ACRP Challenge: Environmental Interactions Stormwater Management

January 2022- May 2022

Pennsylvania State University

University Park, PA

Facility Advisor:

- **Meg Handley**

Team Members:

- **Joseph Pecaitis (Undergraduate)**
- **Aatika Sinha (Graduate)**
- **John Boulos (Graduate)**
- **Arianna Parisi (Undergraduate)**

Executive Summary

Throughout this proposal, a team of 4 members enrolled in the Engineering Leadership program at Pennsylvania State University have taken up the ACRP challenge presented to them within this program. The team chose the design challenge III. D., *New tools and approaches to stormwater management methods, water use at airports, and dealing with negative impacts of standing water,* and have proposed a solution that will more effectively collect, and treat this water to be reused in the surrounding area. Currently, there are many different solutions that are in use over several different airports, however the airport in question, State College airport, uses a drainage ditch system to complete this task. After extensive research on the current solution it was devised that this type of system does not eliminate all pollutants from getting into the water table and the environment, and the airport has to outsource the treatment of this water to a municipality. The team has come up with a solution to more effectively collect, and treat the water on site to eliminate pollutants along with improving the drainage system at State College Airport. The team went through several different stages of prototyping, talking to stakeholders, cost benefit analysis, and risk analysis to verify if this solution was feasible for the surrounding area. Through historical data, and analyzing these processes, the team was able to verify the feasibility and implementation of this system into the State College airport. By implementing this system State College and other airports of similar environmental conditions can not only eliminate the issues that come along with standing and polluted water, but can also make a profit from it if in an agricultural area.

Table of Contents

Problem Statement and Background

Airports all over the world have to be cautious of stormwater and its effects on safety and the environment. Some of the main issues with stormwater runoff are the threats it has on runway safety, and in turn the safety of the airline workers and passengers, as well as the risks it poses to the surrounding ecosystem. Often, methods of dealing with stormwater outside of an airport setting lead to wetlands and standing water, which attracts waterfowl and wildlife to the surrounding area(Water). Wildlife is a major threat to planes and can account for 13,000 strikes per year (DeVault). These strikes can lead to immediate degradation of safety of the operations in airports and are an evident hazard to planes on a runway or taxiway. Another issue regarding stormwater is the amount of water that collects on the runway during periods of rain. This collection of water can cause incidents in the operation of airports. Take into consideration the event on United Express Flight 3363 where the plane was coming in for a landing on a flooded runway and hydroplaned, losing control and sliding off the runway (Udris). This incident was caused by heavy rain and poor stormwater management, providing a prime example of how crucial it is to account for stormwater management when designing airports.

Currently, there is no widely used channel to dispose of the contaminated stormwater; it's free discharge. There are lots of hazards occuring due to water contamination including the blocking of runways and taxiways leading to distractions on airport operation. There have been special cases like in the construction of the Long Beach Airport, which built in underground tanks to help hold and store runoff from the airport runway and taxiways (Airports). This was done, however, not for environmental factors but because southern California encounters intense drought, and this is a way of mitigating that drought. Other than this, most airports do not have any unique systems to reuse or treat the stormwater, with systems only to divert the water off each impervious surface.

This project aims to navigate stormwater management in a way that prioritizes safety and allows for uninterrupted operation when it comes to severe weather. Our solution must be cost effective in terms of materials and labor. Many airports have likely become complacent with their current methods of managing stormwater, so it is important that we are able to persuade them to dedicate the resources needed to implement a design that will advance their safety and sustainability. A low cost-low maintenance solution will be most appealing when it comes time to propose our project. It is also necessary that our design can be implemented while airports are functioning because it is not fathomable for such large hubs of transportation to close for extended periods of time. As a result, it will be ideal that our design utilizes gravity and a downhill flow that can be built above ground, rather than an underground pump system that will require digging directly underneath or near runways and taxiways.

Summary of Research

With the concern of increasing global warming and its effect on animals apart from human beings it became essential to choose a problem statement that could relate to solve one of the issues related to the environment and which significantly reduces the current functional costs. The team went through various problem statements mentioned in the ACRP challenge and ultimately decided to lead with the challenge involving Stormwater management. This problem is large-scale and involves various sections requiring improvements. Broadly, the team set its goal to go through runway temperature maintenance and water channelization but subsequently went more in detail towards current water resources leading to safe, cost-effective and on-time water resources in the airport vicinity.

Gravity-Centered Design

Utilizing a gravity-centered design will be ideal for this project, as it is effective in terms of cost, labor, and maintenance. Open channel systems are commonly used in airport stormwater management design. One main form of open channel is referred to as a swale which can be best thought of as a trench off to the side of the runway with a 3 feet wide to 1 foot deep ratio used to direct water flow following a storm. According to the Best Management Practices Manual of the Florida Department of Transportation, swales must have a slope less than 1% and be no more than 50% smaller than the pavement surface it is meant to help drain. Another common design is a dry retention basin, usually located at least 25 feet from the swale. Dry retention basins must infiltrate at least 6 inches of water per hour and lie 6 feet above the seasonal high groundwater table (Statewide Airport Stormwater Best Management Practices Manual, 2013). With gravity-centered design, it is important to consider the wind patterns in the surrounding area as well as any vegetation or sediment buildup along the edges of the runway that can alter the path of water flow or act as a barrier. The team plans to utilize a concrete swale with an underlying heating system that will be mentioned later in this report to direct stormwater flow toward a retention basin that will ideally lead into a storage tank for further distribution, rather than to be infiltrated into the ground as with the dry retention basin.

Storm Water Pumping Stations

Pumps are utilized daily when it comes to managing and dealing with fluids and water. In the case of airports. Pumps are needed in areas that have little grade and cannot utilize gravity as a means of dealing with runoff. There are 2 main parts to a pumping station. The first is a basin to hold the runoff water. Basins can be above or underground but they have to be below the grade of the surface they are going to be collecting the water from. The next part is the pump itself, in which it sits in the bottom of the basin and pumps the water collected to another place. One case where pumps and pumping stations are used is at O'hare International airport. These pumping stations were installed in the main basins that collected all the stormwater runoff and pumped it to the Chicago Water Reclamation District's sewer system. This had to be done because the basin was below the grade of the sewer system and this water could not be discharged without treatment (O'hare). Moving water around at an airport the size of O'Hare is extremely important because it keeps the airport in operation, in terms of not having to deal with standing water which is dangerous in the airport setting. Another thing to take into consideration when dealing with pumps is the different types and cases they are used for. In the case where water needs to be moved up an elevation of 6 meters or less, a centrifugal pump is used. For elevations of 6 meters to 20 meters, jet pumps or submersible pumps are utilized. Finally, for anything above 20 meters, submersible or vertical inline centrifugal pumps are used (Stauffer). In the proposed design it's likely to take into consideration the use of a pumping system due to the fact that there may not be enough grade to completely have our water management system use gravity.

