AFIT/GEE/CEV/92S-9

A STUDY IN USE AND MANAGEMENT OF DE/ANTI-ICING CONSTITUENTS WITH REGARD TO NEW STORM WATER LEGISLATION

THESIS

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THESIS

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The purpose of this research was to identify management practices of airfield and aircraft de/anti-icing constituents which may be implemented to effectively deal with new storm water legislation.

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Abstract

This research identified use and management practices of airfield and aircraft de/anti-icing constituents which may be implemented to effectively deal with new storm water legislation. Storm water regulations require that airport deicing operations obtain a NPDES permit from the EPA which establishes effluent limitations for contaminants discharged into storm water runoff and which may mandate the use of Best Management Practices. An FAA survey polling civilian airports and a survey distributed to U.S. Air Force installations were used, with a literature search, to identify current use and practices of de/anti-icing constituents. There are four major constituents used--glycol, urea, CMA, and sodium formate. Concerns surrounding the uncontrolled release of the constituents include high BOD rates, nitrate and nitrite enrichment of surface and ground waters, impaired aesthetic water quality, ammonia formation from the degradation of urea, and the overall toxicity of such chemicals to aquatic life. There are several options that exist for managing the runoff of de/anti-icing constituents and ensuring compliance with new legislative criteria. Such innovative options include alternative constituents such as potassium acetate; alternative application procedures such as centralized facilities and greater use of anti-icing operations; collection alternatives using porous surface materials combined with drainage systems and holding tanks; and treatment alternatives such as mobile recovery units to recycle deicing fluids for re-use.

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I. Introduction

General Issue

In November 1990, the U.S. Environmental Protection Agency (EPA) implemented the final rules and regulations regarding National Pollutant Discharge Elimination System (NPDES) storm water discharge permits (5:68). The new regulations, based on requirements in the Water Quality Act of 1987, require specific industrial activities to obtain and comply with NPDES permits for all storm sewer systems that discharge into public surface waters (5:68). The new NPDES storm water regulations govern runoff from transportation facilities, with specific references to airport de/anti-icing operations (60:1). The new regulations establish more stringent limits and standards for de/anti-icing constituents in storm water discharge effluent. Previously, airport operations were not required to have storm water permits for their activities. Hence, storm water compliance has not been an important management issue. New regulations and requirements stipulate, however, that airport operations must be permitted and must comply with storm water standards and criteria defined by the EPA. Violations of these new standards could result in large fines and restrictions on certain routine airfield operations. The new federal regulations will require the U.S. Air Force to more effectively manage storm water runoff produced from such de/anti-icing operations.

Specific Problem

The purpose of this research was to identify use and management practices of aircraft and airfield de/anti-icing agents which may be implemented to help ensure U.S. Air Force compliance with new NPDES storm water legislation.

Research Objectives

There were four main investigative questions within the context of this research problem. These investigative questions were as follows:

1. The first investigative question was twofold:

   A. What are the major chemical constituents and substances associated with airfield and aircraft de/anti-icing operations?

   B. What are the qualitative environmental effects to ground and surface waters of introduction of these substances into the storm water waste stream?

2. What are the applicable federal rules and regulations and Air Force guidance and policies relevant to storm water runoff due to airfield and aircraft de/anti-icing operations?

3. What are the current management practices being used at various airport locations throughout the United States, including military and civilian operations?

4. What methods and management practices can be implemented to effectively ensure compliance with the new legislative criteria?

Scope and Limitations

The major assumption of this research was that the management practices relating to aircraft and airfield de/anti-icing operations within the Air Force closely parallel those that are currently in existence and being used in the civilian community. Thus, data obtained from civilian airports is readily transferrable to the Air Force.

This research consisted of a review of applicable literature including technical journals, reports, commercial brochures, and other sources of information concerned with the potential harmful effects of airfield and aircraft de/anti-icing operations. Included in the research was a review of appropriate and relevant federal storm water legislation and regulations and applicable Air Force regulatory guidance. A limit on the research scope is the focus on federal regulations; state or local regulations were not addressed.

The research also included a survey of U.S. Air Force installations by means of a questionnaire intended to reveal current use and management practices of aircraft and airfield de/anti-icing constituents. The surveyed installations were within the confines of the continental United States and Alaska, maintained active runways and were located above 35 degrees latitude. The selection was based on the assumption that these locations would be more likely to conduct aircraft and runway de/anti-icing operations on a regular basis. Overseas bases were not considered in the survey sample due to time constraints and the added complexity of considering host nation as well as U.S. storm water rules and regulations.

The survey questionnaire sent to each Air Force installation within the chosen sample consisted of two parts. The first part focused on de/anti-icing operations and practices with regards to runway pavements. This area of responsibility comes under the jurisdiction and authority of the Base Civil Engineer. The second part focused on aircraft de/anti-icing operations which is the primary responsibility of base logistics personnel within the U.S. Air Force.

In conjunction with the results obtained from the Air Force questionnaire, the study focused on the results obtained from a Federal Aviation Administration (FAA) survey questionnaire. The FAA survey polled over 100 civilian airports with regard to their de/anti-icing operations. In fact, the Air Force survey paralleled the FAA study because of the many similarities that exist between Air Force and civilian airfield and aircraft de/anti-icing operations. This resulted in a broader sample of the population and contributed significantly to the informational database that was compiled.

One limitation of the research was the inability to validate the effectiveness of specific management practices with respect to the new storm water requirements. In order to validate the effectiveness of a particular management practice, it would be necessary to gather data derived from water quality samples. However, the requirement to collect water quality samples is newly mandated by the recent storm water legislation; therefore, the data is unavailable for the purpose of this study. A follow-on study of water quality samples taken from various locations and representing various storm water management practices for de/anti-icing constituents could be conducted. Water quality sampling data could then be correlated with management practices to determine the practices that are most effective in satisfying the legislative criteria.

This research focused on the compilation of existing methods, practices, and suggested management practices of de/anti-icing operations, obtained from both a literature review and survey results, that might prove effective in ensuring compliance with the current legislative criteria.

Definition of Key Terms

There are some fundamental terms which were used throughout this study that must be defined.

Anti-icer refers to a chemical constituent, or process, that prevents ice from forming on an aircraft or pavement surface.

Deicer refers to a chemical constituent or process which removes existing ice from an aircraft or pavement surface. Ice formation is generally the result of melting and refreezing of snow, snow compaction, freezing of existing surface water, freezing water vapor, and freezing rain (18:12-13).

Biochemical Oxygen Demand (BOD) is the amount of oxygen required by microorganisms in order to aerobically oxidize organic waste material (36:117).

BOD_5 is the amount of oxygen that is consumed by microorganisms present in organic waste material during the first five days of the biodegradation process (36:117).

Regulated storm water, as defined by Title 40 of the Code of Federal Regulations (40 CFR), Part 122, consists of storm water runoff, surface runoff, and infiltration and drainage, resulting from storm events, or snow melt processes (58:47995).

Runoff is defined as "any rainwater, leachate, or any other liquid that drains over land from any part of the facility" (15:3).

Storm water is defined as "storm water runoff, snow melt runoff and surface runoff and drainage" (58:48065).

Organization of Study

This chapter discussed the need to identify current use and management practices of aircraft and airfield de/anti-icing agents, as well as the need to identify management practices which could ensure NPDES storm water compliance within the U.S. Air Force. Chapter II consists of a literature review regarding de/anti-icing practices, the qualitative effects of de/anti-icing constituents on surface and ground waters, and innovative options for managing runoff. Chapter II also identifies applicable federal storm water criteria and standards, as well as relevant Air Force regulations and guidance on storm water runoff due to industrial airport de/anti-icing operations. Chapter III describes the survey methodology used to meet the research objective and answer the investigative questions. Chapter IV introduces the survey findings, provides a subsequent analysis, and categorizes predominant use and management practices for airport de/anti-icing operations. Finally, Chapter V discusses conclusions and makes recommendations for further research.

II. Literature Review

Introduction

The new NPDES storm water regulations govern storm water runoff from U.S. transportation facilities with specific references to airport de/anti-icing operations (60:1). The new regulations establish more stringent limits and standards for de/anti-icing constituents in storm water discharge effluent resulting from U.S. airport operations. The passage of the storm water regulations reflects a growing public concern with regard to water quality within the United States and forces airport managers and others to take action regarding potentially adverse environmental effects associated with airport de/anti-icing operations. The purpose of this chapter is threefold. First, current information on the potentially adverse environmental effects to water quality from runway and aircraft de/anti-icing chemical constituents is presented. Second, applicable federal rules and regulations and Air Force guidance and policies on storm water runoff due to industrial (civilian and military) airport operations are identified and discussed. Finally, innovative aspects of pavement and aircraft de/anti-icing operations which might provide more effective management practices are discussed.

A review of the pertinent literature indicated there were four principal chemicals used in airport de/anti-icing operations. The four chemical constituents in use, or that potentially could be used for airport de/anti-icing operations, include glycols, urea, calcium magnesium acetate (CMA), and sodium formate (10:51-54). The environmental impacts of de/anti-icers are summarized in the following passage:

> The primary concerns associated with the uncontrollable release of deicer-laden runoff to receiving waters include high BOD, organic enrichment of receiving waters, impaired aesthetic quality, ammonia formation from urea degradation, and the potential presence of animal carcinogen 1,4-dioxane as a contaminant of ethylene glycol. (50:1)

The literature generally indicated that storm water laden with de/anti-icing agents may result in significant adverse environmental effects on both surface and ground waters (50:1).

The Federal Aviation Administration embraces the "clean aircraft concept" in the interest of flight safety. The underlying philosophy of this mandate is that aircraft wings and other critical surfaces must be free of frost or ice through the use of either manual methods, heated water, or freezing point depressant (FPD) fluids, prior to takeoff (50:2). Ice bonded to a surface at, or near, the freezing point (32°F) is relatively easy to remove by mechanical methods. However, scraping and other mechanical removal techniques are not very effective for very cold and strong ice bonds (59:32). As the name implies, an FPD fluid depresses the freezing point of water to a much lower temperature than the standard 32°F (50:2). Thus, in general, it is considered more efficient and economical to use chemical constituents for aircraft de-icing operations (59:32).

Basic chemistry dictates that any water-soluble substance is capable of lowering the freezing point of water and in turn can be used to melt frost, snow, or ice (59:32). However, ice-melting efficiency, cost, corrosivity, and overall environmental impact may vary greatly depending on the constituent. For example, as pointed out in one study, the overall ice-melting efficiency of a chemical de/anti-icing agent is limited by its overall chemical structure. The study points out that the maximum area of ice which can be undercut by any substance can be represented by the following relationship:

$$\text{AREA OF UNDERCUT} = \frac{(\text{mass of chemical})(\text{particles per molecule})}{(\text{molecular weight})(\text{temperature below freezing})}$$

(56:23).

In theory, therefore, the more efficient de/anti-icing agents would more likely be those with lower molecular weights and a greater number of disassociative (individual) ions (59:32). More efficient chemical constituents would tend to correlate with lower costs and amounts used.

Another critical factor relevant to a de/anti-icing agent's use and effectiveness relates to its corrosive properties. De/anti-icing agents used in and around aircraft operational facilities including aircraft, runways, taxiways, and aircraft parking stalls cannot include salts, particularly chloride salts, or any other chemical constituents which are known, or thought to be, corrosive to aircraft aluminum surfaces (59:32).

A third, and recently more important, criteria for evaluating the effectiveness of a de/anti-icing constituent relates directly to the adverse effects it has on the environment (10:54).

Summary. This chapter began with general background information on snow and ice control management and general properties and characteristics of chemical de/anti-icing constituents. Subsequently, the four major chemical constituents are discussed with regard to their general chemical characteristics and their potentially adverse health and environmental effects. These chemical constituents include glycols, urea, calcium magnesium acetate (CMA), and sodium formate. In turn, appropriate federal and other legislative criteria relevant to airport de/anti-icing storm water runoff operations are reviewed, and a discussion of Best Management Practices for controlling the runoff of de/anti-icing constituents is presented.

Chemical De/anti-icing Constituents

Glycols. Many de/anti-icing agents currently used at airport locations include members of the glycol chemical family (23:97). Two important glycol members include ethylene glycol and propylene glycol. Most aircraft deicers in use throughout the United States and Canada have chemical configurations based on either ethylene or propylene glycol (50:2).

Ethylene glycol is "a colorless, odorless, hydroscopic liquid infinitely soluble in water and many organic liquids" (1:43-5). Ethylene glycol has the chemical formula $C_2 H_6 O_2$, and has a freezing point of 8.6°F (-13°C) for pure liquid and a eutectic temperature in aqueous solution of -58°F (-50°C) (59:33). Eutectic temperature is defined as the lowest possible melting temperature obtainable with specified mixtures of certain compounds (19:151).

Oral ingestion of the chemical ethylene glycol can result in depression, respiratory and cardiac failure, kidney damage and brain damage (1:43-10). However, the acute and chronic oral toxicity of ethylene and propylene glycols to humans and other terrestrial life is generally perceived to be low (50:4). None of the glycols used as de/anti-icing agents have been demonstrated to be either a carcinogenic or mutagenic hazard through experimental methods (1:43-13). One exception may be associated with an animal carcinogen known as 1,4 - dioxane which may be present in some technical grades of ethylene glycol. Technical grades of ethylene glycol are used to formulate automotive antifreeze. Some suppliers of aircraft deicers currently use technical grade ethylene glycol to formulate aircraft deicers in certain areas of the United States (50:5). In fact, 1,4 -dioxane has been known to induce tumors in laboratory animals and is thus classified and regulated as a potential carcinogen to humans (50:4).

Propylene glycol appears to be less toxic to humans than ethylene glycol. However, it may cause skin rashes and irritation if held in contact with the skin for any extended period of time (4:3).

From an environmental perspective, ethylene glycol, due to its high solubility and weak sorption to soils, can be highly mobile in the soil/groundwater system (1:43-2). In fact, studies using ethylene glycol in sandy soils show the constituent to follow closely the overall movement of water with little or no retardation taking place (1:43-6). Sorption calculations for unsaturated topsoil models estimate "that only .4% of the ethylene glycol is expected to be sorbed onto soil particles" (1:43-5). According to the IRP Toxicology Guide:

> The properties of ethylene glycol suggest that drinking water exposure from groundwater contamination is likely to be its primary route of exposure from soil/groundwater systems. The movement of ethylene glycol in ground water may result in discharge to surface water. As a result, ingestion exposures may occur resulting from the use of surface waters as drinking water

supplies, and dermal exposures may result from the recreational use of surface waters. (1:43-8)

The acute and chronic aquatic toxicity of both ethylene and propylene glycols was found to be low for both freshwater and saltwater aquatic environments (4:5-6). In addition, both ethylene and propylene glycols are not considered bioaccumulative in nature and exhibit a high degree of biodegradability under normal soil/water conditions. These chemicals are therefore classified as non-persistent agents in the environment (50:5). This biodegradability, however, is a major problem, since both glycol deicing constituents exhibit very high Biochemical Oxygen Demand (BOD) rates in the laboratory setting and thus have the potential to deplete available oxygen supplies in waters receiving the runoff effluent (50:5).

> The biodegradation of glycols is so rapid and extremely oxygen-demanding that it can deplete dissolved oxygen (DO) levels and threaten oxygen-dependent aquatic life in receiving waters. The 5-day biochemical oxygen demand (BOD_5) at 20 °C for ethylene glycol has been reported to be in the range of 400,000 to 800,000 mg/L....The BOD_5 of propylene glycol is considerably higher (about 1,000,000 mg/L). (50:5)

A water quality assessment study by Eckhoff et al., conducted at Salt Lake City International Airport, Utah, found that glycol concentrations of airport storm water effluent reached as high as 2000 mg/L during initial flush stages of storm events (48:3), while BOD_5 measurements ranged as high as 2130 to 3130 mg/L (48:18). Other studies of storm water effluent sampled at Stapleton International Airport in Denver, Colorado, revealed concentrations of ethylene glycol ranging between zero and 5050 mg/L (50:7).

Urea. A second major chemical de/anti-icing constituent is urea. Urea is commonly used to remove ice from runways and airfield pavements. Urea, also known as carbamide, has the chemical formula, H_2NCOH_2N, and is manufactured by reacting ammonia with liquid carbon dioxide (CO_2) under high pressure and temperature conditions (31:3). The major problem with urea occurs during the biodegradation process when the chemical reverts back to ammonia and carbon dioxide, as shown by the following chemical reaction:

$H_2NCOH_2N + H_2O$ --->(Urease)---> $CO_2 + 2NH_3$

(31:3).

