COVER PAGE

Title of Design: Fuel Containment Channels at Eagle County Regional Airport (EGE)

Design Challenge Addressed: Airport Environmental Interactions: Improving methods for containment and cleanup of fuel spills

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Boulder Remediation Services

University of Colorado at Boulder: Undergraduate Senior Environmental Engineering Design

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Executive Summary

Boulder Remediation Services (BRS) is a team composed of six undergraduate students studying at the University of Colorado at Boulder. The team hails from a variety of backgrounds in the College of Engineering and Applied Science ranging from environmental engineering, chemical engineering, applied mathematics, and engineering management. BRS has teamed up with Eagle County Regional Airport (EGE) to design alternatives for fuel spill cleanup and remediation. The goal of BRS is to limit the amount of jet fuel that is released into the environment.

After communicating with liaison's at EGE, BRS has evaluated several possible design alternatives to be used for Jet A fuel cleanup. The alternatives that were assessed are: a heated boom containment system, bioventing, containment channels, and a tiller and absorbent dispenser. A decision matrix was created based on feedback from EGE and the faculty advisor, Professor Corwin. After each alternative was evaluated within the decision matrix, BRS recommended that containment channels would provide the optimal solution for jet fuel spill containment and cleanup.

Containment channels are a system of grooves inset into concrete allowing for containment and redirection of fuel spills. In addition to the containment channels, a vacuum with a nozzle matching the size of the channels is included in the design for quick removal of the spill from the tarmac. The total installed cost for a containment channel system at EGE was found to be $141,000. In their master plan, EGE suggests improving the pavement of the aprons where the airplanes are refueled, therefore installing containment channels would improve the EGE facility and fit in with future plans.

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Problem Statement

The goal of this project is to design an effective method to contain and clean up fuel spills at the Eagle County Regional Airport (EGE). Boulder Remediation Services (BRS) is comprised of six undergraduate students from the University of Colorado at Boulder that are committed to researching and designing various alternatives that will improve fuel spill response at EGE. In this design report, Boulder Remediation Services will provide a summary of all fuel storage and distribution operations at EGE, as well as current fuel spill response methods. A detailed explanation of each proposed alternative will be presented. The evaluation of each alternative will be performed using specific design constraints and criterion that are illustrated in the provided decision matrix. A final design will be selected and explored.

Background

Current Operations

EGE is equipped with both aboveground fuel storage tanks (ASTs) and underground fuel storage tanks (USTs). There are eight USTs located in the South Fuel Farm beneath the General Aviation (GA) terminal on the East side of the Fixed Base Operator (FBO) terminal. There are also two ASTs located in the North Fuel Farm on the north airfield GA that contain both AvGas and Jet A fuel. Both ASTs include a double wall steel construction that mitigate the risk of unwanted discharge. All of the storage tanks at EGE are equipped with Veeder Root Inventory Systems, which continually monitor the inflowing and outflowing fuel to and from each tank. The Veeder Root System provides real time feedback and sends warning notifications to airport officials as soon as a leaking tank is detected, above or underground (Fuel Inventory Control Services | Fuel Management System.). In addition to the monitoring system, both above ground tanks have concrete basins for secondary containment as required by environmental regulations.

The Vail Valley Jet Center (VVJC) owns and operates all fuel storage and transportation operations at EGE. VVJC has 1 defueling and 11 refueling trucks that transport fuel from both North and South Fuel Farms to aircraft parked along the terminal (Airport Master Plan). Fuel is transferred from the storage tanks to the fuel truck via direct hose connection. If a spill were to occur during fueling or defueling operations associated with EGE's ASTs or USTs, it would be contained by surrounding concrete curbs which provide a secondary containment holding capacity of 3,300 and 7,700 gallons, respectively (SPCC). Each mobile refueling truck is equipped with a spill kit that contains oil absorbent materials, including pads, booms, and granular absorbent. Additionally, VVJC maintains two spill response vehicles: one is stocked with an assortment of oil absorbent materials and the second is equipped with a vacuum pump system and two 55-gallon collection barrels (SPCC).

EGE has two drainage areas that could potentially be affected by fueling operations. There are drains on both the North and South Ramps. The storm water on the North Ramp drains to the west and south into the Retention Pond, and the storm water on the South Ramp drains to the west and north into Detention Pond "A", as seen in Figure 1. The Airport storm water system is designed to retain storm water on-site. No discharge of storm water from pollutant-affected areas enters surface waters of the State (Airport Master Plan).

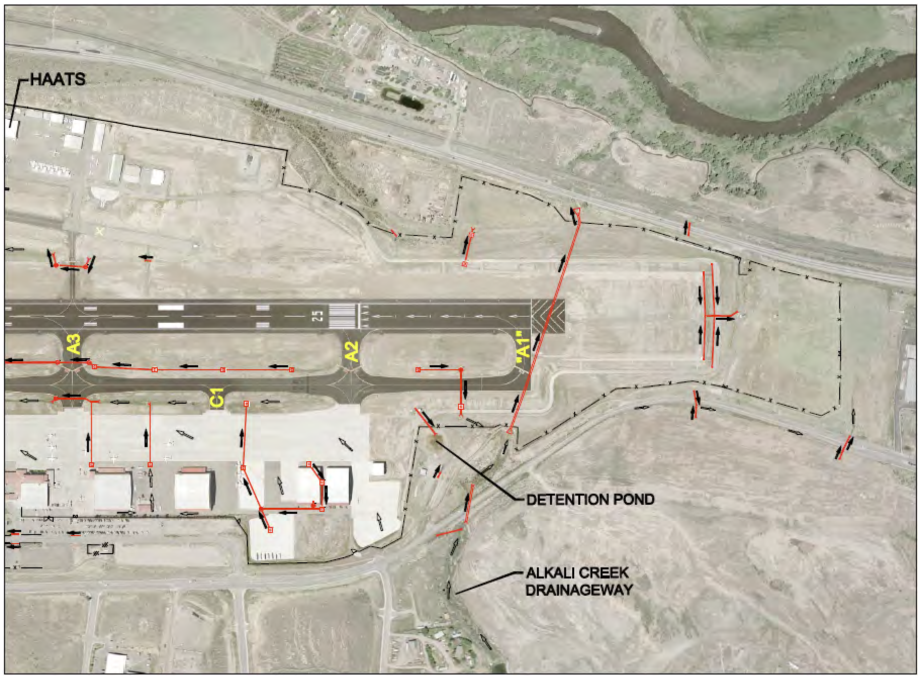

Figure 1: EGE Water Drainage

When a fuel spill occurs at EGE, the Aircraft Rescue and Fire Fighting (ARFF) crew is immediately notified and a response team is deployed. If a spill is larger than the ARFF can handle, the Eagle County Hazmat team is contacted and additional support is supplied. For smaller spills on paved surfaces that are less than 25 gallons, standard clean up includes the application of absorbent pads and a final treatment with Micro-Blaze. The ARFF crew wear chemical resistant rubber boots and gloves to protect themselves from direct dermal exposure to spilled fuel. For larger spills, VVJC will mobilize their spill response vehicles which vacuum the spill area and hold the product in their storage drums.

Future Operations

The Airport Master Plan for EGE provides a detailed forecast of the number of customers they expect to serve over the next 15 years. The resort industry in Summit County, Colorado provides the most business for EGE, with ski-driven passengers accounting for 60% of all enplanements (Airport Master Plan). The ski industry shows no indicators that it will see considerable growth over the next 15 years, but natural population growth will most likely result in an increase in customers for EGE. Historical data on population growth within the service area of EGE as well as an estimation for growth until the year 2030 can be found in Figure 2 (Airport Master Plan). As the amount of passengers served at EGE increases, so must the volume of fuel stored and transported at the airport. The increase in fuel handling will increase the potential for spills and thus require more efficient means of containment and remediation.

