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Modifications to an Existing Glycol Retention Pond and Alternative Technologies Review for Aircraft Deicing Operations and Glycol Recovery and Treatment: Dane County Regional Airport

Steven J. Sletten

Embry-Riddle Aeronautical University - Daytona Beach

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**MODIFICATIONS TO AN EXISTING GLYCOL RETENTION POND AND
ALTERNATIVE TECHNOLOGIES REVIEW FOR AIRCRAFT DEICING
OPERATIONS AND GLYCOL RECOVERY AND TREATMENT:
DANE COUNTY REGIONAL AIRPORT**

by

Steven J. Sletten

**A Thesis Submitted to the
Aeronautical Science Department
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Aeronautical Science**

**Embry-Riddle Aeronautical University
Daytona Beach, Florida
Fall 2000**

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This thesis was prepared under the direction of the candidate's thesis committee chair, Mr. Donald Hunt, Department of Aeronautical Science, and has been approved by the members of his thesis committee. It was submitted to the Department of Aeronautical Science and was accepted in partial fulfillment of the requirements for the degree of Master of Aeronautical Science.

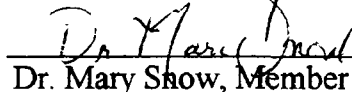
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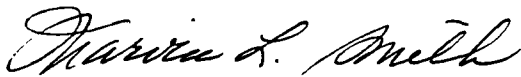
Mr. Donald Hunt, Chair



Dr. Tim Brady, Member



Dr. Mary Snow, Member



MAS Graduate Program Chair



Department Chair, Applied Aviation Sciences

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ABSTRACT

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The purpose of this study was to review new aircraft deicing technologies and developments and surmise which approach may be the most appropriate for the Dane County Regional Airport's (KMSN) expansion plans, size, available funds, and environmental impact reduction efforts. This paper focuses on the emerging glycol source reduction issues that may be most suitable for this particular airport. A new deicing technology at KMSN would reduce the amount of aircraft deicing fluid used, allow for efficient flight operations, limit environmental impact, and lessen the costs of maintaining and operating the current glycol fluid recovery and treatment system.

Storm water discharge regulations are becoming increasingly stringent at airports in the United States. The FAA requires aircraft deicing when weather conditions warrant. The EPA requires that glycol fluid be collected and treated prior to proper disposal. Passenger safety is the foremost concern for airports and airlines and is the cornerstone by which all aircraft deicing decisions are made. The advent of new more environmentally-friendly aircraft deicing technologies is facilitating the balance between aviation safety and environmental protection.

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CHAPTER 1

INTRODUCTION

Like many airports located at higher latitudes, the Dane County Regional Airport (KMSN) in Madison, Wisconsin, must contend with adverse winter weather. Aircraft deicing and anti-icing is a necessary part of this airport's winter operations. Aircraft deicing impacts both safety and the environment and is an important consideration for airport management personnel. Airports have received increasing scrutiny directed toward the environmental impacts from the wintertime use of deicing chemicals and their subsequent occurrence in storm water runoff. The traditional methods of aircraft deicing are changing as environmental and cost pressures have encouraged innovation. The Dane County Regional Airport is interested in incorporating new methods of ground deicing as a way of bettering their facility operations and ensure air travel safety.

The deicing and anti-icing of air carrier aircraft is required by the Federal Aviation Administration (FAA) in the federal aviation regulation (FAR) 14 CFR Part 121.629, "Operating in Icing Conditions" (Aviation Law Reporter, 2000). The FAA closely regulates winter operations for airports and airlines due to overriding safety concerns in terms of setting strict standards for deicing and anti-icing chemicals and activities (Klein, 1999). The FAA regulations state that no pilot may take off in an aircraft that has ice, snow, or frost adhering to the surface in a provision referred to as the "clean aircraft concept" (FAA, 1992). The FAA has developed standards regarding the design and procedures of aircraft deicing facilities and practices at airports. There is

some flexibility in these rules because the FAA does not stipulate which methods or materials must be used to remove ice, snow, or frost. However, the methods and materials must be approved by the FAA and the Society of Automotive Engineers (SAE) (FAA, 1993).

When performing aircraft deicing/anti-icing without storm water discharge controls in place, airport deicing operations can result in environmental impacts (U.S. EPA, 2000). While the FAA is increasing its deicing requirements, the United States Environmental Protection Agency (U.S. EPA) is also increasing pressure for storm water management, thereby risking a conflict between safe aircraft operation and protection of the environment. Many airports now face this dual challenge of simultaneously maintaining public safety while protecting the environment (Switzenbaum, Veltman, Schoenberg, Durand, Mericas & Wagoner, 1999). Airports and airlines are caught in the middle, but several management and technology alternatives are available for controlling the impact of aircraft deicing chemicals on storm water (Mericas & Wagoner, 1994).

The management at the Dane County Regional Airport is assessing their current aircraft deicing/anti-icing system. They would like to consider alternative ways in which operational costs and environmental impact can be reduced while not compromising safety. Possibly the most safety-sensitive of all ramp activities during routine turnarounds is aircraft deicing. Deicing and the clean aircraft concept are extremely critical to flight safety (Hill, 1998).

This paper provides an overview of some of the current and developing industry practices by which aircraft deicing operations are conducted while assessing the

feasibility of adopting new technologies. The Dane County Regional Airport currently employs a fluid application process to deice aircraft. This method is very common in the aviation industry and has been slow to change. The disposal of deicing fluids has not been regulated too heavily until recently, yet now these activities are under considerable regulatory scrutiny throughout the nation. In some instances, notices of violations (NOVs) have arisen at airports due to fish kills associated with chemical-laden storm water runoff from deicing and anti-icing procedures (Fronapfel & Malinowski, 1997). The airport can use this information to best implement a ground-deicing program to reduce the environmental impact and operational costs associated with the use of their glycol retention pond, while meeting the needs of the tenant airlines.

Statement of the Problem

Due to airport terminal expansion and other growth initiatives planned at the Dane County Regional Airport, modifications to the design, location, and operation of the glycol retention pond will need to be considered further. The retention pond is physically in the way of future tarmac and terminal expansion plans due to its present location just south of the gate and tarmac area shown in Figure 1. Other concerns that the glycol pond presents are that it emits a strong odor, and if winds are from the south, the unpleasant odor often finds its way into the busy terminal building. Also, the retention pond is an open body of water that attracts waterfowl and brings about a concern of birds interfering with aircraft flight operations (D. Jensen, personal communication, May 11, 2000). From a financial standpoint, the glycol aeration system in the pond is relatively expensive to operate, and the discharge of glycol-impacted wastewater into the city's

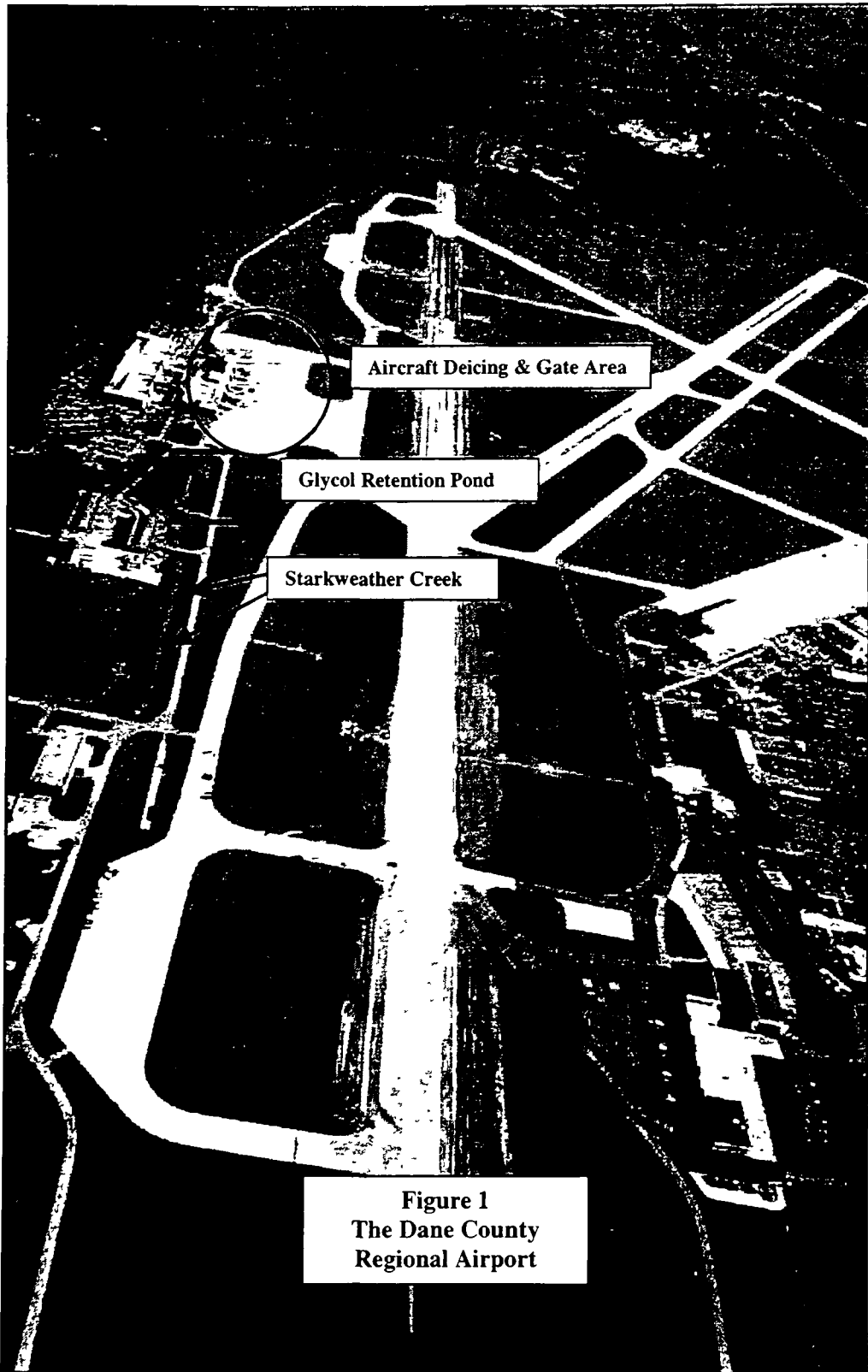


Figure 1
The Dane County
Regional Airport

publicly owned treatment works facility has associated fees (T. Astfalk, personal communication, May 23, 2000).

The Dane County Regional Airport is fortunate that the publicly owned water treatment works does not object to receiving the treated glycol effluent from the retention pond. Some municipalities have made it clear that they would refuse to receive the most concentrated part of the deicing agents at their treatment plants if a thorough impact analysis has not been conducted. Much of this issue stems from new deicing agents with less glycol but with additives having unknown effects (OSL analyzes environmental risk...1998). The Dane County Regional Airport reduces the glycol concentrations to levels required by their storm water discharge permit prior to discharging water to the publicly owned treatment works (POTW) or into waterways (T. Astfalk, personal communication, May 23, 2000).

