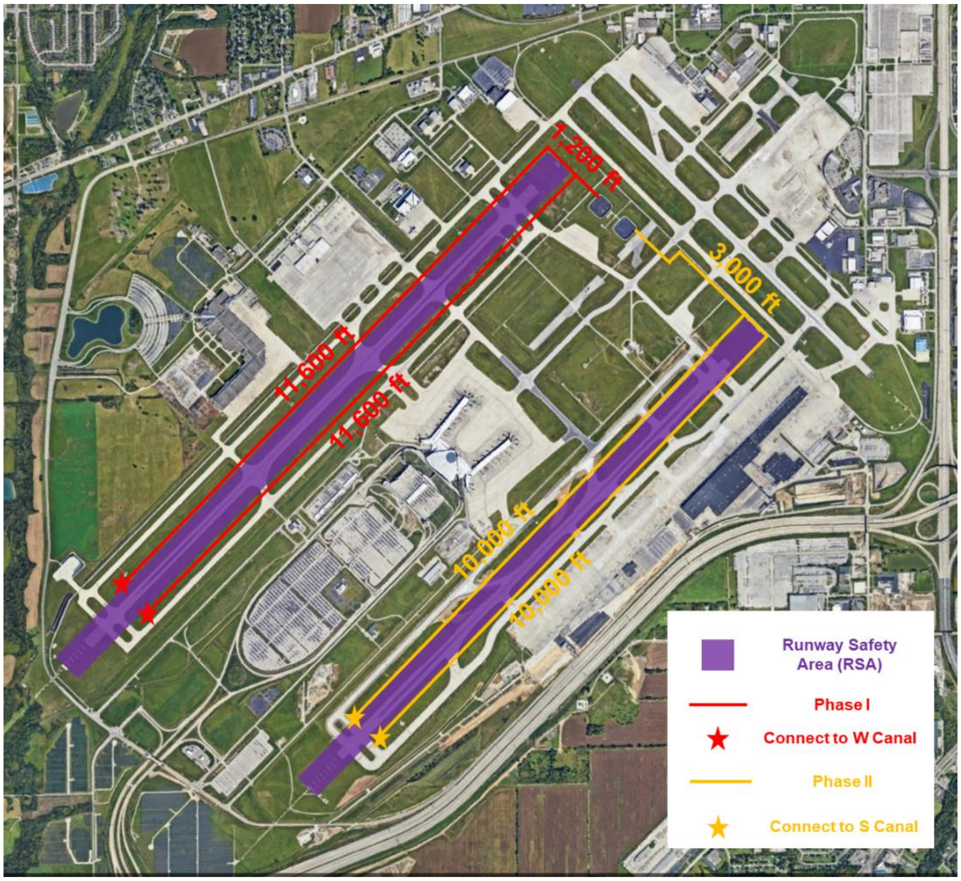
Benefit-Cost Analysis

Benefit-Cost Analysis (BCA) is a systematic approach to identifying, quantifying, and comparing projected benefits and costs of implementing new designs. It is a common tool used in public infrastructure projects to demonstrate the applicability of a new design (U.S. Department of Transportation, 2023). A 10-year benefit-cost analysis has been conducted to further understand the financial impacts of the bioswales at the airport.

This study uses Indianapolis International Airport (IND) as an example to demonstrate the benefit/cost incurred by implementing the bioswale system at medium hub airports. However, the conclusion is generally applicable to all medium hub airports in the United States. Figure 8 demonstrates optimal locations for bioswales and the construction schedules in two years. All bioswales are located outside the Runway Safety Area (RSA) to provide safety for aircraft in cases of undershooting, overrun, or veering off the runway (FAA, 2022). The crosswind runway is not taken into consideration due to the fact of its low utilization and its general-aviation focus functionality.

Figure 8

Optimal Locations for Bioswales and the Construction Schedule at IND



Note: Map Data: Google (2018).

Costs

Costs are distributed among three major stages: research and development (R&D),

construction, and operation & maintenance. The first stage consists of all necessary R&D expenses. In this stage, students spend considerable time and resources to fully understand the current problems, analyze the problems, interview experts, and propose solutions. The total costs for R&D stage are $17,915. Table 5 shows the breakdown details of the costs.