This hydrolysis reaction is accelerated in soil environments and principally depends on the presence of a soil enzyme called urease (50:6). Once the urea is hydrolyzed to ammonia, the ammonia is converted to nitrite (NO_2-), and then to nitrate (NO_3-) by nitrifying soil organisms. The process is illustrated by the following chemical reactions:

$2NH_3 + 3O_2$ ---(Nitrosomonas)---> $2NO_2^-$ +2H+ +$2H_20$

$2NO_2^- + O_2$ ---(Nitro bacteria)-> $2NO_3^-$ (36:123).

The breakdown of urea to ammonia is highly temperature-dependent. Consequently, it might be expected that urease activity will be minimal during the winter when the ground is frozen (50:6). This temperature dependency was verified in a 1973 study of river waters conducted by W.H. Evans et al. and is explained in the following passage:

> Urea will degrade to ammonia at a rate depending on the bacterial state of the river water and on the water temperature. Under normal conditions no breakdown may be expected to occur at temperatures below 8°C for 14 days contact. In river waters with a high suspended solids content, simulating extreme winter river conditions, a maximum breakdown of 3-6 per cent daily of the original urea levels was found for temperatures not exceeding 8°C during the first 7 days contact. (24:975)

In contrast, however, more recent studies involving nitrate/nitrite levels at various Canadian and European airport locations revealed the following:

> Maximum reported values for these airports ranged from 0.85 to 58 mg/L (nitrate) and 0.12 to 8.88 mg/L (nitrite). The high frequency of excessive ammonia and nitrate/nitrite levels does not corroborate the anticipated slow degradation processes for urea during wintertime. (50:8)

Urea in deicer storm water effluent would not contribute significantly to BOD_5, but would contribute to the nitrogenous oxygen demand (NOD) present in airport runoff during near-freezing temperature conditions (50:6). NOD is the oxygen demand created by the oxidation of ammonia present in organic waste material. Whereas BOD may cause immediate loss of oxygen, the effect of NOD is delayed by 5-8 days (36:123-126). Urea itself may have little impact on aquatic and terrestrial life. However, the formation of ammonia and nitrate substances from urea usage is a critical environmental concern. The overall acute toxicity of ammonia to aquatic life is relatively high, since LC_{50} amounts generally range between 1 and 10 mg/L (50:6). LC_{50} is the dose of a toxic agent administered over a short period of time that will cause adverse effects in 50 percent of the affected population (63:35-36). Because the Canadian government is so concerned with the urea runoff problem, it has proposed a maximum allowable limit of 1.0 mg/L for ammonia-nitrogen constituents in storm water discharge (50:6). Urea and its subsequent breakdown products can also result in lake eutrophication (excessive algal growth) and algal blooms in surrounding surface waters, particularly if nitrogen is the limiting nutrient in a particular given aquatic environment (31:8).

> Algal blooms can create a number of problems, including tastes and odors in drinking water and fish kills associated with algal toxins and/or oxygen depletion. Two groups of blue-green algae, Microcystis and Anabaena, produce toxins that result in sickness or death to birds and mammals drinking the water. (31:8)

One important health consequence involving the use of urea is that nitrate "impairs the ability of blood hemoglobin to transport oxygen resulting in 'blue baby syndrome' (methemoglobinemia) in infants. The federal drinking water standard to protect against this effect is 10 mg/L nitrate, or 10 mg/L total nitrate and nitrite" (50:6). "Blue baby syndrome" might be more common to rural farm areas where well water is vulnerable to nutrient pollution and is the primary source of potable drinking water (36:111).

The potential does exist for ground water contamination resulting from excessive concentrations of urea (55:5). In fact, the conclusion of one study concerning the environmental impact of urea at several Canadian airport locations was as follows:

> It is, however, possible that groundwater contamination is occurring at some airports particularly where porous sandy soils, perforated stormwater pipes and high urea consumption are combined. Groundwater contamination is a concern at sites such as Charlottetown Airport where the groundwater recharge area for the city's drinking water wells is located beneath the airport. The sandy soil of the Charlottetown site would facilitate the downward movement of pollutants. (55:16)

Ammonia and nitrate pollutants were subject to analysis in a 1982 U.S. Geological Survey study, concerning a sewage plume in a highly porous and permeable sand and gravel aquifer in Cape Cod, Massachusetts. The study indicated the overall distribution and behavior of ammonia and nitrate constituents was as follows:

> [that] ammonia [moved] readily in the aquifer and that oxidization of ammonia to nitrate [was] the primary cause of attenuation of ammonia concentrations in the plume. Nitrate, the end product of nitrification, is the stable species of nitrogen in an oxidizing groundwater environment and moves through the aquifer without reacting with other chemical constituents or with the sediments. (33:24)

Thus, it is clear that urea and the nitrite/nitrate constituents associated with its chemical degradation are seen as potential threats to groundwater aquifers.

Various studies have verified the significant environmental impact of urea usage. For example, nine water quality studies involving Canadian airports at different operating locations discovered the presence of urea and its chemical by-products in storm water effluent and found established limits were exceeded at all nine airport locations. The limits for ammonia were exceeded at 7 of 9 locations, while the limits for nitrate/nitrite were exceeded at 5 of 9 locations (50:8). Additional studies at various airports also revealed the following:

> Transport Canada (1990a) determined that as much as 64 to 100% of the applied urea may discharge directly to surface waters via overland flow. Soil infiltration and plant uptake were considered to be generally minimal processes affecting the fate of urea in wintertime, although some soil infiltration and ground water contamination were considered possible where porous sandy soils predominate. (50:7)

<u>Calcium Magnesium Acetate (CMA)</u>. Calcium magnesium acetate (CMA) is a solid, pelletized de/anti-icing agent with the chemical formula $CaMg_2(C_2H_3O_2)_2$ (25:49). As a result of the adverse effects of normal de-icer salts, the Federal Highway Administration supports the use of calcium magnesium acetate as a potentially powerful and effective alternative. Ordinary deicing salts, particularly sodium chloride (NaCl), can significantly damage and adversely effect "vegetation,

soils, aquatic eco-systems, domestic water supplies, vehicles, bridge decks, and concrete pavements" (41:3-1). Due to the corrosivity effects of normal road salts, they are not generally acceptable for airport use and applications. Salt concentrations as high as 35,000 mg/L, the rough equivalent of seawater, have been detected in road surface runoff effluent (41:3-2). In addition, CMA may prove to have potential for use as an airfield deicing agent. Although the overall environmental effects of CMA are largely unknown, there has been some research conducted in this area. The research tends to indicate that CMA is generally an acceptable alternative with minimal environmental effects (41:3-7). According to an early study by the New York State Energy Research and Development Authority in February 1988, it was expected that the use of CMA would tend to increase overall water hardness. However, the study did not determine this increase to be a potentially serious or devastating environmental effect involving the use of the constituent (41:3-7). The study also indicated that

> although the acetate ion is mildly toxic to some fish, it decomposes readily and would probably not reach toxic levels. The decomposition of acetate could result in localized oxygen depletion in water bodies. (41:3-8)

Tests have shown that CMA is much less corrosive to exposed metals than sodium chloride (salt) deicing agents (41:3-9). Furthermore, calcium magnesium acetate was "found to be noncorrosive and as effective as salt, but more effective than urea" (45:1).

The calcium and magnesium cations resulting from CMA applications behave as described in the following passage:

> Calcium and magnesium cations have high affinities for the cation exchange sites on soil particles and because calcium precipitates to form calcium carbonate (limestone), calcium and magnesium ion mobility in soil is limited. In contrast to sodium cations, calcium and magnesium cations, increase the soil's permeability and aeration. (25:45)

CMA can actually reverse the adverse affects of road salts. The Massachusetts Department of Public Works was successful in lowering groundwater sodium levels by switching to CMA use in order to control ice and snow versus using normal chloride salts. In Freetown, Massachusetts, the levels of sodium in private wells was reduced from 52 mg/L to 26 mg/L over a relatively short time period of two years (25:45). This is important since high sodium intake can be associated with heart disease, hypertension, and blood circulatory problems in humans (25:47).

In addition, the study pointed out that elevated levels of sodium and chloride constituents can result in a phenomenon known as lake density stratification which can ultimately lead to dissolved oxygen (DO) depletion within certain lacustrine environments. DO levels in the bottom layer (hypolimnion) are reduced during the winter. As temperatures rise (or fall) in the spring and autumn seasons, it is critical that a seasonal mixing of these stratified layers occur within the lake environment. This mixing process ensures that proper oxygen levels are maintained at the bottom-most layers of the lake in order to effectively sustain the aquatic organisms that exist there (36:140-141). According to one study,

> salt entering a lake environment can lower the lake's center of gravity by increasing the density of its bottom waters. First Sister Lake in Ann Arbor, Mich., experienced complete DO depletion (anoxia) in bottom waters when the concentrations of sodium and chloride reached 55 mg/L and 136 mg/L, respectively. (25:47)

The study points out that the use of CMA would not contribute to the DO depletion problem presented by normal salt deicers (25:47).

According to the literature, the only major environmental impact of CMA use and application is associated with the acetate ion's ability to biodegrade. Microorganisms use oxygen as they degrade the acetate ions; this oxygen consumption could create a "localized oxygen depletion" (25:47). However, according to one study, this would not be the case at all and the following circumstances would be more valid:

> Acetate will not create BOD problems. Soil and soil microbes capture and degrade much of the applied acetate, thus preventing its transport in runoff....And, because BOD is temperature-dependent, BOD is exerted gradually in the cold surface waters found near deicing operations. These factors eliminate the likelihood of oxygen depletion in virtually all cases. (25:47)

Consequently, CMA will have poor mobility in the soil and will not likely reach and contaminate ground waters (25:49). In addition, corrosion tests involving calcium magnesium acetate on aluminum highlight the noncorrosive characteristics of this important deicing compound (25:50).

One major drawback in the use and application of the CMA chemical is pointed out in a journal article written by Alan Rabideau et al. This study hypothesized that in urban areas served by combined storm/sanitary sewer systems, the bulk of the de/anti-icing constituents end up in the sewer system and subsequently are processed through the waste water treatment plant (POTW). The study further stated that "because of the chemical nature of CMA, significant increases in organic loadings to POTW's may result from CMA application in urban areas that use combined storm/sanitary sewer systems" (46:311). This may not be a problem for the Air Force since the majority of bases within the United States do not have combined sewer systems. Currently, storm water runoff flows into various rivers, streams, creeks, and other drainage channels instead of the wastewater treatment system (47:7). However, the use of CMA deicers could still pose potential problems for Air Force treatment plants should stormwater runoff infiltrate into the sanitary sewage system (47:7). The Rabideau study points out that within the Buffalo, New York, area a partial or complete CMA substitution for normal road salt de/anti-icers would be significant since "increased organic loadings are likely to result in increased aeration, nutrient addition, and additional sludge handling capabilities" (46:314). In conclusion, the study points out that the consequences of such an impact on POTW operations should be fully and thoroughly considered prior to switching over to CMA deicing constituents in areas supported by combined sewer systems (46:315).

A critical blow to potential use of CMA for airfield operations came as a result of a test evaluation report, #WRDC/MLS 90-101, issued on 27 August 1990 by the WRDC/MLC--Materials Laboratory at Wright-Patterson AFB, Ohio. The report concluded that three chemical compounds (CMA de/anti-icing compounds) submitted by Chevron Chemical Company had failed various de/anti-icing corrosion specification requirements. The recommendation and final conclusion of the evaluation report was not to use any of these three CMA compounds for either aircraft or taxiway deicing purposes within the U.S. Air Force (13:3). Further testing of variations of the CMA de/anti-icing chemical compound is most certainly to follow.

Sodium Formate. A fourth potentially useful airport de/anti-icing constituent is sodium formate, which is chemically known as $NaCHO_2$ (3:83). Sodium formate has shown de/anti-icing potential comparable to routine salt deicing constituents in speed, application rate and overall operating temperature limitations (52:1).

When compared to urea, sodium formate is believed to be faster, operates at lower temperatures, and requires lesser amounts in order to obtain the same desired effect. Sodium formate is also thought to be less toxic to aquatic species than the ammonia produced by urea biodegradation (52:1). Sodium formate was found to be environmentally safer than urea.

> Sodium formate is readily biodegradable with a maximum BOD of 0.23 g O_2/gram of sodium formate, about 1/10th that of urea's maximum. Sodium formate is also not a fertilizer and does not contribute to possible eutrophication of waterways. (52:1)

A negative aspect of sodium formate is its potential contribution to increased sodium levels in ground water, especially in areas where shallow wells are the predominant potable water supply. This effect on groundwater is expected to be largely localized and transient in nature, and thus should not present a significant problem except under extreme circumstances (52:1). However, some researchers claim that sodium concentrations are indeed important since "all salts are toxic when they are present in concentrations high enough to exert an unfavorable osmotic pressure" (3:84). This holds true for sodium formate compounds as well, given high enough concentrations in surface and ground waters (3:84).

Two other adverse and critical effects of sodium formate pertaining to airport applications involve its corrosive potential to jet engines and concrete surfaces. Engine manufacturers such as General Electric (GE) are concerned about potential corrosion to engine turbine blades once a deicer constituent (sodium formate) reacts to form sulfate compounds in the engine combustion chamber and ultimately sticks to the turbine blade material (52:2). An early report by the California Department of Transportation (DOT) reported that sodium formate caused excessive spalling of concrete and thus was found to be unacceptable as an alternative deicer. The California DOT made this decision even though sodium formate was shown to be as effective as sodium chloride in melting ice (51:7). However, these results seem to have been contradicted by a test study completed by William Slinkard, in March 1985, when he concluded the following:

> The tendency of Ca and Ca Mg formate to promote cracking and spalling of concrete is a serious impediment to their use as deicers and essentially eliminates them from consideration. On the other hand, Na formate <u>was</u> acceptable for use on concrete contrary to an early report by the California DOT. (51:8)

One advantage in the application of sodium formate as a de/anti-icing agent is stated in the following excerpt from the Slinkard study:

> High Na+ content of some communities's drinking water is a problem and the use of Na+-containing deicing salts has been restricted. Na formate would be preferred over Na chloride, since the formate salt contains no chloride to pollute existing water supplies. Na formate would not, however, alleviate potential problems from Na+ contamination. (51:9)

<u>Summary</u>. This first portion of the literature review has dealt with the human health effects and overall adverse environmental impacts of chemical de/anti-icing constituents. The discussion principally dealt with the four chemical constituents predominantly used for airport de/anti-icing operations. The second portion of this chapter discusses federal rules and regulations relevant to de/anti-icing storm water runoff operations at airport locations, while the final portion of this chapter considers innovative aspects for managing runoff of de/anti-icing constituents.

Storm Water Rules and Regulations

Pollutants in storm water discharges from many sources remain largely uncontrolled despite the legislation that has evolved in response to concerns regarding water quality. The "National Water Quality Inventory, 1990 Report to Congress" provided a general assessment of water quality and indicated that "roughly 30% of known cases of water quality impairment are attributable to storm water discharges" (62:1).

In further response to the water quality dilemma, the Environmental Protection Agency (EPA) Storm Water Discharge regulations became effective on December 17, 1990. The regulations require the EPA to establish storm water regulations and standards under the National Pollution Discharge Elimination System (NPDES) permit program. NPDES programs have traditionally focused on reducing point source pollutants in discharges from municipal wastewater treatment plants and industrial process wastewater (44:52), but the "definition of point sources is now being expanded to include sources previously considered as nonpoint" (42:1409).

In the past, efforts to improve water quality have focused on reducing point source pollutant discharges from industrial process wastewater and municipal sewage treatment plants (62:1). The original intent of Congress was to focus on end-of-pipe discharges and to develop methods for controlling them (42:1409). However, the definition of point sources has been expanded to include sources previously considered as nonpoint. Many activities once exempt from the permitting process are now included. EPA has broadly defined storm water "discharges associated with industrial activity" to include over 100,000 facilities, particularly airports (62:1).

The regulations require that industrial activities that result in "direct storm water discharges to waters of the United States and storm water discharges through municipal separate storm sewers" must obtain a NPDES permit from the EPA (14:2). U.S. Air Force base activities meet the regulatory definition of industrial activities and are therefore included under NPDES provisions.

Any airport activity that may yield storm water runoff is covered by the new regulations. Such activity includes airport de/anti-icing operations as well as maintenance, fueling, mechanical repairs, aircraft refurbishment, painting, cleaning, and lubrication (26:58). The NPDES permit program identifies and establishes effluent limitations for contaminants that can be discharged into storm water runoff (26:58).