Members of the management of the Dane County Regional Airport intend to assess their situation and gather information to help them decide what changes could be implemented to improve their current aircraft deicing program and reduce overall glycol effluent discharge. Considerations include modifying the current glycol retention pond by covering it thereby reducing the amount of odor and extent of exposure of the unit. Other possibilities include investigating alternative aircraft deicing concepts that could be used to reduce the amount of glycol that is generated at the airport.

Some of the researched and implemented forms of aircraft deicing programs include a designated central deicing facility, preventive anti-icing, forced-air deicing, infrared deicing technology, hot water aircraft deicing, and varying glycol content in accordance with ambient air temperature (U.S. EPA, 2000). In a general sense, the

variables of overall cost to install and implement a given program, along with the amount of glycol effluent reduction will be used as comparisons for the alternative deicing technologies. Other factors, such as the availability of land, the volume of aircraft traffic, and local political issues also will be considered.

In 1991, the Dane County Regional Airport constructed the first glycol retention pond in the state of Wisconsin. Air carriers at this airport utilize an average of 50,000 to 80,000 gallons of glycol-based deicer per year (Dane County Regional Airport, 1999). As a result of warmer than usual weather, 32,285 gallons of glycol-based deicing fluid were used during the 1998-1999 season (Mead & Hunt, 1999). The contents of the glycol retention pond are discharged to the Madison Metropolitan Sewerage Commission's sanitary sewer or released directly into Starkweather Creek (see Figure 1). The recipient of the discharge often depends on the time of year and how much biodegradation has occurred in the glycol remaining in the retention pond. During extremely cold winter months, such as January and February, very little natural biodegradation occurs, therefore the deicing fluid collected is often discharged to the publicly owned treatment works. In other months when deicing is conducted, there tends to be more sunlight and warmer temperatures, promoting a natural breakdown of the glycol fluid (T. Asfalk, personal communication, May 22, 2000). During these months the fluid is discharged directly into the creek.

Sampling the groundwater quality is an important component of the overall monitoring process. For example, the groundwater below the Gardermoen International Airport in Oslo, Norway, is contaminated with deicing components and remedial efforts are in full swing. The Norwegian Pollution Control Agency will require the airport to

introduce new aircraft and runway deicing practices prior to the 2000-2001 winter season (Groundwater situation at.....1999). These are situations that airports try to avoid. Regular monitoring of groundwater quality is important to reduce the spread of contaminants and potentially incur environmental legal responsibility.

Review of Related Literature

A review of the literature regarding aircraft deicing procedures using glycol, as well as alternative aircraft deicing technologies, indicates that a large majority of airports still use glycol-based products for aircraft deicing and anti-icing (U.S. EPA, 2000). Many of the new alternative technologies to deice aircraft have either not yet been certified by the FAA, or they have not been determined by airlines and airports to be the safest, and the most cost-beneficial deicing methods. These less-polluting deicing methods are only in very limited use (Schwartz, 1999). By and large, innovative technologies take time to be proven, certified and accepted in an industry. Research and development is underway to examine several of the alternative technologies that are being promoted for use in aircraft deicing procedures.

The use of ethylene and propylene glycol has been a standard for many years in the aviation industry and is considered a proven and safe technology. Type I propylene glycol-based aircraft deicing fluid is the material most commonly used by the U.S. Air Force (Cornell, Pillard & Hernandez, 2000). Type I fluid is used in military and commercial aviation because of its effectiveness to remove ice and its cost. Recently, Type II and IV anti-icing fluids also are used because of the safety aspects that they present. Preventing ice and snow buildup on critical aircraft surfaces allows for safer flying conditions.

The U.S. Air Force does not have the same operational concerns as do airlines regarding scheduled passenger service. Airlines minimize the amount of delay in departure, or hold over time. The U.S. Air Force flight personnel usually can depart an air force base without waiting in line for other aircraft to take off. If there is a delay, the departure schedule for a military aircraft often can be adjusted to allow for convenient departure and application of deicing fluid

However, with increasing concerns regarding overall cost reduction and the toxicological impact of releasing deicing chemicals into the environment, airport managers are considering the implementation of new “environmentally friendly” technologies. Despite considerable interest in developing aircraft deicing fluids other than propylene-based and ethylene-based glycol, little progress has been made in adopting their use (U.S. EPA, 2000). Consequently, ethylene glycol and propylene glycol remain the most widely used products for aircraft deice and anti-ice operations.

Because ethylene glycol is listed as a hazardous air pollutant under the Clean Air Act, it is subject to reporting requirements when released in quantities of more than 5,000 pounds in a 24-hour period. Propylene glycol is not listed as a hazardous air pollutant and, therefore, does not have the associated reporting requirements. Propylene glycol also has a lower toxicity from the manufacturers’ formulated fluid additives, so some airports have switched to propylene glycol in part to meet demands of local citizens’ groups or consent decrees (U.S. EPA, 2000). The trend in the aviation industry is for the increased use of propylene glycol in the U.S. and the continued use of ethylene glycol in Canada (S. Barash, personal communication, May 16, 2000). This is a shift that has taken place in the past few years.

According to some technical experts, refinements in deicing technology and developments in the composition of deicing/anti-icing fluids are proceeding at a very rapid pace with significant advances from year to year (Hill, 1998). This progress certainly holds promise for many airports that are depending on technical advancements to modify deicing operations. For many in the industry, these advancements have not come very quickly, and the cost of new technologies must always be taken into consideration. It will be interesting to see what the future holds for this area of technological advancement.

Many airports plan to expand, yet such plans increasingly are being fought by community groups that use environmental issues to support their own agendas. The ability of airports to thrive and grow in the future relies on finding solutions to environmental problems (Leib, 1999). With the introduction of new deicing technology, the FAA, airlines, and airports have to be convinced that an alternative is, first and foremost, safe, and that it also makes good financial sense. Airlines typically select procedures for deicing and anti-icing their aircraft which are then approved by the FAA (U.S. EPA, 2000). If the use of new forms of deicing methods should dissuade passengers from using a particular air carrier, or if specialized mechanical devices, such as mobile infrared heaters, are prone to damage multi-million dollar aircraft during deicing operations, then alternatives will not be well-received (S. Belcher, personal communication, May 26, 2000).

Anti-icing fluids (e.g., Type II and IV) are in greater use now because airlines can extend hold over times and reduce secondary aircraft deicing requirements. With the growth of the air transportation industry, the use of aircraft deicing/anti-icing fluids is

likely to increase. This use of deicing fluids will be weighed against the storm water discharge permits, and other environmental mandates, to which each airport must adhere. If limits on the release of deicing fluids by the aviation industry are established at the national level then alternative deicing measures will take on greater importance and undergo more rigorous review.

Issues such as those noted above are those with which airports and air carriers must contend when attempting to alter their current practice of glycol fluid aircraft deicing. In many ways this boils down to a business decision made by the airport personnel and the tenant airlines using the airport. As noted earlier, aviation safety is the bottom line issue. But, the reduction of environmental impact, monetary cost, and operational delays also play a hand in the decision-making process. There are going to be changes to deicing methods in the aviation industry, but to date, it is difficult to determine just what the leading new technology will be and whether that technology will significantly reduce glycol usage.

Aircraft Deicing

The use of glycol-based fluids to deice aircraft is a very common and accepted method within the aviation industry. Ethylene glycol ($C_2H_6O_2$) - and propylene glycol ($C_3H_8O_2$) - based fluids (collectively referred to as glycol) are recognized as effective in removing and preventing snow and ice contamination on aircraft before takeoff (McCready, 1998). These two glycols are the basis for all commercial aircraft deicing materials used in North America (Mericas & Wagoner, 1994). Effective aircraft deicing operations are mandatory for safe air travel. It has been estimated that approximately 13,736,946 gallons of aircraft deicing/anti-icing fluids are use in a typical year in North

America (Cancilla, Martinez & Van Aggelen, 1998). In a typical winter, for example, Chicago O'Hare International Airport (KORD) alone uses more than 1.5 million gallons of aircraft deicing fluid (Cornell, Pillard & Hernandez, 2000).

This deicing and anti-icing fluid is typically sprayed onto aircraft from boom-mounted trucks that allow an operator to direct a stream of glycol-based fluid to desired locations on the aircraft. This liberal spraying of fluid, often during a precipitation event, generates polluted storm water runoff and subsequent flow into receiving waters.

Deicing a single large commercial aircraft requires 500 to 1000 gallons of deicing fluid on average (Betts, 1999). Costs are high for the many gallons of product used as well as those costs associated with an impact on the environment. The deicing of one large aircraft can result in a pollution load equal to the daily wastewater of 5,000 people (Leib, 1999). Estimates have shown that almost half of the glycol-based deicing fluid applied to aircraft ends up in storm water runoff (Mericas & Wagoner, 1994). However, the amount of deicing/anti-icing fluid required to adequately deice an aircraft is highly dependent on applicator variability, airplane size, and the weather conditions (Sills & Blakeslee, 1992). Each aircraft type has different deicing requirements and airports must accommodate them all. With the correct information, equipment, and modifications to the aircraft deicing process, overall cost and pollution load can be reduced (Evans, 1995).

In the case of the Dane County Regional Airport, the deicing fluid runoff is currently collected, stored, and treated before it is released into the environment. This requirement results from a storm water discharge permit issued in 1996 by the Wisconsin Department of Natural Resources (WDNR) (WDNR, 1996). The airport accomplishes

this task by using a glycol retention pond (D. Jensen, personal communication, May 11, 2000).

From a national regulatory standpoint, all airports in the United States must meet standardized storm water regulations. Airports are considered to be sources of water discharge associated with industrial activity. Industrial facilities are defined by their standard industrial classification (SIC) code. Transportation by air has SIC codes of 4581 – airports, flying fields, and services, and, 4512 – air transportation, scheduled (Hopcroft, Vitale & Anglehart, 1989).

Airports must address water quality impact that the EPA or a state environmental protection agency requires in a water quality certificate or in a National Pollution Discharge Elimination System permit. These permits are issued under Sections 401 and 402, respectively, of the Federal Water Pollution Control Act (the “Clean Water Act”) (Dept. of Transportation, 1996). Water quality concerns are often further complicated when an airport routinely conducts winter deicing operations and seasonal water quality standards are incorporated into permit requirements.

Members of management at the Dane County Regional Airport would like to explore ways in which the volume of glycol-based deicers and anti-icers can be reduced, while continuing to provide effective, safe, “clean” aircraft conditions. They would also like to minimize air carrier operational concerns such as time at the gate and departure delays. A reduction in glycol use will help the airport and tenants to remain in compliance with the managing authorities and, at the same time, take a proactive stance in reducing glycol-based effluent emissions. Airports and air carriers around the country are pursuing new systems and materials that can detect, remove and prevent ice

contamination of aircraft without harming neighboring waters and wildlife (McKenna, 1995). These actions and considerations are all part of addressing aviation safety while being a steward to the environment.

Runway Deicing

Impacted storm water runoff also is generated at airports from runway deicing and anti-icing activities. Although runway and airfield deicing is not the focus of this study, a brief look at what the Dane County Regional Airport is doing to mitigate its environmental impact reflects natural resources protection efforts and an overall national trend. Traditionally, the most commonly used runway deicing/anti-icing agent was a combination of ethylene glycol and urea (Mericas & Wagoner, 1994). The Dane County Regional Airport has switched to the use of potassium acetate as their runway deicer/anti-icer (Dane County Regional Airport, 1999). Potassium acetate is much more environmentally friendly since it neither has a high oxygen demand nor does it release ammonia when it breaks down in water.

