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Preliminary Data Summary

Airport Deicing Operations (Revised)

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This report on deicing fluids does not set forth any regulatory requirements under the Clean Water Act. It is intended solely as a presentation of information of which EPA is currently aware concerning the use of deicing fluids at airports. Thus, it does not impose any requirements on any party, including EPA, states, permitting authorities, POTWs, or the regulated community. This report was prepared using information from the following sources: review of selected literature, reports, and advisories; meetings with several interested parties; personal visitation with several persons and airport personnel; the experience of the authors; and other information solicited from stakeholders.

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1.0 EXECUTIVE SUMMARY

The deicing and anti-icing of aircraft and airfield surfaces is required by the Federal Aviation Administration (FAA) to ensure the safety of passengers; however, when performed without discharge controls in place, airport deicing operations can result in environmental impacts. In addition to potential aquatic life and human health impacts from the toxicity of deicing and anti-icing chemicals, the biodegradation of propylene or ethylene glycol (i.e., the base chemical of deicing fluid) in surface waters (i.e., lakes, rivers) can greatly impact water quality, including significant reduction in dissolved oxygen (DO) levels. Reduced DO levels can ultimately lead to fish kills.

This Preliminary Data Summary provides information about the air transportation industry and the best practices being employed for aircraft and airfield deicing operations, as well as for the collection, containment, recovery, and treatment of wastewaters containing deicing agents. This study was conducted to meet the obligations of the EPA under Section 304(m) of the Clean Water Act, in accordance with the consent decree in Natural Resources Defense Council and Public Citizen, Inc. v. Browner (D.D.C. 89-2980, as modified February 4, 1997). EPA hopes that this study will serve as an objective source of information that can be used by airports, airlines, state and local regulators, and citizen groups.

Deicing involves the removal of frost, snow, or ice from aircraft surfaces or from paved areas including runways, taxiways, and gate areas. Anti-icing refers to the prevention of the accumulation of frost, snow, or ice on these same surfaces. Deicing and anti-icing operations can be performed by using mechanical means (e.g., brooms, brushes, plows) and through the application of chemical agents. Typically, airlines and fixed-base operators (i.e., contract service providers) are responsible for aircraft deicing/anti-icing operations, while airports are responsible for the deicing/anti-icing of airfield pavement. Although compliance with environmental regulations and requirements associated with deicing/anti-icing operations may be shared between the airlines/fixed-base operators and the airports (e.g., airport authority) as co-permittees, the airport is ultimately responsible for the management of the wastewater that is generated. This responsibility is typically outlined in the airport's discharge permit.

Deicing/anti-icing operations are typically performed from October through May at many of the nation's airports. Although low DO levels are less likely to occur during the coldest period of the deicing season, as the season ends and temperatures rise, airports are still conducting deicing operations. In addition, the snow dump piles containing deicing agents melt, releasing chemicals into receiving streams. EPA believes that more information is necessary to fully determine the effect of temperature on the reduction of DO in receiving streams caused by the biodegradation of deicing chemicals. However, EPA believes that there has been evidence that impacts could occur in some regions throughout much of the deicing season. For example, during past deicing seasons, airports experienced fish kills caused by their discharges. This may be due to reduced DO levels or the aquatic toxicity of the deicing chemicals.

For the purposes of this study, EPA focused on approximately 200 U.S. airports with potentially significant deicing/anti-icing operations. Such airports receive a minimum of one inch, on average, of snowfall annually and conduct at least 10,000 operations (i.e., aircraft take-offs or landings) annually, excluding general aviation[1] operations. These airports are very diverse in terms of climate, location, existing infrastructure, size, type and mix of tenants, resources, and ownership structure. EPA collected technical and economic information on these airports from a variety of sources including: industry questionnaires, site and sampling visits, meetings with industry and regulatory agencies, and literature. In addition, the study includes information that may be applicable to airport deicing operations and the management of associated wastewaters from the U.S. military and from airports in Canada and Europe.

The Phase I Storm Water Discharge Permit regulations specifically cover the direct discharge of deicing agent contaminated storm water from airports into the nation's surface

[1] General Aviation (GA) operations are the portion of civil (i.e., non-military) aviation which encompasses all facets of aviation except air carriers (e.g., passenger and cargo airlines).

waters. Although these regulations were developed by EPA, they are implemented, in most cases, by individual states. When developing individual airport storm water discharge permits, states may take into account local water quality issues. This leads to a large disparity in permit requirements from airport to airport. EPA found that the airports that have accomplished the most in terms of wastewater collection, containment, and recycling/treatment programs were most likely to be striving to comply with stringent storm water discharge permits. EPA finds that, on average, these airports have achieved 70% collection efficiency of the aircraft deicing/anti-icing fluids applied. They have also spent an average of nearly $20 million, over a period of several years, to finance the necessary equipment and infrastructure changes. EPA notes that since the implementation of EPA's Storm Water Discharge Permit regulations and the resulting increase in the use of best management practices, fewer severe environmental incidents have been reported.

Specific pollutant control practices and technologies implemented at a specific airport are dependent on a variety of factors such as climate, existing infrastructure, cost, and state and local environmental regulations. However, in general, EPA found the following trends among U.S. airports:

- Increased use of propylene glycol-based aircraft deicing fluids over use of ethylene glycol-based fluids;
- Increased use of anti-icing fluids as a means of reducing the volumes of deicing fluid needed;
- Increased efforts by the industry to procure fluids with additives that are less toxic to aquatic life;
- Increased use of alternative airfield pavement deicing chemicals, such as potassium acetate, as a replacement for urea or ethylene glycol-based pavement deicers;
- Increased acceptance and commercial use of source reduction technologies (e.g., forced air and infra-red deicing equipment) used in combination with traditional methods for aircraft deicing;
- Increased use of systems for glycol recycling/recovery from spent aircraft deicing fluid; and

- Increased use of collection, containment, and treatment (on-site or off-site at the Publicly Owned Treatment Works (POTW)).

In addition, more technology vendors are supplying the industry with the equipment and contract management services for containment, collection, recycling/recovery, and treatment technologies. This healthy competition has reduced the costs of these technologies and contract services and made them feasible at some small to medium-size airports.

As part of this study EPA has developed estimates of pollutant loadings to the environment from airport deicing operations. EPA estimates that prior to the implementation of the Phase I Storm Water Discharge Permit regulations (pre-1990) the industry discharged approximately 28 million gallons (50% concentration) of aircraft deicing fluid (ADF) annually to surface waters. This equates to annual discharges of approximately: 14 million gallons of ADF concentrate (prior to dilution with water for application); 12.6 million gallons of pure glycols; or approximately 100 million pounds of BOD_5.

EPA estimates that, due to the best management practices put into place under the storm water permit regulations, current discharges are 21 million gallons of ADF (50% concentration) per year to surface waters with an additional 2 million gallons discharged to POTWs. EPA estimates that this will be further reduced to less than 17 million gallons of ADF (50% concentration) per year discharged to surface waters when the requirements of all airport storm water permits are fully implemented. The volume discharged to POTWs is expected to steadily increase.

Finally, EPA estimated possible reductions in discharges of ADF if effluent limitations guidelines and standards were implemented for airport deicing operations. Assuming that all airports with potentially significant deicing operations could achieve a 70% collection efficiency of ADF applied, EPA estimates that discharges to surface waters from airport deicing operations could be reduced to approximately 4 million gallons ADF (50% concentration) per year (approximately 12.5 million pounds BOD_5 per year). This would likely result in greatly increased volumes discharged to POTWs, as well as an increase in the use of source reduction technologies, recycling/recovery and treatment systems. In addition, FAA projects that the demand for air transportation services will continue to grow. This may result in increased airport deicing and anti-icing operations. However, with the implementation of pollution control practices and technologies, industry growth may not result in an increase in deicing/anti-icing chemicals discharged to the environment.

EPA believes that most POTWs are equipped to handle discharges from airport deicing/anti-icing operations. However, based on a survey of POTWs that currently accept such discharges, airports must control the flow and the BOD loading discharged to the POTW. Most airports use a combination of wastewater storage and controlled discharge to avoid discharging a "slug-dose" of deicing agent contaminated wastewater to the POTW. In addition, because deicing discharges are seasonal, the airports must slowly "ramp-up" (or acclimate) the POTW at the beginning of each deicing season to avoid an upset.

The economic conditions of the air transportation industry are complex in nature. For the purposes of the study, EPA collected information on airport financial management and ownership structures as well as air carrier (i.e., airline) finances to provide an economic overview of the industry. Airport ownership structures are varied (e.g., public v. private, city council v. independent authority) and lead to the use of different financial accounting practices between airports. In many cases, much of the cost of capital improvements are likely to be passed-through to the airlines as higher fees or to the passenger in the form of passenger facility charges (PFCs). Airlines, generally, operate with low profit margin and may also pass costs through to the passenger in the form of higher ticket prices for certain routes. EPA found that the largest cost to the airlines associated with aircraft deicing was the cost of delaying departure of the aircraft. Therefore, the airlines have a great interest in providing input on the various approaches that an airport may consider when trying to control discharges from airport deicing operations. For instance, depending on an airport's runway and taxiway configuration, the use of centralized deicing pads may potentially create or reduce departure delays. However, the greatest potential economic impact to the industry from implementing capital improvements to reduce discharges from airport deicing operations may be a reduction of quality or frequency of service to airports that do not serve large cities (i.e., smaller airports). For example, an airline may choose to operate less flights per day into a particular airport or to operate smaller aircraft on that route. For this reason, EPA believes the collection of airline route-specific data may be necessary to perform a full analysis of the industry's economic and financial condition.

2.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is required by Section 301(d) of the Federal Water Pollution Control Act Amendments of 1972 and 1977 (the "Act") to review and revise every five years, if appropriate, effluent limitations promulgated pursuant to Sections 301, 304, and 306. Effluent limitations guidelines and standards (or "effluent guidelines") are technology-based national standards that are developed by EPA on an industry-by-industry basis, and are intended to represent the greatest pollutant reductions that are economically achievable for an industry. These limits are applied uniformly to facilities within the industry scope defined by the regulations regardless of the condition of the water body receiving the discharge. To address variations inherent in certain industries, different numeric limitations may be set for groups of facilities (i.e., subcategories) within the industry based on their fundamental differences, such as manufacturing processes, products, water use, or wastewater pollutant loadings. The limits and standards that are developed are used by permit writers and control authorities (e.g., Publicly Owned Treatment Works or "POTW") to write wastewater discharge permits. The permits may be more stringent due to water quality considerations but may not be less stringent than the national effluent guidelines. EPA has issued national technology-based effluent guidelines for over 50 industries.

EPA conducted a study of airport deicing operations (the Study) to collect engineering, economic, and environmental data for use in determining whether national categorical effluent limitations guidelines and standards should be developed for this category of dischargers. A secondary purpose of the Study was to provide information to permit writers, control authorities, airports, and airlines in developing pollutant control strategies for discharges from airport deicing operations. EPA was required to conduct the Study under Section 304(m) of the Clean Water Act (CWA), in accordance with a consent decree in *Natural Resources Defense Council and Public Citizen, Inc. v. Browner* (D.D.C. 89-2980, as modified February 4, 1997). The consent decree required that EPA, at a minimum, address the following:

"a. The effectiveness of the current storm water permitting system and the comparative effectiveness of an effluent guideline approach;

b. A characterization of wastewater from deicing operations in terms of pollutant concentrations, volumes, and environmental impacts;

c. The feasibility and effectiveness (in different geographic regions) of various deicing material management technology including complete capture or recycling, product substitution (e.g., propylene glycol for ethylene glycol), and alternative deicing methods (e.g., infrared heating);

d. For each technology, management measure or maintenance activity examined, the types of appropriate numeric or otherwise objective measurable goals, surrogate indicators, performance measures, or operation or design criteria (including zero discharge) that have been or could be effectively employed;

e. The cost and cost minimization opportunities of deicing material management; and

f. The status and trends of deicing chemical use in the airport industry and in the development and use of prevention and treatment technologies."

EPA collected and reviewed data from numerous sources to fulfill the requirements of the consent decree and to increase its understanding of technical, economic, and environmental issues related to airport deicing operations. Technical issues include: aircraft, runway, and taxiway deicing processes; deicing equipment; wastewater generation; wastewater collection, and handling; and pollution prevention/treatment technologies. Economic issues include significant economic and financial aspects of the air transportation industry (i.e., airports and airlines). Environmental issues include impacts from discharges of storm water contaminated with deicing/anti-icing chemicals.

This document discusses the Agency's findings about whether regulatory development of national categorical effluent limitations guidelines and standards should be undertaken for this category of dischargers and to meet the objectives of the consent decree. The document describes data-collection activities (Section 3.0), a technical profile of the industry (Section 4.0), climatic influences and deicing/anti-icing agent- contaminated storm water generation and discharge (Section 5.0), pollution prevention opportunities (Section 6.0), wastewater collection, treatment, and disposal (Section 7.0), and wastewater characterization (Section 8.0). This document also discusses the toxicity of deicing/anti-icing fluids (Section 9.0), provides an environmental assessment of the impacts associated with airport deicing/anti-icing (Section 10.0), and provides estimated pollutant load removals and costs to manage wastewater from deicing operations (Section 11.0). Trends in the industry (Section 12.0), the relationship a national effluent guideline would have to other regulations (Section 13.0), and an economic profile of the industry and facility economic data (Section 14.0) are also included. A glossary of frequently used terms and acronyms is also included (Section 15.0).

3.0 DATA-COLLECTION ACTIVITIES

EPA collected data from a variety of sources, including existing data from previous EPA and other governmental data-collection efforts, industry-provided information, data collected from questionnaire surveys, and site visit and sampling data. Each of these data sources is discussed below, as well as the quality assurance/quality control (QA/QC) and other data-editing procedures. Summaries and analyses of the data collected by EPA are presented in the remainder of this document.

Sections 3.1 and 3.2 describe EPA's 1993 screen questionnaire and EPA's mini-questionnaires, respectively. Section 3.3 discusses EPA site visits and Section 3.4 discusses EPA sampling. Data submitted by airports is presented in Section 3.5, and Section 3.6 discusses meetings with various interested parties. Finally, Section 3.7 discusses technical literature, Section 3.8 discusses other data sources, and Section 3.9 presents the references for the section. Appendix A contains information regarding the location of airports referenced in this section.

3.1 1993 Screener Questionnaire

In 1992, EPA began developing effluent limitations guidelines and standards for the Transportation Equipment Cleaning Industry (TECI). The scope of the TECI regulation at that time included: facilities that clean the interiors of tank trucks, rail tank cars, and tank barges; facilities that clean aircraft exteriors; and facilities that deice/anti-ice aircraft and/or pavement. Initial data-collection efforts for this program related to airport deicing operations included development and administration of a screener questionnaire, the U.S. Environmental Protection Agency Aircraft and Pavement Screener Questionnaire administered in 1993. The screener questionnaire was developed, in part, to enable EPA to: (1) identify facilities that perform TECI-Aircraft operations; (2) evaluate facilities based on wastewater, economic, and operational characteristics; and (3) develop technical and economic profiles of the industry. Subsequent to distribution of the screener questionnaire, EPA decided not to include the aircraft segment as part of the TECI effluent guideline as a result of a revision to the EPA's storm water program that required storm water permits to address wastewater discharges from these practices (EPA's storm water program is discussed in Section 13.1) and an assessment that this segment's activities were significantly different than other TECI segments' activities.

Facilities chosen to receive a screener questionnaire were selected from the Aircraft Site Identification Database (a subset of the TECI Site Identification Database). This database contained information for 3,957 facilities that potentially perform aircraft exterior cleaning and/or aircraft or pavement deicing/anti-icing operations (e.g., airlines and fixed based operators (FBOs)). Facilities listed in the database were a stratified random sample of the 4,778 facilities that compose the total potential industry population. EPA mailed the screener questionnaire to a statistical random sample of 760 facilities that potentially perform aircraft exterior cleaning and/or aircraft or pavement deicing/anti-icing operations (TECI-Aircraft operations).

Following the screener questionnaire mailout and analyses of responses, EPA estimated that, in 1993, there were 588 facilities (i.e., airlines and FBOs) that perform deicing/anti-icing operations. For the purposes of this Study, EPA used responses from facilities that perform deicing/anti-icing operations to develop a technical profile of the industry and to identify trends in the industry. Additional details concerning the 1993 screener questionnaire are presented in a report entitled <u>Development of Survey Weights for the U.S. Environmental Protection Agency Aircraft and Pavement Screener Questionnaire</u> (1).

3.2 Mini-Questionnaires

To collect more detailed and current information, albeit from fewer facilities, EPA mailed mini-questionnaires to various industry representatives and other interested parties. Due to Paperwork Reduction Act concerns, EPA selected only a small portion of the industry (major and regional airports and airlines, technology vendors, and POTWs) to receive a questionnaire. Airlines were asked to submit only financial data, while airports were asked to submit financial and technical information. Technology vendors and POTWs were asked to provide only technical information. The Air Transport Association (ATA) provided one collective questionnaire response for the 12 major carriers while eight regional airlines were each sent questionnaires. See Section 14.0 for additional information on the airline questionnaires.

EPA selected a technically representative group of recipients based on a set of selection criteria for each questionnaire type. EPA requested data through the 1998-1999 deicing season to obtain the most up-to-date data available from the industry. The data are used to describe and characterize the industry, and estimate current and projected pollutant discharge loadings from the industry. Unlike the 1993 screener questionnaire, the mini- questionnaires are not considered a statistical survey of the industry. The report entitled Methodology for Selection of Mini-Questionnaire Recipients (2) describes EPA's selection methodology and presents questionnaire recipients. These mini-questionnaires are discussed in more detail in Sections 3.2.1 through 3.2.3.

3.2.1 Airport Questionnaire

The airport questionnaire requests information from airports regarding aircraft and airfield pavement deicing and anti-icing activities performed at an airport and associated wastewater handling and treatment, in addition to airport structure, finances, and operations. EPA used two primary criteria to select airport mini-questionnaire recipients: airport size and mean annual snowfall. Airport size groupings and mean annual snowfall groupings were defined independently, and then combined to form airport categories. EPA identified data gaps by first identifying categories for which data are already available via EPA-sponsored site visits (see Section 3.3), and then determining which categories require data, or additional data, through questionnaires. EPA selected nine airports that represent airport categories for which little or no data were available to complete a questionnaire.

3.2.1.1 Airport Questionnaire Development

EPA sent a draft version of the questionnaire to representatives from two industry trade associations (American Association of Airport Executives (AAAE) and the Airport Council International - North America (ACI-NA)) for review and comment. Comments from AAAE and ACI-NA were incorporated into the final version of the questionnaire.

The questionnaire included two parts:

1. Part A: Technical Information

   - Section 1: General Information,
   - Section 2: Airfield Pavement Deicing/Anti-icing Operations,
   - Section 3: Aircraft Deicing/Anti-icing Operations,
   - Section 4: Aircraft and Pavement Deicing/Anti-icing Fluid Collection, Treatment, and Disposal; and

2. Part B: Airport Structure, Finances, and Operations.

Part A requested technical information concerning deicing operations at airports. Information was used to develop an industry profile and estimate pollutant discharge loadings from airfield pavement and aircraft deicers/anti-icers. Part A also requested information regarding deicing chemical collection, disposal, and treatment practices, which was used to identify and evaluate applicable pollution prevention and wastewater collection and treatment techniques available to the industry. Part B requested information necessary to develop a general industry economic profile (see Section 14.0 for additional information).

3.2.1.2 Airport Questionnaire Administration

EPA mailed the airport questionnaire in June 1999 to nine selected airports. One airport voluntarily submitted a questionnaire. The Agency completed a detailed engineering review of the questionnaires and contacted by telephone respondents who provided incomplete or contradictory technical information. The information gathered from the questionnaires was entered into EPA's Airport Matrix, a database that contains information on all aspects of airfield pavement and aircraft deicing for the airports for which detailed information is available (via EPA site visits or the questionnaires). The Airport Matrix was used to characterize the industry, validate EPA's snowfall and operations groups, and estimate baseline pollutant loadings discharged to U.S. surface waters and to POTWs.

3.2.2 Vendor Questionnaire

Vendors that received a questionnaire included manufacturers, businesses, and operators of equipment used to collect, control, recycle/recover, treat, or reduce the generation of glycol-contaminated wastewater from aircraft and airfield pavement deicing and anti-icing. EPA identified nine vendors that specialize in certain aspects of these areas based on information obtained during engineering site visits to airports and meetings with industry representatives. In general, EPA selected vendors for which little or no data were previously available.

3.2.2.1 Vendor Questionnaire Development

A draft version of the questionnaire was sent to one treatment technology vendor, Inland Technologies, Inc. (Inland), for review and comment. Comments from Inland were incorporated into the final version of the questionnaire. The questionnaire was divided into the following sections:

- Section 1: General Information;
- Section 2: Information on Specific Equipment and Services;
- Section 3: Rates and Charges;
- Section 4: Future Operations;
- Section 5: Wastewater Treatment and Recycling/Recovery;
- Section 6: Process Influent and Effluent;
- Section 7: Residuals and Solid Waste; and
- Section 8: Additional Information.

The questionnaire requested information necessary to identify and characterize the types of equipment manufactured, leased, or operated by the vendor. The questionnaire also requested information necessary to assess costs to the industry for operating the equipment and to further characterize wastewater treatment and recycling/recovery operations.

3.2.2.2 Vendor Questionnaire Administration

The vendor questionnaire was mailed in June 1999 to nine selected vendors and one Canadian vendor. The Agency completed a detailed engineering review of the questionnaires and contacted by telephone respondents who provided incomplete or contradictory technical information. The information gathered from the questionnaires was summarized in a report and was used to provide costs for managing wastewater from airport deicing operations.

3.2.3 POTW Questionnaire

EPA developed the POTW questionnaire to obtain information from POTWs that accept or have accepted wastewaters containing airport deicing chemicals. EPA selected POTW questionnaire recipients based on the general characteristics of the discharges they receive or once received (e.g., receive discharges of all aircraft deicing/anti-icing agent-contaminated wastewater, receive discharges of only low-strength agent-contaminated wastewater). EPA obtained information regarding POTWs from EPA site visits, discussions with airport, airline, and POTW trade association members, discussions with treatment technology vendors, and literature and newspaper searches.

3.2.3.1 POTW Questionnaire Development

A draft version of the questionnaire was sent to a representative for the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) for review and comment. Comments from MWRDGC were incorporated into the final version of the questionnaire. The questionnaire was divided into the following two sections:

- Section 1: General/Background Information; and
- Section 2: Information Regarding the Acceptance or Rejection of Wastewater Containing Deicing Chemicals.

The questionnaire requested information regarding potential pollutants in wastewater discharges to POTWs from airports, data to characterize the types of discharges the POTW receives, and potential environmental impacts from accepting deicing wastewater containing deicing agents. These data were used to assess the potential impacts that wastewater discharges from airport deicing operations may have on POTW operations.

3.2.3.2 POTW Questionnaire Administration

The POTW questionnaire was mailed in August 1999 to nine selected POTWs. The Agency completed a detailed engineering review of the questionnaires and contacted by telephone respondents who provided incomplete or contradictory technical information. The information gathered from the questionnaires was summarized in a report and was used to provide additional information on environmental impacts from the discharge of wastewater containing deicing agents.

3.3 EPA Site Visits

The Agency conducted 16 engineering site visits at airports to collect information about aircraft, runway, and taxiway deicing processes; deicing equipment; and deicing wastewater generation, collection, handling, and treatment technologies. During these site visits, EPA also evaluated potential sampling locations (as described in Section 3.4). One visit was conducted in April 1997, prior to the formal commencement of this Study, and was used to gather preliminary information about the industry. EPA site visits to the remaining airports examined a range of deicing activities and management practices and took place from September 1997 through March 1999.

EPA used information collected from literature searches and contact with trade association members to identify representative airports for site visits. In general, the Agency considered the following three criteria to select facilities that encompassed the range of deicing/anti-icing operations, wastewater characteristics, and wastewater treatment practices:

1. Size of airport;
2. Geographic location of airport (i.e., typical winter climate); and
3. Technologies in place (e.g., pollution prevention practices, collection techniques, and on-site wastewater treatment facilities).

Airport-specific selection criteria are contained in site visit reports (SVRs) prepared for each airport visited by EPA. Unfortunately, EPA was unable to visit all airports that represent the broad range of size, location, and technologies and, therefore, used questionnaire data (see Section 3.2.1) to augment EPA's site visit program.

During the site visits, EPA collected the following information:

- General airport and deicing operations information, including size and age of the airport, the party(ies) responsible for aircraft and pavement deicing, and current airline tenants;
- A general description of deicing/anti-icing operations, including equipment used, location(s) of deicing operations, chemicals used, and pollution prevention techniques employed;
- Volumes, specific procedures, and type of fluid used for aircraft and pavement deicing/anti-icing;
- Wastewater characterization information, including the typical volume of ADF-contaminated storm water generated, collection methods used, and pollutant concentrations;
- On-site wastewater treatment data, including the treatment technologies used, treatment costs, monitoring, discharge, and permit information; and
- Airport financial information.

This information is documented in the SVR for each airport visited.

3.4 EPA Sampling

During the Study, the Agency conducted six sampling episodes. Two of these were conducted to obtain data on ADFs. EPA conducted one episode to analyze Type I undiluted ethylene glycol-based ADF and conducted another to analyze Type I undiluted propylene glycol-based ADF. The four remaining episodes were conducted to obtain untreated glycol-contaminated wastewater characterization data and treated final effluent data from airports performing a variety of collection and treatment techniques.

To obtain representative sampling data for the industry, EPA collected the following samples:

- Storm water outfall which drains aircraft deicing/anti-icing areas (sample collected during the deicing season, but not concurrent with a deicing event);
- Wastewater discharge to a POTW from an airport retention basin used to collect ADF-contaminated wastewater;
- Influent to and effluent from an anaerobic biological treatment system used to treat ADF-contaminated wastewater at an airport;
- Influent to and effluent from a reverse osmosis treatment system used to treat low-strength ADF-contaminated wastewater and to recover glycol for further processing;
- Influent to and effluent from an aerobic biological treatment system used to treat ADF-contaminated wastewater;
- Undiluted propylene glycol-based aircraft deicing fluid;
- Undiluted ethylene glycol-based aircraft deicing fluid;
- Trip blank(s);

- Equipment blank(s); and
- Duplicate wastewater samples.

In general, the following classes of pollutants were analyzed:

- Whole effluent acute toxicity (WET)
  - *Pimephales Promelas* (Fathead Minnow),
  - *Ceriodaphnia Dubia*;
- Volatile organics (at only two sampling episodes);
- Semivolatile organics (including tolyltriazoles);
- Metals;
- Glycols;
- Biochemical oxygen demand, 5-day (BOD_5);
- Total organic carbon (TOC);
- Hexane extractable material (HEM) and non-polar material (SGT-HEM); and
- Ammonia as nitrogen.

The undiluted ADFs were diluted to 50% solutions with reagent grade water and analyzed for all pollutant classes except BOD_5, glycols, WET, HEM, and SGT-HEM. Section 8.3 discusses the results of EPA's sampling effort.

During the sampling period, field measurements of temperature, pH, nitrate/nitrite, ammonia, and glycol concentration were collected for each sample point. Wastestream flow, production data (i.e., number and type of aircraft deiced/anti-iced), and any information on nondeicing/non-anti-icing operations that generate wastewater that is commingled with deicing/anti-icing wastewater were also collected when available.

During the sampling episode, EPA and EPA contractor personnel collected and preserved samples and shipped them to EPA contract laboratories for analysis. Sample collection and preservation were performed according to EPA protocols as specified in the Quality Assurance Project Plan for Field Sampling and Analysis at Airports (QAPP) (3) and the EAD Sampling Guide (4).

In general, grab samples were collected from all sample streams. These streams are not expected to significantly vary over time (i.e, samples were collected subsequent to extended equalization). EPA collected the required types of quality control samples as specified in the QAPP, such as trip blanks and duplicate samples, to verify the precision and accuracy of sample analyses. The list of analytes for each episode, analytical methods used, and the analytical results, including quality control samples, are included in the Sampling Episode Report (SER) prepared for each sampling episode.

3.5 Data Submitted by Airports

Facilities that discharge wastewater or storm water directly to surface waters of the United States must have a National Pollutant Discharge Elimination System (NPDES) permit, which can establish effluent limitations for various pollutants and require that facilities monitor the levels of these pollutants in their effluent. POTWs may also require facilities to monitor pollutant levels in their wastewater prior to discharge. EPA requested permit and self-monitoring data from airports at which EPA conducted site visits as well as from those that responded to the airport questionnaire. Self-monitoring data were submitted in various formats, including daily and monthly summaries. The monitored pollutants varied among airports; however, most airports monitor for BOD_5 and/or glycols. These data were used to support EPA's operations and snowfall groupings and were used in combination with EPA's sampling data to estimate pollutant loadings discharged to U.S. surface waters (see Section 11.1). Table 3-1 at the end of this section summarizes the specific types of data collected from individual airports.

3.6 Meetings with Federal Agencies, Industry Representatives, Trade Associations, and Technology Vendors

Between 1997 and 1999, EPA participated in several meetings with the Federal Aviation Administration (FAA), fluid formulators, airlines, industry associations, technology vendors, and other interested parties to discuss environmental and operational issues related to aircraft deicing and anti-icing operations. The purpose of the meetings was to gather current detailed information about the industry. These meetings served as a forum for the transfer of information between EPA and industry representatives on all aspects of airport deicing operations, including wastewater collection and treatment technologies. EPA participated in meetings with the following groups:

- Federal Aviation Administration;
- Airport, airline, and fixed based operator (FBO) representatives:
  - American Association Airline Executives (AAAE),
  - Airport Council International - North America (ACI-NA),
  - Air Transport Association (ATA),
  - Regional Airlines Association (RAA),
  - Dames and Moore (a consultant to airlines and airports), and
  - Air Canada; and
- Deicing/anti-icing fluid and treatment technology vendors:
  - AR Plus and VQuip,
  - Council for Environmentally Sound Deicing (CESD)/Lyondell Chemical Company (formerly ARCO),
  - EFX Systems,
  - Inland Technologies, and

– Union Carbide.

In addition to meetings, EPA also attended the following industry conferences:

- The Seventh Annual Aircraft and Airfield Deicing Conference and Exposition held in Washington, DC in August 1998;
- Society of Automotive Engineers (SAE) G-12 Deicing Facilities Subcommittee Meeting in Orlando, FL in October 1998;
- National Aviation Environmental Management Conference in Columbus, OH in March 1999;
- Airport Deicing Summit (hosted by the Albany International Airport Authority) in March 1999;
- The Clean Airport Summit held in Chicago, IL in April 1999;
- SAE G-12 Committee Meeting in Toronto, Canada in May 1999;
- The Eighth Annual Aircraft and Airfield Deicing Conference and Exposition held in Washington, DC in August 1999; and
- SAE G-12 Deicing Facilities Subcommittee Meeting in Washington, DC in November 1999.

By participating in these meetings and conferences, EPA was able to obtain up-to-date information about aircraft and airfield deicing/anti-icing methods, wastewater collection and treatment practices, and economic and financial aspects of the industry. EPA used this information throughout its analyses and incorporated it into this report.

3.7 Literature

EPA performed several Internet and literature searches to identify papers, presentations, and other applicable materials for use in the Study. Literature sources were identified using the Dialog® service. Literature collected by EPA covers such topics as the toxicity of ADFs and their components, estimates of the volume of ADF used by the industry, glycol mitigation techniques, alternative fluid types, pollution prevention practices, economic and financial data, and environmental impacts. EPA also collected information from the U.S. Air Force, which conducted its own study of deicing and anti-icing operations at Air Force bases.

EPA used data from these literature sources to estimate pollutant loadings to the industry and to identify and describe deicing operations and practices, available treatment technologies and their performance, toxicity data, environmental impacts, and trends in the industry.

3.8 Other Data Sources

In addition to the sources listed above, EPA collected data from the Permit Compliance System and Toxics Release Inventory databases. These databases classify facilities that discharge wastewater using four-digit Standard Industrial Classification (SIC) codes. EPA used SIC code 4581 (Airports, Flying Fields, and Services) to identify facilities in the Permit Compliance System and Toxics Release Inventory databases that potentially discharge aircraft and/or pavement deicing/anti-icing wastewater. The Agency also used these databases to calculate and/or validate pollutant loading estimates to the industry.

EPA also collected data from state, local, and other federal agencies. EPA spoke with some state permitting agencies (e.g., NY, CT, WI) and local permit or pretreatment agencies (e.g., Albany, Windsor Locks) during site visits to gain a better understanding of local issues. EPA also collected data from the United States Geological Survey (USGS), which has been performing a study at General Mitchell International Airport in Milwaukee, Wisconsin. The USGS collected glycol samples from the airport’s outfalls and downstream of the receiving waters. In addition, although EPA does not use a similar toxicity scale, the Agency acquired an acute toxicity scale from the U.S. Fish and Wildlife Service that compares concentration to toxicity. EPA Region 3 provided permit and sampling data for two airports in its jurisdiction, Ronald Reagan Washington National Airport and Dulles International Airport. EPA also acquired, from FAA, operations and enplanement data for one full year, which were used in the airport questionnaire development, and several advisory circulars, which were used to better understand the industry and its current regulations. EPA also obtained extensive economic and financial information from published reports by FAA, the Department of Transportation (DOT), the Bureau of Transportation Statistics (part of DOT), and the General Accounting Office.

EPA also collected data from Environment Canada, the Canadian federal agency responsible for environmental protection and conservation, and Transport Canada, the Canadian federal agency responsible for transportation issues. Specifically, EPA collected information about the Canadian Glycol Guidelines and the Canadian Water Quality Guidelines for Glycols developed in the 1990s. Environment Canada and Transport Canada provided EPA with several final, and in some cases draft, reports describing studies they have conducted to evaluate the effect and fate of ADFs in the environment. These reports included results from several aquatic toxicity studies performed using formulated ADFs. See Section 13.3 for more information regarding the Canadian guidelines.

3.9 References

1. Eastern Research Group, Inc. Development of Survey Weights for the U.S. Environmental Protection Agency Aircraft and Pavement Screener Questionnaire (DCN T10343).

2. Eastern Research Group, Inc. Methodology for Selection of Mini-Questionnaire Recipients. (DCN T10545).

3. Eastern Research Group, Inc. Quality Assurance Project Plan for Field Sampling and Analysis at Airports. February 10, 1999 (DCN T10233).

4. Viar and Company. EAD Sampling Guide. June 1991 (DCN T10218).

Table 3-1

Summary of Data Submitted by Airports

Airport	Permit Information (a)	Analytical Monitoring Data	ADF Usage Volumes
Airborne Air Park	✔		✔
Albany International	✔	✔	✔
Anchorage International	✔		✔
Baltimore-Washington International	✔	✔	✔
Billings Logan International	✔		✔
Bradley International	✔	✔	✔
Buffalo International	✔		✔
Chicago O'Hare International	✔	✔	✔
Cleveland Hopkins International	✔		✔
Dallas-Ft. Worth International	✔	✔	✔
Denver International	✔		✔
Des Moines International	✔		✔
Duluth International	✔		✔
General Mitchell International	✔	✔	✔
Greater Rockford	✔	✔	✔
Kansas City International	✔	✔	✔
Key Field (Meridian)	✔		✔
Logan International	✔	✔	✔
Minneapolis-St. Paul International	✔		✔
Newark International	✔		✔
Portland International	✔		
Richmond International	N/A		
Ronald Reagan Washington National	✔	✔	✔
Seattle-Tacoma International	✔		✔
Salt Lake City International	✔		✔
Tri-State (Huntington)	✔		✔
Washington Dulles International	✔	✔	✔

N/A - Not applicable (i.e., no current storm water permit in place).
(a) Although general permit information were available, specific permit information (e.g., monitored parameters and frequency) was not always provided.

4.0 TECHNICAL PROFILE

This section presents an overview of the air transportation industry (Section 4.1), a description of airport deicing/anti-icing operations (Section 4.2), and a profile of the airport deicing operations "industry" (i.e., airports that have deicing/anti-icing operations) (Section 4.3). Information presented in this section is based on data provided by facilities in response to screener questionnaires, mini-questionnaires, EPA site visits and sampling episodes, and data collected from other non-EPA sources (see Section 3.0).

4.1 Air Transportation Industry Overview

EPA is mainly concerned with deicing/anti-icing activities at facilities classified within Standard Industrial Classification (SIC) code 4581 (Airports, Flying Fields, and Airport Terminal Services). There are different types and sizes of airports, as well as aircraft serving these airports, depending on the airport and its location. For example, some airports that serve only cargo carriers generally service only large jets. The Federal Aviation Administration (FAA) has created several different classification codes for airports and aircraft. These classifications are mainly used for FAA funding purposes.

4.1.1 Airport Types and Sizes

There are currently 18,345 civil landing areas[1] in the U.S., which include airports as well as landing areas developed specifically for helicopters and seaplanes (1). Although the FAA is responsible for controlling all airspace, it does not control all airports. The FAA has identified 3,344 airports that are currently important to national transportation (1). Most of these airports are owned by the cities or counties they serve and only a few airports are privately owned. Of the approximately 15,000 civil landing areas that are not considered important to

[1]Note that civil landing areas do not include stand-alone military landing areas (i.e., military landing areas that are not located at a public airport).

national transportation, 1,000 do not meet the minimum criteria to be considered important; 1,000 are located at inadequate sites, are redundant to publicly owned airports, or have too little activity to qualify for inclusion; and the remaining 13,000 are not open to the general public (1).

Airport size can be measured either by enplanements or operations. The FAA defines airport size based on enplanements. Commercial service airports are those that are publicly owned, receive passenger service, and have 2,500 or more annual enplanements. Primary commercial airports are those with more than 10,000 annual enplanements; nonprimary commercial service airports are those with annual enplanements ranging from 2,500 to 10,000. According to the FAA, in January 1998 there were 413 primary commercial airports and 125 nonprimary commercial service airports (1). The FAA further classifies primary commercial airports by hubs. Large hub airports are defined as those airports with 1% or more of all U.S. enplanements, medium hubs are those with 0.25% to 0.9999% of enplanements, small hubs are those with 0.05% to 0.2499% of enplanements, and nonhubs are those with 10,001 to 0.0499% of enplanements. In addition to commercial service, there are classifications for general aviation (GA) and reliever airports. Most civil aircraft operations occur at GA airports, which comprise 95% of all airports and service 98% of all registered civil aircraft. Reliever airports are typically general aviation airports that are located near a commercial service airport and serve as a reliever to congested airports. The number of airports in each category is listed below.

<table>
<tr><th colspan="3">Category</th><th>Number of Airports</th><th>Percentage of U.S. Enplanements</th></tr>
<tr><td rowspan="5">Commercial</td><td rowspan="4">Primary</td><td>Large hub</td><td>29</td><td>67%</td></tr>
<tr><td>Medium hub</td><td>42</td><td>22%</td></tr>
<tr><td>Small hub</td><td>70</td><td>7%</td></tr>
<tr><td>Nonhub</td><td>272</td><td>3%</td></tr>
<tr><td>Non-primary</td><td>Other</td><td>125</td><td><1%</td></tr>
<tr><td colspan="3">Relievers</td><td>334</td><td>0%</td></tr>
<tr><td colspan="3">General aviation</td><td>2,472</td><td>0%</td></tr>
</table>

Source: Reference (1).

The FAA also maintains records of airport operations (number of arrivals and departures) for FAA-towered or contractor-towered airports. EPA is not aware of any FAA airport size categories defined by airport operations. Operations are divided into the following aviation categories that are described below: air carrier, air taxi, general aviation, and military operations.

Aviation Category	Definition
Air carrier	A certified aircraft with a seating capacity of more than 60 seats or a maximum payload capacity of more than 18,000 pounds carrying passengers or cargo for hire or compensation; includes U.S. and foreign flag carriers. The four types of air carriers are: majors, nationals, large regionals, and medium regionals.
Air taxi	An aircraft designed to have a maximum seating capacity of 60 seats or less or a maximum payload capacity of 18,000 pounds or less carrying passengers or cargo for hire or compensation; may also be referred to as a commuter aircraft if noncertified.
General aviation	Takeoffs and landings of all civil aircraft, except those classified as air carriers or air taxis.
Military	All classes of military operations (e.g., Air Force, Army, Navy, U.S. Coast Guard, Air National Guard) at FAA air traffic facilities.

Source: Reference (2).

Section 14.1 provides a detailed profile of significant economic and financial aspects of U.S. airports.

4.1.2 Geographic Location of Airports

Airports are distributed throughout the entire U.S., and more likely to be located near population centers. According to the FAA, 70% of the U.S. population resides within 20 miles of at least one of the 538 commercial airports (1). A large percentage of primary hub commercial airports (97% in 1996) are located adjacent to environmentally sensitive areas (i.e., water bodies) such as wetlands, rivers, coastal areas, creeks, and lakes (3).

4.1.3 Types of Airlines

Airlines are classified by the services they offer and their annual revenues. The four classifications for airlines are: major, national, regional, and cargo. They all operate under federal regulations; however, the regulations to which a particular airline is subject depends on their aircraft fleet. Section 14.2 provides a detailed profile of significant economic and financial aspects of U.S. airlines.

Major airlines earn annual revenues of $1 billion or more in scheduled service. There were 12 major airlines in the U.S. in 1996 (4). These carriers generally can provide scheduled service with large aircraft (i.e., aircraft with 61 or more seats and a payload of more than 18,000 pounds) (4).

National airlines earn annual revenues of between $100 million and $1 billion in scheduled service (4). Many of the airlines in this category serve particular regions of the country, although this is not required. These carriers mostly operate medium and large size jets (4).

Regional carriers are airlines whose services are generally limited to a single region of the country. These carriers are divided into three groups: large, medium, and small. Large regional carriers earn annual revenues of between $20 million and $100 million and operate aircraft with more than 60 seats. Medium regional carriers earn annual revenues of less than $20 million, but operate aircraft similar to large regional carriers. Small regional carriers, often called commuters, are the largest segment of the regional airline business and mostly operate planes that have less than 30 seats. There is no revenue cut-off for this group (4).

Regional airlines may be private business carriers, commercial airlines, charter airlines, or airlines that provide a combination of these services. Private business carriers represent about 60% of the flights of regional airlines. Regional airlines serve all airports served by the major airlines as well as 300 smaller airports that are not served by any major airline. At larger airports, all of the regional airlines typically operate out of one gate area. However, some regional airlines that are affiliated with major airlines (e.g., American Eagle, which is affiliated with American Airlines) may have their own gate areas or use the same gate areas as their larger affiliate. Although regional airlines carry about 10% of all airline passengers, they represent about 40% of all flight operations. Regional airlines conduct a disproportionately large number of flight operations per passenger because their aircraft are smaller, and, therefore, carry fewer passengers per operation. In addition, their aircraft have a higher utilization rate, shorter flights, and spend less time on the ground between flights.

Cargo carriers are airlines that primarily carry cargo using aircraft called "freighters" (4). Freighters are essentially passenger aircraft with all or nearly all of the passenger seats removed. There is no revenue cut-off for this group.

4.2 Deicing/Anti-Icing Operations

A major concern for the safety of passengers is the clearing of ice and snow build-up on runways, taxiways, roadways, gate areas, and aircraft. Two basic types of deicing/anti-icing operations are generally performed at an airport: the deicing/anti-icing of aircraft, and the deicing/anti-icing of paved areas, including runways, taxiways, roadways, and gate areas. The most common technique for the deicing/anti-icing of aircraft is the application of chemical deicing/anti-icing agents. Deicing of runways, taxiways, and roadways is most commonly performed using mechanical means but may also be performed using chemical agents. The anti-icing of paved areas is typically conducted with anti-icing chemicals. The following subsections describe the methods and materials used to deice and anti-ice aircraft and paved areas at airports.

4.2.1 Aircraft Deicing/Anti-icing

Aircraft deicing involves the removal of frost, snow, or ice from an aircraft. Aircraft anti-icing generally refers to the prevention of the accumulation of frost, snow, or ice. Both are typically discussed as one operation throughout this section.

The responsibility for performing deicing/anti-icing varies between airports, but it is usually performed by a combination of individual airlines and fixed-based operators (FBOs). Airlines typically select procedures for deicing/anti-icing their aircraft, which are then approved by the FAA. EPA is aware of only one airport authority, Westchester, New York, that performs aircraft deicing. Even in this case, the airport authority functions as an FBO when performing deicing operations.

In the deicing/anti-icing process, aircraft are usually sprayed with deicing/anti-icing fluids (ADF) that contain chemical deicing agents; however, nonchemical methods are also performed. Deicing/anti-icing occurs when the weather conditions are such that ice or snow accumulates on an aircraft. During snowstorms, freezing rain, or cold weather that causes frost to accumulate on aircraft surfaces including the wings, deicing is necessary to ensure the safe operation of aircraft. Studies have concluded that even very little icing, if located on critical aircraft surfaces (e.g., leading edge of the wing), can cause significant decreases in lift. Typical tests show that 1/32nd of an inch of ice accumulation along the leading edge of a large jet or 1/64th of an inch on a smaller aircraft can decrease lift on takeoff from 12% to 24%, depending on the size of the aircraft (5).

The typical deicing season runs from October through April. In colder areas the deicing season may extend over a longer period, and in warmer climates the deicing season may be shorter, with the exception of frost removal, which may rarely be done.

ADF works by adhering to aircraft surfaces to remove and/or prevent snow and ice accumulation. Nonchemical methods use mechanical or thermal forces to prevent, remove, or melt ice and snow. Two types of deicing are performed: wet-weather and dry-weather deicing, depending on a number of climatic and operational factors. Wet-weather deicing is performed during storm events that include precipitation such as snow, sleet, or freezing rain. Dry-weather deicing is performed when changes in the ambient temperature cause frost or ice to form on aircraft but no precipitation is present. Dry-weather deicing may also be performed on some types of aircraft whose fuel tanks become super-cooled during high-altitude flight, resulting in ice formation at lower altitudes and after landing. Dry-weather deicing may occur at temperatures up to 55° Fahrenheit (F), but generally requires a significantly smaller volume of deicing fluid than wet-weather deicing.

During typical wet-weather conditions, 150 to 1,000 gallons of ADF may be used on a single commercial jet, while a much smaller volume, as little as 10 gallons, may be used on a small corporate jet (6, 7, 8). An estimated 1,000 to 4,000 gallons may be needed to deice a commercial jet during severe weather conditions (9). Aircraft anti-icing fluids are applied in much smaller volumes than their deicing counterparts. A commercial jet requires approximately 35 gallons of fluid for anti-icing after deicing (7). Generally, dry-weather deicing requires 20 to 50 gallons of deicing fluid, depending on the size of the aircraft (7, 10).

4.2.1.1 Fluid Types

Aircraft deicers are categorized into four classes: Type I, Type II, Type III, and Type IV. Not all types are currently used. Fluid types vary by composition and allowed holdover times (i.e., the amount of time the residual fluid will protect an aircraft from ice formation). Type I is the most commonly used fluid and is used primarily for aircraft deicing. These types of fluids, which contain either ethylene glycol or propylene glycol, water, and additives, remove accumulated ice and snow from aircraft surfaces. Types II, III, and IV were developed for anti-icing and form a protective anti-icing film on aircraft surfaces to prevent the accumulation of ice and snow. Anti-icing fluids are composed of either ethylene glycol or propylene glycol, a small amount of thickener, water, and additives. The additives in aircraft deicing and anti-icing fluids may include corrosion inhibitors, flame retardants, wetting agents, identifying dyes, and foam suppressors.

Type II and Type IV fluids were designed for use on all types of aircraft while Type III fluids were designed for use on smaller, commuter aircraft. Most of the larger U.S. airlines use Type IV fluids exclusively for aircraft anti-icing because of its increased holdover time, but many smaller and regional airlines use Type II fluids due to cost considerations (Type IV fluids require specialized application equipment). According to a representative from the Regional Airlines Association (RAA), Type III fluids are not currently used, and are not available for purchase.

FAA regulations do not stipulate which fluid should be used but recommend that commercial carriers and owners of private aircraft use fluids that meet the standards set by the Society of Automotive Engineers (SAE) (see Section 13.5). All current formulations in the U.S. use either ethylene glycol or propylene glycol as a freezing point depressant. Diethylene glycol is also an approved freezing point depressant; however, no diethylene glycol-based deicing fluids are currently used in the U.S.

Temperature and weather conditions dictate the required concentration of glycol in any type of fluid. Some entities that perform deicing vary the glycol concentration based on weather conditions (concentrations may range from 30% to 70% glycol). This is referred to as "blending to temperature." Others use the same concentration regardless of weather conditions. Those who use the same concentration throughout a deicing season typically use a concentration applicable to worst-case cold weather conditions (usually around 50% glycol). This conservative practice may result in fewer operator mistakes and is particularly suited to smaller airports that lack storage for preparing multistrength solutions.

Type I fluids are commonly purchased as concentrated glycol solutions (8% water, 90% glycol, and <2% additives) and diluted as needed prior to application. Type II and IV fluids are sold preformulated to the appropriate concentration (33% water, 65% glycol, and 2% additives) and do not require dilution prior to application.

4.2.1.2 Fluid Uses

All ADFs work by lowering the freezing point of water. ADF is applied to ensure that the freezing point of any water on aircraft remains at a temperature not greater than 20° F below the ambient air or aircraft surface temperature, whichever is lower (FAA Advisory Circular

No. 20-117). All ADFs must lower the freezing point of water to -18° F or lower when applied. A typical Type I deicing fluid contains approximately 50% to 60% glycol after being diluted for application. This concentration will depress the freezing point of water to between -40° F and -50° F. Current formulations of propylene glycol-based ADFs require a greater concentration of glycol than ethylene glycol-based ADFs to attain the same freezing point depression. The minimum freeze point for ethylene glycol-based ADFs (approximately -58° F) occurs when the fluid consists of approximately 60% ethylene glycol and 40% water. The minimum freeze point for propylene glycol-based ADFs (-75° F) is lower than that for ethylene glycol-based ADFs, but occurs at a higher glycol concentration.

The main difference in capability among all of the different fluid types is the holdover time. Holdover time is the period of time when ice or snow is prevented from adhering to the surface of an aircraft (i.e., the amount of time between application and takeoff). Type I fluids have between a 6- and 15-minute holdover time in a light snow. Because of this brief time span, Type I fluids are used for deicing and for only short-term anti-icing protection. Although rarely used, Type II fluids provide approximately a 45-minute holdover time in a light snow. Type IV fluids can provide up to a 70-minute holdover time, depending on atmospheric conditions. Because anti-icing fluids are more expensive than deicing fluids, larger amounts of Type I fluids are commonly used to remove snow and ice and then much smaller amounts of anti-icing fluid are applied if necessary.

Most larger airlines use both Type I and Type IV fluids, while smaller commercial airlines may use both Type I and Type II fluids or no anti-icing fluids at all. Smaller airlines have been generally unable to afford the specialized equipment required to apply Type IV fluids, although some small airlines may be deiced by FBOs that use Type IV fluids. Also, some small airlines have recently purchased used Type IV application trucks from larger airlines who have upgraded to trucks that can apply both Type I and Type IV fluids. Airlines that can afford to invest in specialized equipment first evaluate if Type IV fluids are necessary at each of their stations by analyzing historical weather data, airline operations figures, airport infrastructure, and airport congestion. For example, increased holdover times provided by Type IV fluids may not be necessary at small airports with short taxiing times and no congestion.

Although Type IV fluids are more effective at preventing ice formation than Type I fluids, they are not as effective at depressing the freezing point of water. Therefore, airports located in colder regions may use Type I fluids for both deicing and anti-icing.

4.2.1.3 Fluid Application

Deicing fluids are generally heated to 150° F to 180° F prior to application, while anti-icing fluids are typically applied at ambient temperatures. All fluid types are usually applied under pressure using a nozzle. The pressure of the liquid hitting the surface of the aircraft physically removes some of the snow and ice, while the high temperature and chemical properties of the fluid melts the remaining snow and ice. The solution that remains on the aircraft helps prevent further snow and ice build-up. Special nozzles are necessary to apply anti-icing fluids due to their high viscosity. When ambient temperatures are above 26° F, the FAA allows the use of hot water (heated to 140° F) to melt and remove snow and ice followed by application of anti-icing fluid. Most airlines do not currently use this method because it is considered to be too dangerous and could compromise passenger safety. A major concern with hot water deicing is flash freezing (i.e., freezing on contact with aircraft) and the potential to build thick layers of ice both on the aircraft and on the ground.

ADF is generally stored in either above-ground storage tanks, underground storage tanks, tank trucks, or mini-bulk (450-gallon) containers. Type I fluids are either diluted in mixing vessels, or mixed as they are pumped into deicing trucks or tank trucks using a proportioner. This device pumps both concentrated deicing fluid and water simultaneously at predetermined flow rates to achieve a desired solution concentration. If the fluid requires heating prior to application, it is heated in mixing vessels or in trucks.

ADF is typically applied using deicing trucks or fixed booms. Some deicer trucks contain multiple storage compartments to carry deicing fluids of varying strengths or types. Storage tanks may be equipped with thermal blankets to heat the fluids. Deicing trucks typically have a movable boom with a cherry picker equipped with a nozzle at the end of the boom. An operator in the cherry picker basket directs the high-pressure spray at aircraft surfaces, while a driver moves the truck. Specially designed deicing trucks may be used to deice areas of the aircraft that are low to the ground or hard to reach, such as landing gear.

Some airports are equipped with fixed-boom deicing equipment, which typically includes a permanently mounted boom with a nozzle, or a cherry picker with a nozzle, that moves along the boom. Pumps supply ADF from mixing tanks to the boom. Because fixed booms are less mobile than deicing trucks, deicing trucks may be needed to deice hard-to-reach areas not serviced by the booms.

Prior to application, many operators test their ADF to determine its glycol concentration. Densitometers and refractometers are two types of equipment often used to measure glycol concentrations in the field. After deicing operations are complete, some fluid may remain in deicing trucks and mixing vessels. This fluid is typically stored in the trucks or pumped into a storage tank until the next deicing event. The fluid (including Type I fluid diluted to application strength) may be stored at the end of the deicing season for use the following season.

Aircraft deicing and anti-icing operations usually occur at terminal gates, gate aprons, taxiways, or pads. Aircraft deicing/anti-icing pads may be located near terminals and gates, along taxiways serving departure runways, or near the departure end of runways. Each airport may use only one or a combination of all of these locations for deicing/anti-icing. The amount and type of deicing performed at each location may vary. For example, an airport with aircraft deicing/anti-icing pads may allow only minimal deicing (i.e., engines and wheel base) at gates, the minimum amount of deicing necessary to move the aircraft safely, and require all other deicing to be conducted at the pad.

If deicing is not conducted at the gate, then, prior to takeoff, an aircraft will taxi to airport-approved deicing/anti-icing locations. Depending on the deicing location design, several aircraft may be deiced simultaneously on a single deicing pad. Deicing trucks and/or fixed booms apply the appropriate ADF. From one to four deicer trucks may be used for deicing a single aircraft, depending on its size and weather conditions. Estimates based on EPA site visits to airports indicate that deicing application time may range from 5 to 20 minutes, while anti-icing application time ranges from 4 to 6 minutes. When holdover times are exceeded prior to takeoff, secondary deicing/anti-icing is necessary. Secondary deicing/anti-icing is typically conducted at a remote deicing/anti-icing pad adjacent to the runway, if available. However, many airports are not equipped with remote deicing/anti-icing pads, and aircraft must return to the gate or other designated deicing/anti-icing locations for secondary deicing/anti-icing, which can substantially delay their departure. The need for secondary deicing will likely decrease as more airlines use Type IV fluids to extend the allowable holdover time.

4.2.1.4 Variables That Affect Fluid Use

The variables that affect the volume of deicing fluid used and the time needed to deice aircraft include: ambient temperature; amount of snow and ice build-up on aircraft; aircraft type and size; type/severity of current precipitation; deicing fluid glycol concentration; aircraft surface temperature; relative humidity; solar radiation; wind velocity and direction; deicing procedure used; proximity to other aircraft, equipment, and buildings; aircraft component geometry and surface roughness; and the deicing personnel. Climatic- and weather-related influences are the predominant variables that affect fluid usage and are described in Section 5.0.

The FAA has issued regulations on when and how to conduct deicing/anti-icing operations to ensure safe air travel. They have also published advisories and guidance for designing aircraft deicing facilities and for conducting aircraft deicing/anti-icing under various weather conditions and aircraft types. However, the aircraft pilot is ultimately responsible for determining whether the deicing performed is adequate. The pilot may inspect the aircraft after deicing and order additional deicing or anti-icing.

EPA learned from data-collection efforts that one of the most significant operational factors affecting fluid usage is personnel. A large portion of aircraft deicing staff, particularly at larger airports, is newly hired and trained each year. High employee turnover results from low pay and poor work conditions (e.g., exposure to storm events and fluid). In addition, airlines at hub airports tend to use temporary employees for aircraft deicing. Although the cost of fluid can prevent wasting fluid, many of these new hires are initially taught that "a little is good, but more is better," and spray more fluid than is necessary due to the potential liability associated with improperly deicing an aircraft. Although new hires receive eight hours of FAA-mandated training, industry sources tell EPA that three years of experience is required to become adept at aircraft deicing. Personnel turnover is generally much lower at smaller airports because aircraft deicing staff at these airports tend to have other responsibilities, such as baggage handling or maintenance. See Section 6.2.16 for additional information on personnel training and recent industry efforts to improve this factor.

4.2.1.5 Dry-Weather Deicing

Dry-weather deicing, also referred to as clear ice deicing, may be performed whenever ambient temperatures are cold enough to form ice on aircraft wings (below 55° F). Dry-weather deicing is also used to defrost windshields and wingtips on commuter planes and is usually conducted throughout the entire deicing/anti-icing season.

Airplane models MD-80s and DC-9s are more likely to require dry-weather deicing than other aircraft because their fuel tanks are located under their wings. The tanks may become super-cooled during flight, causing frost or ice to form on the wings when the aircraft lands. Generally, only a small volume of aircraft deicing fluid is needed to remove this ice, approximately 20 to 50 gallons per aircraft. Some airlines are attempting to eliminate the need for dry-weather deicing by retrofitting these aircraft with specially designed thermal blankets; however, these blankets have caused corrosion problems in electric systems.

4.2.1.6 Nonchemical Deicing Methods

Nonchemical deicing methods use mechanical or thermal means to remove ice and snow from aircraft. Dry, powdery snow can be swept from aircraft using brooms or brushes. Hot air blowers can also be used to remove snow mechanically with forced air and also to melt ice and snow. In addition, some smaller aircraft are equipped with inflatable pneumatic or hydraulic boots that can expand to break ice off of the leading edges of wings and elevators.

Mechanical snow removal methods (e.g., using nylon brooms and ropes to remove snow from parked aircraft) are typically only used in the early morning because they are time- and labor-intensive and would be too disruptive to airline schedules during the day. Mechanical methods are typically also used in conjunction with fluid application and are dependent on climate and operational variables. Personnel must be properly trained and provided with appropriate equipment so as not to damage navigational equipment mounted on aircraft. Airlines typically use brooms to remove as much snow and ice as possible before applying conventional aircraft deicing fluids.

Forced-air/hot-air deicing systems are currently in operation at a few U.S. airports and are being assessed by several airlines (see Section 6.2.3 for more detailed information). These systems use forced air to blow snow and ice from aircraft surfaces. Some systems allow deicing fluids to be added to the forced air stream at different flow settings (e.g., 9 and 20 gpm), while other systems require separate application of deicing fluid. Several vendors are currently developing self-contained, truck-mounted versions of these forced-air systems, and most systems can be retrofitted onto existing deicing trucks.

A similar method to truck-mounted forced-air systems is the double gantry forced-air spray system. The gantries support a set of high- and low-pressure nozzles, which blast the aircraft surfaces with heated air at 40 to 500 pounds per square inch. When weather conditions are severe, a small volume of water and glycol may be added to the air stream to remove dense coverings of snow and ice. Use of the gantry system is limited because it is a permanently mounted system and has been known to cause bottlenecks and delay aircraft departure.

Another alternative to chemical deicing/anti-icing methods is infrared (IR) heating of aircraft. One IR system consists of an open-ended hangar-type structure with natural gas powered IR generators suspended from the ceiling. The IR wavelengths are targeted to heat ice and snow, and minimize heating of aircraft components. The IR energy and wavelength may be adjusted to suit the type of aircraft. Although the system can deice an aircraft, it cannot provide aircraft with anti-icing protection. Consequently, when the ambient temperature is below freezing, anti-icing fluid is typically applied to the aircraft after it leaves the hangar. Testing is being planned to determine if it is possible that melted snow and ice can refreeze prior to Type IV application following IR deicing. Since the aircraft surfaces are dry, the volume of anti-icing fluid required is less than for typical anti-icing operations. In addition, a small amount of deicing fluid may be required for deicing areas of the aircraft not reached by the IR radiation, such as the flap tracks and elevators. The system, therefore, does not completely replace glycol-based fluids, but greatly reduces the volume required. See Section 6.2.5 for additional information on IR deicing.

4.2.2 Pavement Deicing/Anti-icing

Pavement deicing/anti-icing removes or prevents the accumulation of frost, snow, or ice on runways, taxiways, aprons, gates, and ramps. A combination of mechanical methods and chemical deicing/anti-icing agents are used for pavement deicing at airports. Runway deicing/anti-icing is typically performed by the airport's operating authority or a contractor hired by the authority. Some ramp, apron, gate, and taxiway deicing/anti-icing may be performed by other entities, such as airlines and FBOs that operate on those areas. Pavement deicing typically occurs during the same season as aircraft deicing, but may be shorter than the aircraft deicing season.

4.2.2.1 Mechanical Methods

Mechanical methods, such as plows, brushes, blowers, and shovels for snow removal, are the most common form of runway deicing, and may be used in combination with chemical methods. Airports generally own multiple pieces of snow removal equipment and have employees trained to operate them. Because winter storm events can be unpredictable, personnel trained in pavement deicing/anti-icing may be available at an airport 24 hours a day during the winter season.

4.2.2.2 Chemical Methods

Because ice, sleet, and snow may be difficult to remove by mechanical methods alone, most airports use a combination of mechanical methods and chemical deicing agents. Common pavement deicing and anti-icing agents include ethylene glycol, propylene glycol, urea, an ethylene glycol-based fluid known as UCAR (containing approximately 50% ethylene glycol, 25% urea, and 25% water by weight), potassium acetate, sodium acetate, sodium formate, and calcium magnesium acetate (CMA). Sand may be used to increase the friction of icy paved areas, but it may be detrimental to the mechanical workings of aircraft. Salt (i.e., sodium chloride or potassium chloride) may be used to deice/anti-ice paved areas that are not used by aircraft (e.g., automobile roadways and parking areas) but are not considered suitable for deicing/anti-icing taxiways, runways, aprons, and ramps because of their corrosive effects. Potassium acetate has also been reported as potentially degrading insulation in electrical systems (e.g., runway lights). An industry workgroup is currently investigating this issue.

Many airports perform deicing of heavy accumulations of snow and ice using mechanical equipment followed by chemical applications. Pavement anti-icing may be performed based on predicted weather conditions and pavement temperature. Deicing and anti-icing solutions are applied using either truck-mounted spray equipment or manual methods. Section 6.5 further discusses pavement deicing/anti-icing operations.

4.3 Airports with Deicing/Anti-Icing Operations

The number of airports performing deicing/anti-icing operations in the U.S. is unknown. In addition, the amount of deicing/anti-icing fluids or agents used varies greatly among airports, as does the amount of wastewater generated. Factors affecting the amount of deicing/anti-icing fluids used and the volume of wastewater generated include airport size, airport location and weather, and airlines using the airport. These and other industry characteristics are described in the following subsections.

4.3.1 Number of Airports Performing Aircraft and Runway Deicing

EPA is not aware of any sources estimating the number of airports performing aircraft and pavement deicing operations. EPA also recognizes that not all airports that perform deicing/anti-icing operations contribute significant pollutant loadings to the environment from these activities. For example, a large airport in Florida may deice aircraft only approximately 10 days per year for defrosting purposes. These operations are not likely to significantly impact the surrounding environment (or publicly owned treatment works (POTW)) because only a small amount, if any, of spent deicing fluid enters the environment, and pollutant loadings from these airports would be negligible. Therefore, for purposes of this study, EPA focused on airports that potentially perform significant deicing/anti-icing operations.

4.3.1.1 Number of Airports Potentially Performing Significant Deicing/Anti-Icing Operations

EPA determined potentially significant deicing/anti-icing operations based on airport size and weather. In general, deicing/anti-icing operations include aircraft deicing, which is typically performed by airlines or a FBO, and pavement deicing, which is typically performed by airports. EPA received aircraft operations and total enplanement data from the FAA for over 400 airports, and used aircraft operations data as a measure of airport size for the following reasons. First, aircraft deicing is performed on a per-aircraft basis, which is more closely related to airport operations than enplanements. Second, the volume of aircraft deicing fluid (ADF) required for deicing is not impacted by whether or not the aircraft is fully loaded with passengers. For the purposes of this study, EPA selected a benchmark of 10,000 operations per year (excluding general aviation) to represent significant operations; therefore, the Agency excluded airports with less than 10,000 annual operations from further analyses. EPA did not include general aviation in its operation measurement because EPA believes that most general aviation aircraft do not operate during deicing conditions.

EPA also used weather information to identify airports that are likely to perform potentially significant deicing/anti-icing operations. For the purposes of this study, EPA determined that mean annual snowfall (including ice pellets and sleet) of less than 1 inch would not result in significant deicing operations; therefore, EPA excluded airports in regions with annual snowfall less than 1 inch from further analyses.

As a result, EPA focused on wastewater generated and the impact associated with deicing events at airports with annual operations greater than 10,000 (excluding general aviation) and an average of 1 inch or greater of snowfall per year. Figure 4-1, located at the end of this section, shows a geographic representation of the estimated 212 airports that meet these criteria. As expected, these airports are highly concentrated in the eastern part of the U.S. where the population is more dense. Few airports are located in the far South, where there is little or no snowfall. EPA is aware that other airports (e.g., private, military, or non-FAA-towered) may exist that meet the criteria defined above; however, EPA was limited by the data provided by the FAA.

4.3.1.2 Other Estimates of Number of Airports

In a survey of the top 125 busiest airports in the U.S. (including territories) conducted by the National Resources Defense Council (NRDC) in 1996, 61 airports supplied data concerning deicing activities at the airport. Out of the 61 airports that responded, 51 answered that they perform deicing, eight answered that they do not perform deicing, and two answered that they only rarely deice (6). The eight airports that do not deice are located outside the continental U.S. (e.g., Puerto Rico, Virgin Islands), or are located in very warm climates (e.g., Fort Lauderdale, FL, Phoenix, AZ). Both Los Angeles International and San Francisco International responded that they did not deice in the timeframe for which data were requested, which suggests that there are several airports along the coast of California which may perform no deicing. Overall, the majority of large airports do deice (6).

Air Transport Association members have indicated that the deicing industry primarily comprises 40 airports and 25 airlines, while American Association of Airport Executives (AAAE) members have stated that approximately 90% of deicing operations are performed at 10% of airports (11). AAAE distributed a questionnaire in 1993 to 340 airports to collect information about deicer usage and aircraft operations. Of the 59 airports that responded to the questionnaire, approximately one-half reported using glycol-based ADFs (11).

EPA did not use the results of the NRDC study to estimate the total number of airports that perform deicing operations because the survey was limited only to the 125 busiest airports, which does not cover all airports that EPA believes perform significant deicing operations. Similarly, EPA did not rely on ATA and AAAE members' assessments of the number of airports performing significant deicing/anti-icing operations because they are not based on statistically valid surveys.