Interseasonal Heat Transfer

The primary function of Interseasonal Heat transfer is to heat and cool buildings without burning fossil fuels by means of exploiting Ground Source energy and ThermalBanks. The major advantages of Interseasonal Heat transfer is its reliability and cost-effectiveness. Due to the fact that it utilizes Solar energy as its primary source, it helps to save over 75% of carbon emissions compared to using a gas boiler for heating. Also, using the Renewable Cooling method through re-cycling winter colds saves over 80% of carbon emissions compared to using standard air conditioning. It reduces harmful emissions by recycling solar energy instead of burning fossil fuels. It links to standard underfloor heating, fan coil units, chilled beams, and air handling units with low maintenance costs. Ground Source energy is the Interseasonal Heat Transfer that can help you address the key issue of combating global warming in a practical and nature-friendly way. Protecting the environment sits at the heart of sustainability. The urgent demand is to build an environment that accounts for green solutions for designing and is innovative in nature.

The “Ground Source Energy” has two-way functionality of heating as well as cooling. Architects, consultants, and building owners have realized that ground source energy can be exploited the whole year-round to provide significant reductions in Carbon-di-Oxide emissions and heating/cooling costs. The method utilized is from the idea that heat can be extracted from the ground via fluid circulating through an array of pipes in the ground to provide heating to buildings in winter. The ground acts as a “heat-source” and also can be used as a “heat sink” for extracting heat out of the building during winters. For the ground to be used as a ThermalBank it is necessary to ensure that there is a balance of heat extracted and heat deposited in the ground over the course of time. For this purpose, “Thermal modeling” of the complete system is necessary to ensure that this balance is achieved in a sustainable manner over the years (ICAX).

What is solar energy?

The sun is an incredible and renewable resource that has the power to fuel life on earth and provide clean, sustainable energy to all of its inhabitants. In fact, more energy from the sun reaches our planet in one hour than is used by the entire population of the world in one year. The sun’s energy can be converted into electricity through solar photovoltaic (PV) modules (photo = light, voltaic = electricity).

How does solar energy work and why should we use solar energy?

PV modules absorb sunlight (direct or indirect) and convert the energy into a usable form of electrical current. The sun shines all over the world, making solar electricity viable anywhere. Because solar can be paired with batteries for energy storage, solar electric systems can be independent of the utility grid, making them cost-effective for remote locations. Solar modules have no moving parts making maintenance costs low, and they are highly reliable with a long service life of 25+ years of guaranteed electricity. Solar electricity relies on the sun's light as its fuel source, so there is no need to drill for petroleum-based fuels, refine them, or deliver them to the site. As you can see, there are a lot of advantages to using solar energy.

Solar energy return on investment?

One way to determine whether someone is getting a good return on solar energy investment is to look at the entire lifespan of the system. Most solar project systems last between 25 and 30 years. If the payback period is eight years, it’s a surety for “making money” on the system for 17 to 23 years.

Therefore, as a team, it was a well thought decision for choosing to operate the runway and taxiway concrete heating system, and water treatment plant by solar panel system using the reserved area in the airport. Also, in the non-snow seasons, the generated power will be used in runway lighting and external services.

Water Treatment Plant

A Water Treatment Plant (WTP) generally takes water from the ground, surface, or rainwater sources, makes it drinkable, and distributes it to water storage tanks or directly to people. Water Treatment Plants (WTP) generally are smaller operations than Wastewater

Treatment Plants WWTP) because of the water quality coming in. WTPs pull water from a local river, stormwater, lake, or well. This water is generally clean (compared to sewage!) and just needs a bit of cleaning and disinfection. Small amounts of pollutants (turbidity) are removed and the water is fit for human consumption and use in our homes, businesses, and industries.

Problem-Solving Approach

Problem Formulation and Background Investigation

Throughout the beginning of this project, the team prioritized an equal and democratic way of choosing the design challenge. Through discussion and voting on the challenges, our team settled on the environmental interactions challenge specifically dealing with the improvement of stormwater management at airports. The team framed the design challenge using an exercise that helped outline the project and where it needed to go. This exercise led to the specific problem and goal that this project was trying to solve and accomplish. The problem at hand is improving the water quality of stormwater runoff. The specific question formulated from this activity was " How can we improve the stormwater runoff quality? "

To get a deeper insight on water runoff and issues with it, the team reached out to several industry experts to help understand this issue more. Through an interview with David Peshkin, it was evident that the stormwater runoff in colder climates was an issue that needed to be dealt with. Peskin explained how certain chemicals used to de-ice planes and treat the runways are toxic to the environment. From this intel, our team thought it would be best to focus on collecting, and treating this water before it goes back into the environment or is repurposed for some additional use. Some of the current solutions to this problem cause other issues for the airports. One example is the use of water retention ponds. Although these ponds are a great way of filtering and sorting runway runoff, they often attract wildlife which causes major safety concerns for the operation of airports. From this research and narrowing of scope, it was decided that our solution has to take into consideration the collection and treatment of stormwater runoff from the impermeable surfaces of an airport's runway.

Brainstorming Approach

To lead into brainstorming, the team took a multi-step approach. Key themes were first derived from research found in the previous section of this report. Then the team was able to form key insights from both the identified themes and previous interviews with stakeholders and ACRP Expert Advisors. Once the key insights were gathered, the team was able to begin brainstorming realistic and relevant solutions.

After sharing important findings with one another at the end of the research phase, the group derived the overarching themes. One of these key themes was the importance of mitigating standing water. If standing water is left on the runway, many possible dangers may ensue such as hydroplaning or the potential to attract wildlife. Wildlife collisions, specifically with birds, have been known to cause extreme damage to planes as hinted at previously. Another key theme was environmental sustainability. If the team is to develop a water treatment plant to reuse stormwater, it is crucial that the water will not cause any harm or pollution to the surrounding environment after having been contaminated with the chemicals and oil on the runway.