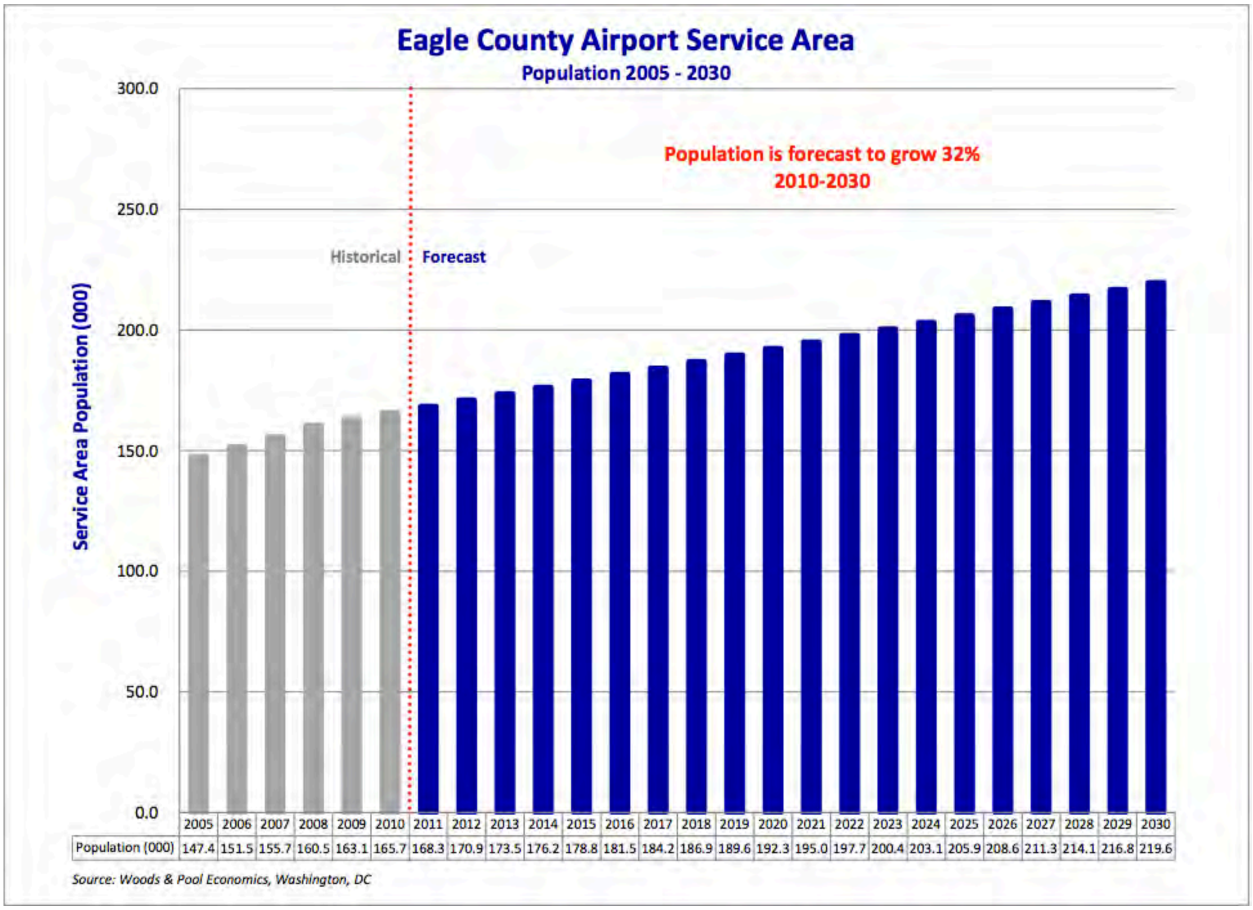

Figure 2: EGE Service Area Population Growth

Regulations

EGE is required by state and federal law to follow all pertinent environmental regulations. All of the alternative designs presented by Boulder Remediation Services will obey all regulations protecting the environment from hazardous material release. “Release” includes “any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment, including abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance, pollutant, or contaminant” (Reporting Environmental Releases In Colorado). EGE is required by law to report all fuel spills greater than 25 gallons from regulated aboveground or underground storage tanks to the Division of Oil and Public Safety (OPS) at the Colorado Department of Labor and Employment within 24 hours. Any amount of release that produces a visible sheen on waters of the state (including surface water, groundwater, dry gullies leading to surface water or storm sewers) must also be reported to the Colorado Environmental Release and Incident Reporting line (Reporting Environmental Releases In Colorado).

Before any fueling operations can be legally performed, a Spill Prevention, Control, and Countermeasures (SPCC) document must be written and approved. An approved SPCC demonstrates that all risks associated with fuel spills are understood and there are measures taken to mitigate the risk of contaminating groundwater, surface water, and soil (Oil Spills).

EGE currently has an approved SPCC through the work of the VVJC. Professional Engineer Paul Sorensen stamped his approval and co-signed the document with VVJC Operations Manager Thomas Kohl, confirming that the SPCC was within the regulations outlined by the Oil Pollution Prevention Code of Federal Regulations, Title 40, Part 112 (ECFR-Code of Federal Regulations). EGE must continually monitor their storage tanks and fueling operations to insure that they are following the details outlined in their SPCC. OPS performs regular field inspections and possesses the authority to prohibit EGE from continuing their use of USTs if any of the following conditions exist:

(1) Required spill prevention equipment is not installed, or functional;

(2) Required overfill protection equipment is not installed, or functional;

(3) Required leak detection equipment is not installed, or functional;

(4) Required corrosion protection equipment is not installed, or functional; or

(5) Upon the discovery of a significant violation that poses an imminent threat to human health or safety or the environment. In addition to delivery prohibition, OPS may also require the removal of product from the tank.

(6) Failure to register or maintain current registration on an UST (Storage Tank Regulations).

The Colorado Department of Public Health and Environment (CDPHE) Hazardous Materials and Waste Management Division regulates the maximum contaminant levels (MCLs) for the compounds found in Jet A fuel. Remediation of fuel spills must provide enough decontamination to reach the MCL for each compound so that runoff from the spill site does not harm the local environment.

Literature Review

Containment Booms

A containment boom is typically a 10 to 20 foot long temporary barrier used to restrict the spread of liquid contamination. Containment booms are primarily used during oil or fuel spills that occur on water. Since oil and most fuels are both hydrophobic and less dense than water, a spill will float on the water's surface. For this reason, containment booms are designed to float on the surface of the water, collecting the fuel or oil that has been spilled. Fuel spills that occur on land also pose a high risk of covering a large surface area, and can infiltrate local water supplies through existing drainage channels. To prevent either situation from occurring, containment booms are also utilized during land based fuel spills. The sorbent material included in containment booms varies and can be divided into three major categories: natural organic, natural inorganic, and synthetic. The following table, Table 1, illustrates the differences between each sorbent material used in various containment booms (Understanding Oil Spills and Oil Spill Response).

Table 1: Containment Boom Materials

Containment Boom Materials				
Sorbent Type	**Typical Composition**	**Oil Retention**	**Advantages**	**Disadvantages**
Natural Organic	peat moss, straw, hay, sawdust, ground corncobs, feathers	3-15 times their weight	inexpensive, readily available	non-reusable, may soak up water as well as oil, making disposal more difficult
Natural Inorganic	clay, perlite, vermiculite, glass, wool, sand, volcanic ash	4-20 times their weight	inexpensive, readily available	non-reusable
Synthetic	man-made materials such as polyurethane, polyethylene, nylon fibers	up to 70 times their weight	can be washed and reused, relatively high oil retention capabilities	relatively expensive

Bioventing

Bioventing is a custom approach for in-situ remediation of fuel-contaminated soil. It is designed for microbial biodegradation of the fuel and is for use in the unsaturated zone of the subsurface during winter conditions. The process involves drilling small wells and inserting pipes that will deliver steam to the subsurface. The steam heats the soil and provides air and water to better facilitate microbial activity. Verde Environmental Micro-Blaze® will also be injected into the wells to provide more microbes and nutrients. The resulting products are simply carbon dioxide and water and are safe for entry into groundwater (Micro-Blaze Emergency Liquid Spill Control).