4.3.2 Annual ADF and Pavement Deicer Usage

The volumes of aircraft and pavement deicing/anti-icing fluids or agents used has varied greatly over the past decade. EPA has identified several sources that estimate the amount of aircraft and/or pavement deicer usage. EPA did not consider any one source as correct or absolute. The data presented in this section are informative only and are not necessarily directly comparable. In general, the data show that deicer usage has increased, probably due to the combination of the following factors: 1) deicer usage is highly dependent on weather conditions, which can vary greatly from year to year; 2) deicer users report volumes in different fluid concentrations, which are sometimes incorrectly compared to one another; 3) an airline crash in 1992 heightened awareness of the potential danger associated with ice, which resulted in increased fluid usages for the next several years; and 4) increased usage of anti-icing (i.e., Type II and IV) fluids may have decreased the volume of deicing (i.e., Type I) fluids required.

1992 FAA Survey

In 1992, the FAA conducted a survey of airport deicing/anti-icing operations at U.S. airports to address operational practices and storm water controls at that time. Results of the survey were used to assist airports in complying with the EPA's recently promulgated storm water program (see Section 12.1). Ninety-six airports, representing a wide range of airport sizes and locations, responded to the questionnaire. However, several major airports did not submit a questionnaire and several respondents did not fully answer all questions. Therefore, the data collected from the survey should be considered anecdotal information and not a statistical representation of the industry at that time.

According to the FAA survey, the predominate aircraft ADF used at that time was ethylene glycol; only 24 airports reported using any propylene glycol. Only four airports in the survey reported using anti-icing fluids (Type II) (12).

According to the FAA survey, most airports used urea and/or ethylene glycol for pavement deicing. For airports that reported using ethylene glycol for pavement deicing/anti-icing, volumes ranged from 200 gallons to 187,000 gallons per airport. Twenty-nine airports combined reported using over a total of 800,000 gallons of ethylene glycol as a pavement deicer between 1989 and 1991. For airports that reported the use of urea as a pavement deicer, volumes ranged from 100 pounds to 715 tons per airport. Twenty-seven airports reported a combined total use of over 4,000 tons of urea as a pavement deicer between 1989 and 1991. One airport reported using calcium magnesium acetate (CMA) and another reported using potassium acetate. Several airports noted using UCAR, a pre-mixed solution of ethylene glycol, urea, and water. Propylene glycol was allowed as a runway deicer subsequent to the FAA survey (12).

According to the FAA survey, the average annual volume of ethylene glycol used for aircraft deicing by all respondents between 1989 and 1991 was approximately 2.16 million gallons. Individual airports reported ethylene glycol use for aircraft deicing ranging from 0.6 to 520,000 gallons per year. As expected, the largest volumes were generally associated with the FAA large hubs. For the same time period, only 650,000 gallons of propylene glycol were used with individual airports reporting propylene glycol use ranging from 75 gallons to 250,000 gallons per year. Only a few airports reported using Type II fluids, from 300 to 10,000 gallons per year (12).

<u>1993 AAAE Survey</u>

According the AAAE survey discussed above, most deicer usage reported involved glycol-based ADFs. ADF usage for the 59 airports that responded to the survey ranged from 0 to 1,200,000 gallons per year (Note: AAAE's report did not specify the basis year for glycol usage data). The median glycol usage was 3,650 gallons per year, and the mean was 44,600 gallons per year. AAAE found that seven airports (12% of the respondents) used more than 50,000 gallons of glycol per year; these respondents accounted for 85% of the total glycol used by all respondents. AAAE also found that 44 airports (75% of the respondents) used less than 20,000 gallons of glycol per year; these respondents accounted for only 6% of the total glycol used by all respondents (11).

<u>Other Non-EPA Estimates</u>

Researchers estimate that at least 11 million gallons of concentrated ADF were used at the 20 largest airports in North America during the winter of 1992-1993 (8). Environment Canada has estimated that an average of 14 million gallons of concentrated ADF are used in North America in a typical year (13).

1992 EPA Screener Questionnaire

Based on an analysis of results from EPA's screener questionnaire (see Section 3.1), the Agency estimates that 5.3 million gallons of ADF were used in 1992. Note that the screener questionnaire did not specify whether the reported volume is as concentrated or applied volumes; therefore, these data likely represent multiple dilutions. ADF volumes ranged from 1 gallon per year to 672,393 gallons per year per facility (note that multiple "facilities" (i.e., airlines and FBOs) may operate at a given airport). Ethylene glycol, urea, and sand were the most common pavement deicing agents in 1992. The estimated total volume of liquid pavement deicers used in 1992 was 12,300 gallons, with volumes ranging from 10 to 5,500 gallons per facility. The estimated total volume of solid pavement deicers used in 1992 was 950,000 pounds, with amounts ranging from 20 to 234,544 pounds per facility. Other pavement deicers reported as being used in 1992 include propylene glycol, potassium acetate, CMA, and sodium formate (14).

Post-1993 EPA Deicing Study Data-Collection Activities

EPA used data collected from site visits and mini-questionnaires to estimate ADF usage. The following table summarizes the range of ADF volumes used by fluid type for these airports. Note that there are wide ranges due to differences in climate and severity of weather conditions in the years for which data were requested.

Fluid Type	Range of Volumes Used Per Airport (Gallons/Year)
Type I ethylene glycol-based	3,500 - 700,000(a)
Type II/IV ethylene glycol-based	600 - 180,000
Type I propylene glycol-based	257 - 833,000(a)
Type II/IV propylene glycol-based	2,500 - 143,000

Source: Reference (14).
(a) These volumes are expressed as "concentrated" volumes (i.e., they do not account for water addition).

In general, most U.S. airports reported that both ethylene glycol- and propylene glycol-based fluids are used at their airport; however, several airports reported that only propylene glycol-based fluids are used. The range of applied ADF volumes (after accounting for dilution of Type I fluids) per airport is 514 to 2,134,000 gallons per year (15).

EPA estimates a current annual national ADF applied usage volume of 35 million gallons at 212 facilities based on information collected from EPA's 1999 mini-questionnaires (see Section 3.2) and site visits conducted between 1997 and 1999 (see Section 3.3) and the extrapolation methodology described in Section 11.0. Note that as discussed in Section 11.0, not all ADF applied is discharged.

According to EPA site visits and the mini-questionnaire, the most common pavement deicer is potassium acetate, although several facilities still use urea. Most airports also use sand to help increase friction between aircraft and pavement surfaces. Several airports noted that they recently discontinued the use of urea and/or ethylene glycol due to environmental concerns, such as high biochemical oxygen demand (BOD).

4.4 References

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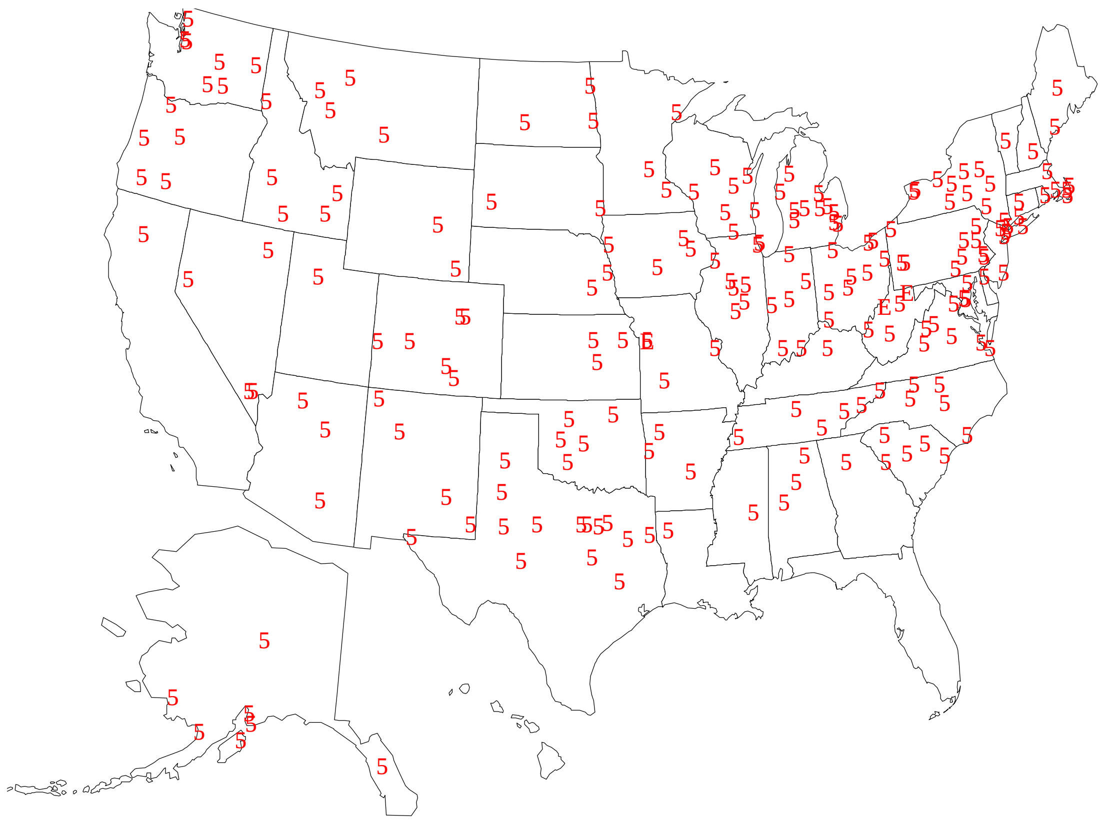

Figure 4-1

Geographic Distribution of Airports with Annual Operations Greater than 10,000 and Mean Annual Snowfall Greater than 1 Inch

5.0 CLIMATIC INFLUENCES AND DEICING/ANTI-ICING AGENT-CONTAMINATED STORM WATER GENERATION AND DISCHARGE

This section discusses the impact that climatic factors such as temperature, precipitation, and humidity (i.e., atmospheric moisture) have on deicing/anti-icing agent usage, which subsequently impacts the amount of contaminated storm water generated and pollutant concentrations discharged. Section 5.1 discusses various types of climatic conditions that result in the need for airport deicing operations. Section 5.2 discusses methods to measure these conditions, and examines each method as a possible indicator of the amount of deicing/anti-icing agents used. Section 5.3 describes EPA's estimate of the total deicing/anti-icing agent-contaminated storm water volume generated, and Section 5.4 discusses discharge of contaminated storm water. Appendix A contains information regarding the location of airports referenced in this section.

5.1 How Climatic Conditions Affect Deicing/Anti-icing Chemical Usage

Most airport deicing/anti-icing operations typically occur due to low temperatures and/or precipitation. Without these environmental factors, significant airport deicing/anti-icing operations would probably not exist. Airports generally use significant volumes of deicing/anti-icing agents because of some form of precipitation (i.e., storm event). While it is true that several airports use deicing/anti-icing agents when there is no precipitation, the volumes of agents used under these conditions are typically very small compared to the volumes used during storm events. In most cases, deicing/anti-icing agents used during nonstorm (i.e., dry-weather deicing) events are retained on or evaporate from the pavement, and do not enter an airport's storm water collection system. Because fluid used during dry-weather deicing is relatively small compared to that during storm events and does not generally generate contaminated storm water, EPA believes the vast majority of contaminated storm water is generated during precipitation events.

Precipitation includes snowfall, rainfall, sleet (including freezing rain), and ice. Each of these conditions affect the volume and type of deicing/anti-icing agents required to adequately prevent ice from forming on aircraft and pavement surfaces. Although there are no specific guidelines for the volume of deicing/anti-icing agents required based on precipitation type, deicing/anti-icing agents are generally used in greatest quantities when the ambient temperature is near or below freezing and there is heavy (or wet) accumulating snow or ice falling or forming on surfaces. In contrast, relatively small volumes of deicing/anti-icing agents are required for dry, powdery snow conditions, which can be removed easily using mostly mechanical methods.

Rain at or near freezing temperatures may also require significant deicing/anti-icing agent usage as a precaution because a slight temperature decrease would result in significant ice or snow formation. Unlike snow, ice strongly adheres to aircraft and pavement surfaces, making it more difficult to remove. Freezing rain is said to require the most deicing/anti-icing agent usage because the rain freezes on contact with the aircraft or pavement surface and coats to form a solid layer of ice.

5.2 Correlating Climatic Conditions to Deicing/Anti-icing Agent Usage

When considering the impact of climatic conditions on deicing operations, EPA evaluated the following four different climatic measures: 1) mean annual snowfall, 2) snowfall duration, 3) mean annual days below freezing, and 4) heating degree days. Each of these measures is described in more detail below, including the advantages and disadvantages of correlating each measure to deicing/anti-icing agent usage.

5.2.1 Mean Annual Snowfall

Mean annual snowfall can be measured in terms of depth of snow or liquid equivalence of snowfall. Depth of snow is a measure of the snow height relative to a ground point that is considered zero depth; it is commonly measured by the National Oceanic and Atmospheric Administration (NOAA) in inches. Liquid equivalence measures snow density and can be used to compare snowfall density in two different regions. Liquid equivalence converts the depth of snowfall in a given region to a liquid volume. For example, if Denver received 12 inches of snow and New York received 4 inches of snow, the amount of snowfall, in terms of liquid equivalence, may be the same if the snowfall in New York were significantly "wetter."

Mean annual snowfall is a good measure of the intensity of precipitation over a deicing season; however, it does not differentiate between an area with 10 5-inch storms and an area with two 25-inch storms. Although both areas have a total of 50 inches of snow per year, the deicing/anti-icing chemical usage at airports in these areas would differ greatly (assuming all other operational factors are equivalent).

EPA believes that mean annual snowfall, in terms of snowfall depth, is the best measure to use when correlating deicing/anti-icing agent usage to weather because these data are readily available for most airports and measure the total amount of precipitation received over a deicing season. Appendix B contains mean annual snowfall data for select U.S. cities and Appendix C contains a contour map of the U.S. in terms of snowfall depth. EPA is aware that there are several other site-specific factors, such as the type of precipitation (e.g., freezing rain versus dry snow), number of operations, aircraft size, and applicator training, that dictate the amount of deicing fluid used.

5.2.2 Snowfall Duration

Duration of snowfall is another potential measure of deicing/anti-icing agent usage. This measure records the time duration of snowfall and may indicate the amount of time for which deicing/anti-icing agents are applied; however, it does not measure snowfall intensity. Atlases typically include snowfall durations.

5.2.3 Mean Annual Days Below Freezing

Another potential measure of deicing/anti-icing agent usage is the mean number of days in a year during which the temperature falls below 32° F. While this measure is a good indicator of how cold the ambient temperature is and the potential for deicing, it does not actually measure precipitation. Therefore, an airport may be in a very cold location with a high number of days below 32° F, but may be in a dry climate and experience very little precipitation. This airport would probably use less deicing/anti-icing agents compared to another airport in a warmer location (on average) with more snow or ice.

5.2.4 Heating Degree Days

The final measure considered by EPA is number of heating degree days per year (an engineering index of heating fuel requirements), calculated by finding a daily mean temperature (calculated from the maximum and minimum temperatures recorded for the day), and subtracting it from 65° F. For example, if the mean temperature for a given day is 40° F, then there are 25 heating degree days associated with that calendar day. If the daily mean temperature is 65° F or greater, then there are zero heating degree days. These data are kept by the National Weather Service, a division of NOAA. However, heating degree days are a measure of temperature, not precipitation, and therefore, may not correlate to deicing/anti-icing agent usage. According to a NOAA representative, the colder the temperature, the less precipitation is likely to occur, such as in Northern Canada, which receives little snowfall even though it is extremely cold (1). Thus, deicing/anti-icing agent usage would be less in very cold, dry areas than in cold, moist areas.

5.3 <u>Volume of Contaminated Storm Water Generated</u>

EPA is not aware of any estimates of the annual volume of storm water contaminated with deicing chemicals that is generated by airports. In fact, the amount of storm water generated by deicing/anti-icing operations can be highly variable from year to year and is difficult to quantify because it is very site- and storm-specific. The volume of storm water generated from deicing operations is a function of precipitation, deicing/anti-icing agent usage, and airport wastewater containment and collection techniques. Even during particular precipitation events, many airports do not know how much deicing/anti-icing agent-contaminated storm water is generated because they are not able to contain all of it. For these airports, contaminated storm water either runs off to grassy areas where it is retained or percolates into the ground. EPA is aware that, to make a more accurate conclusion regarding total storm water generation, more site-specific information including the size and runoff coefficient(s) of the drainage areas and storm water drainage and control structures would be required.

EPA also recognizes that site-specific airport deicing/anti-icing procedures will affect the volume of contaminated wastewater generated. If an airport performs deicing/anti-icing operations only in designated areas, lesser volumes of contaminated wastewater will be generated than at an airport that does not limit deicing/anti-icing operations to a designated area (all other factors being equal). Specifically, the unconstrained airport would generate a greater volume of contaminated wastewater with lower pollutant concentrations. Therefore, EPA recognizes that each airport generates a unique volume of contaminated wastewater.

Other storm water discharges associated with industrial activities at airports include discharges from aircraft fueling, cleaning, and maintenance areas, car rental services, and washing areas. The volume of storm water generated from these other sources is site-specific and may not be commingled with deicing/anti-icing contaminated storm water. For the purposes of this study, EPA did not specifically consider storm water other than that from aircraft and airfield pavement deicing areas.

EPA obtained estimates of collected contaminated wastewater volumes from airports that the Agency visited. Albany International Airport collects between 15 and 25 million gallons of contaminated wastewater per year. Bradley International Airport collected 350,000 gallons of contaminated wastewater in January 1999. Minneapolis-St. Paul International Airport collects approximately 9 million gallons of contaminated wastewater per year.

While EPA recognizes that the volume of contaminated wastewater is unique to each airport and deicing season, estimating a general range of volume of deicing/anti-icing agent-contaminated wastewater generated in the U.S. is important to evaluating past, present, and future pollutant concentrations discharged from deicing/anti-icing operations. For the purposes of this study, EPA estimated the volume of contaminated wastewater using the estimated aircraft deicing/anti-icing fluid (ADF) usage volume (provided in Section 11.1) and the range of glycol concentrations (i.e., ethylene glycol and propylene glycol) in contaminated storm water. Using sampling data provided by the industry and from EPA's data-collection efforts, EPA determined that a nondetect glycol concentration is a reasonable lower bound of expected glycol concentrations. Because airports use different analytical methods with different analytical detection limits, EPA used a common detection limit of 10 mg/L. For the upper bound, EPA used the highest detected glycol concentration from the sampling data, 47,000 mg/L (2). Using this range of glycol concentrations and EPA's estimate of the total annual volume of ADF applied (based on EPA's estimate of the 212 airports with potentially significant deicing operations), EPA estimates that the annual volume of ADF-contaminated storm water generated in any specific year ranges between 300 million and 1.4 trillion gallons per year. Based on a visual inspection of the arrayed sampling data, EPA believes that an average of approximately 7 billion gallons of contaminated storm water is generated per year. (See Section 11.1 for a discussion of pollutant loadings discharged to surface waters.)

5.4 Method of Contaminated Storm Water Discharge

Based on EPA's data-collection activities for this study, airports discharge storm water contaminated with deicing agents either directly to surface waters or both directly to surface waters and indirectly to a POTW. Specifically, EPA identified 11 airports that hold both direct and indirect discharge permits versus 13 airports that hold only direct discharge permits (3). In addition, one airport did not hold a discharge permit (the airport uses evaporation), and one airport holds only an indirect discharge permit. Section 13.2 describes permit conditions.

The choice of utilizing direct, indirect, or a combination of wastewater discharge results largely from airport infrastructure; the choice of best management practices employed at the airport; the stringency of the state NPDES permit; and whether the POTW will accept wastewater from airport deicing operations. Although the discharge of wastewater generated from deicing/anti-icing activities is typically the responsibility of the airport where these activities take place, there are often several other entities involved (e.g., airlines, fixed-based operators (FBOs)). In some cases, airlines and/or FBOs are co-permittees on airport discharge permits. For example, Des Moines International Airport has an NPDES permit with co-permittees. The City of Des Moines is the owner and operator of the airport and acts as the airport's representative and coordinates co-permittee efforts to achieve permit compliance. The co-permittees are tenants of the airport facility, including airline companies, FBOs, military or other government establishments, and other parties that have contracts with the airport authority to conduct business operations on airport property that result in storm water discharges associated with industrial activities (including deicing areas).

5.5 References

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6.0 POLLUTION PREVENTION

EPA's storm water program combined with local environmental issues such as fish kills and odor problems have prompted airports and airlines to investigate a wide range of pollution prevention practices designed to eliminate or minimize the environmental impact of aircraft deicing/anti-icing fluids (ADFs) and airfield pavement deicing/anti-icing chemicals without compromising safety. This section summarizes the pollution prevention practices used by U.S. airports, military bases, and foreign commercial airports, and provides information about pollution prevention methods and technologies currently under development. Practice- or technology-specific costs are provided where available. Additional cost information provided by technology vendors and airports is included in Section 11.2

To date, there are four basic approaches to pollution prevention for aircraft deicing/anti-icing operations: (1) elimination of glycol-based fluids through the development of an environmentally benign alternative fluid; (2) minimization of the volume of fluid applied to aircraft through the development of better fluids, improved application methods, and innovative aircraft deicing technologies; (3) development of collection and disposal strategies that prevent the release of ADF-contaminated wastewater to the environment; and (4) development of glycol recycling methods. Approaches to pollution prevention for airfield pavement deicing/anti-icing operations include: (1) adoption of alternative pavement deicing/anti-icing chemicals that are less harmful to the environment; (2) reduction or elimination of pavement deicing/anti-icing chemicals through the implementation of alternative deicing/anti-icing technologies; and (3) minimization of the amount of agents applied through the use of good maintenance practices, preventive anti-icing techniques, and runway condition monitoring systems. Although each approach is discussed separately, a combination of pollution prevention practices are typically used at U.S. airports. The pollution prevention practices selected by an airport or airline for use at a particular airport often depend on a variety of airport-specific factors, including climate; total amount of chemical deicing and anti-icing agents applied; number of airlines; aircraft fleet mix; number of aircraft operations; costs; presence of existing infrastructure; availability of land; and impact on aircraft departures. EPA recognizes that some of the pollution prevention practices discussed in this section may not be practical or economically feasible for all U.S. airports.

Section 6.1 discusses alternative aircraft deicing/anti-icing agents, and section 6.2 describes aircraft deicing fluid minimization methods. Section 6.3 presents aircraft deicer/anti-icer collection and containment methods. Section 6.4 discusses glycol recycling and Section 6.5 presents pollution prevention practices for airfield parent deicing/anti-icing operations. Appendix A contains information regarding the location of airports referenced in this section.

6.1 Alternative Aircraft Deicing/Anti-Icing Agents

One plausible solution to the environmental problems associated with glycol-based ADFs is their replacement with more environmentally benign products. Despite considerable interest in developing substitute ADFs, little progress has been made. Most of the current research is thought to be in a preliminary stage and it will likely be some time before a suitable replacement is found. Substitute products need to be biodegradable and less toxic than current products, but must also contain compounds that are noncorrosive to aircraft parts. To be economically viable, substitute chemicals must be inexpensive and at least as effective in maintaining air safety as the glycol-based fluids they replace.

The National Aeronautics and Space Administration’s Ames Laboratory in California is attempting to develop effective, non-glycol-based aircraft deicing and anti-icing agents (1). The current status of the project is unknown, but the research is believed to be progressing slowly.

The U.S. Air Force has also expressed interest in finding an environmentally benign substitute for glycol-based ADFs (2). The Air Force Office of Scientific Research is currently funding a number of research projects designed to discover a nontoxic, biodegradable ADF. Many of these projects focus on discovering how naturally occurring antifreeze molecules inhibit ice crystal growth. For example, Professor John Duman at the University of Notre Dame is exploring the structure of antifreeze molecules found in overwintering larvae of the beetle *Dendroides canadensis* to determine how these molecules inhibit ice crystal growth. A similar project directed by Professor Chi-Hing Cheng-DeVries of the University of Illinois is investigating antifreeze molecules found in polar fish. The goal of these projects is to synthesize a naturally occurring compound that can be formulated into an effective, nontoxic, anti-icing agent.

6.2 Aircraft Deicing Fluid Minimization Methods

Since it is unlikely that any new products will be available in the near future, the U.S. Air Force and some domestic carriers have been investigating ways to reduce the volume of ADF used, without compromising safety. The ADF minimization methods described in this section enable pollution to be reduced through source reduction.

6.2.1 Type IV Anti-icing Fluids

Aircraft anti-icing fluids are designed to adhere to aircraft surfaces and prevent ice and snow build-up for set periods of time, known as holdover times. Currently, two types of aircraft anti-icing fluids are used in the United States, Type II and Type IV fluids. Although Type I fluids can provide limited anti-icing protection, they are primarily used for deicing aircraft, are generally applied in much larger volumes, and typically provide less than 15 minutes holdover time. Type II and Type IV fluids are similar to Type I fluids, but contain thickening agents, usually polymers, that provide improved anti-icing properties. The viscosity of anti-icer fluids decreases with wind shear, which enables the fluids to be shed from aircraft surfaces during takeoff. Type IV fluids represent the most recent advances in aircraft anti-icing agents and provide longer holdover times than Type II fluids. Although holdover times vary with weather conditions, the typical holdover time for a Type II fluid is approximately 45 minutes in a light snow. Type IV fluids, however, may provide protection for as long as 70 minutes under the same weather conditions (3). Due to their improved anti-icing capabilities, Type IV fluids have been credited with reducing the amount of deicing fluid used by eliminating repeated deicing and anti-icing of aircraft prior to takeoff (4). Most of the larger U.S. carriers now use Type IV fluids exclusively for anti-icing.

One potential disadvantage of using Type IV fluids is the possibility for increased airfield contamination. Because Type IV fluids adhere to aircraft surfaces, greater use of Type IV fluids may increase the volume of fluid deposited on runways and adjacent grassy areas. Since runways rarely have contaminated storm water collection systems, anti-icing fluids shed from aircraft during takeoff enter the environment and may contaminate soils, groundwater, and nearby streams. Although some components of anti-icing fluids, such as glycols, are easily degraded by microorganisms present in soils, other components, such as tolyltriazoles, are believed to persist in the environment (see Section 10.1.2).

6.2.2 Preventive Anti-icing

Preventive anti-icing is the application of glycol-based anti-icing fluid prior to the start of icing conditions or a storm event to limit ice and snow build-up and facilitate its removal. The principal advantage of this method is an overall reduction in the volume of glycol-based fluids applied to aircraft. Anti-icing fluids are applied in much smaller volumes than their deicing Type I counterparts. A Boeing 727, for example, can be anti-iced using approximately 35 gallons of fluid, whereas deicing requires at least 150 gallons of Type I fluid and may be as much as 2,000 gallons during a severe storm event. To be effective as a preventative, anti-icing fluids must be applied to aircraft prior to the advent of icing conditions or a storm event.

The U.S. Air Force has also experimented with preventive anti-icing techniques and has concluded they can be effective in reducing the volume of fluid applied to aircraft, provided operations personnel carefully coordinate their activities with local weather reports (2). The U.S. Air Force has not implemented widespread use of preventive anti-icing practices due to concerns that anti-icing fluids may degrade aircraft parts, particularly those made from composite materials, when the fluids are left on for extended periods (5).

One drawback to preventive anti-icing is the problem of obtaining accurate weather forecasts containing enough information for operations personnel to make informed decisions. Inaccurate forecasts may result in unnecessary anti-icing. Operations personnel typically rely on local weather stations to provide accurate and timely weather forecasts; however, several U.S. airlines have established meteorological groups, which provide weather forecasts for major destinations. The National Center for Atmospheric Research in Boulder, Colorado, has developed a new weather forecasting system specifically designed for use at airports that provides snowfall forecasts thirty minutes in advance of precipitation. The system is known as Weather Support to Deicing Decision Making (WSDDM) and its development was funded by the Federal Aviation Administration (FAA) (6). Forecasts are based on information collected from surface weather stations, snow-weighing gauges, and Doppler radars located at or near the airport. The information is processed by computers and displayed graphically on video monitors at the airport. During the 1997-1998 winter season, the system was tested by Delta and U.S. Airways at La Guardia airport in New York and by United and American at O'Hare airport in Chicago. In July 1998, the WSDDM system became available commercially from ARINC, a company specializing in aviation communication and air traffic management systems. The system costs approximately $100,000 to install. It is currently in operation at La Guardia airport, where it is used by Delta for managing aircraft deicing/anti-icing and by the New York Port Authority for managing airfield snow removal. Airlines hope this system will provide sufficient storm warning information to perform preventive anti-icing of aircraft prior to the arrival of a storm, enabling airlines to continue to operate safely with less deicing fluid.

Anti-icing fluids are sometimes applied to aircraft to provide overnight protection from frost and storm events. This practice is purported to greatly reduce the volume of Type I fluid needed to remove ice and snow from aircraft surfaces the following morning. For example, a fixed-base operator at one airport reported applying Type IV fluid for overnight protection to one of two aircraft parked side by side. A major snow storm occurred during the night and both aircraft were deiced the next morning using Type I fluid. The aircraft treated with Type IV fluid required 860 gallons of Type I fluid to deice, while the untreated aircraft required 1,820 gallons

(7). Several airlines, however, have expressed concern that anti-icing fluids may dry out and damage aircraft if left on for extended periods (8).

Several U.S. airlines (United, Delta, American, and Midwest Express) have experimented with anti-icing aircraft immediately after landing (1). The intent is to prevent ice and snow build-up while the aircraft is at the gate, and consequently reduce the amount of deicing and anti-icing required before departure. For aircraft with short turn-around times, the protection afforded by preventive anti-icing may even eliminate the need for further deicing prior to departure. Study results indicate this practice saves time and reduces the amount of Type I fluid used during a storm event (1).

6.2.3 Forced-Air Aircraft Deicing Systems

Forced-air aircraft deicing systems have been available for many years, but have not seen widespread application in the United States primarily due to their high cost over conventional deicing systems. The first systems used a high-pressure air jet to blast ice and snow from aircraft surfaces, which has proven to be very effective for removing dry, powdery snow from cold, dry aircraft surfaces. All Nippon Airways, for example, has used forced-air systems for over 20 years to remove overnight accumulations of snow at several northern airports in Japan and believe it removes dry snow faster than using deicing fluids. All Nippon Airways personnel can reportedly remove 5 cm of snow from a passenger jet in about 15 minutes using a forced-air deicing system.

In the past, U.S. carriers were less enthusiastic about forced-air systems because they were not very effective for removing ice and wet snow; conditions that are typical for most U.S. airports. In recent years, however, the development of new hybrid systems, which combine forced-air with fine sprays of heated Type I fluids, have rekindled interest in this technology.

In the early 1990s, FMC Corporation (formerly Aviation Environmental Compliance Inc.) developed a forced-air aircraft deicing system designed to remove snow and ice from aircraft surfaces using a high-pressure air stream combined with a fine spray of glycol-based aircraft deicing fluid. The system is known as the AirFirst Deicing System™ and can be used in an air-only mode for removing light snow and ice. The system consists of a self-contained, truck-mounted unit fitted with a turbine engine and a dual source nozzle. The dual source nozzle allows deicing fluid to be added to the air stream to help remove ice and protect against freezing precipitation (2, 5).

Today, forced-air aircraft deicing systems are also manufactured by Premier, Global, and Vestergaard and are similar to the FMC AirFirst Deicing System™. The Premier system, known as the Hybrid Deicing System™ (HDS), was developed in collaboration with Allied Signal and consists of a centrifugal compressor, an ADF storage tank with heater, a high-pressure fluid pump, and a coaxial nozzle. The coaxial nozzle is designed to emit a high-velocity stream of heated ADF surrounded by a high-velocity air jet. The compressed air exits the nozzle at approximately 750 miles per hour. ADF can be applied at either 9 gpm (7,500 psi) or 20 gpm (3,300 psi), depending on the weather conditions. The unit can also be operated in an air-only mode for removing dry snow. HDS units are currently used by Delta Airlines at General Mitchell International Airport in Milwaukee, Wisconsin, and by the U.S. Navy at the Brunswick Naval Air Station in Maine. For the 1998-1999 deicing season, Delta estimates the HDS unit enabled the airline to reduce the volume of ADF used in Milwaukee by about 85% (9, 10).

The Vestergaard system is mounted on Vestergaard's Elephant Gamma Deicer truck and uses forced air combined with an ADF spray to deice aircraft. The unit supplies forced air at a pressure of 56 psi and can be operated with or without ADF injection. The first Vestergaard forced-air system was purchased by All Nippon Airways last year and is currently used at the Nagano Airport in Japan to remove snow from aircraft parked at the airport overnight.

The Global system, known as AirPlus™, is a self-contained unit weighing approximately 85 pounds that consists of a compressor and two articulated nozzles (one for ADF and the other for forced air). Unlike the other forced-air systems where the compressor is mounted on the truck, the compressor on the Global system is mounted under the operator's seat in the enclosed cab attached to the articulated boom. AirPlus™ can be operated in four different modes: (1) forced air only; (2) forced air with ADF injection; (3) ADF and forced air (supplied by separate nozzles); and (4) ADF only. The forced air exits the forced air nozzle at 725 miles per hour (about 1,350 cfm) with a pressure of 11 psi. ADF can be injected into the air stream at approximately 10 gallons per minute. The second nozzle can provide either heated Type I fluid at 60 gallons per minute or Type IV fluid at 20 gallons per minute. The cargo carrier, Emery Worldwide, tested the unit at Dayton International Airport in Ohio during the 1998-1999 deicing season. For the 1999-2000 deicing season, five AirPlus™ systems will be used by American Airlines at Chicago O'Hare International Airport and two will be used by Skyway Airlines (a division of Midwest Express) at General Mitchell International Airport in Milwaukee. According to Global representatives, the AirPlus™ system can reduce the volume of ADF used by an airline by at least 30 percent.

The forced-air systems cost approximately $250,000. FMC and Global also market retrofit kits for use on existing deicing trucks that cost between $80,000 and $100,000 (2). To date, only a limited number of hybrid forced-air deicing systems have been purchased by U.S. carriers (e.g., Delta, United, American, Northwest, Emery Worldwide, Skyway, and Federal Express). Airlines have been cautious about investing in this new technology for a variety of reasons, the most important being concern the high-velocity air jet will damage aircraft surfaces. When a forced-air system is used to remove ice, airlines are concerned that ice chunks blasted from aircraft surfaces at high velocity will injure ramp personnel or damage aircraft. Many airlines are also worried the forced-air systems will be more expensive to maintain and less reliable than traditional deicer trucks. Some airlines believe that widespread use of forced-air systems will result in higher purchase prices for ADF due to reduced demand. Despite these problems, forced-air deicing systems offer several benefits to the airline industry, including reductions in the volume of fluid purchased, less frequent refilling of deicer trucks, and reduced costs for wastewater disposal.

The principle environmental benefit of the hybrid forced-air deicing systems is their ability to minimize the volume of fluid required to deice aircraft; however, glycol-based anti-icing fluids may still need to be applied in certain weather conditions. While conventional deicing with large volumes of hot Type I fluids provide temporary anti-icing protection by heating the aircraft surface, forced-air deicing systems provide little anti-icing protection. Consequently, the time between completion of deicing and application of anti-icing fluids may be less than with conventional deicer trucks.

The U.S. Air Force has also experimented with forced-air deicing and has developed a system that uses forced hot air to remove snow and ice from aircraft surfaces. The forced hot air is supplied by MA1A compressors, which have been fitted to existing deicer trucks. The forced hot air system does not eliminate glycol-based ADFs, which are typically applied to aircraft after treatment with forced hot air. Nevertheless, it greatly reduces the volume of fluid required to effectively deice aircraft. The forced hot air system is currently in use at several northern Air Force bases (5, 11, 12, 13).

6.2.4 Computer-Controlled Fixed-Gantry Aircraft Deicing Systems

An alternative approach to aircraft deicing are the fixed-gantry systems, which are self-contained “car wash style” aircraft deicing systems. Fixed-gantry systems have been installed at only a few airports worldwide, and, although purported to deice aircraft quickly and efficiently, they have failed to receive widespread approval from the industry. EPA knows of no U.S. airports at which fixed-gantry systems are in use today.

In the typical fixed-gantry system, aircraft taxi onto the gantry pad and nozzles mounted on the gantry frame spray the aircraft with hot deicing fluid. The nozzles are controlled by computers that are programmed to deliver the appropriate amount of fluid uniformly over the entire aircraft for a variety of aircraft types and sizes. The deicing process takes approximately 8 to 12 minutes (5). Runoff is collected either in gutters or trench drains and pumped to storage tanks for treatment, recycling, or disposal (14). Gantry systems are typically located on taxiways near the end of the principal departure runway, reducing the time between aircraft deicing and take-off (3).

Deicing Systems AB (DSAB), based in Kiruna, Sweden, is a leading manufacturer of fixed-gantry deicing systems. DSAB installed its gantry system at the Munich Airport in Germany in 1992 at a cost of approximately $5 million. The system consists of a computer-controlled, movable steel frame fitted with nozzles. The frame passes over the parked aircraft while the computer controls the operation of the nozzles, starting and stopping the flow from each nozzle as appropriate, depending of the type of aircraft. The speed of the gantry can be adjusted to suit prevailing weather conditions. The gantry is 70 meters wide and 21 meters high and can deice aircraft ranging in size from the Fokker 100 to the Boeing 747-400. The Munich system also includes a collection system for spent aircraft deicing fluid. The collected runoff is sent to an on-site glycol recycling facility also operated by DSAB (5).

In addition to Munich, DSAB has installed its gantry system at the Kallax Airport in Lulea, Sweden and the Standford Field Airport in Louisville, Kentucky. United Parcel Service (UPS) purchased the DSAB gantry for its hub operations at Stanford Field Airport in 1988 at a cost of approximately $6 million. The system purchased by UPS was designed to deice Boeing 727s, Boeing 757s and McDonnell Douglas DC-8s (15).

An alternative gantry system, called the Whisper Wash™, has been developed by Catalyst and Chemical Service, Inc. The Whisper Wash™ is a portable deicing system that uses both deicing fluid and high-pressure hot air to deice/anti-ice aircraft. The system consists of adjustable, cantilevered arms mounted on two modified flat-bed trailers. To accommodate different types of aircraft, the height of the arms is adjusted using hydraulic jacks. Each arm supports two sets of nozzles; one set delivers high-pressure hot air while the other delivers low-pressure deicing fluid. The nozzles used to deliver the deicing fluid are specially designed low-shear nozzles, which can be used to apply Type IV fluids as well as Type I fluids. The Whisper Wash™ system can also be operated in an air-only mode to remove light snow. According to the manufacturers, Whisper Wash™ can reduce ADF usage by up to 70% and can deice an aircraft in less time than is required for convention deicing using deicing trucks. Two versions of the system are currently available: a large system capable of handling wide-bodied aircraft and a small system capable of deicing general aviation aircraft and commercial narrow-bodied aircraft. The system costs $1.2 million, with annual maintenance and labor costs of approximately $209,000. The manufacturer also offers an optional ADF-containment system consisting of a perforated pipe installed around the perimeter of the deicing area, which drain to sumps. Currently, no commercial application of the Whisper Wash™ system is known (5,6).

Proponents of the computer-controlled gantry systems assert that these systems: (1) quickly and efficiently deice aircraft using the minimum volume of aircraft deicing fluid, (2) can be operated by personnel with minimum training and experience, and (3) can collect as much as 80% of the deicing fluid sprayed (5). Despite these purported advantages, fixed-gantry systems are not popular with airlines or airport authorities. Airports are reluctant to invest in fixed-gantry systems because they require a relatively large capital investment and require considerable space that cannot be converted to other uses during good weather conditions. Airlines dislike fixed gantries because they can cause bottlenecks and delay aircraft departure. Some users argue that gantry systems actually apply more deicing fluid than necessary because they deice aircraft indiscriminately, including areas that may not require deicing. In addition, gantry systems cannot deice engine inlets, the undercarriage, or the underside of aircraft wings, making it necessary for airlines to perform additional deicing using traditional deicer trucks (5). According to recent reports, dissatisfaction with the performance of their fixed-gantry systems prompted UPS and some European airports to dismantle them.

6.2.5 Infrared Aircraft Deicing Technology

In recent years, a new method of aircraft deicing has been developed that relies on infrared radiation. The leading manufacturers of infrared-based aircraft deicing systems are Radiant Energy Corporation (formerly Process Technologies, Inc.) and Infra-Red Technologies, Inc. Radiant Energy markets a fixed-hangar deicing system known as InfraTek™, while Infra-Red Technologies markets a mobile system known as Ice Cat™. Both systems have the potential to greatly reduce the amount of glycol-based fluids used for aircraft deicing. Neither system is widely used by airlines or airports, although the InfraTek™ system is currently in commercial use at three U.S. airports. A third system, under development by Sun Lase Inc., is designed to use computer-controlled infrared lasers to deice aircraft. Each system is described in detail below.

InfraTek™

InfraTek™ was developed under a Cooperative Research and Development Agreement between Radiant Energy and the FAA. Under the agreement, Radiant Energy developed the system and FAA provided expertise, advice, and test aircraft. A prototype was tested at Rochester International Airport in February 1996. Tests conducted by the FAA in March 1996 demonstrated that the InfraTek™ system could deice a Boeing 727 in six minutes, the approximate time required to deice an aircraft using conventional fluids (17). Additional testing conducted by the FAA and Radiant Energy showed that the infrared radiation did not damage aircraft components. The FAA measured aircraft surface temperatures during deicing and found that they never exceeded 94° F. Based on these results, the FAA approved deicing/anti-icing procedures that use the InfraTek™ system for commercial aircraft in 1997 (18).

The InfraTek™ system consists of an open-ended, hangar-type structure with infrared generators suspended from the ceiling. The infrared generators, called Energy Processing Units (EPUs), are fueled by natural gas. The infrared wavelengths are targeted to heat ice and snow, while minimizing the heating of aircraft components. The energy and wavelength generated by the EPUs can be adjusted to suit aircraft type. The system, operated similarly to a car wash, is controlled by computer and is designed to be operated by one person. Prior to deicing, the hangar floor is heated for 30 minutes to facilitate the melting of ice from aircraft landing gear and the underparts of the wings and fuselage. Once the floor is heated, the system is ready to receive aircraft. Aircraft taxi or are towed into the open-ended hangar immediately before takeoff. Typically, a six-minute cycle is used, which includes two minutes at full EPU power followed by four minutes at half power. The cycle time can be shortened for aircraft covered with a light frost.

Although the system can deice aircraft, it cannot provide anti-icing protection. When the ambient temperature is below freezing, precipitation can rapidly freeze on aircraft surfaces after it leaves the InfraTek™ hangar. Consequently, anti-icing fluid is applied to the aircraft when necessary to protect the aircraft during taxiing and takeoff. In addition, a small volume of deicing fluid may be required to deice areas of the aircraft not reached by the infrared radiation, including the flap tracks and elevators. While the InfraTek™ system does not completely eliminate glycol-based fluids, it greatly reduces the volume required. Radiant Energy estimates that the system reduces the volume of glycol-based deicing fluids applied to aircraft by approximately 90% (19). InfraTek™ is reportedly less effective with snow (as compared to ice), where the crystal structure of the flakes is thought to diffuse and reflect the infrared radiation rather than absorbing it (3). Radiant Energy is, therefore, considering adding blowers to remove loose snow from aircraft surfaces and improve efficiency.

The first commercial InfraTek™ system was installed at Buffalo-Niagara International Airport in March 1997 and is used for deicing general aviation and commuter aircraft. The hangar installed at Buffalo is 42 feet high, 111 feet wide, and 126 feet long and is capable of deicing aircraft as large as the ATR 72. In bad weather, it can deice four or five aircraft per hour (20). Customers are charged a fixed fee based on the size of their aircraft (i.e., wing span and fuselage length), as opposed to conventional deicing using Type I fluids, where charges are based on the volume of fluid applied. Customers prefer the fixed-fee payment structure because it enables them to budget for winter operations more accurately. Due to the success of the InfraTek™ system, Buffalo-Niagara International Airport is considering installing a larger system capable of handling commercial jets and cargo aircraft.

Radiant Energy installed its second commercial InfraTek™ system at the Oneida County Airport in Rhinelander, Wisconsin in February 1998. This system is similar in size to the one installed at Buffalo-Niagara International Airport, but is slightly taller, allowing British Aerospace 146 commuter aircraft to be deiced (21). A third InfraTek™ system has been installed at Newark International Airport by Continental Airlines for use during the 1999-2000 winter. This system is capable of deicing narrow-bodied commercial aircraft as large as the Boeing 737, and will be used primarily by Continental Airlines, although general aviation and other commercial airlines have also expressed interest.

In addition to reducing fluid use, deicing using the InfraTek™ system reportedly costs less than traditional deicing with deicing agents. InfraTek™ reportedly deices a Boeing 727 for under $350, compared with the cost of approximately $5,000 for deicing the same aircraft with glycol-based fluids (2).

Radiant Energy markets several different hangar sizes for the InfraTek™ system. The smallest system is designed to handle small general aviation and corporate aircraft, while the largest system is designed to handle large passenger jets and cargo aircraft. The largest system currently available is 95 feet high, 275 feet wide, and 320 feet long, which can accommodate aircraft as large as the Boeing 747 (19). The capital cost of the InfraTek™ system depends on the size of the hangar and ranges from $1 million to $4 million (5).

The principle disadvantages of the InfraTek™ system are its physical size and aircraft processing capacity. Land-locked airports located in urban areas may have difficulty finding sites for the InfraTek™ system, particularly since the selected site must both comply with FAA regulations and be convenient for aircraft taxiing to active runways. Airlines worry that the system's limited processing capacity will cause bottlenecks, resulting in unnecessary delays. While airport-wide implementation of the InfraTek™ system may be impractical at large airports with heavy traffic volumes, implementation may be practical at smaller airports that do not have congestion problems or by some tenants at larger airports (e.g., commuter airlines, general aviation). Airlines are also concerned about the potential for melted precipitation to refreeze in aerodynamically quiet areas, possibly resulting in the wing flaps and elevators malfunctioning. Although Radiant Energy reports that it has not seen any evidence that refreezing occurs in these areas, the company plans to undertake a test program with APS Aviation, Inc. to study the issue (22).

Ice Cat™

The Ice Cat™ system is a mobile, truck-mounted system that uses infrared radiation to remove frost, ice, and snow from aircraft surfaces. Infrared radiation is provided by an array of flameless infrared emitters (i.e., catalytic heaters) fueled by natural gas, propane, or butane. The infrared emitters are mounted on an articulated boom fitted to a specially designed truck. The boom lifts and positions the infrared emitters approximately 2 to 5 feet above the aircraft surface. Each unit is computer controlled. Depending on the size of the aircraft, one or two Ice Cat™ trucks may be used to deice an aircraft. According to the manufacturer, the deicing process requires approximately 6 to 10 minutes to complete, during which infrared radiation melts ice and snow accumulated on the aircraft and raises the temperature of the aircraft skin. By raising the temperature of the aircraft skin, Ice Cat™ temporarily prevents residual surface water and/or precipitation from freezing on aircraft surfaces. Sensors mounted on the boom monitor the surface temperature of the aircraft to ensure it never exceeds 140° F (23).

Infra-Red Technologies sponsored a demonstration of the Ice Cat™ in November 1997 at Kansas City International Airport where it was used to deice a Beechcraft Queen Air. Further tests were conducted in March 1998 at Kansas City where Ice Cat™ was used to deice a Boeing 727 and at the Pittsburgh National Guard Base where it was used to deice a military KC-135 supertanker. Ice Cat™ has also been tested by Transport Canada using an Air Canada Boeing 737 and Fokker F-428 (23). Infra-Red Technologies has continued to improve Ice Cat™ and recently added a spray system designed to apply a light coating of Type IV (anti-icing) fluid.

Ice Cat™ is reportedly a cost-effective alternative to deicing with traditional glycol-based aircraft deicing agents. According to the manufacturer, Ice-Cat™ can deice a Boeing 737 for as little as $5 (23). The cost of the system is unknown, but is believed to be comparable to that of traditional deicer trucks.

Despite its purported advantages, no commercial application of the Ice Cat™ system is currently known. Although Ice-Cat™ is equipped with temperature sensors, many U.S.

airlines are worried that it may damage aircraft by overheating the aircraft's skin. In addition, the large size of the infrared panels may make Ice-Cat™ difficult to maneuver in the confined space of the gate area. Airlines are concerned about the potential for collisions between Ice-Cat™ and parked aircraft.

<u>Sun Lase Inc.</u>

Sun Lase Inc. is currently developing an infrared laser-based system designed to quickly and efficiently deice aircraft. The system will use a high-power, infrared (i.e., 10-micron wavelength) laser beam to melt ice on aircraft surfaces. The laser beam will be generated by CO_2 lasers and directed at the aircraft surface using mirrors. The mirrors will be controlled by computer, allowing the laser beam to be moved across the aircraft in a predetermined manner. The computer will control the laser alignment and simultaneously monitor the thermal temperature of the aircraft skin. The laser beam will cover a surface area of approximately 1 square meter and deliver an intensity of 2.5 Watts/cm^2. For safety, the laser beam will be combined with red light to enable operators to observe the position of the beam. The lasers can be mounted on a truck or on telescopic poles. The system is designed to be operated by one person. Sun Lase has applied for a U.S. patent and is currently constructing a prototype (24).

6.2.6 Hot Water Aircraft Deicing

The FAA permits aircraft to be deiced using hot water followed by the application of an anti-icing fluid when ambient air temperatures are above 27° F (3). None of the major U.S. airlines currently use this method because they believe it would compromise the safety of passengers and ground operations staff. Airlines are concerned about flash freezing and the potential to build up thick layers of ice both on the aircraft and on the pavement. The water may also enter and freeze on flap tracks, elevators, and other aircraft parts, potentially affecting aircraft handling and performance. Water freezing in hoses, nozzles, and tanks when deicer trucks are not in use is also a concern.

6.2.7 Varying Glycol Content to Ambient Air Temperature

Although Type I fluid can be purchased in a prediluted ready-to-use form, many airlines and fixed-base operators prefer to purchase their Type I fluid in concentrated form (approximately 90% glycol) and dilute to a glycol concentration appropriate to the local weather conditions (13, 25). Some airlines mix Type I fluids specific to each deicing event based on prevailing weather conditions, thereby minimizing the amount of deicing fluid sprayed. For example, Delta Airlines uses a “Local Area Expert,” a person well trained in deicing operations, to determine the glycol concentration appropriate for the prevailing temperature. This practice enables Delta to use Type I fluids containing as little as 30% glycol, rather than the typical 50/50 glycol and water mixture, when weather conditions are mild.

A similar practice is used at Denver International Airport where the airport’s FBO supplies airlines with Type I fluids containing glycol concentrations that are appropriate for the ambient air temperature. The FBO purchases Type I fluid in a concentrated form, stores it in 20,000-gallon storage tanks at the airport’s glycol recycling facility, and mixes it with water in a 10,000-gallon tank equipped with a mixer. The concentrated fluid and water are metered into the mixing tank in the appropriate proportions and a built-in densitometer is used to verify the glycol concentration.

Due to storage problems and concerns about human error, some airlines prefer to mix Type I fluids to meet historical temperature minimums. Northwest Airlines, for example, analyzes historical temperature data for a given airport and selects a glycol content to match the lowest temperature the airport is likely to experience. This practice may result in fewer mistakes and is particularly suited to some smaller airports that lack storage for preparing multiple-strength solutions.

Where possible, the U.S. Air Force also adjusts the glycol concentration of its aircraft deicing fluids based on ambient air temperatures. At some bases, the Air Force uses deicer trucks with two-chamber tanks: one for concentrated aircraft deicing fluid and the other for heated water. The flow rate from each tank can be adjusted to alter the glycol concentration of the fluid as it is applied to aircraft. One disadvantage of the two-chamber deicer trucks is that the water may freeze when the trucks are not in use. This problem caused personnel at some northern bases to remove the baffles and create a single tank in which the deicing fluid can be mixed to meet prevailing or anticipated weather conditions prior to application (13).

6.2.8 Enclosed-Basket Deicing Trucks

Airlines typically use open-basket configurations, called “cherry pickers,” to apply ADF. The open baskets provide little protection for personnel, who are frequently sprayed by aircraft deicing and anti-icing fluids. An enclosed-basket design is now available that improves operator working conditions (2). By enabling operators to get closer to the aircraft, the enclosed basket reportedly reduces over-spray and helps to minimize the volume of fluid used to deice aircraft. As a result, some airlines have reported 30% reductions in aircraft deicing fluid usage. As a result of these benefits, many U.S. airlines now employ a fleet of enclosed-basket deicing trucks at their hubs and larger stations. Several companies manufacture the enclosed-basket deicing trucks, including Simon Aviation Ground Equipment, Elberta Industries, Premeir, and FMC (5).

6.2.9 Mechanical Methods

The volume of ADF applied to aircraft can be minimized by mechanically deicing the aircraft prior to chemical deicing (2). The U.S. Air Force, for example, uses brooms, squeegees, and ropes to remove ice and snow from aircraft surfaces (26, 27). These methods are more effective at removing snow rather than ice. When performed incorrectly, they can damage aircraft antennas and sensors. Mechanical methods are generally only practical for smaller aircraft; for large aircraft, they can be prohibitively time-consuming and labor intensive. Despite these drawbacks, Northwest Airlines uses brooms fitted with long handles to remove snow from large passenger aircraft. This method is used only in the early mornings, when it is least disruptive to Northwest’s departure schedule.

6.2.10 Aircraft Deicing Using Solar Radiation

At several U.S. Air Force bases, aircraft parked on ramps are oriented to maximize the melting of accumulated snow and ice by sunlight. This method reduces the volume of aircraft deicing fluid used during the winter season, but is practical only for general aviation and certain military flights that can be delayed without negative economic or operational impacts (13, 26).

6.2.11 Hangar Storage

Many general aviation aircraft and some commuter and military aircraft are stored in hangars overnight and during storm events, eliminating the need for aircraft deicing. In addition, heated aircraft hangars are sometimes used to deice aircraft. In either case, anti-icing may be necessary in certain weather conditions to prevent ice and snow from accumulating on aircraft surfaces during taxiing and takeoff. After leaving the hangar, aircraft are anti-iced by spraying with a small volume of glycol-based anti-icing fluid (typically 2 gallons for very small aircraft). Because of the small volumes applied, the volume of ADF-contaminated wastewater generated is much less than would have been generated had aircraft been stored outdoors. The Tri-State Airport in Huntington, West Virginia, for example, estimates that their 84-foot-by-120-foot heated aircraft hangar saved approximately 1,500 gallons of Type I fluid last year and estimates that a new 70-foot-by-100-foot heated hangar will save an additional 1,000 gallons of Type I fluid during the 1999-2000 deicing season. Tri-State Airport handles approximately 46,000 operations each year of which approximately 70% are conducted by general aviation aircraft that are easily stored in aircraft hangars.

6.2.12 Aircraft Covers

Where hangar space is not available, aircraft covers or blankets are sometimes used as an alternative method to minimize frost, ice, and snow accumulation on aircraft surfaces (28). Aircraft covers are typically used for small general aviation aircraft to protect the wings, tail, and engine inlets. There are currently two types of covers available: solid and mesh covers.

Solid covers are made from nylon or canvas and should not be used in strong winds. In cold weather, they tend to become hard and freeze to the wings, making them difficult to remove. Mesh covers are made from a very fine mesh fabric and are designed for use in windy conditions. They are easier to remove in cold weather but provide less protection, tending to leave residual ice on wing surfaces (29).

Northwest Airlines experimented with aircraft covers for large passenger aircraft, but was dissatisfied with their performance. Northwest found them to be relatively easy to install, but difficult and time-consuming to remove as they become hard and inflexible when cold. In some instances, condensation trapped between the wing and the cover froze, binding the cover tightly to the wing surface. In addition, covers that came in contact with the pavement picked up grit, which damaged aircraft surfaces as the covers were pulled into place. Based on this experience and the high cost of the covers (approximately $10,000), Northwest concluded that aircraft covers are impractical for use on large passenger aircraft.

6.2.13 Thermal Blankets for MD-80s and DC-9s

The MD-80 and DC-9 aircraft are particularly prone to icing. Fuel stored in tanks located below the aircraft's wings becomes super-cooled during flight. Ice forms on wing surfaces as the aircraft descends and lands, and may form on days when the ambient air temperature is well above freezing. This ice is removed prior to takeoff by applying a small volume of ADF, typically 25 to 50 gallons, in a process known as "clear ice" deicing. Although the volume of fluid used is small, "clear ice" deicing is regularly performed on these aircraft throughout the winter months. Consequently, many airlines operating large fleets of MD-80s and DC-9s are attempting to eliminate the need for "clear ice" deicing by retrofitting these aircraft with specially designed thermal blankets. The blankets are bonded to the wing surface and consist of nickel-plated carbon fibers sandwiched between fiberglass layers. The blankets are manufactured by Allied-Signal Aerospace and cost approximately $35,000 (2). The airlines are pleased with the overall performance of the blankets and believe they significantly reduce the volume of aircraft deicing fluid used for "clear ice" deicing of MD-80s and DC-9s.

6.2.14 Ice-Detection Systems

Pilots and aircraft deicing crews often have difficulty detecting ice on aircraft wings, particularly at night when visibility is poor. Consequently, aircraft are deiced whenever ice is suspected to be present. This conservative approach is appropriate from a safety standpoint, but may lead to unnecessary application of ADFs. One solution is the use of ice-detection systems. Although some ice-detection systems are known to have difficulty detecting ice on painted surfaces and composite materials, most systems improve safety while increasing the efficiency of aircraft deicing/anti-icing operations.

There are currently two types of ice-detection systems available: a remote system and a wing-mounted system. SPAR Aerospace markets a remote detection system developed by Cox and Company. The system is known as the Contamination Detection System™ (CSD-1) and uses an infrared camera to detect ice and evaluate the integrity of anti-icing fluids on aircraft surfaces (4). The camera can be used at distances of 58 feet from the aircraft. The CSD-1 is reported to be capable of detecting clear ice films as thin as 0.01 inches and can detect ice crystals forming in Type IV fluids (25). The system costs approximately $60,000 (5).

Allied-Signal Aerospace has developed a wing-mounted system known as the Clean Wing Detection System™. This system uses sensors mounted in the upper surface of the wing to detect surface contamination. The sensors can identify the type of contamination (e.g., frost, ice, snow, and deicing/anti-icing fluid) and measure its thickness (4). The system is also designed to measure the performance of anti-icing fluids and can determine when additional deicing/anti-icing is warranted. The cost of this system depends on the number of sensors installed and ranges from $50,000 for four sensors to $75,000 for eight sensors (2).

BF Goodrich, a leading manufacturer of in-flight ice detectors, markets a remote detection system, called the IceHawk™ Wide Area Ice Detector, which uses an infrared light beam to detect ice, snow, and frost on aircraft surfaces. The IceHawk™ is designed to detect frozen contamination up to 60 feet from the aircraft and has been approved by the FAA to replace the tactile inspection. The system works by scanning the aircraft surface with a polarized infrared beam. The system analyzes the polarization of the reflected signal and generates an image on a color, LCD monitor. Infrared signals reflected from surfaces contaminated with ice, frost or snow are unpolarized. These areas are displayed on the monitor in red. The system can detect ice covered by deicing and anti-icing fluids and can be used in any lighting or weather conditions without recalibration. The units are portable and may be either handheld or mounted on deicer trucks and are currently being used by Delta Airlines, Federal Express, and the U.S. Air Force. BF Goodrich is also developing an onboard version of the IceHawk™ in which the sensor is installed above a passenger window in the fuselage at a position behind the wing. The company has tested a prototype of the new system on an FAA Boeing 727 last winter and plans to conduct additional testing during the 1999-2000 winter (30).

6.2.15 Airport Traffic Flow Strategies and Departure Slot Allocation Systems

More effective airport management plans and better communication during storm events can help avoid unnecessary repeated application of ADF, particularly at the busier and more congested airports. The FAA recommends that airport management collaborate with the airlines, FBOs, air traffic control, and other interested parties to develop communication procedures and traffic flow strategies for winter operations. Winter traffic flow strategies can identify the shortest taxiing routes and minimize holdover times for deiced aircraft, thereby reducing or eliminating the need for repeated deicing/anti-icing and reducing the amount of fluid used for secondary deicing (31).

Some airports have instituted a departure slot allocation system to reduce delays caused by runway congestion and enable aircraft to depart immediately after being deiced. Using this system, air traffic control estimates the number of departures possible based on the particular weather conditions and assigns departure times (slots) to aircraft before they are deiced. Since the number of departures is normally reduced during snow and ice conditions, the available departure slots are usually allocated to airlines based on their percentage of the total flights scheduled that day. For example, on a typical day, the schedule may have 200 flights, with 70%

of the departures by airline A, 25% by airline B, and 5% by airline C. If the departure rate is reduced to 20 aircraft every hour due to bad weather, then air traffic control will assign 70% of available departure slots (14 slots) to airline A, 25% (5 slots) to airline B, and 5% (1 slot) to airline C. This practice is particularly beneficial at large, congested airports where it enables airline operations personnel to coordinate the deicing of an aircraft with its allocated takeoff time.

One problem encountered by airports using the slot allocation system is the difficulty of enforcing compliance. While most airlines voluntarily comply with the slot allocation system, aircraft from some airlines start taxiing even though they have not been allocated a departure slot. For the slot allocation system to work effectively, air traffic control must police the system by denying errant aircraft takeoff clearance.

Several airlines cancel inbound flights prior to or during severe weather conditions. This traffic flow strategy reduces the volume of fluid used by reducing the number of aircraft requiring deicing. For example, at General Mitchell International Airport in Milwaukee, Wisconsin, some airlines cancel flights and transport passengers by bus to nearby Chicago O’Hare International Airport.

6.2.16 Personnel Training and Experience

An important factor affecting the efficiency of aircraft deicing/anti-icing operations is the training and experience of personnel involved in aircraft deicing/anti-icing. Most airlines and FBOs do not have employees dedicated to aircraft deicing/anti-icing and use ground operations personnel (e.g., baggage handlers, mechanics) or hire temporary staff. Due to low pay and poor working conditions, employee turnover is typically high. Consequently, a large portion of aircraft deicing/anti-icing staff, particularly at larger airports, is newly hired and trained each year. Due to inexperience and concerns about the consequences of inadequate deicing/anti-icing, new hires often spray more fluid than necessary. While the eight hours of FAA-mandated training received by new hires ensures the safe operation of aircraft, several years of experience may be necessary for an employee to become efficient at aircraft deicing/anti-icing. Well-trained and experienced deicing/anti-icing personnel improve the efficiency of aircraft deicing/anti-icing operations and minimize the volume of fluid used, while ensuring passenger safety.

The training and experience of airport personnel may also affect the efficiency of aircraft deicing/anti-icing operations. Airport personnel are typically responsible for clearing taxiways, gate areas, ramps, aprons, and deicing pads. When these areas are not adequately cleared, snow and ice accumulate on the undercarriage and the underside of aircraft during taxing and must be removed prior to takeoff. As a result, poor winter maintenance of airfields tends to increase the volume of aircraft deicing fluids applied by making it necessary to perform secondary aircraft deicing at departure runways.

6.2.17 Other ADF Minimization Practices

Additional sources of ADF discharges to the environment include spills from overfilling deicer truck tanks and leaks from worn or defective fittings on deicer trucks and other application equipment. These sources of ADF can be greatly reduced by equipping deicer trucks with dripless fittings and automatic filling shutoff valves. At Albany International Airport, all deicer trucks are required to be fitted with sight gauges and automatic filling shutoff valves that prevent tanks from being filled above 80% of their capacity. The cost of retrofitting existing deicer trucks was approximately $250 per truck (32).

Unnecessary releases of ADF to the environment can also be reduced by locating ADF storage tanks within the boundaries of the designated aircraft deicing/anti-icing collection and containment areas. At Denver International Airport, for example, deicer trucks are refilled from ADF storage tanks located on the aircraft deicing/anti-icing pads. Since the deicer trucks do not leave the containment area, any spills or leaks from defective fittings or overfilled tanks are collected along with the other ADF-contaminated storm water.

6.2.18 Glycol Minimization Methods Currently Under Development

Foster-Miller, Inc. is developing a surface treatment or coating that would provide anti-icing protection by preventing ice and snow from adhering to aircraft surfaces. Theoretically, this technology combined with the forced-air deicing system discussed in Section 6.2.3 could greatly reduce the need for glycol-based ADFs by enabling snow and ice to be easily blown from aircraft surfaces. Foster-Miller is currently evaluating possible aircraft surface coatings. The project is funded by the Department of Transportation's National Center for Environmental Research and Quality Assurance (33).

Professor Victor Petrenko of Dartmouth's Thayer School of Engineering is developing an alternative deicing technique that uses electricity to loosen ice from aircraft surfaces. The electricity disrupts the orientation of surface water molecules, breaking bonds between the ice crystals and the metal substrate. Similar to the surface coatings discussed above, this method would rely on forced-air to blow snow and ice from aircraft surfaces. To date, the method has only been demonstrated in the laboratory using steel and other solid materials. Additional research will be necessary to determine whether the electrical current used to loosen the ice will interfere with sophisticated aircraft navigational equipment and electrical systems.

Polaris Thermal Energy Systems, Inc., in association with Transport Canada and Continental Airlines, is investigating the possibility of introducing heated fuel in wing fuel tanks to prevent frost, ice, and snow from forming on wing surfaces when the aircraft is on the ground. Polaris believes this method will be especially advantageous for MD-80s and DC-9s, where fuel stored under the wings tends to become super-cooled during flight, causing clear ice to form on the surface of the wings after the aircraft has landed. In preliminary tests conducted by Polaris and Transport Canada, the method has proven effective in minimizing the volume of deicing fluids required. One test, conducted by Polaris in March 1997, demonstrated that the method could, under certain weather conditions, eliminate the use of conventional glycol-based deicing fluids. The test was conducted at Cleveland's Hopkins International Airport using an MD-80 owned by Continental Airlines. The aircraft arrived at the airport at 1:08 a.m. with approximately 8,000 pounds of super-cooled fuel stored in its tanks. Polaris introduced 1,000 pounds of heated fuel (heated to approximately 85° F) into the aircraft's fuel tanks at 2 a.m. Polaris monitored the wing temperature using infrared photography and found the surface temperature rapidly increased by 10° F. Additional heated fuel was added at 2:20 a.m. and 3:00 a.m., raising the average wing surface temperature to 79° F. Although the ambient temperature was about 18° F and a light to heavy snow fell during the early morning hours, the aircraft did not need deicing with conventional fluids prior to its scheduled 7:40 a.m. departure. Polaris estimates the cost of heating the fuel was approximately $40 (34). While this method may reduce discharges of ADF to U.S. surface waters by reducing the overall volume of ADF applied to aircraft, it may result in additional cross-media impacts (e.g., increased air emissions).

6.3 Aircraft Deicer/Anti-icer Collection and Containment Methods

In response to EPA's 1990 storm water program and state and local requirements, many U.S. airports are collecting wastewater from aircraft deicing/anti-icing operations to prevent or minimize discharges at storm water outfalls. Airports use a variety of collection methods, including gate and ramp area drainage collection systems, storm sewer plugs, designated aircraft deicing pads, temporary aircraft deicing pads, storm drain valves, and specially designed glycol-vacuum vehicles. Individual airports often rely on a combination of these collection strategies, varying the collection method to suit tenant requirements, utilize existing infrastructure, or adapt to site-specific constraints. Collected wastewater may then be processed to recycle/recover glycol, treated on site, discharged to a publicly owned treatment works (POTW), or a combination of these methods. The following subsections describe in detail the various wastewater collection methods used by the industry. Federal aid from the FAA-administered Airport Improvement Program may be used to finance construction of wastewater collection systems and storage facilities (35). Funding for this program, however, is limited and deicing/anti-icing wastewater collection projects must compete with other important airport improvement projects, such as resurfacing airport runways, upgrading runway lighting systems, and constructing new taxiways.