Oxygen demand from chemicals is damaging to bodies of water because it depletes the oxygen necessary for aquatic life (Minsk, 1998). Ammonia is an environmental concern because it contributes to nitrogenous oxygen demand and is potentially toxic to aquatic life (Mericas & Wagoner, 1994). Fortunately, most airports in the United States use a recently developed alternative to urea for runway deicing, such as sodium acetate, sodium formate, calcium magnesium acetate, and potassium acetate (U.S. EPA, 2000). The use of acetate-based deicers as a replacement for urea and glycol-based chemicals alleviates the concern for the release of ammonia, nitrate, and glycol to the storm water runoff (Sills & Blakeslee, 1992).

Storm Water Runoff

As important as it is for aircraft deicing to occur for the sake of air travel safety, there are also other important operational concerns that must be taken into account by airlines and airports during efforts to deice aircraft. Many of the operational concerns rest with expediting the flow of aircraft traffic on the ground, increasing the holdover times (HOT) of aircraft, while controlling the environmental release of storm water runoff. Holdover time is defined as:

Holdover time – estimated time deicing or anti-icing fluid will prevent the formation of frost or ice and the accumulation of snow on the protected surfaces of an aircraft. Holdover time begins when application of a deicing or anti-icing fluid commences and expires when the deicing or anti-icing fluid applied to the aircraft loses its effectiveness. (Dept. of Transportation, 1996)

Propylene glycol was used as a deicer/anti-icer at the Dane County Regional Airport during the 1998-1999 winter season. However, a mixture of propylene and ethylene glycol has been recorded in the past (WDNR, 1996). The total glycol use was 32,285 gallons (undiluted) for the 1998 –1999 season (Mead & Hunt, 1999). The estimated glycol usage averages 44,000 gallons (undiluted) per year (WDNR, 1996). As effective as propylene glycol and ethylene glycol are in removing and preventing ice and snow accumulation on aircraft surfaces, they also bring about expensive, and often involved processes of collecting and treating the spent fluids. These processes reduce the amount of used glycol that is released into the environment. If these efforts are not taken, then airport flight operations may have to be curtailed in some instances. If the released glycol is not first collected and treated, then regulated discharge limits may be exceeded and aircraft deicing operations may have to be reduced.

Large international airports have invested millions of dollars in building centralized aircraft deicing areas that are able to accommodate several large aircraft simultaneously while collecting and treating the deicing fluids dispensed on them (Schwartz, 1998). However, centralized deicing facilities may be practical only for the largest airport operations due to their cost and physical size (U.S. EPA, 1999). Many airports have to adhere to effluent limitation guidelines established either on a case-by-case basis with state regulators or at the federal level by the United States Environmental Protection Agency (Schwartz, 1999). Generally, airports must have specifically engineered containment systems in place to prevent deicing fluids from being released directly into the environment. In most cases, National Pollution Discharge Elimination System storm water permits indicate what effluent restrictions exist particularly if discharges enter a waterway directly.

In the case of the Dane County Regional Airport, Starkweather Creek is located directly adjacent to the glycol retention pond and serves as an approved recipient for treated glycol effluent emissions (Mead & Hunt, 1999). At times, the discharged glycol fluid also is directed to the municipal wastewater treatment plant through the sewer system. Often, it is necessary for airports to discharge storm water directly to a municipal wastewater treatment plant because they do not have an on-site treatment option (Black, 1999). However, many airports pay millions of dollars each season for sewer surcharges to accommodate their spent glycol-based fluids (AR Plus, 2000). Managers of the Dane County Regional Airport would like to become less dependent on the publicly owned treatment works facility for waste water discharge by reducing the

amount of and effectively treating the remainder of the spent glycol generated at the airfield (T. Astfalk, personal communication, May 24, 2000).

Glycol Fluid Types

Aircraft deicers are categorized into four classes: Type I, Type II, Type III, and Type IV. Not all types are currently used by airlines at airports. Fluid types vary by composition and holdover times. Type I is the most commonly used fluid and is used primarily for aircraft deicing. The Type I fluid was designed to remove accumulated ice and snow from aircraft surfaces (U.S. EPA, 2000). Type I fluids are often heated to 180 to 200 degrees Fahrenheit before they are sprayed onto aircraft to help melt ice and snow adhering to the aircraft (Sills & Blakeslee, 1992). Types II, III, and IV were developed for anti-icing and form a protective film on surfaces to prevent the accumulation of ice and snow. Regarding the purposes of fluids, there two commonly used terms. Deicing is defined as "... the process of removing accumulations of snow, frost, slush, and/or ice from the aircraft critical surfaces, crevices, additional openings, and hinge points..." (Young, 1998). While anti-icing is defined as "...the process of preventing further accumulations of snow, frost, slush, and/or ice on clean aircraft critical surfaces by the application of fluids...which...prevent the formation of ice or snow crystals" (Young, 1998).

Type II and Type IV fluids are the most commonly used for anti-icing purposes (U.S. EPA, 2000). Type IV fluids are the most advanced type offering the longest holdover times when in concentrated form (Weingardt, 1999). Type III fluids are not currently used and are not available for purchase in the aviation industry (S. Barash, personal communication, May 16, 2000). The leading manufacturers of aircraft deicing

fluids are Union Carbide, ARCO Chemical, and Octagon Chemical (Switzenbaum et al., 1999).

Interestingly, certain areas of the aviation industry have not recognized all of the effects of thickened deicing fluids. The deicing fluid is thickened through the use of additives made to absorb precipitation into the liquid so snow or ice will not form on the metal wing. This is especially true of Type IV anti-icing fluids in use with regional airlines. If thickened fluids are allowed to build up on, say, control-tab surfaces, aircraft controllability can be compromised. Regional aircraft, especially those that are propeller driven, often do not attain the same velocity on takeoff as larger commercial aircraft. At slower speeds, these aircraft need a smooth airflow over their surfaces providing lift. Anti-icing fluids are designed to shear off wing surfaces during take off to enable this necessary smooth flow (Europe prepares for winter...., 1999).

Generally, most glycol fluid use in the United States is propylene based, rather than ethylene-based. This has come about due to the federal government's Comprehensive Environmental Response Compensation and Liability Act (CERCLA) requirements. Propylene glycol does not have any reporting requirements under CERCLA (U.S. EPA, 1995). Additionally, propylene glycol is generally less toxic than ethylene glycol (Sills & Blakeslee, 1992). Neither ethylene glycol nor propylene glycol is classified as hazardous wastes under the federal government's Resource Conservation and Recovery Act (RCRA) (U.S. EPA, 1995). Regardless of the type of glycol-based fluid that is used, containment and disposal have continued to pose problems for many airports. In part because of environmental concerns, airports have constructed and

dedicated areas as deicing stations, which have built-in retention/detention systems (Black, 1999).

On a less publicized note, ethylene glycol and propylene glycol are both considered volatile organic compounds for air regulation purposes. These factors have led to increased interest in quantifying glycol air emissions from aircraft deicing and anti-icing operations (McCready, 1998). The release of untreated concentrations of glycol into the environment presents toxicity and health effects that have raised concern (Switzenbaum et al., 1999). Recorded fish kills in bodies of water near airports are examples of this health problem. The U.S. EPA is conducting research to determine if the further regulation of deicing fluid runoff is warranted on a nation-wide basis in light of CERCLA and local storm water permit relevant regulations (Switzenbaum et al., 1999). If so, this may result in significant restrictions on wintertime operations at some airport facilities.

Dane County Regional Airport's Expansion

The future plans for the Dane County Regional Airport include facility expansion. Due to an increase in air passenger volume and aircraft flight operations, engineers have developed expansion plans for the passenger terminal building and the airside tarmac area. These plans include an increase in the number of aircraft gates, more square footage in the terminal building, and the availability of more parking space for smaller commuter aircraft (D. Jensen, personal communication, July 10, 2000). The total number of enplanements (each time an aircraft takes off or lands) from July 1998 through June 1999 at the Dane County Regional Airport was 142,477 (Mead & Hunt, 1999). As

the airport continues to increase its passenger volume and number of flight operations, the airport infrastructure must be modified to meet the expected demand.

There has been tremendous growth in the aviation industry in recent years, and expansion and infrastructure issues are something that many of the nation's airports are contending with. Aviation is the fastest growing mode of transportation in the United States, increasing twice as fast as motor-vehicle travel (Stenzel, Trutt, Cunningham & Kassel, 1996). In fact, the FAA expects worldwide air travel to increase by 5.8% annually between 1998 and 2008 (Betts, 1999).

The aviation industry is constantly looking at ways to improve environmental performance. One means is to implement programs to better manage the disposal of effluents and to use more environmentally responsible methods of deicing aircraft. There must be an acceptable balance between concern for the environment and the need to expand the air transport infrastructure (International Air Transport Association, 1992). Since the Dane County Regional Airport is making notable infrastructure changes to their facility, it is an opportune time to assess new approaches and modifications in their aircraft deicing operations.

Storm Water Drainage System

The growth of the Dane County Regional airport will affect the operation of the current glycol retention pond. The physical location of the pond conflicts with the airport's planned expansion and long-term development. The location of the glycol retention pond is shown in Figure 1. The glycol-fluid collection and drainage system will also be impacted in the expansion plans. The designed storm water drainage system encompasses all of the aircraft gate locations and conveys the captured spent glycol-

based fluid to the retention pond. The system is a key component for specifically collecting spent glycol fluid that would otherwise drain off of the airfield. A separate glycol-fluid collection system is important. If all storm water and industrial wastewater (i.e. fuel and oil spills) flow to the same drain, the contaminants become mixed and consequently more difficult and expensive to treat (Jurgensen, 2000).

The airport has invested significant funds in designing and building their current deicing/anti-icing collection, treatment and storage system. The 2-million gallon retention pond was constructed in 1991 and first used during the 1991/1992 deicing season. The storm sewer modifications also were made at that time to isolate runoff from the east apron adjacent to the terminal where 94 percent of the glycol is applied to aircraft. Storm water runoff from the gate deicing process is retained in the pond during the deicing season (WDNR, 1996). With new deicing technologies and advancements in the aircraft-deicing field, better application technologies and capture technologies can be introduced to potentially phase out the use of the glycol retention pond.

An issue that the airport staff may consider is how upcoming construction efforts may influence the topography at the airport. As a case in point, after spending millions of dollars on a new storm water collection system, the Cincinnati/Northern Kentucky International Airport (KCVG) was disappointed to learn that the construction of new buildings had changed the local drainage pattern at their airfield. This caused the deicing chemicals to flow to a new drainage basin outside their designed glycol storm water collection system (Evans, 1995).

Airport Tenant Permit Associations

Airports and airlines customarily work together in performing aircraft deicing practices. Air carriers are responsible for aircraft deicing and anti-icing. The air carriers determine when deicing is required on the basis of aircraft weight specifications and aircraft surfaces requiring application (Simpson, 1997). However, an airport has a strong interest in aircraft deicing/anti-icing operations because of their storm water permit requirements. The Dane County Regional Airport, and the airport tenants who are co-permittees, are responsible for the proper compliance with the storm water permit and exercising best management practices for glycol fluid use (WDNR, 1996). Ultimately, however, the airport has a responsibility to provide for the infrastructure associated with storm water runoff and conduct an on-going monitoring program to maintain permit compliance (Simpson, 1997).