There is a natural presence of microbes in the soil that are able to break down the constituents of jet fuel. An EPA study has shown that kerosene, one of the main and most harmful ingredients in Jet A, is readily biodegradable in only 28 days with less than 60% theoretical oxygen. The study also concludes that aerobic conditions and a suitable nutrient supply affect the rate and thoroughness of biodegradation. Sorption to the soil also limits the bioavailability of the fuel and prevents biodegradation (Kerosene/Jet Fuel CAD). Temperature is also a determining factor in the rate of microbial degradation and is especially important for EGE in the winter months, where the average soil temperature is 42°F (Dotsero Series). EPA studies claim that temperature may be the single most important parameter in the rate and effectiveness of microbial biodegradation. Temperatures that are too high will result in decreased activity, however, temperatures in the thermophilic range (120 to 140°F) are shown to be optimal for the decomposition of organic matter such as the hydrocarbons in jet fuel (Iqbal).

Containment Channels

The idea behind a containment channels can be traced back to the aerospace industry and NASA. Engineers noticed the need to reduce standing water on roads to cut back on hydroplaning accidents. To achieve this goal, grooves were cut into the highway to allow for the drainage of pooled water on roadways. (Dunbar). Fuel spills on land tend to spread evenly as that is the natural tendency of liquids. Channels placed near areas prone to fuel spills could double as a holding reservoir or as a guide to redirect a fuel spill to a safe holding location.

Concrete exists with imperfections such as pores, cracks and a potential to allow permeation through its boundaries. A fuel spill occurring on cracked concrete allows direct infiltration into bare earth. A solution to liquid absorption is to add an admixture to the concrete to make a hydrophobic surface and self-healing micro scale cracks (Hycrete).

Tiller & Absorbent Dispenser

A tiller and absorbent disperser employs the use of a large rear-tined lawn tiller, equipped with an absorbent dispenser that sprays the affected area as it is churned by the tiller. This method combines elements of bioventing with the utility of a handheld absorbent dispenser. The tiller allows for oxygen to be introduced to microbes beneath the surface, which is used as fuel to increase their degrading activity. Aerobic degradation of hydrocarbons is an important and effective method for remediation of spilled contaminants, so increasing microbial activity is a desirable and simple method for achieving this goal. More importantly, this method employs the use of absorbent over the affected area to increase our ability to contain and clean a spill. The spraying of absorbent over the tilled area will help to contain the spill and prevent it from spreading and further penetrating the soil while the microbes can continue to degrade. The typical absorbent product can hold up to six times its weight in hydrocarbons, so it is efficient and easily cleaned after it has soaked up the remaining spill (Kengro).

Problem Solving Approach

Boulder Remediation Services has developed a list of constraints and criteria used to evaluate each design alternative. The design guidelines outlined by the FAA as well as the expectations of the customer were equally considered in developing the constraints and criteria. Boulder Remediation Services took into account what the design is supposed to accomplish and what factors will create a successful product. If a proposed alternative does not meet the constraints and criteria, it will be filtered out and not given a thorough analysis. Some of these factors include the budget at EGE, the seasonal variation in airport traffic, the challenges of extreme winter weather, and the type of fuel spills that occur.

The constraints that will help determine which alternatives are evaluated are based on external and situational factors. They are as follows:

- Cost effective: The design must be of reasonable initial cost to the airport and is preferred to have low operational and maintenance costs. The cost will be evaluated using net present value.
- Ease of implementation: The design is preferred to fit in well with current methods being used at the airport or would require minimal work to install or use.
- Relevance to customer needs: The design must address the main issues facing the airport. The main fuel spill issue at EGE is above ground spills.
- Innovation: The design must be creative and solve the problem in a unique way.

The criteria express the desired level of functionality and requirements that must be met by the design to be considered a viable alternative for the final solution. They will help further narrow down the alternatives and are as follows:

- Prevent contamination: The design must effectively prevent fuel from contaminating the ecosystem. This can be either by cleanup or quick remediation of the spill.
- Dependable: The design must be trusted to perform its intended purpose repeatedly and in varying conditions.
- Environmental impact: The design must have minimal impact on the surrounding ecosystem. Therefore, the use of harsh chemicals to clean a spill is not desired.

The constraints and criteria were used to develop a decision matrix. The matrix rates each alternative against six categories and assigns a weight to each category. These weightings will be assigned by the team, with input from EGE. The decision matrix template is shown below in Table 2.

Table 2: Decision Matrix Template

Decision Matrix					
Criteria	**Weight**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
Capital cost	0.13				
O&M costs	0.18	Rated on a scale of 1 to 10			
Ease of implementation	0.12				
Contamination control	0.2				
Dependability	0.2				
Innovation	0.05				
Environmental impact	0.12				
TOTAL	1				

Some design alternatives were immediately filtered out based on the constraints and criteria for the following reasons: they were utilizing existing technology in a way that is already being practiced, they were too expensive, or they were ineffective at addressing the most common type of fuel spill at EGE.

Soil vapor extraction (SVE) was eliminated as a possible alternative because of high energy costs and decreased effectiveness in winter conditions. SVE is an energy intensive process when using three phase or six phase heating of the ground. Electrodes are inserted in the ground and electricity is run through them to heat the soil and volatize the constituents of the fuel. This vapor is then vacuumed from the soil or captured as it rises to the surface. This could be a problem in the winter as much of the ground is covered in snow and ice, preventing the gases from escaping. SVE raises the soil to very high temperatures, which can kill many microbes in the soil that would otherwise contribute to biodegradation. Portable adsorbent dispersers were considered for cleanup of small spills on paved surfaces. This idea was not evaluated any further because it is already in widespread use in many airports, including at EGE. Better fueling procedures were considered as a possible process design goal, but were not pursued any further. The VVJC at EGE already has a SPCC plan in effect that governs the safety regulations and operating procedures of filling and emptying tanks and mobile refueling vehicles. The procedures are in accordance with FAA guidelines and appear to be sound.

Required Interactions

Our contact and chaperone at Eagle County Airport was Captain Bryan Kohrmann of the ARFF. Initially we believed a phone call would suffice as supplying us with enough information, however upon further research it was evident that a visit was needed. Two trips were made throughout the semester. One trip was to vaguely inspect the fueling locations and operations to determine what could be done to help environmental interactions. The second was made to take measurements and ask more detailed questions in person. Bryan Kohrmann helped on both occasions by escorting us to all areas of interest. He was extremely helpful in providing us with EGE operational guidelines, figures of EGE, and fuel spill incident reports. Captain Kohrmann pointed out the areas of concern to us that would have otherwise gone unnoticed. Direct interaction with Hycrete failed to occur, however a Hycrete W1000 distributer, Green Depot, responded to our price inquiries. Joe Kearns of Green Depot provide an estimate for our W1000 requirement. Another contact of ours at the airport was Tom Kohl, the operations manager at the Vail Valley Jet Center. Tom provided detailed protocol on what to do in case of spills. This was laid out in the 2011 VVJC SPCC, but Tom provided personal testament on what actually occurs. Phone calls were made to Elastec American Marine and Front Range Rubber regarding material pricing for the heated boom containment system alternative.

Alternative 1: Heated Boom Containment System

Brief Description

The first design alternative BRS has to offer aims to solve fuel spill containment issues during winter operating conditions. When fuel is spilled on powder or packed powder snow, or unconsolidated ice, conventional lightweight hydrophobic containment booms may allow fuel to pass beneath them. The HBCS is a modified version of existing containment booms that includes an electric heating element to melt through any snow or ice and insure direct contact between containment boom and solid ground. The HBCS's newly designed quick connect system allows first responders to efficiently combine multiple lengths of booms if the volume of a spill requires a large area of containment. The HBCS booms are filled with shredded rubber from recycled automotive tires and are protected by a durable Hypalon/Neoprene shell that can be cleaned and reused for multiple spills without concern for cross contamination. Shredded tire rubber is readily available, relatively inexpensive compared to other types of fill, and provides the perfect amount of added weight to the HBCS to aid in its ability to sink through snow or ice. Each boom is 16 feet long and weighs roughly 240 pounds.