By delving deeper into these themes, the team developed key insights that would later help to develop a plausible solution. Some of these insights were touched on in the previous paragraph such as deterring wildlife, ensuring proper channeling of water, and preventing toxins on the runway from contaminating runoff. Since the team will focus primarily on the collection and treatment of stormwater, some other insights include treating the water so that it meets EPA standards and is not harmful to the environment as well as the necessity for long-term water storage in case of a sudden influx of stormwater or the inability to use the water in a timely manner.

The team began to brainstorm ideas on how to address these key insights in the final solution. The team divided its scope into 5 broad sections: collection, transport, storage, treatment, and reuse. After brainstorming a variety of solutions for these sections, the team collaborated on a decision matrix to narrow down which possibilities are the most rational and deserving of further attention in the upcoming prototyping phase. In terms of collection, the team believes some form of open channel, whether it be made of sediment or concrete, will be ideal to carry runoff from the runway toward treatment. The water will likely be transported via some combination of gravity-centered and pump design depending on how the slope of the topography and the volume of water present affects its velocity. As for the water storage, the team's top ideas consisted of some form of above or below ground tank, or even just storing the water in the treatment plant itself. In the said treatment plant, the team decided that some sort of filtration method will be necessary while also occasionally being supplemented with a chemical treatment to rid the runoff of chemicals such as oils, fuels, and even chemicals used to deice runways. The team's ultimate goal is to be able to reuse runoff to benefit the surrounding area through means of agricultural use or as tap water at the airport itself.

Stakeholder Feedback

The team met with a Penn State alumni biweekly named Nate Lehigh, who has professional experience in water resources management and handling stormwater. After sharing the previous ideas with Mr. Lehigh, he suggested that the team utilize gravity as much as possible in their design to reduce cost, labor, and maintenance. This reinforced that the team is on the right path by planning for an open channel system, but also needs to ensure that the design will not rely significantly on pumps to transport the water. Mr. Lehigh also recommended that the team aim for reusing the stormwater agriculturally because it will be more cost-effective and overall a much simpler process than trying to attain tap water quality. This feedback guided the team during the solution development and prototyping phase.

The team also met with Barry Bratton, an associate for ADK Consulting & Executive Search with expertise in airport and runway safety, operations, and security. Mr. Bratton supported the team's ideas, but suggested narrowing the scope down to a specific airport and location/climate since airports can be vastly different and the proposed ideas may not be applicable to some. The team followed his guidance and focussed solely on State College Airport in State College, PA, which will be addressed further later on in the report. He also stressed the importance of identifying the necessity of onsite water treatment that will appeal to airport operators' main concerns of safety and cost-effectiveness. The team took this into account and planned to emphasize these improvements through risk and cost analyses.

Conclusions from Research

After consulting with advisors and stakeholders, the team chose to narrow the scope of the project to focus solely on water collection and treatment once it has left the runway, negating the relevance of the research conducted on interseasonal heat transfer and solar energy. Based on the remaining research, it was noted that gravity-centered design is more appealing in terms of maintenance and cost, but a pumping system will still likely be required to move the water to a higher elevation if it is to be transported into a treatment plant. Other key insights were gathered from the stakeholder feedback such as the importance of preventing standing water to avoid hydroplaning and the presence of wildlife. All of these key insights led to the development of an overall statement summarizing the team's general goal for the project.

Point-of-View Statement

Our team met Mr. Peshkin, a chief engineer for Applied Pavement Technology, and Mr. Barry Bratton, an associate for ADK Consulting & Executive Search . We were amazed to learn of the negative impacts of precipitation on safety, the runway itself, and the environment. It would be revolutionary to mitigate these issues in a system that simultaneously benefits the environment.

Technical Aspects:

Solution Selection

By the end of the ideation phase, the team wanted to incorporate methods of collecting, transporting, storing, and treating stormwater in order for airports to recycle it in a more efficient way than simply draining it into the surrounding land. Some ideas for collection included a concrete open channel, a ditch open channel, or a drainage/piping system. In terms of transporting the stormwater, the team wanted to utilize gravity-centered design as much as possible, but a pumping system is also inevitably required to transport the water to the treatment plant. The water will also need to be stored before and after treatment; first to prevent overflow in the plant, and second to preserve the clean water until it can be distributed for proper use. The team brainstormed using an above or underground tank or possibly even storing the water in a section of the plant itself. For the final step, the actual treatment itself, the conclusion was drawn that there will be both chemical and filtration techniques; filtration will be used to remove the larger particles from the stormwater flowing into the system, and chemical treatment will ensure that the water reaches the necessary quality standard.

Decision Matrix

In order to finalize which ideas to use for the collection and storage of the water, the team completed a decision-matrix, which provided a way of numerically selecting the best solution. The team selected the most important metrics: cost effectiveness, sustainability, maintenance, effectiveness, ease of installation, and environmental aspects. These metrics were then weighed depending on their level of importance to the final goal. Once these categories were weighted, the team scored each solution's ability to accomplish each of these metrics, which was done by averaging all of the team members' individual scores for each one and multiplying that average by the metrics’ respective weight. The option that scored the highest for water collection, movement, storage, and treatment was determined to be the final solution. From this decision matrix, the team decided that their best overall system was an open channel collection system, leading by gravity to a water treatment plant where the water will be lifted to a holding tank for it to be treated. The decision matrix used for water collection is shown below.

Factor	Weight	Side Channel	Weighted Side Channel	Drain Gates/Pipe Systems	Weighted Gates	Ditch open channel	Weighted Ditch	Concrete open channel	Weighted Concrete
Cost Effective	3.5	4	14	2.5	8.75	4.75	16.625	3.5	12.25
Sustainability	4.25	3.75	15.9375	3.25	13.8125	3.5	14.875	4	17
Maintenance	3	3	9	2.5	7.5	2.75	8.25	4.25	12.75
Effectiveness	3.75	3.5	13.125	4.25	15.9375	2.75	10.3125	4	15
Ease of Installation	3.25	3.5	11.375	2.25	7.3125	4	13	3.75	12.1875
Environmental	5	4.25	21.25	3	15	3.5	17.5	4.75	23.75
	Totals:		84.6875		68.3125		80.5625		92.9375

Figure 1: Decision Matrix for Water Collection system.

Rapid Prototyping

The point of rapid prototyping was for the team to begin analyzing the feasibility of implementing their design. The team's first physical prototype depicts the pathway of the concrete open channel alongside the runway/taxiway (Figure 2). The prototype was not to scale in order to better display the curvature and drainage grates of this collection system.