Background (1972-1990). In 1972, the Clean Water Act (CWA) was passed which prohibited "the discharge of any pollutant to waters of the U.S. from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit" (62:1). The NPDES permit specifies a treatment technology that should be used in order to manage these point sources (42:1409).

Many changes have taken place since the introduction of storm water legislation in 1972. In 1973, storm water discharges were exempted from permit conditions, unless the discharges were determined to be major contributors to water pollution. After much litigation, the storm water regulation was revised in 1979 and 1980 to require individual permit applications from storm water dischargers (44:53). Permit requirements for Air Force bases were required on a state-by-state basis.

More rounds of litigation and proposed regulations followed in the 1980's until the Water Quality Act (WQA) was passed in 1987 (44:53). No national permit requirements for Air Force bases existed until this Act and subsequent storm water regulations of the 1990's (49). The WQA required that states determine the magnitude of their water quality problem and reduce their sources of pollution. Non-point sources were now being considered in addition to traditional point sources (20:363). The WQA established a two-phase approach to storm water discharge permits. The first phase required permits for "significant known or identifiable pollutant discharges," and the second phase identified procedures for small discharges not currently under permit (5:69). In conjunction with the criteria of the phased approach, the WQA defined three general classes of storm water discharges: 1) discharges associated with certain industrial activities, 2) discharges from large municipal storm water systems, and 3) discharges that have already received a NPDES permit (5:69).

Under subsection 402(p) of the WQA, entitled "Municipal and Industrial Storm Water Discharges," the EPA and the States were prohibited from requiring permits for discharge composed solely of storm water until 1 October 92. An exception was made for "discharges associated with industrial activity" (58:47992). The WQA "clarified that permits for discharges associated with industrial activity must meet all of the applicable provisions of section 402...including technology and water quality standards" (58:47992-47993). The final rules and regulations implementing the NPDES permit program under the WQA were signed on 31 October 1990 and published in the Federal Register on 16 November 1990. It became effective 17 December 1990 (14:1).

Industrial Activity. U.S. Air Force bases meet the regulatory definition of industrial activity and are therefore included under the NPDES. Pertinent sections of the NPDES provisions govern storm water discharges resulting from, or associated with, industrial activities.

The federal regulations include "transportation facilities which have vehicle maintenance shops, equipment cleaning operations or airport deicing operations" among facilities engaging in industrial activity (14:3-4). EPA specifically includes airports as industrial facilities and requires them to obtain permits "if storm water is discharged directly or indirectly into a river, stream or other 'surface' water or into a separate storm water collection system" (34). Airports with existing storm water discharge permits are not required to take additional action under the new rule until the expiration of their permits (34).

In addition to industrial activities such as airport deicing, the regulations require a NPDES permit application for certain facilities which discharge storm water associated with industrial activity. The term, "associated with industrial activity," includes "Federal, State and municipal facilities which are or have been involved in activities similar in nature to the industrial activities defined within the regulations" (14:1). Discharges associated with industrial activity include "storm runoff from industrial plant yards, immediate access roads and railroad sidings, drainage ponds, material handling sites, refuse sites, process wastewater sites, equipment handling/maintenance areas, residual treatment areas, and loading/unloading areas" (5:69).

Regardless of whether the storm water is discharged directly to surface waters or into a separate municipal storm water point source, Federal, State, and municipal facilities must obtain a permit (8:14). Facilities which already have storm water discharge permits must also comply with the new requirements and submit the appropriate information 180 days prior to expiration of the current permit (14:1).

Discharges from certain areas of military installations, such as office buildings and accompanying parking lots, are excluded from the definition of "associated with industrial activity," as long as the storm water is not mixed with storm water resulting from those practices considered industrial activity or associated with industrial activity (14:2-3).

EPA and State Relationship. The new NPDES regulations are being implemented by EPA and its regional offices. However, in most states, EPA has delegated authority to the state-level environmental regulatory agencies. These states are responsible for their respective NPDES programs. Some states have delegated further "to regional water quality control agencies. Therefore, most municipal applicants will deal with state and/or regional regulators on a routine basis and will deal with EPA less frequently" (9:61).

Currently, national numerical effluent limitation standards for many constituents, including de/anti-icing agents, do not exist. Various criteria may be selected by the EPA as "the Administrator determines [is] necessary to carry out the provisions of the [Clean Water] Act" (57:subsection 402(a)(1)). States with delegated authority from the EPA are responsible for ensuring compliance with standards. Industrial activities requiring permits will be subject to the standards and criteria imposed by the State. "EPA will work with the States to coordinate development of model permits for selected classes of industrial storm water discharges" (58:48002). Thirty-eight states and one territory have approved programs. The requirements of the approved states must be at least as stringent as the federal program. States have the option of being more stringent if they so choose (58:48002).

There are a number of factors considered when determining whether or not a storm water discharge is in violation of the standards imposed, or if the discharge is a significant contributor of water pollution. Such factors include the location of the discharge with respect to the waters, size of the discharge, quantity and nature of the constituents, and any other factors deemed important (58:48063). EPA or the delegated state should use any available water quality or sampling data to determine whether a violation or significant contribution has occurred (58:47993).

Storm Water Controls. Section 402(p)(3)(iii) of the CWA requires storm water discharges from industrial facilities to comply with technology-based controls and quantitative water quality standards established for receiving waters. Permits for discharges "shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and systems, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants" (57:subsection 402(p)(3)(iii)).

Traditionally, NPDES permits have contained chemical-specific numerical effluent limits. Effluent guidelines are not always

> available to prescribe these effluent limits nor to guarantee water quality sufficient for the protection of indigenous aquatic life. To improve water quality, the Act provides for water pollution controls supplemental to effluent limitations guidelines. Best Management Practices (BMPs) are one such supplemental control. Pursuant to sections 304 and 402 of the Act, BMPs may be incorporated as permit conditions. In the context of the NPDES program, BMPs are actions or procedures to prevent or minimize the potential for the release of toxic pollutants or hazardous substances in significant amounts to surface waters. BMPs, although normally qualitative, are expected to be most effective when used in conjunction with numerical effluent limits in NPDES permits. (61:1-2)

Best Management Practices may include "establishing a pollution prevention committee; employing traditional storm water management practices; conducting risk assessments; developing inventories of production materials; identifying or constructing alternative storage areas not exposed to storm water; spill prevention and response; and employee training" (8:20).

USAF non-point pollution policy dated 5 May 1987 references Best Management Practices as

> methods, measures,or practices to prevent or reduce water pollution, including, but not limited to, structural and nonstructural controls, and operation and maintenance procedures. BMPs may be applied before, during, or after pollution-producing activities in order to reduce or eliminate the introduction of pollutants into water bodies. (17)

USAF policy, therefore, requires that effective measures be taken at Air Force installations to limit the introduction of pavement and aircraft de/anti-icing constituents into storm water runoff.

Industrial dischargers may also implement best available technology (BAT) and best conventional pollutant control technology (BCT) to control storm water discharges. "BAT treatment requires maximum economically achievable pollution reduction, and primarily applies to priority pollutants such as biochemical oxygen demand, total suspended solids, pH, and fecal coliform. Industrial discharges must also have water-quality-based controls where necessary" (44:54). Physical or structural controls may include "first-flush division systems, detention and retention ponds, swirl concentrators, porous pavement and grass swales" (8:20).

Permit Application Options. Airports have three options in order to comply with the regulation-- individual, group, or general permits.

Individual Permit. The first option, individual permit, is usually least preferred because of cost. Individual permits must contain descriptions of the facility, topographic information, site maps, certification that all outfalls contain only storm water, spill history, and quantitative data. The individual permit required the submission of sampling data for each outfall at each facility by 18 November 1991 (5:70,72).

Group Permit. The second option allows airports and other industrial facilities with "similar processes or similar expected discharges to join together and submit a two-part group permit application" (34). Many airports are proceeding with the group permit procedure. In Part 1 of the two-part process for group permit application, the applicants demonstrate and justify that the participants are "sufficiently similar to justify a group application," and specify which facilities will submit sample data (5:70). After approval of Part 1, Part 2 consists of submitting quantitative data for "10 percent of the facilities, or at least 10 and no more than 100 facilities in total. While only 10 percent of the participating facilities must submit storm water sampling results, all facilities must annually submit test data after the permit has been issued" (5:70).

General Permit. General permits may be issued to cover a specific industrial category or all industries. A facility that does not belong to a group permit application may qualify for the general permit if the facility submits a Notice of Intent (NOI).

The NOI confirms that the facility proposes to be covered under a general permit (8:16). NOIs include a "site-specific 'pollution prevention plan' containing enforceable 'best management practices'...[and] existing quantitative data about a facility's storm water pollutant discharges" (8:16). The permitting agency specifies the information required in the NOI. Information required "may range from minimal identification of the facility to a full permit application" (5:72).

Facilities covered by a general permit will have to perform "annual or semi-annual sampling and testing for eight conventional pollutants, as well as others, in storm water discharges" (8:16). There is more risk involved in this option since the general permit does not guarantee that all discharges generated by a particular kind of aviation activity will be allowed (26:58).

Samples. When required from the applicants, the storm water quality samples should be analyzed for certain characteristics or parameters. They should at least be analyzed for oil and grease, pH, BOD_5, chemical oxygen demand (COD), total suspended solids (TSS), total phosphorus, total Kjeldahl nitrogen, and nitrate plus nitrite nitrogen. In addition, samples should be analyzed for:

- any pollutant limited in an effluent guideline for an industrial subcategory to which the base or portion of the base is subject;
- any pollutant listed in the base NPDES permit for its process wastewater, if the base is operating under an existing NPDES permit;
- parameters known or anticipated to be present in the discharge;
- flow measurements or estimates of the flow rate, and the total amount of discharge for the storm event(s) sampled, and the method of flow measurement or estimation; and
- the date and duration (in hours) of the storm event(s) sampled, rainfall measurements or estimates of the storm event (in inches) which generated the sampled runoff and the duration between the storm event sampled and the end of the previous measurable storm event (in hours). (14:11-12)

Enforcement. By February 4, 1991, the Clean Water Act required EPA or a delegated state to issue permits (either individual, group, or general) for industrial storm water discharges and large municipal storm sewer systems. Full compliance is required no later than three years after the permit is issued (8:14). "Enforcement under the CWA is grounded in the doctrine of strict liability. Strict liability provides that any sample result that exceeds an absolute numerical permit limitation or stream quality standard constitutes a violation of the

Act" (27:109). Penalties have been established for polluters who violate the permit provisions (42:1406).

CAA, CERCLA and RCRA Regulations. In addition to the conventional storm water regulations and the NPDES permit program, other laws and regulations, such as the 1990 Clean Air Act (CAA) Amendments, the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), and Resource Conservation and Recovery Act (RCRA), may factor into the way de/anti-icing operations are conducted. Under the CAA Amendments, ethylene glycol was added to the list of hazardous air pollutants. Ethylene glycol is also a regulated CERCLA hazardous waste and reportable under the Superfund Amendments and Reauthorization Act (SARA), Title III. It is reportable above certain threshold levels. There is a reportable quantity of one pound per each release per twenty-four hour period. Ethylene and propylene glycols are not affected as of yet under RCRA. However, the EPA may redefine the term "hazardous waste." This new definition could impact de/anti-icing operations in the future. The general consensus by a panel of experts with the Federal Aviation Administration is that these "new" regulations will not impact de/anti-icing operations, although their opinion is only speculative (64). The focus of this study remains on the newly-regulated NPDES permit program and conventional storm water regulations.

Innovative Aspects and Management Practices

The last part of this chapter identifies newer and innovative aspects of pavement and aircraft de/anti-icing operations which might provide more effective management practices. This portion is divided into four sections-- alternative chemical constituents, application alternatives, collection alternatives, and treatment alternatives.

Alternative Chemical Constituents. The three principal runway chemical alternatives for pavement de/anti-icing found in the course of the research include potassium acetate, calcium magnesium acetate (CMA), and sodium formate. Potassium acetate (commercially known as Chevron

E-36 liquid runway deicer) can be used in lieu of urea and glycol constituents and thus eliminate these constituents from airport runoff.

Potassium acetate contains no ammonia, nitrates, or nitrites and has the lowest BOD rate of any existing runway deicer (53). To date, potassium acetate has been found to be safe for aircraft while passing all civilian material compatibility tests (per AMS 1432) (21:2). Potassium acetate underwent testing at Eielson AFB, Alaska, during the winter of 1991, with great success (39). In fact, potassium acetate is considered an acceptable runway deicing alternative by Air Force standards and is either being used or tested at 7 U.S. bases (38). Approval by FAA officials is also expected for use at civilian airports in the near future (2). Early test results indicate that potassium acetate is fully functional at much lower temperatures, does not evaporate, remains on the pavement surface much longer, and is environmentally safe (11). The environmental compatibility of the chemical is attributed to the fact it has a BOD_5 of only .27 gm O_2/gm (versus .83 gm O_2/gm for propylene glycol), and contains no hazardous components as described by SARA Title III, Section 302 (21:4,8).

Other potential runway chemical alternatives include CMA and sodium formate. Both have been accepted by the Federal Aviation Administration as suitable runway de/anti-icers. However, Air Force and military corrosion specifications have prevented full-scale use of these two constituents pending further testing for corrosivity (2). All prospective deicing chemicals must meet the requirements set forth in the military specification MIL SPEC MIL D-83411 (37).

Currently, there is no aircraft de/anti-icing alternative readily available and suitable to warrant the replacement of ethylene and propylene glycol chemical mixtures (64).

Application Alternatives. The information obtained from the literature review and commercial industry brochures indicated there were three principal alternatives to current de/anti-icing agent application practices.

First, in order to most effectively control the runoff of de/anti-icing constituents, it may be more appropriate to centralize the de/anti-icer's point of application. This concept cannot be readily applied to pavement applications, but may be feasible for aircraft applications. The use of a single point deicing location reduces a non-point source pollution problem to a point source pollution problem and, therefore, can be more effectively managed. United Parcel Service (UPS) in Louisville, Kentucky, utilizes a $20 million centralized de/anti-icing application facility with great success. Two other similar facilities have been proposed for Toronto, Ontario, in order to deal with future aircraft deicing operations (35). Additionally, at Charles De Gaulle Airport in Paris, France, Air France has experienced no delays due to deicing since incorporating a centralized deicing facility that combines manual application with a fixed mechanical system (64).

Second, more effective use of anti-icing methods and management practices may be considered to minimize deicing operations. Anti-icing procedures are directed and referenced in AFR 91-15, Real Property Operations and Maintenance: Snow and Ice Removal and Control (18:13). Anti-icing uses considerably less amounts of chemicals than deicing operations. There is a requirement for up to five times the chemical amount to deice the pavement compared to that required for anti-icing that same surface (29).

Finally, the literature pointed out that the application of de/anti-icing chemicals should be in response to the real-time temperatures of both runways and aircraft. For pavements, Runway Ice Detection Systems (RIDS) utilize flush-mounted sensors, central processing units and software to monitor actual surface temperature and precipitation and icing conditions. In turn, RIDS uses weather forecasts in combination with sensor data to create a "pavement temperature forecast" (29). This can be critical since the pavement temperature can vary from the ambient air temperature by as much as 20 to 30 degrees Fahrenheit (29). In 1990, a four-year unfunded requirements contract was awarded to a firm to construct and install RIDS at 28 Air Force bases (29).

Similarly, sensors installed in the leading edges of aircraft wings and on the upper fuselage might also be effective in monitoring real-time icing conditions in order to more effectively manage the application and use of aircraft deicing constituents (40).

Other aircraft devices include electro-expulsive devices in the leading edges of the wings. A high amperage pulse applied to conductive strips inside a polyurethane plastic layer causes the ice to vibrate loose. The Electro Expulsive Separation System (EESS) is capable of removing any ice ranging from a mere frost coating to a layer 2.5 centimeters thick (6:36).

Collection Alternatives. The literature indicated that the adverse effects of de/anti-icing constituents are increased where virtually no attempt is made to collect or delay runoff and thereby minimize its overall environmental effects. The UPS facility in Louisville, Kentucky, uses a layer of porous tarmac at their centralized deicing location. It is estimated that more than 95% of the spent de-icer is collected rather than allowing it to run off to the surrounding environment (32:5).