6.3.1 Aircraft Deicing Facilities

As airport authorities began to grapple with the problems of collecting wastewater from aircraft deicing operations and meeting NPDES permit limits, they soon realized that wastewater could be collected more efficiently by confining aircraft deicing operations to small, designated areas where provisions for containment and collection could be installed. As a result, several U.S. airports constructed specially designed aircraft deicing facilities called aircraft deicing pads. Denver International Airport, Salt Lake City International Airport, Pittsburgh International Airport, Baltimore Washington International Airport, Dayton International Airport, Minneapolis-St. Paul International Airport, and Detroit Metropolitan Wayne County Airport are currently using deicing pads. In Canada, Toronto's L.B. Pearson International Airport and Montreal's Dorval International Airport have constructed large deicing facilities consisting of multiple deicing pads.

In general, aircraft deicing pads consist of a concrete or asphalt platform, a drainage collection system, and a wastewater storage facility. The platform is graded and sometimes grooved to channel wastewater to the drainage collection system. The collection system typically consists of trench or square drains connected to underground storm water pipes, which are usually fitted with diversion boxes to allow ADF-contaminated wastewater to be diverted to a wastewater storage facility during the deicing season. The wastewater is stored in detention ponds, tanks, or underground concrete basins. The pads are typically designed to accommodate more than one aircraft at a time and are usually divided into individual aircraft deicing bays. Some pads also include snow melters (discussed in Section 6.3.7) for disposal of ADF-contaminated snow collected on and around the deicing pad. The resultant wastewater is collected by the pad's drainage collection system and diverted to the wastewater storage facility.

Aircraft are deiced on the pads using conventional deicer trucks or fixed-boom applicators. To avoid collisions, deicer trucks are parked in designated areas when aircraft are entering or exiting the pad. Fixed-boom applicators are less popular with airlines and are known to be installed at only three aircraft deicing pads in the U.S. (one pad at Denver International

Airport and two pads at Pittsburgh International Airport (20)). When not being used for deicing, the pads often serve as aircraft parking aprons or holding pads.

Since most commercial aircraft are able to taxi prior to deicing and can be deiced with their engines running, aircraft deicing pads may, upon approval by FAA, be located on taxiways, on cargo or general aviation ramps, near departure runways, or adjacent to passenger terminals. The FAA recommends that pads should be constructed to accommodate the largest aircraft the airport serves (i.e., widest wingspan and longest fuselage) and should have sufficient capacity to handle peak periods of aircraft departures without causing departure delays (35). Deicing pads may also require additional personnel for monitoring aircraft movements on the pad and managing wastewater collection. The number, location, and size of aircraft deicing pads required for a particular airport depends on the number of operations, the types of aircraft using the airport, the meteorological conditions typically experienced, the availability of land, and the physical layout of the airport. For some airports, deicing pads may be unnecessary due to efficient ADF-collection systems installed at the passenger terminals and cargo ramps (see Section 6.3.2).

The largest and most technologically advanced aircraft deicing pads are located in Canada at Montreal's Dorval International Airport and Toronto's L.B. Pearson International Airport. These airports have constructed centralized aircraft deicing facilities that include storage tanks and filling stations for aircraft deicing/anti-icing agents and control towers for monitoring deicing operations and controlling traffic flow. The Montreal pad accommodates up to seven aircraft at a time and has a laser guidance system to assist pilots in maneuvering and parking aircraft on the deicing pad (36).

The Toronto pad consists of four deicing bays, but is currently being expanded to six bays. Once the expansion is completed, the deicing facility will be able to accommodate up to six Boeing 747s and will cover an area of 65 acres. Each deicing bay is approximately 328 feet wide and 780 feet long. A high-density polyethylene liner, installed underneath the deicing bays, collects any fluid that seeps through the concrete pad. Inset lighting assists pilots in positioning aircraft on the pad, while surveillance cameras are used to record activities on the pad. An electronic sign board system provides pilots with deicing operational information, minimizing verbal communication requirements. Wastewater from aircraft deicing/anti-icing operations is collected in 14 diversion vaults, which are equipped with automated diversion valves. A pump located in the bottom of each diversion vault pumps samples of the wastewater to a small, on-site laboratory, where the glycol concentration is measured. If the glycol concentration is less than the Canadian voluntary guideline of 100 mg/L (see Section 13.3.1), the wastewater is discharged through the storm water drainage system. If the glycol concentration is greater than 100 mg/L, the operator diverts the wastewater to one of three underground storage tanks. The storage tanks have a combined capacity of approximately 3.5 million gallons. The stored wastewater is either trucked to a glycol recycling plant or discharged to a local POTW (37).

Although the principal environmental advantage of deicing pads is their ability to collect a high percentage of the aircraft deicing fluid sprayed, the wastewater they collect has a high glycol content, an important advantage for airports considering glycol recovery/recycling. For example, at Denver International Airport, aircraft deicing pads collect wastewater with glycol concentrations of approximately 20 percent (20). By collecting wastewater with high glycol concentrations, Denver's aircraft deicing pads make its on-site glycol recycling economically viable.

Aside from their environmental benefits, deicing pads provide several operational and safety advantages. First, they allow aircraft to move away from the gate area so that arriving flights have access to gates. Second, they allow for much more efficient spraying of aircraft, especially for aircraft with wide wing spans, such as the new Boeing 777. Third, they ease ramp and gate area vehicle congestion. Fourth, they improve safety and working conditions for baggage handlers, maintenance engineers, and other airline personnel working in the gate area. Finally, they improve passenger safety by enabling aircraft to be deiced closer to the departure runway, decreasing the time between deicing and takeoff and reducing the potential for an aircraft to exceed its holdover time.

Despite these advantages, some airlines have been reluctant to use aircraft deicing pads. Airlines are primarily concerned that aircraft deicing pads may create a bottleneck, resulting in departure delays. To prevent unnecessary delays, the FAA recommends deicing pads be constructed with bypass taxiways that allow aircraft not requiring deicing to proceed without hindrance to active runways. Airports serving a wide range of aircraft types can often reduce congestion by constructing separate aircraft deicing pads for general aviation, cargo, commuter aircraft, and large passenger jets. For example, Pittsburgh International Airport has constructed five aircraft deicing pads: two for large passenger jets, one for cargo carriers, and two smaller pads for commuter aircraft (20).

Airlines also complain of congestion on aircraft deicing pads caused by the presence of deicer trucks from several different airlines. Currently, most passenger airlines deice their aircraft using their own deicer equipment. The presence of multiple deicer trucks increases the potential for collisions with aircraft or other airport vehicles. This problem can be solved by air carriers allowing their aircraft to be deiced by a single carrier or a fixed-based operator. At Dorval International Airport in Montreal, for example, aircraft deicing/anti-icing is performed exclusively by the airport's FBO, Aeromag 2000. Similarly, aircraft deicing/anti-icing at the L.B. Pearson International Airport's new central deicing facility is conducted by Hudson General Aviation Services, Inc. However, due to liability issues and concerns over equitable access to deicing pads, airlines often have difficulty agreeing on who should provide aircraft deicing services at deicing pads and which fluid formulations should be used. These issues are particularly difficult to resolve at airports that have no dominant carrier and a large number of competing airlines.

Although not limited to aircraft deicing pads, one environmental problem encountered by airports is the tracking of aircraft deicing and anti-icing fluids from the pad onto nearby taxiways and runways. This problem is caused primarily by fluids dripping from aircraft after they have left the deicing pad, but may also be caused by jet blast, drippage from aircraft undercarriages, and the wheels of airport vehicles carrying fluid across the pad's threshold.

For some airports, deicing pads may be impractical due to their physical size and capital and operational costs. The construction costs for aircraft deicing pads vary with the size and complexity of the system. For example, Denver International Airport constructed three deicing pads with drainage collection systems for approximately $2 million per pad (1). Dorval International Airport's pad, complete with storage facilities, new deicer equipment, laser guidance system and control tower, cost approximately $22 million.

6.3.2 ADF Collection Systems for Ramps and Passenger Terminal Gate Areas

At most airports, aircraft deicing operations are performed on aircraft parking ramps or at the passenger terminal gates. To collect wastewater generated at these locations, some airports have installed new collection systems or modified existing storm water drainage systems. The typical collection system consists of graded concrete pavement with trench or square drains connected to a wastewater storage facility via a diversion box. The storage facility may consist of detention ponds (covered or uncovered), tanks, or underground concrete basins. The diversion box allows uncontaminated storm water to be diverted to storm water outfalls.

The construction or modification of drainage collection systems with their associated underground piping, diversion boxes, and storage facilities can be extremely expensive, especially for larger airports that have several passenger terminals and a large number of gates. In addition to the expense, these projects are often disruptive to airline operations. Many U.S. airports already experience delays due to congestion, and temporary gate closures would exacerbate the situation. Similar to deicing pads, ADF may be tracked outside the containment area onto nearby runways and taxiways.

Because of the large drainage area typical of passenger terminals and aircraft parking ramps, large volumes of very dilute wastewater are collected. Airports located in urban areas may not have sufficient land available to construct storage facilities large enough to accommodate the volume of wastewater generated. The relatively low glycol concentrations typical of wastewater collected by these systems make glycol recycling/recovery difficult and expensive; however, low glycol concentrations can be an advantage to airports that discharge their wastewater to a POTW.

The principal advantage of installing ADF collection systems at aircraft parking ramps and passenger terminals is that they enable airports to collect wastewater from aircraft deicing and anti-icing without requiring airlines to alter their winter operating practices. Many airlines believe that deicing and anti-icing aircraft at these locations is an unavoidable part of winter operations, because aircraft can be damaged by taxiing prior to being deiced. For example, aircraft engines may be damaged by ingesting ice shed from aircraft surfaces during taxiing. Aircraft with engines mounted on the rear fuselage, such as the MD-80, are particularly at risk. Consequently, most airports with deicing pads (discussed in Section 6.3.1) allow airlines to conduct some limited gate and ramp deicing. Several U.S. airports, such as Kansas City International, Greater Rockford, Bradley International, Minneapolis-St. Paul International, and Albany International, have installed new collection systems or modified existing storm water drainage systems to enable them to collect ADF-contaminated storm water from these areas. Several example systems are described below. Additional information about ADF collection systems, including the systems used at Dallas-Ft. Worth International and Albany Interntional Airports, is provided in Section 7.1.

Kansas City International Airport, Kansas City, MO (KCI)

Kansas City International Airport is currently constructing a new collection system at its passenger terminals. The new system consists of trench drains strategically located 240 feet from the face of the terminal buildings. Wastewater from aircraft deicing/anti-icing operations combines with small amounts of storm water runoff, enters the trench drains, and is conveyed through underground pipes to a two-celled, concrete storage basin. Due to the large size of the drainage area, the storage basin was constructed with a capacity of 2 million gallons. The collected wastewater is discharged at a controlled rate to a POTW.

Greater Rockford Airport, Rockford, IL (RFD)

At the Greater Rockford Airport in Rockford, Illinois, UPS has constructed an aircraft parking ramp with two separate drainage areas, each with its own collection system. Both drainage collection systems are connected through diversion boxes to the airport's treatment facility and to the airport's storm water outfall on the Rock River. The drainage system on the southern part of the ramp drains approximately 33% of the UPS ramp. During the winter, aircraft deicing/anti-icing operations are typically restricted to the southern part of the ramp. At peak traffic times, such as the Christmas season, UPS can expand the area used for aircraft deicing/anti-icing to the northern part of the ramp by diverting the wastewater from that area to the airport's treatment system (discussed in Section 7.2.1). The treatment system has a combined storage capacity of 21 million gallons.

The separate drainage areas provide UPS with maximum operational flexibility, while also providing the airport with the flexibility needed to efficiently manage the wastewater generated. The principal advantage of this design is that it enables the airport to minimize the dilution of the wastewater during precipitation events by reducing the drainage collection area. Storm water that is not contaminated with ADF is discharged directly to the Rock River.

Bradley International Airport, Windsor Locks, CT (BDL)

Construction plans for a new passenger terminal at Bradley International Airport near Hartford, Connecticut, include two independent drainage collection systems, one for clean storm water and one for ADF-contaminated storm water. Rectangular drains (one for each drainage system) will be installed side by side in the gate areas. During aircraft deicing operations, the clean storm water drains will be closed using drain inserts (discussed in Section 6.3.4) to prevent ADF-contaminated storm water from entering the clean storm water drainage system. Drains for the ADF-contaminated storm water drainage system will be opened, allowing the wastewater to be collected in underground storage tanks. Although the dual drainage system is expensive, airport personnel believe it will be more efficient and require less monitoring than single drainage systems where contaminated storm water tends to remain in storm water pipes long after deicing/anti-icing operations have ceased and be washed out during periods of heavy rainfall.

Minneapolis-St. Paul International Airport, Minneapolis-St. Paul, MN (MSP)

Minneapolis-St. Paul International Airport has avoided the large capital expenditures associated with construction of a new collection system by using existing infrastructure to collect ADF-contaminated storm water. At this airport, storm water pipes located at the passenger terminal are turned into temporary retention systems by inserting specially designed compression plugs. The plugs are installed prior to the beginning of the deicing season and removed in late spring. The contaminated storm water is pumped out periodically and transferred by truck to the airport's detention ponds. Careful management of the retention systems enables the airport to collect enough wastewater with high glycol concentrations to make glycol recycling/recovery economically viable. Inland Technologies, Inc., under a contract with Northwest Airlines, currently operates an on-site glycol recycling/recovery system, which is described in detail in Section 6.4.

6.3.3 Temporary Aircraft Deicing Pads

Temporary aircraft deicing pads are specially designed platforms used to collect contaminated wastewater generated during aircraft deicing and anti-icing operations. They are constructed from reinforced rubber or polypropylene mats and sometimes use inflatable air or foam berms to contain contaminated wastewater. The temporary pads cost less than permanent structures, are portable, and can be assembled on taxiways close to departure runways. Although EPA does not know of any U.S. airports using this collection method, four types of temporary aircraft deicing pads are currently available and are discussed in detail below.

<u>Ro-Mat™</u>

Ro-Mat™ is manufactured by the Danish company A/S Roulunds Fabriker and consists of a thick rubber mat that can tolerate temperatures ranging from -50° C to 50° C. The mat is grooved and reinforced with steel cables. The grooves are designed to channel wastewater to existing drainage systems, such as open trenches or trench drains, located at the sides of the mat. The mat can be placed on an asphalt or concrete taxiway and can be moved if necessary. The Ro-Mat™ costs approximately $22 per square foot (5, 38).

The Ro-Mat™ is currently in use at Copenhagen International Airport in Denmark, where it is located on a taxiway close to the departure runway. The system was installed in 1992 at a cost of approximately $1.6 million, and consists of the Ro-Mat™, a drainage collection system, and wastewater storage tanks. The system is reportedly capable of collecting up to 75% of sprayed aircraft deicing fluid. The glycol concentration of the collected wastewater is relatively high, typically ranging from 25.8% to 32.5% (5, 38).

<u>Latimat™</u>

Environmental Cleaning Systems, Inc. has developed a containment pad system called Latimat™, which consists of a pad with inflatable air or foam berms. The containment pad is portable and can be manufactured in a variety of sizes to meet customer requirements. The largest Latimat™ available can accommodate a Boeing 747 aircraft (39).

<u>Pure Mat™</u>

Recovery Systems, Inc. manufactures a containment system similar to Latimat™ called Pure Mat™. The Pure Mat™ consists of a pump and a chemically resistant mat attached to a flexible berm. The pump transfers wastewater from the containment area to a storage tank for future treatment, recycling, or disposal. The system can be used for either aircraft deicing or washing (5).

Remote Aircraft Wash Platform and Portable Evacuation System™

Aviation Environmental, Inc. manufactures a containment system designed for use as an aircraft deicing pad and wash rack. The system consists of a chemical and sun-resistant polypropylene liner, a foam berm, and an 18-horsepower pump. It can be situated on either concrete or asphalt and is attached to the surface using a batten-bar fastening system made from aluminum. Aircraft enter the containment area by compressing the berm. Collected wastewater is pumped from the containment area to storage tanks. The system is custom-made to meet individual customer requirements (5, 40).

6.3.4 Storm Drain Inserts

Storm drain inserts or plugs are used by some airports to close storm drains and prevent glycol-contaminated wastewater from entering storm water drainage systems. Some airports, such as Minneapolis-St. Paul International Airport, have designed their own inserts, while other airports use manufactured inserts.

One company that manufactures storm drain inserts is AR Plus. This company manufactures inserts that consist of a steel plate with a gate valve, a mounting bracket with sealing mastic, and a detachable valve driver. The inserts are mounted directly beneath the storm drain grate with the steel plate bolted to the mounting bracket. During periods of aircraft deicing/anti-icing, the valves are closed manually using the detachable valve driver, thereby preventing ADF-contaminated storm water from entering the storm water drainage system. The valves can be opened when deicing/anti-icing activities cease, allowing uncontaminated storm water to pass through the drain. The steel plate containing the valve is removed for maintenance by removing the bolts that attach the plate to the mounting bracket (41).

AR Plus manufactures the inserts in standard valve diameters of 6, 8, and 10 inches. The 6-inch valve is the most commonly used. The inserts cost between $1,200 and

$1,800 and have a life expectancy of approximately 7 years. AR Plus also manufacture custom-made inserts for drains of unusual shape or size or to meet individual customer specifications.

Drain inserts are often used in conjunction with glycol vacuum vehicles (discussed in Section 6.3.5) to collect contaminated storm water. To enable the vacuum trucks to efficiently collect fluid retained above the insert, the drain inserts are typically mounted approximately 2 inches below the storm drain grate. Although the inserts may be mounted lower to allow the storm drains to be used as sumps, AR Plus does not recommend this practice because the valves are more difficult to inspect and maintain. In addition, residual ADF retained in the drain after evacuation may be washed into the storm water drainage system when the valve is opened.

The inserts may also be used in an emergency to prevent fuel and other spills from entering storm water drainage systems. The sealant used in the inserts was specially selected for its chemical resistance to both glycol and aviation fuel.

In response to customer comments, AR Plus is currently developing a new system that will automate the valves so that an operator could close or open several valves by pushing a single button.

6.3.5 Glycol Vacuum Vehicles

Specially designed vacuum vehicles provide an alternative approach to the collection of wastewater generated by aircraft deicing/anti-icing operations. Vacuum vehicles offer a number of advantages over traditional collection systems: (1) they are versatile, enabling wastewater to be collected at gate areas, ramps, aircraft parking aprons, taxiways, and aircraft holding pads; (2) they are cost-effective, enabling airports to avoid the high capital costs of installing traditional drainage collection systems or deicing pads; and (3) they can collect spent aircraft deicing fluid in high concentrations, making glycol recovery/recycling economically feasible. Critics of vacuum vehicles state that they are slow moving, have insufficient collection capacity, require regular maintenance by trained personnel, and cause ramp and gate area congestion. Some airports also believe that the airport-wide use of vacuum vehicles is impractical and prohibitively expensive for airports with high traffic volumes because a large number of units would be necessary to efficiently collect the wastewater generated.

Vacuum vehicles are typically used in conjunction with storm drain inserts or valves that prevent ADF-contaminated storm water from entering storm water drainage collection systems. The contaminated storm water ponds around the closed drain grates or surface depressions and vacuum vehicles collect the ponded fluid. Aircraft parking ramps and gate areas must be cleared of snow prior to vacuum vehicle use, since collecting large quantities of clean snow along with contaminated storm water significantly lowers the efficiency of vacuum vehicles.

Several U.S. airports currently use vacuum vehicles, including Minneapolis-St. Paul International Airport, Baltimore Washington International Airport, Indianapolis International Airport, Bradley International Airport, Portland International Airport, Washington Dulles International Airport, Ronald Reagan Washington National Airport, and General Mitchell International Airport. The U.S. Air Force has also experimented with glycol vacuum vehicles and currently uses them at several bases. During deicing operations most military aircraft must be deiced prior to starting their engines; therefore, military aircraft are typically deiced where they are parked. For the military, glycol vacuum vehicles represent a low-cost collection alternative to the installation of expensive underground drainage collection systems for large aircraft parking ramps (5, 42).

Suppliers of specialized glycol vacuum vehicles for the collection of aircraft deicing fluids include Vactor Manufacturing, Tennant, Tymco, and VQuip/AR Plus. Products manufactured by these companies are discussed in detail below.

<u>Vactor Manufacturing</u>

Vactor Manufacturing of Streator, Illinois, has developed a vacuum truck specially designed for glycol collection called the Glycol Recovery Vehicle (GRV™). The GRV™ consists of a front-mounted spray bar and a rear-mounted vacuum pick-up nozzle. A preheated emulsifying agent is applied to pavement surfaces using the spray bar. The emulsifying agent helps to break the cohesion between the deicing fluid and the pavement. The fluid is then vacuumed from the pavement surface by the 8-foot-wide vacuum pick-up nozzle. Once inside the collection chamber, changes in air pressure and differences in density cause the deicing fluid droplets and other debris to fall to the bottom of the chamber. The air stream is passed through a cyclonic separator to remove any fine droplets remaining in the air stream before it is released to the atmosphere (3). GRVs™ cost approximately $262,000.

Three GRVs™ are currently used at Minneapolis-St. Paul International Airport, primarily to collect wastewater from aircraft deicing operations performed at remote locations on the airfield. The GRVs™ are owned by the glycol recycler Inland Technologies, Ltd, but are leased, operated, and maintained by Northwest Airlines. Other airports using GRVs™ include Cincinnati-Northern Kentucky International Airport, Baltimore Washington International Airport, Milwaukee's General Mitchell International Airport, Toronto's L.B. Pearson International Airport, Washington Dulles International Airport, Portland International Airport, Detroit International Airport, Des Moines International Airport, and Ronald Reagan Washington National Airport (beginning winter 1999).

Tennant

Tennant, based in Minneapolis, Minnesota, manufactures pavement scrubbers and street sweepers. The company currently offers two models that are specially adapted for collecting ADF-contaminated wastewater from aircraft deicing operations. Both models are similar in design; however, the smaller model has a collection capacity of 120 gallons, while the larger model has a collection capacity of 510 gallons. Dual high-speed brushes scrub off stains, spills, and dirt, while picking up other debris at the same time. The debris hopper is made of heavy-duty stainless steel. The optional Solution Recovery System on each model allows the operator to scrub for longer periods of time. An optional squeegee attachment is also available for picking up spills. Both units have a cleaning path width of 50 inches. The smaller model costs approximately $57,000, depending on the specifications of the unit, while the larger model costs approximately $89,000. These scrubbers are also used to collect debris and spills during the nondeicing season (43).

Tennant's scrubbers are effective in small- to medium-sized airports. Both Niagara Falls Air Reserve Station in New York and the Groton-New London Airport in Connecticut currently use Tennant scrubbers (5). The Connecticut Department of Transportation first used Tennant scrubbers at Bradley International Airport but found their limited capacity was better suited to the smaller Groton-New London Airport.

Tymco, Inc.

Tymco, based in Waco, Texas, manufactures regenerative air street sweepers that use a high-velocity air jet to blast debris from pavement surfaces. The air is then drawn into a hopper where the air stream loses velocity and the heavier pieces of debris are collected. The top of the hopper is fitted with a screen to prevent light-weight materials, such as paper, from escaping from the hopper. The air stream then enters a centrifugal dust separator before being returned to the compressor. The centrifugal separator removes small particles from the air stream (44).

Tymco manufactures its sweepers in a variety of sizes, the smallest being Model 210, which is designed for use in parking lots. Tymco's largest and most powerful sweeper is Model 600, which is used by airports and the U.S. Air Force to collect debris on runways, aprons, and ramps. Tymco also sells a modified version of this sweeper, equipped with the company's Liquid Recovery System (LRS). The LRS system enables the sweeper to collect fluids from pavement surfaces, including wastewater from aircraft deicing operations. The modified sweeper has a 700-gallon storage capacity and costs approximately $75,000. Tymco also sells retrofit kits that allow existing models to be equipped with an LRS. The kit costs approximately $8,500. Tymco sweepers equipped with the LRS have been used at Indianapolis International Airport and at the Niagara Falls Air Reserve Station in New York. Personnel at Indianapolis International

Airport have reportedly expressed dissatisfaction with the efficiency of the LRS-equipped sweeper, which in their opinion tends to leave a large amount of residual fluid on pavement surfaces. In contrast, personnel at the Niagara Falls Air Reserve Station are reportedly pleased with the performance of their LRS-modified sweepers (5, 44).

AR Plus and VQuip

In the early 1990s, VQuip, in association with AR Plus, developed a vacuum truck specially designed to collect glycol-contaminated wastewater from aircraft deicing/anti-icing activities. A prototype unit was tested at Toronto's L.B. Pearson International Airport in 1992 (45). Unfortunately, this prototype tended to leave behind a residue and had difficulty picking up Type II fluids because of their thickening agents. Based on this experience, VQuip added a higher volume vacuum fan and a spray boom designed to remove residual fluid from pavement surfaces (1).

Today, AR Plus markets two types of VQuip vacuum units: the truck-mounted Ramp Ranger™ and larger trailer-mounted units. Both types are currently in use at Bradley International Airport in Hartford, Connecticut. The truck-mounted Ramp Ranger™ uses a high-pressure water spray, rotating brooms, and a rear-mounted, 8-foot, vacuum nozzle with squeegee to collect contaminated wastewater and other debris. Wastewater is collected in a 875-gallon storage tank mounted on the rear of the truck. Debris is swept into a hopper that has a capacity of 5 cubic yards of material. The Ramp Ranger™ travels at between 2 and 3 miles per hour and has a cleaning width of 120 inches. By using the high-pressure water spray, the Ramp Rangers™ can clean residual ADF from airfield pavements. Tests conducted by VQuip showed that the first pass of the Ramp Ranger™ reduced residual glycol on pavement surfaces to less than 100 mg/L (46).

The trailer-mounted units are towed by closed-cab tractors. These units do not have brooms or a debris hopper, but have a large-capacity collection tank. The original trailer-mounted Ramp Rangers™ were equipped with an 1,800-gallon wastewater storage tank. The

Ramp Ranger™ costs approximately $250,000. AR Plus also rents the units to airports and airlines for approximately $100 to $110 per hour of operation (47).

In response to customer comments, AR Plus and VQuip developed a new high-capacity vacuum unit with a 1,000-gallon-per-minute collection rate and a larger storage tank. The new unit is similar to the trailer-mounted unit described above, but has a 4,000-gallon wastewater storage tank and two self-priming hydraulic pumps located in front of a 12.5-foot vacuum nozzle. To remove residual ADF from pavement surfaces, the new unit is equipped with three independent rotary jets supplied with water from a storage tank mounted on the rear of the tractor. The new unit operates at 2 to 3 miles per hour when water blasting and 5 miles per hour when collecting fluid.

In addition to ADF, the Ramp Ranger™ collects slush and debris from airfield pavements. In previous models, collected slush tended to form a separate layer in the storage tank. To help mix the tank contents and hasten melting of the slush, the new model is equipped with a built-in 100-gallon-per-minute recirculation pump. Debris from airfield pavements is collected in the wastewater storage tank rather than in a separate debris collection hopper. The storage tank is equipped with a discharge pump specially designed for handling fluids containing solids. A rotating blade mounted in front of the pump intake protects the pump from any large pieces of debris.

AR Plus and VQuip successfully completed field trials using a prototype of the high-capacity vacuum unit during the 1998-1999 winter season and began marketing the new model in June 1999. The unit price is approximately $250,000.

6.3.6 Mobile Pumping Station with Fluid Concentration Sensor

AR Plus and VQuip have developed a trailer-mounted, computer-controlled pumping unit capable of measuring the glycol concentration of the wastewater and diverting it, based on glycol content, to one of three designated storage tanks. The unit, called the

Interceptor™, is currently in use at Bradley International Airport in Connecticut and Washington Dulles International Airport in Virginia. The Interceptor™ is particularly useful for airports engaging in glycol recovery/recycling programs.

The Interceptor™ consists of a diesel engine, two pumps, a microprocessor, two refractometers, two temperature probes, three flow meters, and three fluid discharge ports with automated valves. The wastewater enters the unit through two flexible hoses attached to ports at the rear of the unit. The hoses are connected to two submersible, self-priming, hydraulic pumps. The pumps may be used to pump ADF-contaminated wastewater from sumps, tanks, or dammed storm water drainage pipes. Each pump has a capacity of 400 gallons per minute and can be operated independently (47).

After entering the unit, the wastewater passes through a refractometer and temperature probe. The refractometer measurements are used to calculate the glycol concentration of the wastewater. Measurements are made once per second and recorded by the microprocessor. Wastewater temperature is measured continuously by the temperature probe, recorded by the microprocessor, and used for making temperature compensations in calculations of glycol concentration. The microprocessor analyzes the data once every 15 seconds and opens and closes valves to the discharge ports based on the glycol concentration. The unit has three discharge ports, two of which have diameters of 4 inches, while the third has a diameter of 3 inches. The 4-inch discharge ports are used for discharging wastewater with low and medium glycol concentrations. The 3-inch discharge port is used for discharging wastewater with high glycol concentration (typically greater than 15 percent). The glycol concentration ranges for the discharge ports are set by the manufacturer, but can be adjusted to meet customer requirements. Flow meters are used to measure the volume of wastewater discharged through each port.

The Interceptor™ is designed to be operated with minimum operator supervision and has a self-diagnosis system for identifying problems. When problems are encountered, the unit automatically closes all discharge ports, shuts off the unit, and activates a flashing blue beacon located on the top of the unit.

The Interceptor™ can be used for ethylene glycol- or propylene glycol-contaminated wastewater and can measure glycol concentrations between 10,000 ppm and 500,000 ppm with an accuracy of 10,000 ppm. AR Plus and VQuip hope to improve the refractometer so that glycol concentrations of 500 ppm can be detected.

6.3.7 Containment and Collection Practices for Snow Contaminated with Aircraft Deicing/Anti-icing Fluids

U.S. airports that experience heavy snowfalls typically collect snow from aircraft parking ramps and aprons, and transport it to designated collection areas referred to as snow dumps. Because most aircraft deicing/anti-icing operations are conducted at passenger terminals and aircraft parking ramps, snow collected from these locations may be contaminated with ADF, as well as small amounts of pavement deicing/anti-icing agents. Consequently, snow dumps that are used for disposal of contaminated snow should include provisions for collecting or containing the contaminated melt water. At Albany International Airport, for example, two concrete pads, each with its own drainage collection system, are used to store snow contaminated with deicing/anti-icing chemicals. As the snow melts, the melt water flows into the drains and is conveyed to the airport's wastewater storage units (32). A similar system is currently under construction at Buffalo-Niagara International Airport (7). EPA believes that collection of melt water at snow dumps used for ADF-contaminated snow has not yet become common practice.

An alternative approach taken by several North American airports is the use of specially designed, high-performance snow melters. The units may be stationary or portable, and typically consist of a tank which is equipped with a heating system and filled with water. Snow is dumped into the tank using a front-end loader. At Chicago O'Hare International Airport, for example, portable snow melters are strategically positioned at the passenger terminals and cargo aprons so that the snow melt generated drains to the airport's storm water collection system. The snow melters are manufactured by Aero Snow and are powered by jet fuel. Each unit is capable of melting 600 tons of snow per hour. The snow melters cost approximately $14 million each, but can be leased for $6,000 per hour per unit.

A similar system is used at Toronto's L.B. Pearson International Airport, where snow melters manufactured by Trecan Combustion Limited are used to melt ADF-contaminated snow collected from the passenger terminals. Discharge from the snow melters is collected in underground storage tanks (also used for storing wastewater from aircraft deicing/anti-icing operations) and discharged to a local POTW (5, 48). The principal disadvantages associated with snow melters are the air emissions and the operating costs.

6.4 <u>Glycol Recycling</u>

Due to the high biochemical oxygen demand exerted by glycol-based ADFs, many POTWs either refuse to accept ADF-contaminated wastewater from airports or charge high fees for its treatment. To alleviate this problem and meet NPDES permit requirements, several U.S. airports now recover glycol from ADF-contaminated wastewater. Although a variety of on-site treatment systems are available (see Section 7.2), glycol recycling offers airports the additional benefit of offsetting some of their treatment costs by generating revenue from the sale of the recovered glycol.

Recycling systems rely on a series of standard separation techniques to remove water and suspended solids and, in some cases, surfactants, corrosion inhibitors, and other additives from ADF-contaminated wastewater. The typical glycol recycling system is operated as a batch process due to the variation in influent composition. The glycol recycling process generally consists of several steps, which may include filtration, ion exchange, nanofiltration, flocculation, reverse osmosis, evaporation, and distillation. Filtration is the first step in all glycol recycling systems because it removes suspended solids and prevents plugging of subsequent processing units. Once filtered, the wastewater may be passed through a series of ion-exchange columns to remove dissolved solids such as chlorides and sulfates. Nanofiltration and/or flocculation may be used to remove polymer-based additives, such as thickening agents, corrosion inhibitors, and surfactants. Water may be removed using distillation, evaporation, or reverse osmosis. Recycling systems that use distillation to remove water can produce products with glycol concentrations as high as 98 percent. However, because distillation is an energy-intensive separation method, distillation-based recycling systems have relatively high annual operating costs (49). Consequently, several recycling companies have developed less energy-intensive recycling systems that remove water using evaporation, vapor recompression, or reverse osmosis. Typical products from evaporation-based systems contain between 50 and 60% glycol, whereas those from reverse osmosis-based systems contain only about 10% glycol.

Glycol recovery systems also generate process wastewater containing small amounts of glycol and, in some cases, ADF additives. All glycol recovery systems currently in operation in the U.S. discharge their process wastewater to a POTW via a storage tank or detention pond.

Although most recycling systems can successfully recover glycol from ADF-contaminated storm water with glycol concentrations as low as 2.5% (50), airports involved in glycol recycling strive to collect wastewater with the highest possible glycol concentration. ADF-contaminated wastewater with low glycol concentration is segregated from that with high glycol concentration and stored in tanks or ponds. Ponds are sometimes equipped with covers to reduce glycol degradation by sunlight. In situations where the glycol concentration of the collected wastewater is very low, preconcentration techniques, such as reverse osmosis, can be used to increase the glycol concentration. Preconcentration methods, however, must be followed by additional steps and generally have higher capital and operating costs. In addition, reverse osmosis systems are easily fouled and may require considerable maintenance (20).

The first U.S. airport to experiment with glycol recycling was Stapleton Airport in Denver, Colorado. Prior to Stapleton's closure in 1995, Continental Airlines operated an aircraft deicing pad where storm water runoff consistently contained glycol concentrations of more than 20 percent. The runoff from this pad was collected and the glycol recovered for profit, thereby demonstrating the financial feasibility of glycol recycling from aircraft deicing/anti-icing operations. Since that time, interest in glycol recovery has increased, and today on-site recycling of ADF-contaminated wastewater is successfully performed at several U.S. airports, including Denver International Airport, Bradley International Airport, and Minneapolis-St. Paul

International Airport. Some U.S. airports collect a portion of their wastewater from aircraft deicing/anti-icing operations for off-site glycol recycling, including Newark International Airport, Des Moines International Airport, Cleveland Hopkins International Airport, Pittsburgh International Airport, Detroit Wayne County Metropolitan, and Albany International Airport. Salt Lake City International Airport and Washington Dulles International Airport will begin on-site recycling during the 1999-2000 deicing season, while T.F. Green State Airport in Providence, Rhode Island, and General Mitchell International Airport in Milwaukee, Wisconsin, are planning pilot recycling programs for the 1999-2000 deicing season. Buffalo Niagara International Airport in Buffalo, New York, plans to begin an ADF recycling program during the 2000-2001 deicing season.

6.4.1 Glycol Recyclers

There are currently five principal companies providing glycol recycling services for airports and airlines. These include Aircraft Deicing Services, Inc., The Environmental Quality Company, Inland Technologies, Ltd., AR Plus, and Deicing Systems AB. Each company's recycling system is discussed in detail below.

Aircraft Deicing Services, Inc.

Aircraft Deicing Services, Inc. (ADSI) designed and constructed the on-site glycol recycling facility currently in operation at Denver International Airport. The ADSI recycling system uses distillation to remove water from the fluid, but cannot separate mixtures of ethylene glycol and propylene glycol. Consequently, the airport allows airlines to use only propylene glycol-based ADFs.

Denver International Airport collects ADF-contaminated storm water with high glycol concentrations (up to 25%) from aircraft deicing pads. The contaminated wastewater is stored in detention ponds and tanks prior to treatment at the on-site glycol recycling facility. The fluid is preheated using a heat exchanger prior to entering an 8,000-gallon flocculation tank. The fluid is treated with chemicals designed to speed the flocculation of surfactants, wetting agents, corrosion inhibitors, and thickening agents. The flocculation tank is cleaned annually and only trace amounts of residual solids accumulate in the tank. After flocculation, the fluid passes through two additional heat exchangers before entering a series of three packed vacuum distillation towers. Vapor from the distillation towers is condensed in an air-cooled chiller. The condensate, which typically contains about 15 to 40 ppm glycol, is discharged to a holding pond prior to discharge to a POTW. The product, which typically contains approximately 98% propylene glycol, is sold to various secondary markets. The glycol concentration of the product can be varied to meet customer needs. The profits from the sale of the recovered propylene glycol are shared between the City of Denver (who owns and operates the airport) and ADSI.

The facility can process wastewater at a rate of between 7 to 24.5 gpm for influent glycol concentrations above 10 percent. Although wastewater with glycol concentrations above 10% is preferable, this system is capable of treating wastewater with glycol concentrations as low as 2.5 percent. ADSI is also considering investing in additional equipment that would allow treatment of storm water with glycol concentrations as low as 20 ppm. The facility is capable of processing 12 to 15 million gallons of wastewater each year, and recovered 245,000 gallons of recovered propylene glycol during the 1997/1998 deicing season (50).

The Environmental Quality Company

The Environmental Quality Company (EQ) is an environmental management company based in Wayne, Michigan, that assists airports in managing wastewater from aircraft deicing operations. The company currently recycles wastewater collected at Pittsburgh International Airport and the Detroit Wayne County Metropolitan Airport. Wastewater collected at these airports is trucked to Michigan Recovery Systems, Inc., a subsidiary of EQ based in Romulus, Michigan. The plant can produce a 99% pure glycol product, but cannot separate mixtures of propylene glycol and ethylene glycol. The recycling system is operated as a batch process and can process wastewater with glycol concentrations as low as 1 percent. The water is removed using a high-efficiency evaporator followed by distillation. The product is treated with a proprietary polishing process prior to sale. Process wastewater is discharged to a POTW, while solid wastes are disposed of off site as a RCRA nonhazardous waste. The facility processes approximately 5 million gallons of wastewater per year (51).

EQ has also developed a glycol recycling system capable of separating mixtures of ethylene glycol and propylene glycol. In 1997, the company was approached by Salt Lake City Airport Authority to design, construct, and operate a glycol recycling facility at Salt Lake City International Airport. The recycling system was constructed in 1998-1999 and is scheduled to begin operating in January 2000.

The recycling system installed at Salt Lake City International Airport is a two-step process. In the first step, a high-efficiency evaporator will concentrate the glycol to a concentration of approximately 80 percent. In the second step, vacuum distillation will remove additional water and separate ethylene glycol from propylene glycol. The glycol concentration of the influent will be approximately 2%, while the purity of the recovered glycol will be approximately 99 percent. The plant is designed to handle 72,000 gallons of wastewater per day and is expected, based on fluid usage logs and anticipated wastewater capture rates, to operate for about 280 days each year. EQ is responsible for marketing the product, which will be sold to secondary markets. Process wastewater generated by the plant will be held in storage tanks and discharged to the local POTW.

The capital costs for construction of the recycling facility were approximately $4.5 million, of which approximately $1 million was the cost of the distillation column required to separate ethylene glycol and propylene glycol mixtures. In addition to capital costs, the Airport Authority also incurs the plant's annual operating expenses, which are projected to be $760,000. The revenues from sale of ethylene glycol and propylene glycol are estimated to be $460,000 per year, leaving a shortfall of $300,000, which will be covered by an increase in landing fees. The airport's tenants were consulted during the planning and decision-making process and agreed to pay higher landing fees, provided the Airport Authority continued to allow airlines to use both ethylene glycol- and propylene glycol-based ADFs.

Inland Technologies, Ltd.

Inland Technologies, Ltd. (Inland) is a waste management company based in Truro, Nova Scotia, specializing in the disposal and treatment of a wide range of liquid and solid wastes. In 1992, following Environment Canada’s introduction of its 100 mg/L voluntary glycol guideline (discussed in Section 13.3.1), Inland was approached by a number of Canadian airports to dispose of glycol-contaminated wastewater generated during aircraft deicing/anti-icing operations. After considering the available disposal options and evaluating the secondary markets, Inland concluded that glycol recycling could provide a cost-effective means by which Canadian airports could meet the new guideline.

The recycling system developed by Inland removes water from ADF-contaminated wastewater using mechanical vapor recompression. The principal components of the system are a heat exchanger, an evaporation tank, a cyclone, and a steam compressor. The recovery process is monitored and controlled by computer. To conserve energy and improve efficiency, the influent is preheated in a heat exchanger using heat from the hot distillate and recovered product. The influent is then evaporated in the evaporation tank. Following evaporation, the glycol/steam mixture enters the cyclone where steam is separated from the recovered glycol product. The steam is then compressed and used as a heat source for the evaporation tank and heat exchanger. The recovered glycol passes through the heat exchanger before being further purified by proprietary polishing filters. The distillate is typically discharged to a POTW, while the recovered glycol may be sold to secondary markets or reformulated into a Type I fluid (52).

Inland has designed its recycling system to be self-contained and portable. The units are mounted on trailers and are capable of processing 264 gallons of wastewater per hour. The typical influent contains at least 5% glycol, which may be either ethylene glycol or propylene glycol. Because the boiling points of ethylene glycol and propylene glycol are very close, the system cannot separate mixtures of these glycols. The typical recovered product is approximately a 50% glycol and 50% water solution, although the process can achieve concentrations as high as 60% glycol. The distillate (i.e., process wastewater) typically contains 0.5% glycol (25, 52).

Inland's first recycling unit was installed at Montreal's Dorval International Airport in Quebec, Canada in 1996. Inland does not currently recover glycol from spent aircraft deicing fluids collected at Dorval International Airport because the airport is able to inexpensively dispose of wastewater at a nearby wastewater treatment plant. The facility instead recovers glycol from spent aircraft deicing fluids collected at several other Canadian airports (Montreal-Mirabel International Airport, Quebec City Airport, Ottawa International Airport, Thunder Bay Airport, and Winnipeg International Airport) and trucks it to the Dorval facility for recycling. Inland currently operates four skid-mounted processing units at Dorval.

Inland's first U.S.-based glycol recycling facility was installed in the spring of 1997 at the Minneapolis-St. Paul International Airport in Minnesota. At this airport, Inland processes glycol-contaminated storm water from aircraft deicing/anti-icing operations under a contract with Northwest Airlines. Inland charges Northwest a fixed fee for use of the glycol recycling system, while Northwest receives a portion of the revenues from the sale of the recovered product. The fee charged by Inland is based in part on the unit operating costs for the glycol recycling system, which are approximately $0.10 to $0.20 per gallon of recovered product. For the three years that the facility has been operational, the sale of the recovered product has always covered the operating costs. The Minneapolis-St. Paul facility also recovers glycol from spent deicing fluid collected at Des Moines International Airport in Iowa. Approximately 4,000 to 5,000 gallons of ADF-contaminated wastewater is trucked from the Des Moines airport to the recycling facility at the Minneapolis-St. Paul International Airport each winter.

Currently, Inland has glycol recycling facilities at four North American airports (Dorval International Airport in Montreal, L.B. Pearson International Airport in Toronto, Minneapolis-St. Paul International Airport in Minnesota, and Washington Dulles International Airport in Virginia). Inland's Canadian facilities typically recover ethylene glycol, while its facilities at Minneapolis-St. Paul International Airport and Washington Dulles International Airport recover the more profitable propylene glycol. In all cases, Inland personnel operate the glycol recycling system and market the recovered product. Because the demand for pure, concentrated glycol product is generally greater than the demand for its 50% glycol solutions, Inland sells most of its product to Consolidated Recycling based in Troy, Indiana, where it is concentrated and purified using distillation. Inland has also developed a method for producing a reformulated Type I fluid by blending their 50% glycol product with additives such as wetting agents, corrosion inhibitors, and flame retardants. Inland expects to begin marketing its reformulated Type I fluid in the near future.

AR Plus

AR Plus is an aviation focused environmental firm based in Ontario, Canada that collects and recycles aircraft deicing fluid for airlines, and provides assistance to airports in managing wastewater from aircraft deicing operations. AR Plus manages a glycol collection and recycling process at Bradley International Airport in Windsor Locks, Connecticut, as well as several other North American locations.

The recycling system developed by AR Plus uses reverse osmosis to remove water from ADF-contaminated storm water. The system consists of three processing steps: (1) flocculation to remove additives and suspended solids; (2) reverse osmosis to remove water; and (3) microfiltration as a final polishing step. The system installed at Bradley International Airport is capable of processing 20,000 gallons of wastewater per day and is operated as a batch process. The glycol concentration of all wastewater received by the recycling facility is measured using a digital refractometer. This initial analysis enables AR Plus to segregate wastewater based on glycol content. Wastewater with glycol concentrations of less than 10% is processed by the system's two reverse osmosis units, which increase the glycol concentration to between 8 and 10 percent. The type of membrane used in the reverse osmosis units was selected by AR Plus for its ability to resist fouling by polymeric additives and other contaminants found in ADF-contaminated storm water. The membranes are cleaned periodically to enhance operational efficiency. Concentrate from the reverse osmosis units and collected streams with glycol concentrations above 10% are processed through a proprietary process, which removes additional contaminants. The process wastewater from the reverse osmosis units contains less than 100 ppm glycol and is discharged to a POTW.

As part of the sampling program for this study, EPA collected grab samples of the influent to wastewater treatment, effluent from the first reverse osmosis unit, and the process wastewater discharged to the POTW. As shown in the following table, the reverse osmosis treatment system was able to remove most of the pollutants detected in the influent sample, including tolyltriazole. Data provided by AR Plus show that the glycol concentration in the effluent discharged to the POTW ranges from <2 mg/L to 120 mg/L, while the chemical oxygen demand ranges from 30 mg/L to 180 mg/L. The average glycol concentration is approximately 70 mg/L, while the average chemical oxygen demand is approximately 112 mg/L.

Pollutant	Influent to First RO Unit	Effluent from First RO Unit	Effluent to POTW
Propylene Glycol (mg/L)	160,000	8,720	62.7
Ethylene Glycol (mg/L)	3,010	27.0	ND(10)
Tolyltriazole (mg/L)	90	5.9	0.13
Phenol (ug/L)	277	45.9	ND(10)
Total Organic Carbon (mg/L)	35,300	1,320	11.3
Ammonia as Nitrogen (mg/L)	22.7	4.7	0.29
Hexane Extractable Material (mg/L)	173	ND(6)	ND(5)

ND - Not detected (followed by the detection limit).

Although the AR Plus glycol recycling system can process either propylene glycol or ethylene glycol, it cannot separate mixtures of these chemicals. Due to the higher value and greater demand for recovered propylene glycol, AR Plus processes propylene glycol-based ADF at Bradley International Airport. At other locations, however, AR Plus handles storm water contaminated with ethylene glycol-based fluids. The recovered glycol may be sold to secondary markets or reformulated into ADF. AR Plus in association with Octagon Process, Inc. (Octagon), has developed a method for producing a reformulated Type I fluid by blending their glycol product with concentrated propylene glycol and additives (e.g., wetting agents, flame retardants, corrosion inhibitors). AR Plus and Octagon have begun marketing their reformulated fluid to domestic airlines and FBOs. AR Plus charges Bradley International Airport a fee for processing wastewater with glycol concentrations less than 10%, but shares the revenue from the sale of the recovered glycol.

<u>Deicing Systems AB</u>

Deicing Systems AB (DSAB) is a leading European glycol recycler based in Kiruna, Sweden. The company markets a closed aircraft deicing system in which spent ADF is collected from aircraft deicing pads, reprocessed into Type I fluid at an on-site plant, and reapplied to aircraft. DSAB currently operates glycol recycling facilities at the Munich Airport in Germany, the Oslo Airport in Norway, and the Lulea Airport in Sweden (14).

The DSAB system was designed to collect wastewater from aircraft deicing and anti-icing operations with the highest possible glycol concentration by minimizing dilution from precipitation. The system installed at the Munich Airport, for example, collects runoff with an average glycol concentration of 18.6 percent. Once collected, the fluid is passed through filters and cationic and anionic ion exchange columns to remove suspended solids and dissolved salts, respectively. The fluid is then preheated by heat exchangers before entering the facility's two distillation towers. The distillation towers are operated in series, with the resulting process wastewater containing less than 1.5% (15,000 ppm) glycol. The glycol concentration of the product is monitored using a densitometer and typically contains approximately 55% glycol. The product is reformulated on site into a Type I fluid by adding additives such as wetting agents and corrosion inhibitors. The recycling process is controlled and monitored by computer, and DSAB conducts an extensive quality control program to ensure that the reformulated fluids meet the European standards for Type I fluids established by the International Organization for Standardization (i.e., ISO 11075, <u>Aircraft Deicing/Anti-icing Newtonian Fluids ISO Type I</u>) (5, 14). One disadvantage of DSAB's recycling/reformulation process is that it can successfully recycle only Type I fluids. DSAB reportedly experienced problems processing anti-icing fluids, whose polymer-based thickening agents tend to clog filters (5, 14).

DSAB's largest recycling/reformulation facility is located at the Munich Airport and can process 1,320 gallons/hour. The systems installed at the Lulea and Oslo airports are smaller than the Munich system and have capacities of 80 gallons/hour and 530 gallons/hour, respectively. Currently, no North American application of the DSAB recycling/reformulation system is known (49).

6.4.2 Current Uses for Recovered Glycol

Most glycol recovered from aircraft deicing/anti-icing operations is sold to chemical manufacturers for use in other glycol-based products. Recovered propylene glycol is used in several industries, including coatings, paints, and plastics. Recovered ethylene glycol is used primarily as anti-freeze in the automobile and coal industries and as a feedstock in the manufacture of polyester fibers for the garment industry. At some European airports, recovered glycol is reused as an aircraft deicing fluid after the addition of wetting agents and corrosion inhibitors.

In contrast to European practices, recovered glycol is not currently reused for aircraft deicing/anti-icing in the U.S. or Canada. North American airlines have been reluctant to use fluids made from recycled ADF due to safety issues and liability concerns. Despite this reluctance, two Canadian recyclers, Inland and AR Plus, have developed methods that enable recovered glycol to be reformulated at on-site facilities and reused as Type I fluids.

Before the reformulated fluids can be used on aircraft, recyclers must demonstrate that their fluids meet the same aerodynamic, corrosion, and performance standards required for new fluids. These standards are set by The Society for Automotive Engineers (SAE) (see Section 13.5) and, for Type I fluids, can be found in Aerospace Material Specification (AMS) 1424. The certification process involves independent laboratory testing, which is conducted at the Scientific Material International (SMI) laboratory in Miami and the Anti-Icing Materials Laboratory (AMIL) of the University of Quebec in Chicoutimi, Canada. The testing consists of material comparability tests, aerodynamic performance tests, and stability tests.

To date, Inland's reformulated fluid has been independently tested by the AMIL and SMI laboratories. According to Inland, the results show that the reformulated fluid conforms to SAE specifications. Inland plans to conduct trials to ensure that their fluid meets SAE fluid quality standards under field conditions. The company hopes to receive SAE certification for its recycling/reformulation process, which will allow Inland to sell its reformulated fluid without having each batch of fluid independently certified (25, 52).

As mentioned earlier, the AR Plus recycling/reformulation process is a collaborative effort with Octagon, an ADF formulator. AR Plus processes spent ADF in batches and sends a sample of each batch of recovered glycol to Octagon for analysis. Based on the results, Octagon calculates the correct amount of each additive needed to reformulate the fluid to meet SAE Type I specifications. AR Plus blends the recycled glycol with additives and concentrated propylene glycol provided by Octagon to produce a reformulated Type I fluid, a sample of which is sent to Octagon for analysis and certification. The blending process is conducted at the AR Plus on-site recycling facility at Bradley International Airport.

Both Inland and AR Plus expect the reformulation of the recovered glycol into a Type I fluid to greatly improve the profitability of the recycling process, particularly in Canada where use of ethylene glycol-based ADF predominates.

6.4.3 Operational and Economic Issues

Several factors affect the profitability of glycol recycling, including: (1) volume of fluid used; (2) glycol concentration of collected wastewater; (3) frequency of wastewater generation; (4) transportation costs for the wastewater and/or recovered glycol; (5) processing costs; and (6) commercial value of the recovered product. For the recycling process to be profitable, the revenues generated from the sale of the recovered glycol must equal or exceed the costs of collection and recovery. However, because glycol recycling reduces the amount and strength of wastewater, which reduces wastewater disposal costs, recycling may represent a cost-effective method of disposal even when the revenues from the sale of recovered glycol do not offset the costs of collection and recovery. For example, airports with very high POTW discharge costs may benefit from reduced BOD and hydraulic loading surcharges.

One of the most important factors affecting the cost-effectiveness of glycol recycling is the amount of glycol in the wastewater. In general, the higher the glycol concentration of the wastewater, the easier and more cost-effective it is to process. The concentration of glycol in aircraft deicing/anti-icing runoff varies widely and is dependent on the method of collection and prevailing weather conditions. Currently, airports collect wastewater with 5% to 20% glycol concentrations using glycol vacuum vehicles (described in Section 6.3.5), storm drain inserts (described in Section 6.3.4), and/or aircraft deicing pads with drainage collection systems (described in Section 6.3.1). In the early 1990s, wastewater with glycol concentrations above 15% were thought necessary to make glycol recycling economically viable (49). Over the last two to three years, ADF recyclers have improved their processing capabilities, so that today wastewater with glycol concentrations of greater than 5% are generally considered economically feasible to recycle (20).

The value of the recovered glycol depends on the type of glycol and its concentration and purity. The market demand for ethylene glycol is generally lower and more volatile than the demand for propylene glycol. A 50% solution of propylene glycol sells for between \$0.75 and \$1.10 per gallon, while a 50% solution of ethylene glycol sells for between \$0.38 and \$0.68 per gallon. This difference is most likely because the range of industrial uses for ethylene glycol is narrower than that for propylene glycol. Consequently, most recyclers prefer to process propylene glycol-based ADF.

Although 50% glycol solutions can be sold for use as antifreeze in the automotive industry, most other industries require concentrated glycol feedstocks with high purity. As a result, the concentrated product produced by distillation-based recycling systems has a higher value than the 50% glycol solutions produced by reverse osmosis, vapor recompression, and evaporation-based systems. A highly purified propylene glycol product currently sells for between \$2.00 and \$2.50 per gallon.

As mentioned previously, mixtures of ethylene glycol and propylene glycol are difficult and expensive to separate due to the similarity of their boiling points. Recovered product that contains a mixture of propylene glycol and ethylene glycol may be difficult to sell. Mixtures of glycols are typically sold for the same price as recovered ethylene glycol products, even when the percentage of ethylene glycol is low. As a result, most airports and airlines currently recycling ADF either allow only one type of fluid to be used (Denver International Airport and Bradley International Airport) or segregate the waste streams (Minneapolis-St. Paul International Airport). The only exception is Salt Lake City International Airport, where the on-site recycling facility was designed to separate mixtures of ethylene glycol and propylene glycol.

In the past, glycol recycling was considered applicable only for major airports where large volumes of aircraft deicing and anti-icing fluids are sprayed throughout the winter season and which had the capital to invest in large on-site distillation-based systems. Recent developments have shown that on-site recycling can be successful at smaller airports, such as Bradley International Airport. In addition, some small airports have been be able to transport their wastewater to nearby recycling facilities, often with the transportation costs paid for by the recycler. As a result, several U.S. airports are reported to be considering incorporating glycol recycling into their wastewater management plans, including Ronald Reagan Washington National Airport, Dallas-Ft. Worth International Airport, Buffalo Niagara International Airport, and Dayton International Airport. Nevertheless, glycol recycling may not be feasible at all U.S. airports. The volume of fluid used at very small commercial airports and U.S. Air Force bases, for example, may still be insufficient to make recycling economically viable for these facilities (42). Glycol recycling may also be uneconomical for airports located far from secondary glycol markets (e.g., Anchorage International Airport); however, recent developments in the reformulation of recovered product into Type I fluids may make on-site reuse possible.

6.5 Pollution Prevention Practices for Airfield Pavement Deicing/Anti-icing Operations

This section discusses the pollution prevention practices currently in use or under development for airfield pavement deicing/anti-icing operations. These practices include: (1) use of alternative pavement deicing/anti-icing agents; (2) implementation of alternative pavement deicing/anti-icing methods; and (3) adoption of pavement deicing/anti-icing agent minimization practices.

6.5.1 Alternative Airfield Pavement Deicing/Anti-icing Agents

Historically, urea, ethylene glycol, or a combination of the two were the pavement deicing/anti-icing agents most commonly used by U.S. airports for deicing/anti-icing airfield pavements. Propylene glycol was approved by the FAA for runway deicing/anti-icing in October 1990. Although these chemicals are very effective deicing/anti-icing agents, they have long been recognized as having an impact on the environment. This concern led to the development of several alternative pavement deicing/anti-icing products that have low aquatic and mammalian toxicities, biodegrade readily in the environment, and exert lower biochemical oxygen demand than glycol-based products. New products include solid and liquid pavement deicers/anti-icers that contain potassium acetate, sodium acetate, sodium formate, potassium formate, or calcium magnesium acetate (CMA) as the freezing point depressant. The solid pavement deicers/anti-icers are applied using the same mechanical spreaders used for urea, while the liquid deicers/anti-icers are applied using the same spray booms used for glycol-based products.

U.S. airports were initially apprehensive about replacing traditional pavement deicers/anti-icers with the new products because of higher purchase costs and concern that some of these products may contribute to the corrosion of airfield electrical systems (e.g., runway lights). An industry workgroup is currently investigating this issue. Today, many U.S. airports have phased out urea and glycol-based products, most replacing them with potassium acetate-based deicers/anti-icers. The U.S. Air Force, which banned the use of ethylene glycol-based aircraft and pavement deicing/anti-icing products in 1992, now uses potassium acetate, sodium acetate, and sodium formate on runways and taxiways at its bases. Although urea is still widely used both by commercial airports and the U.S. Air Force, several major U.S. airports have recently discontinued its use, including Dayton International Airport, Minneapolis-St. Paul International Airport, Bradley International Airport, Newark International Airport, and Duluth International Airport.

6.5.2 Alternative Airfield Pavement Deicing/Anti-icing Methods

One method for eliminating pavement deicing and anti-icing chemicals is heating the pavement to maintain its temperature above the freezing point of water, thereby preventing ice formation. In addition to the environmental benefits associated with eliminating discharges of potentially harmful chemicals to the environment, heated pavement systems have the potential to improve passenger safety.

The leading manufacturer of heated pavement systems is Superior Graphite Company, a Chicago-based manufacturer of graphite and carbon products. In the early 1990s, this company developed the SNOWFREE™ Heated Pavement System, which uses an electrical current as the heat source. The system includes a base layer consisting of copper cables, installed perpendicular to the runway surface, embedded in a 2-inch thick conductive material composed of a mixture of synthetic graphite and asphalt. The pavement surface consists of a 2-inch layer of asphalt. Electricity passing through the conductive layer generates enough heat to maintain the temperature of the pavement surface slightly above freezing, preventing ice from forming and melting any snow that may accumulate. The system may be used on runways, taxiways, highway bridges, and ramps.

Superior Graphite Company believes the system will be effective at aircraft touchdown points and high-speed turnoffs. The system was tested at the Chicago O'Hare International Airport during the 1994 and 1995 winter seasons, where a prototype was installed on one of the airport's taxiways. The system reportedly performed well with little maintenance required, but was expensive to operate. The cost to heat a 10,000-foot runway is estimated at approximately $3,000 per hour. Installation costs are approximately $15 per square foot. Although the system is expensive to operate, the company believes that these costs are largely offset by savings in deicing/anti-icing chemicals, application equipment, and labor costs. The New Jersey Department of Transportation plans additional tests of the system during the 1999/2000 winter, with an evaluation report published the following summer. No commercial application of the SNOWFREE™ system is currently known (5, 53).

A similar heated pavement system is reportedly being developed by Thermacore, Inc., based in Lancaster, Pennsylvania. The Thermacore system would use heated pipes to maintain the pavement temperature above the freezing point of water. The heating system would be activated automatically by pavement temperature sensors (discussed in Section 6.5.3) installed on the runway. The current status of this project is unknown (54).

Thermal Power Corporation, based in Almont, Michigan, manufactures a truck-mounted pavement heating system called the Heat Master™. The system was initially developed for preheating asphalt pavements for repair work, and consists of a heating panel capable of emitting 120,000 BTUs. The Heat Master™ was tested in 1994 on a runway at a general aviation airport located near Pontiac, Michigan. The test results reportedly show that the unit can melt ice layers as thick as 1.5 inches without damaging the runway surface, painted lines, or in-pavement lights. EPA currently knows of no commercial application of the Heat Master at a U.S. airport (5).

6.5.3 Airfield Pavement Deicing/Anti-icing Minimization Practices

Applying deicing/anti-icing agents in conditions where ice and snow adheres to pavement surfaces is extremely important for the safe operation of aircraft and ultimately for passenger safety. Unnecessary or over-application of pavement deicing/anti-icing agents, however, is not only harmful to the environment but also wasteful of airport resources. This section describes the methods used by U.S. airports to minimize the amount of agents applied to airfield pavements, including: (1) adopting good winter maintenance practices; (2) using preventative anti-icing when icing conditions are forecast; and (3) using runway surface monitoring systems to provide detailed information about runway conditions.

6.5.3.1 Good Winter Maintenance Practices

Airport managers that follow good winter maintenance practices can prevent unnecessary or over-application of pavement deicing/anti-icing chemicals. Good winter maintenance practices for airports are outlined in the FAA Advisory Circular, AC 150/5200-30A, Airport Winter Safety and Operations (31). These practices include:

- Prompt treating of airfield pavements using either mechanical methods (i.e., sweepers, displacement plows, rotary plows) or anti-icing chemicals to prevent strong bonds from forming between the frozen precipitation and the pavement surface;
- Using mechanical methods to remove dry snow from airfield pavements, rather than applying deicing/anti-icing chemicals;
- Applying pavement anti-icing chemicals prior to a storm event or icing conditions, when weather forecasts indicate that ice or snow will bond to pavement surfaces;
- Applying pavement deicing/anti-icing chemicals at rates recommended by the manufacturer;
- Frequently recalibrating chemical and abrasive spreading equipment to ensure an optimal application rate;
- Monitoring weather conditions and obtaining accurate weather forecasts from the National Weather Service or a private contractor;
- Preventing snow from drifting across runways and taxiways by installing snow fences or constructing snow trenches;
- Avoiding heavy applications of sand, which can insulate ice and snow from solar radiation and deicing chemicals;

- Storing solid pavement deicing/anti-icing chemicals in enclosed buildings to prevent product degradation and leaching by storm water; and

- Wetting solid deicing/anti-icing chemicals prior to application to increase their effectiveness and reduce the potential for light-weight particles to be blown off the pavement by strong winds and/or jet blast.

These practices also improve airport safety and minimize delays for airport tenants.

6.5.3.2 Preventive Anti-Icing

By applying pavement anti-icing chemicals, such as aqueous potassium acetate, prior to the onset of freezing conditions or a storm event, airport managers can prevent strong bonds from forming between the pavement surface and ice molecules, enabling snow and ice accumulations to be removed easily using sweepers and plows. The FAA estimates that the correct application of pavement anti-icing chemicals can reduce the overall quantity of pavement deicing and anti-icing agents used at an airport by between 30 and 75 percent (55).

Correctly timing the application of anti-icing chemicals is extremely important. To be effective, anti-icing chemicals should be applied to a clean pavement while the pavement surface temperature is still above freezing. Accurate weather forecasts, combined with pavement surface temperature data, are essential for airport managers to correctly time the application of pavement anti-icing chemicals. Advanced weather forecast systems, such as the Weather Support to Deicing Decision Making system (discussed in Section 6.2.2) and runway surface condition monitoring systems (discussed in Section 6.5.3.3) are particularly useful tools for assisting airport managers with these decisions.

6.5.3.3 Runway Surface Condition Monitoring Systems

One of the best means of preventing unnecessary application of pavement deicing/anti-icing agents is using runway surface condition monitoring systems. These devices measure the pavement temperature and detect surface contamination, such as water, ice, snow, and residual deicing/anti-icing chemicals. The typical system consists of several remote sensors embedded in the runway pavement that collect and transmit data to a control center where the data are processed by computer and displayed on monitors (55).

By enabling airport maintenance staff to continuously monitor runway surface conditions, sensors improve passenger safety and prevent unnecessary application of pavement deicing/anti-icing agents. Maintenance staff can predict freezing conditions by tracking changes in pavement temperature and can apply pavement anti-icing chemicals in a timely manner. At Dallas/Ft. Worth International Airport, for example, runways and taxiway bridges are equipped with temperature sensors, which let airport personnel monitor pavement conditions and apply anti-icing agents before pavement temperatures dip below the freezing point.

Although air temperature can be used to predict the onset of freezing conditions, it is far less reliable than pavement condition sensors. Changes in pavement temperature generally lag behind changes in air temperature and can be affected by other factors, such as humidity, wind velocity, and traffic intensity. Consequently, airports that rely solely on air temperature to decide when and how anti-icing chemicals should be applied may not be using these chemicals effectively and may apply chemicals when they are not needed (31, 55).

The FAA provides guidance to airports considering installing or updating runway monitoring systems in Advisory Circular 150/5220-13B, Runway Surface Condition Sensor Specification Guide (55). In this document, FAA recommends installing remote sensors at three locations on runways: (1) the aircraft touchdown area; (2) the midpoint; and (3) runways exits. Runways that are 3,000 feet in length need at least three sensors; longer runways need additional sensors. The FAA also recommends that sensors be installed on taxiways and aprons (55). In general, the remote sensors are expensive to install and require frequent maintenance by specially trained personnel. The cost of installation depends on the number of sensors and the complexity of the system required. For commercial airports, installing these systems typically costs more than $100,000 (5).

One of the leading manufacturers of pavement condition monitoring systems in the U.S. is Surface Systems, Inc. (SSI), which developed the Road/Runway Weather Information System (RWIS™) for use by highway maintenance agencies and airport authorities. RWIS™ consists of surface condition sensors, atmospheric sensors, subsurface temperature probes, a data processing unit, and display software. Data on current pavement conditions is provided by SSI's FP2000 sensors, which are installed flush with, and colored to match, the pavement surface. The FP2000 sensor measures the pavement temperature and can detect surface water and measure its freezing point, depth, and deicing/anti-icing chemical concentration. Subsurface probes, installed approximately 17 inches below the FP2000 sensors, are used to measure the ground temperature; these data are used to predict future pavement surface temperatures. Atmospheric sensors are installed at the side of the runway and measure air temperature, relative humidity, wind velocity and direction, and the type and rate of precipitation. Data collected by the atmospheric and FP2000 sensors are transmitted to a data processing unit, which evaluates and stores the data at 1-minute intervals. The processed data are displayed graphically on monitors with pavement conditions color-coded. The system can also provide weather forecasts that predict pavement conditions up to 24 hours in advance. These forecasts are derived by evaluating data provided by the National Weather Service and SSI's remote sensors. SSI sensors are currently used at St. Louis' Lambert International Airport in Missouri, Springfield's Capital Airport in Illinois, Albuquerque International Airport in New Mexico, Ft. Wayne Airport in Indiana, Akron/Canton Regional Airport in Ohio, and Cincinnati/Northern Kentucky International Airport in Kentucky (56).