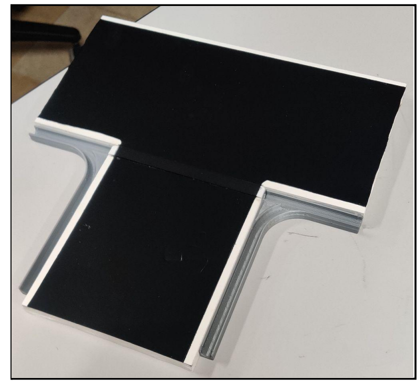

Figure 2: Initial Rapid Prototype

However, after the team discussed the prototype with stakeholder David Peshkin, he stressed that a trench or ditch-like structure cannot be placed alongside the runway due to the risk of a plane accidentally rolling off the runway and getting caught. He also warned again about the open channel possibly attracting wildlife. Adjustments were made to cover the open channel with grates as seen in Figures 3 and 6. The grates will allow aircraft to smoothly run over the channel if necessary and prevent both the possibility of exposed water that may attract wildlife as well as blockages that can come from natural debris.

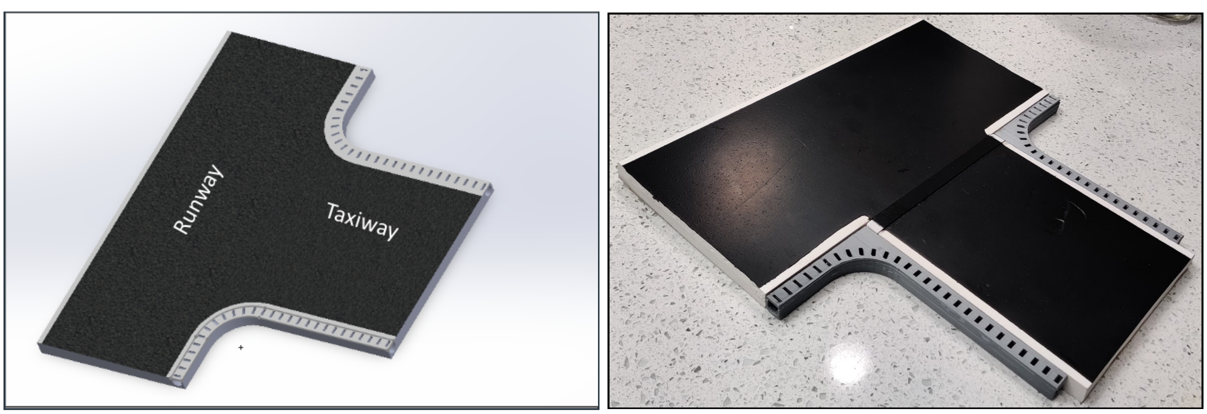

Figure 3: Final SolidWorks and physical depictions of open channel prototype

Rather than develop a physical prototype of the treatment plant, it was more practical for the team to create a CAD image that more accurately depicts the tanks, plant room, and other systems. The location of this treatment plant is shown on a bird's-eye-view image of the State

College Airport. The most ideal place for it is near the taxiway away from high traffic areas and any possible land that overlaps with military operations.

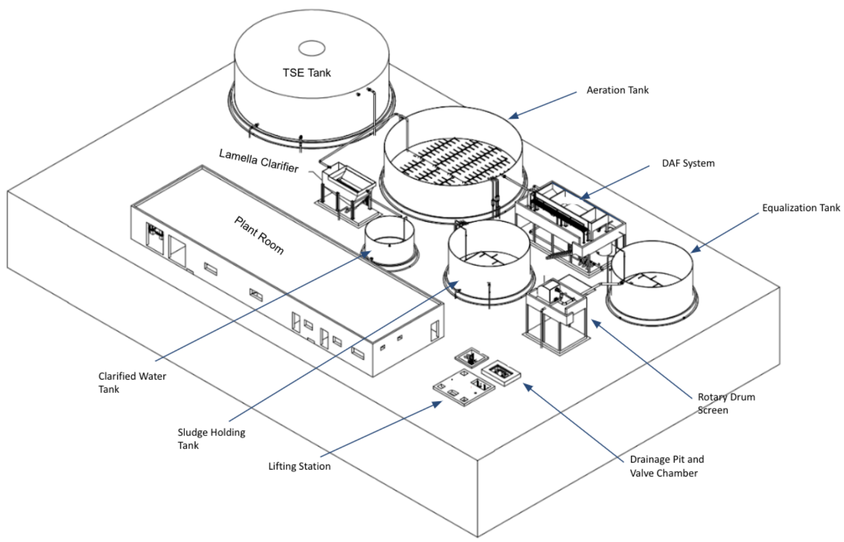

Figure 4: CAD Drawing of Stormwater Treatment Plant

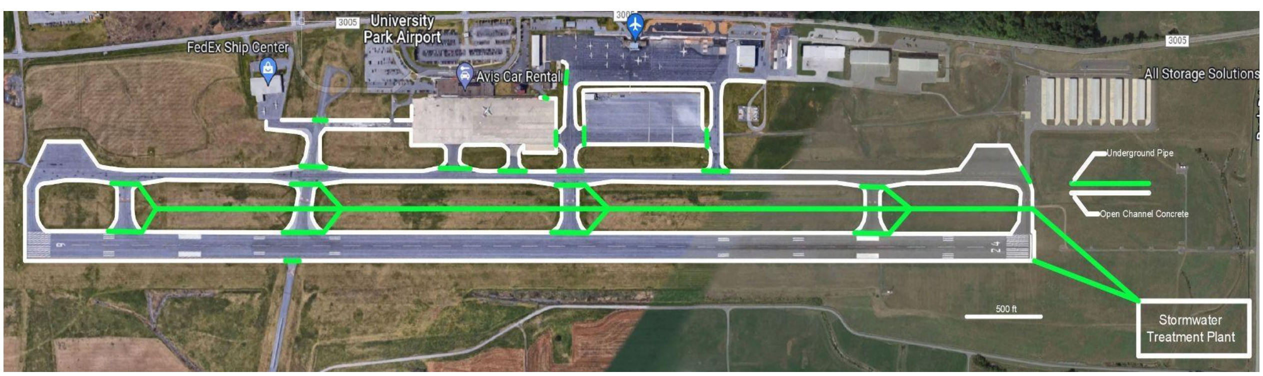

Figure 5: Estimated Location of STP and Concrete Open Channel at State College Airport