The tenants at the Dane County Regional Airport, along with the county, share responsibility for compliance with state environmental regulations. The county is the airport owner/operator. Although the management works cooperatively with the tenants and airport operator, at most commercial airports, the airport management does not have direct control over most flying activities. Thus, the management may not have any control over the types or amounts of aircraft deicing/anti-icing fluids that are used or even how they are used. Nevertheless, the airport management is responsible for the safe operation of the airport (American Association of Airport Executives, 1999).

Because the permit responsibilities rest on the shoulders of the airport and airlines together, there is a greater need for these two groups to unite and make key material and operations decisions together. This is an area that can be addressed through

constructive discussion and negotiation between representatives of the airport and airlines operating at this airfield.

Flight Safety Considerations

Aviation professionals know that it is critical for the safety of the passengers and for aerodynamic performance to have flight control surfaces free of ice and snow. Ice and snow also can impede the accuracy of sensors that provide vital information to the cockpit. Due to the need of the flying public and our nation's economy to use air travel in winter weather conditions, it has become a requirement for aircraft deicing to occur (FAA, 1993). Today's highly mobile society demands constant air travel within the limits of flight safety (Simpson, 1997).

The primary importance of aircraft deicing is to allow for safe and efficient winter aircraft operations during weather conditions that would otherwise not allow aircraft to fly. Aircraft deicing and anti-icing is a complex operation because it involves many different variables. Some of these variables, such as equipment and personnel can be managed and controlled. Other variables that cannot be controlled, such as the weather, require being addressed in a critically short response time. In either case, a certain level of risk is associated with the outcome of the deicing/anti-icing operation (Trempe, 2000).

Airlines generally train ramp and fleet-service personnel to perform such tasks as deicing of aircraft but not necessarily on the critical nature of such work to flight safety. However, this mindset is changing as training is being conducted at the National Transportation Safety Board headquarters to stress the safety implications of aircraft deicing and anti-icing (Fiorino, 1998). The viewpoint today is that what use to be the

lowest job on the ramp is now designated to the most responsible fleet-service personnel. The advances in equipment technology are also helping in this regard.

The accumulation of ice or snow on flight control surfaces can occur in a variety of weather conditions. Ice and snow commonly build-up on aircraft waiting to depart thereby compromising takeoff safety. As little as 0.8 millimeters of ice on the upper wing surface increases drag and reduces airplane lift by 25 percent (New help for deicing decisions....1999). Devastating aircraft accidents and unnecessary fatalities have occurred due to the lack of proper deicing procedures of aircraft.

In January 1982, an Air Florida Boeing 737 crashed into the Potomac River during a snowstorm after departing Washington National Airport due to the accumulation of ice and snow on the wings (Air Florida 90, 2000). In another instance, an Air Ontario Fokker F-28 airliner crashed on take-off from Dryden, Canada, due to an accumulation of ice on the wings (Chute & Wiener, 1996). The FAA's deicing protocols contained in 14 CFR, Part 121.629 were imposed after US Air Flight 407 (F-28) crashed during takeoff at New York's LaGuardia Airport during a winter storm in March 1992 (Mericas & Wagoner, 1994). Among the causes of this accident determined by the National Transportation Safety Board were the prolonged delay between the aircraft deicing and takeoff in conditions conducive to airframe and wing surface icing (von Thaden, 1995).

There are numerous other takeoff accidents in which wing surface ice contamination was a contributing factor in the cause of the crash. At least 61 air carrier accidents in the past 24 years have been attributed to aircraft icing specifically ground icing (Von Thaden, 1997). These horrific aircraft accidents serve to underscore the

importance of proper aircraft deicing practices to help ensure passenger safety and an effective national air transportation system.

Nevertheless, the aviation industry remains somewhat unaware of certain aspects of winter flight operations. For instance, pilots are required to use their eyes to judge snowfall rates and thus determine how much ice protection they have considering the aircraft's most recent anti-icing treatment. This is a major safety consideration for them and their passengers (Aviation Week & Space Technology, 1995). Scientific research has determined that the potential for snow and ice to form on an airplane's wings and fuselage corresponds to the amount of water in the snow (called liquid equivalent snowfall rate) rather than to visibility, which has traditionally determined deicing and takeoff decisions (McDonald & Hales, 1997).

In the study of a number of takeoff crashes due to icing, the visibility at the time of the accidents varied widely (New help for deicing decisions....1999). This is why technological advancements in detecting and removing ice from aircraft are so important. The pilots are often the most constrained people to make accurate judgments regarding ice and snow accumulation from their position inside the aircraft, yet the decision to take off rests with the pilot in command. More recently, trained personnel conducting the aircraft deicing are communicating information to the pilot in command. This has provided more accurate and safe aircraft departure judgments to now be made.

Environmental Background

The 1972 amendments to the Federal Water Pollution Control Act (Clean Water Act) prohibit the discharge of any pollutant to navigable waters from a point source. A National Pollution Discharge Elimination System permit allows for pollution discharge to

occur with limitations. Subsequent modifications to the Clean Water Act, which occurred in the late 1980s and early 1990s, brought about further storm water requirements. These requirements were directed toward industrial activities, including airports (U.S. EPA, 1998).

The Dane County Regional Airport is required to have a deicing/anti-icing fluid collection system in place to comply with Wisconsin's Department of Natural Resources storm water discharge regulations (WDNR, 1999). Like most commercial airports in the United States, the Dane County Regional Airport is considered an industrial facility and is permitted to discharge an established limit of glycol (in the form of used deicing fluid) into the environment. This discharge limit is based on glycol concentration levels, and other chemical parameters, measured in the retention pond discharge water (WDNR, 1999).

Although specific numeric effluent limitations for the Dane County Regional Airport are not included in the storm water permit, the biological oxygen demand (BOD) may not be greater than 50 mg/L. This applies to a 4 cubic feet per second stream flow of Starkweather Creek. To address glycol discharges, BOD levels over a five-day period are used to indirectly regulate effluent discharge levels because of the relatively high oxygen demands of glycol (WDNR, 1996). After treatment, the glycol fluid is released into Starkweather Creek during a five-day period and chemical testing is conducted to prevent a BOD level of 50 mg/L from occurring. A further definition of biological oxygen demand is:

The quantity of oxygen (in mg/L) consumed during the biodegradation of organic matter over a specified period of time, usually the first five days. A high level is usually associated with a low availability of dissolved oxygen and is detrimental to aquatic life. (Minsk, 1998)

As would be expected, there is a typical seasonal fluctuation of BOD in waters receiving runoff laden with deicing chemicals. The BOD is likely to be significantly higher during the winter when aircraft deicing is occurring (Halm, 1996)

The Dane County Regional airport took a proactive stance in designing and building storm water runoff controls at their facility. The glycol retention pond was operational in 1992, four years prior to the issuance of the WDNR storm water permit. Earlier, in 1990, the WDNR began an inventory of storm water discharge rates at industrial facilities. This inventory included the Dane County Regional Airport. Outfall water sampling was conducted at several airport locations to determine the quality of storm water draining into the sanitary sewer system and the environment (T. Astfalk, personal communication, May 23, 2000). This work at the airport was originally initiated due to resident complaints of unpleasant odors emanating from Starkweather Creek. A concern was raised regarding the impact on aquatic life in the stream due to untreated airfield storm water runoff (P. Lubke, personal communication, July 17, 2000).

In June 1996, the Dane County Regional Airport was issued a Wisconsin Pollution Discharge Elimination System permit (Mead & Hunt, 1999). Under the terms of this permit, the airport is required to submit an annual report to the Wisconsin Department of Natural Resources. The annual report summarizes the storm water monitoring of the past year and notifies the state of any changes to their storm water pollution prevention plan (Mead & Hunt, 1999). The parameters to be monitored are presented in the Wisconsin Administrative Code requirements NR 216.07 for tier 2 transportation facilities (WDNR, 1996).

Parameters that are routinely monitored from the effluent in the glycol retention pond include biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), phosphorous, nitrogen, pH, lead, and zinc (WDNR, 1996). The levels of these chemicals help define the quality of effluent being released into the environment. Samples of spent deicing fluid that are captured in the approximately 2-million gallon retention pond are analyzed in a laboratory (T. Astfalk, personal communication, May 25, 2000).

The airport's pollution discharge permit expires in 2000 (WDNR, 1996). There remains a possibility that stricter glycol-based effluent controls may be placed on the airport facility. This certainly provides a reason why the use of alternative deicing methods to reduce the use of glycol-based fluids is important. It is a key element in the source reduction program and best management practices that the Dane County Regional Airport is trying to implement. This is a united effort because all of the tenants at the airport must adhere to the site specific pollution prevention plan requirements specified in the airport's storm water permit (WDNR, 1996).

National Airport Pollution Prevention

The current national storm water regulatory framework combined with local environmental issues such as fish kills have prompted airports and airlines to pursue a wide range of pollution prevention practices. These practices are designed to reduce the amount of environmental impact from aircraft deicing. Presently, there are four standard approaches to pollution prevention for aircraft deicing/anti-icing operations. These approaches include: (1) removal of glycol-based fluids through the introduction of an environmentally benign alternative fluid; (2) a reduction of the volume of fluid applied to

aircraft through the development of better fluids, improved application methods, and innovative aircraft deicing technologies; (3) innovation of collection and disposal strategies that prevent the release of glycol-contaminated wastewater into the environment; and (4) enhancement of glycol recycling methods (U.S. EPA, 2000).

These four methods are usually used at various locations in some combination with each other. The practices that are put in place by individual airports across the United States take into account a variety of airport specific factors. These factors can include climate; total amount of chemical deicing fluid types applied; number of airlines; aircraft fleet mix; number of aircraft operations; costs; availability of land; existing infrastructure; and impact on aircraft departures (U.S. EPA, 2000).

The Dane County Regional Airport has unique issues to address regarding their own pollution prevention initiatives. The airport has been considered pro-active in its approach to environmental matters, and a cooperative working relationship has developed with the Wisconsin Department of Natural Resources (P. Lubke, personal communication, July 17, 2000). The size of this airport will play a part in what pollution prevention solutions it adopts. As a regional airport, the volume of air traffic and the amount of deicing fluid used by the Dane County Regional Airport is considerably less relative to its large hub counterparts. However, there are still similar operational concerns, and regardless of airport size, environmental impact can occur.

Concerns have been expressed by national environmental organizations that under the national storm water program, smaller airports have not been held to the same level of review as larger airports. While larger airports that use over 100,000 gallons of deicing

fluid per year are required to monitor their outflows, sensitive receiving waters near smaller airports are left at risk (Stenzel, Trutt, Cunningham & Kassel, 1996).

Conversely, national aviation groups have expressed the idea that many states with National Pollution Discharge Elimination System permitting authorization (Wisconsin is an authorized state) have developed individualized programs for satisfactorily controlling pollutants from specific airports. These individualized programs will adequately protect the water quality requirement of the State (American Association of Airport Executives, 1999). Each airport is unique and a pollution discharge permit issued for each airport takes in specific operational components that exist. But from a federal government and natural resource defense organizations' viewpoint, these individual programs are not stringent enough. There should be across the board national standards placed on all airports for the quality of storm water that they discharge.