Advantages & Disadvantages

The advantages and disadvantages of this alternative are summarized in Table 3

Table 3: HBCS Advantages & Disadvantages

Heated Boom Containment System	
Advantages	**Disadvantages**
Effective at containing spills on snow and ice	Spills over snow and ice are not of great concern to EGE
Materials are resistant under harsh conditions	HBCS booms are much more costly than typical containment booms
Boom is easy to transport and operate	The boom is not self-powering, so it requires an external energy source
Recycled rubber material used to fill boom makes it a sustainable design	Consistent application of absorbent may be disadvantageous when heavier application is needed in certain areas

Cost

The major cost associated with the HBCS is its capital cost. The durable materials used in the construction of each boom add to the relatively high cost for a single boom. However, once a boom is purchased there are no maintenance costs, and extremely minimal energy costs. The estimated 20-year lifespan of HBCS booms make them a very attractive value as most booms used for land based fuel spills are not reusable. The breakdown of material costs is outlined in Table 4 below.

Table 4: HBCS Cost Analysis

Heated Boom Containment System Cost Analysis (Price per Boom)				
Material	**Unit Price**	**Quantity**	**Total Price**	**Source**
Shredded Tire Rubber	$0.10/lb	240 lbs	$24	ffrubber.com
19-Guage Hardware Cloth	$0.68/ft^2	16 ft^2	$11	homedepot.com
Resistance Heating Wire	$0.95/ft	48 ft	$45.39	morelctricheating.com
Heat Shield	$6.25/ft^2	16 ft	$100.00	Amazon.com
Hypalon/Neoprene Shell	$1.06/ft^2	54 ft^2	$57.24	elastec.com
Total Material Cost:			**$237.63**	

Alternative 2: Bioventing

Brief Description

The design to accomplish a custom implementation of bioventing will be a standalone system with everything needed for soil remediation on one mobile platform. This allows for quick and easy deployment to anywhere on the grounds of EGE and minimal personnel required for operation. All components of the design will be installed and transported on a double-axle flatbed trailer. The major objectives the design will accomplish are soil augering, steam injection, and Micro-Blaze® application.

The holes for steam injection into the subsurface are created using a gas powered auger. There will be four, six-foot deep holes drilled and perforated pipes will be inserted into the holes. Each injection pipe has a radius of infiltration of about six feet, allowing treatment of 100 cubic yards of soil for each treatment. A steam generator will be used to produce dry steam and inject it into the ground. The top part of the injection pipes will be connected to the steam generator with appropriate hoses. The steam generator operates on #2 diesel fuel and electric power and also requires a water feed. The electric power will be supplied by a generator that runs on unleaded gasoline. There is a large water tank and electric transfer pump to supply water at the required rate and pressure. The steam generator, electric generator, water tank, and water pump are all mounted on the trailer for ease of initial assembly and transport.

After the soil has been treated with steam injection, the Micro-Blaze® concentrate will be mixed with the water from the storage tank to a 3% concentration. Verde Environmental recommends that one gallon of Micro-Blaze® concentrate be used for every ten cubic yards of contaminated soil. To treat 100 cubic yards of soil, 10 gallons of Micro-Blaze® will be combined with 330 gallons of water. The steam delivery hoses will be removed from the aluminum pipes and the Micro-Blaze® solution will be poured down the pipes to reach the contaminated subsurface soil. The solution may also be applied on the soil surface with a hand held pump sprayer.

Advantages & Disadvantages

The advantages and disadvantages of this alternative are summarized in Table 5.

Table 5: Bioventing Advantages & Disadvantages

Bioventing	
Advantages	**Disadvantages**
Custom design	Only effective for spills over open ground
Proven and effective methods	Only able to treat unsaturated zone of subsurface
In-situ	High capital cost
Minimal labor required for operation	Can only treat finite amount of soil per operation

Cost

The cost of this design is broken into capital and operation and maintenance (O&M). The capital costs include all the components necessary to assemble the design thus far. The O&M costs are dependent on the extent of use and are reported on a basis of the amount of soil that is affected per treatment. The O&M costs include Micro-Blaze® concentrate, gas, and water for various uses. These costs also include the estimated labor for operation. There are likely few maintenance costs involved with this design. In comparison to the option of hiring an external form to manage the cleanup, this design has a much cheaper operating cost. A Canadian company typically charges $50 to 90 per cubic meter of soil treated by in situ biopiles using bioremediation (Hambly). If 500 cubic yards of soil needed to be treated, their cost would be anywhere from $19,000 to $34,000. This custom bioventing design would cost less than $14,000. The payback period for a project with a high capital cost like this one is an important consideration. In this case, time is not really a factor, but rather the amount of soil treated. When compared to the median cost of biopile treatment methods at $70 per cubic meter, the payback period for the bioventing design is reached once 240 cubic yards of soil have been treated. This could be reached during one cleanup or over multiple separate cleanups. A summary of the estimated costs are shown in Table 6.

Table 6: Bioventing Cost Estimate

Cost Estimate		
Category	**Capital**	**O&M (per 100 yd^3)**
Soil Auguring	$ 1,568.00	$ 2.00
Steam Generation	$ 5,911.00	$ 7.00
Micro-Blaze® injection	$ -	$ 304.00
Self-containment	$ 2,920.00	$ 2.00
Miscellaneous	$ 1,500.00	$ 80.00
TOTAL	**$ 11,899.00**	**$ 395.00**

Alternative 3: Containment Channels

Brief Description

Containment Channels are a collaboration of a hydrophobic admixture and grooved concrete. BRS's containment channels allow the control of a large fuel spill by passively guiding the fuel to a predetermined location. For small spills that fail to create a flow, the channels would act as small containment reservoirs. The hydrophobic properties would reduce porosity and penetration of fuel into the concrete, which would make cleanup easier than that for fuel spilled on traditional concrete. BRS's containment channels are specific for each scenario allowing for lower costs and higher effectiveness. The channels are inset into wet concrete by a custom shaping trowel. The trowel will differ depending on the requirements of the channels.

Advantages & Disadvantages

The advantages and disadvantages of this alternative are summarized in Table 7.

Table 7: Containment Channels Advantages & Disadvantages

Containment Channels	
Advantages	**Disadvantages**
Passive system	Extremely high capital cost
Allows channels to act as holding ponds for small spills, facilitating clean-up	Ice and debris can inhibit flow through the channels during winter conditions
Able to drain large spills into a holding tank	Requires drainage infrastructure
Removal of standing water around aircraft at fueling station	

Cost

For a preliminary cost estimate, BRS chose Hycrete W1000 as the admixture. The W1000 concrete is accompanied by a cost of $3.7 per cubic foot (Concrete That Fears Water No More). The price of Hycrete coupled with the surface area gives a liberal estimate of $133,000.

With further research the price will decrease slightly due to an increase in efficiency and ideal placement. Man-hours were estimated at 300 man-hours to clear the existing concrete with heavy machinery and 300 man-hours to lay the channels. Demolition and construction labor billed at $20 per man-hour gives a total price of $12,000 for labor. Including these estimations, the final cost of implementing containment channels comes out to be $145,940 for the Eagle County Regional Airport. The cost estimates can be seen in Tables 9 & 10 below.

Table 8: Containment Channel Costs

Containment Channel Costs		
Location	**Surface Area (ft^2)**	**Cost (\$ per ft^2)**
Fuel Farm	100	3.7
Apron	36,000	3.7
AARF UST	100	3.7
Total		**133,940**

Table 9: Man Hour Costs

Man Hour Costs			
Job	**Hours**	**Price (\$/hr)**	**Total (\$)**
Removal	300	20	6000
Placement	300	20	6000
Total			**12,000**

Alternative 4: Tiller and Absorbent Dispenser

Brief Description

The fourth design alternative proposed by Boulder Remediation Services is a tiller and absorbent dispenser. When contaminant is spilled on soil, the tiller is used to aerate the soil and increase microbial activity and hydrocarbon degradation. The absorbent is then dispensed over the soil in order to soak up the contaminant and prevent it from spreading through the soil and into the water table. Based on past incidents at the airport, we expect to encounter spills of no more than 100 gallons (Kohrmann). As this alternative is a surface remediation solution, we are chiefly concerned with spills from fuel trucks, as the storage tanks are below ground and have been incident free in the past. Based on previous incidents, we expect the area of the spill to cover no more than a 25-foot radius (Kohrmann).