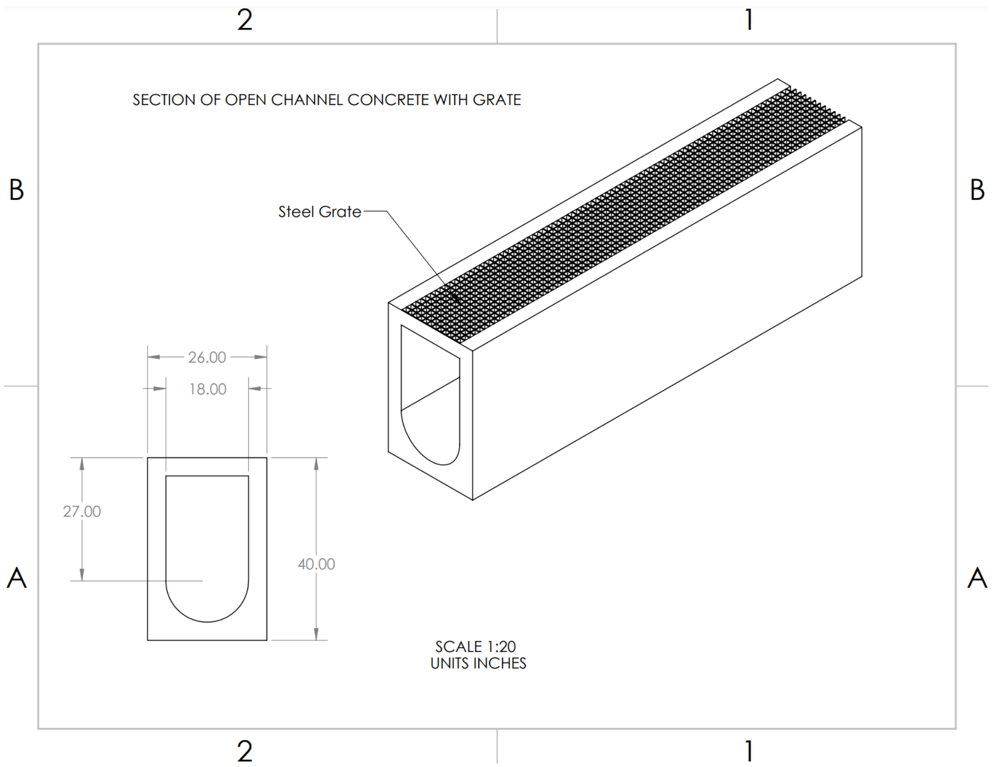

Figure 6: Cross Section of Open Channel Concrete

Architectural Aspect of Proposed STP Model

The rapid prototyping led to a well thought and feasible architecture of the model shown above. The proposed model makes use of drilling horizontal holes at the intersection of the runways and taxiways. The holes are internally linked with the Stormwater Treatment Plant (STP) and thus with the filtration process. The concept of this model is based on gravity-centered design and makes use of NCDR machines. The water channels are completely underground which doesn't impact the existing function of the taxiways and runways by any means. The gravity-centered design and inner water channel design makes sure that the least amount of pollutants from the land, air, etc. enters the water table and surrounding environment..

During the water processing, the water goes through various phases from screening to clarification to its treatment and ultimately for its utilization. During the screening phase, stormwater is carried by a lifting station, where it will be separated into two screens. Each screen has an 89m3/hr filtration capacity, and the solids will be collected and disposed off as solid waste in accordance with the local authorities' standards. The screens are also capable of cleaning themselves automatically Next phase involves equalization. During this phase, the screened stormwater will enter the equalization tank, where it will be balanced at peak flow. To avoid sedimentation and stagnancy within the equalization tank, coarse bubble aeration using tubular diffusers mixes the stormwater. Equalized pre-aerated stormwater will be separated into two equal streams and pumped to the primary treatment area for coagulation, flocculation, and lamella primary settling. The third phase involves the primary treatment of the Equalized pre-aerated stormwater. Here, the equalized effluent will be pumped to the DAF system for primary treatment, where TSS and non-soluble COD will be removed to an extent of up to 85 percent. The supernatant will be pumped to the aeration tank for further biological treatment.

Following primary treatment, stormwater will flow by gravity to the Aeration Tank to begin secondary biological treatment. The aerobic environment in the aerator will be achieved through the use of fine bubble diffused aeration and the PVC media filter, where the live microorganisms will be concentrated and have greater contact. The aeration also keeps the liquor in a completely mixed regime. The two streams will be served by a dedicated aeration air blower. The semi-digested mixed liquor from the Aeration-MBBR Tank flows into the Clarifier Tank, and the supernatant overflows into the Clarified water tank for further treatment. The clarifier sludge will be recirculated to the anoxic tank, which will then flow to the anoxic tank to maintain the Mixed Liquor Suspended Solids (MLSS) at the aeration tank via RAS pump per stream. Excess sludge will be disposed of in the sludge holding tank for further processing. The clarified water will then be collected and treated with disinfection dosing in the clarified water tank.

The clarified water will be pumped for tertiary treatment after disinfection. The disinfected stormwater will be pumped to the filtration system to further filter any carry-over solids. The multi-media filtration system, which contains different grades of filtration media, is equipped for this purpose. The trapped solids at the filters will be periodically back washed manually by using the filtered water which will be collected at backwash tanks and backwash pumps. The product transfer pump will transfer the final product from the backwash tank. The sludge from the primary and secondary treatment areas will be collected in a sludge holding tank for thickening before being fed to a centrifuge. The thickened sludge, up to 5%, will be pumped to the centrifuge using a sludge transfer pump. The dried sludge will be collected using a sludge disposal pump and disposed of as manure in accordance with regulations. The centrifuge's drained wastewater will be collected at the drain pit and pumped to the equalization tank. The PLC will control the dedicated working air blowers for aeration, which will provide the required air for each aeration tank. All other tanks (equalization tank, sludge holding tank, clarified water tank, and MMF backwash tank) will be supplied with air via the common working air mixing blowers. Diffusers are installed in each tank to diffuse and supply air. Aeration is accomplished through the use of fine pore diffusers, while air mixing is accomplished through the use of coarse bubble diffusers (Baruth).

Once water is treated it can be put to use in agriculture and in possible other uses that aren't up to tap water standards, like cleaning planes and cars from the surrounding area. This water can also be sold to the surrounding farms to maintain a profitable solution.

Safety Risk Assessment:

Because the team's solution is to establish a stormwater treatment plant on the airport's property and create an open channel system near the runway/taxiway, it is evident that numerous hazards can arise and must be assessed. This way, the team can utilize the benefits of a Safety Management System such as being able to "foster a positive safety culture that can help improve system safety" and to "reduce isolated analysis and decision-making using integrated safety management principles" as listed in the F.A.A. Safety Management System Manual (Safety Management System Manual, 2019). In accordance with the F.A.A. AC 150/5200-37, Introduction to Safety Management Systems for Airport Operators, the team followed a 5 phase process to thoroughly establish safety risk management.