Many airports in the United States accelerated their own innovative and reasonable approaches to preventing and capturing storm water pollutants from their property. As in the case of the Dane County Regional Airport, these approaches were largely negotiated at the state and local level, taking into account an airport's unique operations and climate conditions (Morris, 2000).

Aircraft Deicing Fluid Minimization Methods

It has been stated that development in aircraft deicing technology and fluid composition are proceeding at a very rapid pace from year to year (Hill, 1998). There have been other technological developments underway in both ground-based equipment, ice detection instrumentation, benign deicing chemical formulations, and "ice-phobic"

materials (Proctor, 1995). While the evidence of environmental harm from aircraft deicing/anti-icing chemical runoff is mounting, the number of technologies available to mitigate their effects also is increasing (Betts, 1999). Much technological development currently is underway. Some technology is in the form of ice detection and some involves new ways to deice aircraft which includes high-pressure air (Prill & O'Malley, 1999).

The ground deicing industry is advancing at an ambitious pace, and it is driven by environmental and cost pressures. New technological developments can come about in one or two years based on regulatory approval and industry acceptance. One of the challenges that new technology faces involves convincing airlines and airports to upgrade infrequently used deicing equipment, which seldom wears out (Proctor, 1995). The U.S. Air Force and some domestic air carriers have been leaders in investigating ways to reduce the volume of aircraft deicing fluid without compromising safety (U.S. EPA, 2000). Hopefully, as with any new technological development, safety enhancement will be a byproduct of deicing innovation.

Pollution Prevention Initiatives

The glycol minimization methods reviewed in this paper serve to reduce pollution levels through source reduction. This concept is very intriguing to the management at the Dane County Regional Airport as well as managers of many other airports around the world. The objective of this research is to review these new aircraft deicing technologies and to surmise which one(s) may possibly be the most suitable for the Dane County Regional Airport's expansion plans, size, available funds, and environmental impact reduction efforts.

The list of deicing technologies addressed in this study is not all-inclusive. The focus of this paper centers on the emerging technologies that may be most suitable for this particular airport. Many methods have been developed and tested to aid in deicing aircraft, and advances in this area will continue. However, some methods have reached more mainstream acceptance than others. Conclusions drawn by the airport staff and tenant airlines serving Dane County Regional Airport may ultimately involve alternatives not presented here because they have not yet emerged in the industry. The future may prove to have more favorable deicing products and processes than have been addressed, and certification time may be the restricting factor for the Dane County Regional Airport.

The Dane County Regional Airport management personnel are faced with reducing the effects of aircraft deicer on receiving waters and would like to evaluate their options. A number of national studies have been conducted to develop a better understanding of the impact on aquatic life in water bodies near airports (McCready, 1998). An understanding of a wide variety of variables is essential for selecting cost effective solutions. These solutions can include reducing the amount of deicer applied under varying conditions, where deicer falls during application, how much and where deicer drips off the aircraft, and how much shears off the aircraft during takeoff and where it lands. The following pollution prevention initiatives address some of the issues presented above and can assist the management staff in making decisions regarding deicing technology modifications and glycol-fluid source reduction. From the research conducted on current and future deicing/anti-icing technology and trends, the following subject areas can provide a basis for change to occur.

Alternative Aircraft Deicing/Anti-icing Agents

One potential solution to the environmental problems associated with glycol-based deicer and anti-icers is to replace them with a less environmentally damaging product. A benign replacement product would need to be biodegradable and less toxic than current glycol-based products. It must also contain chemical compounds that are non-corrosive to aircraft parts. Also, to be economically viable, any new chemical fluid must be approximately the same price as the glycol fluids that they replace (U.S. EPA, 2000).

Specifically, the NASA, Ames Research Center in California has been involved with research on an environmentally-friendly deicing/anti-icing fluid. This new product purportedly is non-toxic, biodegradable, and has a lower BOD than propylene glycol fluids. The fluid is also congruous with almost all current deicing and anti-icing fluids. It is non-glycol based and cost competitive (McDonald & Hales, 1997).

The airlines need aircraft deicing products to follow FAA regulations for winter operation. The airlines essentially drive the aircraft glycol fluid market. The FAA has approved the use of ethylene glycol and propylene glycol as chemical deicers (U.S. EPA, 2000). All aircraft deicing and anti-icing fluids must conform to specific fluid specifications established by the Society of Automotive Engineers (SAE), the International Standardization Organization (ISO), and the Association of European Airlines (AEA) (FAA, 1993).

There is a group that has been meeting recently to discuss the development of new aircraft deicing fluids. This group is known as the Society of Automotive Engineers SAE

G-12 deicing committee (Barker, 1999). The influential members of this group representing chemical manufacturers, airlines, airports, and equipment vendors are working to come up with new formulations of deicing fluid. They also wish to have the glycol manufacturers reveal what their proprietary formulation additives are for current products. Knowledge of these additives would help to identify toxicity characteristics that exist in deicing fluid and thus end speculation regarding what unknown toxins are entering the environment. Outcomes from this working group may in fact bring about significant changes in the near future that would have a direct bearing on the way airports effectively manage their deicing storm water programs. The Dane County Regional Airport may wish to wait and see what developments come from the SAE G-12 group as they work with aircraft deicing and anti-icing manufactures to gain complete knowledge of glycol-based fluid toxicity levels.

There may be other breakthroughs in aircraft deicing that are currently being studied as well. A recent initiative involves a program with Dartmouth College to develop novel ice-protection strategies for aircraft using electrical effects to control ice adhesion (Aviation Week & Space Technology, 2000). There also is work being done for a permanent anti-icing surface treatment for aircraft which can be used in combination with heated forced-air deicing to rapidly deice aircraft without chemicals (Westmark, 1997). Such new technological breakthroughs can provide revolutionary improvements in the performance of a relatively antiquated glycol fluid deicing technique. These are changes that could ultimately make chemical-based deicing and anti-icing fluids obsolete in the aviation industry.

Type IV Anti-icing Fluids

The newest glycol-based fluids introduced in the past few years is the Type IV anti-icing agent. Type IV fluids are the most advanced type, offering the longest holdover times when in concentrated form (Weingardt, 1999). Type IV fluid provides a thicker film and a greater amount of fluid can be applied which absorbs more freezing precipitation before the freezing point is reached resulting in a greater holdover time (Dennis, 1998).

Type IV fluids, which have entered the European market during the past three years, are now in general use in the colder countries, particularly Germany, Switzerland, and throughout Scandinavia. However, Type II remains the most widely used anti-icing agent in some countries, such as in the United Kingdom, largely because of the milder climate here than in northern Scandinavia or interior European countries. Type I fluid is used little in Europe, and the regular practice, in contrast to that in the United States, involves a one-step application of either Type II or Type IV (Europe prepares for winter..., 1999).

As effective as these Type II and Type IV anti-icing formulations are, there are some environmental and operational aspects that must be taken into consideration. The Type IV fluids tend to have a higher degree of aquatic toxicity. The same additives that help the fluid spread evenly on the wing, prevent corrosion to the aircraft, and color the fluid so it can be seen, also add to the toxicity levels (Weingardt, 1999).

From an operational and safety standpoint, Type IV fluids are designed to shear off the wing surface when an aircraft reaches a given speed during the take-off roll. If the

speed at rotation is too low, the fluid will not disperse. This has implications for smaller aircraft types such as the regional turboprops (Europe prepares for winter..., 1999). An incident involving Type IV fluid and a BAe 146/RJ prompted British Aerospace to issue a warning about Type IV fluid. The incident involved the accumulation of fluid and obstructed movements of control surfaces (Europe prepares for winter..., 1999). The BAe 146 and regional turboprops are aircraft that make frequent flights to and from the Dane County Regional Airport (Coffman & Associates, 1991).

Lastly, the use of Type IV fluids has the disadvantage of possibly increasing airfield contamination. Because this type of anti-icing fluid adheres to the aircraft surfaces, greater use of Type IV fluids may increase the volume of fluid deposited on runways and grassy areas (U.S. EPA, 2000). In the case of the Dane County Regional Airport, this would introduce more glycol and additive components to parts of the airfield that are not designed to collect glycol to the pond. The additives present in Type IV fluid, such as tolyltriazoles, are believed to persist in the environment (U.S. EPA, 2000).

Until recently, deicing fluids were thought to be relatively harmless because glycol, their major component, is not highly toxic. But the additives are considerably more toxic than glycol (Guterman, 1999). Tolyltriazoles are toxic to aquatic life and, therefore, have recently raised more concern about airports and airlines that discharge spent fluids into waterways (Sparaco & Hughes, 1995). More research is being conducted to determine just how toxic are compounds such as tolyltriazoles after they have been treated and discharged.

To address issues of how much and where anti-icing fluid is released from the aircraft, a model of deicer fate and transport is required. There are tools being developed

such as the Airport Deicing Management Model (ADMM) that can help answer such questions (Viscardi & Lengel, 1998). Also, biological oxygen demand (BOD) monitoring instruments can be used at receiving water locations throughout the airport to provide real-time monitoring of storm water quality. These electronic instruments have an operating range of 30 to 140,000 mg/L of BOD and provide a direct measurement of aircraft deicer compounds (G. Frigon, personal communication, August 22, 2000). The extent of storm water problems must be quantified, and that is why gathering as much accurate data as possible is important.

Preventive Anti-icing

One approach that has been explored is the application of glycol-based anti-icing fluid onto aircraft surfaces prior to the start of icing or snow conditions. Much of this strategy relies on obtaining accurate weather forecasts so that anti-icing fluid can be applied at just the right time. The National Weather Service (NWS) is the primary source of weather forecasts and warnings for the entire United States. The NWS is expanding the network of modern NEXRAD (Next Generation Weather Radar) using Doppler radar, this network of systems can discriminate between rain and snow cells in the atmosphere over a radius of about 150 miles to provide early notice of advancing snowfall events (Minsk, 1998). Relying on local weather forecasts can be somewhat inaccurate at times leading to the unnecessary application of Type II or Type IV anti-icing fluid. With deicing/anti-icing fluids ranging from \$2 to \$4 a gallon, applying anti-icing fluid when it is not required can cost an airline thousands of dollars in a single day (New help for deicing decisions.....1999). Additional sources indicate that Type IV anti-icing fluid can command a price of \$6 per gallon (Switzenbaum *et al.*, 1999).

There is a new data gathering and display system to aid airline and airport personnel in making detailed weather decisions. The system is known as the Weather Support to Deicing Decision Making (WSDDM™), and is funded by the FAA (U.S. EPA, 2000). The system is providing snowfall “nowcasts” up to 30 minutes in advance of weather events so airlines can reduce takeoff delays, increase safety, and save money during deicing procedures (New help for deicing decisions....1999). With more accurate weather information, less anti-icing fluid is required, and less fluid is collected in the storm water runoff system. Type II and Type IV commercial anti-icing fluids provide varying holdover times. Type II provides 30 minutes of holdover time while Type IV boosts holdover time to nearly 1 hour (Young, 1998).