Table 5

First Stage: Research & Development Costs

Item	Rate	Multiplier	Qty.	Subtotal	Notes
Graduate Student	$22/hr	4 students	180	$15,840	15 hours/week*4 students*12 weeks
Faculty Advisor	$50/hr	1 advisor	30	$1,500	2.5 hours/week*1 advisor*12 weeks
Airport Expert	$35/hr	1 expert	5	$175	2.5 hours/test*1 expert*2 tests
Physical Model	$400/each	1 model	1	$400	Based on actual spent for building the model
Subtotal				$17,915	

Note: The Graduate Student Rate is based on the 2022 Purdue University Student stipend. A physical model has been made for test and experiment purposes. The testing and experiment were conducted at Purdue University Airport (LAF), requesting escort from airport professionals.

Costs related to construction are categorized under the second stage, which contains a two-phase construction plan within a two-year time frame. To minimize the impact of construction on the daily operation and reduce the airport's budgeting pressures, the construction is divided into two phases in a two-year timeframe. This allows at least one runway to achieve maximum operational efficiency while the construction partially affects another runway.

The first phase of the construction aims to implement the bioswales at the full length of the longest primary runway at the airport, along with the connection canals leading to the airport’s pump/watershed leading towards the treatment facility. The second phase aims to implement the bioswales at the other primary runways at the airport.

The unit price of materials per foot-long bioswale is calculated in Table 6. The total cost of the two-phase construction based on IND is $4,384,328. Table 7 shows the breakdown details of the costs for this stage.

Table 6

Bioswales Material Unit Costs (per foot long bioswale)

Item	Rate	Unit Cost	Notes
Endophyte Blue Fescue	$26/lb	$0.91/foot long bioswale	$26*0.01 lbs/sqft*3.5 ft
Soil	$0.75/ft^3	$1.35/foot long bioswale	$0.75/ft^3*1.8 ft^3/ft long
Silica Gravel	$1.85/ ft^3	$5.55/foot long bioswale	$1.85/ ft^3*3 ft^3/ft long
Silica Sand	$0.75/ft^3	$7.5/foot long bioswale	$0.75/ft^3*10 ft^3/ft long
Clay	$0.4/ft^3	$0.4/foot long bioswale	$0.4/ft^3*1 ft^3/ft long
Subtotal		$15.71/foot long bioswale	

Note: All rates are based on 2022 national average price.

Table 7

Second Stage: Construction Costs

Stage	Item	Rate	Multiplier	Qty.	Subtotal	Notes
Phase I	Design[1]	$35.7/hr	10 engineers	240	$85,680	40 hours/week*6 weeks
	Labor[2]	$18.2/hr	50 workers	480	$436,800	40 hours/week*12 weeks
	Material[3]	$15.71/foot bioswale	1 foot	24,400[4]	$383,324	$15.71/foot long bioswale*24,400 ft
	Equipment[5]	$2000/day	2 teams	168	$336,000	12 weeks*7 days/week*2 teams
	Operation Interruption[6]	$10,202/day	1 day	84	$856,968	12 weeks*7 days/week
	Contingency Budget				$104,939	Based on 5% of the total projection
	Subtotal				$2,203,711	
Phase II	Design	$35.7/hr	10 engineers	240	$85,680	40 hours/week*6 weeks
	Labor	$18.2/hr	50 workers	480	$436,800	40 hours/week*12 weeks
	Material	$15.71/foot bioswale	1 foot	23,000[4]	$361,330	$15.71/foot long bioswale*24,400 ft
	Equipment	$2000/day	2 teams	168	$336,000	12 weeks*7 days/week*2 teams
	Operation Interruption	$10,202/day	1 day	84	$856,968	12 weeks*7 days/week
	Contingency Budget				$103,839	Based on 5% of the total projection
	Subtotal				$2,180,617	
Total					$4,384,328	

Note: 1) Based on the median of 2021 Civil Engineers Wages Published by U.S. Bureau of Labor Statistics. 2) Based on the median of 2021 Construction Laborers Wages Published by U.S. Bureau of Labor Statistics. 3)Based on calculations in Table 6.4) Based on calculations in Figure 8. 5) Based on a 25 people field construction team standard equipment daily rental rate. 6) Based on the assumption that 12% operation will be affected resulting in a 12% airfield revenue loss due to construction. The number is based on 2021 IND Annual Financial Statement.