The first phase is to "describe the system", which has been done previously in this report. The second phase is to "identify the hazards". The team did this by analyzing hazards that may arise during construction/implementation as well as those which may occur once the system is operational. The third phase is to "determine the risk", which was done by assessing the identified hazards for the possible effects they may have on daily airport operations, the functionality of the system, runway safety, etc. The fourth phase is to "analyze the risk", or in other words assess the severity of each risk in order to determine which pose the biggest threat and, thus, require the most attention. The risk level of each item was determined on a scale from 1 (low risk) to 5 (very high risk) based on the amount of disruption it would cause in terms of safety or operation as recently stated. The hazards, risks, and analyses are outlined in the first half of the risk management diagram in Figure 7 (Introduction to Safety Management Systems (SMS) for Airport Operators, 2020).

Risk ID			Current Risk				
Ref No.	Area	Name	Risk Details	Financial Impact ($ M)	Likelihood	Impact	Current Risk level
1	Health & Safety	Working near and against runway	1. Damage to runway; 2. Cannot work during takeoff and landing; 3. Increased cost/work time	0.1	4	4	High
2	Operational	Abundance of Rainfall	Flooding	-	3	4	High
3	Operational	Shortage of rainfall	STP will not work as well; possibly not enough water to initiate flow off of runway		3	4	High
4	Operational	Freezing	Restrict flow through pipes; possible damage to pipes/system	-	4	5	Very High
5	Operational	Power Outage During Storm	Cannot collect/move water through pumping system; may be more difficult to clear runway		2	4	Medium
6	Operational	Blockage	Possible debris caught in system, restricting flow		3	3	Medium

7	Health & Safety	open Channel	It is possible that a slipping craft will be inside the open channel.		3	5	High
8	Operational	Mechanical issues independent of power	Pumps are damaged		2	3	Medium
9	Construction	Channels pass by taxi way	Cutting the taxi way to pass the channel		5	4	Very High
10	Legal & Compliance	Delay of Federal/State Permit	Delay in construction --> increase cost/time		5	3	High

Figure 7: First half of Risk Management Assessment outlining hazards/risks as well as the risk levels before mitigation

It is not enough to acknowledge the possibility of these risks, there must also be a plan to address them if they arise. This is outlined in the final phase of the safety risk management process. The fifth phase is to "treat the risk", and while the team can not physically treat the risk, the team developed plans to mitigate each one, typically through means of control or transfer techniques. Some key mitigation strategies the team established are the implementation of precast concrete channels to minimize the disruption to airport operations and prevent damage to the runway when installing the treatment plant. If there is an abundance of rainfall, there will be a reserve inside the STP to store the water until the system is ready to process it, that way no runoff is wasted or allowed to contaminate the surroundings. On the other hand, if there is a shortage of rainfall, the system is set up so that only half of it will run to still treat the little runoff that there is without causing damage to its integrity or the environment. Regarding concerns about freezing temperatures in the winter, the team do not foresee this as an issue since the runoff entering the system will already have the deicing chemicals from the runway in it which will prevent the system from freezing. These key mitigation strategies, as well as others, can be seen in the second half of the risk management diagram in Figure 8.

Risk ID	Risk Acceptance / Treatment / Control						Risk Control	
Ref No.	Risk Mitigation (transference / acceptance / management plan)	Financial Impact ($ M)	Owner	Likelihood	Impact	Residual Risk Level	Risk Control Effectiveness	
1	Implementation of pre-cast channels	0.1	Construction	4	3	High	Improving	4
2	Increase channel size; make reserve in STP; less treatment and increase capacity by 25%	-	Client	3	2	Medium	Improving	2
3	Collect water from drainage/rooftops of building; run STP at half power STP is designed on 2 steams	1.5	Client	3	2	Medium	OK	2

4	Water entering system should still have deicing chemical in it to prevent system from freezing	0.1	Client	4	3	High	Improving	4
5	Solar energy; backup batery; utilize gravity wherever possible		Client	2	2	Low	OK	2
6	Daily inspection of drainage system; manually remove debris from the top of the cover		Client	2	2	Low	OK	2
7	cover all channels by heavy duty channel grates steel cover	0.2	Client	2	2	Low	OK	2
8	Each pumps will be working as a set of 2 + one standby		Client	1	3	Low	OK	2
9	NDCR pipes to be used instead of open channel in the connection of runway and taxiways	(0.1)	Construction	2	2	Low	OK	2
10	Obtain license during design		Construction	3	2	Medium	OK	3

Figure 8: Second half of Risk Management Assessment outlining how the risks will be addressed as well as the risk levels after mitigation

Impacts of the Proposed Design:

The team had to go through various official sources to analyze the impacts of the proposed product design. While making a good analysis on the precipitation levels at State College was essential, it turned out to bring more light towards the associated risks and cost benefits. During the same time, it was found that the current water channel for the State College airport utilizes water being brought from an off-site source. The off-site source brings in water to the airport at a high cost margin and with certain delays at times. Our product design is cost efficient as well as removes any kind of hindrances that can be caused while transporting the water from an outside source.

The main idea behind this water channel is to keep the Storm Water Plant (STP) in the vicinity of the airport. The water collected from various sources that was not being utilized efficiently or was being drained to a retention pond can now be efficiently channeled for better utilization and consumption. The water being treated is highly acceptable for purposes like cleaning the airplanes, irrigation and any other similar tasks. The treated water is under the criteria of gray water at 85% water purity; this level of water filtration doesn't support drinkability but will help with any other uses of water at a much cheaper price.

While going through the analysis on the precipitation levels throughout the years based on the previous years precipitation trends, we could define the maxima and minima, highest and lowest temperatures, mean and median et al of the water received in varied forms. It helped us analyze the amount of water (in gallons) that once collected through the airport will generate a huge amount of water resource that can be utilized via Airport Authorities. During the Ideation phase and making decisions through the Decision Matrix, it was found that Gravity-based water channels suit best for the implementation. Gravity-based design will have minimal effect on the already existing runways and taxiways and hence will minimize the construction loads. Our treatment plan has also been researched and thought of to improve the quality of water while maintaining a cost budget. The treatment process goes through various filtration models including sand and sludge filtration. Moreover, the grate covering above the water channels helps to minimize the impurities in water as much as possible . The fundamental impacts are covered in terms of cost saving by the airport that can only increase in the upcoming times. We propose to build an ecosystem that is low on cost and a more viable option cutting the transportation issues.