Scandinavian Airlines and other major airport users at Copenhagen Airport are planning to use a commercial product known as RoMat (7:4). RoMat is a fluid control system consisting of deeply-ribbed, steel-belted, rubber matting. This rubber matting is equipped with special aluminum ramps to allow the airplanes access onto the mat. Deicing fluid is carried off the deicing platform and channeled into holding tanks by a gutter system located along the edges of the mat (12;7:7).

Other, less elaborate techniques which might be used for runway applications include simple vacuum sweep equipment. Wurtsmith AFB, Michigan, employs this procedure to control constituent runoff (2).

The use of natural topography and overland drainage patterns to temporarily collect and detain effluent in detention ponds, lagoons and open ditches can also be an option. The effectiveness of detention basins on nutrient mass loadings was demonstrated in one study in which nutrient loadings were substantially reduced in those surface waters discharged from the basin (28:63).

The use of grassy swale areas has also been shown to be effective in reducing the levels of pollutants in runoff. One study evaluating the removal of urban storm water pollutants by means of grassy swale areas indicated that swale treatment processes are an effective method of reducing pollutants from storm water runoff (43:183).

Treatment Alternatives. Two predominant treatment alternatives were seen in the literature as possibly viable options for controlling the environmental impact of de/anti-icing constituents. These include recycling and subsequent re-use of the constituent. At Oslo Airport, Fornebu, Norway, a deicing recovery system has been designed and installed to handle de/anti-icing effluent from two major airports located in the area (32:7). As a brand new airport, Denver International Airport (DIA) will use multiple collection systems for contaminated stormwater. One hundred percent (100%) collection is expected at the new airport. Twenty percent (the allowable limit) of the contaminated storm water will be pumped to the sanitary sewer, while the remaining 80% will be collected and stored in three 500,000 gallon storage tanks for off-site treatment and recycling. On-site recycling is being planned for, however, and expected in the future (64).

Other private firms, such as De-Icing System Incorporated, have developed mobile recovery plants to help offset the costs of a permanent recycling plant (fixed in one location). This mobile unit consists of self-contained processing equipment and is roughly the size of a semi-tractor trailer. The system can process over 20,000 liters of collected deicing solution over a period of two days at a recovery rate of 95 percent (54). Although the cost of recycling de/anti-icing constituents may not be justified for most individual Air Force installations, recycling might be feasible if supported and maintained under some form of a cooperative agreement between installations and airfield users. This may prove viable at joint-use civilian and military runway locations, or in situations where the Air Force shares runway operations with other branches of the military, such as the Navy, Army, or Marines.

Conclusion

The storm water regulations require that industrial activities, including airport deicing operations, releasing storm water into nearby waters or storm water sewer systems, obtain a NPDES permit from the EPA. Any airport activity that may yield storm water runoff is covered by the new regulations. The NPDES permit program identifies and establishes effluent limitations for contaminants that can be discharged into storm water runoff and may mandate the use of BMPs. These regulations were promulgated in an effort to improve the water quality standard and reduce the negative human health and environmental effects associated with nonpoint source pollution. In particular, de/anti-icing constituents, including glycols, urea, calcium magnesium acetate, and sodium formate, are affected.

There are several options that exist for managing the runoff of de/anti-icing constituents and ensuring compliance with new legislative criteria. Such innovative options include alternative constituents such as potassium acetate; alternative application procedures such as centralized facilities and greater use of anti-icing operations; collection alternatives using porous surface materials combined with drainage systems and holding tanks; and treatment alternatives such as a mobile recovery unit to recycle deicing fluids for re-use.

III. Methodology

Overview

This chapter describes the steps taken to answer the four investigative questions posed in Chapter I. These investigative questions examined the current uses of aircraft and airfield de/anti-icing agents and the management practices that can be implemented to effectively ensure compliance with new legislative criteria. The following investigative questions were answered using literature reviews and survey questionnaires:

1. The first investigative question was twofold:

    A. What are the major chemical constituents and substances associated with airfield and aircraft de/anti-icing operations?

    B. What are the qualitative environmental effects to ground and surface waters of introduction of these substances into the storm water waste stream?

2. What are the applicable federal rules and regulations and Air Force guidance and policies relevant to storm water runoff due to airfield and aircraft de/anti-icing operations?

3. What are the current management practices being used at various airport locations throughout the United States, including military and civilian operations?

4. What methods and management practices can be implemented to effectively ensure compliance with the new legislative criteria?

Data Collection Procedures

The first investigative question was answered by conducting a literature review to determine the uses and effects of major constituents used in de/anti-icing procedures for aircraft and airfields. The qualitative effects of the constituents on surface water and groundwater were determined from a review of available data concerning biochemical oxygen demand (BOD), nitrogen oxygen demand (NOD), dissolved oxygen (DO), human/animal/aquatic life effects, and aesthetics.

A literature review was conducted of journals, reports, and regulations obtained through the use of the literary search services offered by Dialog Information Services, Inc., Defense Technical Information Center (DTIC), and ENFLEX-CD ROM services.

The research also involved several manual searches of appropriate journal and periodical material at various library locations, including the Environmental Protection Agency (EPA) Library in Cincinnati, Ohio, the Air Force Institute of Technology (AFIT) Library at Wright-Patterson AFB, Ohio, and the Wright State University library in Dayton, Ohio. Research also involved close cooperation with the Air Force Civil Engineering Support Agency (AFCESA) at Tyndall AFB, Florida, and the Federal Aviation Administration (FAA) in Washington D.C.

The second investigative question was answered by means of a literature review that identified federal storm water regulations and criteria for compliance. Such regulations limit allowable concentrations of constituents in storm water discharges and include NPDES Permit Application Regulations for Storm Water Discharges Final Rule (40 CFR Part 122 NPDES Permit Application, Part 123 State Program Requirements, and Part 124 Procedures for Decision-making) and pertinent sections of the Clean Water Act [i.e. Section 402(p)].

The third investigative question was answered by using both primary and secondary sources. Primary sources of information consisted of two instruments-- an FAA survey questionnaire and a USAF survey questionnaire that paralleled the FAA questionnaire. The first survey, an FAA questionnaire, polled over 100 civilian airports and was used to identify non-military applications and industry practices regarding de/anti-icing agents. The FAA survey was distributed in February 1992 and results were received from the Federal Aviation Administration officials in May 1992. The FAA instrument consisted of two parts: Part 1 consisted of questions regarding runway or pavement de/anti-icing operations, and Part 2 consisted of questions regarding aircraft de/anti-icing operations. Results of the FAA survey provided a broad and accurate sample of current civilian management practices regarding airport de/anti-icing operations throughout the United States.

The second survey instrument was restricted to military airfield operations and was distributed to a select sample of Air Force installations. The intent of the USAF survey questionnaire was to identify current military uses and management practices of airfield and aircraft de/anti-icing constituents. The Air Force instrument was sent to the base environmental management office at each selected base and also consisted of two parts: Part 1 consisted of questions regarding runway or pavement de/anti-icing operations, and Part 2 consisted of questions regarding aircraft de/anti-icing operations.

Internal validity of the Air Force instrument was assumed because it was largely based on the existing FAA survey questionnaire. The Office of Management and Budget (OMB) approved the FAA survey questionnaire, giving it the approval number OMB 2120-0561. A copy of the USAF survey questionnaire is provided in Appendix A.

Selected Sample

The sample chosen to complete the Air Force survey instrument was selected using a nonprobability sampling. Nonprobability sampling incorporates a variety of approaches or considerations that can be used to select cases to include in the sample (22:273). First, a true cross-section was not the aim of the research; only some general idea of the range of management practices regarding de/anti-icing operations was sought. There was no need or desire to generalize to a population parameter. This limited objective does not require probability sampling or random selection (22:273,279).

Second, the research used purposive sampling. Purposive sampling is "a probability sample that conforms to certain criteria" (22:275). One type of purposive sample is judgment sampling. "Judgment sampling occurs when a researcher handpicks sample members to conform to some criteria" (22:275). The sample used in this study conformed to two basic criteria-- Air Force bases that conduct de/anti-icing operations on a regular basis, and bases located within the continental United States and Alaska. Those Air Force installations selected within the continental United States have active runways and are located above 35 degrees latitude. These bases were more likely to conduct aircraft and airfield de/anti-icing operations on a regular basis. A list of Air Force installations included in the distribution of the Air Force survey is provided in Appendix B.

Third, bases located overseas were not included in the survey sample due to time constraints and the added complexity of considering host nation as well as U.S. storm water rules and regulations.

Various limitations were associated with the nonprobability sampling. First of all, there was no control over who completed the Air Force survey questionnaire. Second, those bases who responded may not have represented a true cross-section of all bases that received the questionnaire. The respondents of the questionnaire decided for themselves whether or not they would participate in the study (22:274). Data were compiled from those bases that returned and responded to the Air Force survey questionnaire. To ensure greater participation, efforts were taken to precede the mailing of the survey questionnaires with telephone calls. Calls were also made following the mailing of the survey questionnaires if a response was not forthcoming from the surveyed base.

Data Analysis Procedures

Data from both the FAA and USAF instruments were compiled and correlated in order to establish a broader data base. Data were assumed to be representative of the population encompassing all (civilian and military) airport de/anti-icing operations.

An analysis of each of the two instruments' results identified the various differences and commonalities among civilian commercial airports and U.S. Air Force military bases. Data derived from both survey instruments were nominal in nature. Data quantification was in the form of a number count with modal analysis used to measure a central tendency. The data identified the most common practices involving airport de/anti-icing operations, as well as unique or differing techniques which appeared to be effective in addressing new storm water compliance issues.

In addition to the survey instruments, a literature review was conducted to identify and further elaborate practices of both civilian and military industry de/anti-icing operations. The various practices of de/anti-icing operations identified from the literature review have been presented in Chapter II; those from the survey questionnaires are presented in Chapter IV.

Summary

The final step in this study was to generalize the findings and provide recommendations for base environmental management offices. Information obtained from the literature review and from the two survey instruments was integrated to identify the practices that can be implemented to effectively ensure compliance with the new storm water legislative criteria. In this step, the fourth investigative question was answered.

IV. Results and Analysis

Overview

The purpose of the research was to investigate the use and management practices of de/anti-icing constituents with regard to new storm water legislation.

This chapter consists of three parts. First, the chapter begins with a description and analysis of the data obtained through the Air Force de/anti-icer and storm water questionnaire. Second, the chapter continues with a discussion of the predominant use and management practices for airport de/anti-icing operations using information obtained through a Federal Aviation Administration (FAA) survey and questionnaire. Finally, this chapter concludes with a comparison of the data obtained from the Air Force survey with the data results of the FAA survey in order to determine similar and dissimilar de/anti-icing practices.

USAF Survey Analysis

The Air Force survey (Appendix A) was sent directly to 49 Air Force and Air National Guard operational bases. Appendix B contains the distribution list for this chosen sample. The overall response rate to this survey was 59 percent (29 of 49). Approximately 14 percent of the total respondents (4 of 29) indicated de/anti-icing operations were not conducted at their installations due to climate and geographical location. Thus, 86 percent of the respondents (25 of 29), or 51 percent of the total sample surveyed (25 of 49), provided data and information regarding their current de/anti-icing operations. The two major areas of concern within the Air Force survey were pavement and aircraft de/anti-icing methods and practices.

USAF Pavement Application Findings. The data obtained on USAF pavement de/anti-icer application practices have been provided in Appendix C. The findings indicated that 76 percent (19 of 25) of the installations used pavement deicers in and around the operational airfield. Figure 1 depicts the types of predominant pavement chemicals used by the respondents (Table 1 of Appendix C). Urea was the most frequently used chemical constituent within the sample. The survey also revealed that only 8 percent (2 of 25) of the respondents pre-wet their dry chemical constituents in order to enhance their overall effectiveness and longevity (Table 2).

Similarly, 12 percent (3 of 25) of the respondents indicated their installations were equipped with Runway Ice Detection Systems (RIDS) (Table 2). RIDS is used as a preemptive measure in determining when weather conditions are prime for icing to occur on airfield pavements. The survey also revealed that only 20 percent (5 of 25) of the respondents used anti-icing measures in their airport operations (Table 2).

The survey indicated that de/anti-icing constituents were drained, and most often disposed of, by means of overland flow to ditches and open areas as well as by storm sewer systems (Table 3).

Surprisingly, none of the respondents indicated that collection, treatment, or recycle/re-use of their de/anti-icing constituents were being conducted (Table 4).

Finally, only one respondent indicated it maintained a unique management method for controlling runway pavement deicer application (Table 5). This installation uses a Batts metered-flow deicing system in order to apply Chevron E-36 (potassium acetate) pavement deicer. The Batts metered system controls the rate of application of the potassium acetate. This controlled rate of application was thought to be responsible for a significant reduction in the amounts of runway deicing chemicals used.

<u>USAF Aircraft Application Findings</u>. The data obtained on USAF aircraft de/anti-icer application practices have been provided in Appendix D. The findings indicated that 96 percent (24 of 25) of the installations used aircraft deicing constituents. Figure 2 illustrates the types of aircraft de/anti-icing chemicals used by the respondents

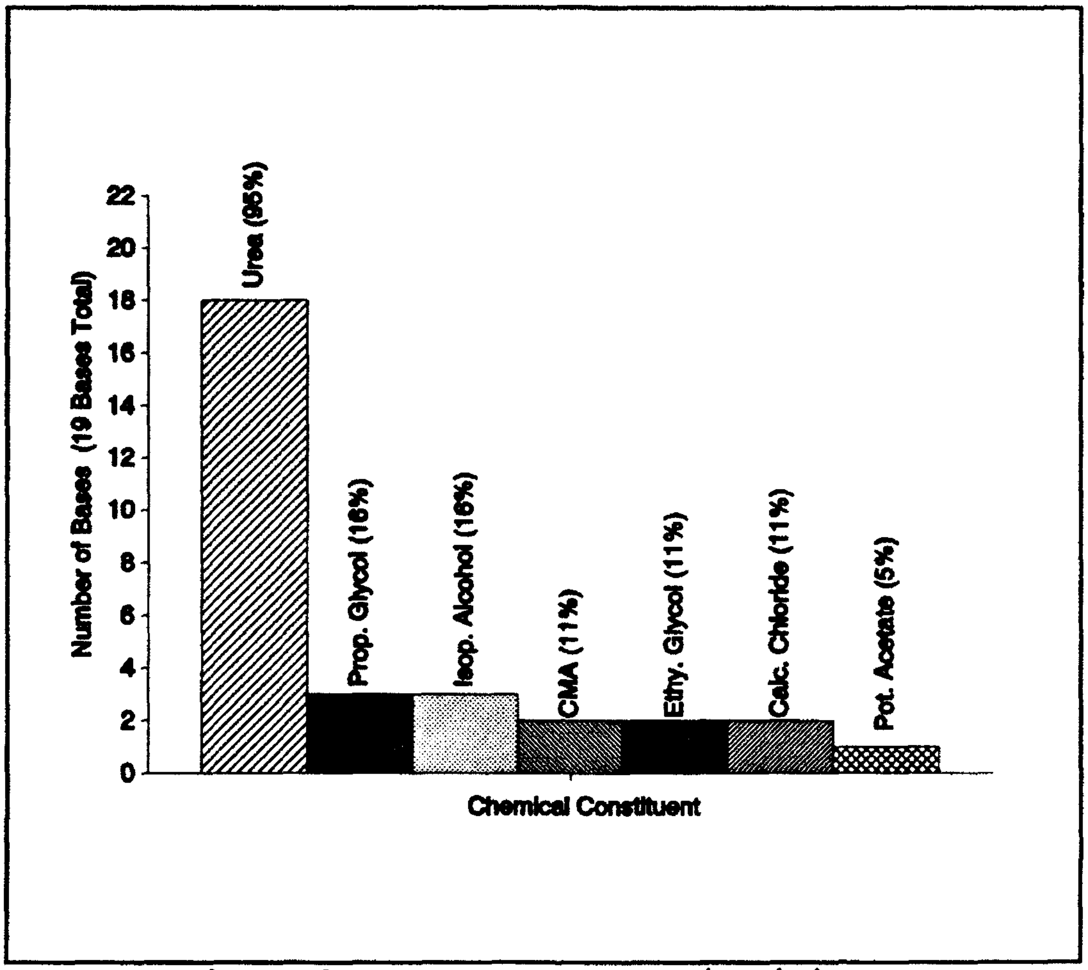

Figure 1. USAF Pavement De/Anti-icers

(Table 1 of Appendix D). None of the bases utilized a central location for application of their aircraft deicers. Figure 3 depicts the locations used by the respondents for deicing aircraft (Table 2). Similar to the pavement deicing results obtained, the respondents indicated that little or no means for collecting, treating, or recycling/re-using spent aircraft deicers are currently in place (Table 3). In fact, only one base indicated it collected its aircraft deicer fluid; this by means of a vacuum sweeper unit (Table 4). This installation indicated it also treated collected deicing constituents at an off-site location by means of contractor personnel. Another installation indicated it was in the process of activating a centralized pull-through hangar to minimize the environmental effects caused by uncontrolled runoff of aircraft de/anti-icing constituents (Table 4). One installation indicated it treated roughly 5 percent of its aircraft deicing effluent on-site by means of retention ponds and lagoons. None of the survey respondents indicated they recycled or re-used their aircraft deicers. However, a particular installation indicated it was in the process of installing a deicing fluid recovery system to deal with spent aircraft de/anti-icers.