The costs of the third stage include all necessary spent associated with the operation & maintenance of the bioswales. A ten-year costs projection has been made. The total ten-year operation & maintenance cost is $398,287. Table 8 shows the breakdown of the 10-year cost projection. Table 9 shows the total costs in the first 10-year period.

Table 8

Third Stage: Ten-year Operation & Maintenance Costs Projection

Year	Item	Rate	Multiplier	Qty.	Subtotal	Notes
1	N/A	N/A	N/A	N/A	$0	Construction in Progress. See table X for details
	Subtotal				$0	
2	Labor[7]	$15/hr	2 workers	60	$1,800	12 times/year*1 hour + 4 times/year*12 hours
	Equipment[8]	$40/hr	1 machine	48	$1,920	4 times/year*12 hours
	Material[9]	$15.71/foot bioswale	1 foot	1220	$19,166	5% annual deterioration rate*24,400ft
	Contingency Budget				$1,145	Based on 5% of the total projection
	Subtotal				$23,031	
3-10	Labor	$15/hr	2 workers	120	$3,600	12 times/year*2 hour + 4 times/year*24 hours
	Equipment	$40/hr	1 machine	96	$3,840	4 times/year*24 hours
	Material	$15.71/foot bioswale	1 foot	2370	$37,233	5% annual deterioration rate*47,400ft
	Contingency Budget				$2,234	Based on 5% of the total projection
	Subtotal (Annually)				$46,907	
	Subtotal (8 years)				$375,256	$46,907*8 years
Total					$398,287	

Notes: 7) Including monthly inspection and quarterly maintenance. The number is based on the median of airport maintenance labor salary. 8) Based on 25HP mower average hourly rental rate. 9) Based on 5% annual deterioration rate.

Table 9

Total Costs

Stage	Cost
First Stage: Research & Development	$17,915
Second Stage: Construction	$4,384,328
Third Stage: Ten-year Operation & Maintenance	$398,287
Total	$4,800,530

Benefits

Implementing bioswales at the airport produces significant tangible benefits to the airport operator. Medium hub airports report an average cost of $2 million to distillate or dispose of aircraft deicing fluid annually. At airports with existing glycol treatment facilities, a large portion of the deicing fluid is caught near the deicing pad and sent to the airport's glycol treatment facilities. As stated in the technical description section, the bioswale is able to decrease the glycol concentration by 30%. Therefore, the bioswales system can save 30% of glycol treatment costs at the airport.

Moreover, as the calculation in the costs section suggests, the 10-year cost of constructing and operating bioswales at a two-runway medium hub airport is around $4.8 million. Wessler Engineering (n.d.) describes that the new IND stormwater treatment facility, including two one-million-gallon glycol treatment pounds, cost $130 million. Considering the pre-treatment capability of the bioswale, the glycol treatment pound could be designed with up to 30% less capacity due to the 30% pretreatment performance by bioswales, thus saving a considerable amount of money. This suggested that by keeping the bioswales' function in mind during the expansion or building new glycol treatment facilities, the airport can have more potential savings. After the calculation, the total benefit of using bioswales at the airport with existing glycol treatment facilities is $5.1 million in a 10-year timeframe. While at the airport without an existing treatment facility, the benefit is $44.1 million in a 10-year timeframe. Table 10 details the benefits of implementing bioswales at the airport with existing glycol treatment facilities. Table 11 shows the additional benefit of considering bioswales solutions when expanding/building new glycol treatment facilities.

Table 10

Benefit Resulting from the Implementation of Bioswales at the Airport with Existing Glycol Treatment Facilities.

Item	**Rate**	**Multiplier**	**Subtotal**	**Notes**
Saving of Sewer Charges Related to Glycol Processing	$0.6 million/year	8.5 years[10]	$5.1 million	$2.0million/year *30%
Total Ten-year Benefit (Airports with existing facilities)			$5.1 million	

Notes: 10) Bioswales constructed in Phase I comes into service in Year 2. Bioswales constructed in Phase II comes into service in Year 3.

Table 11

Benefit Resulting from considering bioswales solutions when expanding/building new glycol treatment facilities.