The forecasts from the WSDDM™ system are based on information collected from surface weather stations, snow-weighing gauges, and Doppler radar located at or near a specific airport. The system costs approximately \$100,000 to install (U.S. EPA, 2000).

The WSDDM™ system was tested at Denver (KDEN), Chicago (KORD), and New York (KLGA) airports, and is now in operation at KLGA. The Port Authority of New York and New Jersey estimates WSDDM™ has resulted in savings of \$1-2 million annually at KLGA alone. The system may also be installed and operational at Pittsburgh (KPIT), Minneapolis/St. Paul (KMSP), KDEN, and KORD (Shein, 2000). This accurate weather forecasting system may become a standard feature at airports that are regularly besieged by winter weather.

This new deicing technology is a direct result of scientific research. As previously stated, the potential for snow to become ice on an airplane’s wings and

fuselage corresponds to the amount of water in the snow rather than visibility (Shein, 2000). Studies determined that large, dry snowflakes limiting visibility were less a threat than small heavy flakes holding more water. The snow-weighing gauges used in the WSSDM™ system measure the actual liquid content of the snow (New help for deicing decisions...1999).

The Dane County Regional Airport could incorporate site-specific weather forecasting system to allow operations personnel to make very informed decisions regarding deicing/anti-icing fluid applications. With the critical timing of preventive anti-icing of aircraft prior to the arrival of a storm, airports and airlines could continue to operate safely while using less deicing fluid. Precise and timely weather predictions can dramatically help in this regard (Prill & O'Malley, 1999).

Forced-Air Aircraft Deicing Systems

Another alternative that the Dane County Regional Airport could consider for overall glycol fluid reduction is the use of a forced-air aircraft deicing system. These systems have been available for many years, but they have not seen general application in the United States mainly due to their high cost over conventional deicing solutions (U.S. EPA, 2000). Forced-air systems have been used to remove overnight accumulations of snow at airports in northern Japan for many years. The international airline that implements this practice believes that it removes dry snow faster than using deicing fluids (U. S. EPA, 2000).

For several years, United States Air Force (USAF) also has experimented with forced-air deicing (Barker, 1999). The USAF has developed a system that uses forced hot air to remove snow and ice from aircraft surfaces. The forced hot air is supplied by

compressors, which have been fitted to existing deicer trucks. The forced hot air system does not entirely eliminate glycol-based deicing/anti-icing fluids. These fluids typically are applied to the aircraft surface after treatment with forced hot air. However, this method greatly reduces the volume of glycol fluid required to provide a surface free of ice and snow contaminant. The forced hot air system is currently in use at several northern Air Force bases such as Ellsworth AFB, and Minot AFB (U.S. EPA, 2000).

Of particular interest is the work that Delta Airlines has been doing at nearby Mitchell Airport (KMKE) in Milwaukee, Wisconsin. They have been using high-pressure forced-air systems that inject a relatively low volume of glycol. Delta Airlines reduced the amount of glycol used by 70% during 1998 -1999 first 42 snow and frost events (Betts, 1999). Representatives from Delta firmly believed that the aviation industry will embrace a combination of glycol fluid and forced air as the preferred method of deicing aircraft (Prill & O'Malley, 1999).

In addition, American Airlines used forced-air with glycol fluid injected into the air stream for the first time in the winter 1999-2000 season at KORD. Ten of their fifty deicing trucks have been converted to forced-air/glycol mist, and over 90% of their operations personnel were so satisfied with the results that a strong emphasis was made to order more trucks. The forced-air system provides the option of injecting 6 gallons per minute of heated Type I glycol fluid or Type IV fluid. The option to use all glycol or just air also exists (Jane's Airport Review, 1999). It is up to the operator to decide depending on the specific conditions. The forced-air/glycol mist is less harmful to the skin of all types of aircraft than the traditional application of heated glycol fluid (J. Walsh, personal communication, August 21, 2000).

All of the major manufactures of aircraft deicing equipment are working on some form of forced air deicing technology. The major manufactures include Premier, Vestergaard, Global and FMC. (Jane's Airport Review, 1999). The advancements in this technology certainly look promising to improve upon standard fluid application systems now in place.

Computer Controlled Fixed-Gantry Aircraft Deicing Systems

Fixed-gantry systems offer another approach to aircraft deicing. They have been coined as a "car wash style," self-contained deicing system in which an aircraft is "soaked" with glycol-based fluid (U.S. EPA, 2000). Although the theory behind this method of deicing seems appealing, only a few airports worldwide have installed them and they have failed to receive widespread approval from the aviation industry (U.S. EPA, 2000). Some of the features specific to the gantries ("car washes") are that they provide a designated area for aircraft deicing operations and, therefore, facilitate coordination with air traffic control. This type of operation provides a centralized approach to the collection, treatment, and possible recycling of deicing fluid. This deicing process takes about 8 to 12 minutes to perform (U.S. EPA, 2000).

It is interesting to point out that it generally takes 12 minutes to deice a large aircraft using conventional deicing methods (Von Thaden, 1997). The response from pilots utilizing fixed-gantries generally has been favorable because they are assured of complete coverage of aircraft deicing fluid in an efficient manner (von Thaden, 1997). However, gantry systems are not to deice engine inlets, the undercarriage, or the underside of aircraft wings making it necessary for aircraft to perform additional deicing using traditional deicing boom trucks (U.S. EPA, 2000).

The few fixed-gantry systems that are used around the world are computer-controlled gantry deicing facilities. Each type of aircraft is assigned a preset series of spray instructions allowing a variety of aircraft types to be deiced using the same gantry. Typically, gantry systems are centrally located and used with a sloped and isolated deicing pad to ensure runoff is captured (Mericas & Wagoner, 1994).

In the past, airports have been hesitant to invest in fixed-gantry systems because they require a relatively large capital investment and require considerable land space that cannot be converted to storage use during fair weather periods. Airlines do not tend to favor the adoption of these systems because they can cause bottlenecks and delay aircraft departure (U.S. EPA, 2000). This feature probably would not pose a problem at the Dane County Regional Airport, however, due to the lack of heavy banks of flights arriving or departing the airport. But, land space, capital expenses, and the fact that aircraft would have to deice away from the gate area may pose issues of concern at this airport.

The Whisper Wash™ forced air deicing/anti-icing system is a portable gantry-type deicing system that uses both deicing fluid and high-pressure hot air to deice and anti-ice aircraft. There are adjustable cantilevered arms which are mounted on flatbed trailers. The arms contain over 40 pairs of opposing proprietary nozzles which deice and anti-ice the entire wing and tail in a single pass as the aircraft taxis underneath (Gaughan, 1999). This gantry design is slow to break into the market since it has yet to be applied at a commercial airport (U.S. EPA, 2000). This system could significantly reduce the amount of glycol used with gantry operation. Additionally, because it is portable (flat bet truck trailers), this system could offset dedicated building structures and use of land area. New

technological advances from the traditional fixed-gantry systems can make this pollution prevention method appealing.

Infrared Aircraft Deicing Technology

In the past four to five years, a new method of aircraft deicing technology has been developed that is dependent on infrared radiation. Infrared technology has been used for many years. For example, airport maintenance crews have used it to melt snow off plows. It is only within the past few years that testing has applied this heat source to aircraft surfaces (Thermal deicing system...1999). The two principal companies that manufacture infrared-based aircraft deicing systems are Radiant Energy Corporation and Infra-Red Technologies, Inc. (U.S. EPA, 2000). Radiant Energy markets a fixed-hanger deicing system known as InfraTek™, while Infra-Red Technologies markets a mobile system known as the Ice Cat™.

Both of these infrared systems have the potential to greatly reduce the amount of glycol-based fluids that traditionally are used for aircraft ground deicing (U.S. EPA, 2000). Although neither one of these systems is widely in use by airlines or airports, there has been a lot of attention given to the Radiant Energy infrared system. This is primarily because it has been approved for use by the FAA and is currently in use at three U.S. airports (Radiant Aviation Systems, 2000). Formal FAA approval came in April 1997 (Shein, 2000). The FAA has certified the system for use on commercial aircraft and has approved it for Airport Improvement Program funding (Schwartz, 1999).

InfraTek™ was installed and tested at the Oneida County Airport (KRHI) in Rhinelander, Wisconsin in February 1998. It has been used successfully to deice aircraft that serve this northern airport, such as the Beech 1900, Saab 340, and Dash 8 (Shein,

2000). United Express Airlines used the Rhinelander InfraTek™ system exclusively and the personnel were very happy with the results (Airport Equipment & Technology, 1999).

The InfraTek™ system also has operated at the Buffalo Airport (KBUF) in New York, and more recently, at the Newark International Airport (KEWR) in New Jersey. The infrared system installed at Newark has allowed for larger aircraft, such as the Boeing 757, to be deiced (Shein, 2000). Continental Airlines has been the dominant user of the InfraTek™ system at this hub airport and has been making operational refinements to it during its first two years of use (Radiant Aviation Systems, 2000).

Until the installation of a larger infrared-base system and structure, the Radiant Energy systems were used predominantly for smaller, commuter and regional aircraft. The Newark system has proved that large commercial aircraft can be safely deiced in a busy airport operational setting. Because it was a relatively mild winter when the system was in use, it is still considered somewhat a test operation for the airline industry. Although greatly reduced, the use of Type IV anti-icing glycol-base fluid was still required, and the removal of heavy snow from aircraft prior to entering the infrared system sometimes requires manual labor (L. Raney, personal communication, July 26, 2000). Radiant Energy Corporation acknowledges that this method is not a replacement for glycol fluid use altogether because anti-icing treatment most often is applied after the ice has melted off and the aircraft exits the InfraTek™ structure (Schwartz, 1998).

Radiant Energy's patented system, InfraTek™, is certainly poised for main-stream acceptance by airlines and airports alike due in part because the FAA has modified their design of aircraft deicing facilities (AC 150/5300-14). These design changes are still in

draft form, but will most likely be incorporated into the final edition to the above noted FAA advisory circular (American Association of Airport Executives, 1999).

The operating costs of InfraTek™ at full power for one hour are about \$125 for the natural gas to power the infrared heaters, and one person can operate the system (Bremer, 1998). The capital cost of the InfraTek™ system depends on the size of the hangar and ranges from \$1 million to \$4 million (U.S. EPA, 2000). There are a variety of systems that are available for consideration, and each system can accommodate aircraft ranging in size from a small Cessna or Piper single engine aircraft to a Boeing 747 (Radiant Aviation Systems, 2000).

Reportedly, the InfraTek™ system has a cost of \$250-\$350 per aircraft treatment which is approximately one-tenth the cost of traditional chemical deicing. The cost of deicing a Boeing 727 aircraft is approximately \$5,000 using conventional glycol-base fluids (McDonald & Hales, 1997). However, this technology requires a drive through building large enough to contain the aircraft and preferably should be located adjacent to active runways. Follow-up chemical deicing or anti-icing usually is required to provide surface contaminant protection and prevent the re-freezing of water in the aircraft's moving parts (Switzenbaum *et al*, 1999).