Advantages & Disadvantages

The advantages and disadvantages of this alternative are summarized in Table 10.

Table 8: Tiller & Absorbent Disperser Advantages & Disadvantages

Tiller and Abosrbent Disperser	
Advantages	**Disadvantages**
Quick application	Ineffective against spills penetrating deeper than 18" into the soil
Prevents mobilization of contaminant through soil and groundwater	Snow and ice may neutralize the remediation; removal will take time and may cause the spill to penetrate too far
Non-toxic	Unable to address spills that do not happen on top of soil (i.e asphalt, concrete, etc.)
Consistent application over a given surface area	Consistent application of absorbent may be disadvantageous when heavier application is needed in certain areas
Capable of covering large areas as compared to handheld dispensers	
Aerobic degradation supplements the utility of the absorbent	
Cost-effective	
In-situ	

Cost

The cost associated with this design comes mostly in the form of up front capital. Buying the tiller and hopper represent most of the capital costs. The purchase of absorbent will be associated with operating cost, and will be a function of the frequency of spills at EGE. Other operating costs include fuel for the tiller as needed. The design is relatively simple and durable, so maintenance costs are not anticipated to be noteworthy. The summary of cost estimates is shown below in Table 11.

Table 9: Tiller & Absorbent Disperser Costs

Cost			
Sorbent Type	**Capital**	**O & M**	**Maintenance**
Tiller	$2,500	Fuel as needed	Small repairs
Hopper	$500	-	Small repairs
Absorbent	-	~$150/spill	-

Decision Matrix

A weighted decision matrix was used to grade each of the alternatives. The decision matrix was developed from the constraints and criteria along with applicable regulation set forth by the FAA. The matrix also takes into account the wishes of the FAA design competition and EGE. Each category was given a weight from zero to one to determine its importance. Then, each alternative is scored on a scale of one to ten in each category. The sum of the weighted averages is the overall score for that alternative. The alternative with the highest score will be selected for the final design.

The final criteria were the following: Capital Cost, O&M Cost, Ease of Implementation, Contamination Control, Dependability, Innovation, and Environmental Impact. Each alternative was given a score out of 10 for each of the criteria. The weighting of the criteria, along with the scoring for each alternative is summarized in the Decision Matrix shown in Table 12.

Table 10: Completed Decision Matrix

Decision Matrix					
Criteria	**Weight**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
Capital cost	0.13	8	5	3	6
O&M costs	0.18	9	8	10	8
Ease of implementation	0.12	8	7	5	8
Contamination control	0.2	5	7	9	5
Dependability	0.2	7	8	9	9
Innovation	0.05	8	5	6	5
Environmental impact	0.12	8	9	8	9
TOTAL	1	7.38	7.26	**7.65**	7.31

The containment channels were selected for satisfying the constraints and criteria the best, therefore scoring highest in the decision matrix. They address the most common and relevant problem at EGE and airports everywhere, which is fuel spills over paved surfaces during fueling operations. The containment channels have a very high capital cost, but essentially no O&M cost once installed. EGE already has equipment in place to handle runoff of fuel and oil mixed with water. The construction process would be intrusive, but the dependability of the channels and the effectiveness they provide is a very strong positive side. There are no harsh chemicals that must be used for the channels to perform their duty, making them very environmentally friendly. The containment channels are an excellent choice to solve the most relevant problem at EGE in an efficient manner.

Technical Description of Containment Channels

Most fuel spill incidents at EGE occur on the fueling apron (Korhmann). The spills on the apron are mostly confined to the region directly underneath the mobile fuel truck, the fueling line, and the aircraft's wing fuel vents. Upon inspection, the fueling apron at EGE was littered with stains of past spills that lacked complete clean up in the aforementioned regions. Although there has been no environmental impacts seen in local groundwater samples, the remnants of hydrocarbons is unsettling. Our goal is to allow for the containment of fuel spills of any size, and promote the complete removal of all hazardous constituents.

Background

Containment channels are a system of grooves inset into concrete promoting containment and redirection of spilt fuel. The inspiration behind the design arose from highway grooves. Systems of grooves on a highway surface allows for the removal of standing water. Concrete is naturally porous and can retain liquid or fuel. In order for maximum clean up efficiency, fuel would bead on top of a surface and have minimal infiltration into the surface. Applying an admixture to the concrete can help hydrophobic properties to promote an impenetrable surface.

Initially we reviewed the incident reports on EGE grounds and found no major spills that occurred in the same location. What we found out through interviews was that the fueling apron was the location for numerous spills under five gallons. These spills occur frequently and do not require formal incident reports. Due to the large surface area covered by the fueling aprons, we determined five specific areas that had the highest risk for spills and designed containment channels around these areas.

The method to achieve the goals mentioned above first began as a membrane added to the grooves of the channels. This proved to have a higher initial cost than an admixture as well as a lifetime of around 5 years in the Colorado climate. Sunlight and abrasion both significantly reduce a hydrophobic membrane's lifetime. The idea of a hydrophobic membrane was quickly discarded and replaced by hydrophobic admixtures.

Our design was developed in accordance with EGE's plan to repave the fueling apron. The master plan of EGE specifies locations and dates of planned repaving. We took this repaving plan into account when determining what alternatives were too costly. Our intention was to play off of the planned repaving and incorporate the admixture and troweling techniques simultaneously. The combination of repaving and incorporating our design reduces our capital cost significantly. Funding for the channels can now exclude demolition and concrete costs and can be represented by the admixture and installation techniques alone. A schematic of the current fueling apron conditions at EGE can be seen below in Figure 3 (Airport Master Plan).