A similar system, called ICELERT™, has been developed by Findlay Irvine and is currently used at commercial airports, military bases, and on highways in Finland, Austria, Canada, Spain, Italy, Hungary, Britain, and Ireland. ICELERT™ is a surface condition monitoring system that uses information from pavement surface sensors, ground temperature probes, and atmospheric sensors to predict icing conditions. ICELERT™'s sensors measure pavement surface temperature, concentration of deicing/anti-icing chemicals in surface water, ambient air temperature, barometric pressure, dew point, wind velocity and direction, and precipitation. The system uses these data together with information from local meteorological agencies to provide 24-hour forecasts of pavement conditions (57).

The principal disadvantage of these systems is the high capital and operating costs associated with installing and maintaining the remote sensors. These costs can be avoided by using portable sensors, mounted on airport maintenance vehicles. These devices use infrared-based technology to measure the pavement temperature and display the results on a monitor or gauge mounted on the vehicle dashboard. Companies currently manufacturing portable pavement temperature sensors include Sprague Heavy Duty Technology Group and Control Products, Inc. The portable sensors cost between $2,500 and $2,700, and are used at some U.S. Air Force bases (5).

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7.0 WASTEWATER CONTAINMENT AND TREATMENT

Many airports have installed wastewater containment and treatment systems, often in combination with pollution prevention controls described in Section 6.0, to comply with discharge requirements for storm water contaminated with deicing agents. This section describes the types of containment and treatment technologies used by airports and available treatment performance data for these technologies. Table 7-1, at the end of this section, summarizes the airport systems described in this section; costs for these systems are included in Section 11.0. Note that the glycol recycling systems described in Section 6.4 also serve as “wastewater treatment” in that they remove glycol and other pollutants of concern from airport deicing/anti-icing fluids (ADF)-contaminated wastewater. Appendix A contains information regarding the location of airports referenced in this section.

7.1 Wastewater Containment

Of significant concern for contaminated storm water discharges, both directly to surface waters and indirectly to publicly owned treatment works (POTWs), is the high variability and unpredictability in hydraulic and pollutant loading. Airports have large impervious areas for gates, aprons, ramps, taxiways, runways, roads, and parking lots, which contribute to hydraulic loading. Major winter storms can require application of large amounts of aircraft and pavement deicing chemicals within a short period of time that can result in a “slug” loading of these chemicals in storm water discharges. To help mitigate storm water flow variability and slug discharges, many airports have constructed storm water containment systems either as part of the original airport design or in response to more recent storm water discharge requirements. Common types of storm water containment at airports are retention ponds, underground storage basins, and storage tanks.

The cost of these structures and their associated drainage systems is directly proportional to the size of the area serviced by the system and the volume of precipitation expected. As a result, at most airports, these systems service only those areas where aircraft deicing operations are performed. Furthermore, many airports also incorporate diversion devices (e.g., valves and gates) such that deicing operation areas are only serviced when glycol or a surrogate parameter is detected in storm water, which further reduces the size and cost of the containment system. EPA identified several airports that use containment systems to control discharges of ADF-contaminated wastewater to surface waters and POTWs (described below), and believes other airports may have constructed containment systems.

Runoff from runways and other large paved areas are generally discharged without treatment because of the high cost of controls. However, discharges from these areas may contain high pollutant loadings. For example, during a 1998 conference and exposition sponsored by the American Association of Airline Executives and the Airport Council International - North America, a consultant working for Portland International Airport indicated that runway deicing operations contributed one-third of total deicing-derived biochemical oxygen demand (BOD) discharges to surface waters. Although many airports have stopped using glycol-based chemicals for pavement deicing, their increased use of Type IV deicing fluids, designed to shear from aircraft surfaces during takeoff, may contribute to pollutant loadings discharged from runway areas. EPA currently knows of only one U.S. airport, Chicago’s O’Hare International Airport, and two European airports, Munich Airport in Germany and Stockholm-Arlanda Airport in Sweden, that collect a portion or all of the contaminated storm water from runways and taxiways. Airport wastewater containment systems are also described below.

Portland International Airport, Portland, OR (PDX)

Currently, ADF-contaminated wastewater from the gate areas is discharged directly to the Columbia Slough via nine major outfalls. The Columbia Slough flows to the Willamette River (1).

A long-term plan being developed jointly between the airport and the airlines, in accordance with a NPDES permit issued by the Oregon DEQ, includes an airport-wide deicing runoff containment system. The system will use in-line BOD meters to monitor glycol concentrations in runoff. Higher-strength ADF-contaminated wastewater collected near the terminal areas will be conveyed to storage tanks followed by controlled discharge to a POTW. Lower strength wastewater will be diverted to a 13-million-gallon, aerated retention pond for biological pretreatment prior to controlled discharged to the Columbia Slough in compliance with the waste load allocations for BOD_5 specified in the Columbia Slough TMDL. See Section 13.2.2 for a description of Portland's TMDL-based permit (1, 2).

Billings Logan International Airport, Billings, MT (BIL)

Storm water contaminated with ADF enters the storm drain system that flows to four detention ponds operated in series. Storm water enters the first pond, which overflows to the second pond, and so forth. Overflow from the fourth pond is discharged to a nearby creek. In general, the first pond is large enough to contain all glycol-contaminated wastewater generated during the winter. Spring precipitation then usually fills all four ponds, resulting in the eventual discharge of the collected glycol-contaminated wastewater. Airport personnel indicated that most of the glycol has biodegraded in the ponds prior to discharge.

Chicago O'Hare International Airport, Chicago, IL (ORD)

Deicing/anti-icing fluids from all of the aircraft deicing/anti-icing areas and 50% to 70% of the pavement enter Chicago O'Hare International Airport's storm water drainage systems and are collected and retained in one of the airport's two storm water detention ponds, the South Detention Pond and the North Airfield Detention Pond. The South Detention Pond has a capacity of approximately 1,120 acre-feet and services the southern part of the airfield, which includes wastewater from aircraft deicing/anti-icing operations conducted at the airport's passenger terminals and cargo ramps. The Northern Detention Pond has a capacity of 45 acre-feet and services an aircraft deicing pad storm water drainage system. Both ponds discharge at a controlled rate to local POTWs. Total wastewater discharge fees range from $800,000 to $1 million per year and are based on the volume of wastewater treated, BOD_5, and suspended solid loadings.

Contaminated storm water from the northern part of the airfield, including portions of two runways and their associated taxiways, drains into nearby creeks. Airport managers are working on plans to construct a storm drainage system around these runways and taxiways, which will collect the contaminated storm water and convey it through underground pipes to a detention pond for eventual discharge to a POTW.

Minneapolis-St. Paul International Airport, Minneapolis, MN (MSP)

Minneapolis-St. Paul International Airport uses compression plugs in their storm water system (discussed in Section 6.3.2) to collect ADF-contaminated wastewater for subsequent glycol recycling/recovery. The airport estimates that more than 40% of all fluid applied is collected in the storm water retention system. However, some collected wastewater is too dilute for economically viable glycol recycling/recovery. Dilute wastewater is evacuated as needed using pump trucks and transported to one of two 1-million-gallon, nonaerated storage ponds dedicated for lower strength wastewater. (Three ponds and associated equipment, including a boiler and recirculation system to protect against pond freezing, were constructed in 1993 at a cost of $1 million.) The ponds are alternately filled and then slowly discharged to the POTW. On average, the low-strength ponds contain wastewater with propylene glycol concentrations of 2 percent. Wastewater discharge fees include $0.056 per pound of chemical oxygen demand (COD) for concentrations greater than 500 mg/L, as well as sewerage fees assessed by wastewater volume, for a total annual cost ranging from $150,000 to $200,000.

Dallas/Ft. Worth International Airport, Dallas, TX (DFW)

In 1999, the Dallas/Ft. Worth International Airport constructed nine deicing pads at a cost of over $16 million for deicing/anti-icing operations with a total of 53 aircraft positions. The airport is now able to collect and contain all ADF runoff generated on these pads. The deicing pads are strategically located around the airport near both runway thresholds and terminal egress taxiways. All pads are common use facilities, and each airline is free to select the pad that best suits its needs. Operational experience has shown that the airlines primarily use the threshold pads during intense periods of deicing.

When deicing/anti-icing activities are occurring, the runoff from the pads is directed to collection tanks located at each deicing pad. The collection tanks have a combined volume of over 1.5 million gallons and can be emptied by tank trucks within 24 hours. Precipitation and runoff from the pads immediately after deicing is also collected to ensure that no residual deicing fluid remains.

The airport has contracted the collection of deicing runoff to Inland Technologies. Inland is obligated to pick up by tank truck all fluid collected in the collection tanks. Depending on the concentration of the runoff, or their system capacity, Inland may either recycle, biologically treat on site, or ship off site the fluid they collect. For biological treatment, Inland will use the airport's detention ponds which were constructed in 1997 at a cost of $1.7 million. The ponds are covered and lined with membranes. The combined capacity of the detection ponds is 6 million gallons. Following biological treatment, the fluid may be discharged to the POTW, which requires the wastewater to have a BOD_5 of less than 250 mg/L. The POTW charges a hydraulic loading fee of $1.07/1,000 gallons.

Following completion of deicing/anti-icing operations, the airport ensures that any ADF runoff remaining on the pads is removed prior to directing runoff to the airport's pretreatment system. This system is specially designed to collect "first flush" precipitation contaminated with oil and grease from spills on ramps and gate areas. Specifically, storm water enters drains and flows to diversion boxes that each contain an inflow pipe and two outflow pipes positioned one above the other. The lower outfall pipes drain to the airport's pretreatment plant. The upper outfall pipes discharge to the airport's general storm water collection system and ultimately to U.S. surface waters during periods of high storm flow (3).

Denver International Airport, Denver, CO (DIA)

At Denver International Airport, aircraft deicing operations are performed primarily at specially designed deicing pads (discussed in Section 6.3.1) where large volumes of high concentration ADF-contaminated wastewater are collected for glycol recycling/recovery. In addition, limited aircraft deicing is performed in the gate areas. Airport personnel estimate that approximately 70% of all ADF applied at the deicing pads and gate areas is subsequently collected. Runoff from the gates flows by gravity to the east and west detention ponds, which have a combined capacity of 12 million gallons. The ponds are a component of a large wastewater collection system project constructed in 1995 at a total cost of $36 million. (Airport construction was completed in 1994, and airfield operations began in 1995.) One of the ponds is separated into two cells. When the first cell is full, the wastewater is pumped to the second cell, where it is mixed for 12 hours to homogenize the wastewater prior to discharge. Since the other pond has only one cell, this pond is not mixed prior to discharge. The wastewater from each pond is tested to determine its characteristics and discharged at a controlled rate to the POTW. The POTW places surcharges on excess BOD, total Kjeldahl nitrogen, and hydraulic flow. Airport personnel stated that these surcharges total approximately $550,000 per year.

Salt Lake City International Airport, Salt Lake City, UT (SLC)

Salt Lake City International Airport has constructed specially designed aircraft deicing areas where runoff is collected for subsequent glycol recycling/recovery (see Section 6.4.1, Environmental Quality Company (EQ)). However, some collected wastewater is too dilute for economically viable glycol recycling/recovery. EQ dedicated one of three, newly constructed, 3-million-gallon detention ponds for lower-strength wastewater, which is discharged to a POTW. The ponds are part of a large wastewater collection system and glycol recycling/recovery project constructed in 1998 at a total cost of $28 million. Each detention pond is lined with clay and a membrane liner, and covered with a floating membrane to reduce degradation of glycol by ultraviolet light and bacterial action. Currently, wastewater with BOD concentrations greater than 200 mg/L are subject to a POTW surcharge of $0.05/lb BOD.

Buffalo-Niagara International Airport, Buffalo, NY (BUF)

In areas where aircraft deicing/anti-icing operations are performed, Buffalo-Niagara International Airport installed storm water collection systems equipped with diversion valves to direct storm water to either an underground storage basin (ADF-contaminated wastewater) or an underground storm water detention basin (non-ADF-contaminated wastewater). The ADF-contaminated wastewater storage basin is lined with a membrane and has four chambers, each with a capacity of 50,000 gallons. Wastewater from the storage basin is discharged to a POTW, which requires the airport to meter their discharge based on glycol loading. Wastewater with BOD concentrations greater than 250 mg/L is subject to an additional surcharge of between $0.10 and $0.105 per gallon. The annual BOD surcharge ranges from $1,800 to $2,400.

Kansas City International Airport, Kansas City, MO (MCI)

In the main gate and terminal areas where aircraft deicing/anti-icing operations are performed, Kansas City International Airport is upgrading their existing storm water collection systems to include diversion valves to direct storm water to either a concrete storage basin (ADF-contaminated wastewater) or a series of storm water retention ponds (non-ADF-contaminated wastewater). The storage basin consists of two, 1-million-gallon chambers operated in parallel with one filling while the second is discharging to the POTW. Wastewater is discharged at a controlled rate based on flow and BOD_5 loading.

The Federal Aviation Administration (FAA) and Kansas City International Airport funded modifications to the POTW to handle the ADF-contaminated wastewater discharged from the airport. The total capital cost of upgrading the storm water collection system, installing the storage basin, and upgrading the POTW is estimated to be $8.5 million, of which 75% will be funded by the FAA and the remainder by the airport.

Baltimore/Washington International Airport, Baltimore, MD (BWI)

Baltimore/Washington International Airport has invested approximately $22 million on deicing control facilities including three deicing pads, each equipped with runoff drainage and collection systems, storm water diversion trenches at multiple locations at the passenger terminal gates, and glycol vacuum trucks. Under nondeicing conditions, storm water is directed to the airport storm water drainage system. During deicing events, diversion valves are actuated to direct ADF-contaminated wastewater to collection vaults for transfer to temporary storage tanks. Two of the three deicing pads each include two 20,000-gallon, above-ground temporary storage tanks. Wastewater from these tanks is transported to the third deicing pad via tank truck. The third deicing pad includes a lift station to transfer wastewater from all three deicing pads to a central wastewater storage area, which includes a 600,000-gallon, above-ground storage tank surrounded by a 5- to 6-foot concrete containment wall. From the central storage area, wastewater is discharged at a controlled rate to the POTW based on BOD loading. Wastewater discharge fees are $0.0024 per gallon (4).

Des Moines International Airport, Des Moines, IA (DSM)

All aircraft deicing operations are performed on an apron rebuilt in 1995 to allow collection of all runoff from this area. The airport collects approximately 30% of all ADF applied. The airport is currently constructing a 4-million-gallon storage tank (cost: $8 million) to contain runoff from the apron beginning in the 1999/2000 deicing season (2). During the winter months, when deicing events are likely to occur, wastewater from the tank will be discharged at a controlled rate to the POTW. For the remainder of the year, the tank contents will be discharged directly to surface waters. The tank will be equipped with a TOC analyzer to indicate the presence of glycol.

Hopkins International Airport, Cleveland, OH (CLE)

Hopkins International Airport uses compression plugs (discussed in Section 6.3.2) in their storm water system to collect ADF-contaminated wastewater for subsequent glycol recycling/recovery. However, they consider some of the collected wastewater to be too dilute (i.e., less than 11% glycol content) for economically viable glycol recycling/recovery. Dilute wastewater is evacuated as needed using pump trucks and transported to one of eight 21,000-gallon storage tanks dedicated for lower-strength wastewater. Dilute wastewater from the storage tanks is then discharged at a controlled rate to the POTW. Wastewater discharge fees are $0.04 per gallon.

Washington Dulles International Airport, Herndon, VA (IAD)

Washington Dulles International Airport is implementing an ADF-contaminated wastewater collection and storage system for use beginning in the 1999/2000 deicing system. Wastewater will be collected from deicing operation areas using glycol vacuum vehicles (see Section 6.3.5) and transferred to storage tanks. Wastewater with high glycol content (7% or greater) will be stored in a 500,000-gallon storage tank and in twenty 20,000-gallon storage tanks for eventual transport for on-site glycol recycling/recovery. Dilute wastewater (<7%) will be stored in a 300,000-gallon storage tank for discharge at a controlled rate to a POTW. The airport plans to begin discharging to the POTW in January 2000.

Prior to implementing this system, most storm water runoff at Washington Dulles International Airport, including that from the primary and two of the three secondary deicing areas, drained into Horsepen Lake, a man-made impoundment, either by overland flow or through storm drains after traveling three to four miles. The total drainage area for the lake is 23 square miles. Water from the lake is discharged to Broad Run, a tributary to the Potomac River.

Munich Airport, Germany (MUC)

At Munich Airport, a system of drainage channels connected to underground pipes is used to collect contaminated storm water from the runways and convey it to a wastewater storage complex. The storage complex consists of an underground concrete storage basin with a capacity of 16 million gallons and a lined detention basin with a capacity of 21 million gallons. Wastewater from the storage complex is discharged at a controlled rate to a local wastewater treatment plant. Contaminated storm water from the airport's taxiways is also collected and treated on site as described in Section 7.2.3 (5).

Stockholm-Arlanda Airport, Sweden (ARN)

Stockholm-Arlanda Airport installed a high-density polyethylene membrane with a bentonite and sand lining beneath the airport's new runway to prevent seepage of aircraft and pavement deicing/anti-icing chemicals into an aquifer that lies directly beneath the runway. The membrane collects storm water from the runway and diverts it to a storm water drainage system. The membrane is monitored using leak detection equipment and groundwater monitoring wells (5).

7.2 Wastewater Treatment

This section describes on-site wastewater treatment used by airports to control deicing chemical discharges to surface waters and POTWs.

7.2.1 Biological Treatment

Because of the high oxygen demand of ADF-contaminated wastewater, many airports rely on biological treatment as a cost-effective and efficient treatment technology. The principle advantages of biological treatment specific to airport deicing operations include: (1) capability to treat both high-strength and dilute wastewaters, (2) capability to treat wastewater containing ethylene glycol, propylene glycol, or a mixture of both, (3) capability for use with any wastewater collection system (systems described in Sections 6.3 and 7.1), and (4) competitive treatment costs as compared to glycol recycling. Where feasible, airports generally choose off-site biological treatment via discharge to a POTW. Table 13-1, at the end of this section, lists facilities known to discharge to a POTW and their discharge requirements. However, several airports choose on-site biological treatment for a variety of reasons including: (1) limited hydraulic or loading capacity at the POTW, (2) high POTW wastewater treatment and/or conveyance fees, (3) inability of local POTW to handle highly variable pollutant loadings, and (4) airport infrastructure constraints. Wastewater treatment at these airports is described below.

Airport biological treatment systems generally include a means of wastewater equalization to avoid system upset by flow variability and slug loadings. Airports using pond-based biological treatment systems generally use their ponds for both wastewater equalization and wastewater treatment (see discussion of Greater Rockford Airport below). Other airports use ponds solely for wastewater equalization. For example, Albany International Airport, discussed below, operates extensive wastewater equalization in ponds prior to biological treatment.

Note that any airport operating contaminated storm water containment systems, where wastewater is retained through warmer spring months, likely achieves some degree of natural biological degradation of glycol prior to discharge. One example is Billings Logan International Airport discussed earlier in this section.

<u>Greater Rockford Airport, Rockford, IL (RFD)</u>

Greater Rockford Airport operates an aerobic biological treatment system consisting of a 16-million-gallon aerated detention pond, a settling pond, a recycling pump, and a chemical addition building. The system was constructed in 1994 at a capital cost of $1.8 million. Estimated annual operating costs (i.e., electricity, chemicals) are $108,000 and estimated annual labor costs are $60,000 to $75,000. Contaminated storm water enters a detention pond, which is lined and fitted with four mechanical and 12 aspirating aerators. Wastewater is retained in the detention pond during the deicing season, and released in spring or early summer. During this time, microorganisms present in the pond biodegrade ethylene and propylene glycols. The biodegradation of glycol is temperature-dependent and mainly occurs during the spring and early summer months when ambient temperatures are higher. Airport personnel estimate that the BOD_5 of contaminated storm water entering the detention pond during the deicing season may reach a high of 2,000 mg/L. By midsummer, biodegradation has reduced the BOD_5 to less than 30 mg/L (typically 10 mg/L). Prior to discharge, the treated wastewater is transferred to the 5-million-gallon settling pond and then slowly discharged to the Rock River over a two- to three-week period.

The pond system has operated for five years with minor sludge buildup that has not required removal. Airport personnel anticipate that any sludge removed from the ponds in the future would be land-applied on site.

The table below presents EPA's sampling data for Greater Rockford Airport's wastewater treatment system. Note that during the 1998-1999 deicing season (when EPA collected samples at Greater Rockford Airport), BOD_5 concentrations in the pond did not exceed 100 mg/L. In addition, during the three-week period immediately preceding collection of the influent sample, ambient temperatures were unseasonably warm with daily highs reaching above 70°F on five separate days. Consequently, EPA believes that some treatment had already occurred prior to collection of the influent sample. This conclusion is further supported by the analytical data, which shows that glycols, known to biodegrade rapidly, were not detected in the influent sample. Note that the treatment system removed toxic additives (e.g., tolyltriazole).

Pollutant	Influent Concentration	Effluent Concentration
Propylene Glycol (mg/L)	ND (5)	ND (5)
Ethylene Glycol (mg/L)	ND (10)	ND (10)
Tolyltriazole (mg/L)	0.12	0.013
Phenol (ug/L)	ND (10)	ND (10)
Total Organic Carbon (mg/L)	12	9.0
Ammonia as Nitrogen (mg/L)	46	0.27
Hexane Extractable Material (mg/L)	100	ND (6)

ND - Not detected (followed by the detection limit).

The airport submitted weekly monitoring data for the wastewater treatment facility detention pond for September 28, 1998 through July 7, 1999. The airport also submitted daily discharge monitoring data for July 20, 1999 through August 26, 1999. These data are summarized below.

	Detention Pond Concentration		Discharge Concentration	
Pollutant	Average	Range	Average	Range
Biochemical Oxygen Demand, 5-Day (mg/L)	37	ND (10) - 98	5.3	3 - 10
Ammonia as Nitrogen (mg/L)	24	ND (0.5) - 82	0.5	0.5 - 0.55
Total Suspended Solids (mg/L)	38	ND (5) - 325	7.1	ND (5) - 12

Duluth International Airport, Duluth, MN (DLH)

Duluth International Airport operates storm water retention ponds equipped with aeration systems to biologically degrade glycol and improve water quality prior to discharge to surface waters. The airport plans to upgrade the aeration system to include filtration and chlorination.

Albany International Airport, Albany, NY (ALB)

Albany International Airport operates an anaerobic biological treatment system consisting of two fluidized bed biological reactors currently operated in parallel with the capability of operating in series when required. Each unit is 14 feet in diameter, 35 feet in height (including a 4-foot freeboard), and packed with 10 tons of granular activated carbon. The treatment system was constructed in 1998 at a capital cost of $3.2 million and is preceded by a total of 11 million gallons of deicing storm water retention and equalization (retention ponds and a storage tank). The airport collects and treats approximately 70% of all ADF applied.

The treatment system was designed and constructed by EFX Systems, Inc. and Clough-Harbour Technical Services, LLC to meet the Airport Authority's design-build performance specifications. These requirements included: (1) a minimum influent flow rate of 100 gallons per minute (an annual total of 31 million gallons), (2) reduction of the propylene glycol concentration from an average of between 4,800 and 7,500 mg/L to below the detection limit of 1 mg/L, and (3) reduction of COD by greater than 90 percent.

Deicing storm water is recirculated through the unit to increase the residence time and equalize influent characteristics. Under anaerobic operating conditions, glycol is converted primarily to methane gas, carbon dioxide, and biomass. Some glycol is also converted to propionic acid. The system is self-sustaining by reusing methane for process and space heating. Final effluent is stored prior to either commercial spray irrigation to the airfield or discharge to the POTW during winter months. The system includes separators to capture and return carryover bed carbon. Excess biomass, which is too fine to be removed by the separators, exits with effluent for discharge through airfield spray irrigation.

EPA's sampling data for Albany International Airport are presented below. Note that the treatment system removed toxic additives (e.g., tolyltriazole) as well as glycol. This analysis was conducted prior to establishment of aerobic polishing filtration units, which reportedly reduce effluent to below threshold limits for all permit parameters.

Pollutant	Influent Concentration	Effluent Concentration
Propylene Glycol (mg/L)	2,700	ND (5)
Ethylene Glycol (mg/L)	ND (10)	ND (10)
Tolyltriazole (mg/L)	>2.00	0.107
Phenol (ug/L)	109	ND (10)
Total Organic Carbon (mg/L)	2,420	ND (10)
Ammonia as Nitrogen (mg/L) (a)	88.1	87.2
Hexane Extractable Material (mg/L)	ND (6)	ND (5.5)

ND - Not detected (followed by the detection limit).
(a) According to airport personnel, the ammonia concentration indicates an anomaly condition not representative of typical deicing wastewater at Albany International Airport. Subsequent ammonia analysis conducted by the airport established maximum effluent concentrations of less than 45 mg/L. Subsequent to EPA's sampling episode, the airport installed an aerobic polishing filtration unit, which reportedly reduces ammonia concentrations to less than 5 mg/L.

The airport installed and began operating the EFX biological treatment system during the 1998-1999 deicing season. The system was required to undergo an acceptance period where the system was operated 30 consecutive days at an average daily applied loading rate of 3,500 kg COD/day (10% above the design maximum loading rate). The results from this acceptance period are presented below.

Pollutant	Influent Concentration		Effluent Concentration	
	Average	Range	Average	Range
Propylene Glycol (mg/L)	4,400	3,400 - 5,500	0.28	ND (0.05) - 0.85
Biochemical Oxygen Demand, 5-Day (mg/L)	NA	NA	57	39 - 75
Chemical Oxygen Demand (mg/L)	8,600	420 - 9,300	110	70 - 610

NA - Not available.

Airborne Air Park, Wilmington, OH (ILN)

Airborne Air Park operates a pilot-scale reciprocating subsurface aerobic/ anaerobic biological treatment system in which glycol-contaminated wastewater flows through beds of gravel that is planted with wetland plants. The reciprocating design, whereby wastewater is alternately transferred between pairs of partner cells, enhances biological degradation. The full-scale system is currently under construction for use beginning in the 2000-2001 deicing season to treat all dry-weather flows and nonpeak wet-weather flows from areas where aircraft deicing is performed. Airport personnel estimate that 90% of ADF-contaminated wastewater will be treated by the system. The cost of the treatment system is not known.

Biological degradation occurs primarily via bacteria attached to the gravel and secondarily by the wetland plants. Bacteria populations are both aerobic and anaerobic, with aerobic bacteria degrading glycols and anaerobic bacteria degrading excess biological solids. Performance data for the pilot-scale treatment system are presented below.

Subsurface Treatment System Type	Removal Rate (lb COD per mgal per ft^3 of substrate)	Average Influent COD (mg/L)	Average Effluent COD (mg/L)	Range of Influent COD Treated (mg/L)	Range of Effluent COD (mg/L)
Conventional	0.6	959	783	100 to 500	24 to 380
Reciprocating	7.5	1960	383	260 to 12,000	42 to 2,990

7.2.2 Oil/Water Separation

Some airports operate oil/water separators to mitigate any potential petroleum spill. Chicago O'Hare International Airport operates an oil/water separator consisting of a skimmer and underflow weir at each inlet to its storm water retention pond. Greater Rockford Airport operates a static inclined plate oil/water separator prior to the inlet to its aerated detention pond. Seattle/Tacoma International Airport in Washington State separately conveys contaminated storm water collected from areas where aircraft deicing operations are performed and industrial wastewater generated at the airport to an on-site industrial waste treatment system. The system consists of storage/equalization, settling, and dissolved air flotation prior to its discharge to the Puget Sound. (Note that the airport plans to discharge to a POTW in the future.) Dallas/Ft. Worth International Airport incorporates baffles in storm water diversion boxes to separate any oil and grease. In addition, ADF-contaminated wastewater is routed through a grit chamber and oil skimmer prior to entering the airport's new detention basins. Anchorage International Airport in Alaska operates watershed protection stations which include (in addition to other controls described in Section 7.2.3) oil/water separators to skim and remove petroleum products from drainage ditches flowing to nearby lakes. Oil/water separation is not useful in removing glycol and other dissolved pollutants in ADF-contaminated wastewater.

7.2.3 Land Application

Albany International Airport disposes of some of its effluent from their on-site anaerobic biological treatment system via airfield spray irrigation as a cost-effective alternative to discharging to the POTW. Installation of the irrigation pipe gallery array covering approximately 40 acres cost less than $110,000 plus airfield maintenance labor. Spray irrigation is performed at a rate of 150 gallons per minute and BOD loading of less than 10 pounds of BOD per acre per day. Their New York State discharge permit allows irrigation discharge of up to 500 pounds of BOD per acre per day when soil temperatures are above 50° F. Biological treatment plant effluent is continuously monitored via a 24-hour composite sampler to ensure adherence to permit requirements.

Almost all U. S. airports maintain vegetative swales between impervious areas to help mitigate storm water runoff and allow deicing chemicals to degrade naturally. For example, Anchorage International Airport maintains oversized open drainage swales to allow natural biodegradation, filtration, settling, and evaporation of storm water runoff. To a limited extent, existing wetland receive some of the ADF-contaminated storm water for natural degradation. Duluth International Airport conveys some ADF-contaminated storm water to retention areas that do not drain to surface waters, where the storm water is allowed to evaporate and infiltrate the ground.

Baltimore/Washington International Airport has constructed infiltration facilities throughout its airfield designed to temporarily store and infiltrate runoff from the first one-half inch of each rain event into the underlying soils. The infiltration facilities consist of gravel-filled trenches installed parallel to runways and taxiways. Excess water overflows the trenches and is directed either to storm water retention areas or to specially designed overland flow through grass meadow strips and a shrub bed prior to discharge (6).

At the Munich Airport, contaminated storm water from the airport's taxiways is collected and treated by a specially designed biodegradation system installed approximately 1 foot beneath the taxiway surface. This system consists of two layers of impervious fabric enclosing a 1-mm thick layer of bentonite powder. The top fabric layer is overlain with a layer of loosely packed sand, which is seeded with bacteria to biodegrade aircraft and pavement deicing/anti-icing chemicals (4).

7.3 References

1. Letter from Cheryl R. Koshuta, Port of Portland, to Shari H. Zuskin, U.S. EPA. November 1, 1999 (DCN T11067).

2. Letter from Scott F. Belcher, Air Transport Association, to Shari Zuskin Barash, U.S. EPA. November 4, 1999 (DCN T11063).

3. Letter from Darcy Zarubiak, Dallas/Ft. Worth International Airport, to Shari Zuskin, U.S. EPA. December 22, 1999 (DCN T11085).

4. Maryland Aviation Administration. Aircraft Deicing Plan Update, Baltimore/Washington International Airport. August 1998 (DCN T10697).

5. U.S.A.F. Air Combat Command. Literature and Technology Review Report for Aircraft and Airfield Deicing. September 1997 (DCN T10450).

6. Maryland Aviation Administration. Interim Report, Mass Balance Study Aircraft Glycol Deicers, Baltimore/Washington International Airport. September 1998 (DCN T10698).

Table 7-1

Summary of Wastewater Containment and Treatment at Airports

Airport	ADF-Contaminated Wastewater Collection/Treatment
Portland International Airport (PDX)	High strength to POTW Low strength to pond and direct discharge
Billings Logan International Airport (BIL)	Retained in a series of ponds; direct discharge in spring
Chicago O'Hare International Airport (ORD)	Retained in ponds; discharge to POTW
Minneapolis-St. Paul International Airport (MSP)	High strength to glycol recycling Low strength to ponds; discharge to POTW
Dallas/Ft. Worth International Airport (DFW)	Retained in detention basins; discharge to POTW
Denver International Airport (DIA)	Deicing pad runoff to glycol recycling. Gate runoff to detention ponds; discharge to POTW
Salt Lake City International Airport (SLC)	High strength to glycol recycling Low strength to detention pond; discharge to POTW
Buffalo-Niagara International Airport (BUF)	Retained in underground storage basins; discharge to POTW
Kansas City International Airport (MCI)	Retained in storage basins; discharge to POTW
Baltimore/Washington International Airport (BWI)	Retained in storage tanks; discharge to POTW Runway and taxiway runoff to infiltration system
Des Moines International Airport (DSM)	Retained in storage tank; discharge to POTW
Hopkins International Airport (CLE)	High strength to glycol recycling Low strength to storage tanks; discharge to POTW
Washington Dulles International Airport (IAD)	High strength to glycol recycling Low strength to storage tank; discharge to POTW
Munich Airport (MUC)	Runway runoff to basins; discharge to POTW Taxiway runoff to on-site biodegradation treatment system
Stockholm-Arlanda Airport (ARN)	Runway runoff drainage system to direct discharge
Greater Rockford Airport (RFD)	Retained in aerated detention pond; direct discharge in summer
Duluth International Airport (DLH)	Retained in aerated retention pond; direct discharge
Albany International Airport (ALB)	Retention ponds and storage tank to on-site anaerobic fluidized bed reactor; discharge to POTW or land application
Airborne Air Park (ILN)	Drainage to on-site reciprocating aerobic/anaerobic treatment system; direct discharge

8.0 WASTEWATER CHARACTERIZATION

As part of the characterization of airport deicing operations, EPA assessed what constituents may be present in airport deicing/anti-icing fluid (ADF)-contaminated wastewater. Information presented in this section is based on data provided by the industry, EPA's compliance data, and EPA's site visit and sampling programs. Section 8.1 presents industry self-monitoring data; Section 8.2 presents data from EPA's permit compliance system (PCS) database; Section 8.3 presents wastewater characterization data collected during EPA's sampling program; and Section 8.4 discusses multi-sector general permit application data. All tables appear at the end of this section. Appendix A contains information regarding the location of airports referenced in this section.

8.1 Industry Self-Monitoring Data

During the course of the study, EPA obtained storm water sampling data from five airports. In general, these data represent discharges of ADF-contaminated wastewater; however, some airports submitted data for nondeicing season discharges. Although the length of the deicing season may vary among airports and also from year to year at a given airport, EPA analyzed only data collected during the airport's reported deicing season (e.g., October through March). These data are described and summarized in this section.

EPA also received storm water monitoring data from Transport Canada and Environment Canada for five Canadian airports. These data were collected as part of a study designed to assess the effectiveness of the Canadian voluntary glycol guideline (discussed in Section 13.3.1), to identify problems in wastewater management, and to develop better storm water monitoring programs. These data are also described and summarized in this section.

In general, each airport monitored a unique set of parameters, which were generally dictated by state and local permit requirements. In addition, some parameters can be analyzed by multiple analytical methods, making it difficult to directly compare data submitted by different airports. For example, glycols are analyzed by several different methods, the detection limits of which vary from 1,000 mg/L to less than 1 mg/L. Therefore, a nondetect value at an airport using an analytical method with a high detection limit may in fact have a higher glycol concentration than a detected value at an airport using an analytical method with a low detection limit.

The data presented in this section generally represent discharges from the winter of 1997-1998 and/or the winter of 1998-1999, with some exceptions. EPA recognizes that some of the pollutant discharge concentrations presented in this section may not represent current pollutant discharges from the airports because several of the airports discussed in this section have recently implemented pollutant control technologies (e.g., Milwaukee's General Mitchell International Airport).

EPA recognizes that the data presented in this section may have several limitations. First, the data represent only a small subset of wastewater discharges from airport deicing/anti-icing operations. Second, the data submitted by some airports were collected during only one deicing season. Third, some of the data submitted by airports include samples collected on days when no deicing/anti-icing operations were conducted. However, like the PCS data presented in Section 8.2, EPA considers the effluent monitoring data a "snapshot" of pollutant discharges to surface waters that may occur at airports. The data submitted by each airport are summarized below.

<u>Bradley International Airport, Windsor Locks, CT (BDL)</u>

Bradley International Airport submitted analytical data for storm water outfall and in-stream samples for the winters of 1990-1991, 1993-1994, 1996-1997, 1997-1998, and 1998-1999. The outfall samples were collected from 13 different outfalls. The in-stream data were not included in this summary because they do not represent ADF-contaminated wastewater discharges. The discharge data summarized in Table 8-1 are presented by general location and outfall. Some outfalls were sampled hourly for eight consecutive hours while a single grab sample was collected at other outfalls. Outfall data are presented as either an average of hourly sampling data or as the single grab sample result as applicable. As shown by the data in Table 8-1, most ADF-contaminated wastewater discharges at BDL occur at Outfalls 2 and 3, which service the passenger terminal and aircraft deicing pad areas.

Washington Dulles International Airport, Herndon, VA (IAD)

Washington Dulles International Airport submitted analytical data for samples collected at the outfall from Horsepen Lake, a man-made impoundment located at the airport's northern property boundary. In general, the airport collected samples twice per day for 90 days between December 1998 and April 1999. Sampling generally coincided with deicing operations; however, EPA assumes, based on nondetect glycol values, that minimal deicing/anti-icing occurred in April. The following data summarize the Horsepen Lake outfall data, excluding the April 1999 data.

	Average Concentration (mg/L)	Range (mg/L)	Number of Data Points
Propylene Glycol	<61.1	ND (5) - 986	124
Ethylene Glycol	<5.52	ND (5) - 34	124

< - Maximum concentration.
ND - Not detected (followed by detection limit).

Logan International Airport, Boston, MA (BOS)

Logan International Airport submitted analytical data for storm water sampling performed as part of its National Pollutant Discharge Elimination System (NPDES) storm water permit application. The airport collected samples in March 1991, January 1992, and March 1992. The airport also collected samples in June 1991; however, these data are not included in this summary because they do not represent storm water discharges during deicing operations. Although the data were collected from several years ago, EPA believes they represent current deicing operation conditions at Logan.

Storm water runoff samples were collected and analyzed for several parameters, including BOD_5, ammonia, metals, ethylene glycol, and propylene glycol. Samples were collected at the north and west outfalls, which directly drain to the adjacent harbor. The following data summarize the results of storm water sampling during deicing events.

Date	North Outfall (mg/L)				West Outfall (mg/L)			
	PG	EG	BOD_5	Ammonia	PG	EG	BOD_5	Ammonia
3/15/91	120	110	8,320	2.3	240	95	5,500	2.9
1/23/92	ND (1)	1,100	592	5.3	130	280	531	3.8
3/19/92	<141	<641	N/A	N/A	<218	481	N/A	N/A
Avg.	**<87.3**	**<617**	**4,456**	**3.8**	**<196**	**285**	**3,016**	**3.35**

< - Maximum concentration.
PG - Propylene glycol.
EG - Ethylene glycol.
ND - Not detected (followed by the detection limit).
N/A - Not available.

Baltimore/Washington International Airport, Baltimore, MD (BWI)

Baltimore/Washington International Airport performed a glycol mass balance study using data collected during the 1997-1998 deicing season. The goal of the study was to determine the percentage of glycol discharged relative to the volume of glycol sprayed on aircraft. The airport collected daily grab samples between October 24, 1997 and April 30, 1998 from two watersheds that receive storm water discharges from the airport. The following table summarizes the glycol and COD results for the Kitten Branch Watershed and Muddy Bridge Branch Watershed.

1997-1998 Season	Kitten Branch Watershed	Muddy Bridge Branch Watershed
Average glycol concentration (mg/L)	<10	<8.7
Range of glycol concentrations (mg/L)	ND (6) - 630	ND (6) - 30
Range of COD concentrations	ND (10) - 400	ND (10) - 690
Range of ammonia concentrations (mg/L)	ND (1)	ND (1) - 1.3
Number of Data Points	159	159

< - Maximum concentration
ND - Not detected (followed by detection limit).

General Mitchell International Airport (MKE)

General Mitchell International Airport submitted analytical data from a study conducted during the winter of 1996-1997. The purpose of the study was to assess the water quality impacts that aircraft deicing fluids have on receiving streams. From November 1996 through April 1997, the airport conducted a monitoring program for flow, water quality parameters (e.g., BOD_5, glycols), and toxicity from 10 sampling stations, including two sampling stations that directly measured runoff from the airport. The remaining sampling stations were located in receiving streams both upstream or downstream of the airport. Because the other sampling stations may not represent contaminated storm water discharges, only data for the two airport sampling stations are summarized below.

	Outfall #1	Outfall #7
Average EG Concentration (mg/L)	170	123
Average PG Concentration (mg/L)	5,080	1,460
Average BOD_5 Concentration (mg/L)	3,510	917
Number of Data Points	4	4

EG - Ethylene glycol.
PG - Propylene glycol.

The airport also conducted acute and chronic whole effluent toxicity (WET) tests for both fathead minnows and *Ceriodaphnia dubia* for one sampling event on April 11, 1997.

Data from this event were used to establish acute and chronic toxic criteria for the fathead minnow and *Ceriodaphnia dubia* as follows:

Species	Duration	Aircraft Deicing/Anti-icing Fluid Concentration (mg/L)
Fathead minnow	96-hour LC_{50}	1,650
	7-day IC_{25}	90
Ceriodaphnia dubia	48-hour LC_{50}	3,150
	7-day IC_{25}	1,015

LC_{50} - Lethal concentration at which 50% of the test population dies.
IC_{25} - Concentration at which 25% of the test organisms had inhibited growth, reproduction, or survival of the young.

Transport Canada/Environment Canada

Five Canadian airports were studied as part of the Transport Canada/Environment Canada joint study of storm water monitoring at airports. For two of the airports, Quebec City and Victoria, samples were collected at two outfalls. EPA believes the Canadian data are relevant since some U.S. airports experience weather conditions that are similar to those experienced by the Canadian airports. Note that Canada has a voluntary glycol guideline of 100 mg/L. The following table summarizes the analytical data.

Airport	Range of Total Glycol Concentration (mg/L)	% of Samples that Exceeded 100 mg/L	Range of Ammonia Concentration (mg/L)	Range of BOD_5 Concentration (mg/L)
St. John's	ND (1) - 120	1	ND (1) - 1.85	ND (1) - 89
Quebec City (A)	ND (1) - 30,200	17.2	ND (0.03) - 197	ND (1) - 3,900
Quebec City (B)	ND (1) - 2	0	ND (0.02) - 4.63	3 - 47
Thunder Bay	ND (1) - 437	5.9	ND (0.03) - 106	ND (1) - 703
Victoria (A)	ND (1) - 7	0	ND (0.03) - 27	ND (1) - 29
Victoria (B)	ND (1) - 77	0	ND (0.03) - 11	ND (1) - 28
Halifax	ND (5) - 130,000	28	ND (0.05) - 55	1 - 31

ND - Not detected (followed by detection limit).

Based on the data available to EPA, the range of glycol concentrations at these Canadian airports is generally lower than those at U.S. airports presented in this section. This is most likely a result of Canada's voluntary guideline. The ammonia concentrations at Canadian airports are significantly higher than those at the U.S. airports presented in this section. This is most likely because the Canadian airports use urea as a pavement deicer, which many U.S. airports are eliminating in favor of alternate pavement deicing agents.

8.2 Permit Compliance System (PCS)

EPA's PCS database contains compliance, enforcement, and permitting information for facilities that hold an NPDES permit. NPDES, which is authorized under Section 402 of the CWA, requires permits for the discharge of pollutants from any point source into waters of the United States.

The PCS database includes the following information for each facility included in the database:

- Facility NPDES permit number;
- Facility name;
- Pipe number and description (i.e., code and description of each NPDES-permitted discharge point);
- Name and description of analyzed parameters;
- Average quantity and/or concentration limit (and maximum and minimum limits, if applicable);
- Units of measurement for limits;
- Average quantity and/or concentration of parameter during monitoring period (and maximum and minimum measurements, if applicable); and
- Units of measurement for monitoring parameters.

In 1998, EPA's Office of Compliance extracted PCS records for Standard Industrial Classification (SIC) code 4185 (Airports, Flying Fields, and Airport Terminal Services) for the 1997-1998 deicing season (i.e., September through March) for EPA's Office of Water. EPA recognizes that the pollutant discharge concentrations from this period may not represent current industry pollutant discharges because several airports have recently implemented contaminated storm water collection and/or treatment techniques and/or POTW discharge that would not be reflected in the 1997-1998 data.

The PCS database excerpt for SIC code 4185 contained information for 42 different airports from across the U.S. However, some of these airports are small or general aviation airports or are in southern locations, where few deicing operations are expected to occur. EPA compared the airports in the PCS database to the list of airports thought to have potentially significant deicing/anti-icing activities (see discussion in Section 4.3.1) and determined that 14 of the airports in the PCS database were on this list.

Using information in the PCS database for the 14 airports, EPA evaluated each permitted outfall and types of parameters to determine whether the outfall discharges wastewater containing deicing/anti-icing chemicals. For example, if an airport is required to collect and analyze storm water for glycol at a particular outfall, then EPA considered the outfall as discharging wastewater containing deicing/anti-icing chemicals. In contrast, if an airport is required to analyze only for oil and grease and volatile organic pollutants at a particular outfall, then EPA considered the outfall as not discharging wastewater containing deicing/anti-icing chemicals and eliminated it from further analyses.

After EPA edited the database using the above criteria, information from 10 airports remained in the database. These airports include:

- Chicago O'Hare International (ORD);
- Louisville International - Standiford Field (SDF);
- Baltimore/Washington International (BWI);
- Minneapolis-St. Paul International (MSP);

- Newark International (EWR);
- Westchester County (HPN);
- Tompkins County (ITH);
- Syracuse Hancock International (SYR);
- Nashville International (BNA); and
- Salt Lake City International (SLC).

Table 8-2 summarizes effluent monitoring data for direct discharges for these airports, grouped by discharge location and/or similar discharge characteristics (e.g., runway or terminal outfalls).

It is important to recognize that the data presented in Table 8-2 have certain limitations, such as: 1) EPA was not able to verify for all airports that the outfalls presented in Table 8-2 are representative of wastewater discharges containing deicing/anti-icing chemicals, 2) the data represent only a small subset of wastewater discharges from airport deicing/anti-icing operations, 3) the data were collected during only one deicing season (the winter of 1997-1998), and 4) the data may not represent current deicing/anti-icing operations at these airports. However, EPA considers the effluent monitoring data a “snapshot” of pollutant discharges to surface waters that may occur at airports.

8.3 EPA Sampling Data

To supplement the analytical data available from the industry, EPA undertook a sampling program consisting of six sampling episodes. The goals of the sampling program were to: (1) identify pollutants present in wastewater from aircraft deicing and anti-icing operations; (2) determine the possible range of concentrations for each pollutant identified; and (3) assess the effectiveness of different wastewater treatment methods currently used at U.S. airports. To achieve these goals, EPA collected the following samples:

- Ethylene glycol-based aircraft deicing fluid (i.e., a Type I fluid);

- Propylene glycol-based aircraft deicing fluid (i.e., a Type I fluid);

- Influent to and effluent from an anaerobic biological treatment system used to treat ADF-contaminated wastewater at Albany International Airport;

- Wastewater discharge to a POTW from a retention basin used to collect ADF-contaminated wastewater at Kansas City International Airport;

- Influent to and effluent from a reverse osmosis system at Bradley International Airport used to recover glycol from low-strength ADF-contaminated wastewater for further processing;

- Storm water outfall which drains aircraft deicing/anti-icing areas at Bradley International Airport (sample collected during the deicing season, but not concurrent with a deicing event); and

- Influent to and effluent from an aerobic biological treatment system used to treat ADF-contaminated wastewater at Greater Rockford Airport.

These samples were analyzed for a large number of conventional and nonconventional pollutants and, in a few cases, for whole effluent toxicity. Table 8-3 lists the classes of pollutants analyzed as well as the analytical methods used.

The analytical data for the wastewater recovery and treatment systems, including an assessment of their efficiency, is presented in Section 6.4.1 for Bradley International Airport and Section 7.2.1. for Albany International Airport and Greater Rockford Airport. This section presents the analytical results for the two Type I fluids (Section 8.3.1) and for several raw wastewater samples and one storm water outfall sample (Section 8.3.2). Section 8.3.3 discusses the analytical results.

8.3.1 Type I Aircraft Deicing Fluids

Based on data provided by the industry, EPA estimates that more than 90% by volume of all ADF fluids sprayed in a given deicing season are Type I, with Type IV fluids comprising most of the remaining 5% to 10% and Type II fluids being largely obsolete. Since Type I fluids are used in much greater quantities than Type II and Type IV fluids, EPA analyzed samples of two Type I formulations as control or background samples for the sampling program.

There are currently three principle manufacturers/formulators of Type I fluids in the U.S.: Union Carbide, Lyondell (formerly ARCO), and Octagon Process. Union Carbide's Type I fluids contain ethylene glycol as the freezing point depressant, while those of Lyondell and Octagon contain propylene glycol. In recent years, the mammalian toxicity of ethylene glycol, combined with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) reporting requirements (see Section 13.2.1) and the proliferation of propylene glycol recovery, have made propylene glycol-based fluids dominant in the U.S. However, some carriers continue to use ethylene glycol-based products, and, at a few U.S. airports, the volume of ethylene glycol-based fluid applied to aircraft exceeds that of propylene glycol-based fluid. Consequently, EPA decided to analyze both an ethylene glycol-based Type I fluid (trade name UCAR™ Aircraft Deicing Fluid Concentrate, Union Carbide) and a propylene glycol-based Type I fluid (trade name Octaflo™ Concentrate, Octagon Process).

The samples were collected directly into sample containers and shipped to EPA contract laboratories for analysis. Chemical preservation was not required for these samples, although they were shipped on ice to maintain a sample temperature of 4° C. The samples were diluted with reagent grade water to a 50% solution prior to analysis to represent fluid as applied to aircraft. EPA recognizes that airlines sometimes dilute Type I fluid concentrate to solutions containing less than 50% ADF, but believes the 50% dilution is most typical of industry practices.

The samples were analyzed for volatile organics, semivolatile organics (including tolyltriazoles), metals, total organic carbon (TOC), and ammonia as nitrogen. Table 8-4 lists analytes detected in the diluted samples as well as their concentrations. EPA did not analyze the ADF samples for glycols, biochemical oxygen demand, or acute toxicity. Some of this information is available from fluid formulators, who collect environmental data both to comply with Society of Automotive Engineers' fluid certification reporting requirements (see Section 13.5) and to assist customers with waste management issues. Table 8-5 summarizes the data provided by the fluid manufacturers/formulators.

Table 8-4 should not be viewed as a comprehensive list of all pollutants present in wastewater from aircraft deicing/anti-icing operations. The fluids are known to contain a variety of additives, including wetting agents, fire suppressants, and potentially toxic corrosion inhibitors, many of which could not be included on the list of analytes because their identity was unknown and is considered proprietary by the fluid manufacturers.

8.3.2 Characterization of Wastewater from Aircraft Deicing/Anti-icing Operations

To characterize raw wastewater from aircraft deicing/anti-icing operations, EPA collected samples from a variety of airport wastewater storage facilities. These samples included wastewater from a portable storage tank at Bradley International Airport, an uncovered concrete basin at Kansas City International Airport, a storage tank and two detention ponds at Albany International Airport, and an aerated detention pond at Greater Rockford Airport. EPA also collected one storm water outfall sample at Bradley International Airport to characterize direct discharge of ADF-contaminated storm water. Sample fractions were preserved as specified by the analytical methods, packed in ice, and shipped overnight to EPA contract laboratories for analysis. All samples were analyzed for semivolatile organics (including tolyltriazoles), glycols, metals (including potassium), TOC, ammonia as nitrogen, BOD_5, hexane extractable material (HEM), and silica-gel hexane extractable material (SGT-HEM). Whole effluent toxicity (WET) tests were performed on samples collected at Kansas City International Airport and Bradley International Airport. The sample from Albany International Airport was also analyzed for volatile organic compounds.

Each sampling point and the sample collection method are briefly described below. Table 8-4 lists the analytes detected in the wastewater samples as well as their concentrations.

<u>Albany International Airport, Albany, NY (ALB)</u>

Aircraft deicing/anti-icing at Albany International Airport is performed using only propylene glycol-based fluids, and is permitted only in designated areas where a drainage collection system consisting of graded pavement surfaces, catch basins, trench drains, and wet wells are installed. Wastewater collected in the wet wells is pumped through force mains to the airport's wastewater storage area, which consists of a 6-million-gallon lagoon, a 2.3-million-gallon lagoon, and a 2.5-million-gallon above-ground tank. The lagoons are equipped with piping systems and blowers to provide gross diffusion aeration and a recirculation pump to move wastewater from the pond center to the edge. The primary purpose of the aeration and recirculation systems is to reduce glycol stratification within the lagoons. On March 24, 1999, EPA collected a grab sample of wastewater from the small lagoon and a composite sample from the storage tank and large lagoon. Grab samples were also collected from the large lagoon and the storage tank for analysis of HEM and SGT/HEM. EPA also analyzed a sample of effluent from the treatment system. The analytical data for the effluent sample of is provided in Section 7.2.1.

<u>Kansas City International Airport, Kansas City, KS (KCI)</u>

At Kansas City International Airport, airlines and fixed-base operators use either ethylene glycol- or propylene glycol-based fluids for aircraft deicing/anti-icing. Wastewater from aircraft deicing and anti-icing operations are collected at the passenger terminal using a trench drain system specifically designed for this purpose. The wastewater, combined with any storm water runoff, enters the trench drains and is conveyed by underground pipes to a concrete storage basin. The storage basin consists of two 1-million-gallon cells: the west cell and the east cell. The storage cells are operated in parallel, with one filling while the other is discharging to a local POTW. Because the storage cells are uncovered, rain water dilutes the wastewater and sunlight helps to degrade the glycols present. EPA collected a grab sample of wastewater from the west cell on February 25, 1999. The cell was approximately half-full at the time of sampling and had received wastewater from aircraft deicing/anti-icing operations since February 15, 1999.

Bradley International Airport, Windsor Locks, CT (BDL)

At Bradley International Airport, aircraft deicing and anti-icing operations are performed using propylene glycol-based fluids and are conducted on the airport's aircraft deicing pad, at the passenger terminal, and on the cargo ramps. Wastewater is collected at the passenger terminal and cargo ramps using vacuum trucks, while wastewater generated at the deicing pad drains into a sump. The collected wastewater is transferred to several 20,000-gallon temporary storage tanks located at the airport's glycol recycling facility (discussed in Section 6.4.1). The wastewater is segregated based on the glycol concentration, which typically varies between 1% and 30% (i.e., between 10,000 mg/L and 300,000 mg/L), depending on the volume of fluid used and the type of precipitation. EPA collected a wastewater grab sample from one of the temporary storage tanks on March 9, 1999. EPA also analyzed a sample of effluent from the treatment system. The analytical data for the effluent sample are provided in Section 6.4.1.

Storm water from the southern areas of the airfield, including the passenger terminal areas and the remote deicing pad (with the exception of that collected as described above), flows to Outfalls 3-1 and 3-2. On March 9, 1999, EPA collected a grab sample of the combined outfalls from an above-ground channel at a point down stream from the outfalls where the two streams combine. Although the sample was collected during the deicing season, it was not collected concurrent with a deicing event.

Greater Rockford Airport, Rockford, IL (RFD)

Aircraft deicing/anti-icing operations are performed at the airport's deicing pad and on a ramp at the cargo facility, where wastewater collection systems have been installed. Although the airport authority allows its tenants to use either propylene glycol- or ethylene glycol-based fluids, most of the fluid used at the airport is ethylene glycol-based. The wastewater collected at the airport's deicing pad and the cargo facility is conveyed via underground pipes and a diversion box to a 16-million-gallon aerated detention pond, where aerobic biological treatment takes place. Wastewater collected during the deicing season is retained in the detention pond until midsummer, when the treated fluid is discharged to a nearby river. The rate of biodegradation is dependent on temperature; biodegradation occurs primarily in spring and summer months when ambient temperatures are above 40° F.

EPA collected a grab sample of wastewater from the detention pond on April 14, 1999, following the close of the deicing season. During the three weeks immediately preceding the sampling episode, ambient temperatures were unseasonably warm, with daily highs reaching above 70° F on five separate days. A review of analytical data provided by the airport indicates that some treatment had already occurred prior to the sampling episode. This conclusion is further supported by EPA's data, which show that glycols, known to biodegrade rapidly, were not detected in the wastewater sample. Consequently, the sample is not representative of raw wastewater from airport deicing/anti-icing operations, at least with respect to glycol levels. EPA also analyzed a sample of effluent from the treatment system. The analytical data for the effluent sample of is provided in Section 7.2.1.

8.3.3 Discussion of Sampling Results

Analytical results for the Type I fluids show that the composition of Type I fluids varies considerably. For example, three volatile organic compounds (ethylbenzene, toluene, and m- + p-xylene) and three metals (antimony, manganese, and thallium) were detected in the propylene glycol-based fluid, but were not detected in the ethylene glycol-based fluid. Similarly, two semivolatile compounds (di-n-butyl phthalate and n-dodecane) and one metal (chromium) were detected in the ethylene glycol-based fluid, but not in the propylene glycol-based fluid.

The concentrations of the analytes that were detected in both fluids also differed. The ethylene glycol-based fluid contained higher concentrations of bis(2-ethylhexyl) phthalate, aluminum, boron, cadmium, and sodium, while the propylene glycol-based fluid contained higher concentrations of 5-methyl-1H-benzotriazole, arsenic, barium, calcium, copper, iron, lead, tin, zinc, and ammonia. Pollutant concentrations that differed by more than an order of magnitude include those for bis(ethylhexyl) phthalate, 5-methyl-1H-benzotriazole, arsenic, boron, cadmium, and thallium.

In general, pollutants detected in the Type I fluids were also detected in the raw wastewater samples. However, a number of analytes were detected in at least one of the Type I fluids, but were not detected in any of the raw wastewater samples. These analytes include ethylbenzene, toluene, m- + p-xylene, di-n-butyl phthalate, n-dodecane, antimony, boron, selenium, and thallium. There are several possible reasons for these results. First, wastewater from aircraft deicing/anti-icing operations is typically diluted by storm water, which may mask the presence of these pollutants. Second, the Type I fluids analyzed for this study may not have been used at the airports that were sampled. Third, biological activity in the storage units may have degraded some pollutants.

Several analytes were detected in at least one of the raw wastewater samples but not in either of the Type I fluids analyzed. These analytes include n-hexadecane, phenol, n-tetradecane, magnesium, silver, titanium, and vanadium. Other analytes were detected in both Type I fluids and in all raw wastewater samples; however, the concentration of the analyte was generally greater in the raw wastewater samples. These analytes include aluminum, barium, calcium, iron, sodium, and ammonia as nitrogen. There are several possible sources of these pollutants. First, they may be constituents of anti-icing fluids (i.e., Type II and Type IV fluids) or other Type I formulations. Second, they may be present in the water used at the airport to dilute the Type I fluid concentrate. Third, they may be present in precipitation. Fourth, they may be constituents present in pavement deicing/anti-icing agents. Fifth, they may be pollutants rinsed from aircraft or pavement surfaces during aircraft deicing operations. Pollutants were generally detected in higher concentrations in the raw wastewater sample collected at Bradley International Airport because the airport purposely attempts to collect wastewater with the highest possible ADF concentration for processing through its on-site glycol recycling system.

Although pavement deicing/anti-icing was not the primary focus of the sampling program, EPA included ammonia as nitrogen, potassium, magnesium, sodium, and calcium on the list of analytes measured in raw wastewater samples. Ammonia is a common degradation product of urea (a solid pavement deicer), while potassium acetate, calcium magnesium acetate, sodium acetate, and sodium formate (common pavement deicer/anti-icers) are potential significant sources of the remaining pollutants.

Ammonia concentrations in the raw wastewater samples ranged from 3.9 mg/L to 88 mg/L. Ammonia concentrations greater than 5 mg/L are known to be toxic to aquatic organisms, including the test species used in the whole effluent toxicity tests. The highest ammonia concentrations were found in wastewater samples collected at Albany International Airport, which reported using urea for deicing a newly constructed apron near the passenger terminal. Urea was used on this apron during the 1998-1999 winter, because application of potassium acetate (i.e., the pavement deicing/anti-icing typically used at Albany) would have voided the manufacturer's one-year warranty on the apron construction. Bradley International Airport and Greater Rockford Airport both reported using urea for runway and taxiway deicing. Note that the ammonia concentration in the storm water outfall from Bradley International Airport, 1.1 mg/L, was significantly less than 5 mg/L.

Concentrations of potassium in the raw wastewater samples varied considerably. The highest concentrations were detected in wastewater samples collected at Albany International Airport and Greater Rockford Airport, where potassium levels were approximately 60,000 μg/L. All of the airports sampled reported using potassium acetate on airfield pavements, mostly applied to runways and taxiways. None of the airports sampled reported using sodium acetate, calcium magnesium acetate, or sodium formate for airfield deicing/anti-icing.

In general, pollutants detected in the raw wastewater sample from Bradley International Airport were also detected in the storm water outfall. However, many pollutants detected in the outfall were not detected in the raw wastewater sample, likely because the outfall is diluted by storm water from non-deicing areas. Two pollutants, antimony and boron, were detected in the outfall but not in the raw wastewater. These pollutants may be contributed by natural sources.

8.4 Multi-Sector General Permit Application Data

As described in Section 13.1.3, Part 2 of the Multi-Sector General Permit application includes quantitative data based on samples collected during storm events from outfalls containing storm water discharges associated with industrial activity. The American Association of Airport Executives submitted a group permit application on behalf of 700 airports. Part 2 of the application included sampling data for 59 airports considered to be representative of the group. Sampling parameters included oil and grease, pH, BOD_5, COD, total suspended solids (TSS), total phosphorus, total Kjeldahl nitrogen, and nitrate plus nitrite nitrogen. Data from only one airport are relevant to airport deicing operations. The remaining data were collected during summer rain events when potential sources of pollutants consisted of aircraft fueling, cleaning, and maintenance.

Table 8-1

Summary of Storm Water Monitoring Data from Bradley International Airport

Group	Location	Date	Average BOD Concentration (mg/L)	Average Ammonia Concentration (mg/L)	Average Ethylene Glycol Concentration (mg/L)	Average Propylene Glycol Concentration (mg/L)
Southeast drainage	Outfall 1A	2/14/91	28	2.6	11.2	NA
		2/27/91	560	6.1	43.8	NA
		3/13/91	11	0.33	0.12	NA
		3/4/97	30	0.36	ND (10)	ND (10)
		3/14/98	NA	NA	ND (50)	ND (50)
		2/2/99	76	2.7	ND (10)	ND (10)
		3/15/99	>190	0.87	ND (10)	ND (10)
	Outfall 1B	2/14/91	31	2.5	10.4	NA
		2/27/91	520	6.1	20.8	NA
		3/13/91	3	0.11	ND (0.1)	NA
		3/14/98	NA	NA	ND (50)	ND (50)
	Outfall 14	3/14/98	NA	NA	ND (50)	ND (50)
Terminal drainage (South)	Outfall 2	2/14/91	8,300	2.3	11,700	ND (500)
		2/27/91	6,700	1.9	6,600	ND (50)
		3/13/91	32	0.24	10.5	ND (10)
		1/28/94	NA	<1.8	<150	17,000
		3/9/94	NA	3.1	<103	370
		3/4/97	69	0.61	40	9.1
		3/14/98	NA	NA	ND (50)	ND (50)
		2/2/99	>87	21	ND (10)	<280
		3/15/99	50	2.2	ND (10)	<29
	Outfall 3-1	2/14/91	22,000	4.6	22,500	13,000
		2/27/91	3,200	3.7	24,000	12,000
		3/13/91	2	0.32	0.29	ND (10)
		1/28/94	NA	<0.7	ND (100)	17,000
		3/9/94	NA	3.2	<99	11,000
		3/4/97	>304	1.13	ND (10)	700
		3/14/98	NA	NA	ND (100)	250
		2/2/99	>94	12	ND (10)	1,400
		3/15/99	>190	1.6	<1,700	<340
	Outfall 3-2	3/14/98	NA	NA	ND (1,000)	3,600
		2/2/99	>94	29	ND (10)	1,200
		3/15/99	>190	3.8	ND (10)	180

Table 8-1 (Continued)

Group	Location	Date	Average BOD Concentration (mg/L)	Average Ammonia Concentration (mg/L)	Average Ethylene Glycol Concentration (mg/L)	Average Propylene Glycol Concentration (mg/L)
West drainage	Outfall 5	3/14/91	6	1.2	1.9	NA
		2/27/91	ND (2)	0.18	ND (0.1)	NA
		3/13/91	ND (2)	0.22	ND (0.1)	NA
		3/4/97	5.6	0.76	ND (10)	ND (10)
	Outfall 7	2/2/99	ND (2)	0.22	ND (10)	ND (10)
		3/15/99	ND (15)	0.14	ND (10)	ND (10)
	Outfall 8	2/2/99	10	7.7	ND (10)	ND (10)
		3/15/99	ND (15)	0.71	ND (10)	ND (10)
	Outfall 9	3/4/97	1.2	0.16	ND (10)	ND (10)
		3/14/98	NA	NA	ND (50)	ND (50)
		2/2/99	ND (2)	1.5	ND (10)	ND (10)
		3/15/99	ND (15)	0.33	ND (10)	ND (10)
	Outfall 10	2/14/91	ND (2)	1.2	ND (0.1)	NA
		2/27/91	ND (2)	0.92	ND (0.1)	NA
		3/13/91	2	0.75	ND (0.1)	NA
		3/14/98	NA	NA	ND (50)	ND (50)
		2/2/99	ND (2)	0.65	ND (10)	ND (10)
		3/15/99	ND (15)	0.53	ND (10)	ND (10)
Northeast drainage	Outfall 13-1	2/14/91	8	0.54	1.7	NA
		2/27/91	ND (2)	0.23	ND (0.1)	NA
		3/13/91	ND (2)	0.2	ND (0.1)	NA
		3/4/97	7.8	19.6	ND (10)	ND (10)
		3/14/98	NA	NA	ND (50)	ND (50)
		2/2/99	7.6	0.46	ND (10)	ND (10)
		3/15/99	>190	1.1	ND (10)	2,100
	Outfall 13-2	2/14/91	2	0.47	ND (0.1)	NA
		2/27/91	ND (2)	0.13	ND (0.1)	NA
		3/13/91	2	0.51	0.17	NA
		3/14/98	NA	NA	ND (50)	ND (50)

> - Minimum concentration.
< - Maximum concentration.
NA - Not available.
ND - Not detected (followed by detection limit).