Additional Survey Information. Additional data concerning permits and anticipated future practices have been provided in Appendix E. In addition to the information requested concerning pavement and aircraft de/anti-icing operations, the USAF survey requested additional information regarding the installations' status on permit conditions and compliance issues. Fifty-two percent (13 of 25) of the respondents indicated they are currently under, or have applied for, either NPDES permits or similar discharge permits (Table 1 of Appendix E). Additionally, 16 percent (4 of 25) of the respondents indicated they were currently not in compliance with regard to their effluent limits as a result of their de/anti-icing operations.

For those bases out of compliance, the survey inquired about anticipated strategies the installations were planning in order to remedy their non-compliance status (Table 2). Two of the bases are due to close within the next two years and are therefore taking minimal actions toward compliance. A third base hoped to negotiate permit modifications based on newly-identified point source discharges. A fourth respondent indicated no defined course of action to deal with stringent permit limitations on runoff.

Federal Aviation Administration (FAA) Survey Analysis

The FAA survey, OMB 2120-0561, was distributed to 96 civilian airports in various locations throughout the continental U.S. and Alaska in the spring of 1992. A major assumption of this research was that the use and management practices relating to airfield de/anti-icing

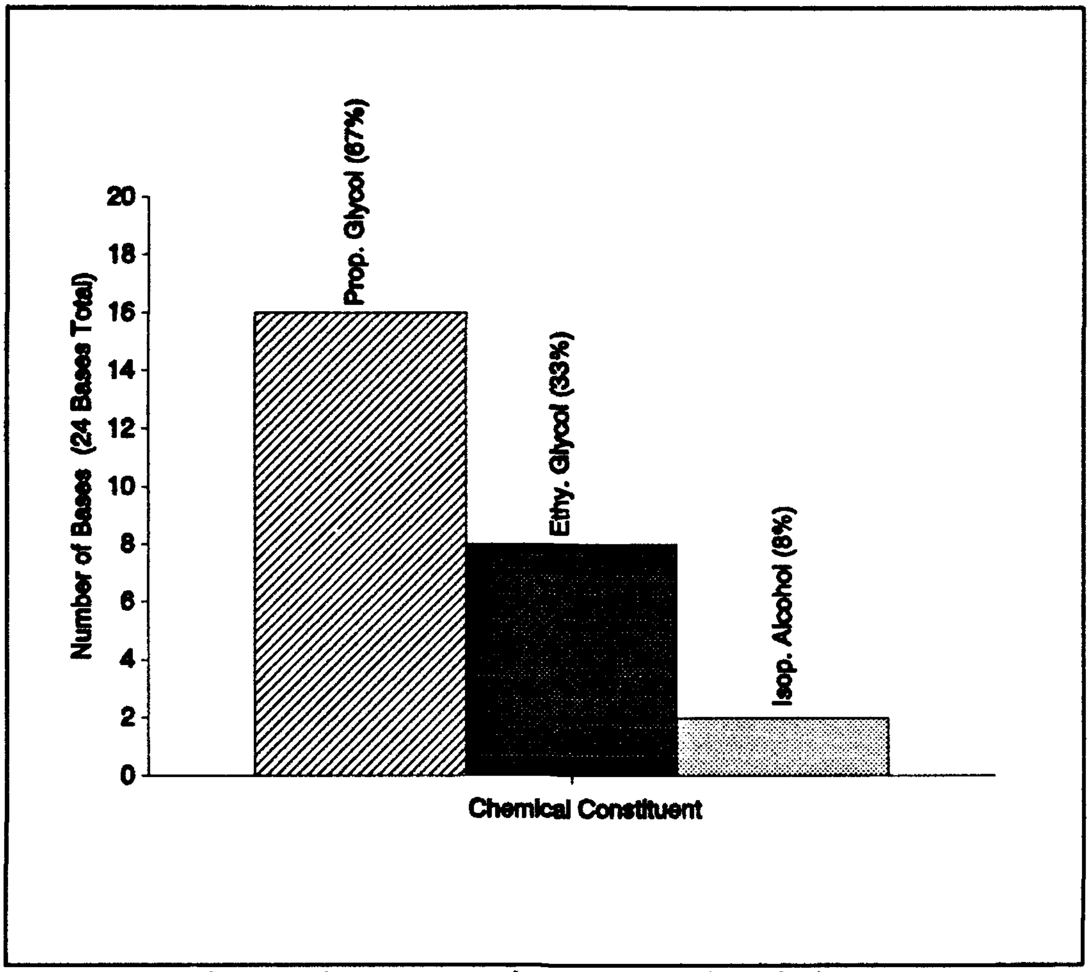

Figure 2. USAF Aircraft De/Anti-icers

operations within the Air Force closely paralleled those used at civilian airports.

The response rate to the FAA questionnaire was 100 percent (96 of 96). This portion of Chapter IV identifies trends in civilian airport deicing operations and compares them with similar data obtained through the Air Force survey instrument. The FAA survey, as with the Air Force survey, focused on two main airport deicing use and management issues--pavement and aircraft de/anti-icing methods and practices.

<u>Civilian Airport Pavement Application Findings</u>. The data obtained on civilian pavement de/anti-icing application practices have been provided in Appendix F. Figure 4 indicates the types of predominant pavement chemicals used by the respondents (Table 1 of Appendix F).

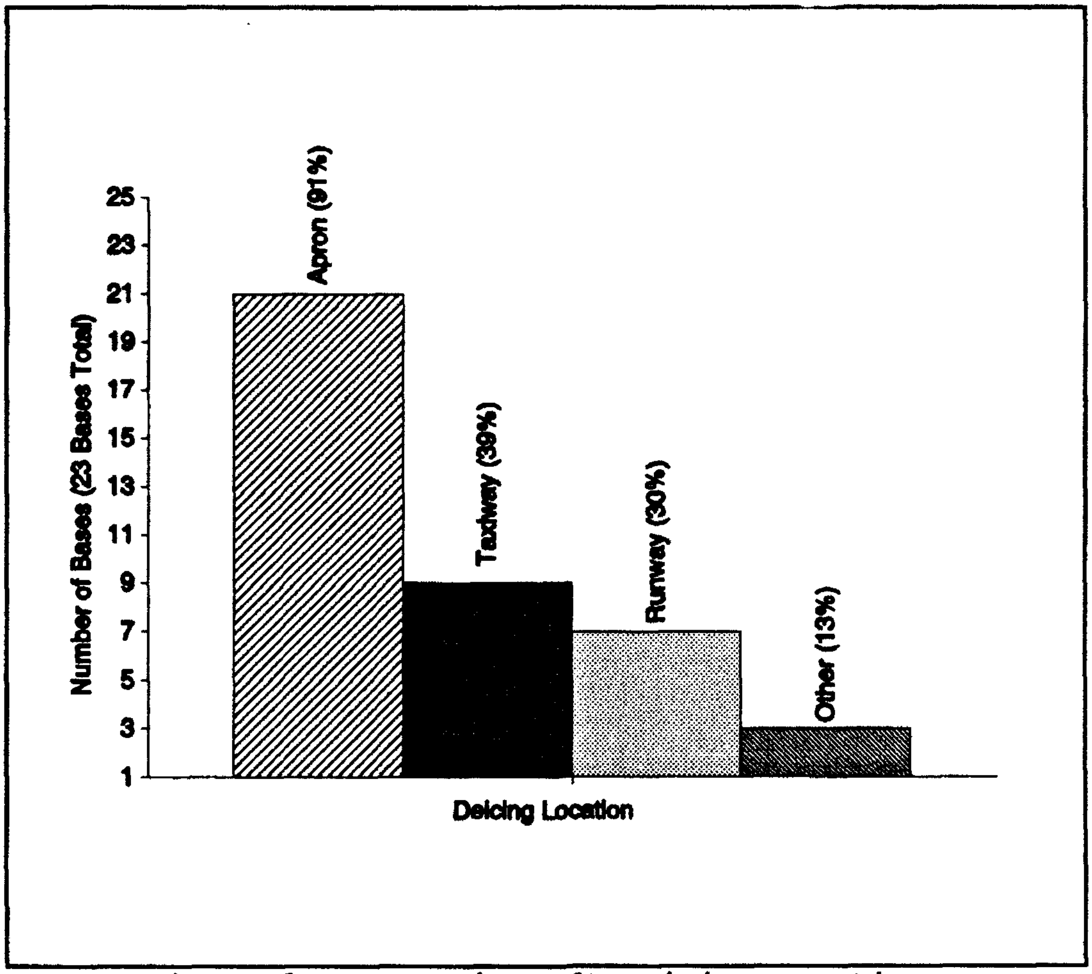

Figure 3. USAF Aircraft Deicing Locations

Approximately 56 percent of the surveyed airports (54 of 96) indicated they performed pavement deicing at their location.

The respondents indicated ethylene glycol was the most frequently used constituent (50 percent). However, urea was rated a significant second at 41 percent.

The FAA survey also indicated that only 14 percent (7 of 51) of the respondents used pre-wet solid chemicals (Table 2). This result is comparable to the 8 percent of Air Force installations that pre-wet their dry chemicals in order to enhance the effectiveness of the pavement deicing constituent.

Responses to questions regarding the use of runway sensors for detecting icing conditions indicated that 50 percent (28 of 56) of the airports do employ such methods (Table 2). This contrasts sharply with

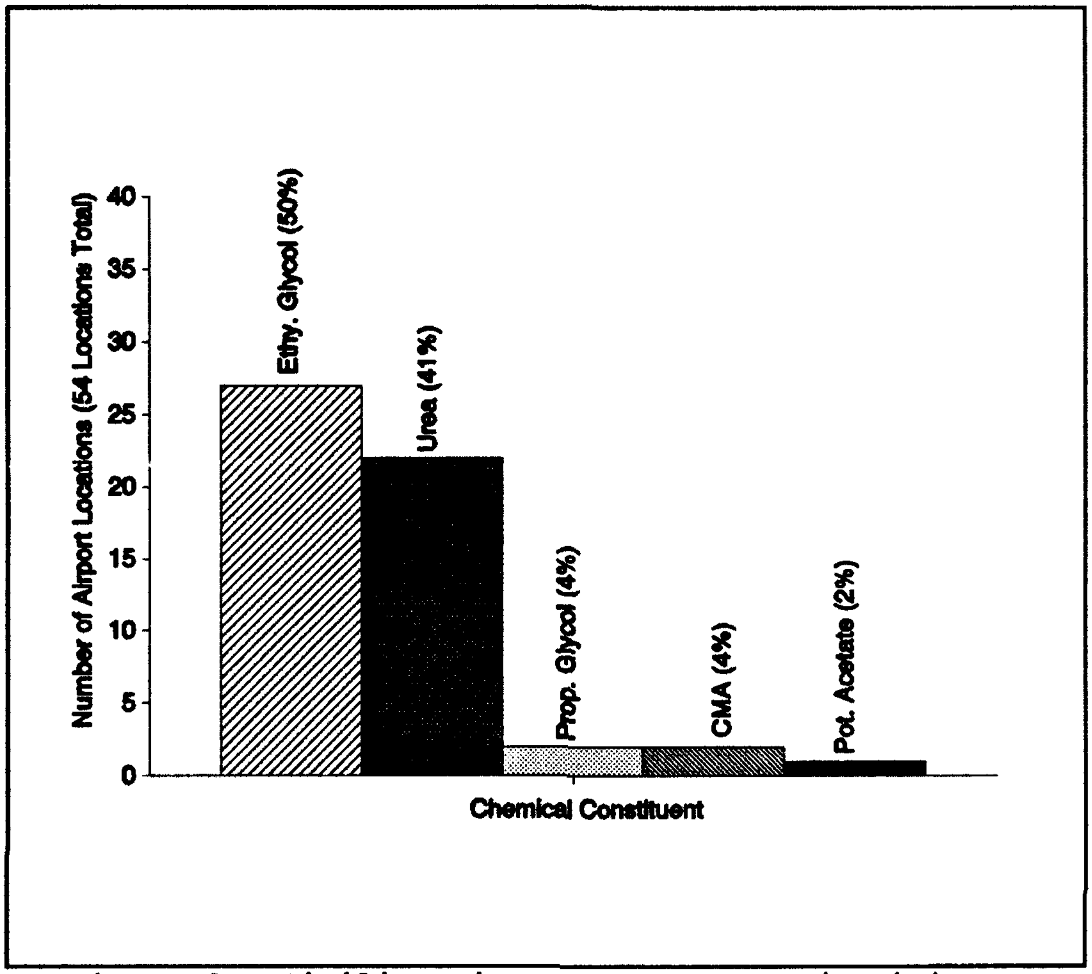

Figure 4. Civilian Airport Pavement De/Anti-icers

the results of the Air Force survey which indicated only a 12 percent usage of RIDS devices for determining icing conditions.

Approximately 57 percent (37 of 65) of the respondents indicated that anti-icing was performed to some degree at their respective airports (Table 2). Again, this is in sharp contrast to the information received from the Air Force survey which indicated that only 20 percent of the bases performed anti-icing practices.

The FAA survey indicated, much like the Air Force study, that de/anti-icing constituents were drained and disposed of by means of overland flow to ditches and open areas, in addition to disposal by means of storm sewer systems (Table 3). However, 9 percent (5 of 55) of the civilian airports indicated they collected and treated their spent de/anti-icing constituents (Table 4). Three of these five airports indicated they used retention/detention ponds and lagoons to accomplish this collection. Additionally, three of these five airports used a combined domestic wastewater treatment system to treat runoff, while one of these five indicated they used an industrial pre-treatment system to treat de/anti-icing runoff. Two additional airports indicated the partial use of retention/detention ponds and lagoons, respectively, as a result of local drainage and topography. The seven airports that used, partially or completely, collection and treatment practices varied distinctly from the Air Force data in that none of the responding Air Force bases indicated they collected or treated their spent de/anti-icing constituents.

Interestingly, none of the civilian airports indicated they either recycle or re-use their spent pavement de/anti-icers (Table 4). This was exactly the case with the Air Force installations as well.

Civilian Aircraft Application Findings. The data obtained on civilian aircraft de/anti-icing application practices have been provided in Appendix G. The findings indicated that 71 percent (68 of 96) of the respondents used aircraft de/anti-icing constituents. Figure 5 depicts the types of chemicals used at these airports (Table 1 of Appendix G).

With respect to collection and treatment of de/anti-icing runoff, 7 percent (5 of 68) of the airports indicated they collected and treated their spent aircraft de/anti-icing constituents (Table 2). Four of these five airports indicated they used retention/detention ponds and lagoons for this purpose. Two of these five airports also used domestic wastewater treatment systems to treat spent deicers. Two other airports used an industrial wastewater treatment system and an industrial pre-treatment system, respectively, to treat deicing runoff.