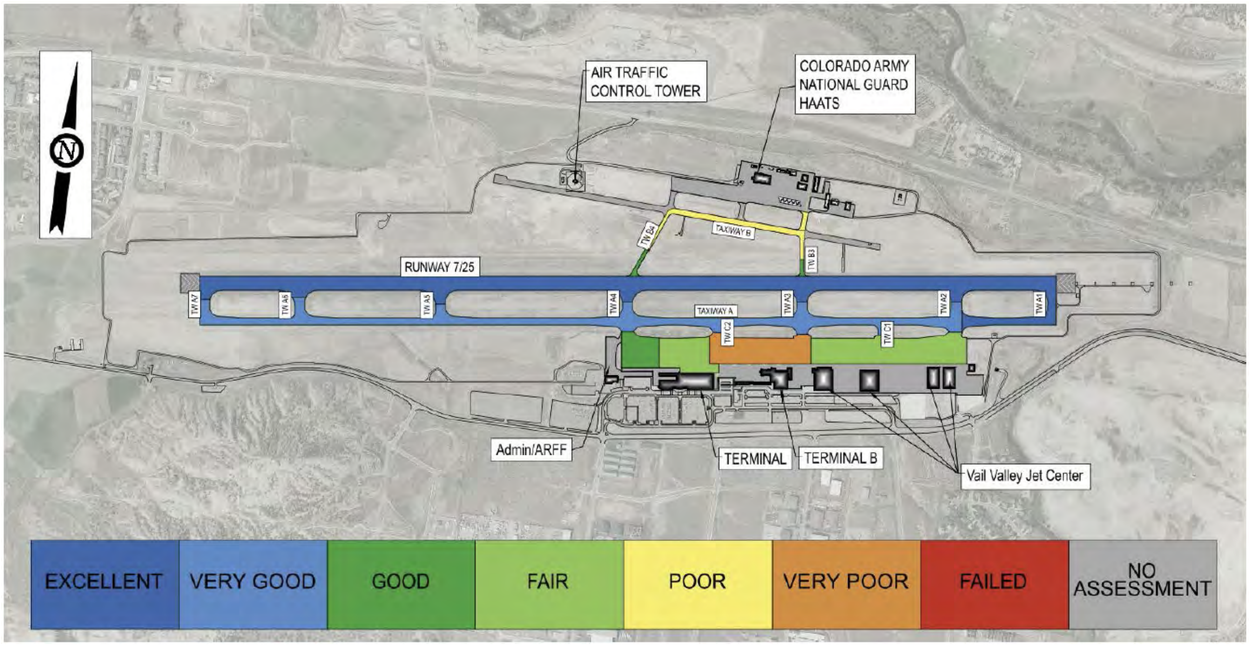

Figure 3: EGE Pavement Conditions

Design Layout

The figure below, Figure 4, shows an overhead view of the proposed containment channel design layout. The purple shaded area labelled as the Terminal contains the five most heavily trafficked gates for commercial air travel at EGE. The five locations in front of these gates are the most used areas of the GA Apron for fueling and boarding operations, and are the areas our design focuses on. To the west of the GA Apron are two spots for deicing operations, shaded blue in the figure. The commercial de-ice area and the entire GA Apron has a slight grade so that any runoff drains to the north and west (USGS). There are trench drains that collect runoff from the de-ice area and lead to a glycol recovery tank, which then leads to the detention pond, shaded teal in the figure. The grooved concrete sections, shaded green, the trench drain, and the concrete channels, colored red, are the focus of our design.

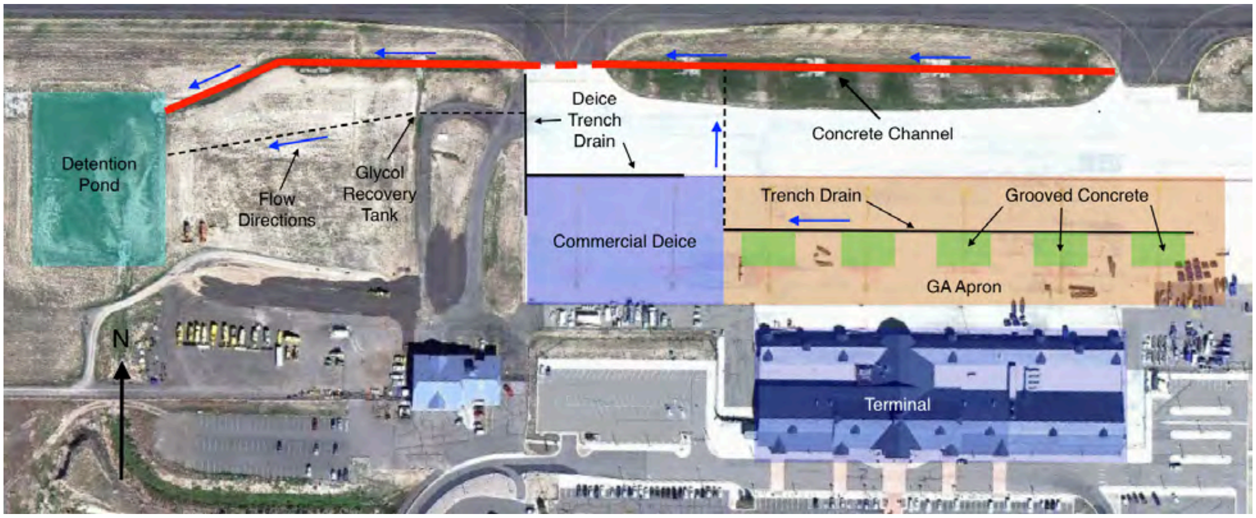

Figure 4: Design Layout

The green shaded sections of the GA Apron are where containment channels are to be implemented. The area of each green section is 100 feet by 80 feet, which is sufficient to cover almost any spill that would occur during fueling operations with commercial aircraft (Kohrman). The areas to be grooved with containment channels are aligned so that they are centered under the fueling and venting ports on the most common aircraft that use gates one through five. The location of the containment channels allows them to catch any fuel that is spilled or sprayed from the aircraft or fueling equipment. The channels run with the slight gradient of the GA Apron from south to north. At the north end of the five areas outfitted with containment channels, there is a trench drain that runs east to west across the GA Apron. The trench drain is similar to the one used in the de-icing area to the west. The trench drain is covered with a metal grate and positioned so that the back wheels of parked aircraft are not resting on it. The trench drain allows runoff from a fuel spill or simply precipitation to flow to the west. Then, the drain turns to the north and routes under the concrete to the concrete channel, labeled in red in Figure 4.

Currently, the labeled location of the concrete channel is overgrown and has pooling problems. EGE plans to fix these channels to promote flow to the detention pond (Kohrmann).

The detention pond allows trace amounts of fuel and other substances to settle and filters them out through the bottom layer of the pond. The runoff from this pond drains to the Eagle River and is tested quarterly by EGE. All water quality samples tested at this location have been within EPA regulations (Kohrman).

Containment Channel Description

The five areas of the GA apron that are to be grooved with containment channels are each 8,000 square feet. The areas are grooved with one inch wide and one half inch deep grooves, spaced three inches apart. The stated dimensions result in 300 channels, each 80 feet long. Figure 5, seen below, illustrates the layout of the containment channels and the trench drain.

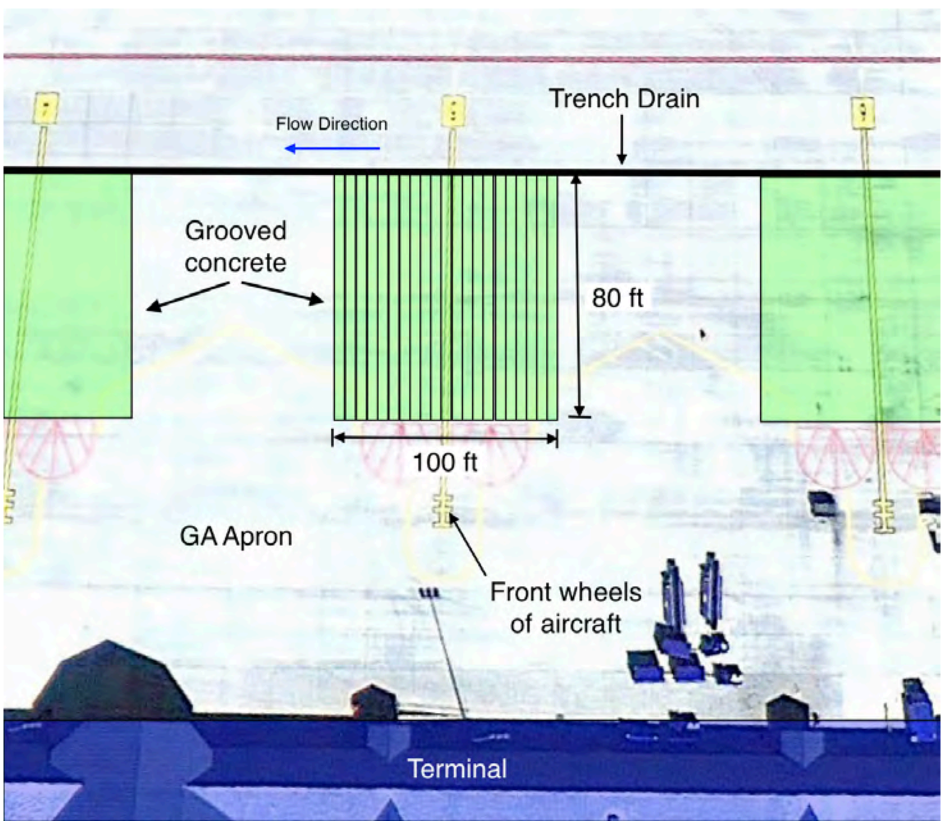

Figure 5: Containment Channels

The channels will be installed by hand using a grooving tool that cuts through the wet concrete before it cures. The channels run from south to north and have a slight gradient of 0.006

feet/foot to allow fuel or other liquids to flow into the trench drain. Using these stated specifications and calculations shown below in Table 13, the containment channels in each grooved area of concrete will have a storage capacity of 624 gallons. The storage represents the amount of standing liquid that the channels could contain if there was no flow to the trench drains. The flow that each area of channels can handle was calculated using the Manning Equation, shown below. The result of the Manning Equation shows that each channel can carry a flow of jet fuel of 0.75 gallons per minute to the trench drain, resulting in a total flow of 225 gallons per minute for each grooved area of concrete.