Table 8-2

Summary of PCS Data for Airports with EPA-Estimated Potentially Significant Deicing/Anti-Icing Operations

Airport	Discharge Point(s)	Parameter	Average Effluent(a)	Range of Data Points	# of Data Points
Chicago O'Hare International (ORD)	0110, 0210, 0310, 0410, 0610, 0810, 081A - Storm water (NW drainage)	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	111 NA 10.8 1,080	1.1 - 1,650 6.9 - 7.6 0.2 - 50 232 - 3,370	36 36 36 36
	0910, 1010, 1110, 1120, 1130, 1140 - Storm water (N drainage)	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	134 NA 11.2 645	1 - 2,150 6.0 - 7.6 0.2 - 50 227 - 1,620	34 34 34 34
	1210 - Storm water (NE drainage)	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	40.2 NA 3.4 1,200	2.5 - 141 6.9 - 7.5 0.6 - 10 105 - 2,080	6 6 6 6
	1410 - Storm water (SE drainage)	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	117 NA 35.1 1,050	9.2 - 342 6.7 - 7.6 2.6 - 85 624 - 1,340	6 6 6 6
	3720, 3730, 4710 - Storm water (SW drainage)	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	291 NA 8.28 1,740	0.9 - 3,100 6.8 - 7.6 0.7 - 37.5 211 - 8,470	17 17 17 17
	091A, 091B - drainage from deicing activities	BOD_5 (mg/L) pH (S.U.) NH_3 - N (mg/L) TDS (mg/L)	381 NA 50 727	264 - 497 7.3 50 616 - 837	2 2 2 2
Louisville International - Standiford Field (SDF)	011, 021, 031, 041, 061 - Storm water/ deicing fluid runoff	Benzene (ug/L) BOD_5 (mg/L) Ethylbenzene (ug/L) Naphthalene (ug/L) NH_3 - N (mg/L) Oil and grease (mg/L) DO (mg/L) pH (S.U.) TSS (mg/L) Toluene (ug/L) Xylene (ug/L)	<7.62 77.7 <8.48 <15.2 <17.2 <1.27 7.9 NA 473 <5 <5	<5 - 97 3 - 1,250 <5 - 127 <5 - 361 <0.03 - 171 <1 - 3.5 0.270 - 13.0 7.0 - 9.1 2.00 - 3,530 <5 <5	27 27 27 27 27 27 27 27 27 27 27

Table 8-2 (Continued)

Airport	Discharge Point(s)	Parameter	Average Effluent(a)	Range of Data Points	# of Data Points
Baltimore/ Washington International (BWI)	306A and 307A - Outfall 003 (runway, terminal, and deicing pad drainage)	BOD_5 (mg/L)	1,010	23 - 2,510	4
		EG (mg/L)	<10	<10	4
		TKN (mg/L)	12.8	2 - 27	4
		pH (S.U.)	NA	6.7 - 7.5	4
	007A and 703A - Storm water runoff (from taxiway, terminal, and ramps)	BOD_5 (mg/L)	412	197 - 769	4
		EG (mg/L)	<10	<10	4
		Petroleum Hydrocarbons (mg/L)	1	1	1
		TKN (mg/L)	2.25	2 - 3	4
		pH (S.U.)	NA	6.7 - 7.1	4
Minneapolis-St. Paul International (MSP)	010M and 01AM - Mother Lake and Duck Lake drainage (runways and taxiways)	BOD_5 (tons/mo)	0.1	<0.001 - 0.5	10
		BOD_5 (mg/L)	90.9	1 - 694	10
		BOD_{40} (mg/L)	5.50	2 -10.0	4
		PG (mg/L)	137	9.4 - 596	5
		EG (mg/L)	14.4	4.1 - 32.6	3
		COD (mg/L)	243	6 - 1,880	10
		NH_3 - N (mg/L)	11.5	0.09 - 50.6	10
		NH_3 (mg/L)	0.638	0.002 - 5.27	10
		TKN (mg/L)	20.2	0.3 - 75	9
		Oil and grease (mg/L)	2.28	0.8 - 7.7	7
		DO (mg/L)	7.02	1.8 - 9.7	10
		pH (S.U.)	NA	7.1 - 8.5	10
		P (mg/L)	0.329	0.07 - 0.83	8
		TSS (mg/L)	15.3	2 - 76	10
		Toluene (mg/L)	0.002	0.002	1
	020M, 030M, 03AM - Minnesota River North and Snelling Lake drainage (terminal, runway, and taxiway drainage)	BOD_5 (tons/mo)	14	0.1 - 83	18
		BOD_5 (mg/L)	497	5 - 2,140	18
		BOD_{40} (mg/L)	319	8 - 676	12
		PG (mg/L)	313	3.2 - 1,660	14
		EG (mg/L)	95.8	2.6 - 561	10
		COD (mg/L)	763	2.9 - 4,320	18
		NH_3 - N (mg/L)	19.4	0.48 - 124	18
		NH_3 (mg/L)	0.671	0.02 - 10.7	18
		TKN (mg/L)	48.4	1.3 - 290	18
		Oil and grease (mg/L)	3.90	1.2 - 9.6	17
		DO (mg/L)	4.82	0.9 - 9.6	18
		pH (S.U.)	NA	6.8 - 8.1	18
		P (mg/L)	0.114	0.01 - 0.41	16
		TSS (mg/L)	15.6	5 - 54	18
		Benzene (ug/L)	4.7	0.1 - 12	4
		Ethylbenzene (ug/L)	2.7	0.2 - 5	4
		Toluene (ug/L)	6.2	0.2 - 23	6
		Xylene (ug/L)	16.3	3 - 30	4

Table 8-2 (Continued)

Airport	Discharge Point(s)	Parameter	Average Effluent(a)	Range of Data Points	# of Data Points
Minneapolis-St. Paul International (cont.)	040M - Minnesota River South drainage area (terminal and cargo areas)	BOD_5 (tons/mo)	10	0.001 - 41	6
		BOD_5 (mg/L)	641	5 - 1,210	6
		BOD_{40} (mg/L)	26.0	18 - 34	2
		PG (mg/L)	853	137 - 1,830	4
		EG (mg/L)	27.9	1.7 - 54.2	4
		COD (mg/L)	1,250	37 - 3,170	6
		NH_3 - N (mg/L)	44.2	0.04 - 172	6
		NH_3 (mg/L)	8.18	0.003 - 42.7	6
		TKN (mg/L)	77.5	1 - 235	6
		Oil and grease (mg/L)	15.8	2.8 - 67	6
		DO (mg/L)	4.72	1.9 - 7.6	6
		pH (S.U.)	NA	8.2 - 8.7	6
		P (mg/L)	0.378	0.18 - 0.73	6
		TSS (mg/L)	32.8	10 - 67	6
		Benzene (ug/L)	0.45	0.3 - 0.6	2
		Ethylbenzene (ug/L)	1.7	1.7	1
		Toluene(ug/L)	18	1.8 - 34.6	2
		Xylene (ug/L)	1.2	1.2	1
Newark International (EWR)	006A - Storm water from terminal	TOC (mg/L)	16	9 - 23	7
		Hydrocarbons (mg/L)	2.45	1 - 3.9	7
		pH (S.U.)	NA	6.1 - 7.0	7
		TSS (mg/L)	11.3	3 - 38	7
	008A, 009A, 013A, 014A, 014B, 015A - Storm water from runway	TOC (mg/L)	83.5	7 - 1,120	32
		COD (mg/L)	189	49 - 338	7
		Hydrocarbons (mg/L)	<1.98	<0.4 - 8.8	39
		pH (S.U.)	NA	5.1 - 7.5	39
		TSS (mg/L)	<12.5	<2 - 64	39
Westchester County (HPN)	001A and 003A - Storm water from ponds	BOD_5 (mg/L)	2.82	2 - 7.2	14
		PG (mg/L)	32.8	0.05 - 220	12
		Oil and grease (mg/L)	5	5	14
		pH (S.U.)	NA	6.9 - 8.6	14
	004A, 008A, 009A - Storm water from buildings and hangars	BOD_5 (mg/L)	4.92	2 - 37	21
		PG (mg/L)	0.134	0.05 - 0.82	18
		Oil and grease (mg/L)	5	5	21
		pH (S.U.)	NA	6.3 - 8.8	21
	005A, 006A, 007A - Storm water from taxiways and ditch drainage	BOD_5 (mg/L)	2.53	2 - 8.4	19
		PG (mg/L)	0.213	0.05 - 1.3	17
		Oil and grease (mg/L)	5	5	19
		pH (S.U.)	NA	6.0 - 8.0	19
Tompkins County (ITH)	001M, 004M, 005M - Storm water runoff	BOD_5 (mg/L)	<3	<3 - 3	18
	002M - Storm water from deicing/fueling pad	Oil and grease (mg/L)	<0.5	<0.5 - 0.5	7
		pH (S.U.)	NA	6.8 - 7.5	7

Table 8-2 (Continued)

Airport	Discharge Point(s)	Parameter	Average Effluent(a)	Range of Data Points	# of Data Points
Syracuse Hancock International (SYR)	001M, 003M, 004M, 005M, 006M, 007M - Storm water runoff	BOD_5 (mg/L)	<334	<4 - 3,500	30
		Oil and grease (mg/L)	<6.18	<4 - 26	36
		pH (S.U.)	NA	6.8 - 8.2	36
		TSS (mg/L)	<11.5	<4 - 19	6
		NH_3 - N (mg/L)	7.3	0.17 - 24.3	14
		Benzene (ug/L)	<2.5	<1 - <5	12
Nashville International (BNA)	002G - Effluent from treatment basin	BOD_5 (mg/L)	38.1	3 - 98	7
		HEM (mg/L)	<6.71	<1 - 14	7
		COD (mg/L)	<69.6	<20 - 130	7
		DO (mg/L)	8.64	6.4 - 11.9	7
		pH (S.U.)	NA	7.2 - 8.6	7
		TSS (mg/L)	32.7	18 - 55	7
Salt Lake City International (SLC)	001A, 002A, 003A - Storm water discharge from terminal, runway, apron, and cargo areas	BOD_5 (mg/L)	332	11 - 1,050	11
		Nitrate/Nitrite (mg/L)	4.73	0.9 - 9	5
		Oil and grease (mg/L)	9	8 - 10	2
		COD (mg/L)	835	104 - 3,880	12
		pH (S.U.)	NA	6.6 - 9.5	21

(a) Data represent only the 1997-1998 Deicing Season.

Key:

BOD_5	-	5-day biochemical oxygen demand.
BOD_{40}	-	40-day biochemical oxygen demand.
COD	-	Chemical oxygen demand.
DO	-	Dissolved oxygen.
EG	-	Ethylene glycol.
HEM	-	Hexane extractable material (i.e., oil and grease).
NA	-	Not applicable.
NH_3	-	Ammonia - un-ionized.
NH_3-N	-	Ammonia as Nitrogen.
P	-	Phosphorus.
PG	-	Propylene glycol.
TDS	-	Total dissolved solids.
TKN	-	Total kjeldahl nitrogen.
TSS	-	Total suspended solids.
<	-	Not detected or maximum concentration.

Table 8-3

Standard Analytical Methods for Parameters Included in EPA's Airport Deicing Sampling Program

Parameter	Method Number
Ammonia as nitrogen	350.2
Biochemical oxygen demand (5-day)	405.1
Total organic carbon	415.1
Glycols	624
Metals (including potassium)	1620
Volatile organic compounds	1624C
Semivolatile organic compounds (including tolyltriazoles)	1625C
Hexane extractable material	1664
Silica-gel treated hexane extractable material	1664
Whole effluent toxicity: Fathead Minnow (*Pimephales promelas*) Cladoceran (*Ceriodaphnia dubia*)	NA

NA - Method number not applicable. Analytical methods per Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Fresh Water and Marine Organisms, U.S. EPA, August 1993.

Table 8-4

Analytical Results for Analytes Detected in Type I Aircraft Deicing Fluids (50% Solution), Raw Wastewater from Airport Deicing/Anti-Icing Operations, and a Stormwater Outfall EPA Sampling Data

		Type I Deicing Fluids (50% Solution)		Raw Wastewater Samples					Storm Water Outfall Samples
				Albany International Airport					
Priority Pollutant Code	Analyte	Ethylene Glycol-Based Fluid	Propylene Glycol-Based Fluid	Small Lagoon	Composite of Large Lagoon and Tank	Kansas City International Airport	Bradley International Airport	Greater Rockford Airport	Bradley International Airport
	VOLATILE ORGANICS (μg/L)								
P038	ETHYLBENZENE	ND(100)	580	ND(10)	NA	NA	NA	NA	NA
P086	TOLUENE	ND(100)	620	ND(10)	NA	NA	NA	NA	NA
	M- + P-XYLENE	ND(100)	2,800	ND(10)	NA	NA	NA	NA	NA
	SEMIVOLATILE ORGANICS (μg/L)								
	N-HEXADECANE	ND(500)	ND(100)	ND(10)	ND(10)	ND(10)	110	ND(10)	ND (10)
P066	BIS(2-ETHYLHEXYL) PHTHALATE	7,200	350	>200	ND(10)	ND(10)	ND(100)	ND(10)	ND (10)
P068	DI-N-BUTYL PHTHALATE	100	ND(100)	ND(10)	ND(10)	ND(10)	ND(100)	ND(10)	ND (10)
	N-DODECANE	3,000	ND(100)	ND(10)	ND(10)	ND(10)	ND(1,000)	ND(10)	ND (10)
	5-METHYL-1H-BENZOTRIAZOLE	2,000	2,200,000	>2,000	2,200	17,000	90,000	120	200
P065	PHENOL	ND(500)	ND(100)	110	64	93	280	ND(10)	ND (10)
	N-TETRADECANE	ND(500)	ND(100)	ND(10)	ND(10)	ND(10)	140	ND(10)	ND (10)
	GLYCOLS (mg/L)								
	ETHYLENE GLYCOL	NA	NA	ND(10)	ND(10)	3,200	3,000	ND(10)	ND (10)
	DIETHYLENE GLYCOL	NA	NA	ND(5.0)	ND(5.0)	>20,000	15,000	ND(5.0)	ND (5.0)
	PROPYLENE GLYCOL	NA	NA	2,700	1,200	16,000	160,000	ND(5.0)	180

ND - Analyte not detected (followed by detection limit).
NA - Not analyzed.
> - Minimum concentration.

Table 8-4 (Continued)

Priority Pollutant Code	Analyte	Type I Deicing Fluids (50% Solution)		Albany International Airport		Raw Wastewater Samples			Storm Water Outfall Samples
		Ethylene Glycol-Based Fluid	Propylene Glycol-Based Fluid	Small Lagoon	Composite of Large Lagoon and Tank	Kansas City International Airport	Bradley International Airport	Greater Rockford Airport	Bradley International Airport
	METALS (μg/L)								
	ALUMINUM	230	120	530	1,100	860	1,100	270	69
P114	ANTIMONY	ND(20)	91	ND(2.0)	ND(2.0)	ND(2.0)	ND(20)	ND(2.0)	2.3
P115	ARSENIC	24	360	ND(1.0)	ND(1.0)	2.8	ND(1.0)	3.4	ND (1.0)
	BARIUM	3.0	24	89	86	60	36	31	91
	BORON	1,400	36	ND(26)	ND(26)	ND(26)	ND(26)	ND(26)	220
P118	CADMIUM	240	6.7	1.0	1.4	3.4	11	ND(1.0)	ND (1.0)
	CALCIUM	1,100	2,000	38,000	36,000	34,000	33,000	14,000	41,000
P119	CHROMIUM	3.5	ND(1)	2.7	3.6	5.0	7.2	3.7	ND (1.0)
P120	COPPER	20	44	ND(9.0)	14	14	44	9.2	ND (9.0)
	IRON	230	670	3,500	9,200	1,200	3,400	810	7,100
P122	LEAD	53	110	6.6	9.5	15	50	4.3	ND (2.0)
	MAGNESIUM	ND(89)	ND(70)	7,100	7,400	2,500	2,000	3,000	12,000
	MANGANESE	ND(1.0)	40	1,100	1,000	170	140	360	1,600
P123	MERCURY	NQ	NQ	ND(0.2)	ND(0.2)	ND(0.2)	0.29	ND(0.2)	ND (0.2)
	POTASSIUM	20,000	NA	64,000	57,000	13,000	ND(900)	64,000	ND (900)
P125	SELENIUM	NQ	890	ND(2.0)	ND(2.0)	ND(20)	ND(20)	ND(2.0)	ND (20)
P126	SILVER	ND(5.0)	ND(4.0)	ND(5.0)	ND(5.0)	ND(5.0)	6.6	ND(5.0)	ND (5.0)
	SODIUM	36,000	24,000	62,000	63,000	11,000	10,000	7,900	75,000
P127	THALLIUM	ND(1.0)	330	ND(1.0)	ND(1.0)	ND(1.0)	ND(10)	ND(1.0)	ND (1.0)
	TIN	1,100	1,300	12	12	20	180	ND(5.0)	ND (4.0)
	TITANIUM	ND(3.0)	ND(4.0)	6.4	11	68	44	9.1	ND (5.0)
	VANADIUM	ND(11)	ND(10)	ND(10)	ND(10)	ND(10)	16	ND(10)	ND (10)

ND - Analyte not detected (followed by detection limit).
NQ - Analyte not quantified due to matrix interference.

Table 8-4 (Continued)

Priority Pollutant Code	Analyte	Type I Deicing Fluids (50% Solution)		Albany International Airport		Raw Wastewater Samples			Storm Water Outfall Samples
		Ethylene Glycol-Based Fluid	Propylene Glycol-Based Fluid	Small Lagoon	Composite of Large Lagoon and Tank	Kansas City International Airport	Bradley International Airport	Greater Rockford Airport	Bradley International Airport
P128	ZINC	190	440	110	130	140	340	45	ND (10)
	CLASSICAL WET CHEMISTRY (mg/L)								
	AMMONIA AS NITROGEN	3.0	5.4	88	84	3.9	23	46	1.1
	BIOCHEMICAL OXYGEN DEMAND (5-DAY)	NA	NA	12,000	9,800	5,100	39,000	>7.3	61
	TOTAL ORGANIC CARBON (TOC)	410,000	210,000	2,400	2,500	3,000	35,000	12	26
	SILICA-GEL TREATED HEXANE EXTRACTABLE MATERIAL	NA	NA	ND(5.0)	ND(5.0)	6.0	65	ND(6.0)	ND (5.0)
	HEXANE EXTRACTABLE MATERIAL	NA	NA	ND(6.0)	ND(6.0)	10	170	100	ND (5.0)
	WHOLE EFFLUENT TOXICITY (LC 50, endpoint (%))								
	CERIODAPHNIA DUBIA (48-HOUR ACUTE)	NA	NA	NA[1]	NA[1]	58	1.2	NA[1]	>100
	PIMEPHALES PROMELAS (96-HOUR ACUTE)	NA	NA	NA[1]	NA[1]	40	3.1	NA[1]	>100

ND - Analyte not detected (followed by the detection limit).
NA - Analyte not analyzed.
> - Minimum concentration.
1 - Wastewater expected to be toxic to aquatic life due to high ammonia concentration.
LC 50, endpoint (%) - Percentage of raw wastewater that kills 50% of the aquatic test population (i.e., the lower the percentage, the greater the aquatic toxicity). When less than 50% of the test populations dies in all sample concentrations tested up to and including the 100% raw wastewater, the results are reported as >100%.

Table 8-5

Analytical and Toxicity Data Provided by Fluid Formulators for Type I Aircraft Deicing Fluids

Parameter	UCAR™ Aircraft Deicing Fluid Concentrate	Octaflo Concentrate
Ethylene glycol (% weight)	92	N/A
Propylene glycol (% weight)	N/A	88
Chemical oxygen demand (mg O_2/mg of fluid)	1.14	NA
Percentage biodegradation	69 (5-day)	61 (7-days)
	85 (10-days)	84 (14-days)
	96 (20-days)	93 (21-days)
Rainbow trout (LC_{50}, 96-hour)(mg/L)	17,100	NA
Fathead minnows (LC_{50}, 96-hour)(mg/L)	22,000	1,250
Daphnia magna (LC_{50}, 48-hour)(mg/L)	NA	750

N/A - Not applicable.
NA - Data not available.

9.0 TOXICITY OF DEICING/ANTI-ICING AGENTS

During aircraft and airfield deicing operations, deicing agents are released to the land, air, and surface waters. Release of these agents may adversely affect the environment, aquatic wildlife, and human health. Aircraft deicing/anti-icing fluids (ADFs) typically contain water, glycols, and additives. The toxicity exhibited by ADFs is due in part to the presence of glycols (which typically make up approximately 45% to 65% of the total fluid by weight when applied), but is also due to the additives contained in the fluids. Although additives comprise a small percentage of ADFs (e.g., less than 2%), they may be responsible for a disproportionate share of the toxicity of ADFs. The toxicity of pavement deicing agents is mainly due to the application of glycols and urea; however, there are other more benign pavement deicing agents currently used.

Several toxicity studies have been performed using pure ethylene glycol and propylene glycol but few studies have been performed using formulated ADFs. The formulations are considered trade secrets, and only limited information is currently available on the actual chemical compositions of formulated ADFs. Some information is available on the types of compounds that may be included as additives in ADFs. The fluid manufacturers indicate that their formulas change often, potentially as often as every year. In general, toxicity studies are available for pavement deicers either from literature sources or from the manufacturers.

Sections 9.1 and 9.2 discuss toxicity tests performed to determine the aquatic and mammalian (including human) health effects of pure ethylene glycol and propylene glycol and of formulated ADFs containing ethylene or propylene glycol, respectively. Section 9.3 discusses tests performed using pure diethylene glycol and formulated deicing/anti-icing fluid containing diethylene glycol, a freezing-point depressant that is commonly used in deicing/anti-icing fluids in Europe. Diethylene glycol is also a byproduct in the manufacturing of ethylene glycol. This section also discusses the toxicity of isopropanol, another possible freezing point depressant alternative. Section 9.4 discusses the toxicity of runway deicing chemicals which include urea, potassium acetate, sodium formate, calcium magnesium acetate, and others. All tables are presented at the end of this section.

9.1 Comparison of Pure Ethylene Glycol to Pure Propylene Glycol

Ethylene glycol and propylene glycol are synthetic clear liquid substances that absorb water. Ethylene glycol is classified as a hazardous air pollutant (HAP) by Congress, and is required to be reported by users under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) if 5,000 pounds or more in a 24-hour period are released to the environment (see Section 13.2.1 for more information on CERCLA reporting). Propylene glycol is similar in chemical and physical properties to ethylene glycol, but is not classified as a HAP and is not required to be reported if released. In addition to its use as a deicing/anti-icing agent, propylene glycol is commonly used in small amounts as a food additive and in cosmetics and certain medicines to absorb moisture.

Several toxicity studies have been performed using pure ethylene glycol and propylene glycol. The results of these studies generally show that both ethylene glycol and propylene glycol are similar in aquatic toxicity and are fairly nontoxic to the aquatic environment.

Ethylene glycol has been proven to be toxic to mammals, especially humans, when directly ingested (1). It is also classified as a teratogen (likely to cause birth defects) if ingested in large doses (1). When propylene glycol is ingested in regulated amounts as a food additive, it does not have the same toxic effects as ethylene glycol (2). Neither ethylene glycol nor propylene glycol is believed to be toxic by adsorption through the skin or by breathing air containing mists or vapors of either compound.

9.1.1 Aquatic Toxicity

Both ethylene glycol and propylene glycol exhibit similar aquatic toxicity characteristics. Acute and chronic tests have been performed for both glycols. Data were acquired from several sources, particularly individual studies that performed similar tests on both ethylene glycol and propylene glycol. Tests were performed on both freshwater and marine aquatic life. Acute tests were performed to determine the lethal concentration for 50% of the sample population (LC_{50}) over a short period of time (48 to 96 hours). Chronic tests were performed over a longer period of time (7 to 14 days).

Table 9-1 summarizes aquatic toxicity data from studies that directly compare ethylene glycol and propylene glycol under the same or similar experimental conditions. In general, the data show that ethylene glycol and propylene glycol exhibit aquatic toxicological effects at concentrations within the same order of magnitude. Although EPA does not use such a system, the U.S. Fish and Wildlife Service Classification System for Acute Exposures defines "relatively harmless" as any chemical with an LC_{50} above 1,000 mg/L (3). The test results shown in Table 9-1 indicate that ethylene glycol and propylene glycol may be classified as "relatively harmless," as defined by the U.S. Fish and Wildlife Service.

The results show that both ethylene glycol and propylene glycol exhibit acute toxicity (LC_{50}) at a concentration above 10,000 milligrams per liter (mg/L). Toxicity values vary based on the species tested. The lowest LC_{50} for ethylene glycol and propylene glycol occurred at a concentration of 27,600 mg/L and 23,800 mg/L, respectively, among sheepshead minnow during a 96-hour test (4).

Table 9-2 lists additional aquatic toxicity studies performed using either ethylene glycol or propylene glycol. The data from these studies may not be directly comparable to other available data due to differences in experimental conditions (e.g., dissolved oxygen concentration, life stage, temperature). The results of these additional studies generally agree with the data presented in Table 9-1. Table 9-2 presents the additional data sources and their references.

9.1.2 Mammalian Toxicity

There are three main exposure routes for ethylene glycol and propylene glycol: inhalation, oral, and dermal (through skin adsorption). Inhalation and dermal exposure to ethylene glycol are not expected to exhibit toxic effects (2). Data based on human oral exposure (accidental or intentional) of ethylene glycol are available, and several animal studies have been used to corroborate the findings (2). When ingested, ethylene glycol quickly breaks down in the body. As it breaks down, it forms chemicals that crystallize and affect kidney functions, and forms acidic chemicals that alter the body's normal chemical balance (2). Inhalation, oral, and dermal exposure to propylene glycol are not expected to lead to toxic effects, although some data suggest oral exposure to propylene glycol may cause allergic reactions with minor side effects (2). Although propylene glycol is approved for use in small amounts as a food additive for human consumption, the Food and Drug Administration (FDA) recently excluded propylene glycol from its generally recognized as safe (GRAS) status in or on cat food (61 FR 19542). The FDA concluded that there are significant questions about the safety of propylene glycol in cat food based on scientific literature (5). Propylene glycol also quickly breaks down in the body but does not form crystals or acidic chemicals in the body (2).

For both ethylene glycol and propylene glycol, information on several different health effects over varying periods of time (acute and chronic) were collected. These health effects include: lethal effects, systemic effects, immunological and lymphoreticular effects, neurological effects, reproductive effects, developmental effects, genotoxic effects, and carcinogenic effects. Levels of effects are divided into two categories: no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect-levels (LOAELs). LOAELs are classified into "less serious" (i.e., effects not expected to cause significant dysfunction or death) or "serious" (i.e., effects that evoke failure in a biological system and can lead to morbidity or mortality). Below is a summary of the results of several studies (e.g., inhalation, oral, and dermal) compiled by the U.S. Department of Health and Human Services on these different health effects of ethylene glycol and propylene glycol (2).

9.1.2.1 Inhalation Exposure

There are limited data available for ethylene glycol and propylene glycol that describe the human health effects associated with breathing air containing either glycol.

- Lethal - No evidence is currently available in which humans or animals died after inhalation exposure to either glycol. Clinical studies indicate that inhalation of ethylene glycol and propylene glycol is not likely to result in death.

- Systemic - Systemic effects on humans included irritation and reports of headache following inhalation exposure to ethylene glycol; no data are currently available for systemic effects on humans following propylene glycol exposure. Animals exposed to propylene glycol did not experience serious systemic effects.

- Immunological and lymphoreticular - No evidence is currently available that links immunological effects to inhalation of either ethylene glycol or propylene glycol.

- Neurological - No evidence is currently available that links neurological effects to inhalation of either ethylene glycol or propylene glycol.

- Reproductive - No evidence is currently available that links reproductive effects in humans to inhalation of ethylene glycol and propylene glycol; however, in one study, mice exposed to ethylene glycol exhibited increased postimplantation loss (i.e., exhibited increased occurrence of miscarriage). No evidence is currently available that links reproductive effects in animals to inhalation of propylene glycol.

- Developmental - No evidence is currently available that links developmental effects in humans to inhalation of ethylene glycol and propylene glycol; however, mice exposed to ethylene glycol exhibited skeletal malformations and reduced fetal body weight. No evidence is currently available that links developmental effects in animals to inhalation of propylene glycol.

- Genotoxic - No evidence is currently available that links in vivo genotoxic effects in humans or animals to inhalation of either ethylene glycol or propylene glycol.

- Carcinogenic - One study that examined health histories of workers in a chemical plant that were exposed to ethylene glycol concluded that inhalation of ethylene glycol poses negligible cancer risks. No evidence is currently available that links inhalation of propylene glycol to cancer.

9.1.2.2 Oral Exposure

Significant data exist that show the adverse effects associated with oral exposure to ethylene glycol. The main exposure route is direct ingestion. The results show that, when ingested, ethylene glycol can be considered acutely toxic because, even after one ingestion, it can significantly adversely impact human health and may even lead to death. Propylene glycol is a common additive in foods, and is not associated with serious adverse effects following ingestion at low levels.

- Lethal - In cases where humans directly ingested ethylene glycol and died, the lethal amount ranged from 2,379 to 23,786 mg/kg, although some cases exist where the amount ingested is not known. One study concluded that a dose of 1,559 mg/kg of ethylene glycol is lethal (1). Rats and dogs fed similar doses to each other resulted in at least 10% and, in some cases, 100% mortality. No cases were found in which humans died after ingesting propylene glycol. One case did report a horse dying of respiratory failure after ingesting propylene glycol. Studies of oral exposure of propylene glycol to rats resulted in no deaths.

- Systemic - Serious systemic effects in humans and animals occurred following ingestion of ethylene glycol, including cardiovascular, gastrointestinal, renal, and metabolic effects. Less serious effects in animals, including gastrointestinal, hematological, and endocrine effects, resulted after ingestion of propylene glycol.

- Immunological and lymphoreticular - No evidence is currently available that links immunological effects to ingestion of either ethylene glycol or propylene glycol.

- Neurological - Neurological effects were reported in humans, and are among the first symptoms in humans following ethylene glycol ingestion. Such effects include ataxia, slurred speech, irritation, restlessness, and disorientation and may be followed by convulsions and coma. Ingestion of propylene glycol may also result in neurological effects in allergic individuals, including stupor and repetitive convulsions.

- Reproductive - No evidence is currently available that links reproductive effects in humans to ingestion of either ethylene glycol or propylene glycol. Reproductive studies on mice and rats following ingestion of ethylene glycol are inconclusive, and no adverse reproductive effects were found in mice after ingesting propylene glycol.

- Developmental - No evidence is currently available that links developmental effects in humans to ingestion of either ethylene glycol or propylene glycol. Ingestion of ethylene glycol caused harmful developmental effects in mice, including reduced litter sizes, reduced fetal body weight, and malformations. No evidence is currently available that links development effects in mice to ingestion of propylene glycol.

- Genotoxic - No evidence is currently available that links in vivo genotoxic effects in humans to ingestion of ethylene glycol or propylene glycol. Rats receiving oral doses of ethylene glycol exhibited no lethal mutations.

- Carcinogenic - No evidence is currently available that links cancer in humans to ingestion of ethylene glycol. In two different studies performed on mice and rats, ingesting ethylene glycol over a two-year period did not produce carcinogenic results. No information is currently available that links ingestion of propylene glycol to cancer.

9.1.2.3 Dermal Exposure

Dermal exposure of ethylene glycol and propylene glycol is not likely to cause adverse human or animal impacts.

- Death - No evidence is currently available that links death to dermal exposure of either ethylene glycol or propylene glycol.

- Systemic - No serious systemic effects in humans or animals were found following dermal exposure to ethylene glycol or propylene glycol, with one exception. Serious systemic effects were found in an infant with serious burns who was treated with a dermal dressing that included high levels of propylene glycol. The infant suffered acute respiratory acidosis and cardiorespiratory arrest. After being resuscitated, the baby was discovered to have serious neurological damage. Although the actual source of the infant's problem could not be determined, propylene glycol cannot be ruled out as the potential harmful agent.

- Immunological and lymphoreticular - No evidence is currently available that links immunological effects in humans or animals to dermal exposure to ethylene glycol or propylene glycol. However, since propylene glycol is widely used in the pharmaceutical industry for dermally applied medications, several studies were performed to investigate its potential to irritate the skin. The results of the studies show that propylene glycol has "marginal irritant properties."

- Neurological - No evidence is currently available that links neurological effects in humans or animals to dermal exposure to ethylene glycol or propylene glycol.

- Reproductive - No evidence is currently available that links reproductive effects in humans to dermal exposure to ethylene glycol. Pregnant mice dermally exposed to ethylene glycol exhibited no adverse reproductive effects. No evidence is currently available that links reproductive effects in humans or animals to dermal exposure to propylene glycol.

- Developmental - No evidence is currently available that links developmental effects in humans to dermal exposure to ethylene glycol. Pregnant mice exposed to ethylene glycol exhibited no adverse developmental effects. No evidence is currently available that links developmental effects in humans or animals to dermal exposure to propylene glycol.

- Genotoxic - No evidence is currently available that links genotoxic effects in humans or animals to dermal exposure to ethylene glycol or propylene glycol.

- Carcinogenic - No evidence is currently available that links carcinogenic effects in humans or animals to dermal exposure to ethylene glycol. No evidence is currently available that links carcinogenic effects in humans to dermal exposure to propylene glycol. No increase in tumors was found in one study on mice after twice weekly applications of propylene glycol to skin.

Table 9-3 presents toxicity data for humans following dermal, oral, and inhalation exposure to ethylene glycol and propylene glycol. Unlike aquatic toxicity tests, tests performed on humans and animals using ethylene glycol and propylene glycol almost always focused on either ethylene or propylene glycol, but not both, and hence were performed under various conditions. Therefore, the toxicity results are not directly comparable. Accordingly, the data in Table 9-3 show ethylene glycol results followed by propylene glycol results, and not side by side. In addition, no human toxicity data are currently available for inhalation and oral exposure to propylene glycol and dermal exposure to ethylene glycol. It is important to recognize that more studies have been performed using ethylene glycol than for propylene glycol.

9.2 Toxicity of Additives and Formulated Aircraft Deicing/Anti-Icing Fluids (ADF)

ADFs typically consist of a formulation of ethylene glycol or propylene glycol, water, and chemical additives such as flame retardants and corrosion inhibitors. The additives contribute significantly to the overall toxicity of ADFs. For example, available data demonstrate that the additives in ADFs may cause adverse aquatic toxic effects (6). For these reasons, it is important to examine the toxicity of formulated fluids in addition to that of pure ethylene glycol and propylene glycol to determine the toxicological effects of ADFs released to the environment from airport deicing/anti-icing operations. The identity of the actual chemicals used as additives is not known because the ADF manufacturers claim this information confidential; however, general information is known about the types of additives and their possible role in the toxicity of ADFs. Section 9.2.1 discusses this general information. Sections 9.2.2 and 9.2.3 provide available toxicity data for ADFs and compare toxicity among various types of ADFs.

Based on available data, the toxicity exhibited by pure ethylene glycol and propylene glycol is significantly lower, and therefore less toxic, than the corresponding formulated fluids. The reason for this difference is the toxicity of the chemicals that are added, albeit in small amounts, to formulated fluids. Test results indicate that formulated fluids are more toxic than pure glycol substances (1). For example, in a study conducted at Stapleton Airport in Denver, Colorado, a propylene glycol-based ADF exhibited significantly more acute aquatic toxicity than pure propylene glycol. In chronic studies performed at the airport, the concentration that inhibits growth and reproduction in 25% of the test organisms (IC_{25}) of pure propylene glycol for fathead minnows was 6,941 mg/L, whereas the IC_{25} of propylene glycol-based deicing ADF (type unknown) was 112 mg/L (1). The lower the toxic concentration value, the more toxic the substance. Note, however, that both of these studies were performed several years ago, and more recent ADF formulations would likely exhibit less toxicity.

9.2.1 Aircraft Deicing Fluid Components

As stated previously, the identity of many of the chemical compounds that are added to deicing fluids is unknown; however, general information about the types of additives that may be included in fluid packages is known. For example, the Air Transport Association (ATA) prepared a list of deicing fluid constituents in 1994 (7). According to this list, typical ADF components include or have included:

- Ethylene glycol or propylene glycol;
- Water;
- Surfactants (wetting agents);
- Corrosion inhibitors (including flame retardants);
- pH buffers;
- Dyes;
- 1,4-Dioxane; and
- Complex polymers (thickening agents in Type II and Type IV ADFs).

Other common additives (or manufacturing byproducts) include diethylene glycol, ethylene oxide, and acetaldehyde (1).

Deicing fluids are composed mostly of glycol and water. The remaining components comprise approximately 1% or less of Type I fluids and 2% or less of Type II and Type IV fluids (8). ADFs are required to meet performance-based standards that are established by the Society for Automotive Engineers (SAE). SAE standards for deicing fluids can be found in Aerospace Material Specification (AMS) 1424, and for anti-icing fluids in AMS 1428. ADFs would be unable to meet SAE standards without additives. Manufacturers and formulators have attempted to reduce the toxicity of additives present in their aircraft deicing/anti-icing fluid formulations and, when possible, to use environmentally benign chemicals. For example, one manufacturer uses a food-grade dye in its deicing fluids that is photoreactive and readily degrades in the environment. Manufacturers and formulators also stress that some additives perform multiple functions. They claim that they could replace these additives with several less toxic additives, but the combined toxicity may be greater than the toxicity of the original additive (9). As discussed in Section 13.5.3, the SAE fluids subcommittee is currently working to set an ADF toxicity standard in the near future.

The potential adverse environmental and health effects of each of the ADF components are discussed below.

9.2.1.1 Glycol

Fluid formulations contain varying amounts of glycol. Typical Type I ADFs contain approximately 90% glycol (by weight) in concentrated form. As applied, they contain between 30% and 60% glycol (typically approximately 50%), whereas Type II and Type IV ADFs contain higher percentages of glycol, closer to 65 percent. In general, by themselves, both ethylene glycol and propylene glycol are relatively nontoxic to the aquatic environment. Ethylene glycol is fairly nontoxic to mammals, except when ingested. Several documented cases show that ethylene glycol, when ingested, may be lethal. Available data indicate that propylene glycol is nontoxic to mammals. See Section 9.1 for a more detailed discussion on the toxicity of pure ethylene glycol and pure propylene glycol.

9.2.1.2 Surfactants

Surfactants, or wetting agents, are substances that reduce the surface tension of fluids and aid fluids in spreading or adhering to aircraft surfaces. They may comprise approximately 0.4% to 0.5% by volume of deicing fluids (7). Surfactants can be very toxic to aquatic organisms (1). At acutely toxic concentrations (concentration unknown), the primary effect on fish would be damage to gill tissue, although it is not known if these tests were conducted using the same surfactants that are used in deicing fluids (1).

9.2.1.3 Corrosion Inhibitors and Flame Retardants

Corrosion inhibitors act to prevent aircraft components that have been covered with deicing/anti-icing fluids from corroding, and flame retardants act to reduce the flammability hazard created when fluids are applied to metal aircraft surfaces that carry electric currents (6). Corrosion inhibitors may comprise up to 0.5% by volume of ADFs and are present at approximately 100 to 300 mg/L (6, 10). The corrosion inhibitor and flame retardant most commonly used in deicing fluids is 5-methyl-1H-benzotriazole (common name: tolyltriazole or TTZ), although 1H-benzotriazole (common name: benzotriazole or BTZ) may also be used. Aquatic toxicity data available for TTZ (summarized below) indicate that it is significantly more toxic than glycols.

Species	**Duration**	**LC_{50} for TTZ (mg/L)**	**LC_{50} for Ethylene Glycol (mg/L)**	**LC_{50} for Propylene Glycol (mg/L)**
Bluegill sunfish (*Lepomis macrochirus*)	96-h LC_{50}	31	27,540	Not available
Water flea (*Daphnia magna*)	48-h LC_{50}	74	46,300 - 54,700	43,500

Sources: References (6, 11, 12, 13).

Little mammalian toxicity data are available for TTZ, although it is considered harmful if swallowed and may cause irritation on contact (14). According to the Merck Index, it has a lethal dose at which 50% of the test organisms die (LD_{50}) of 720 mg/kg for rats (14). BTZ was identified by Environment Canada's National Water Research Institute as a potentially toxic additive in ADFs (10).

Scientists and researchers are currently studying the toxic effects of tolyltriazoles. In a study performed by D. Cancilla et al. in 1996, results verified the presence of TTZ and BTZ in deicing and anti-icing fluids (15). The results also showed that both TTZ and BTZ have significant Microtox® activity, although TTZ was more acutely toxic than BTZ. Microtox® testing was conducted using the standard method for various exposure times and temperatures.

The median effective toxicity concentration (EC_{50}) was measured as the concentration at which light lost in the sample equals the light remaining in a sample of bioluminescent bacteria. Results for TTZ and BTZ are presented below.

Compound	5-min. EC_{50} (mg/L)	15-min. EC_{50} (mg/L)
Benzotriazole	41	42
Tolyltriazole	6	6

Source: Reference (15).

Another common corrosion inhibitor includes phosphate esters, which may comprise up to 0.125% by volume of deicing fluids (7). Phosphate esters ($(RO)_3PO$) are derivatives formed by phosphoric acids and alkyl or aryl alcohols. The degree of toxicity of phosphate esters varies. Some phosphate esters can be highly toxic and even carcinogenic (17).

Other common corrosion inhibitors include sodium nitrite, sodium benzoate, and borax (17). Corrosion inhibitors are highly reactive with each other and with glycols, which can result in high biological toxicity (1). In general, corrosion inhibitors are considered toxic chemicals because of their high reactivity potential (1).

9.2.1.4 pH Buffers

pH buffers are solutions that maintain the fluid at a constant pH. The addition of alkali or acid would result in only minimal changes to fluid pH. pH buffers are thought to comprise less than 0.25% by volume of deicing fluids (7). A common pH buffer is potassium hydroxide (7), which on its own is highly caustic upon contact, may be lethal upon ingestion, and is extremely corrosive (14). It has an oral LD_{50} of 1,230 mg/kg for rats (14).

9.2.1.5 Colorants or Dyes

Colorants or dyes (organic based) are chemicals used to color deicing fluids. They are thought to comprise less than 0.25% by volume of deicing fluids (7). Deicing fluids are colored to make them visible so that deicing personnel can see where fluids have been applied and where they have fallen to the ground. In general, Type I fluids are dyed orange and Type II and IV fluids are dyed green. Due to the wide range of potential colorants used in ADFs, no useful information could be collected on the toxicity of colorants or dyes.

9.2.1.6 1,4-Dioxane

1,4-Dioxane is used as a wetting and dispersing agent and is thought to comprise less than 0.5 mg/L of deicing fluids (7). Dioxane is a suspected carcinogen and/or teratogen (1). EPA has reason to believe that some fluid manufacturers have removed 1,4-dioxane from their formulations. However, it is present in at least one ADF, although, according to the fluid's manufacturer, its source is as an impurity that occurs at extremely low levels (18). 1,4-dioxane has low acute aquatic and mammalian toxicity and may be irritating to humans on contact; however, it can exhibit significant chronic toxicity (14). Prolonged exposure to 1,4-dioxane has resulted in several human deaths (14). The oral LD_{50} in mice and rats is 5,700 mg/kg and 5,200 mg/kg, respectively (14).

9.2.2 Aquatic Toxicity Data for ADF

Few aquatic toxicity experiments have been performed using formulated ADFs. Those that have been performed used a variety of experimental conditions, making it difficult to directly compare data. Table 9-4 summarizes toxicity data from studies that directly compare ethylene glycol-based and propylene glycol-based ADFs by fluid type under the same experimental conditions. Table 9-4 also summarizes all available data for the fathead minnow and *Ceriodaphnia dubia* because EPA selected these species for its aquatic toxicity tests (see Section 8.1). It is important to note that the formulation of these fluids frequently changes. Deicing fluid manufacturers state that any toxicity data collected using a specific ADF are quickly outdated as they develop less toxic additives. Information provided by an ethylene glycol-based ADF manufacturer shows toxicity in current formulations to be as much as an order of magnitude less than older formulations (8). Aquatic toxicity data from two deicing fluid formulators for concentrated deicing fluid (i.e., Type I) are summarized below. Both of these formulations are currently used in the U.S.

Species	Duration and Endpoint	Type I EG-Based Deicing Fluid Concentration (mg/L)	Type I PG-Based Deicing Fluid Concentration (mg/L)
Fathead Minnow (*Pimephales promelas*)	96-h LC_{50}	22,000	1,250
Rainbow Trout (*Oncorhynchus mykiss*)	96-h LC_{50}	17,100	NA
Water Flea (*Daphnia magna*)	48-h EC_{50}	44,000	NA
Water Flea (*Daphnia magna*)	48-h LC_{50}	NA	750

Reference: (19, 20).
NA - Not available.
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.

The results above and in Table 9-4 show that, for most aquatic species, the current ethylene glycol-based Type I ADFs exhibit acute aquatic toxicological effects at higher concentrations (i.e., are less acutely toxic) than the current propylene glycol-based Type I ADFs. Note that these data were collected under laboratory conditions in compliance with SAE specifications and not under actual field conditions.

Few sources of toxicity data that directly compare Type IV ethylene glycol-based and propylene glycol-based ADFs are available. Toxicity data for Type IV ADF provided by two fluid manufacturers are presented below. Both of these formulations are currently used in the U.S. Note that these data show toxicity results similar to those for Type II ADFs and that data were collected under laboratory conditions in compliance with SAE specifications and not under actual field conditions.

Species	Duration and Endpoint	Type IV EG-Based Deicing/Anti-icing Fluid Concentration (mg/L)	Type IV PG-Based Deicing/Anti-icing Fluid Concentration (mg/L)
Fathead Minnow (*Pimephales promelas*)	96-h LC_{50}	370	NA
Rainbow Trout (*Oncorhynchus mykiss*)	96-h LC_{50}	380	NA
Water Flea (*Daphnia magna*)	48-h LC_{50}	630	975

Reference: (19, 20).
NA - Not available.
LC_{50} - Median lethal concentration that kills 50% of the test organisms.

In general, Type I ADFs, regardless of chemical basis, may be considered "relatively harmless" per the U.S. Fish and Wildlife Service Classification System[1]. In contrast, Type II/IV ADFs, with an LC_{50} in the range of 10 to greater than 1,000 mg/L are considered in the range of "slightly toxic" to "relatively harmless" (3).

Based on the available data, the current propylene glycol-based Type IV fluid exhibits toxicity at similar concentrations to the same manufacturer's current Type I fluid. These results suggest that additives in propylene glycol-based Type IV fluid may not significantly impact aquatic toxicity. However, the ethylene glycol-based Type IV fluid is significantly more toxic to aquatic life than the same manufacturer's Type I fluid.

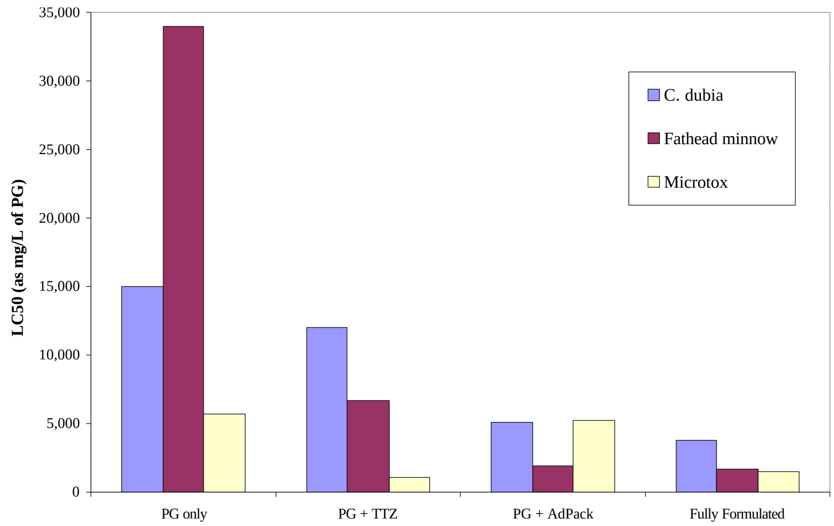
Table 9-5 lists additional toxicity studies performed using either only ethylene glycol-based or propylene glycol-based ADFs on only Type I or Type II fluids. The data from these studies may not be directly comparable due to differences in experimental conditions (e.g.,

[1]Although EPA does not use such a system, the U.S. Fish and Wildlife Classification System for Acute Exposures defines "relatively harmless" as any chemical with an LC_{50} above 1,000 mg/L (3).

temperature, pH). The results of these studies generally agree with the data provided in Table 9-4.

As discussed in Section 8.1, General Mitchell International Airport (GMIA) performed aquatic toxicity tests under actual field conditions (i.e., in-stream sample collection during a storm event). The results show an acute toxic ADF in-stream concentration to fathead minnows and *Ceriodaphnia dubia* above 1,000 mg/L (i.e., LC_{50} > 1,000 mg/L).

Aquatic toxicity tests performed by Cornell, Pillard, and Hernandez show different test organisms to be affected by different ADF components (6, 21). Tests were performed using pure propylene glycol, propylene glycol and TTZ, propylene glycol and the additives package excluding TTZ (e.g., only surfactants, dyes, buffers), and two propylene glycol-based fully formulated fluids (from different manufacturers). The *Ceriodaphnia dubia* (*C. dubia*) and fathead minnow were only highly affected by the propylene glycol and additives package (i.e., excluding TTZ) while Microtox® organisms were only highly affected by the propylene glycol and TTZ (i.e., excluding the additives package). In general, the two formulated fluids (shown below as an average), which yielded similar results, were the most toxic combination to all test species. However, the effects of the fully formulated fluids on each test organism were similar (within an order of magnitude) to the effects of the most highly affected component alone, indicating that the most highly affected component controls the toxicological response as shown in the chart below. These results also suggest very different toxicity mechanisms for macroorganisms (e.g., *C. dubia* and fathead minnow) and microorganisms (e.g., Microtox® organisms) (6, 21). Table 9-6 presents the results of the toxicity tests.



PG - Propylene Glycol

9.2.3 Mammalian Toxicity Data for Aircraft Deicing Fluids

No mammalian toxicity data are currently available for ADFs. However, available aquatic toxicity data for ADFs as compared to pure ethylene glycol and propylene glycol, as well as data indicating the potential for ADF additives to cause adverse health effects in mammals, indicate that ADFs will exhibit mammalian toxicity at lower concentrations than pure glycols. As discussed in Section 9.2.1, some additives are known or suspected carcinogens or teratogens.

9.3 Toxicity of Other Freezing-Point Depressants

Ethylene glycol and propylene glycol are the most commonly used freezing point depressants in ADFs, although other freezing point depressants may be used or are currently being researched for approved use by the industry. Diethylene glycol is an SAE-approved freezing point suppressant for use in ADFs; however, no ADFs that are primarily diethylene glycol are currently approved for use in the U.S. Diethylene glycol-based deicing fluids are more commonly found in Europe, although some formulations used in the United States may contain a small portion of diethylene glycol (17).

Isopropyl alcohol (isopropanol) is currently used by the U.S. Air Force as a pavement deicer, but is not currently an SAE- or FAA-approved freezing point depressant for aircraft deicing (17). Although isopropanol is highly flammable and cannot meet the SAE specifications without the addition of fire suppressants, it may be a viable alternative due to its low cost and effectiveness as a freezing point depressant. EPA believes that research is currently being performed on the use of isopropanol for aircraft deicing.

Sections 9.3.1 and 9.3.2 discuss the toxicity of diethylene glycol and isopropanol, respectively.

9.3.1 Diethylene Glycol

Diethylene glycol exhibits similar toxicity characteristics to ethylene glycol but it has a higher eutectic temperature (i.e., minimum freezing point depression temperature) (22). EPA believes that diethylene glycol is not considered a favorable alternative at this time because of these factors. However, trace amounts of diethylene glycol may be commonly found in ethylene glycol-based ADFs (17).

Diethylene glycol is a clear, colorless, syrupy liquid that may be used as an anti-freeze, but is more commonly used in the petroleum refining industry as a solvent extractor (23). In its pure form, it has a freezing point of approximately -10° C (23). The freezing point of a 40% diethylene glycol and 60% water mixture is -18° C, while that of a 50/50 mixture is -28° C (the freezing point of a 50/50 mixture of ethylene glycol and water is -35° C) (14).

Fewer sources of aquatic toxicity data are available for diethylene glycol as compared to ethylene glycol and propylene glycol. Available data are summarized in Table 9-7 and show that diethylene glycol exhibits aquatic toxicity characteristics similar to ethylene glycol and propylene glycol. Based on these data, diethylene glycol may be considered “relatively harmless,” as classified by the U.S. Fish and Wildlife Service (3).

Diethylene glycol, like ethylene glycol, can be fatal if ingested, but it is not as toxic to mammals or humans via other exposure routes (e.g., inhalation, dermal). Table 9-8 summarizes mammalian toxicity data for diethylene glycol.

Diethylene glycol is an eye and human skin irritant (24). Exposure to diethylene glycol may result in nausea, vomiting, headaches, unconsciousness, convulsions, and even death (24). It can also cause degenerative changes in the kidneys and liver, respiratory failure, cardiovascular collapse, acute renal failure, and brain damage, among others (24).

In one documented case, children were accidentally given oral medication that was contaminated with diethylene glycol (at a median concentration of 14.4%). The median estimated toxic dose of diethylene glycol was estimated at 1.34 mL/kg and caused renal failure, hepatitis, pancreatitis, central nervous system impairment, coma, and death (25).

In a study performed to document clinical signs of toxicity in time-pregnant mice, researchers found that 1,250 mg/kg/day of diethylene glycol was a no-observed-adverse effect-level for maternal and developmental toxicity. Mice fed 5,000 mg/kg/day of diethylene glycol produced significant maternal toxicity (e.g., increased water intake, increased kidney weights) but no developmental toxicity. Mice fed 10,000 mg/kg/day of diethylene glycol produced significant maternal toxicity (e.g., increased water intake, decreased food consumption, increased kidney weights and renal lesions), significant developmental toxicity (e.g., decrease in fetal body weight), and resulted in one death during the study. Researchers found that diethylene glycol was not teratogenic in mice at the doses tested in the study (26).

9.3.2 Isopropyl Alcohol (Isopropanol)

Isopropanol is a commonly used chemical, although it is not commonly used for aircraft deicing. Based on responses to EPA's 1993 screener questionnaire, 14 airports were identified as using isopropanol for aircraft deicing; however, EPA was not able to identify any airports that currently use isopropanol-based ADFs. Reportedly, the National Aeronautics and

Space Administration (NASA) is researching the use of an alcohol-based ADF. A main drawback to an isopropanol-based ADF is that it would be corrosive and highly flammable and would, therefore, need to contain significant amounts of flame retardants, corrosion inhibitors, and other potentially toxic additives. On the other hand, from a cost perspective, isopropanol is significantly less expensive than glycols (27).

Isopropanol is a colorless, flammable liquid, that has a slight odor resembling ethanol and acetone (28). It is used in many industries, including chemical manufacturing and pharmaceutical manufacturing for solvent applications (23). It is commonly used as a deicing agent in liquid fuels. In its pure form, it has a freezing point of approximately -88.5° C (23). Exposure to isopropanol can irritate the eyes, nose, mouth, and throat, and overexposure can even cause death (29). It is regulated under Toxic Substances Control Act (TSCA) and Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and must be reported under TRI only if is being manufactured by a strong acid process, which is not applicable to this industry.

Available aquatic toxicity data show that isopropanol exhibits aquatic toxicity at concentrations similar to but slightly less than glycols. The available data are summarized in Table 9-9. The data also show that isopropanol may be considered “relatively harmless,” as classified by the U.S. Fish and Wildlife Service (3).

Isopropanol is considered toxic if ingested in large enough doses, or through the subcutaneous route. It is considered moderately toxic by intravenous and intraperitoneal routes, and mildly toxic by dermal contact. Human systemic effects can be the result of ingestion or inhalation. Experimentally, it has been shown to be teratogenic and cause negative reproductive effects. It is also considered an eye and skin irritant. Based on inadequate evidence, it is not classified as a carcinogen; however, there is an increased incidence of nasal sinus cancer in workers involved in the manufacture of isopropanol by the strong acid process. Exposure to isopropanol can lead to skin irritation, dizziness, nausea, lowered blood pressure, abdominal pain, and can even lead to coma and death (29). Table 9-10 summarizes mammalian toxicity data for isopropanol.

9.4 Toxicity of Pavement Deicers

Pavement deicing agents may cause significant adverse environmental impacts, although many airports are beginning to use less harmful agents. Pavement and runway deicing and anti-icing agents approved by the FAA include urea, ethylene glycol (including an ethylene glycol-based fluid known as UCAR, containing approximately 50% ethylene glycol, 25% urea, and 25% water by weight), potassium acetate, calcium magnesium acetate (CMA), sodium acetate, and sodium formate. Alternative agents that may be used for runway deicing include isopropanol and propylene glycol. Salts including magnesium chloride, sodium chloride, and potassium chloride are not approved for use in aircraft operational areas because they are corrosive to aircraft. Sand is used on some airfields to increase friction and improve aircraft braking performance. Pavement and runway deicers must meet specifications set by the SAE or the United States military (MIL-SPEC). Until recently, most commercial airports used urea and/or glycols to deice pavement areas. Due to negative environmental impacts from these agents, several airports currently use more environmentally benign agents, such as potassium acetate, sodium formate, and CMA. Corrosion inhibitors are often added to runway deicers to meet the SAE and MIL-SPEC specifications. As discussed in Section 9.2.1.3, corrosion inhibitors may exhibit high mammalian and aquatic toxicity. Each of the approved agents and resulting adverse aquatic and health effects is discussed below. Available information on the biochemical oxygen demand of deicing agents can be found in Section 10.1.2.

9.4.1 Urea

Urea is typically applied to pavement and runway areas in granular form. Urea is a common nutrient for algae and other water plants as a nitrogen source and is not considered toxic. However, urea degrades by hydrolysis to carbon dioxide and ammonia, which can be very toxic to aquatic organisms even at very low concentrations. Once ammonia is formed, it either remains in solution as ammonia or its ionized form (NH_4^+), biologically converts to other nitrogen forms (e.g., NO_3 or N_2), or volatilizes to the air. The following equations show the degradation of urea:

$$NH_2CONH_2\ (urea) + 2H_2O \Rightarrow NH_4^+ + NH_3 + HCO_3^- \qquad (1)$$

$$NH_4^+ + 1.5O_2 \Rightarrow NO_2^- + H_2O + 2H^+ \qquad (2)$$

$$NO_2^- + 0.5O_2 \Rightarrow NO_3^- \qquad (3)$$

Urea is considered to be nontoxic to aquatic organisms but it can irritate the nose and throat, causing a sore throat, sneezing or coughing, and shortness of breath in humans (30). Chronic exposure and acute exposure in high concentrations may cause eye damage, skin redness or rash (dermatitis), or emphysema (31). Toxicity data for urea are summarized below.

Species	Duration	Concentration/Dose
Barilius barna	96-h LC_{50}	>9,100 mg/L
Tilapia mossambica	96-h LC_{50}	22,500 mg/L
Leuciscus idus melanotus	48-h LC_{50}	>10,000 mg/L
Water Flea (*Daphnia magna*)	24-h EC_{50}	>10,000 mg/L
Mosquito (*Aedes aegypti*)	4-h LC_{50}	60,000 mg/L
Freshwater snail (*Helisoma trivolvis*)	24-h LC_{50}	30,060 mg/L (adults)
	24-h LC_{50}	18,255 mg/L (juvenile)
	24-h LC_{50}	14,241 mg/L (egg)
Rat	LD_{50} (oral)	14,300 mg/kg
	LD_{50} (subcutaneous)	8,200 mg/kg
Mouse	LD_{50} (intravenous)	4,600 mg/kg

Sources: References (30, 31).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
LD_{50} - Median lethal dose that kills 50% of the test organisms.
> - Minimum concentration.

Ammonia in its un-ionized form is one of the urea byproducts that may have significant adverse aquatic effects and reported LC_{50} values in the range of 1 to 10 mg/L (31). Aquatic toxicity data for ammonia in its un-ionized form are summarized below.

Species	Duration	Concentration (mg/L)
Fathead minnow (*Pimephales promelas)*	96-h LC_{50}	0.73 - 3.4; 8.2 (hard water)
Goldfish (*Carassius auratus*)	24-96-h LC_{50}	2 - 2.5
Rainbow trout (*Oncorhynchus mykiss*)	24-h LC_{50} (fertilized egg)	>3.58
	24-h LC_{50} (0-50 days old)	>3.58
	24-h LC_{50} (85 days old)	0.068
	24-h LC_{50} (adults)	0.097
Water flea (*Daphnia magna*)	48-h LC_{50}(static test)	189
Water flea (*Daphnia pulex*)	48-h LC_{50} (static test)	187

Source: Reference (23).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
> - Minimum concentration.

The formation of ammonia is highly dependent on the pH and temperature of a given stream. The higher the pH and temperature, the more ammonia is formed (Equation 1). Another potentially toxic byproduct of urea degradation is nitrous acid (formed from nitrite in an acidic solution), which reacts with secondary amines to form nitrosamines, many of which are known carcinogens (33).

The current ammonia criterion (i.e., allowable concentration) established by EPA for use by permit writers is based on toxicity of ammonia to fish and varies with the temperature and pH of the receiving stream. The warmer the stream and the higher its pH, the more likely ammonia will exist in its un-ionized form (i.e., toxic form), and, therefore, the lower EPA's maximum allowable concentration of ammonia should be set. The colder the stream and lower the pH, the higher EPA's maximum allowable concentration may be set. One factor affecting the maximum allowable concentration during cold seasons (i.e., deicing seasons) is that, for the most sensitive invertebrates, the toxicity of ammonia appears to decrease with decreasing temperature. Therefore, it is believed that the maximum allowable concentration of ammonia during cold seasons may be higher than other times of the year.

9.4.2 Ethylene Glycol

The use of ethylene glycol as a runway and pavement deicer is becoming less popular, due to its reporting requirements and adverse environmental impacts. However, it is an effective freezing point depressant and may still be used at airports subject to extreme temperatures. The toxicity of ethylene glycol and its potential impacts are discussed in Section 9.1.

Urea is often combined with ethylene glycol for use as a liquid runway deicer. The mixture is irritating to the eyes and skin (31). Ingestion can lead to mental sluggishness, difficulty in breathing, heart failure, kidney and brain damage, and death (31). Mammalian toxicity data for an ethylene glycol/urea mixture are presented below.

Species	Duration	Dose (mg/kg)
Rat	LD_{50} (oral)	4,700
	LD_{50} (intraperitoneal)	5,010
	LD_{50} (subcutaneous)	2,800
	LD_{50} (intravenous)	3,260
	LD_{50} (intramuscular)	3,300

Source: Reference (30).
LD_{50} - Median lethal dose that kills 50% of the test organisms.

9.4.3 Potassium Acetate

Based on EPA-sponsored site visits, potassium acetate is currently the most commonly used runway and pavement deicer, although airports have expressed concern that it may degrade insulation in electric systems (e.g., runway lights). An industry workgroup is currently investigating this issue. Potassium acetate alone is corrosive, so it is mixed with corrosion inhibitors, and is also slightly flammable. It is typically applied in its liquid form and may be combined with urea prior to application.

Potassium acetate is a common food additive and is relatively nontoxic to mammals in small doses, although it may cause eye irritation (31). The oral LD_{50} of potassium acetate (without additives) is 3,250 mg/kg for rats (14). Data for potassium acetate-based deicers are presented below.

Species	Duration	Concentration/Dose
Fathead minnow *(Pimephales promelas*)	LC_{50} (duration unknown)	>500 mg/L
	7-d LC_{50}	>1,500 mg/L
Rainbow trout (*Oncorhynchus mykiss*)	96-h LC_{50}	>2,100 mg/L
Water flea (*Daphnia magna*)	48-h LC_{50}	>3,000 mg/L
Rat	LD_{50}	>5,000 mg/kg

Source: Reference (31).
> - Minimum concentration/dose.

The identity and toxicity of corrosion inhibitors typically added to potassium acetate runway deicers is not currently known. Most airports are pleased with the performance of potassium acetate deicer, despite its suspected degradation of electric system insulation and higher cost than other deicers.

9.4.4 Calcium Magnesium Acetate (CMA)

CMA is typically applied in a solid granular form. It is an effective anti-icer that is relatively nontoxic to the environment, though it can be cost-prohibitive. Unlike magnesium chloride and other salts, CMA is not corrosive and, therefore, does not contain corrosion inhibitors. Aquatic and mammalian toxicity for CMA are summarized below. In addition, the results of a 28-day oral toxicity study performed on rats showed no observable effects at daily doses of 1,000 mg/kg (31).

Species	Duration	Concentration/Dose
Rainbow trout (*Oncorhynchus mykiss*)	96-h LC_{50}	>1,000 mg/L
Water flea (*Daphnia magna*)	48-h LC_{50}	>1,000 mg/L
Rat	LD_{50} (oral)	>5,000 mg/L
	LD_{50} (dermal)	>5,000 mg/kg
	4-h LC_{50} (inhalation)	4.6 mg/L

Source: Reference (31).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
LD_{50} - Median lethal dose that kills 50% of the test organisms.
> - Minimum concentration.

9.4.5 Sodium Acetate

Sodium acetate is typically applied in its solid form and is "relatively harmless," according to the U.S. Fish and Wildlife standards (31). Sodium acetate is not considered hazardous, but may irritate the skin on contact or irritate the respiratory tract following inhalation of dust. Acute aquatic and mammalian toxicity data are summarized below.

Species	Duration	Concentration/Dose
Water flea (*Daphnia magna*)	48-h LC_{50}	2,400 mg/L
Fathead minnow (*Pimephales promelas*)	24-h LC_{50}	2,750 mg/L
Rat	LD_{50} (oral)	3,530 mg/kg
Mouse	LD_{50} (subcutaneous)	8,000 mg/kg
Mouse	LD_{50} (intravenous)	335 mg/kg

Source: Reference (31).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
LD_{50} - Median lethal dose that kills 50% of the test organisms.

9.4.6 Sodium Formate

Sodium formate is typically applied in a pellet form and is mixed with corrosion inhibitors to meet the required specifications. Mammalian toxicity data for pure sodium formate (based on mice) are as follows (31):

- LD_{50} (oral) = 11,200 mg/kg; and
- LD_{50} (intraperitoneal) = 807 mg/kg.

Toxicity data obtained from a sodium formate deicer manufacturer are summarized below.

Species	Duration	Concentration/Dose
Water flea (*Daphnia magna*)	24-h EC_{50}	4,800 mg/L
	48-h EC_{50}	4,400 mg/L
	24-h EC_0	3,300 mg/L
	48-h EC_0	3,200 mg/L
Zebra fish	96-h LC_{50}	100 mg/L
Rat	LD_{50} (oral)	>2,000 mg/L
	4-h LC_{50} (inhalation)	>670 mg/L

Source: Reference (31).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
LD_{50} - Median lethal dose that kills 50% of the test organisms.
> - Minimum concentration.

Significant exposure to sodium formate deicer may adversely affect people suffering from chronic disease of the respiratory system, skin, and/or eyes. In addition, less sodium formate needs to be applied as compared to several other pavement deicers (e.g., urea) (17).

9.4.7 Alternative Pavement Deicers

Although they are available for use, isopropanol and propylene glycol are not typically used as runway or pavement deicers at commercial airports. EPA is aware of only one airport that mixes propylene glycol with hot sand; the average volume of propylene glycol used is less than 100 gallons per year at this airport. As discussed in Section 9.3.2, isopropanol is a highly flammable liquid that is also highly volatile. It requires special handling requirements and provides minimal anti-icing protection because of its high rate of evaporation. See Section 9.3.2 for a more detailed discussion on the toxicity of isopropanol. However, it is significantly less expensive than other runway deicers on a per gallon basis (27). Propylene glycol's high cost may deter airports from using it as a runway deicer alternative. The toxicological effects of propylene glycol are discussed in Section 9.1.

9.4.8 Chlorides

Magnesium chloride, sodium chloride, and potassium chloride are all used landside (i.e., roadway) but not as runway deicers due to their corrosive effects on aircraft and aircraft components. Salts are commonly used as nutrients and/or dietary supplement food additives in small doses. Large doses may cause adverse human health effects (e.g., gastrointestinal irritation or weakness) (14).

9.4.9 Sand

Sand is nontoxic to the environment and is effective for increasing friction between aircraft and pavement, but may interfere with the mechanical working of aircraft (e.g., engine stalls due to ingestion of sand). Sand is often mixed with other deicing agents (e.g., urea) prior to application.