Cost Benefit Analysis

This cost-benefit analysis (CBA) was performed for State College airport since that is where the proposed solution will be implemented. The team took into account the cost of materials, labor, maintenance, and electricity needed to establish both initial and annual costs as seen in Figure 8.

Initial Costs	$		Quantity	Total
Concrete channels	**$ 100.00**	**per**	**10858**	**$ 1,085,800.00**
Channels cover	**$ 50.00**		**10858**	**$ 542,900.00**
Piping	**$ 60.00**	**per**	**2432**	**$ 145,920.00**
Lifting station	**$ 2,000.00**	**per**	**2**	**$ 4,000.00**
Stormwater Treatment Plant (STP)	**$ 750,000.00**	**per**	**1**	**$ 750,000.00**
			Total	**$ 2,528,620.00**

Annual Variable Costs			its	tal
Labor	50,000.00	per year	2	100,000.00
Maintenance Services	20,000.00	per year	1	20,000.00
Overhead	10,000.00	per year	1	10,000.00
Electrical consumption	3,000.00	per year	1	3,000.00
			Total	133,000.00

Cost Overview	
Total Variable Cost per Unit	$ 133,000.00
Total Initial Cost	$ 2,528,620.00

Figure 8: Initial costs and Annual Variable costs

Since the goal of the STP is to provide water that can be reused at the airport for cleaning or be sold to nearby third parties such as agricultural lands, the team plans to have a return on investment on the solution. In order to calculate a return on investment time, the team considered a time period of 240 days of full operation per year as it depends on the amount of rainfall. An estimated 5% inflation on the cost of maintenance and operation was also taken into account for each successive year. According to the State College Borough Water Authority (Water Rates), the surrounding areas buy their water for $3.00 per 1 cubic meter, but the airport will be able to sell the water at a competitive price of $2.00 per 1 cubic meter. According to the CBA calculation in Figure 9, the total investment on the STP will have a return on investment of less than 4 years, demonstrating the benefit of implementing stormwater treatment plants in all airports in the similar topography or weather conditions, such as central Pennsylvania. As previously stated, the calculation in Figure 9 is performed for State College Airport, but the team is prepared to put these ideas into action and conduct a CBA on a case-by-case basis.

Annual Return	$		Units	Total
Treated water / day	$ 2.00	per day	1700	$ 3,400.00
			Total	$ 3,400.00
Annual Return	$		Units	Total
Treated water	$ 3,400.00	per day	240	$ 816,000.00
			Total	$ 816,000.00
Frist year Costs	$		Units	Total
Construction	$ 2,528,620.00	per year	1	$ 2,528,620.00
Maintenance contract and operation	$ 133,000.00	per year	1	$ 133,000.00
			Total	$ 2,661,620.00
Frist year return of treated water	$ 816,000.00	per year	1	$ 816,000.00

Cost in the End of year 1				**$ 1,845,620.00**
Maintenance contract and operation	**$ 133,000.00**	**per year**	**1.05**	**$ 139,650.00**
Second year return of treated water	**$ 816,000.00**	**per year**	**1**	**$ 816,000.00**
Cost in the End of year 2				**$ 1,169,270.00**
Maintenance contract and operation	**$ 139,650.00**	**per year**	**1.05**	**$ 146,632.50**
Third year return of treated water	**$ 816,000.00**	**per year**	**1**	**$ 816,000.00**
Cost in the End of year 3				**$ 499,902.50**
Maintenance contract and operation	**$ 146,632.50**	**per year**	**1.05**	**$ 153,964.13**
Fourth year return of treated water	**$ 816,000.00**	**per year**	**1**	**$ 816,000.00**
Cost in the End of year 4				**$ (162,133.38)**

Figure 9: Return Investment Calculations

According to the Cost Benefit Analysis calculation in Figure 9, the total investment in a storm water system (water collection, water treatment plant, and annual operation cost considering inflation of 5%) will result in a return on investment including operation cost of less than 4 years.

Appendix A: Contact Information

Team Members

- Joseph Pecaitis
  - Email: jzp5833@psu.edu
- Aatika Sinha
  - Email: aps7175@psu.edu
- Arianna Parisi
  - Email: axp5824@psu.edu
- John Boulos
  - Email: jfb6348@psu.edu

Advisor

- Meg Handley
  - Penn State University, 213 Hammond Building, University Park, PA, 16802
  - Email: mhh11@psu.edu

Appendix B: University Description

Penn State University is an institution of higher education in Pennsylvania. It houses the college of engineering which includes numerous engineering degrees at both the undergraduate and graduate levels. The college of engineering supports an undergraduate minor in engineering leadership in which undergraduate engineers can build the non-technical skills to support the great technical skills they are developing through their engineering curriculum. The engineering leadership development program offers students classes in project management, leadership education and development, business basics, and cross cultural teaming. Students in the minor are dedicated to building these skills in addition to the technical work load required of their discipline's curriculum. The engineering leadership program also offers a graduate program in the form of a master of engineering and an online graduate certificate in Engineering Leadership and Innovation Management.

Appendix C: Interaction with Industry Experts

David Peshkin

Email: dpeshkin@appliedpavement.com

To gain a new perspective on the research, industry expert and chief engineer of Applied Pavement Technology David Peshkin was consulted. Throughout the course of a 30-minute long interview, Peshkin shared their knowledge of runway pavement and design with the team. Peshkin defined the main considerations made when designing a runway, such as the durability of the material, the toxins in runway runoff that pose a threat to the surrounding environment, and the physics behind the slope and texture of the runway. Peshkin also gave his perspective on the team's possible ideas and pointed out noticeable flaws to ultimately lead to a better overall design. Peshkin explained that using permeable pavement in a climate that experiences a significant amount of snow and ice can be hazardous since the ice is difficult to remove, posing a threat to the pavement's integrity as well as runway safety. Peshkin's recommendation to reach for a more creative solution encouraged the team to develop more complex ideas. Peshkin elaborated on the requirement to do a cost-benefit analysis and risk analysis. Along with that, Peshkin emphasized the toxic materials, the influence of gravity, friction, and wildlife.