Table 11: Channel Flow Calculations

Flow Through Each Channel							
n	**Width(in.)**	**Depth (in.)**	**Area (ft^2)**	**R (ft)**	**S (ft/ft)**	**Q (ft^3/sec)**	**Q (gal/min)**
0.018	1	0.5	0.0035	0.0208	0.0060	0.0017	0.7566

Manning's Equation: $Q = \left(\frac{1.49}{n}\right) A R^{\frac{2}{3}} \sqrt{S}$

Assumptions: The slope value of 0.006 ft/ft was found using a USGS topograhic map for Eagle County, Colorado (Gypsum quadrant). The Manning's equation is developed for water flowing through an open channel, so the Manning's Roughness Coefficient (n) used in this design is higher than that describing smooth concrete in an effort to accomodate for the higer viscosity of jet fuel.

According to the VVJC SPCC, the refueling trucks for the commercial aircraft pump jet fuel at a rate of 200 gallons per minute. If there was a problem such as the fuel line coming detached while fuel was flowing, it is stated that the average response time for the pumping to be shut off would be 10 seconds (SPCC). Based on the average response time to stop the spilling fuel, approximately 34 gallons of fuel could be spilled during a commercial refueling incident. The storage capacity of the containment channels design provides complete insurance that the average size spill of five gallons or less will be contained.

The appropriate time for the new trench drain and underground routing to the concrete channel to be installed will be as the existing GA Apron is replaced. When the existing concrete and its base is excavated, the underground routing can be installed before new concrete is poured. As the new concrete is poured, the trench drain can be formed and its grate installed.

Hycrete W1000

Hycrete W1000 is a water based concrete admixture. The mechanism behind Hycrete W1000's hydrophobic properties resides in pore elimination. Polymers are used to block the naturally occurring pores during the curing process. Hycrete tests show that W1000 reduces absorption to less than 1% (Hycrete). A surface limiting water absorption to less than 1% is qualified as hydrophobic by the British Standards Institute. Hycrete has been implemented in parking structures, bridges, building foundations, water tanks, and pools to name a few (Hycrete). The water repellant properties of W1000 can be seen in Figure 6 (Solaripdeia).

Figure 6: Hycrete Hydrophobicity

The grooved areas of concrete will contain the Hycrete W1000 additive to provide hydrophobicity and promote flow within the containment channels. The Hycrete will also decrease visible staining and residue from fuel and oil due to the reduced porosity. Limiting water permeation into the concrete, especially in winter climates, will extend the lifetime of rigid surfaces by reducing expansion and contraction of water phase changes.

Each grooved concrete area is 80 feet by 100 feet and there are five of these areas on the GA Apron. In order to support the weight of commercial aircraft, the concrete must be 18 inches thick (Kohrman). This results in 60,000 cubic feet of concrete that will need to be mixed with the Hycrete additive.

Containment Channel Fuel Recovery Vacuum Head

Eagle County Regional Airport currently uses a fuel response cart equipped with an industrial vacuum and two 55-gallon storage drums when responding to fuel spills on paved surfaces. If the fuel recovered with the vacuum has not been in contact with water or significant debris, it can be removed from the storage drums and reused. The vacuum head currently used in this process (as seen below in Figure 7) is 18 inches wide and designed to be used on smoothly paved surfaces.

Figure 7: Fuel Recovery Vacuum

As a part of the overall containment channels system design, BRS has developed a new vacuum head that will effectively recover spilled fuel from the containment channels. The newly designed vacuum head will fit directly onto the existing vacuum hose and its innovative design will make it simple to use. With a total width of 21 inches, the new vacuum head will decrease fuel spill cleanup time by covering a larger area than the old vacuum head. Instead of the conventional linear design, the containment channel fuel recovery vacuum head has six male fittings spaced three inches apart to fit directly into the containment channels. The vacuum operator will sink the fittings into the containment channels and perform normal vacuuming procedures. The basic design of the new vacuum head can been seen below in Figure 8.

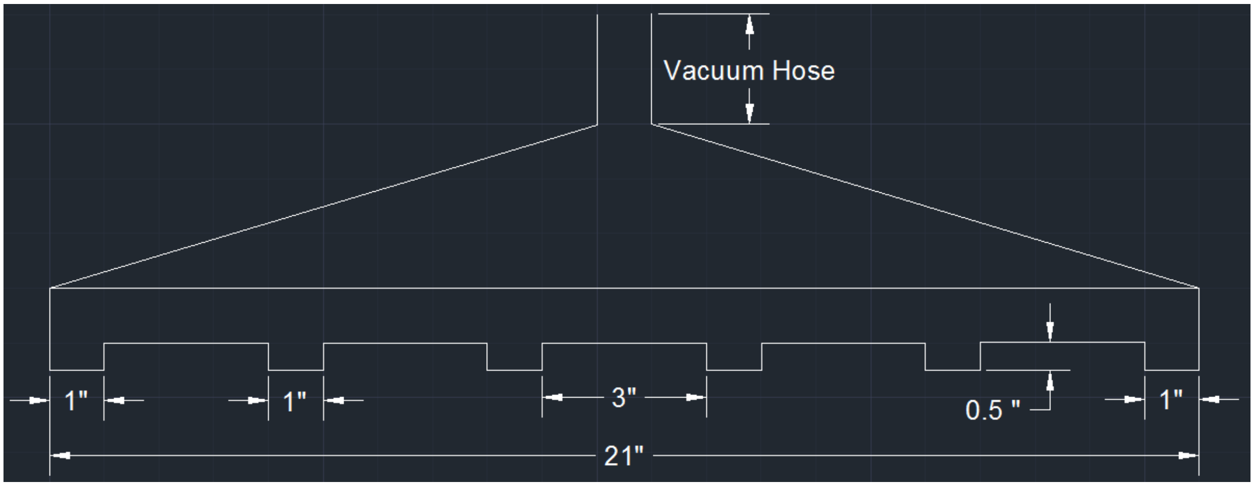

Figure 8: Fuel Recovery Vacuum Head

The design material and layout of the containment channels provides sufficient containment of spilled fuel without the need to apply any absorbent materials. Spilled fuel that is not treated with absorbent mats or clays can be easily recovered and reused. The combination of the containment channels and the newly designed vacuum head provides improvement in fuel spill containment, cleanup, and recovery for future use when responding to any size spill on the fueling apron.

Projected Impacts

The background research conducted by BRS showed that there are already numerous products available to biodegrade any type of fuel that may be spilled at an airport. Microbial absorbents are widely used at airports around the world, and are capable of neutralizing all toxic components of jet fuel within a matter of minutes. During a visit to EGE, BRS learned the extent of the capabilities of Micro-Blaze® through a story told by the ARFF captain Bryan Kohrmann. Mr. Kohrmann explained that a Micro-Blaze® representative applied a dose of the product to a glass of gasoline and proceeded to take a drink from the glass just 30 minutes after applying Micro-Blaze®. It became apparent that the major issue facing fuel spill response at airports was not a lack of chemical treatment, but rather a need for an innovative fuel spill containment and recovery strategy. Implementing containment channels at EGE will provide permanent fuel spill containment that is ready to handle any size fuel spill at any time. Unlike current containment methods, a response crew does not need to deploy booms or absorbent pads, instead, the containment channels begin providing containment as soon as a spill occurs. Through the use of the vacuum head designed for the containment channels, spilled fuel can be easily recovered for reuse. The limiting factor in the implementation of the containment channels is the need to resurface the fueling apron with Hycrete. In the case of EGE, a repaving project is already in progress, so setting containment channels would mesh well with current airport operations.