9.5 References

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Table 9-1

Acute and Chronic Toxicity Data for Pure Glycols for Aquatic Species

Species	Duration and Endpoint	Life Stage	Temp. (° C)	Concentration of Pure Ethylene Glycol (mg/L)	Concentration of Pure Propylene Glycol (mg/L)	Reference
Rainbow Trout (*Oncorhynchus mykiss*)	24-h LC_{50}	0.64 g	12	65,100 (12)	79,700 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	0.64 g	12	54,500 (12)	79,700 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	0.64 g	12	54,500 (12)	51,600 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	0.3 - 5 g	12 - 15	50,800 (12) 45,600 (34) 17,800 (34) 22,810 (35) 24,591 (35) 41,000 (36)	51,600 (12) 45,600 (34) 42,380 (35) 37,067 (35)	Ward et al. 1992 (12) Mayer and Ellersieck 1986 (34) Beak Consultants 1995 (35) Johnson and Finley 1980 (36)
Fathead Minnow (*Pimephales promelas*)	24-h LC_{50}	0.3 g	22	83,400 (12)	77,800 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	0.3 g	22	52,300 (12)	54,000 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	7 d old	25	81,950 (37)	> 62,000 (37)	Pillard 1995 (37)
	72-h LC_{50}	0.3 g	22	52,300 (12)	51,400 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	0.3 - 0.4 g	21 -23	50,400 (12) 57,000 (38)	51,400 (12)	Ward et al. 1992 (12) Mayes et al. 1983 (38)
	96-h LC_{50}	7 d old	25	72,860 (37)	55,770 (37)	Pillard 1995 (37)
	96-h NOEC (mortality)	7 d old	25	39,140 (37)	52,930 (37)	Pillard 1995 (37)
	7-d NOEC (mortality)	7 d old	25	32,000 (37)	< 11,530 (37)	Pillard 1995 (37)
	7-d NOEC (growth)	7 d old	25	15,380 (37)	< 11,530 (37)	Pillard 1995 (37)
Goldfish (*Carassius auratus*)	24-h LC_{50}	6.2 cm 3.3 g	20	>5,000 (39)	>5,000 (39)	Bridie et al 1979 (39)
Clawed Frog (*Xenopus laevis*)	48-h LC_{50}	3-4 weeks old	20.0-20.5	19,350 (35) 15,667 (35)	18,700 (35) 24,285 (35)	Beak Consultants 1995 (35)
Water Flea (*Daphnia magna*)	24-h LC_{50}	<24 h old (0.19 mg)	20	80,600 (12)	70,700 (12)	Ward et al. 1992 (12)
	24-h EC_{50} (immobilization)	<24 h old	20	48,582 (40)	 >10,000 (41)	Lilius et al 1995 (40) Kuhn et al 1989 (41)
	48-h LC_{50}	<24 h old (0.19 mg)	20	54,700 (12) 46,300 (13) 51,100 (13)	43,500 (12)	Ward et al. 1992 (12) Cowgill et al 1985 (13)

Table 9-1 (Continued)

Species	Duration and Endpoint	Life Stage	Temp. (° C)	Concentration of Pure Ethylene Glycol (mg/L)	Concentration of Pure Propylene Glycol (mg/L)	Reference
Ceriodaphnia dubia	48-h LC_{50}	<24 h old	25	34,440 (37)	18,340 (37)	Pillard 1995 (37)
	48-h NOEC	<24 h old	25	24,000 (37)	13,020 (37)	Pillard 1995 (37)
	7-d NOEC (mortality)	<24 h old	25	24,000 (37)	29,000 (37)	Pillard 1995 (37)
	7-d NOEC (reproduction)	<24 h old	25	8,590 (37) 3,469 (35)	13,020 (37)	Pillard 1995 (37) Beak Consultants 1995 (35)
Green Algae (*Selenastrum capricornutum*)	24-h EC_{50}	1,000 cells/mL	24	<6,400 (12)	5,200 (12)	Ward et al. 1992 (12)
	48-h EC_{50}	1,000 cells/mL	24	13,100 (12)	34,100 (12)	Ward et al. 1992 (12)
	72-h EC_{50}	1,000 cells/mL	24	<6,400 (12)	24,200 (12)	Ward et al. 1992 (12)
	96-h EC_{50}	1,000 cells/mL	24	7,900 (12)	19,000 (12)	Ward et al. 1992 (12)
	14-d EC_{50}	1,000 cells/mL	24	18,200 (12)	18,100 (12)	Ward et al. 1992 (12)
	96-h IC_{50}	NR	25	13,067 (35)	20,690 (35)	Beak Consultants 1995 (35)
	96-h IC_{25}	NR	25	8,828 (35)	1,516 (35)	Beak Consultants 1995 (35)
	96-h LOEC	NR	25	13,925 (35)	126 (35)	Beak Consultants 1995 (35)
	96-h NOEC	NR	25	6,963 (35)	37 (35)	Beak Consultants 1995 (35)
	96-h IC_{25}	NR	25	5,336 (42)	20,800 (42)	DuFresne and Pillard 1995 (42)
Duckweed (*Lemna minor*)	96-h IC_{25} (frond growth)	5 plants/ beaker	25	17,115 (42)	12,000 (42)	DuFresne and Pillard 1995 (42)
	96-h LOEC (frond growth)	5 plants/ beaker	25	10,000 (42)	5,000 (42)	DuFresne and Pillard 1995 (42)
	96-h IC_{25} (chlorophyll)	5 plants/ beaker	25	19,848 (42)	21,882 (42)	DuFresne and Pillard 1995 (42)
	96-h LOEC (chlorophyll)	5 plants/ beaker	25	20,000 (42)	20,000 (42)	DuFresne and Pillard 1995 (42)
	96-h IC_{25} (pheophytin)	5 plants/ beaker	25	16,470 (42)	12,000 (42)	DuFresne and Pillard 1995 (42)

Table 9-1 (Continued)

Species	Duration and Endpoint	Life Stage	Temp. (° C)	Concentration of Pure Ethylene Glycol (mg/L)	Concentration of Pure Propylene Glycol (mg/L)	Reference
Duckweed (cont.)	96-h LOEC (pheophytin)	5 plants/ beaker	25	40,000 (42)	20,000 (42)	DuFresne and Pillard 1995 (42)
Sheepshead minnow (*Cyprinodon variegatus*)	24-h LC_{50}	0.74 g	22	81,700 (12)	63,500 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	0.74 g	22	74,800 (12)	52,500 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	0.74 g	22	39,100 (12)	35,900 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	0.74 g	22	27,600 (12)	23,800 (12)	Ward et al. 1992 (12)
Mysid (*Mysidopsis bahia*)	24-h LC_{50}	2.4 mg	22	73,900 (12)	31,000 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	2.4 mg	22	52,600 (12)	27,300 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	2.4 mg	22	43,600 (12)	23,400 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	2.4 mg	22	34,200 (12)	18,800 (12)	Ward et al. 1992 (12)
Marine algae (*Skeletonema costatum*)	24-h EC_{50}	1,000 cells/mL	20	<6,900 (12)	31,500 (12)	Ward et al. 1992 (12)
	48-h EC_{50}	1,000 cells/mL	20	23,900 (12)	19,000 (12)	Ward et al. 1992 (12)
	72-h EC_{50}	1,000 cells/mL	20	29,900 (12)	19,300 (12)	Ward et al. 1992 (12)
	96-h EC_{50}	1,000 cells/mL	20	44,200 (12)	19,100 (12)	Ward et al. 1992 (12)
	14-d EC_{50}	1,000 cells/mL	20	<5,300 (12)	<5,300 (12)	Ward et al. 1992 (12)

LC_{50} - Median lethal concentration that kills 50% of the test organisms.
NOEC - No-observed-effect concentration.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
IC_{25} - Concentration that inhibits growth and reproduction in 25% of the test organisms.
LOEC - Lowest concentration at which effects were observed.
(   ) - Reference for the data provided.

Table 9-2

Additional Acute and Chronic Toxicity Data Sources for Pure Glycols

Pure Glycol Type	Species	Reference
Ethylene Glycol	Rainbow trout (*Oncorhynchus mykiss*)	Beak Consultants 1995 (35)
	Fathead minnow (*Pimephales promelas*)	Mayes et al. 1983 (38)
		Beak Consultants 1995 (35)
	Bluegill sunfish (*Lepomis macrochirus*)	Mayer and Ellersieck 1986 (34)
		Abdelghani et al. 1990 (12)
	Guppy (*Poecillia reticulata*)	Konemann 1981 (43)
	Clawed frog (*Xenopus laevis*)	deZwart and Slooff 1987 (44)
	Water flea (*Daphnia magna*)	Gersich et al. 1986 (45)
		Hermens et al. 1984 (46)
		Calleja et al. 1994 (47)
		Bringmann and Kuhn 1977 (48)
	Water flea (*Daphnia pulex*)	Lilius et al. 1995 (40)
	Ceriodaphnia dubia	Cowgill et al. 1985 (13)
		Pillard 1995 (37)
		Beak Consultants 1995 (35)
	Streptocephalus probscideus	Calleja et al. 1994 (47)
	Chironomus tentans	Aeroports de Montreal 1995 (49)
	Crayfish (*Procambarus sp.*)	Abdelghani et al. 1990 (12)
	Rotifer (*Brachionus calciflorus*)	Beak Consultants 1995 (35)
		Calleja et al. 1994 (47)
	Ciliated protozoan (*Colpidium campylum*)	Beak Consultants 1995 (35)

Table 9-2 (Continued)

Pure Glycol Type	Species	Reference
Ethylene Glycol (con't.)	Green algae (*Selenastrum capricornutum*)	Aeroports de Montreal and Analex Inc. 1994 (50)
	Criptomonad (*Chilomonas paramecium*)	Ward and Boeri 1993 (51)
	Brine shrimp *(Artemia salina*)	Price et al. 1974 (52)
	Shrimp (*Crangon crangon*)	Blackman 1974 (53)
	Polychaeta (*Ophrytrocha labronica*)	Akesson 1970 (54)
Propylene Glycol	Rainbow trout (*Oncorhynchus mykiss*)	Majewski et al. 1978 (55)
	Fathead minnow (*Pimephales promelas*)	Pillard 1995 (37)
	Water flea (*Daphnia magna*)	Kuhn et al. 1989 (41)
	Ceriodaphnia dubia	Pillard 1995 (37)
	Green algae (*Selenastrum capicornutum*)	Dufresne and Pillard 1995 (42)
	Duckweed (*Lemna minor*)	Dufresne and Pillard 1995 (42)
	Harpaticoid copepod (*Nitocra spinipes*)	Tarkpea et al. 1986 (56)

(   ) - Reference for the data provided.

Table 9-3

Human Toxicity Data for Pure Ethylene Glycol and Propylene Glycol

Exposure Type	Health Effect	Exposure/ Duration/ Frequency	NOAEL	LOAEL and Seriousness	Reference
Inhalation	**Ethylene Glycol**				
	Systemic - Respiratory	15 min.		55 mg/L (less serious)	Wills et al. 1974 (57)
	Systemic - Hematological	30 days (20-22 hrs/day)	19 mg/L		Wills et al. 1974 (57)
	Systemic - Renal	30 days (20-22 hrs/day)	19 mg/L		Wills et al. 1974 (57)
	Neurological	30 days (20-22 hrs/day)		19 mg/L (less serious)	Wills et al. 1974 (57)
Oral (ingestion)	**Ethylene Glycol**				
	Death	Once		7,070 mg/kg/d (serious)	Gordon and Hunter 1982 (58)
		Once		4,071 mg/kg/d (serious)	Siew et al. 1975 (59)
		Once		2,379 mg/kg/d (serious)	Walton 1978 (60)
		Once		1,559 mg/kg/d (serious)	Verschueren 1983 (23)
	Systemic - Metabolism	Once		4,332 mg/kg/d (serious)	Cheng et al. 1987 (61)
		Once		7,070 mg/kg/d (serious)	Gordon and Hunter 1982 (58)
		Once		11,238 mg/kg/d (serious)	Heckerling 1987 (62)
		Once		3,171 mg/kg/d (serious)	Parry and Wallach 1974 (63)
		Once		7,600 mg/kg/d (serious)	Peterson et al. 1981 (64)
		Once		4,071 mg/kg/d (serious)	Siew et al. 1975 (59)
		Once		12,839 mg/kg/d (serious)	Spillane et al. 1991 (65)
	Systemic - Respiratory	Once		7,070 mg/kg/d (less serious)	Gordon and Hunter 1982 (58)

Table 9-3 (Continued)

Exposure Type	Health Effect	Exposure/ Duration/ Frequency	NOAEL	LOAEL and Seriousness	Reference
Oral (cont.)	Systemic - Cardiovascular	Once		7,070 mg/kg/d (serious)	Gordon and Hunter 1982 (58)
		Once		3,171 mg/kg/d (serious)	Parry and Wallach 1974 (58)
		Once		4,071 mg/kg/d (serious)	Slew et al. 1975 (59)
	Systemic - Renal	Once		7,070 mg/kg/d (serious)	Gordon and Hunter 1982 (58)
		Once		11,238 mg/kg/d (serious)	Heckerling 1987 (62)
		Once		2,714 mg/kg/d (serious)	Mallya et al. 1986 (66)
		Once		3,171 mg/kg/d (serious)	Parry and Wallach 1974 (63)
		Once		7,600 mg/kg/d (serious)	Peterson et al. 1981 (64)
		Once		4,071 mg/kg/d (serious)	Slew et al. 1975 (59)
		Once		12,839 mg/kg/d (serious)	Spillane et al. 1991 (65)
	Systemic - Gastrointestinal	Once		12,839 mg/kg/d (serious)	Spillane et al. 1991 (65)
	Neurological	Once		9,771 mg/kg/d (serious)	Blakeley et al. 1993 (67)
		Once		4,332 mg/kg/d (serious)	Cheng et al. 1987 (61)
		Once		7,070 mg/kg/d (less serious)	Gordon and Hunter 1982 (58)
		Once		11,238 mg/kg/d (serious)	Heckerling 1987 (62)
		Once		2,714 mg/kg/d (serious)	Mallya et al. 1986 (66)
		Once		3,171 mg/kg/d (serious)	Parry and Wallach 1974 (63)
		Once		4,071 mg/kg/d (serious)	Slew et al. 1975 (59)
		Once		12,839 mg/kg/d (serious)	Spillane et al. 1991 (65)

Table 9-3 (Continued)

Exposure Type	Health Effect	Exposure/ Duration/ Frequency	NOAEL	LOAEL and Seriousness	Reference
Dermal	**Propylene Glycol**				
	Systemic - Hematological	5 days (1x/day)	6,100 mg/kg		Commens 1990 (68)
	Systemic - Respiratory	70 hr (>1x/d)		9,000 mg/kg (serious)	Fligner et al. 1985 (69)
	Systemic - Cardiovascular	70 hr (>1x/d)		9,000 mg/kg (serious)	Fligner et al. 1985 (69)
	Systemic - Metabolism	70 hr (>1x/d)		9,000 mg/kg (serious)	Fligner et al. 1985 (69)
	Systemic - Dermal	20-24 hours		3.2% (less serious)	Hannuksela et al. 1975 (70)
		48 hours once		10 mg (less serious)	Kinnunen and Hannuksela 1989 (71)
		48 hours once		0.2 mg (less serious)	Kinnunen and Hannuksela 1989 (71)
		7 days (2x/day)	104 mg		Trancik and Malbach 1982 (72)
		48 hours once		2.5% (less serious)	Warshaw and Herrmann 1952 (73)
		48 hours once	15 mg	31 mg (less serious)	Willis et al. 1988 (74)
		48 hours once		16 mg (less serious)	Willis et al. 1989 (75)
	Systemic - Dermal	21-22 days		207 mg (less serious)	Trancik and Maibach 1982 (72)
	Immunological/ Lymphoreticular	20-24 hours		3.2% (less serious)	Hannuksela et al. 1975 (70)
	Neurological	70 hours (>1x/day)		9,000 mg/kg (serious)	Fligner et al. 1985 (69)

Note: No human toxicological data are available for inhalation and oral exposure to propylene glycol and dermal exposure to ethylene glycol.
NOAEL - No-observable-adverse-effect-level.
LOAEL - Lowest-observable-adverse-effect-level.
Serious - Effects that evoke failure in a biological system and can lead to morbidity or mortality.
Less Serious - Effects not expected to cause significant dysfunction or death.
(   ) - Reference for the data provided.

Table 9-4

Acute Toxicity Data for Type I and II Formulated Fluids

Species	Duration and Endpoint	Fluid Type	Life Stage	Temp. (° C)	Concentration of Ethylene Glycol Formulated Fluid (mg/L)	Concentration of Propylene Glycol Formulated Fluid (mg/L)	Reference
Fathead Minnow (*Pimephales promelas*)	96-h LC_{50}	I	14 d	20-25	12,000 (76) 10,635 (35)	4,900(76) 1,588(35)	Ward 1994 (76) Beak Consultants 1995 (35)
	7-d NOEC (mortality)	I	7 d	25	6,090 (37)	270 (37)	Pillard 1995 (37)
	7-d NOEC (growth)	I	7 d	25	<3,330 (37)	98 (37)	Pillard 1995 (37)
	7-d IC_{25} (growth)	I	7 d	25	3,660 (37)	110 (37)	Pillard 1995 (37)
	48-h LC_{50}	I	7 d	25	8,540 (37)	790 (37)	Pillard 1995 (37)
	48-h LC_{50}	I	60 d	21	10,940 (77)		Hartwell et al. 1993,1995 (77)
	96-h LC_{50}	I	60 d	21	10,940 (77)		Hartwell et al. 1993,1995 (77)
	7-d LC_{50}	I	60 d	21	10,940 (77)		Hartwell et al. 1993,1995 (77)
	96-h LC_{50}	I	7 d	25	8,050 (37)	710 (37)	Pillard 1995 (37)
	96-h LC_{50}	II	7 d	21-25	210 (76)	100 (76) 18 (77)	Ward 1994 (76) Hartwell et al. 1993, 1994 (77)
	48-h LC_{50}	II	7 d	22 - 25		42 (77)	Hartwell et al. 1993,1995 (77)
	7-d LC_{50}	II	7 d	22		18 (77)	Hartwell et al. 1993,1995 (77)
Rainbow Trout (*Oncorhynchus mykiss*)	96-h LC_{50}	I	0.3-5.0 g	15	10,635 (35)	2,096 (35)	Beak Consultants 1995 (35)
	96-h LC_{50}	I	juvenile	12	3,700 (76)	3,200 (76)	Ward 1994 (76)
	96-h LC_{50}	II	juvenile	11-12	200 (76)	38 (76)	Ward 1994 (76)

Table 9-4 (Continued)

Species	Duration and Endpoint	Fluid Type	Life Stage	Temp. (° C)	Concentration of Ethylene Glycol Formulated Fluid (mg/L)	Concentration of Propylene Glycol Formulated Fluid (mg/L)	Reference
Ceriodaphnia dubia	7-d NOEC (mortality)	I	<24 h	25	8,400 (37)	660 (37)	Pillard 1995 (37)
	7-d NOEC (reprod.)	I	<24 h	25	<3,330 (37)	600 (37)	Pillard 1995 (37)
	7-d IC_{25}	I	<24 h	25	3,960 (37)	640 (37)	Pillard 1995 (37)
	48-h LC_{50}	I	<24 h	25	13,140 (37)	1,020 (37)	Pillard 1995 (37)
	48-h EC_{50}	I	<24 h	21	7,730 (77)		Hartwell et al. 1993,1995 (77)
	96-h EC_{50}	I	<24 h	21	5,384 (77)		Hartwell et al. 1993,1995 (77)
	7-d EC_{50} (reprod.)	I	<24 h	21	1,817 (77)		Hartwell et al. 1993,1995 (77)
Water Flea (*Daphnia magna*)	48-h LC_{50}	I	<24h	20	26,185 (35)	4,192 (35)	Beak Consultants 1995 (35)
	48-h EC_{50}	I	<24h	20-21	7,100 (76)	6,000 (76)	Ward 1994 (76)
	48-h EC_{50}	II	<24h	19-21	120 (76)	280 (76)	Ward 1994 (76)
Sheepshead Minnow (*Cyprinodon variegatus*)	96-h LC_{50}	I	juvenile	22	19,000 (76)	7,000 (76)	Ward 1994 (76)
	96-h LC_{50}	II	juvenile	21-23	270 (76)	290 (76)	Ward 1994 (76)
Mysid (*Mysidopsis bahia*)	96-h LC_{50}	I	<24h	23-26	1,100 (76)	1,800 (76)	Ward 1994 (76)
	96-h LC_{50}	II	<24h	24-25	29 (76)	390 (76)	Ward 1994 (76)
Marine algae (*Skeletonema costatum*)	96-h LC_{50}	I	10,000 cells/mL	20-24	1,200 (76)	510 (76)	Ward 1994 (76)
	96-h LC_{50}	II	10,000 cells/mL	19-21	7 (76)	29 (76)	Ward 1994 (76)

LC_{50} - Median lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
(   ) - Reference for the data provided.

Table 9-5

Additional Aquatic Toxicity Data Sources for Formulated Fluids

Glycol and Fluid Type	Species	Reference
Ethylene Glycol Type I	*Daphnia pulex*	Hartwell et al. 1993; 1995 (77)
	Water flea (*Daphnia magna*)	HydroQual Laboratories 1994 (78)
		Hartwell et al. 1993; 1995 (77)
	Chironamus tentans	Aeroports de Montreal & Analex 1995 (49)
	Green algae (*Selenastrum capricornutum*)	Ward 1994 (76)
		Aeroports de Montreal & Analex 1995 (49)
Ethylene Glycol Type II	*Chironamus tentans*	Aeroports de Montreal & Analex 1995 (49)
	Green algae (*Selenastrum capricornutum*)	Aeroports de Montreal & Analex 1994 (50)
		Ward 1994 (76)
Propylene Glycol Type I	Green algae (*Selenastrum capicornutum*)	Ward 1994 (76)
Propylene Glycol Type II	*Daphnia magna*	Hartwell et al. 1993; 1995 (77)
	Daphnia pulex	Hartwell et al. 1993; 1995 (77)
	Green algae (*Selenastrum capicornutum*)	Ward 1994 (76)

(   ) - Reference for the data provided.

Table 9-6

Aquatic Toxicity Results for Formulated Fluids and Their Components

Species	Solution	Concentrations of Solution Tested PG/TTZ/Adpack (mg/L)	Duration	Concentration measured as PG (mg/L)	Concentration measured as TTZ (mg/L)
Ceriodaphnia dubia	PG + TTZ	10,000/600/0	48-h LC_{50}	1,647	98
		10,000/120/0	48-h LC_{50}	8,770	109
		20,000/110/0	48-h LC_{50}	11,842	68
	TTZ only	0/150/0	48-h LC_{50}	NA	108
		0/180/0	48-h LC_{50}	NA	102
	PG only	31,000/0/0	48-h LC_{50}	15,052	NA
	Fully formulated fluid	5,000/31/P[a]	48-h LC_{50}	3,829	24
		9,400/52/P[b]	48-h LC_{50}	3,224	18
	PG + additive pack	10,000/0/P[c]	48-h LC_{50}	5,122	NA
		11,000/0/P[d]	48-h LC_{50}	4,919	NA
Fathead minnow (*Pimephales promelas*)	PG + TTZ	10,000/120/0	96-h LC_{50}	3,566	43
		20,000/110/0	96-h LC_{50}	6,742	39
	TTZ only	0/150/0	96-h LC_{50}	NA	38
		0/190/0	96-h LC_{50}	NA	65
	PG only	99,000/0/0	96-h LC_{50}	34,060	NA
	Fully formulated fluid	5,000/28/P[a]	96-h LC_{50}	1,716	10
		9,000/52/P[b]	96-h LC_{50}	1,525	8
	PG + additive pack	10,000/0/P[c]	96-h LC_{50}	1,434	NA
		11,000/0/P[d]	96-h LC_{50}	1,866	NA
Microtox®	PG + TTZ	10,000/58/0	15-min EC_{50}	1,127	6
		10,000/600/0	15-min EC_{50}	153	9
	TTZ only	0/48/0	15-min EC_{50}	NA	7
	PG only	10,000/0/0	15-min EC_{50}	5,650	NA

Table 9-6 (Continued)

Species	Solution	Concentrations of Solution Tested PG/TTZ/Adpack (mg/L)	Duration	Concentration measured as PG (mg/L)	Concentration measured as TTZ (mg/L)
Microtox® (cont.)	Fully formulated fluid	10,000/61/P[a]	15-min EC_{50}	950	6
		9,400/52/P[b]	15-min EC_{50}	1,497	8
	PG + additive pack	10,000/0/P[c]	15-min EC_{50}	5,247	NA

Source: Reference (15).
PG - propylene glycol.
TTZ - 4-methyl-benzotriazole and 5-methyl-benzotriazole (common name: tolyltriazole).
NA - Not applicable.
LC_{50} - Lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally
P[a] - Present at an unknown concentration (proprietary information) from Manufacturer 1 (TTZ present).
P[b] - Present at an unknown concentration (proprietary information) from Manufacturer 2 (TTZ present).
P[c] - Present at an unknown concentration (proprietary information) from Manufacturer 1 (without TTZ).
P[d] - Present at an unknown concentration (proprietary information) from Manufacturer 2 (without TTZ).

Table 9-7

Aquatic Toxicity Data for Diethylene Glycol

Species	Duration & Endpoint	Life Stage	Temp. (° C)	Concentration of Diethylene Glycol (mg/L)	Reference
Rainbow trout (*Oncorhynchus mykiss*)	24-h LC_{50}	4.1 cm & 0.64 g	12	87,100 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	4.1 cm & 0.64 g	12	79,800 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	4.1 cm & 0.64 g	12	55,400 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	3.5 - 4.1 cm & 0.42 - 0.64 g	12 - 15	52,800 (12) 62,934 (35)	Ward et al. 1992 (12) Beak Consultants 1995 (35)
Fathead minnow (*Pimephales promelas*)	24-h LC_{50}	3.1 cm & 0.3 g	22	86,800 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	3.1 cm & 0.3 g	22	86,800 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	3.1 cm & 0.3 g	22	86,800 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	3.1 cm & 0.3 g	22	84,100 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	19.1 mm & 0.102 g	24.9	75,200 (79)	Geiger et al. 1990 (79)
Guppy (*Poecillia reticulata*)	168-h LC_{50}	2-3 cm	22	61,000 (43)	Konemann 1981 (43)
Goldfish (*Carassius auratus*)	24-h LC_{50}	6.2 cm & 3.3 g	20	>5,000 (39)	Bridie et al. 1979 (39)
Clawed toad (*Xenopus laevis*)	48-h LC_{50}	3-4 weeks old	20	20,358 (35) 20,496 (35) 3,065 (44)	Beak Consultants 1995 (35) deZwart and Zloof 1987 (44)
Water flea (*Daphnia magna*)	24-h LC_{50}	< 24 h old	20 - 22	>10,000 (48) 78,500 (12)	Bringmann and Kuhn 1977 (48) Ward et al. 1992 (12)
	48-h LC_{50}	< 24 h old	20	47,200 (12)	Ward et al. 1992 (12)
Green algae (*Selenastrum capricornutum*)	24-h EC_{50}	1,000 cells/mL	24	6,400 (12)	Ward et al. 1992 (12)
	48-h EC_{50}	1,000 cells/mL	24	24,000 (12)	Ward et al. 1992 (12)
	72-h EC_{50}	1,000 cells/mL	24	6,400 (12)	Ward et al. 1992 (12)
	96-h EC_{50}	1,000 cells/mL	24	19,900 (12)	Ward et al. 1992 (12)
	14-d EC_{50}	1,000 cells/mL	24	37,000 (12)	Ward et al. 1992 (12)
Sheepshead minnow (*Cyprinodon variegatus*)	24-h LC_{50}	0.74 g	20	90,700 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	0.74 g	20	87,900 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	0.74 g	20	79,600 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	0.74 g	20	62,100 (12)	Ward et al. 1992 (12)

Table 9-7 (Continued)

Species	Duration & Endpoint	Life Stage	Temp. (° C)	Concentration of Diethylene Glycol (mg/L)	Reference
Mysid (*Mysidopsis bahia*)	24-h LC_{50}	2.4 mg	22	54,900 (12)	Ward et al. 1992 (12)
	48-h LC_{50}	2.4 mg	22	43,800 (12)	Ward et al. 1992 (12)
	72-h LC_{50}	2.4 mg	22	42,900 (12)	Ward et al. 1992 (12)
	96-h LC_{50}	2.4 mg	22	36,900 (12)	Ward et al. 1992 (12)
Brine shrimp (*Artemia salina*)	24-h LC_{50}	nauplii	24.5	>10,000 (52)	Price et al. 1974 (52)
Marine algae (*Skeletonema costatum*)	24-h EC_{50}	1,000 cells/mL	20	8,900 (12)	Ward et al. 1992 (12)
	48-h EC_{50}	1,000 cells/mL	20	26,900 (12)	Ward et al. 1992 (12)
	72-h EC_{50}	1,000 cells/mL	20	27,300 (12)	Ward et al. 1992 (12)
	96-h EC_{50}	1,000 cells/mL	20	40,800 (12)	Ward et al. 1992 (12)
	14-d EC_{50}	1,000 cells/mL	20	22,600 (12)	Ward et al. 1992 (12)

LC_{50} - Median lethal concentration that kills 50% of the test organisms.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
(   ) - Reference for the data provided.

Table 9-8

Mammalian Toxicity Data for Diethylene Glycol

Exposure Type	Species	Typical Dose	Amount	Units
Inhalation	Mouse	Lowest published lethal concentration	130	mg/m^3/2 hours
Oral	Human	Lowest published lethal dose	1,000	mg/kg
	Dog	LD_{50}	9,000	mg/kg
	Guinea pig	LD_{50}	7,800	mg/kg
	Cat	LD_{50}	3,300	mg/kg
	Mouse	LD_{50}	23,700	mg/kg
	Rabbit	LD_{50}	4,400	mg/kg
	Rat	LD_{50}	12,565	mg/kg
Dermal	Rabbit (intravenous)	Lowest published lethal dose	2,236	mg/kg
	Mouse (subcutaneous)	Lowest published lethal dose	5,000	mg/kg
	Rabbit (skin)	LD_{50}	11,890	mg/kg
	Mouse (intraperitoneal)	LD_{50}	9,719	mg/kg
	Rat (intravenous)	LD_{50}	6,565	mg/kg
	Rat (subcutaneous)	LD_{50}	18,800	mg/kg
	Rat (intraperitoneal)	LD_{50}	7,700	mg/kg

Source: Reference (23).
LD_{50} - Median lethal dose that kills 50% of the test organisms.

Table 9-9

Aquatic Toxicity Data for Isopropanol

Species	Duration & Endpoint	Life Stage	Temperature (° C)	Concentration of Isopropanol (mg/L)
Fathead minnow (*Pimephales promelas*)	1-h LC_{50}	NA	NA	11,830
	24-h LC_{50}	NA	NA	11,160
	48-h LC_{50}	NA	NA	11,130
	72-h LC_{50}	NA	NA	11,130
	96-h LC_{50}	NA	NA	11,130
Water flea (*Daphnia magna*)	EC_{50} (reproduction)	NA	NA	3,010
	NOEC (reproduction)	NA	NA	2,100
	NOEC (growth)	NA	NA	757
	24-h LC_{50}	NA	NA	9,500
Goldfish (*Carassius auratus*)	24-h LC_{50}	NA	NA	>500
Brown shrimp (*Crangon crangon*)	48-h LC_{50}	NA	NA	1,400
	98-h LC_{50}	NA	NA	1,150
Guppy (*Poecilia reticulata*)	7-d LC_{50}	NA	NA	7,060
Green algae (*Scenedesmus quadricauada*)	7-d EC_0	NA	NA	1,800
Microtox™ (*Photobacterium*) test	5-min EC_{50}	NA	NA	22,800

Source: Reference (20).
LC_{50} - Median lethal concentration that kills 50% of the test organisms.
NOEC - No-observed-effect concentration.
EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.
NA - Not available.

Table 9-10

Mammalian Toxicity Data for Isopropanol

Exposure Type	Species	Typical Concentration/Dose	Amount	Units
Inhalation	Rat	Lowest published lethal concentration	16,000	mg/m^3/4 hours
	Mouse	Lowest published lethal concentration	12,800	mg/m^3/3 hours
Oral	Human	Lowest published toxic dose	223 - 14,432	mg/kg
		Lowest published lethal dose	3,570 - 5,272	mg/kg
	Rat	LD_{50}	5,045	mg/kg
	Dog	LD_{50}	4,797	mg/kg
	Rabbit	LD_{50}	6,410	mg/kg
	Mouse	LD_{50}	3,600	mg/kg
Dermal	Rat	LD_{50} (intraperitoneal)	2,735	mg/kg
		LD_{50} (intravenous)	1,088	mg/kg
	Dog	Lowest published lethal dose (intravenous)	5,120	mg/kg
	Cat	Lowest published lethal dose (intravenous)	1,963	mg/kg
	Rabbit	LD_{50} (skin)	12,800	mg/kg
		LD_{50} (intravenous)	1,184	mg/kg
		LD_{50} (intraperitoneal)	667	mg/kg
	Mouse	LD_{50} (intraperitoneal)	4,477	mg/kg
		Lowest published lethal dose (subcutaneous)	6,000	mg/kg
		LD_{50} (intravenous)	1,509	mg/kg
	Guinea pig	LD_{50} (intraperitoneal)	2,560	mg/kg
	Hamster	LD_{50} (intraperitoneal)	3,444	mg/kg
	Frog	Lowest published lethal dose (par)	20,000	mg/kg

Source: Reference (28).
LD_{50} - Median lethal dose that kills 50% of the test organisms.

10.0 ENVIRONMENTAL IMPACTS FROM THE DISCHARGE OF DEICING/ANTI-ICING AGENT-CONTAMINATED STORM WATER

Deicing/anti-icing agents enter the environment after they are applied to aircraft and paved areas, including runways, taxiways, roadways, and gate areas. It is estimated that approximately 80% of the Type I deicing fluids that are applied to aircraft fall to the pavement (1). Unless they are captured for recycling, recovery, or treatment (either on site or at a publicly owned treatment works (POTW)), deicing agents will flow away to be diluted with other runoff sources or evaporate. If runoff containing deicing agents is not contained or treated, substantial amounts of deicing/anti-icing chemicals may be released to the ground or discharged, where some constituents may degrade but others may ultimately contaminate ground or surface waters. Of the remaining 20% that does not fall to the pavement, an estimated 15% is dispersed to the air while only 5% remains on the aircraft until it shears off during takeoff.

Anti-icing agents make up a smaller percentage of the contaminated storm water runoff than deicing agents. This is because the polymers and thickeners that comprise anti-icing agents make anti-icers more likely to adhere to surfaces and because less volume of fluid is used as compared to deicing agents. Because of these two factors, anti-icing solutions may also result in less air emissions (2). However, anti-icing fluids are more likely to be “carried out” on the plane to runways, which are generally not connected to the airport’s glycol-contaminated wastewater collection system. Some anti-icing fluid drips off the wings during taxiing, while the majority shears off the wing during take-off.

In addition to aquatic and health impacts (discussed in Section 9.0), the biodegradation of glycols released into the aquatic environment can greatly impact water quality in receiving streams, including significant reduced oxygen levels. Section 10.1 discusses, where known, degradability and environmental fate of ethylene glycol and propylene glycol, formulated aircraft deicing/anti-icing fluids (ADFs), alternate freezing-point depressants, and pavement deicing agents. This section also describes the potential effects of direct and indirect releases of aircraft deicing fluids and pavement deicing agents to surface waters and to air. Section 10.2

discusses reports of environmental impacts from the discharge of deicing/anti-icing agent-contaminated storm water. Section 10.3 discusses the effects that the indirect discharge of deicing/anti-icing agent-contaminated wastewater has on POTWs. All tables are located at the end of this section.

10.1 Degradability and Environmental Fate of Deicing/Anti-icing Agents

When released to the environment, ADFs and pavement deicers are generally biodegradable; however, some components require significantly more oxygen to biodegrade than others. Significant oxygen requirements can reduce oxygen levels in receiving streams to the point where the streams do not have enough oxygen to support aquatic life. Sections 10.1.1 through 10.1.4 discuss degradability and oxygen demand as well as environmental fate and bioaccumulation of deicing/anti-icing agents.

10.1.1 Ethylene Glycol and Propylene Glycol

Several environmental effects studies have been performed using pure ethylene glycol and propylene glycol. Both exert a large oxygen demand when biodegrading, which can affect aquatic life by depleting available oxygen in a receiving stream. Propylene glycol requires more oxygen than ethylene glycol to biodegrade (3, 4, 5).

Propylene glycol is more likely to volatilize to the air following aircraft deicing. Both chemicals easily break down in the environment and are not expected to be retained in the tissue of organisms or increase with continued exposure (i.e., bioaccumulate) (4, 5).

Biodegradation

When released into the environment, both ethylene glycol and propylene glycol are expected to partition to surface or groundwater. They are expected to rapidly biodegrade and not to persist in the environment. Biodegradation rates depend on temperature and oxygen conditions and glycols biodegrade more slowly under anaerobic conditions. The half-life of ethylene glycol and propylene glycol in water under aerobic and anaerobic conditions, and in soil are shown below. Note that these data were not conducted under the same laboratory conditions and may not be directly comparable (5).

	Half-Life		
	Aquatic		
Glycol Type	**Aerobic Conditions**	**Anaerobic Conditions**	**Soil**
Ethylene Glycol	2 to 12 days	4 to 48 days	0.2 to 0.9 days (5 - 22 hours)
Propylene Glycol	1 to 4 days	3 to 5 days	Equal to or slightly less than in water

Based on data presented in Sections 9.1.1 and 9.1.2, both ethylene glycol and propylene glycol have a low toxic potential for aquatic and other animal life; however, aquatic life may be indirectly impacted by the glycol's rapid biodegradation. The biodegradation of glycols consumes oxygen and can lead to low oxygen levels in aquatic systems. Anaerobic biodegradation may also release relatively toxic byproducts such as acetaldehyde, ethanol, acetate, and methane (6).

While ethylene glycol and propylene glycol are both highly biodegradable, ethylene glycol requires less oxygen to degrade than propylene glycol, as shown in the following table.

Oxygen Measure	Ethylene Glycol	Propylene Glycol
Literature values for BOD_5 (at 20°C), mg O_2/L glycol	400,000 - 800,000	1,000,000
Literature values for BOD_5 (at 20°C), g O_2/g glycol	0.4 - 0.7	1
Ethylene glycol manufacturer values for theoretical oxygen demand (i.e., ultimate BOD), g O_2/g glycol	1.3	1.7
Propylene glycol manufacturer values for average COD:BOD ratio	2.08	2.23

BOD_5 - 5-day biochemical oxygen demand.
COD - Chemical oxygen demand.
Source: References: (3, 4, 7).

In comparison, the BOD_5 of raw domestic sewage is approximately 200 mg of oxygen per liter of sewage while the BOD_5 of treated effluent (discharged to receiving streams) is about 20 mg of oxygen per liter of effluent (8).

Several variables can greatly affect biodegradation rates, such as the quantity of glycols released, the water temperature, and the chemical and biological quality of the receiving stream. Glycol biodegradation reduces the normal dissolved oxygen content in the receiving stream and may cause the oxygen level to fall below the acceptable level for aquatic survival. When all of the dissolved oxygen in a stream is used, the stream becomes anaerobic and aquatic life is threatened. The amount of dissolved oxygen in water decreases with increasing temperature, and streams are more likely to be threatened by naturally occurring low oxygen levels in the summer.

In tests performed by a propylene glycol manufacturer, the ultimate BOD was determined for varying glycol concentrations, temperature, and time using activated sludge samples that were acclimated to glycols (9). Table 10-1 presents the results of these studies. The results show that, in general, propylene glycol exerts a higher BOD value (in mg of oxygen per liter of glycol) than ethylene glycol, except at the lowest concentrations and lowest temperature tested (1.3 or 3.3 mg/L and 4°C). The results also show that for either glycol, in general, a lower BOD value is expected at lower temperatures.

Since most deicing operations occur when temperatures are low, the BOD_5 at 20°C test (the typical laboratory test temperature) is an overly conservative estimate of the actual oxygen demand that would be measured in the receiving stream. However, in early spring when temperatures may rise and when glycols may be released from melting snow dump piles, the BOD_5 at 20°C may be a more accurate indicator of what is occurring in the environment.

The Streeter-Phelps Model estimates dissolved oxygen (DO) concentrations in a given stream as a function of time. It may be used to determine a DO deficit following a large discharge of pollutants that exert a high oxygen demand when biodegrading, such as ethylene glycol or propylene glycol. The model accounts for temperature, pollutant loading, and rate of stream flow, but not for other oxygen consumption factors such as additional pollutant loadings that use oxygen to biodegrade. In one experiment that used the Streeter-Phelps Model, assuming a 10:1 dilution factor in receiving streams, several iterations and different downstream DO levels and time periods were used to estimate a maximum ethylene glycol loading upstream to ensure safe DO levels. The downstream oxygen levels, or "oxygen targets," are based on guidelines for protection of cold-water and warm-water species. The results showed that to achieve a final DO concentration of at least 6.0 mg/L (assumed minimum concentration for warm-water fish), over a 4-hour retention time, less than 800 mg/L of pure ethylene glycol must be in the discharged effluent. To achieve a final DO concentration of at least 9.5 mg/L (assumed concentration for cold-water fish), over a 4-hour retention time, less than 300 mg/L of pure ethylene glycol must be in the discharged effluent. The longer the discharge retention time, the smaller the amount of glycol that can be discharged without resulting in a DO concentration below the target level. For example, to achieve a final DO concentration of 9.5 mg/L over a 24-hour retention time, less than 48 mg/L of pure ethylene glycol would be encountered downstream. Therefore, according to the Streeter-Phelps model, assuming a 10:1 dilution factor in receiving streams, a wastestream containing 480 mg/L of ethylene glycol could be discharged to a receiving stream with a 24-hour retention time without resulting in a DO concentration of less than 9.5 mg/L (10).

Environmental Fate and Bioaccumulation

Ethylene glycol and propylene glycol are highly soluble in water; therefore, volatilization is not likely to be a significant pathway for removal of ethylene and propylene glycol from water under typical natural conditions. The Henry's Law Constants (at 25°C) for ethylene glycol and propylene glycol are 2.3×10^{-10} atm-m^3/mol and $1.2\text{-}1.7 \times 10^{-8}$ atm-m^3/mol, respectively (5). Propylene glycol will more readily volatilize than ethylene glycol due to its higher Henry's Law Constant; both are considered volatile organic compounds (VOCs) by EPA. If released to the air, both glycols are likely to remain in the vapor phase and are expected to undergo rapid photochemical oxidation via reaction with hydroxyl radicals (5). Several studies confirm that neither ethylene glycol nor propylene glycol significantly volatilize to the air. In a study performed by a propylene glycol manufacturer, a negligible amount of propylene glycol volatilized from a biological treatment reactor, even under favorable conditions (3).

Because both glycols are very soluble in water, biodegradation is the most important process that breaks down ethylene glycol and propylene glycol. Both glycols have a low octanol/water partition coefficient (K_{OW}), which suggests that bioaccumulation is not likely to occur (5). Ethylene glycol and propylene glycol break down very quickly in humans and animals. Studies have found that ethylene glycol was no longer present in body tissues just 48 hours after exposure (5). Crayfish exposed to high concentrations of ethylene glycol (50 to 1,000 mg/L) over a 2-month period did not bioaccumulate significant amounts of ethylene glycol (11). (See Section 9.1 for information on the toxicity of ethylene glycol and propylene glycol.)

10.1.2 Formulated Aircraft Deicing/Anti-icing Fluids

As discussed in Section 10.1.1, both pure ethylene glycol and propylene glycol exert a high oxygen demand on receiving streams, which may significantly affect dissolved oxygen concentrations in these streams. ADFs will exert a lower oxygen demand than pure glycol, primarily because ADFs are diluted with water. Because the additive package is only a small portion of ADFs (typically less than 2%), the chemical additives should not cause a significant increase in the oxygen demand of ADFs. However, some additives may be toxic to the microorganisms that biodegrade them, inhibiting the biodegradation of ADFs, and therefore reducing the BOD measured during laboratory analyses.

Like pure ethylene glycol and propylene glycol, the glycol portion of ADFs is not expected to bioaccumulate and will rapidly biodegrade. Propylene glycol-based ADFs would be expected to biodegrade slightly faster than ethylene glycol-based ADFs, because pure propylene glycol degrades faster than pure ethylene glycol.

A summary of BOD_5 and COD results for Type I, II, and IV ADFs is shown below. The results indicate that ADFs are readily and rapidly biodegraded. Note that the Type I data presented are for concentrated fluid and not as applied fluid. EPA recognizes that the propylene glycol-based Type I fluid has a lower BOD_5 than the ethylene glycol-based Type I fluid which conflicts with BOD data presented in Section 10.1.1. This occurrence may be due to the different volume of glycol used in each formulation or varying testing conditions. In general, Type II and Type IV solutions should have a higher BOD concentration than Type I solutions (as applied) because they contain a higher concentration of glycol. Note that the source for the propylene glycol and ethylene glycol fluid tests are different; data are provided by their corresponding fluid manufacturers. Because the sources are different, test conditions (e.g., temperature, fluid concentration) may have varied, which could yield incomparable results. Although the ultimate BOD values for ADFs are less than that of their corresponding pure glycol, formulated fluids may still pose an oxygen depletion threat on receiving streams.

Fluid Type	**COD (mg/L)**	**BOD, Day 5 (mg/L)**	**BOD, Day 10 (mg/L)**	**BOD, Day 15 (mg/L)**	**BOD, Day 20 (mg/L)**
Type I - EG based (concentrate)	1,260,000	873,000	1,070,000	NA	1,210,000
Type I - PG based (concentrate)	1,400,000	840,000	NA	NA	NA
Type II - PG based	NA	730,000	NA	NA	NA
Type IV - EG based	945,000	463,000	576,000	775,000	935,000
Type IV - PG based	794,000	520,000	NA	NA	785,000

Source: References (12, 13, 14, 15, 16).
NA - Not available.
EG - Ethylene glycol.
PG - Propylene glycol.
COD - Chemical oxygen demand.

Although present in small amounts, fluid additives may impact the biodegradability of ADFs. Limited data are available to assess the impact of ADF additives on the fate of ADFs; however, tolyltriazole (TTZ) can significantly impact the degradability of ADFs. Cornell et al. performed tests on the degradation rate of formulated fluids to assess the effects of the additive pack without TTZ (e.g., surfactants, buffers) and where TTZ was the only additive. It was found that TTZ has a significant impact on the degradation rate. With TTZ present at concentrations that might be found in airport soils, the pseudo-first order biodegradation rate constant for a propylene glycol-based ADF (containing TTZ) was approximately three times smaller than that of pure propylene glycol. The degradation rate also decreased as the TTZ concentration increased. While the additives package (without TTZ) reduced the degradation constant, the presence of TTZ (with and without the additives package) caused a much greater decrease in the degradation rate (17, 18).

TTZ is composed of two isomers, 4-methyl-benzotriazole (4-MEBT) and 5-methyl-benzotriazole (5-MEBT). U.S. Patent 5,503,775 claims that under aerobic conditions, 5-MEBT is biodegradable while 4-MEBT is recalcitrant (17). While current work is being performed to study the effects of TTZ on the biodegradation of ADFs and glycol, EPA believes that no current research is being performed to study the effects of each isomer on biodegradation rates.

Another main concern of ADF additives is their decomposition products. The degradation of several potential fluid additives may result in more toxic compounds than the primary compounds. For example, TTZ is an azo compound. Azo compounds are known to biotransform under anaerobic conditions into more toxic compounds such as aromatic amines and nitro compounds (12). As mentioned above, TTZ may not be very degradable and may bioaccumulate (17). Anaerobic conditions, caused by the high oxygen demand during glycol degradation, may catalyze the formation of more toxic byproducts when additives decompose (12). Environmental fate and bioaccumulation data are currently not available for other ADF additives.

Inhibition testing may be used to measure a compound’s toxic potential on biological systems (e.g., biological wastewater treatment systems). An ethylene glycol ADF manufacturer performed bacteria inhibition testing using Type IV fluid and found the following results.

Fluid Type	IC_{50} (mg/L)	NOEC (mg/L)
Type I - EG based	64,000 (or 6.4% concentration)	NA
Type IV - EG based	9,100 (or 0.91% concentration)	2,500 (or 0.25% concentration)

Source: Reference (13).
NOEC - No-observed-effect concentration.
IC_{50} - Concentration that inhibits growth in 50% of the test organisms.
NA - Not available.

These results show that ethylene glycol-based Type IV ADFs are significantly more toxic to bacteria than Type I fluids. However, Type IV ADFs are not likely to reach POTWs in large concentrations because these fluids are typically carried out beyond collection areas.

The same ADF manufacturer developed air emission rates in 1998. The rates are based on fundamental chemical engineering calculations of mass transport across a boundary layer (i.e., the glycol concentration in a given sample). These rates, shown below, indicate that the use of propylene glycol-based ADFs results in higher air emissions than that of ethylene glycol-based ADFs (2). However, it is important to note that wind and turbulence during storms would disperse the vapor emissions to very low ambient concentrations. These results agree with results predicted based solely on Henry's Law Constant for pure ethylene glycol and propylene glycol (see Section 10.1.1).

Glycol	Product Name	Fluid Type	Glycol Content (% wt.)	Glycol Content (lb/gal)	Glycol Air Emissions (lb glycol per 10,000 gal applied)
Ethylene Glycol	Deicing Fluid Concentrate	I	92	8.52	9.37
	Deicing Fluid XL 54	I	54	4.84	5.32
	Deicing Fluid "50/50"	I	48.4	4.3	4.73
	Deicing/Anti-icing Fluid ULTRA+	IV	64	5.79	6.37
Propylene Glycol	Typical Deicing Fluid "45/55"	I	55	4.78	8.87

Source: Reference (2).

As discussed in Section 4.2.1, up to 4,000 gallons of Type I fluid may be used to deice one aircraft during a severe storm event. Although air emissions factors are relatively low, extensive use of deicing fluids during storm events may result in significant air emissions. Based on the above information, propylene glycol-based ADFs are estimated to result in more than twice the air emissions than ethylene glycol-based ADFs. In addition, the results show that the higher the glycol concentration, the more air emissions are expected to occur. Therefore, it would be expected that Type II and IV fluids would result in greater air emissions than Type I fluids. However, it is important to note that, while Type II and IV fluids would cause higher air emission rates, these fluids are typically applied in much smaller volumes than Type I fluids and are designed to stick to aircraft, which may ultimately reduce net air emissions.

10.1.3 Alternative Freezing-Point Depressants

As discussed in Section 9.3, diethylene glycol and isopropanol are both other freezing-point depressants, although neither is currently used in for deicing/anti-icing aircraft in the U.S. However, diethylene glycol is believed to be used currently in Europe.

Diethylene Glycol

Diethylene glycol, though not used as the main freezing-point depressant in U.S. ADFs, may be found in ethylene glycol-based formulations as a byproduct of the ethylene glycol manufacturing process. Diethylene glycol is biodegradable, though not as easily as ethylene glycol or propylene glycol, is not likely to volatilize to the air, and is not likely to bioaccumulate (based on its low octanol water coefficient) (3, 18, 19). It has an aerobic half life of 3.5 to greater than 20 days, depending on temperature (6). In addition to temperature, degradation rates may also be affected by acclimation. For example, in one study, acclimated bacteria completely degraded a sample of diethylene glycol in 5 days, while unacclimated bacteria degraded only 21% of a diethylene glycol sample (18). Unlike ethylene glycol and propylene glycol, hydrolysis may be an important fate process for diethylene glycol in water because it is easily hydrolyzed.

However, like ethylene glycol, there is potential for more toxic compounds to be formed from anaerobic diethylene glycol degradation (e.g., acetaldehyde, ethanol, and acetate) (6).

Diethylene glycol has a theoretical oxygen demand of 1.51 grams of oxygen per gram of diethylene glycol (18). This theoretical oxygen demand is greater than that for ethylene glycol but less than that for propylene glycol. Several sources have studied the BOD_5 of diethylene glycol, with results ranging from 1.3% to 10% of the theoretical oxygen demand (18). These results are significantly lower than those for ethylene glycol and propylene glycol, indicating that it takes a greater amount of time to completely degrade diethylene glycol.

One propylene glycol manufacturer has conducted studies comparing the biodegradability of diethylene glycol, ethylene glycol, and propylene glycol. BOD_5 data collected during the study were inconsistent and erratic for diethylene glycol, indicating that diethylene glycol is not as readily biodegradable as ethylene glycol and propylene glycol (3). The COD:BOD ratio for diethylene glycol is an order of magnitude higher than that of the other glycols, also indicating that it is not as degradable. The lower biodegradability of diethylene glycol is most likely due to the ether structure of the compound. The data also show that diethylene glycol takes a longer amount of time to biodegrade than ethylene glycol and propylene glycol. A main concern of diethylene glycol degradation is the potential for significant oxygen depletion in receiving streams. Although diethylene glycol requires a similar amount of oxygen to degrade as other glycols, the fact that it takes longer to degrade means that it places a strain, although lesser, on oxygen levels in receiving streams for a longer period of time.

Table 10-2 summarizes diethylene glycol degradation data for four different test conditions. These data show that diethylene glycol is more easily degraded at lower concentrations, in buffered solutions, and at higher temperatures. The removal rates and percent removals for ethylene glycol and propylene glycol are significantly higher than those for diethylene glycol given the same input parameters (3).

In summary, diethylene glycol may be a viable substitute for ethylene glycol and propylene glycol; however, it does not offer any environmental benefits over the glycols currently in use in the U.S. Aquatic and mammalian toxicity values are similar to those of ethylene glycol. Diethylene glycol requires approximately the same amount of oxygen to degrade as ethylene glycol and propylene glycol, but it degrades more slowly. This results in a smaller daily oxygen demand over a longer period of time. This characteristic does not strain oxygen levels as much as the other glycols because the oxygen demand is more gradual; however, diethylene glycol is present in a receiving stream for a longer period of time, which may potentially result in other toxicological effects if present in high concentrations.

Isopropanol

Isopropanol is biodegradable in water, with a half-life of between 2 and 20 days (20). Based on its Henry's Law Constant, it is slightly volatile (21). Upon discharge to water, approximately 77.5% of isopropanol will stay in the water while the remainder volatilizes to the air (20). It is highly soluble in water and is not likely to bioaccumulate; the isopropanol concentration found in fish tissues is expected to be the same as the average isopropanol concentration in the water from which the fish was sampled (20). When released into soil, it is expected to biodegrade, evaporate, or seep into groundwater (22).

Isopropanol has a theoretical oxygen demand of 2.40 grams of oxygen per gram of isopropanol (18). This theoretical oxygen demand is significantly higher than that of glycols. Several sources have studied the BOD_5 (at 20°C) of isopropanol, with results ranging from 60 - 70% of the theoretical oxygen demand for acclimated sludge, indicating that isopropanol is highly biodegradable (18). In addition, based on Monod-type kinetics, the maximum rate of substrate utilization per unit mass of biomass (k_{max}) is very high (4.89E-06) for isopropanol (23). A high k_{max} value also indicates that the pollutant is highly biodegradable. These results show rapid biodegradation of isopropanol which, combined with a high theoretical oxygen demand, can greatly reduce oxygen levels in receiving streams and would result in greater oxygen depletion than either ethylene glycol or propylene glycol.

10.1.4 Pavement Deicers

There are several pavement deicers that are available and in use by airports. As described in Section 9.4, these deicers have varying toxicity. Like toxicity, these agents have vastly different degradability and environmental fate characteristics.

Urea

Excessive urea in receiving streams often accelerates algal blooms in warmer months, due to the additional nitrogen available. Algal blooms consume large amounts of oxygen, resulting in even greater reduced dissolved oxygen concentrations in streams, and may cause eutrophication in lakes. Due to urea's low octanol/water partition coefficient (-1.52 at 20 to 25°C), urea is not likely to bioaccumulate. It is also not likely to volatilize to the air because of its low Henry's Law Constant. It readily leaches from soil into surface and groundwater (24).

Another factor to consider is the effect of temperature on the degradation of urea to ammonia. Studies have shown that urea completely degrades to ammonia in 4 to 6 days in water at 20°C and negligible degradation occurs at temperatures of less than 8°C (likely temperatures of water bodies during deicing events) (25). Therefore, while the use of urea may cause potential toxic effects to the aquatic environment because of ammonia formation, it may not be as large a concern during winter months as it would during spring or summer months.

Urea/Ethylene Glycol Mix

In a biodegradability test performed using a formulated urea and ethylene glycol fluid, the COD was reported as 1.45 pounds of oxygen per pound of fluid and the BOD as 0.94 pounds of oxygen per pound of fluid. The percent of fluid biodegraded after 21 days (at 20°C) was reported as 94% (26).

Potassium Acetate

All forms of potassium acetate are readily biodegradable. It exerts a BOD that is much lower than other runway deicers (e.g., urea). Reported BOD_5 values are in the range of 0.14 to 0.30 grams of oxygen per gram of potassium acetate (12).

Calcium Magnesium Acetate (CMA)

CMA is also readily biodegradable, which makes it a favorable alternative runway anti-icer (26). EPA was not able to locate any information regarding BOD_5 values for CMA.

Sodium Acetate

Sodium acetate is readily biodegradable even at low temperatures. One manufacturer's sodium acetate-based deicer has a BOD_5 of 0.58 grams of oxygen per gram of anhydrous sodium acetate at 20°C. The chemical oxygen demand is 0.78 grams of oxygen per gram of anhydrous sodium acetate (26).

Sodium Formate

Sodium formate is also highly biodegradable; one specific sodium formate-based deicer has a BOD_5 of 0.23 grams of oxygen per gram of sodium formate, but this rate is highly dependent on temperature (26).

Alternative Pavement Deicers

Transport Canada and ADI Nolan Davis, Inc. conducted a three-year evaluation to compare the performance and impacts of urea and glycols in storm water runoff to that of the newer pavement deicing agents (e.g., sodium formate, potassium acetate, CMA) (12). The results show that the newer chemicals are “relatively benign” compared to urea and glycols, and are summarized as follows:

- Sodium formate - had little or no impact on water chemistry. It also was difficult to detect, which indicates rapid degradation. Sodium was more frequently detected than formate, although it was difficult to solely attribute detected sodium concentrations to the application of sodium formate. The fact that formate was difficult to detect indicates that it is not persistent in the environment.

- CMA - had little or no impact on water chemistry, and calcium, magnesium, and acetate were all readily detected.

- Potassium acetate - had little impact on surface water, except that BOD_5 levels significantly increased, which was attributed to increased acetate levels. Potassium acetate was more easily detected than sodium formate and had no discernable impact on groundwater, vegetation, and other soil and stream life.

<u>Sand</u>

Sand, while not degradable, can clog storm drains and contaminate water bodies through increased erosion and sediment buildup.

<u>Salts</u>

Salts are not applied to airside pavements, but runoff from roadside pavements can cause water quality in receiving streams to deteriorate.

10.2 Reports of Environmental Impacts from Airport Deicing Operations

The deicing or anti-icing of aircraft and runways is a necessary operation at many airports during the winter months. The release of deicing/anti-icing agents can negatively impact the environment or local POTWs that receive discharges from airports. As part of this study, EPA reviewed published literature for evidence of environmental impacts on aquatic life, human health, POTW operations, and the quality of receiving waters due to the discharge of deicing anti-icing chemicals.

Literature abstracts were obtained through the computerized information system, DIALOG (Knight-Ridder Information, February 1999), which provides access to scientific journal abstracts such as Pollution Abstracts, Aquatic Science and Fish Abstracts, and Water Resource Abstracts. Newspaper articles were also obtained through DIALOG from 25 randomly selected newspapers serving major northern metropolitan areas. EPA acknowledges that the information in these newspaper articles may not be scientifically accurate or technically representative of actual environmental impacts; however, EPA believed it was important to recognize additional sources of information regarding potential environmental impacts.

In the review of literature abstracts and newspaper articles, environmental impacts were noted from 17 airports and in six general studies. Impacts included: (1) aquatic life effects such as fish kills, growth of biological slimes, elimination of aquatic life, stressed invertebrate communities, and impaired fisheries; (2) effects on wildlife, birds and cattle; (3) human health problems (worker and population exposure - headaches, nausea); (4) aesthetic effects (odor, color, foaming); and (5) effects on the quality of receiving waters (low DO, high BOD, organic enrichment), groundwater, water supplies, and soils. Impacts were mainly due to presence of ethylene and propylene glycol in the receiving streams from storm water runoff. New concerns with the aquatic toxicity of ADF additives were also noted, as well as concerns with the release of other toxic organic chemicals, oil and grease, and metals from airport operations. Table 10-3 summarizes the information collected from the literature.

Specifically, past and current environmental impacts due to the direct discharge of ADF included: (1) aquatic life effects, such as fish kills (four airports), elimination of all aquatic life (two airports), bacterial growth (one airport), concerns with shrimp farming (one airport); (2) aesthetic effects, such as odors and foaming (four airports); (3) effects on the quality of receiving waters, such as exceeding water quality standards (three airports); and (4) effects on water supplies (1 airport).

It is important to note that many of the airports discussed have made improvements in the collection and treatment of deicing fluids over the past 5 years. Contained deicing areas, increased recycling, and newly built storm water retention basins are all examples of recent improvements. Consequently, the information presented in Table 10-3 may not represent current airport deicing operations.

10.3 Effect on POTWs

Pretreatment standards are designed to prevent the discharge of pollutants that pass through, interfere with, or are otherwise incompatible with the operation of POTWs. Section 307(b) of the Clean Water Act authorizes EPA to establish pretreatment standards for pollutants that pass through POTWs or interfere with treatment processes or sludge disposal methods at POTWs. To assess pass-through, EPA generally compares the POTW secondary treatment performance for each pollutant under consideration for regulation to the treatment performance achieved by direct dischargers using best available technologies economically achievable (BAT). This ensures that 1) the wastewater treatment performance for indirect dischargers is equivalent to that for direct dischargers, and 2) the treatment capability and performance of the POTW are considered when regulating the discharge of pollutants from indirect dischargers. Because, at this time, EPA is conducting a study rather than developing effluent limitations for airport deicing operations, a formal POTW pass-through analysis was not performed. However, EPA collected information from POTWs to better understand the impacts wastewater containing deicing/anti-icing chemicals have on POTWs. Appendix A contains information regarding the location of airports referenced in this section.

10.3.1 EPA POTW Questionnaires

As discussed in Section 3.2.3, EPA mailed questionnaires to nine POTWs that accept or have accepted wastewater discharges containing deicing/anti-icing chemicals. EPA received responses to eight of the nine POTW questionnaires. The information collected from these questionnaires, in addition to information collected during site visits, from literature and newspaper searches, and from discussions with airport, airline, and POTW trade association members, was used to assess whether wastewater discharges from airport deicing operations pass through or interfere with POTW operations. Responses to the POTW questionnaires are discussed in the following subsections.

10.3.1.1 Chemicals Typically Found in Discharges

All POTWs surveyed indicated accepting wastewater containing ethylene glycol, propylene glycol, or both. Other chemicals reported in wastewater discharges accepted by the POTWs include potassium acetate, sodium formate, potassium formate, and urea, which are all used as pavement deicers. The Patapsco Wastewater Treatment Plant, which receives discharges from the Baltimore/Washington International Airport, indicated that they accept discharges containing diethylene glycol in addition to ethylene glycol and propylene glycol. See Sections 9.3 and 10.1.3 for more information regarding diethylene glycol.

10.3.1.2 Contribution of Wastewater Containing Deicing/Anti-Icing Chemicals to POTWs

Based on information from the questionnaires, discharges of wastewater containing deicing/anti-icing chemicals do not significantly contribute flow and organic loading to POTW operations. The daily average hydraulic loading for the questionnaire recipients ranges from 1 to 250 million gallons. The percentage of flow from accepted airports relative to total POTW flow ranges from less than 0.01% to 3%, with a mean contribution of approximately one percent. The percentage of BOD accepted from airports relative to total POTW BOD loading ranges from 0% to 41%, with a mean contribution of approximately four percent. Therefore, airports discharging wastewater containing deicing/anti-icing chemicals to POTWs contribute relatively more BOD loading than hydraulic loading.

10.3.1.3 Documented Negative Impacts at POTWs

Several POTWs reported increased secondary sludge generation and operating costs after accepting wastewater containing aircraft and airfield pavement deicing/anti-icing chemicals. Additional sludge is generated as a result of accepting high loads of glycol and other organic materials that are easily digested by biological treatment microorganisms. Based on biological treatment operating principles, if a plant were to receive a sudden load of highly concentrated organic matter, then more waste sludge would be generated. The extra sludge would need to be wasted (i.e., disposed of) in order for the POTW to meet its discharge limitations. Most POTWs have sludge dewatering on site to handle current sludge generation and any excess sludge. However, additional sludge dewatering incurs energy, chemical, and labor costs, in addition to disposal costs. The addition of glycols and other organic matter in POTW influents may also require additional aeration and microorganisms to degrade these pollutants. The Wyandotte Wastewater Treatment Plant, to which the Detroit Metropolitan Airport discharges its wastewater, has experienced significant oxygen depletion in its secondary biological treatment system as a result of accepting wastewater containing glycols from deicing/anti-icing operations. When this occurs, the POTW either increases the oxygen supplied to the treatment system or asks the airport to reduce its discharge flow. Additional aeration also incurs increased operation and maintenance costs due to associated additional energy and labor.

Although all POTW questionnaire recipients currently accept wastewater from airport deicing/anti-icing operations, two POTWs indicated that they have previously rejected wastewater containing airport deicing/anti-icing chemicals. The Moon Township Municipal Authority, which accepts wastewater from the Pittsburgh International Airport, was forced to reject discharges in 1993. Problems began shortly after the airport first began discharging wastewater containing deicing/anti-icing chemicals. The POTW experienced a drop in dissolved oxygen concentrations and a problem with maintaining residual chlorine. The POTW solved these initial problems after working with the airport's contractor to adjust discharge pollutant loads and flow rates. However, even after an agreement was reached, the POTW received several large accidental discharges of wastewater containing deicing/anti-icing chemicals; the most recent accidental discharge caused the plant to completely lose all dissolved oxygen and killed all of the biomass in the treatment system. After this incident, the POTW refused to accept further discharges from the airport. The airport responded by hiring a different contractor to manage discharges of wastewater from deicing/anti-icing operations, and the POTW now accepts the airport's discharges.

The Trinity River Authority Central Regional Wastewater System, which accepts wastewater containing deicing/anti-icing chemicals from the Dallas/Ft. Worth International Airport, experienced a similar situation to that described in Pittsburgh. The POTW received a discharge containing an excessively high glycol concentration, which upset the treatment plant. The POTW then refused to accept discharges until the airport installed holding ponds to control discharges to the POTW. Even with controlled discharge, the POTW must maintain a higher concentration of microorganisms in its treatment system during the winter to better accommodate wastewater discharges containing deicing/anti-icing chemicals.

The Salt Lake City Water Reclamation POTW also experienced a treatment plant upset resulting from the acceptance of airport deicing/anti-icing wastewater from the Salt Lake City International Airport. In this case, the POTW did not require that the airport stop discharging. The problem was solved when the POTW required the airport to control its rate of discharge.

The Columbia Boulevard Wastewater Treatment Plant, which accepts wastewater from the Portland International Airport, requests that the airport avoid discharging during periods of high hydraulic loading. The POTW is forced to bypass its secondary treatment when the hydraulic capacity of the system is exceeded. The POTW's secondary treatment is where treatment of deicing/anti-icing chemicals typically occurs.

Although no documentation was provided, POTWs are also concerned with potential byproducts from the degradation of deicing/anti-icing chemicals (e.g., acetaldehyde). POTWs expressed concern over the fact that byproducts may potentially interfere with or pass through a POTW.