Item	Rate	Multiplier	Subtotal	Notes
Saving of Sewer Charges Related to Glycol Processing	$0.6 million/year	8.5 years	$5.1 million	$2.0million/year *30%
Saving of Building Other Glycol Treatment Facilities	$39 million[11]	1 time	$39 million	
Total Ten-Year Benefit (Airports considering expansion of stormwater treatment facilities)			$44.1 million	

Notes: 11) Based on 30% less capacity of the treatment pound.

Benefit/Cost Ratio

For airports with existing glycol treatment facilities, bioswales systems can save the time of treating glycol by 30% annually. The Benefit/Cost ratio is 1.06. Table 12 shows details. For airports considering expanding to building new glycol treatment facilities, by considering bioswales at the design phase and reducing the treatment pounds accordingly, additional benefits can be achieved. The Benefit/Cost ratio is 9.19. Table 13 shows details.

Table 12

Benefit/Cost Ratio for the Airport with Existing Glycol Treatment Facilities.

10-year total benefit	$5,100,000
10-year total cost	$4,800,530
Benefit/cost ratio	1.0624

Table 13

Benefit/Cost Ratio for Airport Considering Bioswales Solutions When Expanding/Building New Glycol Treatment Facilities.

10-year total benefit	$44,100,000
10-year total cost	$4,800,530
Benefit/cost ratio	9.1865

Sustainability Assessment

The definition of sustainability varies across different industries. The Economic vitality, Operational efficiency, Natural resources, and Social responsibility model (EONS) incorporates operational efficiency into John Elkington's "triple bottom line" accounting framework and has been adopted as the definition of sustainability in the airport industry (Airport Council International, 2017). International Civil Aviation Organization Resolution A40-18 addressed the need to practice environmentally friendly approaches in the aviation industry in the face of the speeding climate change challenge (ICAO, 2019). Implementing the bioswale system at the airport has great benefits from a sustainable development point of view. Table 14 uses the EONS model to show the detail of sustainable impacts of bioswale at the airport.

Table 14

Sustainability Assessment using EONS Model for Bioswale at the airport.

EONS Section	Sustainable Impacts
Economic Vitality $	**(+)** Reduced polluted stormwater treatment costs
	(+) Reduced stormwater treatment facility development costs
	(+) Increased airport reputation, resulting in more business opportunities
Operational Efficiency	**(+)** Increased operational efficiency due to the reduced ponding probability
	(+) Increased operational efficiency due to the reduced stormwater treatment facility workload
	(+) Decreased operational/maintenance workload compared to traditional grass
	(-) Temporarily decrease of operational efficiency during the construction
Natural Resources Conservation	**(+)** Reduced chemical usage during the stormwater treatment process
	(+) Improved water quality due to reduced pollutant discharge to the local watershed
	(+) Power savings due to gravity-fed water management system and reduced water treatment
	(-) Potential decrease of biodiversity in the vicinity area of the airport due to endophyte grass
Social Responsibility	**(+)** Reduce city's water treatment workload. Serves as reserve capacity for major precipitation events
	(+) Better airport reputation and public relationship
	(+) Reduced waterborne diseases vectors
	(+) New educational opportunities for the community

The United Nations (n.d) defined 17 Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development. The agenda is an urgent call for global attention and collaboration in the seventeen most challenging areas. The International Civil Aviation Organization recognized the challenge and suggested that aviation is closely linked to 15 out of the 17 SDGs (ICAO n.d.). The bioswale system at the airport directly contributes to 6 SDGs. Table 15 shows the link between the design and SDGs.

Table 15

Relation with Sustainable Development Goals

SDG	Definition	Effect
3 GOOD HEALTH AND WELL-BEING	"Ensure healthy lives and promote well-being for all at all ages" (UN, n.d.)	Minimizing pollutant concentrations in soil and drinkable water
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" (UN, n.d.)	Proposing innovations for further plant and biodegradation studies
11 SUSTAINABLE CITIES AND COMMUNITIES	"Make cities and human settlements inclusive, safe, resilient and sustainable" (UN, n.d.)	Reducing city's sewage system's workload
13 CLIMATE ACTION	"Take urgent action to combat climate change and its impacts" (UN, n.d.)	Reducing carbon emissions associated with water treatment and power production
14 LIFE BELOW WATER	"Conserve and sustainably use the oceans, seas and marine resources for sustainable development" (UN, n.d.)	Reducing pollutant concentrations in groundwater and ocean
15 LIFE ON LAND	"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reserve land degradation and halt biodiversity loss" (UN, n.d.)	Reducing pollutant concentrations in soil