Financial Analysis

After talking to Joe Kearns of Green Depot, BRS received a cost estimate for the W1000. Mr. Kearns specified a retail cost of $379.95 per 5 gallon pail. He also stated a 20%-30% reduction for volume pricing. Using our estimated volume of 60,000 cubic feet and a known requirement of 1 gallon per cubic yard of concrete, our cost estimate for admixture comes out to

$135,093. EGE’s prior intention to repave the apron allowed us to exclude any costs related to concrete demolition or construction. The weight of the Hycrete W1000 required is 18,900 pounds. The closest Green Depot store to Eagle, Colorado is in Portland, Oregon. Using an online freight shipping estimator, the cost of shipping the load 1162.1 miles to the construction site is $2071 (UShip). The estimated cost of labor for finishing or laying grooves into the wet concrete was determined by using RSMeans. A steel trowel finish garnered an installation cost of $0.2 per square foot. (RSMeans) It is assumed that a custom molding be fabricated and dragged through the concrete to reduce labor costs. Assume the labor cost for troweling be reduced to $0.1 per square foot. A summation of all costs brings forth a price of $141,164 for the W1000 raw admixture, shipping, and labor associated with laying the channels.

Containment channels have the potential to be installed commercially around the world if capital costs can be offset through careful design scheduling. Airports that are planning on resurfacing their fueling aprons can include a containment channel design for approximately $3.5 per square foot. The exact layout and sizing of each containment channel system will vary from airport to airport, but each design will provide sufficient containment for as large of a spill as the customer would like to be protected for.

Funding

Amongst the FAA Airport Improvement Program (AIP), Eagle County Airport is looking for sources of revenue to forward airport improvements and reduce debt. EGE is currently the only airport in Colorado that does not impose parking fees on patrons. Parking fees along with customer facility charges (CFC’s) such as car rental fees, are estimated at having the potential to bring in $650,000 a year. EGE also currently does not charge GA landing fees. The EGE master plan estimates the 2014 potential at $500,000. The implementation of the previously discussed sources could potentially bring in $1.15 million in 2014. Funding of BRS's containment channels would be 12% of one year's newly acquired revenue (Airport Master Plan).

Conclusion

In this design report, Boulder Remediation Services has evaluated four alternative solutions to improving the fuel spill containment and cleanup operations at the Eagle County Regional Airport. A decision matrix was developed based on a number of constraints and criteria in order to provide a framework for choosing the best design alternative. After weighting each alternative based on the decision matrix, the fuel containment channels design alternative was selected. BRS worked alongside ARFF Captain Bryan Kohrmann in deciding which areas of the airport are in highest demand for fuel spill response improvements, and the fueling aprons located at the five most heavily trafficked gates were selected. A series of containment channels and a main drain were designed to be implemented during the future resurfacing of the fueling aprons, which is already in the planning stages at EGE. Improving on existing technologies already in use at EGE, BRS has designed a new vacuum head to be used in cleaning the containment channels of spilled jet fuel. Looking forward, BRS hopes to work with more airports in need of a containment channels system.

Appendix A - Contact Information

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Appendix B - Description of the University

The University of Colorado Boulder (CU-Boulder) is located at the base of the Rocky Mountains at an elevation of 5,430 feet. CU-Boulder is Colorado's largest university and was established in 1876. The University is research driven, and is home to many Nobel Laureates, MacArthur Fellows, and astronauts.

CU-Boulder has consists of several colleges, with the College of Arts and Sciences being the largest. The College of Engineering and Applied Science is ranked 28^{th} nationally, while the Environmental Engineering program is ranked 21^{st} nationally. The Bachelor of Science degree in Environmental Engineering is accredited by the Engineering Accreditation Commission of ABET. The program allows students the opportunity to specialize in one of the following sub-areas of Environmental Engineering: water resources management and treatment, air quality, ecology, remediation, chemical processing, and energy (engineering/EnvEng).

The University also provides students many opportunities for involvement in a variety of clubs, societies and athletics. One society that many of the Environmental Engineers are involved in is the Society for Environmental Engineering (Student Society for Environmental Engineering.). SEVEN provides Environmental Engineering students opportunities to network with other students, as well as department faculty and industry professionals (Environmental Engineering Program | University of Colorado at Boulder.)

CU-Boulder is a prestigious university that provides its students with the necessary skills to succeed at present, as well as in the future. The University not only provides students with an excellent academic curriculum, but it also provides students with numerous opportunities to become involved in research, student societies and clubs, and athletics.

Appendix C – Description of Non-university Partners

Our contact and chaperone at Eagle County Airport was Captain Bryan Kohrmann of the ARFF. Initially we believed a phone call would suffice as supplying us with enough information, however upon further research it was evident that a visit was needed. Two trips were made throughout the semester. One trip was to vaguely inspect the fueling locations and operations to determine what could be done to help environmental interactions. The second was made to take measurements and ask more detailed questions in person. Bryan Kohrmann helped on both occasions by escorting us to all areas of interest. He was extremely helpful in providing us with EGE operational guidelines, figures of EGE, and fuel spill incident reports. Captain Kohrmann pointed out the areas of concern to us that would have otherwise gone unnoticed. Direct interaction with Hycrete failed to occur, however a Hycrete W1000 distributer, Green Depot, responded to our price inquiries. Joe Kearns of Green Depot provide an estimate for our W1000 requirement. Another contact of ours at the airport was Tom Kohl, the operations manager at the Vail Valley Jet Center. Tom provided detailed protocol on what to do in case of spills. This was laid out in the 2011 VVJC SPCC, but Tom provided personal testament on what actually occurs. Phone calls were made to Elastec American Marine and Front Range Rubber regarding material pricing for the heated boom containment system alternative.

<u>Appendix E – Evaluation of Educational Experience</u>

Student Response

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

Yes the FAA Design Competition provided an extremely meaningful learning experience, and will be useful in our future professional endeavors. The design experience taught us how to provide quality deliverables to real clients. This experience improved our teamwork skills, public speaking and the hands on experience that lectures alone could not impart.

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

The main problem that our team experienced was that the competition provided a very open-ended problem statement. In our previous engineering courses all of the problems had one correct answer; however this statement required us to be creative and come up with our own solutions. At points during the process there did not seem to be enough work for all six of us, so at times each of us had some down time, which was frustrating.

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

Our team began the hypothesis process when we first reached out to our airport (Eagle County Regional Airport) and began doing research on fuel spills. In the process we wrote a project proposal, which brought the various aspects together and allowed us to begin collecting our thoughts. In this phase we came up with several possible solutions (although they were all eliminated later in the process) and encouraged us to continue looking. Many designs were eliminated allowing the hypothesis to be continually modified. We know there is no “correct” answer for this design, however being able to find the right fit for the airport (and the feedback from the airport) was key in our process.

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

Our team was lucky enough to be able to work with Eagle County Regional Airport (EGE) and Bryan Kohrmann who was very helpful and able to answer many of our questions. In addition several field trips were taken that allowed the airport to be surveyed so that our design took into account the layout of the airport. Based on information from Mr. Kohrmann we were able to determine the airport's weakness and possible solutions that best fit EGE.

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 taught us how to successfully complete an engineering design. All of us learned a lot about teamwork, research, professional communication and time management. On a more specific case much was learned about the fueling process at an airport and where various fueling situations occur. For the team members that proceed to the workforce, this project has taught us the basics of a design that can be used for many different career choices. The team members that continue on in academia our skills learned from this Competition will enhance the research process and design of experiments. No matter what the team members decide to do in the future, we feel like we have learned skills that will make us successful.

Faculty Response

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

The students use this Competition as a vehicle to get real-world experience in working with an actual client (participating airport) on a relevant, current problem. The students develop the project with the client resulting in a proposal, then investigate several alternative solutions to the problem, and finally design the best alternative. The Competition provides the opportunity for the students to combine all their undergraduate courses into this “capstone” project while improving their skills in written and oral communication.

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

Yes, very much so.

3. What challenges did the students face and overcome?

Recruiting a participating airport, developing a project scope, and then executing the scope within the confines of a single semester.

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

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

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

More assistance in recruiting participating airports. If there were a webpage dedicated to airports that have expressed interest in participating and a brief synopsis of the problem(s) they are facing.

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