Barry Bratton

Email: p3ctacco@gmail.com

Barry Bratton is an associate for ADK Consulting & Executive Search. He highlighted the concern of safe transportation for passengers where areas between runways must be kept clear. Wildlife dangers include free movement of birds and deer and ideally retention ponds should not attract geese. Lots of pavement, large parking areas, runways, etc. remain contaminated by oils and chemicals and are regulated by EPA. Currently, standing water is the major issue with construction standards having no puddles (quarter on pavement cannot be covered in water) and zero retention goal. Retention ponds are easier to manage in mountainous regions due to natural slopes interconnected by drains underneath (one pond fills and water drains to another empty pond). Pumping is used in rare cases (gravity preferred; pump used more in sewage/waste water because water has to go to a certain destination). Perpendicular groves in the runway create channels for water to drain and also help planes maintain traction. The FAA wants to eliminate all trees/environment and only retain impervious surfaces, but EPA is against wildlife destruction and would like an irrigation solution to get water off the airport environment to channel downstream for irrigation use where runoff needs to be clean. The current methods to eliminate this issue is through transfer of fluids down in the hangar, not on the taxiway; instead secondary containment is required. Deicing fluid is relatively benign but still required by EPA to get rid of chemicals and is an easier precautionary method. Limiting factors for landing is convective weather where there is a possibility of thunderstorms or heavy wind; precipitation is a big factor and attention towards the runway conditions is compulsory.

Appendix E: Educational Experience and Evaluation Questions

Students' Perspective

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

The ACRP Design Competition did provide a meaningful learning experience because it taught us how to conduct a project from the ground up. We learned how to analyze the problems with existing solutions in order to establish a stronger foundation for our own ideation. We also learned critical skills such as how to professionally contact and interview industry experts and how to successfully communicate the intricacies of our final solution with a diverse audience.

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

Our team encountered various issues with narrowing the scope of our project that forced us to better comprehend the importance of time management and goal setting. We overcame these issues by consulting various advisors and stakeholders to discuss which aspects of our project had the most potential and could be accomplished in a timely manner. We embraced the importance of having a smaller scope and more depth over a larger scope that contains less information. We also practiced recognizing when our ideas began to overextend our scope and communicating with each other to increase our awareness of the issue.

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

Most of our team did not have prior knowledge about airport operations and stormwater management, but evidently, we still wanted to create a feasible solution. As a result, we based our hypothesis heavily on the feedback and first hand experience that our stakeholders shared with us. We did have one member, however, with extensive knowledge about airport structure and the ability to visit the State College Airport, and their contributions also aided in developing a project that is as realistic as possible.

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

Each meeting we held with industry experts felt appropriate and useful, whether we were interviewing them for knowledge on firsthand experiences or sharing our progress to hear their professional opinions. We specifically chose individuals whose background/experience aligned with our project, so they always had meaningful feedback to provide. They often introduced perspectives we had not considered, allowing us to create a more well-rounded solution.

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?

Since our approach to the project was entirely team-based, it helped enhance both our technical skills, such as researching and risk/cost-benefit analysis, in addition to our non-technical skills, such as time management, teamwork, leadership, communication, etc. The requirements to speak with industry experts also allowed us to practice networking and maintaining relationships that may prove useful in the future. These are all critical skills that will be immeasurably beneficial to our professional careers.

Faculty perspective:

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

Students in our leadership course are learning how to lead within the engineering context. This project provides an exceptional and organized experience for our engineering students to apply the knowledge and their personal leadership style as they lead their teams throughout the semester. The challenges provided mimic a real-world experience giving students an opportunity to practice both technical and non-technical problem-solving skills.

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

Yes, the learning experience was appropriate for the level of our students and fit within the context of our learning environment, per the note above.

3. What challenges did the students face and overcome?

Students faced some challenges getting in touch with experts and through that learned how important it is to talk with the "user" in order to come up with the best solution. Some students tried to jump ahead to the solution and not work through the design process to use all the information gathered in order to come up with a creative solution. They learned that user-centered research is important when coming up with solutions to challenges.

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

We have used this competition as an educational vehicle for the past several years. The competition structure allows us to combine innovative project development via the 5-stage design process while giving student teams opportunities to learn about leadership.

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

Yes. We plan to continue to use it based on the organization, the well thought out options for projects, the support, and the industry contacts. Making some of the appendices into an online form would be helpful, and perhaps allowing for one submission of some appendices if a group is turning in multiple projects.

Appendix F: References

"Airports Embrace Stormwater Management to Protect Water Quality." *Stormwater Report*, 5 Jan. 2021, https://stormwater.wef.org/2020/06/air-land-and-sea/.

Baruth, Edward E., editor. *Water Treatment Plant Design*. 4th ed., McGraw-Hill, 2005.

DeVault, T.L., B.F. Blackwell, J.L. Belant, and M.J. Begier. 2017. Wildlife at Airports. Wildlife Damage Management Technical Series. USDA, APHIS, WS National Wildlife Research Center. Fort Collins, Colorado. 19p.

"ICAX™ Solar Runway Systems Clear Ice from Aircraft Parking Stands Using under Runway Heating." *Solar Runways - Interseasonal Heat Transfer from ICAX*, ICAX, https://www.icax.co.uk/Solar_Runways.html.

Introduction to Safety Management Systems (SMS) for Airport Operators, U.S. Dept. of Transportation, Federal Aviation Administration, 2020, pp. 9–13.

"O'hare Airport Storm Water Basin Pumping Stations." *Allan Integrated Control Systems*, Chicago Department of Aviation, Retrieved from: https://allan-ics.com/project/ohare-airport-storm-water-basin-pumping-stations/.

Safety Management System Manual , U.S. Dept. of Transportation, Federal Aviation Administration, 2019, pp. 2.

Statewide Airport Stormwater Best Management Practices Manual, Florida Department of Transportation , 2013, pp. 32–39.

Stauffer, Beat, and Dorothee Spuhler. "Pumping Stations." *SSWM*, 14 May 2019, https://sswm.info/sswm-university-course/module-2-centralised-and-decentralised-systems-water-and-sanitation-1/pumping-stations.

Udris, Aleks. "This ERJ-145 Accident Could Happen to Anyone. Here's How to Avoid It." *Online Flight Training Courses and CFI Tools*, BoldMethod, 2 Apr. 2014, https://www.boldmethod.com/blog/2014/04/hydroplaning/.

"Water Management at Airports." Eco Airport Toolkit, Retrieved from: https://www.icao.int/environmental-protection/Documents/Water%20management%20at%20airports.pdf

"Water Rates." *State College Borough Water Authority*, 22 Dec. 2021, https://www.scbwa.org/water-rates.