Conclusion

Pollutants in stormwater runoff from airport impervious surfaces can be toxic to local ecosystems in high concentrations, therefore, pretreating the water using natural methods can reduce the harm airport stormwater has on the environment and reduce treatment costs to the airport. This design promotes sustainability by reducing pollutant concentration in water using a low-maintenance design allowing the airport to invest time and money in other aspects of the airport and focus on more sustainable practices. By reducing the annual cost of treating water and maintaining the lawn, airports can spend more money on improving their infrastructure or executing other sustainable projects. Communities benefit from this design because their water source would be less likely to be contaminated by airport-related pollutants. This design aligns with international aviation goals by addressing six of the seventeen United Nations Sustainable Development Goals by reducing pollutants in the soil and water, lowering carbon emissions, and providing educational opportunities for further experimentation.

Furthermore, implementation of the proposed method has the potential for paying dividends as described by the cost-benefit analysis. When retrofitting a current airport bioswale or drainage ditch the cost-benefit analysis is 1.06 with the highest monetary benefit coming from a reduction in water treatment costs for medium hub airports. When taken into consideration during a stormwater retention capacity expansion, the cost-benefit analysis ranges near 9.18 depending on the cost estimate for the construction of a new retention pond with the same or similar capacity the bioswale offers.

Appendix A: Contact Information

Advisor

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Team Members

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Appendix B: Description of the University

Purdue University Description

“Purdue University is a vast laboratory for discovery. The university is known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It’s a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue’s role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. All 50 states and 130 countries are represented” (Purdue Polytechnic Institute, n.d., para. 1-2).

School of Aviation & Transportation Technology Description

“Purdue University’s School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue’s Aviation and Transportation Technology undergraduate majors are world-class educational programs. The mission of the School of Aviation and Transportation Technology is to prepare the next generation of leaders and change agents for the transportation sector. The School of Aviation and Transportation Technology will be the recognized global leader in aviation technology education through excellence in faculty, students, curricula, laboratories, and mutually beneficial partnerships” (Purdue Polytechnic Institute, n.d., para. 3).

Appendix C: List of Industry Experts

Industry Experts	**Title**	**Company**	**Contact Information**
Matthew Grenoble	Airport Superintendent	Sheboygan County Airport Department	Matthew.grenoble@sheboygancounty.com
Adam Baxmeyer	Airport Director	Purdue University	abaxmeye@purdue.edu
Todd Cavender	Director, Environment & Sustainability	Indianapolis Airport Authority	tcavender@ind.com
Jarod Klaas	Sr. Director Planning & Development	Indianapolis Airport Authority	jklaas@ind.com
John Lengel	Vice President of Environmental Stewardship and Resilience	RS&H Inc.	john.lengel@rsandh.com
John Caradus	Chief Executive Officer	Grasslanz	john.caradus@grasslanz.com
Katie Altobello-Czescik	Environmental Specialist	San Diego County Regional Airport Authority	katiea@san.org
Andrew Rardin	Airport Environmental and Wildlife Manager	Paine Field Airport	andrew.rardin@snoco.org
Micah Gould	Market Development Manager I Professional Division	Barenburg USA	mgould@barusa.com
Roxanne Taylor	Environmental Specialist	Lee County Port Authority	rltaylor@flylcpa.com

Appendix E: Evaluation of the 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?

The ACRP University Design Competition provided very meaningful learning experience for the design team, it provided insight to an essential portion of airport environmental planning and operations. The competition inspired the team to explore methods previously employed at airports through interviews with industry experts and previous studies published, additionally, prompting the team to problem solve for further sustainable advancements. The team has learned what benefits the airport can bring to the community and the importance of protecting the community and local environment from potentially harmful and hazardous implications of aviation.