The other infrared technology product on the market is different in that it does not require a large fixed structure for aircraft to pass through. Instead, this is a mobile unit that can be attached to existing airport trucks and boom-mounted equipment. However, to date, the Ice Cat™ system has not been as popular as the Radiant Energy system. The USAF has expressed interest in the Ice Cat™, and the company hopes to sell their product to the government by the end of 2000. The company is developing a new combination

unit that has a blower fan that can spray a Type IV glycol fluid mist while emitting infrared heat. This would serve to deice and anti-ice an aircraft at the same time (R. White, personal communication, May 24, 2000).

The Ice Cat™ unit is equipped with temperature sensors to monitor the amount of heat being applied to the aircraft surface. Even with this technology in place, airlines have expressed concern that aircraft skin may be damaged due to the mobile units getting too close and overheating metal surfaces. Also, the large size of the moveable infrared panels attached to truck-mounted booms can make them awkward to maneuver in confined gate areas (U.S. EPA, 2000). Air carriers also have expressed concern that the moving boom-arms positioned close to aircraft may damage or strike the surface of these multi-million dollar jets. Although these units are computer-controlled, there remains a safety concern due to the skill and experience required of personnel driving the trucks and operating the units (S. Belcher, personal communication, May 26, 2000).

Varying Glycol Content to Ambient Air Temperature

The glycol concentration can be proportioned relative to the outside air temperature and moisture conditions instead of using standard mixtures of glycol and water. Type I aircraft deicing and anti-icing fluid often is blended and applied on aircraft at a mixture of about of 50 weight % water and 50% glycol (McCready, 1998). This is a standard mixture ratio that allows for a high enough concentration of either Type I fluid to be applied to aircraft in ice or snow accumulation conditions. With the recent development of more accurate weather information, the ratio of glycol-based fluid to water could be reduced to accommodate the current conditions. In colder weather conditions, the mixture ratio of water and glycol may be modified to permit more glycol

to be applied. For the sake of safety, many operators err on the side of caution and apply this 50/50 or greater ratio to ensure that the maximum amount of glycol fluid is applied. This practice often occurs regardless of the ambient air temperature or the percentage of moisture in the air. As noted, these factors contribute greatly to ice accumulation on aircraft surfaces.

At the Minneapolis/St. Paul International Airport (KMSP) in Minnesota, the operations staff has recently begun to blend the glycol-based fluid to adapt to the specific weather situations. They have been able to adjust the mixture to make a light blend consisting of 45 % glycol and 55 weight % water (Lamprecht, 1999). This has allowed for significant glycol savings. Lighter blends can be applied at the beginning and end of a winter season. During January and February, the Dane County Regional Airport may use a more concentrated glycol-based fluid, but during other times, varying the amount of glycol will result in a significant source reduction measure. The airport can work with the tenant airlines to develop a plan for varying the glycol amount.

Enclosed Basket Deicing Trucks

The enclosed basket (“cherry picker”) deicing design is becoming popular at airports. In the past, the operators applying the glycol-based fluids would be exposed to the harsh winter elements and to the chemical spray and steam during hot fluid application. This procedure brought about excessive use of glycol fluid because the operator would have to remain a considerable distance from the aircraft and over-spray areas. The enclosed cab used in this method is located at the end of the service truck’s aerial boom. The cab keeps the deicing operator warm and dry during the application. This reduces over-spray as the operator can get closer to the aircraft. Customers using

the enclosed basket report as much as a 30% reduction in consumption of glycol-based deicing and anti-icing fluids (Proctor, 1995).

If enclosed basket applications were utilized at the Dane County Regional Airport, then less glycol fluid would enter in the storm water runoff. The enclosed baskets could be modified to attach to existing equipment as a cost savings measure. Many national airlines now utilize a fleet of enclosed-basket deicing trucks at their hub airports and larger stations (U.S. EPA, 2000). If the enclosed cab was used in concert with forced-air/glycol mist deicing operations, then even less glycol fluid would be used. Many airlines have moved toward this direction and are purchasing pieces of equipment that combine these two technological advancements (J. Coons, personal communication, August 21, 2000).

Biological Treatment Systems

Albany International Airport (KALB), in Albany, New York, can be considered similar in overall size to the Dane County Regional Airport. Both of these airports serve a variety of aircraft types and accommodate a strong regional market. Currently, KALB operates an anaerobic biological system to treat glycol-based deicing/anti-icing fluids. This process uses granular activated carbon as a means to degrade glycol and the carbon mass is contained in large steel tanks. Spent glycol-based fluid is pumped through a carbon bed in the tanks where each particle in the bed is coated with a thin film of microorganisms that treat the glycol. The end products are methane, carbon dioxide and some new biomass (Airport facility treats..., 1999).

This bioremediation system was designed and constructed in 1998 by EFX Systems, Inc., and has reduced the propylene glycol concentrations from approximately

4,800 - 7,500 mg/L to below the detection limit of 1 mg/L. Laboratory data indicated that the anaerobic treatment system removed toxic additives such as tolyltriazoles as well as glycol (U.S. EPA, 2000). The system can easily be expanded if the airport expands, and it is a self-sustaining unit that does not require much land space (Airport facility treats..., 1999). The Dane County Regional Airport may find a system such as this very appropriate for treatment of their spent glycol fluid. There are continual advancements being made to this particular anaerobic biological treatment method to enhance its capabilities.

Another form of biological treatment that is being introduced at airports is collection and treatment of glycol impacted storm water in a man-made wetland system (Airborne Express, 2000). The Airborne Air Park (KILN) in Wilmington, Ohio, operates a reciprocating subsurface aerobic/anaerobic biological treatment system in which glycol-contaminated wastewater flows through beds of gravel containing wetland plants. The biological degradation of glycol occurs primarily from bacteria attached to the gravel and secondarily by the wetland plants (U.S. EPA, 2000). This designed system can handle all of the storm water runoff from the airfield and effectively treat it before it enters a nearby stream.

The Edmonton International Airport (KEDM) in Canada also constructed a wetland facility to treat all of their storm water runoff. This wetland design is covered so that there is no surface water to attract birds and uses 4.4 acres to treat all of the glycol in the airport wastewater (McCormick, 1999). The Edmonton airport staff found that this was the most environmentally, operationally, and financially feasible way to handle the amount of storm water runoff from the airfield. This airport also was expanding, and the

design fit in very well with the deicing pad operation that was already in place (McCormick, 1999).

From a wetlands research perspective, recent studies have shown that root zone soils altered from certain plants readily biodegrade propylene glycol. Some types of vegetation enhance the break down of propylene glycol more than others, but even at near freezing temperatures propylene glycol was degraded by common plant species such as alfalfa (Shupack & Anderson, 2000). Because vegetation tends to slow water and chemical movement after a precipitation event, the Dane County Regional Airport could develop areas of indigenous species of plants that could serve as a natural cleansing system. There may even be a way to modify the current retention pond so that it served as a covered wetland filtration system that could reduce the propylene glycol concentrations in runoff waters. If the amount of glycol used was significantly reduced, and/or a benign fluid was introduced that decreased toxicity, then high BOD levels would not have to be treated in the retention pond. This approach could augment a storm water collection system without causing cumbersome or costly changes.

Fluid Collection Systems for Ramps and Gate Areas

Deicing aircraft at the gate is the preferred method of deicing for most airlines conducting non-hub operations. One of the primary reasons for this preference is that it allows the same personnel that load baggage to also deice aircraft (Switzenbaum *et al.*, 1999). However, with the physical constraints of the gate area, many airlines prefer to deice aircraft at a remote facility to move away from often congested gate areas. Remote deicing facilities also reduce the taxi times from deicing until takeoff, and there are fewer expired holdover times (Department of Transportation, 1996)

Currently, the program at the Dane County Regional Airport deices aircraft at the gates. This procedure is dictated by the infrastructure that exists at the airport and airlines' former practices. In the past, air carriers preferred to deice at the gates so that flexibility in departure status is allowed thereby avoiding the funneling effects of aircraft passing through a designated deicing pad. Some large airports prefer not to deice at the gate areas because of congestion with other aircraft and passengers trying to board and deplane. Generally, airports differ in their choice of aircraft deicing locations due to the unique aspects of operational, climatic, and environmental concerns. With the many advances now being made in aircraft deicing techniques, removing ice and snow from aircraft at a designated area away from the gates may be preferred. New glycol reducing equipment may require added space to operate, so building a separate deicing pad would become the optimal approach.

Glycol Recycling

Recycled glycol is used in Europe for aircraft and runway deicing. In North America, recycled glycol is used to deice coal trains and coal piles, as a raw material for polyester manufacturing, and as an automobile radiator coolant (Mericas & Wagoner, 1994). The use of recycled glycol on aircraft currently is not allowed in the United States. Airlines and aviation regulators question whether spent deicing and anti-icing fluids can be restored to the stringent aerodynamic, anti-corrosion, and overall performance requirements that new fluids must have (McKenna, 1995). Ironically, these same airlines fly to Europe, where their aircraft are treated with recycled glycol fluid.

Change in the U.S. may be close at hand, however, as Inland Technologies, Inc. uses a proprietary system that separates glycol from water and impurities collected on the

airfield during deicing. Recovered and processed glycol can be reused for aircraft deicing in compliance with SAE specifications, the FAA, and Transport Canada regulations. In fact, Inland Technologies has achieved certification for its own brand of recycled Type I fluid (Lamprecht, 1999). It may not be long before it is common to see recycled deicing/anti-icing fluid used on aircraft in the United States. Several of the manufactures of deicing chemicals are interested in meeting the challenge of recycling used deicing fluids. They have expressed interest in recovering used glycol and believe that the industry is at a turning point in recycling glycol. Manufacturing representatives anticipate seeing some dramatic changes in the aviation industry in this regard (Bremer, 1993).

There are a growing number of airports with an on-site glycol recovery program. Regardless of the quantity of spent fluid generated, the fluid cannot be diluted to the point that it contains less than 5% glycol for a recycling option to be considered. Airports therefore need to have a good capturing system in place in order to attempt deicing fluid recycling (Betts, 1999). The relatively small volume of spent glycol fluid generated at the Dane County Regional Airport may no longer be a prohibiting factor for glycol recycling.

The airport could also consider purchasing a scrubbing machine that could be used on the airfield to clean up aircraft deicing fluid. The Reno International Airport (KRNO) recently bought a scrubber for \$90,000 that outperforms the airport's old scrubber (Reno Gazette Journal, 2000). Active glycol collection systems usually rely on some type of roving recovery vehicle which vacuums or otherwise removes deicing fluid from the airport tarmac after deicing events (AR Plus, 2000). A new high-tech scrubber

could effectively pick up excess spent glycol fluid that may be blown off the tarmac area by jet engine exhaust.

Summary

There is a lot of developmental activity occurring in the aircraft-deicing community. Innovative deicing technologies, such as infrared systems, are beginning to enter mainstream service at commercial airports. Pollution prevention initiatives are advancing areas of specialized research in glycol fluid formulation, reduction and application. Each airport is unique in an operational sense, but new deicing standardization may eventually come into place within the aviation industry. An example of such standardization is a universally applied benign deicing fluid to replace the glycol-based fluids currently in use. Until that time comes, however, each airport will have to assess the technological advancements being made in the aircraft-deicing arena and utilize industry approved deicing methods. The statement that “necessity is the mother of invention” applies to the new deicing/anti-icing methods and technology being introduced. Environmental and cost pressures faced by airport managers and airlines have been a strong motivator for change of the existing aircraft deicing technology. The decision as to what equipment may be best for a particular airport to implement still requires a case-by-case assessment and coordination between airline and airport management.