10.3.1.4 Documented Positive Impacts

One POTW has benefitted from accepting wastewater containing deicing/anti-icing chemicals. After implementing a batch discharge system, the Kansas City Todd Creek Wastewater Treatment Plant has experienced a reduction in its final effluent BOD by an average of 3 to 4 mg/L.

10.3.2 Evidence of POTW Pass-Through

Although EPA did not perform a thorough POTW pass-through analysis for this study, EPA compared the ethylene glycol and propylene glycol percent removal achieved by a POTW with that achieved by direct dischargers that have implemented collection and on-site treatment technologies. EPA was not able to find a published source that provides a POTW percent removal (based on activated sludge or an equivalent technology) for ethylene glycol or propylene glycol. However, the Moon Township POTW performed sampling in 1993 to study the effectiveness of ethylene glycol treatment and submitted these data to EPA. The sampling data are summarized below.

Date	Influent Ethylene Glycol Concentration (mg/L)	Effluent Ethylene Glycol Concentration (mg/L)	Percent Removal
4/12/93	36	13	64
4/13/93	20	11	45
4/14/93	2.7	3.5	NR
4/15/93	14	7.9	44
4/20/93	16	4.1	74

NR - Not removed.
Data based on a discharge of 1,500 lbs/day of ethylene glycol from the airport.

The data show that the POTW generally experienced low influent concentrations of ethylene glycol and that the average effluent concentration was approximately 10 mg/L. The POTW was generally able to treat the influent ethylene glycol when the influent concentration was already very low. The average POTW percent removal in the data provided was 57%, as compared to >99% at an EPA sampled airport with on-site biological treatment.

As shown in Section 13.2, most airports with indirect discharge permits have limits or monitoring requirements for glycols and/or BOD. Based on responses to the POTW questionnaire, several POTWs reported that they are able to accommodate wastewater containing deicing/anti-icing chemicals, but these discharges must be monitored with controlled discharge into the sewer system, including a period of acclimation at the beginning of each deicing season. As more airports begin discharging their wastewater containing deicing/anti-icing chemicals, more POTWs will need to control the amount of glycols or BOD that are discharged on a daily basis. These limits will be based on the design requirements and effluent limits achievable at the POTW. Although few adverse effects have resulted from controlled wastewater discharges, POTWs remained concerned about accidental discharges and the potential for deicing/anti-icing chemical byproducts to upset the treatment plant. Additional monitoring is needed to better understand the overall impacts that wastewater from deicing/anti-icing operations have on POTW operations.

10.4 References

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Table 10-1

Ultimate BOD Values for Pure Ethylene Glycol and Propylene Glycol Acclimated Sludge Seeds

Day	Ethylene Glycol BOD Value (in mg O_2/L)	Propylene Glycol BOD Value (in mg O_2/L)
4°C - 1.3 or 3.3 mg/L test substance		
0	0	0
5	150,000	75,000
10	150,000	150,000
17	300,000	225,000
27	525,000	375,000
35	825,000	675,000
4°C - 6.7 or 10.0 mg/L test substance		
0	0	0
5	30,000	0
10	45,000	60,000
17	90,000	120,000
27	165,000	510,000
35	495,000	900,000
4°C - 20.0 mg/L test substance		
0	0	0
5	10,000	0
10	20,000	15,000
17	30,000	40,000
27	65,000	Discarded
10°C - 1.3 or 3.3 mg/L test substance		
0	0	0
5	-75,000	-75,000
10	300,000	675,000
16	600,000	1,050,000
20	825,000	1,200,000
27	1,350,000	1,575,000
35	1,800,000	2,100,000

Table 10-1 (Continued)

Day	Ethylene Glycol BOD Value (in mg O_2/L)	Propylene Glycol BOD Value (in mg O_2/L)
10°C - 6.7 or 10.0 mg/L test substance		
0	0	0
5	0	30,000
10	105,000	615,000
16	360,000	960,000
20	870,000	1,005,000
27	1,005,000	1,140,000
35	1,155,000	1,290,000
10°C - 20.0 mg/L test substance		
0	0	0
5	0	35,000
10	40,000	Discarded
16	350,000	Not Tested

Source: Reference (11).

Table 10-2

Biological Degradation Results for Diethylene Glycol

Parameter	Run			
	1	2	3	4
Diethylene glycol concentration (mg/L)	2,100	1,700	1,000	160
Biomass	acclimated	acclimated	acclimated	acclimated
Temp. °C	19.3	9.8	19.2	19.4
pH	unbuffered	unbuffered	buffered	unbuffered
Detention time (hours)	27	60	48	33
Initial COD concentration (mg/L)	3,100	5,600	3,200	250
Effluent COD concentration (mg/L)	2,300	3,900	1,040	30
Removal rate (1/day)	0.31	0.17	1.1	5.3
Percent removal	25.8	30.4	67.5	88

Source: Reference (3).

Table 10-3

Reported Environmental Impacts from Airport Deicing Operations

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
Seattle-Tacoma International Seattle, WA (SEA)	Miller Creek, Des Moines Creek, Puget Sound	Ethylene glycol in receiving streams due to runoff	Toxic effects on fish	1993 - Tacoma News Tribune reports "death" of Miller Creek due to runoff from airport. Salmon no longer present in creek. Airport to conduct water-quality study. 1995 - Seattle Post-Intelligencer reports environmental group filed lawsuit against airport charging regularly fouling nearby salmon-bearing streams in violation of water pollution laws and permit. Excessive amounts of oil, grease, metals, toxic petrochemicals and ethylene glycol entering Des Moines Creek, Miller Creek and eventually Puget Sound.
Westchester County White Plains, NY (HPN)	Kensico Reservoir	Propylene glycol in reservoir	Population exposure	1999 - New York Times reports propylene glycol found in Kensico Reservoir at levels high enough to set off warning system. Reservoir serves New York City and most of southern Westchester.
	Rye Lake, Blind Brook; Blind Brook WWTP	Deicers in receiving streams due to runoff and in discharges to WWTP	---	1997 - Journal article summarizes program to improve storm water management at airport including construction of detention ponds to lessen impact on receiving waters, separation of deicing runoff, and discharging limited amount of deicing runoff to local WWTP. Concern with protecting NYC water supply and impact of BOD loading on WWTP.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure		Impacts (a)
		Environment	Biota/Effect	
General	Environmental Impact of Deicers in Airport Stormwater Runoff	Deicers in receiving streams and groundwater due to runoff	Toxic effects on aquatic life - fish kills	1990 - Michigan DNR conducted investigation into aircraft and runway deicing. Concerns with aquatic toxicity of ammonia, oxygen depletion, organic enrichment of receiving streams and obnoxious odors during biodegradation process. Article notes fish kills from Lambert Field discharge and impairment to aquatic communities at Pittsburgh, Nashville, and Anchorage. Groundwater contamination at Michigan airports may be occurring. Regulatory action necessary to control indiscriminate releases.
Lambert-St. Louis International St. Louis, MO (STL)	Coldwater Creek	Ethylene glycol in receiving stream due to runoff	Population exposure	1995 - St. Louis Post Dispatch reports thousands of gallons of ethylene glycol entering Coldwater Creek. Residents along creek report foul odors. Airport ordered by EPA and State Department of Natural Resources to make improvements. Airport says cannot meet ordered deadline and faces fines of up to $10,000/day.
Cleveland International Airport Cleveland, OH (CLE)	Rocky River	Toxic chemicals in receiving stream	---	1991 - Columbus Dispatch reports state is in litigation with airport over flow of chemicals into Rocky River. Chemicals detected more than decade ago, but no fish kills attributed.
Detroit Metropolitan Romulus, MI (DTW)	Detroit River	Ethylene glycol in receiving stream	---	1990 - Detroit Free Press reports state officials investigating allegations of airport runoff polluting Detroit River. Ethylene glycol flowing untreated from ponds into storm drains.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
Dayton Municipal Airport Dayton, OH (DAY)	Mill Creek	Ethylene glycol in receiving stream and groundwater	Fish kills; population exposure	1991 - Columbus Dispatch reports fish kill in Mill Creek in 1987. Associated Press reports 1998 - Ohio EPA cites at least seven times since 1978 spills have affected the quality of receiving streams. In 1996, airport paid $2.6 million to settle lawsuit by homeowners for contaminated well water.
Chicago O'Hare International Chicago, IL (ORD)	NRDC Lawsuit	Ethylene glycol releases	---	1998 - Chicago Tribune reports NRDC contends O'Hare has violated federal reporting requirements (time, place, quantity) approximately 180 times since Nov. 1996 in its use of ethylene glycol. Airport reports average use of 241,689 lbs/day. NRDC estimates 84,591 lbs/day being released to environment. EPA investigating allegations.
Cincinnati/ Northern Kentucky International Erlanger, KY (CVG)	Elijah Creek	Deicing chemicals in receiving stream	Effects on aquatic life population exposure; aesthetic effects	1992 - Associated Press reports state has cited airport for discharge of deicing chemicals. Major impact on Elijah Creek. Discharges harmed aquatic life, caused unpleasant odors and discoloration of creek.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
Airborne Express (ABX Air, Inc.) Wilmington, OH (ILN)	Lytle Creek	Deicers in receiving stream	Effects on aquatic life - fish kills; population exposure; effects on wildlife	1998 - Associated Press reports disappearance of aquatic life in Lytle Creek and subsequent disappearance of birds. Foul odors reported. Residents complaining of illness. Thousands of fish killed (bass, blue gill). State EPA issued airport a notice of violation for exceeding limit for deicing runoff. Airport has established a manmade wetland to breakdown deicers before discharge.
Portland International Portland, OR (PDX)	Columbia Slough	Glycols in receiving water due to runoff; urea in land area	Effects on aquatic life (glycols); severe oxygen shortages but no fish kills. Urea increased grass growth, which attracted wildlife and posed a hazard to jets.	1999 - Oregonian reports a Portland Legislator (Randy Leonard) is drafting legislation (the Columbia Slough bill) that would order the airport to stop discharging glycol into any body of water. (Note that the legislation did not pass.) Columbia Slough already badly polluted and very sluggish and cannot handle load of glycol. Airport trying to minimize discharges, but says ban difficult to achieve. In 1998, Oregon DEQ began preparing permit to limit discharge of glycol - some to Columbia Slough, Portland sewers, Columbia River and off-site disposal. Discharges to be corrected by year 2005. Airport stopped using the runway deicer urea and started using potassium formate. Note that Oregon DEQ issued an NPDES permit to the airport to implement BMPs to reduce deicing storm water runoff to the Columbia Slough.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
Minneapolis-St. Paul International Woodland, MN (MSP)	Minnesota River	Glycols in receiving stream due to runoff	Effects on aquatic life - low oxygen levels but no documented fish kills	1993 - Star Tribune reports state issued new permit for airport requiring reduced discharges and extensive monitoring. Glycol is adding stress to Minnesota River and ability to recover from other pollutants, particularly agricultural chemicals.
Greater Buffalo International Cheektowaga, NY (BUF)	Ellicott Creek	Ethylene glycol and propylene glycol in receiving stream	---	1994 - Buffalo News reports on concerns for Ellicott Creek. Residents report seeing foaming material in stream.
Pittsburgh International, Pittsburgh, PA (PIT)	McClarens Run, Enlow Run, and Montour Run	Propylene glycol and urea in receiving water	Fish kills; population exposure	1998 - Pittsburgh Post-Gazette reports Pennsylvania DEP ordered airport to correct long-standing water pollution problems caused by glycol deicers, as well as other groundwater and discharge problems. Strong antifreeze odor also noted. In 1994, airport had agreed to stop harmful deicing practices and paid $60,268 to state's Clean Water Fund. In 1996, skiers, and fishermen complained of headaches and nausea and strong odors. PA DEP filed lawsuit because of permit violations. Violations include urea, glycols, phenol, xylene, ethyl benzene, and oil/grease. Fines up to $25,000/day for past violations. Fish kills occurred in winter of 1992-93 and 1993-94.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
PIT (cont.)	Montour Run and Tributaries	Deicing fluids in receiving streams due to runoff	Effects on aquatic life	1998 - Journal article presents results of 1996 study on impacts of airport runoff on water quality and aquatic life. Principal effects related to runway deicing operations. High BOD due to glycols and urea. High concentrations of ammonia. Organic load stimulated growth of dense biological slimes on streambeds. Invertebrate communities severely stressed and dominated by pollution tolerant species. Fishery of watershed impaired.
Anchorage International Airport Anchorage, AK (ANC)	Lake Hood	Ethylene glycol in receiving stream due to runoff	Toxic effects on wildlife	1991 - Anchorage Daily News reports concerns for wildlife that use Lake Hood. Also concerned with oil/grease and aviation fuel.
Baltimore/ Washington International Baltimore, MD (BWI)	Sawmill Creek, Stony Run, Cabin Branch, Kitten Branch, Muddy Bridge Branch	Ethylene glycol in receiving streams due to runoff	Toxic effects on aquatic life; population exposure; aesthetic effects	1998 - Washington Post/Baltimore Sun report lawsuit filed by NRDC against airport for violating CWA over past 3 years. Residents complain of odor and foaming. Concern for Chesapeake Bay. Problems with $16 million dollar deicing collection system. Concentration of glycol in Sawmill Creek more than 6X level to kill aquatic life.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
BWI (cont.)	Toxicity of Stormwater	Deicing chemicals in receiving streams due to runoff	Potential acute toxicity to aquatic life	1995 - Journal article on study designed to investigate the acute toxicity of storm water from BWI. Samples from winter storm events caused acute toxicity to both fathead minnow and daphnid with LC_{50} values as low as 1.0-2.0% effluent due to glycol-based deicers. High oxygen demand and elevated nitrogen levels also potential problems. Samples from rain events during nonwinter months did not cause acute-toxicity unless associated with fuel spills.
Denver International Airport Denver, CO (DIA)	Third Creek, Barr Lake	Propylene glycol in receiving stream	Effects on aquatic life - all life killed due to low oxygen levels; population exposure; aesthetic effects	1997/1998 - Denver Post/Rocky Mountain News report spills of propylene glycol into Third Creek. All aquatic life for 2 miles in Third Creek killed due to depletion of oxygen. Concern for bird sanctuary at Lake Barr. Farmers concerned for cattle. Complaints about odor and color. In 1998 dam built to protect Third Creek from runoff broke.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure		Impacts (a)
		Environment	Biota/Effect	
General	Management of Aircraft Deicing Fluids	Deicing chemicals in receiving streams due to runoff and in discharges to WWTPs	Toxic effects on aquatic life; POTW operations effects	1994 - Journal article states principal environmental impact of deicing activities is oxygen demand. $CBOD_5$ of ethylene glycol ranges from 400,000-800,000 mg/L and propylene glycol > 1 x 10^6 mg/L (untreated domestic wastewaters is 200-300 mg/L). One-half of deicing fluids ends up in storm water. Ammonia released from urea potentially toxic to aquatic life and contributes to nitrogenous oxygen demand. Various alternative technologies and strategies exist depending upon airport and are discussed in article. Disposal at municipal wastewater treatment plants dependent on plant location, capacity, and charges for treating high-BOD wastes.
General	Management of Deicing Constituents	Deicers in receiving streams and groundwater due to storm water discharges	Toxic effects on aquatic life; aesthetic effects	1992 - Master thesis research identifies use and management practices of deicing constituents (glycol, urea, CMA, and sodium formate). Concerns of discharges include high BOD, nitrate and nitrite enrichment of surface and groundwaters, impaired aesthetic water quality, ammonia formation, and overall toxicity to aquatic life.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
Major International North America	Detection of Aircraft Deicing/Anti-icing Fluid Additives (ADFs) in Water Monitoring Well	Tolytriazoles present in subsurface water samples from airport deicing activities	Toxic effects on microorganisms	1998 - Journal article presents results of research that describes first evidence that constituents within ADFs, other than glycols, are present in subsurface water samples from a major North American airport at environmentally significant concentrations. Tolytriazoles concentrations approximately 25 times higher than reported EC50 values in Microtox assays. Previous glycol levels from well were 24,410 mg/L.
General	Environmental Impacts of America’s Airports	Deicing fluids in receiving streams due to runoff	---	1995 - NRDC study of most important environmental issues and best management techniques to mitigate them. Surveyed 125 busiest airports (46 responded) and in-depth research at government agencies on 50 busiest. Significant environmental impacts common at most airports and regulatory framework currently in place inadequate. Deicing and water quality one of the significant impacts. Study recommends: (1) developing effluent guidelines; (2) addressing worker health and safety from ethylene glycol exposure; (3) lowering threshold of national storm water program to include smaller airports; (4) conducting research on deicing alternatives; (5) requiring airports to report releases in TRI; (6) making storm water pollution prevention plans public.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

Table 10-3 (Continued)

Airport	Site/Study	Exposure: Environment	Exposure: Biota/Effect	Impacts (a)
General	Petition to Require SIC 45, Transportation by Air, To Report Releases of Toxic Chemicals	---	---	1997 - NRDC, Defenders of Wildlife, National Audubon Society, and Humane Society petition EPA to initiate rulemaking requiring airports, airline terminals, and aircraft maintenance facilities to report releases of toxic chemicals listed on TRI. Basis of petition is ranking (3rd) as industry for inclusion in TRI. 58 million pounds of ethylene glycol released/year. Use increasing and cheaper than alternatives. Other toxics include trichloeothylene, methylene chloride, acetone, chloroform, methyl ethyl ketone, isopropyl alcohol, glycol ethers, toluene, xylene and other petroleum distillates. Petition cites examples of ethylene glycol toxicity to humans and wildlife, health effects of other toxics, and significant human and wildlife exposures from deicing operations. Petition published in the Federal Register and awaiting further action.

Sources: DIALOG database (Journals and Newspaper Articles) - February, 1999 Retrieval, Internet and States.

(a) EPA recognizes that not all impacts presented in this table are scientifically based and the Agency takes no position on the accuracy of any conclusion derived from the cited materials. Due to recent improvements in the collection and treatment of deicing fluids at airports, the information presented in this table may not represent current airport deicing conditions.

11.0 POLLUTANT LOADINGS AND COSTS TO MANAGE WASTEWATER FROM AIRPORT DEICING OPERATIONS

EPA evaluated the effectiveness of implementing an effluent guideline to control discharges of wastewater from aircraft deicing/anti-icing operations. EPA developed estimates of pollutant loadings in wastewater discharges from aircraft deicing/anti-icing operations and loadings in storm water discharges from these operations using the current storm water permit regulations as a basis of comparison.

EPA did not consider pollutant loadings in storm water discharges from pavement deicing/anti-icing because EPA believes that, as a result of the implementation of the storm water permit regulations, increased use of alternate agents that contain no glycol and minimal biochemical oxygen demand (BOD) load will continue. Consequently, EPA did not account for loadings from pavement deicers in this analysis.

Estimates of pollutant loadings were developed for the following four cases:

1. Estimated pollutant loadings prior to implementation of the EPA Phase I Storm Water Permit Application Regulations;

2. Estimated current pollutant loadings;

3. Estimated pollutant loadings when storm water permits have been fully implemented; and

4. Estimated pollutant loadings assuming implementation of an effluent guideline.

Section 11.1 describes the methodology used to develop pollutant loadings and presents the results. Section 11.2 provides costing information for managing wastewater from airport deicing operations.

11.1 Pollutant Loading Estimates

Aircraft deicing and anti-icing operations are conducted at passenger terminal gates and aircraft parking ramps where aircraft deicing/anti-icing fluid (ADF) applied to aircraft falls on the pavement, commingles with storm water, and discharges to U.S. surface waters via storm water drainage systems. Some airports collect wastewater from aircraft deicing/anti-icing areas for discharge to publicly owned treatment works (POTWs). Other sources of ADF discharges include leaks from worn or defective fittings on deicer trucks and other application equipment; spills such as overfilling deicer truck tanks, leaks from fluid storage tanks; drips from aircraft during taxiing and takeoff; leaks from containment and collection structures; and leaks from wastewater storage facilities. While these other sources undoubtedly contribute to pollutant loadings, EPA believes their combined contribution is minor compared to that from the spray application of the fluids. EPA, therefore, developed pollutant loading estimates for the industry based solely on estimates of the average volume of fluid sprayed and considered all other sources of ADF discharges to be negligible.

EPA developed pollutant loading estimates using the following six-step method.

1. Compiled a list of U.S. airports that potentially perform a significant number of deicing/anti-icing operations and grouped these airports based on their size and climate.

2. Estimated the total annual volume of fluid used at each airport identified in Step 1 using fluid use data collected from the industry.

3. Estimated the percentage of the fluid sprayed that has the potential to impact U.S. surface waters and calculated the volume of ADF discharged annually to U.S. surface waters for each airport identified in Step 1.

4. Used the estimated volumes calculated in Step 3 combined with information collected from the industry to estimate the pollutant loadings discharged to U.S. surface waters prior to the implementation of EPA's Phase I Storm Water Permit Application Regulations.

5. Used the estimated volumes calculated in Step 3 combined with information collected from the industry to estimate the current pollutant loadings and the loadings remaining after full implementation of the Phase I Storm Water Permit Application Regulations.

6. Estimated the pollutant loadings assuming implementation of an effluent guideline.

The following subsections describe Steps 1 through 6. The report entitled Development of Estimated Loadings in Wastewater Discharges From Aircraft Deicing/Anti-icing Operations describes EPA's methodology in greater detail and presents airport-specific estimates (1).

11.1.1 Airport Groups (Step 1)

As described in Section 4.3.1.1, EPA identified 212 airports that potentially perform significant airport deicing/anti-icing operations and arranged them into 20 Airport Groups based on operations and snowfall characteristics. EPA used the 20 Airport Groups to estimate fluid use for airports for which fluid use data were not available (as described in Section 11.1.2).

11.1.2 Fluid Use Estimates (Step 2)

Although EPA would have preferred to use actual ADF use data for all airports identified as potentially performing significant deicing/anti-icing operations, EPA was unable to do so because it would have required a large number of airports to submit detailed ADF use data. Under the Paper Work Reduction Act, this type of request would require U.S. Office of Management and Budget approval, a process that could not have been completed within the study schedule. Also, EPA realized that many U.S. airports have not collected ADF use data from their tenants for previous seasons.

EPA was able to collect a limited amount of ADF use data directly from airports. To supplement these data, EPA requested national estimates of fluid use data from industry airport and airline trade associations. Unfortunately, EPA did not receive any fluid use data from these organizations; thus, the national estimated fluid use for airports was estimated based on the airport data collected by EPA under this study.

These data were provided by respondents to EPA's 1999 Airport Mini-Questionnaire and by airport authorities during site visits, and consisted of data from 23 U.S. airports. The airports submitted fluid use data in a variety of formats. Several airports provided fluid use data by glycol base (i.e., ethylene glycol and propylene glycol) and fluid type (i.e., Type I, Type II (if applicable) and Type IV). For Type I fluids, some airports reported the volume as a Type I concentrate, while others reported the volume as diluted (i.e., ready-to-use) Type I fluid. A few airports provided fluid use data by glycol base, but not by fluid type. To simplify this analysis, EPA converted available ADF use data for each airport to a single common basis, expressed as Type I fluid at 50% dilution (i.e., as applied). EPA's data conversion methodology is illustrated below using data from the following airports as examples.

Des Moines International Airport, Des Moines, IA (DSM)

This airport provided fluid use data for three consecutive deicing seasons for Type I propylene glycol-based fluid, Type I ethylene glycol-based fluid, Type IV propylene glycol-based fluid, and Type IV ethylene glycol-based fluid. The volumes reported for Type I fluids were for 50% ADF solutions. For each year, EPA calculated the total volume used by adding the volumes of each fluid type and glycol base. EPA then averaged the annual totals to determine the average total annual ADF use.

EPA recognizes that Type II/IV fluids are greater than 50% ADF solutions. Therefore, EPA's simplification to sum Type II/IV fluid volumes into the total as though it were a 50% ADF solution results in a low ADF use bias. EPA believes this bias is not significant because typically less than 10% of ADF use is Type II/IV fluids.

Anchorage International Airport, Anchorage, AK (ANC)

Anchorage International Airport submitted fluid use data for two deicing seasons by glycol base, but not by fluid type. The fluid volumes were reported as concentrated ADF solutions. For each deicing season, EPA calculated the total volume of concentrated fluid used by adding the volumes reported for ethylene glycol-based fluid and propylene glycol-based fluid. EPA then averaged the annual totals to determine the average total annual ADF use. Finally, EPA multiplied the average ADF use by two to convert to a 50% ADF solution basis.

To estimate fluid use for airports for which no data were available, EPA developed fluid use factors. EPA divided the total ADF volume calculated for each airport for which data were available by the total number of aircraft operations performed at the airport and used the result to calculate fluid use factors. For some Airport Groups, fluid use data were available for two or more of the airports in the group. For airports in these groups, EPA calculated an average fluid use factor to represent the group. Fluid use factors could not be calculated for some Airport Groups because no fluid use data were available for airports in these groups. In these cases, EPA estimated fluid use factors based on an engineering assessment of the fluid use factors calculated for other Airport Groups.

Note that the fluid use factors described in this section do not represent fluid use per aircraft deicing/anti-icing operation. For example, the number of annual operations used to calculate the fluid use factors include operations outside of the deicing season, and not all operations during the deicing season correspond to deicing/anti-icing operations. Instead, the fluid use factors are solely for the purpose of normalizing fluid use data among airports of similar size and climate.

Fluid use factors for each Airport Group were then used to estimate fluid use at airports for which fluid use data were not available. For example, the volume of fluid used at airports assigned to a given Airport Group was estimated by multiplying the total annual aircraft operations for each airport by the fluid use factor (in gallons of ADF per operation) for the group.

11.1.3 Estimated Annual Volume of Fluid That Has the Potential to Impact U.S. Surface Waters and POTWs (Step 3)

Not all the fluid sprayed has the potential to impact U.S. surface waters and POTWs since some of the fluid will be lost to the air during spray application, some will remain on the aircraft, and some will be retained in adjacent grassy areas. EPA assumes that only the volume of fluid falling on paved deicing/anti-icing areas has the potential to impact U.S. surface waters and POTWs. Estimates developed by Environment Canada in the early 1980s suggested that the percentage of fluid falling on paved deicing/anti-icing areas could be as low as 50 percent (2). More recent research conducted by Limno-Tech, Inc., an environmental consulting company assisting airports with ADF-contaminated storm water management, indicates that for Type I fluids, approximately 80% of the fluid sprayed falls on paved deicing/anti-icing areas (3). Based on fluid use and fluid collection data provided by several U.S. airports, EPA believes that the more recent estimate made by Limno-Tech is more accurate than the estimate developed by Environment Canada.

For each airport, EPA calculated the estimated annual volume of fluid that has the potential to impact U.S. surface waters and POTWs by multiplying the estimated annual ADF volume used at the airport by 0.8.

11.1.4 Estimated Annual Volume of Aircraft Deicing/Anti-icing Fluid Discharged Prior to the Implementation of EPA's Phase I Storm Water Permit Application Regulations (Step 4)

EPA does not have sufficient fluid use data to directly calculate pollutant loadings discharged prior to implementing the Phase I storm water permit application regulations. As a result, EPA instead estimated these loadings using current ADF use data and other available information.

EPA knows of no airport or airport tenant that implemented wastewater containment and collection practices specifically for wastewater generated from aircraft deicing/anti-icing operations prior to EPA's publication of the storm water permit application regulations on November 16, 1990. Consequently, EPA assumed that no U.S. airports managed wastewater specifically from aircraft deicing/anti-icing operations prior to 1990 (i.e., all U.S. airports were direct dischargers) and that all U.S. airports would have continued to be direct dischargers if EPA's storm water program had not been promulgated.

EPA estimated the pollutant loadings for the 212 airports that potentially perform significant deicing operations by summing the estimated volume of fluid that has the potential to impact U.S. surface waters and POTWs (discussed in Section 11.1.3) and converting the result to pounds of ADF as applied. The results indicate that an estimated 28 million gallons of ADF (50% concentration) were discharged annually to surface waters (with zero gallons discharged to POTWs) prior to the implementation of EPA's Phase I Storm Water Permit Application Regulations. EPA believes that this estimate has a high bias because it reflects increased ADF use since 1990 caused by FAA's 1992 amendments to the aircraft deicing regulations and by industry growth. EPA believes it is appropriate to include this bias to enable comparison to the pollutant loadings estimates developed in Section 11.1.5 (for current loadings) and 11.1.6 (for loadings after implementation of an effluent guideline), which also reflect increased ADF use since 1990.

11.1.5 Estimated Annual Volume of Aircraft Deicing/Anti-icing Fluid Currently Discharged (Step 5)

EPA reviewed all currently available information, including that collected from site visits, industry conferences, questionnaires, and literature sources, to identify airports currently collecting or otherwise managing wastewater from aircraft deicing/anti-icing operations. EPA evaluated the efficiency of ADF wastewater management systems currently used at U.S. airports and used this information to develop four categories of wastewater management performance as shown below:

- Category 1 - Airports with exemplary collection systems capable of collecting an average of 87.5% of the ADF that would potentially impact U.S. surface waters (i.e., 70% of fluid applied).

- Category 2 - Airports with collection systems capable of collecting an average of 51.25% of the ADF that would potentially impact U.S. surface waters.

- Category 3 - Airports that have implemented some type of wastewater collection system, but the system is either incomplete or limited in area. These airports are capable of collecting an average of 25% of the ADF that would potentially impact U.S. surface waters.

- Category 4 - Airports that have no provisions for collecting and treating wastewater from ADF operations (i.e., 0% collection).

All of the airports identified as potentially performing significant aircraft deicing/anti-icing operations were assigned to one of the four wastewater management performance categories based on a review of their ADF wastewater management systems. In this context, management includes wastewater collection systems with either on-site treatment (including glycol recycling) or controlled discharge to a POTW.

EPA estimated the total volume of ADF discharged to U.S. surface waters and POTWs for the 212 airports that potentially perform significant deicing operations by summing the estimated volume of fluid that is <u>not</u> collected for each airport. The results indicate that an estimated 21 million gallons of ADF (50% concentration) are currently discharged directly to surface waters. This represents a 25% reduction from pre-storm-water program estimates. EPA estimates an additional 2.1 million gallons of ADF (50% concentration) are currently discharged to POTWs.

EPA estimates that ADF discharges will be further reduced to an estimated 17 million gallons of ADF (50% concentration) discharged directly to surface waters when the requirements of all storm water permits are fully implemented. EPA also expects the volume of ADF discharges to POTWs to steadily increase. EPA’s estimate of the discharges associated with full implementation of storm water permit regulations are based on the assumptions that Category 3 airports will implement Category 2 levels of control and that Category 4 airports will implement Category 3 levels of control.

11.1.6 Estimated Annual Volume of Aircraft Deicing/Anti-icing Fluid Discharged to U.S. Surface Waters After Implementation of an Effluent Guideline (Step 6)

To estimate the impact of an effluent guideline, EPA assumed that all U.S. airports identified as potentially performing significant aircraft deicing/anti-icing operations would implement wastewater management programs that have collection efficiencies comparable to the Category 1 airports. EPA calculated the total volume of ADF that would be discharged by the 212 airports that potentially perform significant deicing operations (assuming 100% implementation) by summing the estimated volume of fluid that would not be collected at each airport. The results indicate that an estimated 3.6 million gallons of ADF (50% concentration) would be discharged directly to surface waters following the implementation of an effluent guideline. This represents an 87% reduction from the pre-storm-water permit regulation estimates and a 62% reduction from current estimates.

An unknown portion of the additional 62% reduction in direct discharges to U.S. surface waters from current estimates would be discharged to POTWs. This portion would be dependent on the specific ADF collection and mitigation systems implemented by individual airports.

EPA's estimates of the annual ADF volume discharged by airports that potentially perform significant deicing/anti-icing operations for each of the three regulatory scenarios are summarized below.

Case	Estimated Volume of ADF Discharged to U.S. Surface Waters (million gallons/yr)	Estimated Volume of ADF Discharged to POTWs (million gallons/yr)
Discharges prior to implementation of EPA's Storm Water Program	28	0
Current discharges	21	2.1
Discharges following full implementation of storm water permit regulations	17	>2.1
Discharges following implementation of an effluent guideline	3.6	>2.1

11.1.7 Pollutant Loading Estimates

EPA calculated pollutant loadings using the estimated total ADF volumes discharged and converting to pounds of ADF and to pounds of BOD_5. Since the biochemical oxygen demand for Type I fluids differs depending on the glycol-base, EPA calculated a range the for the pounds of BOD_5 using BOD_5 data for propylene glycol-based and ethylene glycol-based Type I fluids. The following table summarizes the pollutant loadings to U.S. surface waters and POTWs.

Case	Estimated Loadings Discharged to U.S. Surface Waters		Estimated Loadings Discharged to POTWs	
	ADF Concentrate (million lbs/yr)	BOD_5 Range (million lbs/yr)	ADF Concentrate (million lbs/yr)	BOD_5 Range (million lbs/yr)
Discharges prior to implementation of EPA's Storm Water Program	126	98 - 102	0	0
Current discharges	95	74 - 77	9.6	7.4 - 7.8
Discharges following full implementation of storm water permit regulations	75	58 - 61	>9.6	>7.4
Discharges following implementation of an effluent guideline	16	12 - 13	>9.6	>7.4

11.2 Costs to Manage Wastewater from Airport Deicing Operations

This section provides costing information for airports that have upgraded their management systems to control wastewater from airport deicing operations. The available cost data from airports is summarized below. The Airport Group for each airport is listed as a means for comparison among airports that would be expected to have similar ADF use, and the Wastewater Management Category is listed to compare airport costs by current estimated ADF-capture efficiency.

Airport Group	Management Category	Airport	Capital Cost (Year Installed)	Annual Operating Cost
A1	1	Denver International (DIA)	$36 million (1995)	$550,000
A2	2	Minneapolis-St. Paul International (MSP)	$1.75 million (1993)	$1.4 million
	2	Chicago O'Hare International (ORD)	$98 million (1996)	$1 million
A4	2	Dallas/Ft. Worth International (DFW)	$1.7 million (1997)	Not available
B2	2	Salt Lake City International (SLC)	$27.8 million (1998)	$760,000
	1	Baltimore/Washington International (BWI)	$22 million (1997)	Not available
C2	2	Bradley International (BDL)	$17.7 million (1999)	Not available
	2	General Mitchell International (MKE)	Not available	$1 million
C3	3	Kansas City International	$8.5 million (1999)	Not available
D1	1	Albany International	$30.25 million (1989-1998)	$325,000
	1	Greater Buffalo International	$5.6 million (1996)	$100,000
E2	1	Greater Rockford	$1.8 million (1994)	$176,000

Tables 11-1 and 11-2 at the end of this section list specific capital and annual operating costs, respectively, provided by airports, vendors, and other contacts. EPA obtained these costs through EPA-sponsored meetings, industry conferences, EPA mini-questionnaires, EPA site visits, and other data submittals provided at EPA's request. These tables provide capital costs for specific components of storm water management systems and annual costs for specific types of operating costs (e.g., labor and electricity). These tables may not represent the full range of costs that airports may incur when designing, installing, and operating a comprehensive management system for wastewater from airport deicing operations.

Section 14.2.3 describes airline deicing costs by major component, including costs of delay, labor and operating costs, materials, and capital costs.

11.3 References

1. Eastern Research Group, Inc. Development of Estimated Loadings in Wastewater Discharges From Aircraft Deicing/Anti-icing Operations. December 1999 (DCN T11074).

2. Transport Canada. State of the Art Report on Aircraft Deicing/Anti-icing. November 1985 (DCN T10669).

3. University of Massachusetts. Workshop: Best Management Practices for Airport Deicing. July 1999 (DCN 10661).

Table 11-1

Capital Costs Incurred by Airports for Management of Wastewater from Airport Deicing Operations

Airport/Source	Description of Management Project	Year Construction Completed or Equipment Acquired	Capital Costs
Dallas/Ft. Worth International Airport (DFW)	Two 3-million-gallon detention ponds with liners and covers; pumping station; diversion box; and grit chamber with oil skimmer	1997	$1.7 million
Minneapolis-St. Paul International Airport (MSP)	Three 1-million-gallon storage ponds with liner, leak detection system, and monitoring wells; an operations center with boiler and recirculation pump for preventing wastewater freezing	1993	$1 million
	Elgin vacuum trucks	Unknown	$275,000 each
Kansas City International Airport (MCI)	Trench drains around passenger terminals; a diversion box; two 1-million-gallon concrete wastewater storage basins; modifications to the Todd Creek Wastewater Treatment Plant	Under construction	$8.5 million (estimated)
Denver International Airport (DIA)	Wastewater collection system for nine aircraft deicing pads and United Airlines gates; three 420,000-gallon wastewater storage tanks; two detention ponds (total capacity 12 million gallons; ADSI glycol recycling plant; glycol storage tanks	1995	$36 million
Albany International Airport (ALB)	Elgin vacuum truck	Unknown	$248,000
	Retrofitting 16 deicer trucks with dripless fittings and automatic filling shut-off valves	Unknown	$4,000
	Construction of a wastewater collection system at passenger terminals and two lined lagoons (one 6-million-gallon lagoon and one 2.3-million-gallon lagoon)	1989	$10 million
	Improvements to the wastewater collection system and construction of a wastewater treatment facility (designed and operated by EFX; see EFX entry later in this table) Improvements to the collection system included: blowers and a recirculation pump for the lagoons; a 2.5-million-gallon tank for wastewater storage; two wet wells (60,000 gallon and 80,000 gallon) with float activated pumps; and four 4,000-gallon portable tanks for storage of wastewater with high glycol content	1989 to Present	$20 million

Table 11-1 (Continued)

Airport/Source	Description of Management Project	Year Construction Completed or Equipment Acquired	Capital Costs
Greater Rockford Airport (RFD)	Wastewater treatment facility (includes a 16-million-gallon lined detention pond aerated with four mechanical and 12 aspirating aerators, a recirculation pump, a 5-million-gallon lined settling pond, two 50,000-gallon static inclined plate, oil/water separators, and storage building)	1994	$1.8 million
Bradley International Airport (BDL)	Two Tennant™ vacuum trucks	1990	$140,000
	One truck-mounted Ramp Ranger™	Unknown	$211,000
	One trailer-mounted Ramp Ranger™	Unknown	$180,000
	One AR Plus Interceptor™	Unknown	$200,000
	Construction of deicing pad including three aircraft deicing stations, a deicing pad control tower, ADF storage area with five 20,000-gallon ADF storage tanks, a siamese drainage collection system with automated drain valves, and two 1-million-gallon underground storage tanks	Summer 1999	$17 million (estimated)
Buffalo-Niagara International Airport (BUF)	Installation of storm drain valves and coating pavement surface with a sealant (cargo and GA facilities only)	1995	$1.2 million
	Construction of an underground storm water pipe for conveying wastewater from the cargo area to a contaminated wastewater storage basin. Also includes the enlargement of the underground wastewater storage basin from its current capacity of 200,000 gallons to a capacity of approximately 1 million gallons	November 1999	$4.2 million (estimated)
Chicago O'Hare International Airport (ORD)	Snow dump improvements including concrete pad, drainage collection system, and piping to existing detention ponds	Planned	$435,000 (estimated)
	Construction of hold pad with drainage collection system and a lined detention pond	1996	$10 million
	Expansion of wastewater storage facility at North Detention Pond including two additional detention ponds and junction control chambers; installation of a drainage collection system for north airfield and aircraft maintenance hangars	Planned	$80 million (estimated)
	Four aboveground storage tanks for ADF with containment structures and deicer truck filling stations	1996	$3.3 million

Table 11-1 (Continued)

Airport/Source	Description of Management Project	Year Construction Completed or Equipment Acquired	Capital Costs
Salt Lake City International Airport (SLC)	Six primary aircraft deicing pads; five secondary deicing pads; three 3-million-gallon detention ponds with membrane liner and cover; drainage collection system for deicing pads and passenger terminals (including piping, diversion boxes, and pumps)	1998	$23 million
	Wastewater storage tank and deicing pad (GA facility)	Unknown	$362,000
	Glycol recycling plant	1998	$4.5 million
G. Frigon/Dames & Moore	Pinch valves	Unknown	$8,000 - $16,000/each
	Butterfly valves	Unknown	$1,200/each
EFX	EFX anaerobic biological treatment system (not including storm water collection and equalization) at Albany International Airport (ALB)	1998	$1.6 million
ATA member	Ice detection system	Unknown	$60,000
	Large blankets (for wings)	Unknown	$10,000/aircraft
AR Plus/VQuip	Storm drain inserts	Unknown	$1,200 - $1,800
	High-capacity vacuum unit	Unknown	$240,000 - $250,000
Air Canada	Wetland for storm water management at Edmonton airport, Alberta, Canada	Under construction	$1 million
AR Plus	6" valve Interceptor™	Unknown	$600 - $800
	3300G Ramp Ranger™	Unknown	$250,000

Table 11-2

Annual Costs Incurred by Airports for Management of Wastewater from Airport Deicing Operations

Airport/Source	Description of Management Project	Year	Operating Costs
General Mitchell International Airport (MKE)	Annual operating costs for vacuum truck and drain valves	1998-1999	$1 million (estimated)
Minneapolis-St. Paul International Airport (MSP)	Detention pond cleaning and sludge removal (cost per pond)	Unknown	$2,600
	Annual operating and maintenance costs for holding ponds, boiler, and associated equipment. Also includes monitoring costs, including biannual sampling from monitoring wells	Unknown	$270,000
	Annual costs for storm water monitoring and analytical analysis	Unknown	$650,000
	Annual POTW charges for wastewater treatment	Unknown	$150,000 - $200,000
	Annual wastewater transportation costs (including trucks and labor), installation/removal of sewer plugs, and maintenance of sewer plugs	Unknown	$350,000
Denver International Airport (DIA)	Annual POTW surcharges for BOD, TKN, and hydraulic load	Unknown	$550,000 (estimated)
Buffalo-Niagara International Airport (BUF)	Per hour energy costs for operation of InfraTek®	Unknown	$100
	Annual BOD surcharge from POTW	Unknown	$1,800 - $2,400
Albany International Airport (ALB)	Annual costs of storm water monitoring at three sites including: (1) quarterly monitoring for volatile organics (benzene, toluene, and xylene) and semivolatile organics; and (2) daily monitoring for glycol from October to May	Unknown	$50,000 (estimate)

Table 11-2 (Continued)

Airport/Source	Description of Management Project	Year	Operating Costs
Albany International Airport (ALB) (cont.)	Annual electricity for aeration of lagoons	1996	$80,633
		1995	$76,187
		1994	$79,823
		1993	$100,959
		1992	$122,557
		1991	$61,561
	Albany County Sewer District glycol/BOD annual disposal charges	1997	$15,756
		1996	$289,545
		1995	$220,381
		1994	$299,341
		1993	$277,369
		1992	$132,815
		1991	$121,044
	Village of Colonie annual conveyance fees	1996	$180,620
		1995	$143,665
		1994	$166,946
		1993	$173,318
		1992	$109,791
		1991	$93,217
Greater Rockford Airport (RFD)	Annual operating costs (e.g. electricity, chemicals) for operation of the airport's wastewater treatment facility	1998	$108,000
	Annual labor costs for operation of the airport's wastewater treatment facility	1998	$60,000 - $75,000
Chicago O'Hare International Airport (ORD)	Per hour cost of leasing and operating Aero Snow™ portable snow melters (per unit)	1998-1999	$6,000
	Annual POTW disposal costs	Unknown	$800,000 - $1 million

Table 11-2 (Continued)

Airport/Source	Description of Management Project	Year	Operating Costs
Salt Lake City International Airport (SLC)	Operating expenses for recycling plant	1998-1999	$760,000
Dallas/Ft. Worth International Airport (DFW)	POTW surcharge for discharges that exceed BOD limit	Unknown	$0.08/lb BOD
	POTW charges	Unknown	$1.07/1,000 gallons
FAA	Operating the InfraTek® system at Rochester International Airport	Unknown	$200 - $500/aircraft
AR Plus	3300G Ramp Ranger™ hourly operation	Unknown	$100 - $110/hr of operation
	2800 Interceptor™ rental	Unknown	$3,500/mo (1-year rental agreement)
		Unknown	$1,850/mo (3-year rental agreement)
		Unknown	$1,200/mo (5-year rental agreement)
	3300 Ramp Ranger™ rental	Unknown	$19,500/mo (1-year rental agreement)
		Unknown	$10,320/mo (3-year rental agreement)
		Unknown	$6,770/mo (5-year rental agreement)
	T4000 Ramp Ranger™ rental	Unknown	$5,215/mo (1-year rental agreement)
		Unknown	$2,765/mo (3-year rental agreement)
		Unknown	$1,815/mo (5-year rental agreement)
	Catch basin inserts	Unknown	$27.30/mo (3-year rental agreement)
		Unknown	$18.75/mo (5-year rental agreement)

Table 11-2 (Continued)

Airport/Source	Description of Management Project	Year	Operating Costs
AR Plus (cont.)	Wastewater treatment costs based on concentration of glycol in collected wastewater	Unknown	No charge (>20% glycol)
		Unknown	$0.07/gal (16 - 20%)
		Unknown	$0.09/gal (11 - 15%)
		Unknown	$0.12/gal (6 - 10%)
		Unknown	$0.15/gal (3 - 5%)
		Unknown	$0.18/gal (<3%)
	Personnel costs	Unknown	$45/hour (project supervisor)
		Unknown	$35/hour (equipment operator)
		Unknown	$30/hour (field technician)
Air Canada	Wastewater treatment costs for Vancouver Int'l at Seattle POTW	1999	$0.15/L of wastewater
EFX	EFX anaerobic biological treatment system @ 200 GPM and influent of 2,000 mg/L of COD (includes amortized capital and annual operating costs)	Unknown	<$3.00/1,000 gallons (annualized)

12.0 TRENDS IN THE INDUSTRY

This section describes trends in the aircraft and pavement deicing industry, including types and amounts of aircraft deicing/anti-icing fluids (ADFs) used (Section 12.1), types and amounts of pavement deicing/anti-icing agents used (Section 12.2), deicing/anti-icing equipment and operations (Section 12.3), and mitigation of wastewater containing spent deicing/anti-icing agents (Section 12.4). (Economic trends within the air transportation industry, including airports and airlines, are described throughout Section 14.0 and specifically within Section 14.2.4.) These trends demonstrate a greatly increased awareness within the past decade of deicing issues and their potential impacts on the environment by airlines, airports, the EPA and other regulatory agencies, and the public.

All of the apparent trends discussed in this section are based on information obtained during EPA’s data-collection activities and subsequent analyses, which are described throughout this report. Note, however, that the vast majority of these sources are not statistically reliable. Accordingly, the trends described in this section should be considered qualitative or anecdotal because available data are insufficient to validate trends statistically. Appendix A contains information regarding the location of airports referenced in this section.

12.1 Trends in the Use of Aircraft Deicing/Anti-icing Fluids

Based on the limited quantitative data available to EPA, propylene glycol-based rather than ethylene glycol-based ADFs are now predominantly used in the U.S. This is a large shift from the status of the industry 10 years prior. This is demonstrated by a letter from the Air Transport Association (ATA) dated March 1989, “Ethylene glycol is the dominant deicer in use by airlines in the U.S. today.... Propylene glycol is an anti-icer that is receiving increasing use because it protects aircraft surfaces for a longer period after application, and because a market shortage of ethylene has introduced supply and cost problems for ethylene glycol” (1).

The shift toward using anti-icing fluids in combination with Type I fluids is demonstrated by an EPA report dated September 28, 1990, "Presently there are two types of fluids available to commercial airlines and airport authorities. Type I fluids are used for deicing only and Type II fluids are used for deicing and anti-icing" (1). Since 1990, fluid manufacturers have developed two anti-icing fluid types, Types III and IV, and have developed ethylene glycol-based anti-icing chemicals (fluid types are described in Section 4.2.1.1). In fact, Union Carbide, an ethylene glycol-based ADF manufacturer, first developed Type IV fluids. (Note that Type II and Type III fluids have since become largely obsolete.)

Three primary factors have influenced changes in the types and quantities of ADFs used by the industry. First, ethylene glycol is listed as a hazardous air pollutant under the Clean Air Act and is therefore subject to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) reporting requirements when released in a quantity of more than 5,000 pounds in a 24-hour period. Propylene glycol is not listed as a hazardous air pollutant and is not reportable under CERCLA. Although airports may qualify for eliminated or reduced reporting requirements via the federally permitted release exemption (2), many airports have moved from dominant use of ethylene glycol-based fluids to increased use of propylene glycol-based fluids in part to avoid the burden associated with recordkeeping and reporting. Note that available toxicity data presented in Section 9.0 indicate that the base glycols exhibit acute aquatic toxicological effects at concentrations within the same order of magnitude; however, the formulated fluids vary by manufacturer. Due to propylene glycol's lower mammalian toxicity, some airports have switched to propylene glycol in part to meet demands of consent decrees or local citizen's groups.

Second, the use of deicing agents increased dramatically in 1992 and 1993 because of new Federal Aviation Administration (FAA)-mandated deicing rules developed following a crash caused by improper deicing at LaGuardia Airport. These regulations prohibit takeoff when snow, ice, or frost is adhering to wings, propellers, control surfaces, engine inlets, and other critical surfaces of an aircraft and are referred to as the "clean aircraft concept" (see Section 13.4.1). Typical tests show that 1/32nd of an inch of ice accumulation along the leading edge of the wing of a large jet or 1/64th of an inch on a smaller aircraft can decrease lift on takeoff from

12% to 24%, depending on the size of the aircraft (3). Several airport operators reported at the American Association of Airport Executives Conference on Aircraft Deicing, August 23, 1993, that the annual volume of aircraft deicing fluids used by U.S. airlines increased threefold since the crash (4). Airlines also increased use of aircraft anti-icing chemicals to extend holding times and reduce secondary aircraft deicing requirements. Total use of ADFs in the future is likely to increase due to continued growth of the air transportation industry.

Third, on November 16, 1990, EPA published the National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges (see Section 13.1). These regulations require airports with deicing and other industrial activities to obtain a storm water discharge permit. Although there are several permitting alternatives, all permits require the development and implementation of a Storm Water Pollution Prevention Plan specifying pollution prevention and best management practices to control pollutant discharges. Consequently, many airlines have further increased use of anti-icing fluids (Type II/IV fluids) to reduce the overall amount of aircraft deicing chemicals used (see Section 6.2.1). In addition, glycol recycling to mitigate glycol-contaminated wastewater has proliferated (see Section 6.4). As a result, some airports have completely substituted propylene glycol-based fluids for ethylene glycol-based fluids because most recycling systems cannot separate the two glycols and because of current strength of the secondary markets for propylene glycol.

EPA obtained recent glycol usage data (of varying quality) from 26 airports. An analysis of these data substantiates trends since 1990 for increased used of propylene glycol-based ADFs and of Type II/IV ADFs, as shown in the table below.

Trend	Percentage of Airport ADF Applied		
	1990	1996 to Present (a)	
		Average Percentage	Range of Percentages
Use of Propylene Glycol-Based ADFs (data from 21 airports)	<50%	78	11 to 100
Use of Type II/IV ADFs (data from 18 airports)	Assumed <1%	6.1	0 to 15

(a) Most data are for the 1996-1997 through the 1998-1999 deicing seasons, although some data include earlier years.

Recent trends in ADF usage are more difficult to characterize. EPA obtained ADF usage data for multiple years (generally for the 1996-1997, 1997-1998, and 1998-1999 deicing seasons) for 15 of the 26 airports. The following summarize EPA's findings regarding trends in propylene glycol-based fluid use during this period: eight airports reported either no change (generally because the airports use only propylene glycol-based fluids) or varying usage (i.e., both increases and decreases) on a percentage basis; three airports reported increasing usage on a percentage basis; one airport reported decreasing usage on a percentage basis; and three airports did not provide sufficient data for this analysis. These data suggest that the industry may be reaching equilibrium in glycol usage in this regard. EPA is aware that airlines are very concerned that increased substitution of propylene glycol-based ADFs for ethylene glycol-based ADFs could result in the loss of a diverse, competitive market of formulated fluids.

The following summarize EPA's findings regarding recent trends in Type II/IV fluid use: three airports reported either no change (i.e., no use of Type II/IV fluids) or varying usage (i.e., both increases and decreases) on a percentage basis; eight airports reported increasing usage on a percentage basis; two airports reported decreasing usage on a percentage basis; and two airports did not provide sufficient data for this analysis. These data suggest that the industry is increasing its usage of Type II/IV fluids.

While use of Type II/IV fluids may reduce the total volume of ADF applied at an airport, spent Type II/IV fluids are more difficult to collect because the fluids are widely dispersed through dripping and sloughing during the taxi and takeoff of aircraft. "Glycol dripping off aircraft once it leaves the deicing pads is our biggest challenge," according to Dan Smith, environmental scientist at Dayton International Airport (5). Because of this, it may be more environmentally beneficial for airports with highly efficient spent ADF collection and mitigation practices to use Type I fluids instead of Type II/IV fluids because Type I fluids are easier to collect then Type II/IV fluids. However, the increased safety that comes with the extended protection of the anti-icers may outweigh benefits related to ease of collection.

In an effort to lessen the environmental impacts of spent ADFs, airlines are pressuring manufacturers to develop more environmentally benign ADFs. ATA is working with the Society of Automotive Engineers (SAE) to require standardized reporting of environmental information for all fluid types. (SAE standards for ADFs are described in detail in Section 13.5.) The proposed revised reporting requirements include data for biochemical oxygen demand (specifically 5 days and 28 days at 5° C and 20° C), chemical oxygen demand (rather than total oxygen demand), additional aquatic toxicity testing (specifically *Ceriodaphnia dubia* as test organism), and 10 trace metals (rather than four) for which water quality criteria exist. The ATA/SAE Environmental Workgroup is also considering imposing an aquatic toxicity protocol or goal that would apply to new fluid formulations. Fluid manufacturers have agreed to continue working on reducing the aquatic toxicity of their products and to work with SAE to consider developing an SAE aquatic toxicity protocol (6).

At the Airport Deicing Summit for New York State on March 25, 1999, two representatives of ADF formulators/manufacturers, one from Octagon Process and one from Lyondell (formerly ARCO), discussed the status of work toward and impediments to developing less toxic aircraft deicing/anti-icing fluids. The Octagon representative stated that deicing/anti-icing additives now comprise only 0.5% of formulated fluids and that manufacturers and formulators continue efforts to make their products more environmentally friendly. However, the representative anticipates only minor incremental improvements in products because of the following factors:

- The variety of replacement chemical additives is small.
- Some possible chemical additives interact and therefore cannot be combined.
- Performance standards are complex. For example, a variety of metals and alloys must be protected from corrosion under a variety of conditions. In addition, the armed forces wish to use commercial rather than military deicing fluids, resulting in an even greater variety of exotic alloys and coatings requiring protection.

- Carcinogenic chemical additives are unacceptable.

- Fluid costs are paramount. Potentially promising alternative freezing point depressants, such as fish fatty acids, would be prohibitively expensive at an estimated $100 per gallon.

- Many individual fluid additives perform multiple functions but may be relatively toxic. These additives could be replaced by multiple, less toxic additives; however, the combined toxicity of the replacement additives can be greater than the toxicity of the original additive (7).

12.2 Trends in the Use of Airport Pavement Deicing/Anti-icing Agents

Based on the limited quantitative data available to EPA, potassium acetate is now predominantly used for pavement deicing/anti-icing in the U.S. This is a change that has occurred over the past two to three years. The change is demonstrated in an EPA report dated September 28, 1990, “Runway deicing materials are normally ethylene glycol, UCAR (by Union Carbide), and pelletized urea.... Alternative materials including calcium magnesium acetate (CMA) are under investigation and used at several airports.” Also in this report, “A solution of potassium acetate with corrosion inhibitors is under investigation as an alternative to glycol-based compounds for airside use, especially for runway deicing and anti-icing” (1).

EPA obtained pavement deicer usage data (of varying quality) from 26 airports. An analysis of these data substantiate trends since 1990 of decreased use of glycols and urea as airport deicing/anti-icing agents and increased use of alternative airfield deicers/anti-icers. Only three airports reported using runway deicing material composed of a mixture of ethylene glycol (50% to 60%), urea (25% to 40%), water (0% to 25%), and dipotassium phosphate (0% to 3%) (e.g., UCAR). One airport reported using small amounts of propylene glycol (75 gallons per year) as a wetting agent for sand.

Fourteen airports reported using urea for pavement deicing within the last three deicing seasons. Of these, six airports have now either discontinued or are phasing out use of urea in favor of sodium acetate, sodium formate, or potassium acetate. The remaining eight airports have not reported plans to discontinue or reduce use of urea. Factors preventing or inhibiting use of alternative pavement deicing/anti-icing agents at these eight airports include: (1) concerns about the possible impact of potassium acetate on electrical systems, (2) increased cost of alternate agents, and (3) greater efficiency of urea.

EPA anticipates that trends toward decreased use of ethylene glycol and urea for pavement deicing/anti-icing will continue because of concerns of the resulting high pollutant loadings in runoff, high potential for aquatic toxicity from the degradation of urea, and the high cost of collecting and mitigating contaminated runoff from paved areas.

12.3 Trends in Deicing/Anti-icing Equipment and Operations

Section 6.2 describes a variety of ADF minimization methods that airports and airlines may implement. Of these methods, only the use of Type IV anti-icing fluids has gained apparent wide-spread use throughout the industry, as described in Section 12.1. However, information available to EPA suggests a trend toward increased use of infrared and forced-air aircraft deicing systems. Both technologies appear to be moving from the experimental or testing phase to permanent, commercial use. EPA also anticipates increased use of ice detection systems for both aircraft and pavement.

Trends among the remaining ADF pollution prevention practices are difficult to evaluate. Airports and airlines have not yet identified an optimum combination of pollution prevention and spent fluid mitigation methods. Changes in fluid price, recycled/recovered fluid secondary markets, and fluid toxicity are also expected to influence the selection of pollutant control practices and technologies. EPA anticipates that future trends within the industry will stratify by small versus large airports and by the specific preferences (based on economic considerations and experience) of major carriers operating at each airport. For example, many airlines, particularly at their hubs and large stations, blend ADFs to temperature and use a fleet of enclosed-basket deicing trucks (8, 9).

EPA has limited information on trends in pavement deicing/anti-icing equipment and operations, other than the increased use of alternative agents described in Section 12.2. EPA believes that the majority of minimization methods described in Section 6.5.3 are standard operating procedures at U.S. airports because they save airport resources. EPA is not aware of any trends in the use of alternative pavement deicing/anti-icing methods described in Section 6.5.2 (e.g., heated pavements).

12.4 Trends in Spent Deicing/Anti-icing Chemical Mitigation

Available data demonstrate an increasing trend toward collecting wastewater contaminated with ADFs using a combination of the practices described in Section 6.3. EPA is aware of several airports that are studying options for collecting contaminated wastewater (e.g., General Mitchell International Airport, Washington Dulles International Airport, Ronald Reagan Washington National Airport, and Portland International Airport). With few exceptions, large airports that perform significant deicing operations have implemented one or more collection systems for wastewater contaminated with ADFs (10). Specific collection controls are determined based largely on cost-effectiveness, which is greatly influenced by airport-specific considerations such as climate, airport layout, airport operations, existing infrastructure, feasibility of glycol recovery/recycling (on site or off site), availability and accessibility of land, and the feasibility of discharging contaminated wastewater to a publicly owned treatment works (POTW).

Collection of ADF-contaminated wastewater has resulted in increased use of the following wastewater management techniques, including:

- Direct discharge at a controlled rate;
- Indirect discharge at a controlled rate;
- On-site wastewater treatment followed by direct or indirect discharge; and
- On-site or off-site glycol recycling/recovery followed by indirect discharge of residual wastewater.

Recent trends appear to favor use of glycol recycling/recovery. Prior to 1995, only Denver's Stapleton Airport performed glycol recycling/recovery. Today, at least 15 airports use on-site or off-site glycol recycling/recovery (see Section 6.4). EPA anticipates a growing use of glycol recycling/recovery as part of a total mitigation strategy as more airports implement wastewater collection systems and while secondary glycol markets remain strong. Several vendors offer wastewater collection and recycling/recovery services via leasing agreements that can be implemented relatively quickly with minimal capital expenditure. However, because recycling/recovery is generally prohibitively expensive for relatively dilute wastewaters, most airports must also use alternative discharge or disposal practices for these dilute wastewaters.

Available information also demonstrates a significant increase in indirect discharge of ADF-contaminated wastewater to a POTW. These include discharges with and without pretreatment. For example, systems used to recycle/recover glycol from spent ADF currently operating in the U.S. discharge residual wastewater to a POTW. EPA is also aware of several more airports that are considering or negotiating discharge of ADF-contaminated wastewater to a POTW.

EPA is not aware of any airports that operated on-site treatment designed to control glycol discharges prior to 1994. Today, EPA is aware of at least four airports that operate or are constructing on-site treatment systems for ADF-contaminated wastewater (see Section 7.0); however, EPA is not aware of any additional airports considering on-site wastewater treatment. In general, airports prefer indirect discharge of wastewater to on-site treatment. Unique instances of high conveyance and discharge fees, the inability of the POTW to accept ADF-contaminated wastewater, or other site-specific considerations cause airports to consider on-site treatment. EPA also recognizes that uncertain future regulatory requirements discourage airports from implementing such capital improvements as on-site wastewater treatment that may be difficult and expensive to retrofit to new requirements.

In contrast to trends in mitigating ADF-contaminated wastewater, EPA is aware of only one airport, Chicago O'Hare International Airport, that collects wastewater contaminated with pavement deicing/anti-icing chemicals from runways and taxiways. EPA is not aware of any additional airports considering collection of these wastewaters, presumably because of prohibitively high collection costs. Substitution of glycol-based and urea-based deicing/anti-icing agents with more environmentally benign agents have greatly reduced environmental incentives to collect and mitigate these wastewaters.

12.5 References

1. U.S. Environmental Protection Agency. Contractor Report - Guidance for Issuing NPDES Storm Water Permits for Airports. September 28, 1990 (DCN T00226).

2. Letter from Robert I. Van Heuvelen, U.S. EPA to Robert Van Voorhees and Carol Lynn Green, Bryan Cave LLP. (DCN T11045).

3. Barry Valentine. What's the Problem We're Trying to Solve. The Airport Deicing Advisor. November 1999 (DCN T11071).

4. U.S. Environmental Protection Agency. Emerging Technology Report: Preliminary Status of Airplane Deicing Fluid Recovery Systems. September 1995 (DCN T04674).

5. Bremer, K. "The Three Rs - Reduce, Recover, and Recycle," Airport Magazine. March/April 1998 (DCN T10361).

6. Stormwater Subcommittee Presentation to SAE G-12 Fluids Subcommittee. October 20, 1999 (DCN T11046).

7. Meeting Summary for Albany Aircraft Deicing Summit. March 1999 (DCN T10542).

8. Meeting Summary between U.S. EPA and Air Transport Association, November 1998 (DCN T10464).

9. Letter from Scott F. Belcher, Air Transport Association to Shari Zuskin Barash, U.S. EPA. November 4, 1999 (DCN T11063).

10. Eastern Research Group, Inc. Development of Estimated Loadings to the Environment from Aircraft Deicing/Anti-icing Study. December 1999 (DCN T11074).

13.0 RELATIONSHIP TO OTHER REGULATIONS

This section discusses other regulations pertaining to deicing/anti-icing operations at airports. Section 13.1 presents an overview of the EPA Storm Water Program; Section 13.2 discusses other national, state, and local permitting issues; Section 13.3 discusses the Canadian guidelines for the discharge of aircraft deicing/anti-icing fluids (ADF)-contaminated wastewater; Section 13.4 discusses Federal Aviation Administration (FAA) regulations for airport and aircraft deicing/anti-icing operations; and Section 13.5 discusses the SAE standards and the role of Society of Automotive Engineers (SAE) in establishing safe and effective ADFs. Appendix A contains information regarding the location of airports referenced in this section.

13.1 EPA Storm Water Program

The 1972 amendments to the Federal Water Pollution Control Act (referred to as the Clean Water Act or CWA), prohibit the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Efforts to improve water quality under the NPDES program have traditionally and primarily focused on reducing pollutants in industrial process wastewater and municipal sewage discharges because these sources have represented pressing environmental problems. However, as pollution control measures were initially developed for these discharges, it became evident that more diffuse sources (occurring over a wide area) of water pollution, such as agricultural and urban runoff, were also major causes of water quality problems.

EPA performed several assessments to estimate the impact of diffuse and other sources on water quality. These included the National Water Quality Inventory Report to Congress (prepared biennially), America's Clean Water - The States' Nonpoint Source Assessment (performed biennially), and the Nationwide Urban Runoff Program. These studies determined background levels of pollutants from urban runoff, as well as other sources including illicit connections, construction site runoff, industrial site runoff, and illegal dumping. The studies noted that elimination of these other sources could dramatically improve the quality of urban storm water discharges.

In part, in response to these studies, Congress passed the Water Quality Act of 1987 (WQA), which contains three provisions specifically addressing storm water discharges. The central WQA provision governing storm water discharges is WQA Section 405, which alters the regulatory approach to control pollutants in storm water discharges by adopting a phased and tiered approach. The new provisions phase in permit application requirements, permit issuance deadlines, and compliance with permit conditions for different categories of storm water discharges. WQA Section 405 adds Section 402(p) to the CWA, which imposed a time limited “moratorium” on permitting of storm water discharges. The legislation also identified five types of storm water discharges that were subject to the moratorium and required a NPDES permit. One type is “discharge associated with industrial activity.”

13.1.1 Storm Water Permit Application Regulations

On November 16, 1990, EPA published the National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges (55 FR 47989; codified in 40 CFR 122). The rule presents a preliminary permitting strategy and permit application requirements for 11 major industrial classifications, and specifically identified “airport deicing operations” as industrial activities, the discharge from which require a permit. The rule also defines storm water to mean storm water runoff, snow-melt runoff, and surface runoff and drainage (§122.26(b)(13)).

The NPDES rule provided three major options for obtaining permits for storm water discharges associated with industrial activity: (1) a notice of intent to be covered by a general permit that provides baseline storm water management practices, (2) group permit applications, and (3) individual permit applications. EPA envisioned implementing these three permitting options over time to reflect priorities within given states. EPA intended that issuance of baseline permits (i.e., issuing one permit to authorize a group of discharges) would be the initial starting point. As priorities and risks within a state are evaluated, classes of storm water discharges would be identified for watershed permitting (typically accomplished via general area-specific permits), industry-specific (group) permitting, or facility-specific (individual) permitting.

On August 16, 1991, September 9, 1992, and September 25, 1992, EPA published "General Permits for Storm Water Discharges Associated With Industrial Activity" (56 FR 40948 and 57 FR 44438). This general permit included the baseline permit requirements intended to initially cover most storm water discharges associated with industrial activities in states without authorized NPDES programs. This permit also served as a model for states with authorized NPDES programs. Section 13.1.2 describes the general permit requirements in detail. Note that EPA did not reissue general permits for storm water discharges at facilities located in areas where EPA is the NPDES permitting authority. Therefore, airports located in these areas that were covered by general permits are now covered by either group or individual permits. General permits for airports located in areas with approved state NPDES programs remain in effect.

On November 19, 1993 and September 29, 1995, EPA published requirements for the "Multi-Sector General Permit" for storm water discharges associated with industry activity based on group permit applications submitted by storm water dischargers in similarly situated industries (58 FR 61146 and 60 FR 50804). This permit includes requirements that are specific to individual industrial sectors. Section 13.1.3 describes in detail the requirements specific to airport deicing/anti-icing operations.

Group permit applications were filed by entities representing groups of applicants that were part of the same subcategory or are otherwise sufficiently similar. The applications identified the participants, and described the industrial activities of participants and why they were sufficiently similar to be covered by a general permit. The American Association of Airport Executives (AAAE) prepared and submitted a group permit application including over 700 airports.