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

The team encountered challenges in refining the focus of the study and creating a digital model for simulated testing of the design suggested. The team was able to refine the focus through an initial review of previous literature and what issues there are in the field. Previous literature lead the team to further explore pollutants in stormwater runoff and the hazards presented and the cost of treating the water. The study at this point turned from a competition with potential prizes to seeking to better understand and prevent ground water pollution at airports. The group overcame the design modeling challenge by conducting thorough analysis in, and learning, coding languages and modeling programs. Ultimately, the group decided to use Arena®, a simulation software, to simulate a rain event on an airport with some given dimensions to figure out how much stormwater will flow through the bioswale and how much filtration would take place. Additionally, the team conducted a physical experiment.

During the experiment, the team ran into a major structural issue because they did not calculate how much the model would weigh at its heaviest correctly. This led to the supports collapsing after the maximum amount of water was poured into the bioswale, as seen in Figure 9.

Figure 9

Collapse of the Physical Model

The model ended up weighing over half a ton at its heaviest, which the group did not anticipate. This was unanticipated because the team underestimated the weight of sand (600lbs), gravel (200lbs), sod (unknown), and water (at most 260). After the collapse, the group employed their masterful problem-solving skills and used all four of their car jacks to prop up the model so the experiment could continue. When the contaminated water was poured into the model, the team ran into a second issue, although less dramatic, where the water drained to the sides of the bioswale and ran along the weed cloth instead of flowing through all the layers. To force the water through the layers, the group created a hole in the bottom of the bioswale and poured the water in such a way that it had to flow through all the layers and be properly filtered. The group was able to see that all their hard work was not lost because although they did not know the pollutant concentrations yet, the color difference between the initial sample and final sample clearly showed that a significant amount of zinc was filtered.

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

The team conducted a preliminary literature review and educated themselves on the problem at hand. The team then began to focus the study on a design to guide and pretreat stormwater to employ environmental means of removing pollutants from stormwater runoff. Additional guidance was received through consulting industry representatives. We then make a 1/3 physical model to test our hypothesis. It is worthy to note that the system was not designed to test different slope angles nor different materials thus future experiments could reveal more optimal angles and composition. The fact that the bioswale became contaminated after a single trial was a further limitation as cost and time made it unfeasible to run multiple trials with fresh material. Lastly, though the bioswale was drained for 30 minutes prior to the zinc-glycol trial, the layers retained limited clean water which contributed dilution, rather than purely treatment, to our results. In a real stormwater event, rain will fall along the length of the bioswale and introduce greater dilution than that seen in the experiment; thus, the study maintains high validity for its results within the context of stormwater treatment.

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

The team interviewed many industry and subject matter experts for guidance and examples of current industry standards. The information and resources obtained through the industry interactions proved to be extremely meaningful and useful in refining the team's focus and directing the team toward the design presented and the simulation of that design. Early interactions guided the team toward the design created while later interactions helped refine and correct missteps in the design. The industry interaction with the Purdue University Airport led to the ability to conduct experiments on our physical model at the airport with Type I aircraft deicing fluid. The interactions were extremely meaningful and useful to the development of the teams design.

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 first developed a better understanding of the environmental impacts the airport has on the local community and global environment and how to study and mitigate those impacts. The study provided the team with the skills to enter the workforce, researching and theorizing innovative means of further airport development for a more sustainable industry. The project taught practical skills of reviewing literature, locating, and interviewing experts, and creating and modeling hypothesized designs.

Faculty Advisor Questions:

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

The students gain more value when they can apply newly learned design skills and sustainability skills to a project that is based on real airport needs. While they learn theoretical information, the learning that occurs through team interaction and expert interactions cannot be easily replaced. Many of these students make contacts that will be a resource throughout their careers.

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

This competition package is one of the choices for a project in a graduate level course in Aviation and Aerospace Sustainability. The course level and context are appropriate and a popular choice of project types.

3. What challenges did the students face and overcome?

The team formed quickly and began working with each other and contacting airport experts. They learned a great deal about airport drainage and water treatment, animal habitats, and vegetation during this project. They also joined together to build a scale model of their improved drainage system so that they could see and touch the system, and notice how it would really work.

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

I definitely will continue to use this competition as an educational vehicle. The knowledge the team gains in 12 weeks is irreplaceable through readings and shorter projects.

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

I would add sustainability as an aspect of the project that should be addressed because this issue is challenging and becoming more and more requested by communities.

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