Interestingly, nearly 99 percent (67 of 68) of the airports indicated they did not recycle or re-use their spent aircraft deicing constituents (Table 2). One respondent did employ methods to recycle/re-use the spent aircraft deicers with a 99 percent recovery rate (Table 2). As with Air Force installations, civilian airfield

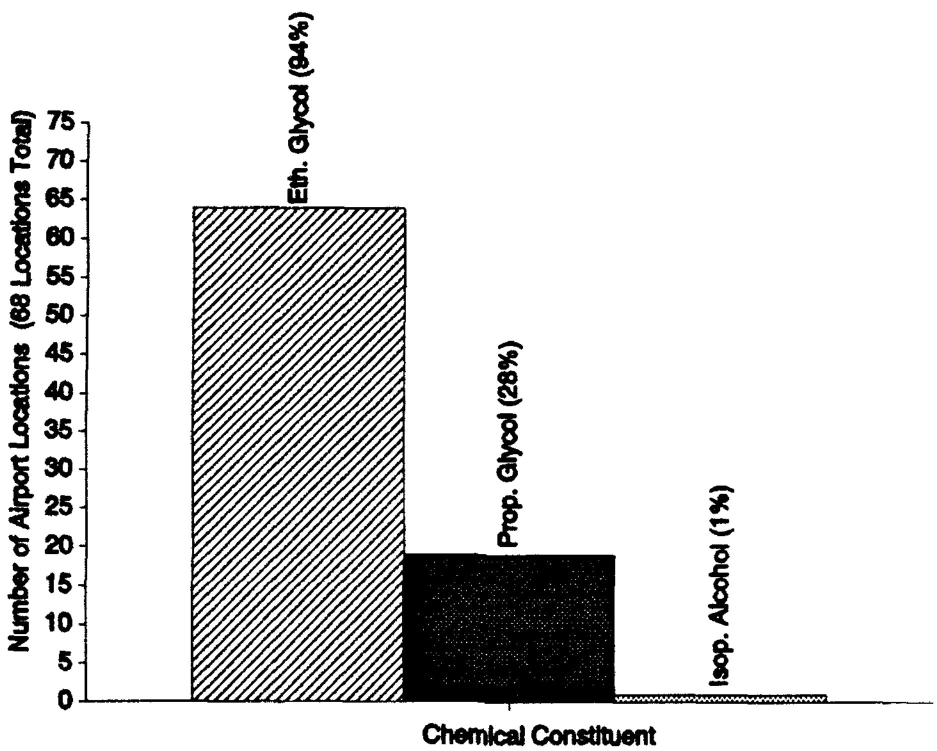

Figure 5. Civilian Airport Aircraft De/Anti-icers

operations do not emphasize collecting, treating, recycling, or re-using their spent de/anti-icing constituents.

It should be noted that there are various factors which determine the percentage of constituents that should be recycled in order to obtain a feasible and economical solution. Such factors include the processes involved, the costs of manufacturing glycol or other constituents, and the volume of constituent used (64). Due to the varying impact of these factors at different locations, there is no consensus as to what this percentage should be.

Conclusion

From the data obtained through both USAF and FAA survey instruments, some distinct conclusions can be drawn with regard to the predominant use and management practices of runway and aircraft de/anti-icing agents.

The predominant pavement deicing constituents used by the Air Force and civilian airports include urea, ethylene glycol, and propylene glycol. Air Force installations primarily used urea, while civilian airports employed ethylene glycol. In general, pre-wetting of chemical solids was not accomplished by either Air Force installations or civilian airports.

A majority of Air Force bases and civilian airports did not use Runway Ice Detection Systems (RIDS) to help identify situations where icing is likely to occur. Likewise, anti-icing methods in dealing with runway icing conditions were not generally used.

Air Force installations and civilian airports tend to use little or no form of collecting, treating, recycling, or re-using spent de-icing constituents. Finally, the major.ty of bases and airport operations do not maintain unique management methods for dealing with runway de/anti-icing constituents.

The predominantly-used aircraft deicers were ethylene glycol and propylene glycol. Aircraft de/anti-icing operations were conducted at various areas; the use of a central location for application of aircraft deice~s was indicated at only two locations.

The respondents to both surveys indicated there was limited emphasis ~laced on collecting, treating, recycling, and re-using spent aircraft deicer constituents. Vacuum sweeping and detention ponds and lagoons seemed to be the methods of choice in situations where collection was accomplished. Treatment methods were limited to retention ponds, drainage ditches, wastewater treatment, and industrial pre-treatment facilities.

In general, the survey findings tend to indicate that civilian airport operations are more advanced in their use of alternative chemical de/anti-icing constituents and control practices. These apparent differences may be due to various factors.

First, the lifetime of commercial airframes are shorter than that of most military aircraft. Subsequently, civilian operations are not as concerned with the effects of corrosion on their aircraft. Thus, alternatives such as sodium formate and CMA may be options for commercial use, but may not be as applicable to Air Force operations.

Second, since the costs associated with snow and ice removal are taken from city municipal operations and maintenance budgets, there may be added incentive on the part of civilian airports to restrict expenditures through varied and, possibly, more economical control measures.

Third, larger volumes of de/anti-icing chemicals may render these control measures more economically feasible on a unit-cost basis. Larger volumes result from an emphasis on public safety and liability due to the huge volume of air traffic often present at civilian airports.

V. Conclusions and Recommendations

Overview

The purpose of this research was to identify use and management practices of airfield and aircraft de/anti-icing agents which may be implemented to help ensure U.S. Air Force compliance with new NPDES storm water legislation. This chapter presents the overall conclusions to the research questions presented in Chapter I as well as some recommendations for future research in this critical area.

Conclusions

Research Question One. The first research question was twofold:
A. What are the major chemical constituents and substances associated with airfield and aircraft de/anti-icing operations?
B. What are the qualitative environmental effects to ground and surface waters of introduction of these substances into the storm water waste stream?

In general, there are four major chemical constituents associated with airfield and aircraft de/anti-icing operations. These chemical constituents include glycol (ethylene and propylene), urea, CMA, and sodium formate.

The principal concerns surrounding the uncontrolled release of runway and aircraft de/anti-icing agents to the environment by means of storm water effluent include high BOD rates, nitrate and nitrite enrichment of both surface and ground waters, impaired aesthetic water quality, ammonia formation from the degradation of urea, and the overall toxicity of such chemical constituents to aquatic life.

Research Question Two. What are the applicable federal rules and regulations and Air Force guidance and policies relevant to storm water runoff due to airfield and aircraft de/anti-icing operations?

The storm water regulations require that industrial activities, including airport deicing operations, releasing storm water into nearby waters or storm water sewer systems, obtain a National Pollution Discharge Elimination System (NPDES) permit from the EPA or authorized state. Any airport activity that may yield storm water runoff is covered by the new regulations. The NPDES permit program identifies and establishes effluent limitations, on a state-by-state basis, for contaminants that can be discharged in storm water runoff and may mandate the use of best management practices.

USAF non-point pollution policy dated 5 May 1987 references Best Management Practices and directs major commands to implement programs to identify non-point source (NPS) pollution at their installations. Such practices would now include appropriate control of de/anti-icing constituent runoff. The "NPS pollution control programs [should have been] in place by 1 December 1987" (16).

Research Question Three. What are the current management practices being used at various airport locations throughout the United States, including military and civilian operations?

From the data obtained through both USAF and FAA survey instruments, some distinct conclusions can be drawn with regard to the predominant use and management practices of runway and aircraft de/anti-icing agents. The major runway deicing constituents are urea, ethylene glycol, and propylene glycol. The Air Force primarily uses urea, whereas civilian airports use ethylene glycol most frequently.

In general, pre-wetting of chemical solids is not accomplished by either the Air Force or civilian airports. Pre-wetting might significantly increase a constituent's retainability and overall effectiveness. Wetted dry chemicals, however, may create operations and maintenance problems for mechanical application equipment, therefore limiting the widespread use and popularity of pre-wetting options.

A majority of Air Force bases and civilian airports surveyed do not use ice detection systems on runways to help identify situations where icing is likely to occur. Likewise, most airfield operations do not use anti-icing methods in dealing with runway icing conditions.

Air Force installations and civilian airports tend to use little or no form of treatment of their spent deicing constituents. Similarly, there seems to be little interest in either collecting, recycling, or re-using runway or aircraft de/anti-icing agents.

Finally, the majority of bases and airport operations do not maintain unique management methods for dealing with runway de/anti-icing constituents; the exception being Eielson AFB, Alaska, where metered application of potassium acetate deicer is being evaluated and tested.

The predominantly-used aircraft deicer is ethylene glycol, followed closely by propylene glycol. There is currently no chemical alternative to glycol for de/anti-icing aircraft. Most of the airport operations data indicated that applications of aircraft deicers occurred at the gate, ramp area, taxiway, and runway. The use of a centralized area for application of aircraft deicers was indicated at only two locations. The respondents to both surveys indicated there was limited emphasis placed on collecting, treating, recycling, and re-using spent aircraft deicer constituents, much like the findings on pavement deicers. In situations where collection was accomplished, vacuum sweeping and detention ponds and lagoons seemed to be the methods of choice. Treatment methods were limited to retention ponds, drainage ditches, wastewater treatment, and industrial pre-treatment facilities.

Finally, recycling and re-use of aircraft de/anti-icing constituents was an extremely limited method of choice for dealing with the runoff problem. The data indicated this activity took place at only one location. In this case, 99 percent of the aircraft deicing agent was recycled and subsequently re-used.

<u>Research Question Four</u>. What methods and management practices can be implemented to effectively ensure compliance with the new legislative criteria?

In general, installations can greatly improve the effectiveness in which they manage their airfield and aircraft de/anti-icing constituents. The following management practices consider environmental perspectives only and do not evaluate the economic feasibility of these options or the overall impact on operational and mission requirements at various Air Force installations.

In the case of runway deicing constituents, there may be a genuine need to switch from the predominant use of urea and ethylene glycol to a more environmentally-acceptable alternative. Three potential candidates include potassium acetate, sodium formate, and calcium magnesium acetate. Potassium acetate has exhibited the greatest potential through limited use and evaluation studies conducted at various operational locations. To date, this runway deicing agent appears to be highly effective in performance, with minimal environmental effects on the surrounding environment. The Air Force should evaluate these constituents regarding their corrosivity and overall environmental impact to determine their feasibility as chemical alternatives.

Installations may find it appropriate to pre-wet their solid chemicals. Dry solid chemicals applied to cold and dry pavements do not effectively adhere and can be easily blown off by wind and the movement of aircraft (56:34). Pre-wetting could effectively increase the retainability and subsequent performance of solid de/anti-icing agents at minimal cost.

Anti-icing measures should be encouraged and effectively used. Anti-icing procedures are directed and referenced in AFR 91-15, <u>Real Property Operations and Maintenance: Snow and Ice Removal and Control</u> (18:13). In general, it may require up to 500% more chemical constituent in order to deice a runway surface as opposed to taking anti-icing measures (29).

The Air Force should study the feasibility of funding and installing effective Runway Ice Detection Systems (RIDS) where appropriate. The installation of this equipment may greatly enhance the use and application of runway deicers since all chemicals need to be applied based upon surface temperature rather than ambient air temperature (59:32). Runway deicers can be employed by metered-application equipment which use the appropriate amount of pavement deicer to deal with weather conditions. This takes a lot of the guesswork out of runway deicer applications and may prevent unnecessary application of the chemical constituent.

The Air Force should consider the use of natural topography and runoff drainage patterns in and around airfields to establish natural and man-made retention ponds and drainage lagoons. Grassy swale areas can also be effectively utilized to minimize the effects of runway deicer effluent.

Ir order to actively control the effects of aircraft deicing constituents, the Air Force should investigate the appropriateness of establishing centralized locations for deicing aircraft at each installation. This location could be a designated area on the flightline or taxiway, or a specially-designed and engineered deicing pad which accommodates aircraft movement and flight operations. A centralized deicing location needs to be equipped with appropriate drainage and collection features to trap spent deicing material. The benefits of a centralized location are twofold: First, it reduces aircraft deicing operations from a non-point (diffuse) problem to a point source pollution problem which is more easily managed and controlled; and, second, it reduces the amount of deicing constituents released into the environment. Strategically locating the centralized deicing facility might reduce operations costs. In theory, the number of aircraft applications could be substantially reduced if deicing practices were managed properly.

The Air Force should assess the value of recycling and re-using collected aircraft deicers. This might be a particularly viable alternative if costs of operation can be shared under a partnership or cooperative agreement with civilian agencies or other branches within the Department of Defense. If recycling is shown to be impractical, then, at the very least, vacuum sweeping and collection of spent aircraft deicers should be accomplished.

The Air Force should install ice sensors in the leading edges of aircraft wings and on the upper fuselage where appropriate and feasible. In this way, aircraft deicers would be applied only when they are truly required by actual weather and real-time surface conditions. Installing electro-expulsive devices such as the Electro Expulsive Separation System (EESS) in the leading edges of the wings to remove ice is another viable option.

In addition, an emphasis on reducing the use of de/anti-icing chemical constituents could mean the Air Force will need to rely more on mechanical methods to remove accumulations of ice and snow. In effect, the purchase and maintenance of a modernized snow and ice removal vehicle fleet should increase a base's efficiency and effectiveness at snow and ice removal from runway surfaces (30).

Recommendations for Further Research

This research effort was prompted by the newly-legislated requirements of the NPDES storm water legislation. As a consequence of the new requirements, the Air Force is dealing with new problems using old methods in conjunction with rapidly-changing developments in de/anti-icing technology.

The major drawback of this research was that actual water quality samples for deicer-laden storm water runoff from most bases was unavailable. Such data could be used to compare the effectiveness of particular management practices. Water quality samples would be strong indicators as to which management techniques were most effective in controlling deicing operation pollutants. This would be most appropriate and beneficial for future research.

Another area of future study involves the feasibility of using mobile recycling units to effectively manage de/anti-icing constituents. The use of a mobile recycling unit may not be justified for most individual Air Force installations, however the use of these units may prove more feasible if supported and maintained under some form of a cooperative agreement between installations and airfield users. This may prove viable at joint-use runway locations.

Lastly, a cost-benefit analysis could be accomplished to evaluate the feasibility of various collection and treatment options for the Air Force. Such analyses might compare recycling/re-use options with pre-treatment.

Appendix A: Base Deicer/Anti-icer & Storm Water Survey

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

REPLY TO ATTN OF: DEVG (Capt Gibbs/Capt Willing, DSN 785-2156)

SUBJECT: DEICER/ANTI-ICER & STORM WATER QUESTIONNAIRE

TO: Environmental Management Office

1. Complying with environmental regulations is an ever-growing concern for the Air Force. In an effort to better comply with new storm water legislation in particular, we have developed a questionnaire concerning the methods and management practices of airfield and aircraft deicer/anti-icing operations. Your input will greatly enhance our study of runoff and the effects of deicer/anti-icing operations at many bases.

2. Please take the time to complete the attached questionnaire and return it in the enclosed envelope by 1 May 92. The questionnaire has been divided into two parts and further subdivided into areas that can be answered with the expertise of Environmental Management, Civil Engineering's Operations and Maintenance section (DEM), and/or Logistics personnel.

3. The data we gather will become part of an AFIT research project and may influence the methods and practices of airfield and aircraft de/anti-icing operations. Your individual responses will be combined with others and will not be attributed to you personally.

4. Your participation is completely voluntary, but we would certainly appreciate your expertise and input. For further information, contact Prof Negri at DSN 785-8388.

MARK N. GOLTZ, Lt Col, USAF
Head, Dept of Environmental Management
School of Civil Engineering and Services

2 Atch
1. Questionnaire
2. Return Envelope

STRENGTH THROUGH KNOWLEDGE

SURVEY CONTROL NUMBER

Due to the nature of this project, factual gathering of data, a USAF survey control number is not required, per 2 Mar 92 telecon with AFMPC/DPMYOS).

WHERE TO SEND QUESTIONNAIRE

Please send your completed questionnaire, along with any additional information, reports, data, etc., to:

ATTN: CAPT DARREN P. GIBBS or CAPT BRUCE L. WILLING
AFIT/DEVG AREA B, BUILDING 125
WRIGHT-PATTERSON AFB, OH 45433
DSN: 785-2156 or FAX: 785-5188

PRIVACY ACT STATEMENT

In accordance with paragraph 8, AFR 12-35, the following information is provided as required by the Privacy Act of 1974:

a. Authority

(1) 5 U.S.C. 301, Departmental Regulations; and/or

(2) 10 U.S.C. 8012, Secretary of the Air Force, Powers, Duties, Delegation by Compensation; and /or

(3) EO 9397, 22 Nov 43, Numbering System for Federal Accounts Relating to Individual Persons; and/or

(4) DOD Instruction 1100.13, 17 Apr 68, Surveys of Department of Defense Personnel; and/or

(5) AFR 30-23, 22 Sep 76, Air Force Personnel Survey Program.

b. Principal Purposes. The survey is being conducted to collect information for use in research aimed at illuminating and providing inputs to the solution of problems of interest to the Air Force and/or DOD.

c. Routine Uses. The survey data will be converted to information for use in research of management related problems. Results of the research, based on the data provided, will be included in written master's theses and may also be included in published articles, reports, or texts. Distribution of the results of the research, based on the survey data, whether in written form or presented orally, will be unlimited.

d. Participation in this survey is entirely voluntary.

e. No adverse action of any kind may be taken against any individual who elects not to participate in any or all of this survey.