Statement of the Hypothesis

An alternative technology for the treatment and recovery of ethylene and propylene glycol would be more cost effective and provide better results in reducing glycol effluent levels than modifying, or continuing with, the current detention pond

recovery and treatment system at the Dane County Regional Airport. Additionally, a revised aircraft deicing fluid application process may provide for safer airport operations while establishing a more environmentally sound and cost-effective method of reducing glycol effluent concentrations.

CHAPTER 2

METHOD

This is a qualitative research study. It provides a disciplined inquiry into the specific needs and issues of the Dane County Regional Airport regarding their current aircraft deicing glycol collection and treatment system. It also provides a background of information for alternative considerations that the airport may wish to pursue for their future airport planning initiatives. The data collected involve a literature review of the current aircraft deicing operations that exist in the industry. They also include a summary of new innovative, FAA approved, aircraft deicing systems, some of which currently are available.

This is an inductive analysis by which a generalization is reached from collecting or observing multiple specific instances (Gay & Airasian, 2000). The data collection involved observation, interviews, and review of product material by the researcher to help ascertain how new technologies compare to the overall cost, efficiency and environmental impact of glycol treatment. This data can be useful in determining how the Dane County Regional Airport can best implement an aircraft deicing operation that will reduce glycol storm water-effluent discharges while providing safe and more cost-effective strategies.

Subjects

The sample population for this study is comprised of a review of the new aircraft deicing technologies that are on the market as well as the methods of modifying the

current glycol collection and treatment system. The researcher attempted to review the data collected and provide some insight into how current and future deicing technologies may compare to the specific deicing operations now in practice at the Dane County Regional Airport. The researcher also worked with the senior airport management staff to solicit input as to their needs, the needs of the commercial airlines that use the airport, and constraints that may exist. Examples of possible constraints include available land space, specific operational concerns, and sensitive environmental areas. Other participants included individuals from government regulatory agencies, deicing equipment vendors, engineering consulting firms, aviation industry professional organizations, and contacts from within the airline and air cargo industry.

Procedures

The procedures involved in the data gathering process were based on discussions with points of contact, a literature review, meeting with KMSN staff in Madison, and the researcher's attendance at a national aircraft deicing conference. The process consisted of digesting the contents of qualitative data, finding common threads in it, and gleaning current information that was relevant to the Dane County Regional Airport's needs and future growth. Noting technological developments and industry trends was an important component in the research process. Also, of equal importance were the equipment costs, physical land constraints, county budgetary issues, operational issues, and airport/airline business relationships that exist at the Dane County Regional Airport. The research that was conducted will be informative and beneficial to the airport staff. However, the research information does not encompass all that could be learned due to the relatively

limited scope of such a project. No qualitative researcher can observe and grasp everything of interest in a given project setting (Gay & Airasian, 2000).

CHAPTER 3

ANALYSIS

The yearly costs to operate the current glycol retention pond are shown in Table 1. These costs are based on the historical use and general amount of glycol-based fluid used to deice aircraft. The required treatment necessary to reduce the chemical effect of glycol released into the environment has costs associated with it. If the amount of glycol were to be significantly reduced, then the costs associated with the treatment and disposal of glycol fluids would be reduced. This is an important consideration in regards to the implementation of new deicing/anti-icing technology and equipment that would reduce, or eventually eliminate, the costs associated with the operation of the glycol retention pond.

Table 1
Annual Costs to Operate the Glycol Retention Pond

Engineering and Operation Contract	\$26,000
Airport Maintenance	\$5,000
Utilities	\$12,000
Discharge to local POTW	\$1,000
Chemical Testing	<u>\$5,500</u>
Total (Mead & Hunt, 1999)	\$49,000

Environmental compliance is a key concern for many airports, and the release of glycol fluids into receiving waters has been under considerable review. The key to reducing the impact on water bodies is by source reduction. If a new technology such as forced-air/glycol mist were to be implemented at the Dane County Regional Airport then the total estimated gallons of glycol generated would be reduced by a factor of ten. Table 2 indicates the savings that could be realized due to the use of forced-air/glycol mist deicing technology versus the conventional glycol fluid application currently utilized. In addition, the recommended use of a vacuum scrubber vehicle would dramatically reduce the amount of glycol runoff entering the storm collection system.

Table 2
Environmental Impact Reduction at KMSN

Conventional glycol deicing application	60 gallons per minute
Forced-air/glycol mist application	6 gallons per minute
Total amount of glycol used in '98-99 season	32,285 gallons
Total estimated gallons used with forced-air glycol mist	3,229 gallons

(Mead & Hunt, 1999)

The modification of the existing deicing equipment at the Dane County Regional Airport is an important component of glycol fluid reduction. Significant cost savings can be realized by modifying existing deicing trucks from conventional glycol application to forced-air/glycol mist. Table 3 indicates the savings that can be realized by retrofitting the existing deicing vehicles as opposed to buying new equipment. In a general sense, the reduced amount of glycol fluid used by new equipment could pay for the cost of retrofitting the existing deicing vehicles in a relatively short period of time. These

savings could also justify the lease or purchase of a vacuum scrubber vehicle to be used when deicing operations occur.

Table 3
Equipment Modifications Cost Analysis

Cost of brand new deicing vehicle	\$250,000
Cost to retrofit existing deicing vehicle	<u>\$70,000</u>
Total cost savings	\$180,000

(T. Polka, personal communication, Sept. 19, 2000)

CHAPTER 4

CONCLUSIONS

The Dane County Regional Airport has a glycol fluid collection, treatment, and storage system in place. There is an increasing effort to balance aviation safety and protection of the environment within the aviation industry. The recent application of storm water discharge permits at airport facilities is helping to mitigate the direct discharge of aircraft deicing fluids directly into receiving waters.

These airport storm water regulations also have generated more environmentally friendly deicing technologies to be explored and developed. The national program to mitigate aircraft deicing fluids has promoted the implementation of airport best management practices and glycol source reduction initiatives.

Because the primary concern with airborne transportation is safety, the use of aircraft deicers and anti-icers will most likely continue. The traditional use of chemical deicers has been a very effective means of assuring a clean aircraft surface free of ice and snow contamination. It is possible for airports to continue their deicing programs, however, almost all will have to implement changes designed to dramatically reduce the discharge of glycol-based fluids into the environment. These source reduction efforts are coming about through technological advancements geared toward improving aircraft deicing by alternative methods.

The two aircraft deicing technologies that appear to be the most feasible are infrared and forced-air/glycol mist application methods. There are commercial systems

in place for both of these technologies and that have demonstrated significant reductions in glycol use without compromising passenger safety. Advances in deicing fluid chemical formulations are also moving ahead to develop benign alternatives to glycol-based solutions without toxic additives. The aircraft deicing industry is rife with activity and it would appear that many changes are on the cusp of developing. New high-tech ice detection equipment as well as computer-driven equipment and management tools have applications for both large and small airports.

CHAPTER 5

RECOMMENDATIONS

The Dane County Regional Airport is planning to expand their facilities. This future airport expansion project will impact the current glycol collection and treatment system. If the airport management implements a newer, less glycol dependent technology, then a glycol retention pond may not be necessary in the future. An on-site biomass treatment system, such as that found at the Albany International Airport, could be constructed to replace the glycol retention pond. This could reduce BOD levels and better prepare spent fluid for release into the environment or to be recycled.

The airport management at the Dane County Regional Airport should require that tenant air carriers use only propylene glycol fluids for deicing. This will allow for recycling efforts to be conducted. The air carriers utilizing the airport should consider purchasing at least two forced-air/glycol mist units as a source reduction measure. This technology has been tested and proven in the industry with good success and would be quick and not cost prohibitive to implement. The existing deicing trucks at the airport may be capable of being modified with the new forced-air/glycol mist equipment. This would provide significant cost saving initiatives as noted in Table 3. Also, the use of a glycol recovery vehicle (vacuum truck) at the gate areas would aid in reducing the amount of ambient glycol remaining on the tarmac surface.

The airport should wait and see what developments occur in the near future with aircraft deicing fluid formulations. Due to the recent work of the SAE G-12 committee,

there may be significant breakthroughs in developing a much more benign fluid. This would most likely resolve the toxicity issue present with current formulations, and perhaps reduce biological oxygen demands in Starkweather Creek as well.

A designated deicing area or pad should be constructed for future airport expansion. Air carriers advocate remote deicing facilities to improve aircraft safety in wintertime operations. Many of the nation's larger airports have developed deicing pads, and this concept can be applied to smaller airports as well. The traffic volume at the Dane County Regional Airport would allow for aircraft to depart without much delay, and perhaps only one central pad would need to be constructed. The physical layout of the airport could support such an area especially if it were aligned with use of the preferred active runway in winter weather conditions.

The type of aircraft that frequent the airport also should be considered. Operators of aircraft such as the DC-9, MD-80s and Regional Jets are not in favor of operating aircraft laden with ice and snow to distant deicing locations for concern that large chunks of ice may break off the wings and be ingested into or by the engines. The airlines that operate these types of aircraft may wish to deice the aircraft at the gate or very close to the gate area. The popularity of Regional Jets should also be addressed. They are considered a "hard wing" aircraft and require even more diligent cleaning of the wing surface (J. Goglia, personal communication, August 21, 2000). The Fokker F-28 aircraft has a similar wing type and has been referenced in two terrible ice-related accidents in this paper.

The airport staff should meet with the largest air carrier operating out of the airport to get their input on what technologies they believe are most favorable. The

deicing practices that this air carrier utilizes at other airports may lend itself to modifications and subsequent use at the Dane County Regional Airport. The InfraTek™ system may present space constraints, and the cost to install such a system would have to be weighed. New modifications to the InfraTek™ system are being implemented as its use in the commercial aviation industry increases. This technology certainly has potential.

Like the infrared technology, the forced-air systems are already in service and have been successful at busy large hub operations. If the airport were to construct a designated deicing pad, then forced-air/glycol mist units could be a viable alternative to the existing deicing/anti-icing practice at the Dane County Regional Airport.

By incorporating into their deicing program the forced-air equipment, a change could be made quickly that does not require significant capital outlay. This change would permit the aircraft to be deiced in the same location that they are currently, yet this alternative would significantly reduce the amount of glycol fluid consumed. The mitigation of glycol consumption and release into neighboring waterways should have both long-term monetary savings as well as immediate and long-term benefits for the health of the environment.

Advanced weather forecasting capabilities also can reduce deicing and anti-icing fluid requirements. The increased accuracy of determining precipitation events is becoming an important factor in many airport deicing programs.

With the application of new technologies occurring in the past three years, and the promise of new industry advances to come, it behooves the Dane County Regional Airport to make adjustments to their deicing operation, but to hold off on major

infrastructure changes. The addition of forced-air/glycol mist technology will work well with the aircraft that serve the airport as well as with and the existing glycol-fluid treatment and collection system. The introduction of this new deicing technology will allow the airport to continue with, and improve upon, the existing WDNR storm water permit requirements.

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