BASE
DEICER/ANTI-ICER & STORM WATER
QUESTIONNAIRE

I. PAVEMENTS (RUNWAYS, TAXIWAYS, APRONS)

A. STORAGE (CE's DEM section):

1. Are pavement deicer/anti-icers used at your base? Check ___No ___Yes

2. What pavement deicer/anti-icers do you use and in what amounts do you store them?

   Describe using table below. (Gallons and pounds approximated to the nearest hundred are sufficient.)

Deicer/Anti-icer	Under/Above Ground Tank Capacity (approx. gal.)	Maximum Amount of Dry Storage (approx. lbs.)	Other (e.g., drums, bags, etc.) (approx. gal./lbs.)
* Ethylene Glycol	___	___	___
* Propylene Glycol	___	___	___
* Airside Urea	___	___	___
* Calcium Magnesium Acetate (CMA)	___	___	___
* Potassium Acetate	___	___	___
* Sodium Formate	___	___	___
* Other:___	___	___	___
Total Capacity:	___	___	___

Comments:___

3. Do you pre-wet your solid chemicals? Check: ___ No ___ Yes

B. APPLICATION (CE's DEM section):

1. Please provide the following percentages for all runway surfaces receiving applications of deicers/anti-icers:

Approximate % of Runway Surface Types:	Approximate % of Total Deicer/Anti-icer Applied:
______Asphalt (Non-Grooved)	______Asphalt (Non-Grooved)
______Grooved Asphalt	______Grooved Asphalt
______Concrete (Non-Grooved)	______Concrete (Non-Grooved)
______Grooved Concrete	______Grooved Concrete
100%	100%

2. Do runways receiving deicer/anti-icer applications have runway sensors for determining surface conditions? Check: ___No ___Yes.

3. Is anti-icing performed at your base? Check: ___No ___Yes.

   If yes, approximately what percentage of all applications are for anti-icing instead of deicing? _______

4. Approximately what total volumes of deicer/anti-icers have you applied to pavements (runways, taxiways, aprons) at your base during the past three winter seasons?

   Describe using table below. (Gallons or pounds approximated to nearest hundred are sufficient.)

	Total Annual Volume (gal./lbs.)		
Deicer/Anti-icer	89-90	90-91	91-92
* Ethylene Glycol	______	______	______
* Propylene Glycol	______	______	______
* Airside Urea	______	______	______
* Sodium Formate	______	______	______
* Calcium Magnesium Acetate (CMA)	______	______	______
* Potassium Acetate	______	______	______
* Other:__________	______	______	______
Total Volume:	______	______	______

5. Referring to Question 4: If you had a significant increase/decrease in use of any particular de/anti-icer agent, please explain the reason briefly (i.e. good weather, etc.):

____

____

____

C. DISPOSAL (DEM and/or Environmental Branch personnel):

1. Where do the spent deicer/anti-icers from pavements (runways, taxiways, and aprons) drain after application? Describe below:

Approximate % of Spent Deicer/Anti-icers Entering

______Storm Sewer

______Sanitary Sewer (to domestic wastewater treatment system)

______Combined (Storm and Sanitary) Sewer

______Spent Deicer/Anti-icer Collection System (for collecting from pavement application)

______Overland Flow to Drainage Ditch

______Overland Flow to Open Area (grassy, earthen, or gravel area)

______Retention/Detention Areas

______Other:________________________ ________________________

100%

2. Are any of the spent deicer/anti-icers from pavement application collected and treated? Check: ___No ___Yes.

If yes, approximately what percent of the total amount applied annually get treated? ______%

3. If treated, is the treatment facility on-site at the base or off-site? Circle on-site or off-site.

4. If spent deicer/anti-icers from pavement applications are treated, indicate the type system with a check mark:

_____Retention/Detention Facility, Lagoon

_____Domestic Wastewater Treatment System (i.e. combined with sewage waste)

_____Industrial Wastewater Treatment System

_____Industrial Pre-treatment System

_____Other:____

5. If checked in question 4, what kind of industrial wastewater treatment or pre-treatment of spent deicer/anti-icers from pavements is performed on-site?

Please indicate with check mark and brief description.

_____Physical:_____________________________________

_____Chemical:_____________________________________

_____Biological:___________________________________

_____Tertiary:_____________________________________

_____Other:____

6. If on-site treatment of spent pavement deicer/anti-icers is performed, how is wastewater sludge (if any) disposed:
____
____

7. Do you collect your spent pavement deicer/anti-icers? Check one:

_____No

_____Yes IF YES, approximately what percent of the total amount applied annually to pavements is collected? _____Describe in what way you collect it:
____
____
____

8. Do you recycle and reuse your spent pavement deicer/anti-icers?

Check one: _____No

_____Yes IF YES, approximately what percent of the total amount applied annually to pavements is recycled and reused? _______Describe in what way you recycle and reuse it:

____

____

____

9. Are pavement deicer/anti-icer personnel trained? Check: ___No ___Yes
IF YES, indicate the frequency and method used:

Frequency	Method
_____Yearly	_____Written Manual
_____Semi-yearly	_____Certifications
_____Quarterly	
_____Hours of Training Yearly	_____Other:____________

10. Briefly describe what (if any) regulations, documents, and/or checklists that currently guide your standard practice and use of pavement deicer/anti-icer:

____

____

____

11. Do you feel your base has any unique method(s) for controlling de/anti-icer runoff (i.e. wet vacuum, centralized de-icing, chemical alternatives/substitutes, special equipment)? Check:___No ___Yes

IF YES, briefly describe: ______________________________

____

____

BASE
DEICER/ANTI-ICER & STORM WATER QUESTIONNAIRE

II. AIRCRAFT -- USE OF DEICER/ANTI-ICERS

A. STORAGE (LG personnel)

1. Are aircraft deicer/anti-icers used at your base? Check ___No ___Yes.
   IF NO, briefly explain:________________________________

2. What aircraft deicer/anti-icers do you use and in what amounts do you store them?

   Describe using table below. (Gallons and pounds approximated to the nearest hundred are sufficient.)

Deicer/Anti-icer	Under/Above Ground Tank Capacity (approx. gal.)	Other Storage (specify) ________ ________ (approx. gal.)
Type I		
* Ethylene Glycol	________	________
* Propylene Glycol	________	________
* Other:________	________	________
Total Capacity:	________	________
Type II (Association of European Airlines)	________	________

Comments:________________________________

3. Please indicate how deicer/anti-icers are transferred from storage (i.e. main or remote) to application areas.

   Show the percentage of time each method is used:

   ______ Truck with Boom ("Cherry Picker")
   ______ Tank Truck
   ______ Pipeline
   ______ Other:________________________

B. APPLICATION (LG personnel):

1. Where are aircraft deicer/anti-icers applied at your base? Please indicate with check mark and provide a brief description:

   ______ Runway, Taxiway, Apron: ______________________

   ______ Centralized location: ______________________

   ______ Other: ______________________

2. What deicer/anti-icer equipment is used? Approximate % of Deicer/Anti-icer Volume:

   ______Truck with Boom ("Cherry Picker")

   ______Stationary Boom or Gantry ("Car Wash")

   ______Hand Held Application

   ______Other: ______________________

   100%

3. Approximately what total volumes of deicer/anti-icers have you applied to aircraft at your base during the past three winter seasons.

   Describe using table below. (Gallons approximated to nearest hundred are sufficient.)

Total Annual Volume (gallons)

Deicer/Anti-icer	89-90	90-91	91-92
Type I			
* Ethylene Glycol	______	______	______
* Propylene Glycol	______	______	______
* Other: ______	______	______	______
Type II	______	______	______

Comments: ______________________

4. Referring to Question 3: If you had a significant increase/decrease in use of any particular de/anti-icer agent, please explain the reason briefly (i.e. good weather):

____
____
____

5. What mixtures of deicers/anti-icers and water do you apply on your aircraft? Enter the approximate percent of time the mixtures below are used:

Mixture	50/50	40/60	Other:_____	Other:_____
* Ethylene Glycol/Water	_____	_____	_____	_____
* Propylene Glycol/Water	_____	_____	_____	_____
* Other:__________	_____	_____	_____	_____

Comments:____
____

6. During the past three winter seasons, how many deicing/anti-icing applications to aircraft did you perform?

Approx. # in 1989-90 Approx. # in 90-91 Approx. # in 91-92

_____ Total Annual _____ Total Annual _____ Total Annual

7. Your deicer/anti-icer applications were to what types of aircraft?

Approximate % of Applications (should add up to 100%):

____ B-52 ____B-1 ____F-16 ____F-15 ____F-111

____C-5 ____C-141 ____C-130 ____KC-10 ____KC-135

____Other:__________________________

C. DISPOSAL (LG and/or Environmental Branch personnel):

1. Where do the spent deicer/anti-icers from aircraft drain after application? Approximate % of Spent Deicer/Anti-icers Entering:

   ______Storm Sewer

   ______Sanitary Sewer (to domestic wastewater treatment system)

   ______Combined (Storm and Sanitary) Sewer

   ______Spent Deicer/Anti-icer Collection System (for collecting from aircraft application)

   ______Overland Flow to Drainage Ditch

   ______Overland Flow to Open Area (grassy, earthen, or gravel area)

   ______Retention/Detention Areas

   ______Other:____
   100%

2. Are any of the spent deicer/anti-icers from aircraft application collected and treated? Check: ___No ___Yes.

   IF YES, approximately what percent of the total amount applied annually get treated? ____%

3. If treated, is the treatment facility on-site at the base or off-site? Check: ____On-site or ____Off-site.

   IF TREATED, is the same treatment system described already for spent deicer/anti-icers from pavement applications? Check: ___No ___Yes.

   IF NO, please COMPLETE the next three questions.
   IF YES, skip to question 7.

4. If spent deicer/anti-icers from aircraft applications are treated, indicate the type system with a check mark:

   _____Retention/Detention Facility, Lagoon

   _____Domestic Wastewater Treatment System (i.e. combined with sewage waste)

   _____Industrial Wastewater Treatment System

   _____Industrial Pre-treatment System

   _____Other:____

5. IF CHECKED in question 4, what kind of industrial wastewater treatment or pre-treatment of spent deicer/anti-icers is performed on-site? Please indicate with check mark and brief description.

_____Physical:____

_____Chemical:____

_____Biological:____

_____Tertiary:____

_____Other:____

6. If on-site treatment of spent aircraft deicer/anti-icers is performed, how is wastewater sludge (if any) disposed:

____

____

7. Do you collect your spent aircraft deicer/anti-icers? Check one:

_____No

_____Yes If yes, approximately what percent of the total amount applied annually to aircraft is collected? ____%

Describe in what way you collect it:

____

____

____

8. Do you recycle and reuse your spent aircraft deicer/anti-icers? Check one:

_____No

_____Yes If yes, approximately what percent of the total amount applied annually to aircraft is recycled and reused? _______

Describe in what way you recycle and reuse it:

____

____

____

9. Are aircraft deicer/anti-icer personnel trained? Check: ___No ___Yes.
IF YES, indicate the frequency and method used:

Frequency	Method
_____Yearly	_____Written Manual
_____Semi-yearly	_____Certifications
_____Quarterly	
_____Hours of Training Yearly	_____Other:____________

10. Briefly describe what regulations, documents, and/or checklists currently guide your standard practice and use of aircraft deicer/anti-icer:

____

____

____

11. Do you feel your base has any unique method(s) for controlling aircraft deicer/anti-icer runoff? Check ___No ___Yes.

IF YES, briefly describe:______________________________________

____

____

III. ADDITIONAL INFORMATION
(Environmental Branch personnel)

1. Does your base have an existing NPDES storm water permit or similar state or local permits for any discharge? Check one:

   _____No

   _____Yes If possible, please include a copy of the permit and any data collected as a part of the permit process.

2. Do you have any reports or water quality data that would provide additional information on any of the questions above?

   _____No

   _____Yes If so, please include a copy of each when you return this questionnaire.

3. Is your base currently in compliance? _____No _____Yes

   IF NO, do you anticipate to be in compliance in (check one):

   _____1 years _____2 years _____3 years

   _____5 years _____Other (please specify)

4. What types of practices do you anticipate bringing on-line or implementing in order to meet compliance (chemical alternatives/substitutes, special equipment, etc.)?

   Describe briefly: ____
   ____
   ____

5. Please complete the following information about your base:

   Address:____

   Point of Contact:____

   Title:____

   Telephone:____
   (Commercial/DSN)

Appendix B: Installations Receiving Base Survey

BASES RECEIVING DE/ANTI-ICING SURVEY

ALASKA

*1. 343 CES/DEV
Eielson AFB AK
99702-5000

2. 3 SPTG/DEVC
22040 Maple Street
Elmendorf AFB AK
99506-3240

3. 673 CES/DEV (Shemya AFB)
APO AP
96512-5000

ARKANSAS

*4. 97 SPTG/DEV
Eaker AFB AR
72317-5000

*5. 314 CES/DEV
Little Rock AFB AR
72099-5000

CALIFORNIA

*6. 9 CES/DEV
6451 B Street
Beale AFB CA
95903-1708

7. 93 CES/DEV
Castle AFB CA
95342-5000

*8. 323 CES/DEV
Mather AFB CA
95665-5000

*9. SM-ALC/EM
McClellan AFB CA
95652-5000

10. 60 CES/DEV
Travis AFB CA
94535-5000

COLORADO

11. 140 TFW/DCS/EM (Stop 22)
Buckley ANG CO
80010-5000

*12. 1003 CES/DEV
Peterson AFB CO
80914-5000

DELAWARE

13. 436 CES/DEV
Dover AFB DE
19902-5000

IDAHO

14. 366 CES/CEV
Mountain Home AFB ID
83648-5000

ILLINOIS

15. 375 CSG/DEV
Scott AFB IL
62225-5000

INDIANA

*16. 305 SPTG/DEV
Grissom AFB IN
46971-5000

KANSAS

*17. 384 SPTG/DEV
384 CES/CCQ Suite 109
McConnell AFB KS
67221-5000

MAINE

*18. 42 CES/DEV
Loring AFB ME
04751-5000

MARYLAND

19. 89 Air Wing
89 SPTG/DEEV
Andrews AFB DC
20331-5000

MASSACHUSETTS

*20. 439 SG/CEED
Westover MA
01022-5000

MICHIGAN

*21. 410 SPTG/DEV
K.I. Sawyer AFB MI
49843-5000

*22. 927 MS/OM
Selfridge ANG MI
48045-5000

MICHIGAN (cont'd)

*23. 379 CES/DEV
Wurtsmith AFB MI
48753-5000

MISSOURI

24. 351 SPTG/DEV
Whiteman AFB MO
65305-5000

MONTANA

*25. 341 CES/DEV
Malmstrom AFB MT
59402-5000

NEBRASKA

26. 55 CES/DEV
Offutt AFB NE
68113-5000

NEVADA

27. Fighter Weapon Center/EM
Nellis AFB NV
89191-5000

NEW JERSEY

*28. 438 SPTG/DEV
McGuire AFB NJ
08641-5000

NEW MEXICO

*29. 27 CES/CEV
Cannon AFB NM
88101-5000

*30. 546 CTW/EM
Kirtland AFB NM
87117-5000

NEW YORK

*31. 416 CES/DEV
Griffis AFB NY
13411-5000

32. 380 CES/DEV
Plattsburgh AFB NY
12903-5000

NORTH CAROLINA

33. 317 SPTG/DEV
Pope AFB NC
28308-5000

34. 4 CES/CEV
Seymour Johnson AFB NC
27531-5000

NORTH DAKOTA

35. 319 SPTG/DEV
Grand Forks AFB ND
58205-5000

36. 5 CES/DEV
320 Peacekeeper Place
Minot AFB ND
58705-5006

OHIO

37. 2750 ABG/EM
Wright-Patterson AFB OH
45433-5000

OKLAHOMA

38. 443 SPTG/EM
Altus AFB OK
73523-5000

*39. OC-ALC/EM
Tinker AFB OK
73145-5000

*40. 71 ABG/DEV
Vance AFB OK
73701-5000

SOUTH CAROLINA

*41. 437 CES/DEV
Charleston AFB SC
29404-5000

*42. 354 CSG/DEV
Myrtle Beach SC
29577-5000

43. 363 CES/DEV
Shaw AFB SC
29152-5000

SOUTH DAKOTA

*44. 28 SPTG/DEV
Ellsworth AFB SD
57706-5000

TENNESSEE

*45. AEDC/DEV
Arnold AFB TN
37389-5000

UTAH

46. OO-ALC/EM
Hill AFB UT
84056-5000

VIRGINIA

47. 1 SG/DEV
Langley AFB VA
23665-5000

WASHINGTON

*48. 92 SPTG/DEV
Fairchild AFB WA
99011-5000

*49. 62 SPTG/DEV
McChord AFB WA
98438-5000

* - Denotes bases responding to base survey instrument.

Appendix C: Survey Findings for USAF Pavement De/Anti-icing

Table 1. USAF Pavement De/Anti-icers: Use and Types

Air Force Base	Pavement Deicers Used	Type of Deicer Used
Base 1	Yes	Urea
Base 2	Yes	Urea
Base 3	Yes	Urea
Base 4	No	Not Applicable
Base 5	Yes	Urea
Base 6	Yes	Urea/CMA
Base 7	Yes	Urea/Ethylene Glycol
Base 8	No	Not Applicable
Base 9	Yes	Urea/CMA
Base 10	No	Not Applicable
Base 11	Yes	Urea
Base 12	No	Not Applicable
Base 13	Yes	Urea/Calcium Chloride
Base 14	Yes	Urea
Base 15	No	Not Applicable
Base 16	Yes	Urea/K-acetate/Isopropyl Alcohol
Base 17	Yes	Urea/Propylene Glycol
Base 18	Yes	Urea
Base 19	No	Not Applicable
Base 20	Yes	Urea
Base 21	Yes	Isopropyl Alcohol
Base 22	Yes	Urea
Base 23	Yes	Urea/Calcium Chloride/ Ethylene Glycol/ Propylene Glycol
Base 24	Yes	Urea/Isopropyl Alcohol
Base 25	Yes	Urea/Propylene Glycol

Table 2. USAF Pavement De/Anti-icing Practices

Air Force Base	Pre-Wet Solid Chemicals	RIDS	Anti-Icing Performed
Base 1	No	No	No
Base 2	No	No	No
Base 3	No	No	Yes
Base 4	Not Applicable	Not Applic.	Not Applic.
Base 5	Yes	No	Yes
Base 6	No	No	No
Base 7	Yes	No	No
Base 8	No	Yes	Yes
Base 9	No	No	No
Base 10	Not Applicable	Not Applic.	Not Applic.
Base 11	No	No	No
Base 12	Not Applicable	Not Applic.	Not Applic.
Base 13	No	No	No
Base 14	No	No	No
Base 15	Not Applicable	Not Applic.	Not Applic.
Base 16	No	No	No
Base 17	No	Yes	Yes
Base 18	No	No	No
Base 19	Not Applicable	Not Applic.	Not Applic.
Base 20	No	No	Yes
Base 21	No	Yes	No
Base 22	No	No	No
Base 23	No	No	No
Base 24	No	No	No
Base 25	No	No	No

Table 3. USAF Pavement De/Anti-icers: Drainage and Disposal

Air Force Base	Drainage & Disposal of Constituents
Base 1	Overland Flow (O.F.)
Base 2	30% O.F./70% Storm Sewer
Base 3	O.F.
Base 4	Not Applicable
Base 5	O.F.
Base 6	O.F.
Base 7	O.F.
Base 8	Not Applicable
Base 9	O.F. to Open Area
Base 10	Not Applicable
Base 11	O.F. to Open Area
Base 12	Not Applicable
Base 13	O.F. to Open Area
Base 14	85% O.F. to Open Area/15% O.F. to Ditch
Base 15	Not Applicable
Base 16	90% Storm Sewer/5% O.F.to Open Area/5% O.F. to Ditch
Base 17	78% O.F.to Storm Sewer/22% Storm Sewer
Base 18	O.F. to Open Area
Base 19	Not Applicable
Base 20	75% O.F. to Ditch/25% O.F. to Open Area
Base 21	70% O.F. to Ditch/30% Storm Sewer
Base 22	O.F. to Ditch
Base 23	80% Storm Sewer/10% O.F. to Ditch/ 10% O.F. to Open Area
Base 24	75% O.F. to Open Area/25% Storm Sewer
Base 25	Storm Sewer/O.F. to Ditch and Open Area

Table 4. USAF Pavement De/Anti-icers: Collecting/Treating/Recycling

Air Force Base	Constituents Collected/Treated	Constituents Recycle/Reuse
Base 1	No	No
Base 2	No	No
Base 3	No	No
Base 4	Not Applicable	Not Applicable
Base 5	No	No
Base 6	No	No
Base 7	No	No
Base 8	Not Applicable	Not Applicable
Base 9	No	No
Base 10	Not Applicable	Not Applicable
Base 11	No	No
Base 12	Not Applicable	Not Applicable
Base 13	No	No
Base 14	No	No
Base 15	Not Applicable	Not Applicable
Base 16	No	No
Base 17	No	No
Base 18	No	No
Base 19	Not Applicable	Not Applicable
Base 20	No	No
Base 21	No	No
Base 22	No	No
Base 23	No	No
Base 24	No	No
Base 25	No	No

Table 5. USAF Pavement De/Anti-icers: Unique Methods

Air Force Base	Unique Methods and Practices
Base 1	Batts Deicer - Computerized Control Rate
Base 2	No
Base 3	No
Base 4	Not Applicable
Base 5	No
Base 6	No
Base 7	No
Base 8	Not Applicable
Base 9	No
Base 10	Not Applicable
Base 11	No
Base 12	Not Applicable
Base 13	No
Base 14	No
Base 15	Not Applicable
Base 16	No
Base 17	No
Base 18	No
Base 19	Not Applicable
Base 20	No
Base 21	No
Base 22	No
Base 23	No
Base 24	No
Base 25	No

Appendix D: Survey Findings for USAF Aircraft De/Anti-icing

Table 1. USAF Aircraft De/Anti-icers: Use and Types

Air Force Base	Aircraft Deicers Used	Type of Deicer Used
Base 1	Yes	Propylene Glycol
Base 2	Yes	Propylene Glycol
Base 3	Yes	Ethylene Glycol
Base 4	Yes	Ethylene Glycol
Base 5	Yes	Isopropyl Alcohol
Base 6	Yes	Propylene Glycol
Base 7	Yes	Propylene Glycol
Base 8	Yes	Propylene Glycol
Base 9	Yes	Propylene Glycol
Base 10	Yes	Ethylene Glycol
Base 11	Yes	Propylene Glycol
Base 12	Yes	Propylene Glycol
Base 13	Yes	Propylene Glycol
Base 14	Yes	Propylene Glycol
Base 15	Yes	Propylene Glycol
Base 16	Yes	Propylene Glycol/ Isopropyl Alcohol
Base 17	Yes	Propylene Glycol
Base 18	Yes	Ethylene Glycol
Base 19	Yes	Ethylene Glycol
Base 20	Yes	Propylene/Ethylene Glycol
Base 21	Yes	Ethylene Glycol
Base 22	No	Not Applicable
Base 23	Yes	Propylene Glycol
Base 24	Yes	Ethylene Glycol
Base 25	Yes	Propylene Glycol

Table 2. USAF Aircraft De/Anti-icers: Application Practices

Air Force Base	Point of Deicer Application	Type of Deicing Equipment Used
Base 1	Apron/Runway/ Refuel Pits	Truck w/ Boom
Base 2	Apron/Alert Pad	Truck w/ Boom
Base 3	Taxiway/Apron	Truck w/ Boom
Base 4	Apron	Truck w/ Boom/ Handheld
Base 5	Apron	Truck w/ Boom
Base 6	Apron	Truck w/ Boom
Base 7	Runway/Taxiway/Apron	Truck w/ Boom
Base 8	Runway/Taxiway/Apron	Truck w/ Boom
Base 9	Apron	Truck w/ Boom
Base 10	Runway/Taxiway/Apron	Truck w/ Boom
Base 11	Taxiway/Apron	Truck w/ Boom
Base 12	Apron/Hammerhead	Truck w/ Boom
Base 13	Apron	Truck w/ Boom
Base 14	Apron	Truck w/ Boom
Base 15	Apron	Truck w/ Boom
Base 16	Apron	Truck w/ Boom
Base 17	Apron/Taxiway	Truck w/ Boom
Base 18	Runway/Taxiway	Truck w/ Boom
Base 19	Apron	Truck w/ Boom
Base 20	Apron	Truck w/ Boom
Base 21	Runway/Taxiway/Apron	Truck w/ Boom
Base 22	Not Applicable	Not Applicable
Base 23	Runway/Taxiway	Truck w/ Boom
Base 24	Apron	Truck w/ Boom
Base 25	Non-responsive	Non-responsive

Table 3. USAF Aircraft De/Anti-icers: Drainage and Disposal

Air Force Base	Drainage & Disposal of Constituents
Base 1	Overland Flow (O.F.)
Base 2	30% O.F./70% Storm Sewer
Base 3	O.F.
Base 4	60% Storm Sewer/30% Sanitary Sewer/ 10% O.F.
Base 5	O.F.
Base 6	O.F.
Base 7	O.F.
Base 8	95% O.F./5% Storm Sewer
Base 9	O.F. to Open Area
Base 10	Non-Responsive
Base 11	O.F. to Open Area
Base 12	Non-Responsive
Base 13	O.F. to Open Area
Base 14	85% O.F. to Open Area/15% O.F. to Ditch
Base 15	Non-Responsive
Base 16	90% Storm Sewer/5% O.F.to Open Area/5% O.F. to Ditch
Base 17	78% O.F.to Storm Sewer/22% Storm Sewer
Base 18	O.F. to Open Area
Base 19	Non-Responsive
Base 20	75% O.F. to Ditch/25% O.F. to Open Area
Base 21	70% O.F. to Ditch/30% Storm Sewer
Base 22	O.F. to Ditch
Base 23	80% Storm Sewer/10% O.F. to Ditch/ 10% O.F. to Open Area
Base 24	75% O.F. to Open Area/25% Storm Sewer
Base 25	Storm Sewer/O.F. to Ditch and Open Area

Table 4. USAF Aircraft De/Anti-icers: Collecting/Treating/Recycling

Air Force Base	Deicers Collected	Deicers Treated	Deicers Recycled
Base 1	No	No	No
Base 2	No	Yes - 5% On-Site Retention Pond	No
Base 3	No	No	No
Base 4	No	No	No
Base 5	No	No	No
Base 6	No	No	No
Base 7	No	No	No
Base 8	No	No	No
Base 9	Yes	Yes - Off Site	No
Base 10	No	No	No
Base 11	No	No	No
Base 12	No	No	No
Base 13	No	No	No
Base 14	No	No	No
Base 15	No	No	No
Base 16	No	No	No
Base 17	No	No	No
Base 18	No	No	No
Base 19	No	No	No
Base 20	No	No	No
Base 21	No	No	No
Base 22	Not Applic.	Not Applicable	Not Applic.
Base 23	No	No	No
Base 24	No	No	No
Base 25	No	No	No

Table 5. USAF Aircraft De/Anti-icers: Unique Methods

Air Force Base	Unique Methods and Practices
Base 1	No
Base 2	No
Base 3	No
Base 4	No
Base 5	No
Base 6	No
Base 7	No
Base 8	Yes - Pull Through Hangar; Not activated
Base 9	Yes - Wet Vacuum on Street Sweeper
Base 10	No
Base 11	No
Base 12	No
Base 13	No
Base 14	No
Base 15	No
Base 16	No
Base 17	No
Base 18	No
Base 19	No
Base 20	No
Base 21	No
Base 22	No
Base 23	No
Base 24	No
Base 25	No

Appendix E: Survey Findings - Additional Information

Table 1. Additional Information: Permit and Compliance Condition

Air Force Base	Existing Permit	Current Compliance
Base 1	No	Yes
Base 2	Yes	No
Base 3	Yes	No
Base 4	No	Yes
Base 5	Yes	Yes
Base 6	No - Group Permit Submitted	Yes
Base 7	No	Yes
Base 8	Non-Responsive	Non-Responsive
Base 9	Yes	No
Base 10	Non-Responsive	Non-Responsive
Base 11	No	Yes
Base 12	Yes	No
Base 13	No	Yes
Base 14	No	Yes
Base 15	No - Permit Pending	Yes
Base 16	Yes	Yes
Base 17	Yes	Yes
Base 18	Non-Responsive	Yes
Base 19	Yes	Yes
Base 20	Yes	Yes
Base 21	Yes	Yes
Base 22	Non-Responsive	Non-Responsive
Base 23	Yes	Yes
Base 24	Non-Responsive	Non-Responsive
Base 25	No	Yes

Table 2. Additional Information: Anticipated Future Practices

Air Force Base	Anticipated Future Practices
Base 1	None
Base 2	Stop Usage - Base Closure
Base 3	Modify Permit to Identify New Point Source Discharges
Base 4	None
Base 5	None
Base 6	None
Base 7	None
Base 8	Non-Responsive
Base 9	Wet Vacuum/Glycol Minimization Plan - Base Closure
Base 10	Non-Responsive
Base 11	None
Base 12	Do Not Anticipate Compliance Due to Stringent Permit
Base 13	None
Base 14	None
Base 15	Awaiting Action on Permit
Base 16	Installing Deicing Fluid Recovery System
Base 17	None
Base 18	None
Base 19	None
Base 20	None - Base Closure
Base 21	Non-Responsive
Base 22	Non-Responsive
Base 23	Storm Water System Study Being Conducted To Look at Containment Measures
Base 24	Non-Responsive
Base 25	None

Appendix F: Survey Findings for Civilian Airport Pavement De/Anti-icing

Table 1. Airport Pavement De/Anti-icers: Use and Types

Number of Airports	Type of De-icer
27 out of 54 (50%)	Ethylene Glycol
22 out of 54 (40.7%)	Urea
2 out of 54 (3.7%)	Propylene Glycol
2 out of 54 (3.7%)	Calcium Magnesium Acetate (CMA)
1 out of 54 (1.9%)	Potassium Acetate

Table 2. Airport Pavement De/Anti-icing Practices

Pre-Wet Solid Chemicals	RIDS	Anti-Icing Performed
Yes: 7 of 51 (13.7%)	Yes: 28 of 56 (50%)	Yes: 37 of 65 (56.9%)
No: 44 of 51 (86.3%)	No: 28 of 56 (50%)	No: 28 of 65 (43.1%)

Table 3. Airport De/Anti-icers: Drainage and Disposal

Number of Airports	Drainage & Disposal of Constituents
32 of 89 (35.9%)	Storm Sewer
33 of 89 (37.1%)	Overland Flow to Open Area
20 of 89 (22.5%)	Overland Flow to Drainage Ditch
4 of 89 (4.5%)	Other

Table 4. Airport Pavement De/Anti-icers: Collecting/Treating/Recycling

Constituents Collected/Treated	Constituents Recycled/Re-used
Yes: 5 of 55 (9.1%)	Yes: 0 of 55 (0.0%)
No: 50 of 55 (90.9%)	No: 55 of 55 (100%)

Appendix G: Survey Findings for Civilian Airport Aircraft De/Anti-icing

Table 1. Airport Aircraft De/Anti-icers: Use and Types

Number of Airports	Type of Deicer Used
64 of 68 (94.1%)	Ethylene Glycol
19 of 68 (27.9)	Propylene Glycol
1 of 68 (1.5%)	Isopropyl Alcohol

Table 2. Airport Aircraft De/Anti-icers: Collecting/Treating/Recycling

Constituents Collected/Treated	Constituents Recycled/Re-used
Yes: 5 of 68 (7.4%)	Yes: 1 of 68 (1.5%); Recovery rate 99%.
No: 63 of 68 (92.6%)	No: 67 of 68 (98.5%)

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This research identified management practices of airfield and aircraft de/anti-icing constituents which may be implemented to deal with new storm water legislation. Storm water regulations require that deicing operations obtain a NPDES permit for discharges into storm water runoff which may mandate the use of Best Management Practices. An FAA civilian airport survey and a USAF survey were used, with a literature search, to identify practices of de/anti-icing constituents. Four major constituents are used-- glycol, urea, calcium magnesium acetate, and sodium formate. Concerns of uncontrolled release of the constituents include high BOD rates, nitrate and nitrite enrichment, impaired aesthetic water quality, ammonia formation from the degradation of urea, and the toxicity of such chemicals to aquatic life. Several options that exist for managing the runoff of de/anti-icing constituents include alternative constituents such as potassium acetate; alternative application procedures such as centralized facilities and greater use of anti-icing operations; collection alternatives using porous surface materials, drainage systems, and holding tanks; and treatment alternatives such as a mobile recovery unit to recycle deicing fluids for re-use.

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