EPA received group permit applications from over 1,200 groups representing over 60,000 facilities from most of the major industrial classifications, except construction activities. The large number of facilities addressed by the regulatory definition of “storm water discharge associated with industrial activity” would have placed a tremendous administrative burden on EPA and states with authorized NPDES programs to issue and administer separate permits for each of these industrial group applicants. To facilitate the process of developing permits for each of the 1,200 group applications submitted, EPA classified the groups into 29 industrial sectors, in which the nature of industrial activity, type of materials handled, and material management practices used were sufficiently similar for the purposes of developing permits. Each industrial sector was represented by one or more groups that participated in the group application process. Airport deicing operations are included in Industrial Sector S (Vehicle Maintenance Areas, Equipment Cleaning Areas, or Deicing Area located at Air Transportation Facilities).

NPDES authorities issue individual permits (or modify existing individual permits to incorporate storm water discharge-related conditions) when warranted by the need for individual control mechanisms, their potential for pollution prevention, and where reduced administrative burdens exist. Section 13.1.4 describes in detail the requirements for individual permit applications.

13.1.2 General Permit (Baseline Industrial General Permit)

Facilities submit a notice of intent (NOI) to be covered by a general permit to authorize storm water discharges (the deadline for submitting a NOI for existing facilities was October 1, 1992). The NOI contains basic information such as the name and address of the facility, the Standard Industrial Classification codes that best represent the principal products or activities provided by the facility, the facility latitude and longitude, a brief description of the discharge and receiving water, and an indication of whether they have sampling data available for storm water discharges. Permits may require additional information where appropriate. Unless otherwise specified, dischargers are automatically authorized to discharge under the general permit by submitting an NOI in accordance with the terms of the permit.

General permit conditions and requirements are summarized below:

- Prohibition of non-storm-water discharges (with some specific exceptions) and discharges that contain a hazardous substance in excess of reporting quantities at 40 CFR 117.3 or 40 CFR 302.4.

- Annual monitoring of storm water discharges from aircraft or airport deicing areas for oil and grease, 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), pH, and the primary ingredient used in the deicing materials (e.g., ethylene glycol, propylene glycol, ammonia) for airports with over 50,000 flight operations per year. Other airports are not required to conduct discharge monitoring unless required by the permitting authority.

- Facilities are subject to record-keeping requirements, but generally do not have reporting requirements. (NOI provisions for reissued permits require dischargers to summarize the quantitative data collected during the previous permit term.) Facilities may collect a minimum of one grab sample from holding ponds or impoundments with a retention period greater than 24 hours. For all other discharges, both a grab and a composite sample are required.

- Estimation of the size of the drainage area and runoff coefficient of the drainage area.

- Preparation, retention, and implementation of a site-specific storm water pollution prevention plan to minimize and control pollutants. Plan requirements are based on traditional storm water management, pollution prevention, and best management practice concepts tailored to storm water discharges associated with industrial activities, and are imposed in lieu of numeric effluent limitations. Specific plan requirements are discussed below.

    - Identification of a team responsible for developing the plan and assisting the plant manager with implementing, maintaining, and revising the plan.

    - Description of activities, materials, and physical features of the facility that may contribute significant amounts of pollutants to storm water runoff. The plan must contain a site map showing storm water drainage, control structures, and areas of potential pollution sources (e.g., material storage and processing and waste disposal). It must also include an inventory of exposed materials, a list of significant spills and leaks that occurred three years prior to the effective date of the permit, an evaluation of the presence of non-storm-water discharges, a description of existing data on the quality or quantity of storm water discharges, and a risk identification and summary of potential pollutant sources.

- Evaluation, selection, and description of the pollution prevention measures, best management practices, and other controls that the facility will implement. At a minimum, the plan must address good housekeeping practices, preventive maintenance, spill prevention and response, inspections, employee training, record-keeping and internal reporting procedures, sediment and erosion control, and management of runoff.

- Description of annual comprehensive site compliance evaluations to confirm the accuracy of the evaluations and descriptions in the plan, determine the effectiveness of the plan, and assess compliance with the terms and conditions of the permit.

13.1.3 Multi-Sector General Permit

Group permit applications could have been filed by an entity representing a group of applicants that were part of the same subcategory or, if such a grouping was not applicable, were sufficiently similar as to be appropriate for general permit coverage under §122.28. The permit application consisted of two parts, Part 1, which was due on September 30, 1991, and Part 2, which was due on October 1, 1992. Part 1 included the following:

- Identification of the participants in the group application by precipitation zone (Appendix E to §122);
- Description of the industrial activities of participants and why they are significantly similar to be covered by a general permit;
- List of significant stored materials exposed to precipitation and materials management practices used to diminish contact; and
- Identification of group members who will submit quantitative data and description of why these selected facilities are representative of the group.

Part 2 of the permit application included submission of information for each representative facility equivalent to information that facilities applying for individual permits are required to submit.

AAAE's group permit application included Part 1 and Part 2 information for 59 airports considered to be representative of the 700 airports comprising the group permit application. Part 2 of the group application did not specify that facilities must sample storm water discharges from areas where deicing/anti-icing activities occurred and/or during times when such operations were conducted. As a result, only one facility indicated that the sampling data submitted were collected from areas where deicing activities were conducted.

EPA reviewed the group permit application to develop permit requirements contained in the Multi-Sector General Permit - Section S. Requirements specific to deicing/anti-icing operations are described in 60 FR 50998 (September 25, 1995) and include the following:

- Dry weather discharges of deicing/anti-icing chemicals are not authorized by this permit. There is no limit, however, on the time between a snowfall and snow-melt for the purpose of including a snow-melt discharge in the definition of storm water.

- Airports that use more than 100,000 gallons of glycol-based deicing/anti-icing chemicals and/or 100 tons of urea on an average annual basis will:

    - Prepare estimates for annual pollutant loadings discharged to storm sewer systems or surface waters, prior to and after implementation of the facility's storm water pollution prevention plan.

    - Monitor outfalls from the airport that collect runoff from areas where deicing/anti-icing activities occur for BOD_5, COD, ammonia, and pH. The airport should monitor these outfalls four times per year, from December through February when deicing/anti-icing activities occur, within the second and fourth years after permit issuance. A minimum of one grab sample and one flow-weighted composite sample should be collected from each outfall. Sampling within the fourth year may be waived if sampling data collected within the second year are less than monitoring cut-off concentrations of 30 mg/L for BOD_5, 120 mg/L for COD, 19 mg/L for ammonia, and between of 6 and 9 standard units for pH.

  - Record precipitation event data.

- The airport will prepare a comprehensive storm water pollution prevention plan that integrates areas of the facility occupied by airport tenants (i.e., co-located industrial activities), regardless of whether or not tenants are co-permittees. The operator(s)/owner(s) (the airport authority) of the airport storm water outfalls is (are) ultimately responsible for compliance with all terms and conditions of this or other NPDES permits applicable to storm water outfalls. Plan requirements specific to deicing/anti-icing operations are described below.

  - Identification of a team responsible for developing the plan and assisting facility management in its implementation, maintenance, and revision.

  - Description of potential pollutant sources and a site map indicating the locations of aircraft and runway deicing/anti-icing operations.

  - Description of the potential pollutant sources from aircraft and runway deicing/anti-icing operations (including apron and centralized aircraft deicing/anti-icing stations, runways, taxiways, and ramps) and identification of any pollutant or pollutant parameter of concern.

  - Requirements for facilities that conduct deicing/anti-icing operations to maintain a record of the types (including the Material Safety Data Sheets) and monthly quantities of deicing/anti-icing chemicals used. Tenants and fixed-base operators who conduct deicing/anti-icing operations will provide records to the airport authority to include in the comprehensive plan.

  - Description of storm water discharge management controls appropriate for each area of operation and a schedule for implementing such controls. Specifically, operators who conduct aircraft and/or runway (including taxiways and ramps) deicing/anti-icing operations will consider alternative practices to reduce the overall amount of deicing/anti-icing chemicals used and/or lessen environmental impacts.

    For runway deicing operations, operators will evaluate: present application rates to ensure against excessive overapplication; metered application of deicing chemical; prewetting dry chemical constituents prior to application; installation of runway ice detection systems; implementation of anti-icing operations as a preventive measure against ice buildup; the use of substitute deicing compounds, such as potassium acetate, in lieu of ethylene glycol, propylene glycol, and/or urea.

For aircraft deicing operations, operators will evaluate current application rates and practices to ensure against excessive overapplication, and consider pretreating aircraft with hot water before applying a deicing chemical, thus reducing the overall amount of chemical used per application. Operators will implement measures determined to be reasonable and appropriate.

- Description of management practices to control or manage contaminated runoff from areas where deicing/anti-icing operations occur to reduce the amount of pollutants being discharged from the site. The airport should consider structural controls such as establishing a centralized aircraft deicing facility, and/or collection of contaminated runoff for treatment or recycling. The plan should consider recovering deicing/anti-icing materials when these materials are applied during nonprecipitation events to prevent these materials from later becoming a source of storm water contamination. The airport will implement and maintain controls determined to be reasonable and appropriate.

- Inspections of areas where deicing/anti-icing operations are conducted at least once per week during deicing/anti-icing application periods.

- Pollution prevention training to inform management and personnel responsible for implementing activities identified in the storm water pollution prevention plan of the components and goals of the plan.

- Comprehensive site compliance evaluations at least annually during periods of deicing/anti-icing operations to ensure that measures to reduce pollutant loadings are adequately and properly implemented in accordance with the terms of the permit, and to determine whether additional control measures are needed.

13.1.4 Individual Permit

Application requirements for individual permits include submitting the appropriate permit application forms and the following supplemental information:

- A site map of the facility including details of drainage and discharge structures, drainage areas, and pertinent features of drainage areas of all storm water outfalls, including paved areas and buildings, significant material storage and disposal areas, structural control measures, materials loading and access areas, chemical application areas, and areas associated with hazardous waste.

- An estimate of the area of impervious surfaces and the total area drained by each outfall and a description of the pertinent features listed above.

- A certification that all outfalls that should contain storm water discharges associated with industrial activity have been evaluated for the presence of non-storm-water discharges.

- Existing information regarding significant leaks or spills of toxic or hazardous pollutants at the facility that have taken place within three years of application submittal.

- Quantitative data based on samples collected during storm events from all outfalls containing storm water discharges associated with industrial activity. Required sampled parameters include oil and grease, pH, BOD_5, COD, TSS, total phosphorus, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen, any pollutant limited in an effluent guideline to which the facility is subject, any pollutant listed in the facility's NPDES permit for its process wastewater (if applicable), and other pollutants as required under §122.21(g)(7)(iii) and (iv). Samples must be collected in accordance with §122.21.

- Flow measurements or estimates, and the total amount of discharge for the storm event(s) sampled.

- The date and duration of the storm event(s) sampled and other related information.

Based on a review of the permit application, the regulatory authority issues a facility-specific permit (or modifies an existing permit) to incorporate unique permit requirements. Requirements typically include discharge monitoring, implementation of best management practices, and an assessment of the impacts of these practices.

13.2 National, State, and Local Limitations

This section discusses current national, state, and local regulations pertaining to the discharge of storm water contaminated with deicing/anti-icing agents.

13.2.1 National Regulations

One of the purposes of this study is to evaluate whether national effluent limitations guidelines and standards are warranted for deicing/anti-icing operations. The only national regulations currently applicable to discharges of airport deicing operations wastewater are EPA's storm water program (see Section 13.1). Ethylene glycol and propylene glycol, however, are regulated by EPA and the Food and Drug Administration (FDA) under several regulations. Ethylene glycol is listed as a Hazardous Air Pollutant (HAP) under the Clean Air Act Amendments of 1990 (propylene glycol is not). Because ethylene glycol is a HAP, it is automatically subject to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and thus reporting requirements. The reportable quantity is 5,000 pounds of ethylene glycol in a 24-hour period, which converts to approximately 1,200 gallons of Type I deicing fluid applied as a 50/50 mixture in a 24-hour period.

Wastewater associated with manufacturing ethylene glycol and propylene glycol is regulated under different subparts of the effluent limitations guideline for organic chemicals, plastics, and synthetic fibers (OCPSF). Although the OCPSF guidelines do not apply to ADF discharges from an airport, effluent limitations have been promulgated for BOD_5, TSS, and pH for both subparts. The monthly average BOD_5 limitations for the manufacture of ethylene glycol and propylene glycol are 30 mg/L and 34 mg/L, respectively. Manufacturers of ethylene glycol and propylene glycol are also both regulated under the Clean Air Act under New Source Performance Standards for the Synthetic Organic Chemical Manufacturing Industry (SOCMI).

The FDA has established regulations for both glycols. The FDA established that propylene glycol is "generally recognized as safe" (GRAS) for human consumption; however, it recently withdrew the GRAS status for the use of propylene glycol in cat food (1). According to FDA guidelines, ethylene glycol can only be used as an indirect food additive for use in adhesives. On an international level, the World Health Organization has set an acceptable daily intake level of propylene glycol at 0 to 25 mg/kg.

13.2.2 State and Local Regulations

The CWA includes a number of programs implemented at the state and local levels aimed at restoring and maintaining water quality. These include state, territorial and authorized tribal water quality standards; state, territorial and authorized tribal nonpoint source management programs; state, territorial and authorized tribal water quality monitoring programs; and the NPDES permit program for point sources. These programs combined with national regulations have produced significant and widespread improvements in water quality over the last quarter-century, but many water bodies remain impaired by one or more pollutants. For example, the National Water Quality Inventory Report to Congress for 1996 indicates that of the nation's water bodies that have been assessed, approximately 40% of these do not fully support water quality standards or uses. The major causes of impairments in water bodies include sediments, nutrients, and pathogens. Other causes include dissolved oxygen, habitat and flow alterations, pH, metals, mercury, and pesticides. Recent EPA regulatory revisions provide increasing emphasis on restoring impaired and threatened waters.

Discharge of deicing agent-contaminated storm water from airports is increasingly controlled by state and local regulations. For example, several states have implemented water-quality guidelines for ethylene glycol; the guidelines vary greatly between states (2). Due to local limitations and considerations given to receiving streams, airport-specific discharge limits can vary widely within a given state. For example, two airports, both in New York, comply with vastly different propylene glycol levels because one airport discharges to a water body that serves as a drinking water intake and, therefore, has more stringent limits than the other airport, which does not. Total maximum daily loads (TMDLs), which are water quality-based maximum loadings for individual streams, can also dictate discharge limits for airports. (TMDLs are described in greater detail below.) Table 13-1 at the end of this section summarizes airport permit data collected by EPA for wastewater from airport deicing operations. EPA collected permit data from site visits and mini questionnaires. EPA also requested permit data from certain airports.

At least nine states have implemented drinking water guidelines and standards for ethylene glycol. The acceptable ethylene glycol concentration in effluent discharges from these states ranges from 100 ppb to 14,000 ppb (or 14 mg/L) (2). At least five states have implemented water quality standards to protect human health or aquatic life, and the acceptable ethylene glycol concentration from these states ranges from 7 ppb to 19,000 ppb (2). EPA was able to identify only one state, New York, that has implemented a drinking water standard for propylene glycol. The state Health Department establishes maximum concentration levels (MCLs) that are protective of public water supplies in New York State. The MCL for propylene glycol was recently revised from 50 ppb to 10,000 ppb (or 10 mg/L) (3).

Although not specifically developed to control the discharges from airport deicing operations, water quality standards for BOD or dissolved oxygen have been widely implemented throughout many states. As a result, permit writers may be indirectly controlling the discharge of ADF-contaminated wastewater by considering the acceptable oxygen levels in the receiving stream.

Airports that discharge to impaired water bodies may be required to meet NPDES permit limits designed to achieve total maximum daily loads (TMDLs). A TMDL specifies the maximum amount of a pollutant that a water body can receive and still meet water quality standards (including a margin of safety and consideration of seasonal variations), and allocates pollutant loadings among point and nonpoint pollutant sources. Section 303(d) of the CWA requires states, territories, and authorized tribes to identify and establish a priority ranking for waters for which existing pollution controls are not stringent enough to attain and maintain water quality standards. EPA intends that TMDLs be established over a 15-year timeframe with TMDLs for the most impaired water bodies established earlier in this timeframe. Priorities must take into consideration the severity of the pollution and uses of the water bodies (e.g., drinking water sources). Although the future impact of TMDLs on airport deicing operations is unknown, airports discharging to receiving streams with dissolved oxygen or nutrient criteria are most likely to be affected.

EPA is aware of only one airport, Portland International Airport in Portland, Oregon, whose NPDES storm water discharge permit incorporates limits based on a TMDL to attain water quality standards in the Columbia Slough. The permit contains limits reflecting BOD_5 waste load allocations to achieve the receiving stream dissolved oxygen criterion. The waste load allocation increases with increased flow in the Columbia Slough. Discharge monitoring is required throughout the deicing season (November 1 through April 30) with more frequent monitoring requirements during and following deicing/anti-icing events. Monitoring is not required from May 1 through October 31 (4).

Based on EPA's data-gathering activities, pollutants that airports typically monitor for in discharges from airport deicing operations to surface waters and/or to POTWs include:

- BOD_5;
- COD;
- TSS;
- Ethylene and/or propylene glycol;
- Copper, lead, and zinc;
- Ammonia as nitrogen; and
- pH.

Many airports are required to monitor only for these pollutants and are not subject to specific concentration limits or action levels. Many of those airports may only be required to monitor for some of these pollutants (i.e., not the entire list). However, at airports that have specific numerical requirements in their permits, limitations are typically placed on BOD_5, TSS, ammonia as nitrogen, glycols, and metals (e.g., copper, lead, zinc). EPA did not identify any airport currently monitoring specifically for pollutants that may be a component of the ADF additive pack (e.g., tolyltriazoles). As discussed in Section 9.2, EPA and current ADF researchers believe the additive pack may be the greatest contributor to the aquatic toxicity exhibited by ADFs. Table

13-2 at the end of this section summarizes the range of limitations for pollutants for which many airports typically monitor and their associated monitoring frequency. This table does not include additional permit provisions such as BMPs and structural controls.

13.3 Canadian Management Measures

In Canada, as in the United States, deicing and anti-icing activities using glycol-based fluids are an important part of winter operations at airports. Unlike the Unites States where propylene glycol-based fluids dominate, airlines in Canada primarily use ethylene glycol-based deicing/anti-icing fluids. Based on conversations with Canadian industry and government representatives, the main reason for using ethylene glycol-based fluids is that ethylene glycol is a more effective freezing point depressant than propylene glycol at low tempertatures.

In the early 1990's, concern about the detrimental effects of glycols on aquatic ecosystems led to the development and promulgation of two different glycol guidelines: (1) the 1994 Canadian Environmental Protection Act (CEPA) Part IV Glycol Guidelines, which established a voluntary guideline recommending discharge limitations for glycol at federal airports; and (2) the 1997 Canadian Water Quality Guidelines for Glycols, which established a voluntary guideline recommending safe ambient concentrations from the discharge of glycols into the environment. These guidelines are described in detail in Sections 13.3.1 and 13.3.2.

In addition to providing environmental protection-based performance targets, the guidelines are designed to assist facilities in promoting compliance with the general pollution prohibitions of the [Canadian] Fisheries Act. The Fisheries Act Section 36(3) (the Act) requires that "no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter such water." A deleterious substance is defined as "any substance that, if added to any water would degrade or alter...the quality of that water so that it is rendered deleterious to fish or fish habitat..." Ethylene glycol and propylene glycol as well as formulated ADFs may be considered deleterious substances according to its definition in the Act. Individual air carriers are responsible for deicing their aircraft and ensuring that they are not in violation with local, provincial, or federal legislation. The Fisheries Act allows individuals to be held responsible for pollution and imposes criminal penalties such as fines and jail time. Therefore, an air carrier may be in violation of the Fisheries Act unless a “due diligence” defense (i.e., a reasonable degree of care and attention was given to avoid harming the environment or humans) is established. Due diligence may include compliance with the glycol guidelines through glycol pollution prevention and mitigation efforts, environmental monitoring, audits, etc.

13.3.1 Canadian Environmental Protection Act (CEPA)

CEPA, originally passed in June 1988, is the principle federal legislation aimed at protecting the environment and the health of Canadians from toxic substances and other pollutants. Part IV of CEPA gives the Minister of the Environment the authority to regulate waste handling and disposal practices and emissions and effluents from federal activities. It also gives the Minister the authority to establish regulations and guidelines that apply to federal lands where regulatory authority would not otherwise exist.

In February 1994, EC promulgated voluntary glycol guidelines for deicing practices at federal airports under Section 53 of CEPA. The guidelines recommend an “end-of-pipe” discharge limit at federal airports and requires that annual reports of the results from monitoring glycol be prepared after each deicing season.

Under the National Airports Policy (NAP), announced in 1994, the Canadian government is commercializing its airports. The largest and busiest airports are being transferred to Canadian Airport Authorities, while the smaller airports are being offered for sale to local community interests. There will be 26 airports that will form part of the NAP. The airports will remain federal property but be operated by an airport authority. Transport Canada will remain the owner/landlord of these airports. Thus, these airports will be subject to federal regulations and guidelines, including the CEPA Glycol Guideline. NAP airports include such facilities as

Vancouver, Victoria, Calgary, Edmonton, Winnipeg, Thunder Bay, Toronto, Ottawa, Dorval, and Montreal-Mirabel.

The glycol guideline established under CEPA sets a 100-mg/L limit for total glycol allowed at the point of discharge. It is based on the prevention of all impacts to aquatic life as determined by an assessment of the available information (pre-1994) on the impacts of glycols and their associated deicing/anti-icing fluids and a review by a multistakeholder working group. The Minister of the Environment decided upon the final CEPA Glycol Guidelines based on this expert scientific assessment and the recommendations of the government-industry working group which included considerations of technological feasibility and socioeconomic factors (5).

Based on the scientific knowledge at that time (pre-1994), the most sensitive effect level reported in scientific literature was based on a study with the common ciliated protozoan *Chilomonas paramecium*. Data gathered from Bringmann et al. (1980) determined that the 48-hour lowest concentration at which effects were observed (LOEC) for growth inhibition in *Chilomonas paramecium* is 112 mg/L of ethylene glycol. Following standard practices, a safety factor of 0.1 was applied to this lowest effect concentration to derive an acceptable concentration of approximately 10 mg/L. A safety factor is applied to account for the uncertainties associated with species-to-species and laboratory-to-field extrapolations. This concentration was then converted to a discharge concentration assuming an "end-of-pipe" dilution ratio of 1:10, resulting in the guideline of 100 mg/L. The sampling point for compliance is the airport's effluent discharge point to a receiving stream (5).

In 1997, industry requested a review of the CEPA glycol guideline. Following the review, the 100 mg/L voluntary guideline remains in place.

13.3.2 Canadian Water Quality Guidelines

The national Canadian Water Quality Guidelines for surface water limits for glycols are developed and promulgated nationally under the auspices of the Canadian Council of Ministers for the Environment (CCME). The CCME comprises 14 intergovernmental (i.e., federal, territorial, and provincial) ministers and is a forum for discussion and joint action on environmental issues of national and international concern. Canadian Water Quality Guidelines are used to protect ecosystems, assess environmental quality problems, and manage competing uses of water resources. These guidelines do not constitute values for uniform national water quality and their use requires local water quality considerations. They are updated as new data become available. Environment Canada serves as the federal member and scientific and technical secretariat for the CCME guidelines task groups, providing the leadership in science assessments and drafting proposed guidelines for national review and approval.

Development of the Canadian Water Quality Guidelines program began in 1984. In 1987, the Water Quality Guidelines Task Group of the CCME published the Canadian Water Quality Guidelines for over 100 substances. Since that time, the Group has published revised guidelines for specific parameters. The guidelines are voluntary, scientifically based, and apply to all situations where glycols may enter the environment (e.g., releases from aircraft deicing, automotive coolants, pipeline dehydrators). They provide recommended ambient environmental concentrations for the protection of aquatic life both for freshwater and marine species. The current freshwater guideline is set at 192 mg/L for ethylene glycol, and at an interim limit of 500 mg/L for propylene glycol. There is currently no recommended freshwater guideline for diethylene glycol due to insufficient data, and no recommended marine guideline for ethylene glycol, propylene glycol, or diethylene glycol due to insufficient data (6).

The current CCME guidelines were derived from acceptable studies from the most sensitive species exposed to each glycol. Data gathered from the Aeroports de Montreal and Analex Inc. in 1994 determined that the LOEC for growth inhibition in green algae to be 1,923.5 mg/L for ethylene glycol. A safety factor of 0.1 is applied to the LOEC to establish a water quality guideline for the protection of freshwater species, which results in the guideline of 192 mg/L. Data gathered from Dufresne and Pillard (1995) determined the 96-h LOEC for frond growth inhibition in duckweed to be 5,000 mg/L for propylene glycol. Applying the safety factor of 0.1 results in the guideline of 500 mg/L. The guideline is considered interim due to limited available data. Additional chronic studies are required to attain full guideline status (6).

The main difference between the CEPA Glycol Guidelines and the water quality guideline is how they were derived and where they are applied. The CEPA guidelines apply at the "end-of-pipe" discharge point at airports, and assume that glycol is combined with non-glycol-contaminated storm water. The limit derivation accounts for dilution. The CCME water quality guidelines apply to much more than airports, and, as a conservative estimate, do not factor other non-glycol-contaminated storm water sources into the limit because they were not specifically derived for airports.

Water quality guidelines for dissolved oxygen were developed as part of the original guidelines established in 1987 and are summarized below.

Species		**Life stage**	**Minimum Dissolved Oxygen Concentration (mg/L)**
Freshwater	Warm-water biota	Early	6
		Other	5
	Cold-water biota	Early	9.5
		Other	6.5
Marine	All	All	>8

Source: Reference (6).

However, even at glycol concentrations below the revised CCME guidelines, the ambient oxygen level may fall below the recommended dissolved oxygen guideline. All CCME jurisdictions recommend that the dissolved oxygen guidelines be used in conjunction with the glycol guidelines.

13.4 Federal Aviation Administration Regulations

The FAA is part of the Department of Transportation and is responsible for regulating and promoting civil aviation. To ensure the safety of air transportation, FAA issues Federal Aviation Regulations (FARs) and advisory circulars. FARs are published in Title 14 of the Code of Federal Regulations and are designed to ensure the safe operation of aircraft, including operation during snow and ice conditions. Advisory circulars provide standards, specifications, and guidance on a wide range of safety issues including winter operations at airports. Under the current regulations, carriers (e.g. airlines) and pilots are responsible for conducting adequate aircraft deicing, while airports are responsible for ensuring that runways, taxiways, and other aircraft operational areas are properly cleared of snow and ice.

13.4.1 FAA Winter Operating Regulations for Aircraft

Snow, ice, and frost on aircraft surfaces can drastically reduce lift, alter handling characteristics, and make the aircraft difficult to control. Because of the safety hazard this poses, FAA has developed regulations that prohibit takeoff when snow, ice, or frost is adhering to wings, propellers, control surfaces, engine inlets and other critical surfaces of an aircraft. This approach is referred to as the “clean aircraft concept.” Although FAA regulations for winter operations differ depending on the size of aircraft and type of operations, all require that snow, ice and frost be removed from aircraft surfaces prior to takeoff and make the pilot ultimately responsible for determining the airworthiness of his/her aircraft.

FAA regulations do not stipulate which methods or materials should be used to remove snow, frost, or ice but recommend that commercial carriers and owners of private aircraft use methods and materials approved by the Society of Automotive Engineers (SAE) (see Section 13.5). However, the FAA requires that the deicing and anti-icing method selected for a particular aircraft be approved for use on that aircraft by the aircraft manufacturer. This approach gives the industry the flexibility to select aircraft deicing and anti-icing methods best suited to their individual operation.

The FAA publishes advisory circulars to assist aircraft operators in developing safe winter operating practices and selecting appropriate aircraft deicing methods. The advisory circulars provide standards, guidelines, and advice designed to help aircraft operators comply with aircraft deicing regulations and operate safely in winter weather conditions. Current FAA advisory circulars recommend that aircraft operators use ethylene glycol- or propylene glycol-based aircraft deicing and anti-icing fluids that meet the standards set by SAE (i.e., SAE-certified fluids). SAE standards for deicing fluids (i.e., Type I fluids) can be found in Aerospace Material Specification (AMS) 1424 and for anti-icing fluids (i.e., Types II, III and IV fluids) in AMS 1428. SAE provides recommended methods for applying deicing and anti-icing fluids in Aerospace Recommended Practice (ARP) 4737.

FAA regulations for winter operations differ depending on the size of the aircraft and type of operations. The most stringent regulations for aircraft deicing/anti-icing are those for carriers conducting scheduled commercial operations of passenger and cargo aircraft. Carriers operating passenger aircraft with more than nine seats, passenger aircraft with turbojet engines, and cargo aircraft with payload capacities of more than 7,500 pounds must comply with regulations contained in FAR Part 121, and are commonly referred to as Part 121 carriers. Aircraft deicing/anti-icing regulations for these carriers are contained in FAR Part 121.629, "Operation in Icing Conditions." This regulation requires Part 121 carriers to follow an FAA-approved aircraft deicing and anti-icing program. Carriers may follow the FAA-approved procedure or develop their own aircraft deicing plan. The FAA-approved procedure requires carrier personnel to conduct a pretakeoff contamination check from outside the aircraft within five minutes of takeoff during conditions in which ice, frost, or snow may adhere to aircraft surfaces. Aircraft deicing plans developed by carriers must be approved by the FAA and are reviewed and revised annually to ensure they incorporate any new information, practices, or procedures. Many carriers have developed their own aircraft deicing plans because this approach allows them more flexibility.

The FAA provides guidance to Part 121 carriers on developing an acceptable deicing plan in Advisory Circular 120-60, "Ground Deicing and Anti-icing Program." Aircraft deicing plans include: (1) a management plan describing operational responsibilities and communication procedures; (2) a description of the aircraft deicing and anti-icing methods used by the carrier; (3) flight and ground crew training procedures including annual reviews and testing; (4) procedures for preflight contamination checks; and (5) holdover tables for estimating snow and ice protection provided by ADFs and procedures for using the tables. Holdover tables included in a deicing plan must be approved by the FAA and must be used whenever deicing and/or anti-icing is performed. When takeoff occurs within the holdover time, carrier personnel are required to conduct a pretakeoff contamination check for frozen contamination within five minutes of takeoff. The pretakeoff contamination check may be made from inside the aircraft provided it is performed by trained personnel and takeoff occurs before the holdover time expires. If the holdover time is exceeded, carrier personnel must either repeat the aircraft deicing process, inspect the aircraft from the outside within five minutes of takeoff, or use an alternate FAA-approved procedure (e.g., wing-mounted ice sensors).

13.4.2 FAA Winter Operating Regulations for Airports

FAA regulates only airports that serve air carriers that operate aircraft with seating capacities of more than 30 passengers. The operations may be either a scheduled or unscheduled service. FAA regulations applicable to airports are published in Part 139 of the Federal Aviation Regulations and stipulate that these airports must be certified by the FAA and hold an operating certificate. For certification purposes, airports are required to compile a manual describing the airport's operating procedures, lines of succession for airport operational responsibilities, and the airport's facilities and equipment. The manual must be approved by the FAA, implemented by the airport, and revised when necessary.

The operating procedures described in the manual must comply with all operational specifications outlined in Subpart D of Part 139. Specifically, Section 313 of Subpart D includes provisions for a snow and ice control plan for airports located in regions where snow and icing conditions regularly occur. The snow plan must include: (1) operational requirements and procedures for the removal of snow, ice, and slush from runways, taxiways, and aircraft parking ramps; (2) a description of the priorities assigned to individual taxiways and runways; (3) names of personnel responsible for implementation of the snow plan and their areas of responsibility; (4) the location of a snow removal coordination center (usually referred to as a snow control center); (5) a list of materials used for snow and ice control and procedures for their application; and (6) procedures for the prompt notification of all aircraft operators using the airport when any portion of the runways or taxiways is not safe for the operation of aircraft.

The FAA allows airports to use chemicals and mechanical methods, such as brooms and snow plows, to keep airfield pavements free of snow and ice. Chemicals used for deicing/anti-icing airfield pavements may be liquids (e.g., potassium acetate or glycol-based fluids) or solids (e.g., airside urea (also called carbamide), calcium magnesium acetate (CMA), sodium formate, and sodium acetate). The FAA requires that airports use only products that meet or exceed SAE specifications. SAE standards for liquid pavement deicers/anti-icers are provided in SAE AMS 1435, while those for solid pavement deicers/anti-icers are provided in SAE AMS 1431A. Airports may also use airside urea meeting the U.S. military specifications provided in MIL SPEC DOD-U-10866D. Vendors of chemical pavement deicers/anti-icers are required to provide the airport with a Material Safety Data Sheet and certification that their product conforms to SAE or U.S. military specifications. Granular materials, such as sand, may be used to improve aircraft braking.

Although there are currently no regulations concerning aircraft deicing with which airports must comply, the FAA recommends in their Advisory Circular 150/5200-30A, “Airport Winter Safety and Operations,” that airports develop local aircraft deicing plans. The plan should include the locations of designated aircraft deicing areas, communication procedures, and traffic flow strategies. The FAA also recommends that airports establish a committee responsible for aircraft deicing issues. The committee members should include representatives from airport management, airline operations staff, fixed-base operators, air traffic control personnel, and other interested parties such as corporate tenants or the military. FAA recommends that the committee meet prior to the beginning of the deicing season to discuss and review the following issues: (1) Part 121 carrier aircraft deicing programs and their effects on airport operations; (2) ground flow strategies to shorten taxiing routes and minimize holdover time for deiced aircraft; (3) takeoff clearances and departure slot allocation procedures; (4) locations for aircraft deicing/anti-icing, including locations for secondary deicing/anti-icing; (5) communication procedures between air traffic control and aircraft waiting to be deiced/anti-iced; and (6) airport collection practices for containment of wastewater generated during aircraft deicing/anti-icing activities, including the responsibilities of individual tenants.

13.5 Society of Automotive Engineers (SAE) Standards for Aircraft Deicing/Anti-Icing Operations

SAE is a professional organization dedicated to improving safety and promoting new technologies in all sectors of the transportation industry through the development of engineering standards. The SAE Aerospace Council is responsible for developing standards for the aircraft industry and is organized into technical committees, each with its own area of specialization. The committee responsible for aircraft deicing and anti-icing issues is the G-12 Committee.

13.5.1 SAE G-12 Committee

The G-12 Committee is a voluntary consensus body responsible for developing standards, material specifications, and recommended practices for all aspects of aircraft deicing and anti-icing. The following subcommittees perform the work of the G-12 Committee:

- Fluids Subcommittee;
- Deicing Facilities Subcommittee;
- Holdover Time Subcommittee;
- Training Subcommittee;
- Ice Detection Subcommittee;
- Methods Subcommittee;
- Future Deicing Technology Subcommittee; and
- Aircraft Ground Deicing Equipment Subcommittee.

Members serve on the G-12 Committee and its subcommittees on a voluntary basis. Members include representatives from the airlines, the FAA, Transport Canada, fixed-base operators (FBOs), airports, fluid manufacturers, equipment manufacturers, airframe manufacturers, and the Airline Pilots Association.

The standards developed by the G-12 Committee are published in a series of documents. SAE standards for aircraft deicing fluids (i.e., Type I fluids) are published in Aerospace Material Specification (AMS) 1424B, while those for aircraft anti-icing fluids (i.e., Types II, III, and IV) are published in AMS 1428C. SAE-recommended practices for the storage, transfer, and application of aircraft deicing and anti-icing fluids are published in Aerospace Recommended Practice (ARP) 4737C. This document also includes SAE-approved holdover tables for use with Type I, II, and IV fluids. SAE specifications for aircraft deicing vehicles are published in ARP 1971 for large-capacity trucks and ARP 4047 for small-capacity trucks. SAE ARP 4902 contains design standards and recommended operation practices for aircraft deicing facilities. Standards for airfield pavement deicing/anti-icing agents can be found in AMS 1435 for liquids and AMS 1431B for solids. Glycol-based airfield pavement deicers/anti-icers must conform to standards contained in AMS 1426C.

The G-12 Committee meets several times each year to review and revise these documents and often participates in joint meetings with the International Organization for Standardization (ISO), SAE’s European counterpart. The SAE/ISO joint meetings provide a forum to exchange technical information and promote international cooperation for the development of uniform standards in Europe and North America.

13.5.2 SAE Standards and Certification for Aircraft Deicing/Anti-icing Fluids

SAE does not dictate the composition of ADFs, but requires that they contain a freezing point depressant and any additives that enable the fluid to meet SAE performance-based standards. To receive SAE certification, fluid formulators are required to submit a sample of the fluid to an independent laboratory for testing. The tests are conducted by the Scientific Material

International (SMI) laboratory in Miami and the Anti-Icing Materials Laboratory (AMIL) of the University of Quebec in Chicoutimi, Canada. The tests are designed to measure the physical properties, material compatibility, aerodynamic performance, anti-icing performance, and stability of the fluid. Physical properties measured include the flash point, specific gravity, pH, refractive index, freezing point, surface tension, and viscosity. SAE material compatibility tests include tests designed to measure the fluid's effect on aircraft parts, including metals, transparent plastics, and painted surfaces. Aerodynamic performance tests are used to ensure that the fluids flow off aircraft surfaces during take-off. Anti-icing performance tests measure the fluid's ability to prevent ice formation on test plates exposed to freezing conditions. Fluid stability tests are used to measure thermal and storage stability, and the effect of hard water and shearing on fluid performance. The fluid sample submitted must be representative of the fluid offered commercially. A new sample must be submitted for testing whenever changes in ingredients or manufacturing processes are made.

Although SAE standards do not specify which freezing point depressants should be used in aircraft deicing/anti-icing fluid formulations, all such fluids currently used in the U.S. contain propylene glycol or ethylene glycol as the freezing point depressant. Since industry specialists believe that glycol has the potential to cause fires in some aircraft electrical systems, SAE requires glycol-based fluids to contain a fire suppressant. Although SAE does not specify which fire suppressant should be used, fluid formulators state there are only two effective fire suppressants currently available for this application, tolyltriazoles and benzotriazoles, both of which are considered to be toxic to aquatic organisms (see Sections 9.2.1.3 and 9.2.2).

13.5.3 SAE Environmental Information Requirements

In addition to meeting performance-based specifications, formulators are required by SAE to provide the following environmental data for their fluids: (1) BOD; (2) total oxygen demand (TOD) or COD; (3) biodegradability; (4) aquatic toxicity; and (5) trace contaminants. To comply with SAE standards, BOD tests should be performed at an incubation temperature of 20°C for a period of 5, 15, 20 or 28 days. The TOD or COD for the fluid should be reported in kilograms of oxygen per kilogram of fluid, while biodegradability should be reported as the ratio of BOD and TOD (or COD).

Aquatic toxicity data should be reported as an LC50 concentration in units of milligrams per liter. SAE requires the aquatic toxicity tests to be performed in accordance with EPA (40 CFR 797.1300 and 797.1400, revised July 1, 1989) or OECD (Organization for Economic Cooperation and Development Guidelines for Testing of Chemicals, Methods 202 and 203) protocols. SAE does not specify which species should be used for the toxicity tests, but requires formulators to use species that have been selected by regulatory agencies for inclusion in discharge permits.

SAE also requires fluid formulators to report the presence of trace contaminants of sulfur, halogens, phosphate, nitrate, and heavy metals (lead, chromium, cadmium, and mercury). Fluid formulators must report the concentration of trace contaminants either as percentage weight or parts per million, and indicate the analysis method used and the detection limits.

Because SAE does not specify the concentration of the fluid to be tested, airlines and FBOs are often unable to directly compare the environmental data provided by different formulators. To remedy this situation, the Air Transport Association (ATA), a trade association representing the principal U.S. passenger and air cargo carriers, asked SAE during the May 1999 meeting to consider incorporating standardized environmental testing and reporting protocols into the SAE fluid specifications for both aircraft and pavement deicing/anti-icing agents. Specifically, ATA recommended that SAE: (1) require that aquatic toxicity tests be performed in accordance with the EPA method for whole effluent toxicity (WET) tests using fluid concentrate as the test sample; (2) specify the test species to be used for WET tests; (3) require that toxicity data be reported in a standardized manner for the fluid concentrate and 50/50 mixture; (4) specify a standard BOD test (e.g., 5-day BOD at 20^{o}C); (5) establish a May 1 reporting date requiring that formulators provide toxicity data for new and reformulated fluids or certification that their fluids have not changed; and (5) consider setting toxicity standards for aircraft deicing/anti-icing fluids using the toxicity of current formulations as the baseline. ATA believes these changes, if adopted by SAE, will enable fluid purchasers to compare the environmental impact of competing fluid formulations and encourage formulators to develop fluids with lower aquatic toxicity. In response, the Fluids Subcommittee created an Environmental Workgroup, comprising representatives from SAE and ATA, which will review the current SAE requirements and assess ATA's recommendations.

13.6 References

1. 61 Federal Register 19542 - 19544 (DCN T10568).

2. U.S. Department of Health and Human Services. Toxicological Profile for Ethylene Glycol and Propylene Glycol. September 1997 (DCN T11084).

3. Meeting Summary for Albany Aircraft Deicing Summit. March 1999 (DCN T10542).

4. Portland International Airport, Portland, OR. NPDES Permit (DCN T11049).

5. Environmental Canada. Scientific Considerations in the Development of a Revised CEPA Glycol Guideline Value. November 1996 (DCN T10376).

6. Environment Canada/Transport Canada. Canadian Water Quality Guidelines for Glycols - An Ecotoxicological Review of Glycols and Associated Aircraft Anti-Icing and Deicing Fluids. May 1999 (DCN T11079).

Table 13-1

Airport Permit Data for ADF-Contaminated Wastewater

<table>
<tr><th>Airport</th><th>Type of Permit</th><th>Parameters Monitored</th><th colspan="4">Effluent Limitation (mg/L unless otherwise noted)</th><th>Frequency</th></tr>
<tr><td>Cleveland Hopkins International (CLE)</td><td>POTW</td><td>COD
NH_3-N
Flow
TSS
pH</td><td colspan="4">1,500 and 12,500 lbs/day
72 and 600 lbs/day
700 gpm and 1 MGD
Monitor
Monitor</td><td>Once/week
Once/week
Once/month
Once/week
Once/month</td></tr>
<tr><td>Tri-State (Huntington, HTS)</td><td>NPDES Storm Water (General)</td><td>pH, TSS, O&G, TOC, BOD_5, TKN, COD, Nitrate-Nitrite, Total P</td><td colspan="4">Monitor</td><td>Once/year for all parameters</td></tr>
<tr><td rowspan="4">Des Moines International (DSM)</td><td rowspan="3">NPDES Storm Water (Individual)</td><td rowspan="3">BOD_5
NH_3-N
EG
pH
DO
BETX
O&G</td><td colspan="2">Outfall A</td><td colspan="2">Outfall B</td><td rowspan="3">Twice/week
Twice/week
Twice/week
Twice/week
Twice/week
Once/month
Once/month</td></tr>
<tr><td>Monthly Avg.</td><td>Daily Max.</td><td>Monthly Avg.</td><td>Daily Max.</td></tr>
<tr><td>100
1.0
125
6 - 9
> 1.0
Monitor
Monitor</td><td>150
1.6
190</td><td>100
37
125
6 - 9
> 1.0
Monitor
Monitor</td><td>150
55
190</td></tr>
<tr><td>POTW</td><td>pH
Flow
COD</td><td colspan="4">5.0 - 10.5
150,000 gpd
10,000 lbs/day</td><td>Once/week
Continuously
Daily or as necessary to control discharge</td></tr>
<tr><td>Duluth International (DLH)</td><td>NPDES Storm Water</td><td>BOD_5, COD, TSS, N, TKN, NH_3-N, P, EG, PG, DEG, O&G, pH</td><td colspan="4">NPDES permit does not require monitoring; however, it is considered a BMP.</td><td>Sampling schedule varies yearly</td></tr>
<tr><td>Anchorage International (ANC)</td><td>NPDES Storm Water (General)</td><td>BOD_5, COD, TSS, O&G, EG, PG, urea, potassium, acetate, NH_3-N, pH, flow</td><td colspan="4">Monitor</td><td>Once/year (during spring snow melt) for all parameters</td></tr>
</table>

Table 13-1 (Cont.)

Airport	Type of Permit	Parameters Monitored	Effluent Limitation (mg/L unless otherwise noted)	Frequency
Seattle-Tacoma International (SEA)	NPDES Storm Water (Individual)	TPH, TSS, Turbidity, Fecal coliform, BOD_5, EG, PG, Cu, Pb, Zn, LC_{50}	Monitor	Eight times/year for all parameters
	NPDES Industrial (Interim)	Flow pH O&G TSS BOD_5 Total glycols TPH Fecal coliform VOAs Semivoas Cu Pb Zn LC_{50}	4,800 gpm 6 - 9 8 (monthly avg.); 15 (daily max.) 21 (monthly avg.); 33 (daily max.) Monitor Monitor Monitor Monitor Monitor Monitor Monitor Monitor Monitor Monitor	Once/day Once/week Once/week Once/week Once/month Once/month Once/month Once/month Once/year Once/year Once/year Once/year Once/year Once/year (based on previous results)
Billings Logan International (BIL)	NPDES Storm Water (Individual)	pH, O&G, BOD_5, COD, TSS, total glycol	Monitor	Monitoring waived until 2000
Newark International (EWR)	NPDES Industrial (Expecting storm water permit approval)	Flow pH TPH COD TSS	Monitor 6 - 9 15 100 100	Once/month Once/month Once/month Once/month Once/month
Logan International (BOS)	NPDES Storm Water (Interim)	O&G TSS pH	15 10 5 - 7	Three times/month Three times/month Three times/month
General Mitchell International (MKE)	NPDES Storm Water (General)	DO, BOD_5, COD, TSS, O&G, pH, TKN, NH_3-N, Total P, Total Glycol, Cu, Pb, Zn, Flow	Monitor	Four times/year for all parameters

Table 13-1 (Cont.)

Airport	Type of Permit	Parameters Monitored	Effluent Limitation (mg/L unless otherwise noted)	Frequency
Buffalo Niagara International (BUF)	POTW	Flow EG + PG BOD_5 O&G pH TSS VOA Semivolatile organics	27,000 gallons/day 10,000 lbs/day 250 100 5 - 12 250 Monitor Monitor	Once/month for all parameters
	NPDES Storm Water	Flow O&G pH TKN NH_3-N BOD_5 EG Surfactants Benzene Toluene	Monitor 15 (daily max) 6 - 9 Monitor 2.4 (daily avg.); 16 (daily max.) 30 (daily avg.) 500 (daily max.) Monitor Monitor Monitor	Once/month Once/month Once/month Once/month Once/month Once/month Once/month Once/month Four times/year Four times/year
Bradley International (BDL)	POTW	Max. daily flow Max. flow rate Flow per batch PG TSS BOD_5 COD pH	288,000 gpd 200 gpm 20,000 gal 125 125 200 600 5.5 - 10	Weekly for all parameters during discharge to POTW
Salt Lake City International (SLC)	Storm Water Industrial	 Flow O&G BOD_5 COD Nitrate-Nitrite pH EG PG	<u>Apr.-Sept.</u> / <u>Oct.-Mar.</u> Monitor / Monitor 10 daily max. / 10 daily max. Monitor / 25(a)/35(b) Monitor / Monitor Monitor / Monitor Monitor / Monitor N/A / 70 N/A / 70	 Once/month Once/month Twice/yr. (Oct-Mr once/yr.) Twice/yr. (Oct-Mr once/yr.) Twice/yr. (Oct-Mr once/yr.) Once/month Once/month Once/month
Greater Rockford (RFD)	NPDES Storm Water	BOD_5 , pH, TSS, N	Monitor	Unknown
Airborne Air Park (ABX)	NPDES Storm Water (Individual)	COD, TSS, pH, NH_3-N, DO, TDS, O&G	Monitor	Four times/month for all paramters (in winter) Once/month for all parameters (in summer)

Table 13-1 (Cont.)

<table>
<tr><th>Airport</th><th>Type of Permit</th><th>Parameters Monitored</th><th colspan="2">Effluent Limitation (mg/L unless otherwise noted)</th><th colspan="2">Frequency</th></tr>
<tr><td rowspan="5">Denver International (DIA)</td><td rowspan="3">POTW</td><td>Flow</td><td colspan="2">Monitor</td><td colspan="2">Continuously</td></tr>
<tr><td>BOD</td><td colspan="2">9 tons/day (daily max.); 7 tons/day (monthly avg)</td><td colspan="2">Once/hour</td></tr>
<tr><td>As
Cd
Cr
Cu
Pb
Hg,
Mo
Ni
Se
Ag
PERC
Zn</td><td colspan="2">0.33
3.4
3.6
6.1
2.2
0.13
0.71
5.6
0.66
2.9
1.5
15.6</td><td colspan="2">Unspecified but representative of discharge</td></tr>
<tr><td rowspan="2">NPDES Storm Water General</td><td></td><td>Wet Weather</td><td>Dry Weather/ Summer</td><td>Wet Weather</td><td>Dry Weather/ Summer</td></tr>
<tr><td>COD
O&G
pH
TSS
PG
EG
BOD
TPH
Total P
Nitrate-Nitrite
TKN
Flow
Chloride
DO</td><td>Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor
Monitor if COD > 75</td><td>Monitor
Monitor
Monitor
N/A
Monitor
N/A
N/A
Monitor
N/A
N/A
N/A
N/A
N/A
N/A</td><td>Once/day
Once/mo.
Once/mo.
Once/mo.
Once/mo.
Four times/yr.
Four times/yr.
Four times/yr.
Four times/yr.
Four times/yr.
Four times/yr.
Four times/yr.
Four times/yr.
Once/week</td><td>Monitoring is required whenever the DIA staff, during the inspection of outfalls, observes or suspects an illicit discharge.</td></tr>
<tr><td rowspan="3">Albany International Airport (ALB)</td><td>POTW</td><td>BOD_5
TSS
COD
Total glycols</td><td colspan="2">240
25
Monitor
Monitor</td><td colspan="2">Once/day for all parameters</td></tr>
<tr><td rowspan="2">NPDES Storm Water General</td><td>BOD_5
Benzene
o-xylene
m+p-xylene
Toluene
Lead</td><td colspan="2">500 lbs/acre (land applied)
0.008
0.005
0.01
0.005
0.05</td><td colspan="2">Once/month for all parameters (except PG)</td></tr>
<tr><td>PG</td><td colspan="2">1</td><td colspan="2">Once/day during deicing season</td></tr>
</table>

Table 13-1 (Cont.)

Airport	Type of Permit	Parameters Monitored	Effluent Limitation (mg/L unless otherwise noted)		Frequency
Minneapolis-St. Paul International (MSP)	NPDES Storm Water (Interim)	$CBOD_5$	900 tons/year		Once/day
		pH	6 - 9		Once/day
		Flow, TSS, NH_3-N,	Monitor		Once/day for all parameters
		O&G, TKN, Total P, DO	Monitor		Three times/week for all parameters
		COD, EG, PG, BETX	Monitor		Once/week for all parameters
	NPDES Storm Water (Interim)	Total Phenols, As, Cd, Cr, Cu, Pb, Hg, Ni, Si, Zn, Cn	Monitor		Four times/year
Kansas City International (MCI)	NPDES Storm Water	pH EG Flow TPH BOD_5 COD TSS O&G	6 - 9 Monitor Monitor 10 (monthly avg.); 15 (daily max.) 30 (monthly avg.); 45 (daily max.) 90 (monthly avg.); 120 (daily max.) 50 (monthly avg.); 100 (daily max.) 10 (monthly avg.); 15 (daily max.)		Once/month Once/year Once/month Once/month Once/month Once/month Once/month Once/month
	POTW	Flow BOD_5	75 gpm 400 lbs/day		Once/day Once/day
Chicago O'Hare International (ORD)	POTW	BOD_5 TSS Flow	Monitor Monitor Monitor		Every 6 million gallons discharged
	NPDES Storm Water		Outfall A	Outfall B	
		Flow pH	Monitor Monitor	Monitor Monitor	Once/month Once/month
			Monthly Avg. / Daily Max.	Monthly Avg. / Daily Max.	
		BOD_5	10 / 20	20 / 40	Once/month
		NH_3-N			
		April-Oct.	1.5 / 3.0	1.5 / 3.0	Once/month
		Nov.-March	3.6 / 7.2	3.6 / 7.2	Once/month
		O&G	15 / 30		Once/month
		TDS	1,000 (Daily Max.)	1,000 (Daily Max.)	Once/month

Table 13-1 (Cont.)

Airport	Type of Permit	Parameters Monitored	Effluent Limitation (mg/L unless otherwise noted)		Frequency	
Portland International Airport (PDX)	NPDES Storm Water				During and one day following deicing events between Nov. 1 and Apr. 30	
			Outfall A	Outfall B	Outfall A	Outfall B
		Flow	Monitor	Monitor	Once/hour	Once/hour
		COD	Monitor	Monitor	Once/3 hours	Once/3hrs
		BOD_5	Monitor	Monitor	Once/6 hours	Once/6hrs
		DO	Monitor	Monitor	Once/6 hours	Once/day
		Bioassay	Monitor	N/A	Twice/year	N/A
		Methanol	N/A	Monitor	N/A	Once/day
		Ethanol	N/A	Monitor	N/A	Once/day
		Propanol	N/A	Monitor	N/A	Once/day
Baltimore/ Washington International (BWI)	POTW	pH	6 - 10		During each batch discharge from 600,000 gallon storage tank	
		BOD_5	7,000 lbs/day			
		TSS	300 mg/L			
		Phosphorus	12 mg/L			
		TPH	100 mg/L			
		Flow	Monitor			
		Cadmium	0.21 mg/L		Once/year	
		Chromium	6.89 mg/L			
		Copper	6.59 mg/L			
		Lead	6.81 mg/L			
		Nickel	2.82 mg/L			
		Zinc	17.85 mg/L			

Key: (a) Monthly average.
(b) 7-day average.

As - Arsenic
BOD_5 - 5-day Biochemical Oxygen Demand
BETX - benzene, ethylbenzene, toluene, and xylene
Cd - Cadmium
COD - Chemical oxygen demand
Cu - Copper
DEG - Diethylene glycol
DO - Dissolved oxygen
EG - Ethylene glycol
Hg - Mercury
LC_{50} - Lethal concentration where 50% of test organisms die
Mo - Molybdenum
N/A - Not applicable
N - Nitrogen
NH_3-N - Ammonia as nitrogen
Ni - Nickel
O&G - Oil and grease
P - Phosphorus
PERC - Tetrachoroethylene
PG - Propylene glycol
TDS - Total dissolved solids
TKN - Total kjedahl nitrogen
TPH - Total petroleum hydrocarbons
TSS - Total suspended solids
VOA - Volatile organics
Zn - Zinc

Table 13-2

Summary of Available Permit Data

Parameters Frequently Monitored	Range of NPDES Limitations	Range of POTW Limitations	Range of Sampling Frequency
Chemical Oxygen Demand (COD)	90-120 mg/L	600-1,500 mg/L 400-12,500 lbs/day	1/day - 1/year
Ammonia	1-55 mg/L	72 mg/L 600 lbs/day	1/day - 1/year
pH	5 - 9	5 - 12	1/day - 1/ year
Total Suspended Solids (TSS)	10-100 mg/L	25-300 mg/L	1/day - 1/year
Oil and Grease (O&G)	8-30 mg/L	100 mg/L	3/week - 1/year
5-day Biochemical Oxygen Demand (BOD_5)	10-150 mg/L 7-9 tons/day 900 tons/year	200-250 mg/L 7,000 lbs/day	1/hour - 1/year
Ethylene Glycol	70-500 mg/L	NA	2/week - 1/year
Propylene Glycol	1 mg/L	10-125 mg/L	1/day - 1/year
Total Glycols	NA	10,000 lbs/day	1/day - 4/year
Copper	NA	6.1 - 6.59 mg/L	4/year - 1/year
Lead	NA	0.05-6.81 mg/L	1/month - 1/year
Zinc	NA	15.6 - 17.85 mg/L	4/year - 1/year

NA - Not available.

14.0 ECONOMIC PROFILE

This section presents a profile of significant economic and financial aspects of the air transportation industry as it relates to airport deicing operations. The demand for airport deicing operations is a derived demand; that is, deicing operations are performed solely to provide the service of transporting passengers and cargo by air. Thus, the economic conditions underlying airport deicing operations are those of the air transportation industry itself. This profile examines airports in Section 14.1, and airlines in Section 14.2. All tables appear at the end of this section.

14.1 Airports

Section 14.1 is divided into four major sections. Section 14.1.1 discusses Federal Aviation Administration (FAA) airport classification and the number of airports, their sizes, and their locations. Section 14.1.2 presents an overview of airport financial management, while Section 14.1.3 describes ownership and management patterns among airports. Finally, Section 14.1.4 discusses issues concerning airport capital financing.

14.1.1 Determining the Number, Sizes, and Locations of Airports

A number of classification systems are used to describe airport size and significance; Section 14.1.1.1 discusses the most important classification systems, and profiles the distribution of airports by level of activity. Section 14.1.1.2 then relates airport activity and snowfall, both likely determinants in the probability of an airport potentially performing significant deicing operations, to the profile developed in Section 4.1.1.1.

14.1.1.1 FAA Airport Size Classifications

The primary source of data on the locations and sizes of U.S. airports is the FAA's Air Carrier Activity Information System (ACAIS) databank. ACAIS contains revenue passenger enplanement and all-cargo data. The database supports the FAA's Airport Improvement Program

(AIP) entitlement activities. AIP funding is largely based on airport activity as determined by annual passenger boardings (by FAA definition, boardings include only revenue-earning customers on aircraft engaged in air commerce), although other criteria apply as well. The ACAIS database contains data for all airports reporting any passenger boarding activity (1).

Another data source is the FAA's congressionally mandated National Plan of Integrated Airport Systems (NPIAS). The NPIAS database identifies 3,344 existing airports that are significant to national air transportation and, therefore, eligible to receive grants under the AIP. Activity and geographical location largely determine inclusion in the NPIAS (2). NPIAS airports account for virtually all commercial airline activity and approximately 92% of general aviation (GA) with complete geographic coverage of the U.S. (3). Although there is some overlap in the airports included in both the ACAIS and NPIAS databases, the NPIAS includes a total of 3,344 existing airports, while the calender year (CY) 1997 ACAIS database contains 1,715 airports.

EPA may find other airport classification systems more suited to its purposes should it choose to undertake an effluent guideline. However, in this report, EPA utilizes the FAA airport definitions because they are frequently used in the industry. The FAA defines airports in the ACAIS database according to passenger boardings. The FAA's definition of revenue passenger boardings is broad and includes enplanements for activities such as sightseeing flights. Although these activities are generally not large, at certain airports (e.g., Grand Canyon, AZ, Juneau, AK), they can form a significant share of aircraft boardings. Below are the descriptions of the different airport classifications.

The first distinction lies between commercial service airports and noncommercial service airports. Commercial service airports are defined as airports with both scheduled passenger service and a minimum of 2,500 revenue passenger boardings on aircraft engaged in air commerce per year. Commercial service airports cannot be privately owned.[1] The number of commercial service airports declined from 568 in 1988 to 529 in 1997, a decrease of roughly 7 percent (3, 4).

Commercial service airports are further subdivided into primary airports, those commercial service airports with more than 10,000 enplanements per year, and nonprimary commercial service airports having between 2,500 and 10,000 annual enplanements. The number of commercial service airports classified as primary airports increased from 396 in 1988 to 417 in 1997. Thus, while the total number of commercial service airports fell between 1988 and 1997, the percentage of airports rated as "primary" increased from 70% of commercial service airports in 1988 to 79% in 1997 (3, 4).

Primary commercial service airports are further classified as hubs (large, medium, small and nonhubs). The designation of hub depends on the percentage of total passenger boardings occurring at that airport, and again, is used primarily for distributing AIP funds. Because definitions of airport size are determined by annual enplanements, the number of hubs and the designation of airports can change from year to year. For example, in CY 1993, FAA classified 65 airports as large and medium hubs. Washington Dulles International was ranked twenty-eighth, Tampa International twenty-ninth, and Baltimore-Washington International thirty-first in passenger boardings; all were medium hubs (5). In CY 1996, there were 71 large and medium hubs; Baltimore-Washington International was ranked twenty-eighth and Tampa International was ranked twenty-ninth in passenger boardings, but both were large hubs while Washington Dulles International was ranked thirty-first, and was still a medium hub.

Airlines also individually designate airports as hubs; these designations should not be confused with FAA hub designations. An airline will define an airport as a hub if that airport is

[1] Boardings at private airports or airports without scheduled commercial service are included in the ACAIS. For example, in CY 1996, Orlando Sanford boarded almost 280,000 passengers (ranked 144 in passenger service); because these were unscheduled commercial flights, Sanford could not be designated a nonhub primary airport. Sanford's boardings were, however, included in total U.S. boardings used to determine the hub status of other airports (1).

used to facilitate connections between airline routes; airline hubs may also be large or small. Los Angeles International, for example, is a large hub by FAA definition, but a nonhub by airline definition because it is not used by any major airline to facilitate connecting service. Conversely, Cleveland Hopkins International is a large hub for Continental Airlines, because it facilitates connections for Continental's route structure, but is a medium hub by FAA definition. Unless otherwise noted, EPA uses FAA's definition of hub throughout this section.

Table 14-1 presents total passenger boardings and the number of airports by FAA definition for CY 1997. This table emphasizes the dominance of large hubs (those with more than 1% of total U.S. enplanements) in the air transportation network.[2] The 30 large hubs in CY 1997 (5.7% of commercial service airports) accounted for 68.6% of the 640.7 million total U.S. passenger boardings. As a group, large hub airports averaged over four times as many annual boardings as medium hubs (3.3 million average annual boardings), and 21 times as many boardings as small hubs (660,000 average annual boardings). Large and medium hubs combined accounted for almost 90% of total U.S. passenger boardings in 1997.

FAA also tracks data on cargo-only service at airports. Statistics are published for those airports where the total annual weight of arriving cargo-only aircraft is at least 100 million pounds.[3] In 1997, 106 airports "qualified" as having significant cargo-only service; activity at qualifying cargo-only airports is also included in Table 14-1. Although qualifying airports generally correspond to large, medium, and small FAA hubs (e.g., 66% of large, medium and small hubs are also qualifying cargo-only airports), two nonprimary commercial service and four noncommercial service airports have a significant amount of cargo-only service.[4]

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[2] FAA defines passenger *enplanements* as the number of revenue passenger boardings on aircraft engaged in air commerce at airports that receive scheduled passenger service.

[3] Gross landed weight of cargo refers to the rated maximum gross landing weight of each cargo-only aircraft type (i.e., the maximum allowable weight of the plane and its potential cargo), and does not measure the actual weight of the cargo carried in those planes.

[4] This includes airports such as Rickenbacker Airport in Columbus, OH, which reported zero boardings in 1997, but landed over 725 million pounds of cargo-only aircraft. Rickenbacker acts as an operational hub for Federal Express, and therefore operates large jet aircraft in poor weather conditions.

Although insufficient data are available to determine this statistically, there may be a trend towards the development of specialized airports with significant cargo service but relatively little passenger service. Airports that fit this pattern tend to be near large cities (e.g., Hulman Regional – Indianapolis, IN; Pease International – Boston, MA; Rickenbacker International – Columbus, OH; Greater Rockford – Chicago, IL; Willow Run – Detroit, MI). Much of the traffic at these airports is express package delivery that is time-sensitive. By utilizing smaller airports, the cargo service airlines avoid the delays common at large passenger airports, yet these smaller airports are convenient to major business sources. Also, from the airports' point of view, investment in cargo service infrastructure may be less costly than passenger service.

Less information is available about GA airports. Some GA airports may have scheduled commercial service, but because they have less than 2,500 annual enplanements, they are not ranked as commercial airports. The 1997 ACAIS database contains some information on 1,186 noncommercial service airports; however, the most current NPIAS contains data on 2,806 GA and reliever airports, and indicates that the U.S. has an additional 15,000 GA airports currently in existence (6).[5]

GA airports are subdivided into reliever airports (334 in 1998), and other GA airports. Airports are designated as relievers if they maintain a certain level of operations per year (50 based aircraft, 25,000 itinerant, or 35,000 local operations per year) or FAA has determined its location desirable for instrument training, and if they are located in a metropolitan statistical area with a population of 250,000. In essence, relievers reduce congestion at major airports in the area by providing an alternate airport for GA aircraft to operate from. Business/executive jets frequently operate out of relievers, and they may be more likely to fly in bad weather than other GA aircraft. Large cargo-only jet aircraft may also use relievers; for example, some qualifying cargo-only airports, such as Rickenbacker, OH and Willow Run, MI are relievers. Nonreliever GA airports are probably a relatively insignificant source of aircraft deicing fluid runoff due to the

[5] GA airports excluded from the NPIAS include more than: 1,000 publicly owned-public use landing strips, 1,200 privately owned-public use landing strips, and 12,000 privately owned- private use landing strips.

level of activity at the airport and the types of aircraft flown at the airport; most GA aircraft apparently do not fly in weather poor enough to require any significant deicing.

Table 14-2 uses ACAIS data from 1993-1997 to track growth in overall air traffic and growth by airport definition. First, commercial service airports account for roughly 99% of all passenger boardings, based on the small difference between figures for total passenger boardings and total passenger enplanements. Overall, both enplanements and boardings grew at an average annual rate of 5.3 percent. Total enplanements at large hubs grew more quickly than total enplanements (an average annual rate of 7.2 percent). Some of this growth is due to increasing the average size of large hub airports, and some due to the increasing number of large hub airports; the average number of enplanements at large hub airports grew at a more moderate 3.9% per year. Nonprimary commercial service airports grew most slowly, both in terms of total enplanements (average annual growth rate of -6%) and average enplanements per airport (average annual growth rate of 0.2 percent).

14.1.1.2 Airports with Potentially Significant Deicing/Anti-Icing Operations

EPA has determined that aircraft operations are likely to be a better predictor of the level of deicing activity than enplanements. The FAA supplied EPA with aircraft operations data by airport; Table 14-3 characterizes airports by non-GA flight operations and FAA airport hub status. GA activities were excluded from the operations classification because GA aircraft either do not fly in weather requiring deicing, or require minimal use of aircraft deicing/anti-icing fluids (ADFs). While large hubs account for almost 70% of passenger enplanement activity (see Table 14-1), they account for less than 50% of non-GA aircraft operations. This reflects the larger size of aircraft operating from large hubs, a result of the large demand for passenger service to those hubs. Also, operations cannot be neatly correlated with hub status and enplanement activity. Within each hub definition, some airports have more operations than airports in the next higher hub grouping (e.g., the largest medium hub had over 311,000 non-GA operations, while the smallest large hub had 210,000 non-GA operations).

EPA cross-classified airports by operations data and snowfall data to estimate the number of airports with the potential for significant deicing/anti-icing operations. For the purposes of this study, EPA selected a benchmark of 10,000 operations per year (excluding general aviation) to represent significant operations, and excluded airports with less than 10,000 annual operations from further analyses. EPA did not include general aviation in its operation measurement because the Agency believes that most GA aircraft do not operate during deicing conditions. Also for the purposes of this study, EPA assumed that mean annual snowfall (including ice pellets and sleet) of less than 1 inch would not result in significant deicing operations; therefore, EPA excluded airports in regions with annual snowfall of less than 1 inch from further analyses. A total of 212 airports met the criteria for operations and average snowfall (see Section 4.3.1.1 for details concerning the criteria to determine these airports).

EPA divided operations data into five subcategories (7):

- Category A: 425,000 ≤ operations < 850,000 per year
- Category B: 210,000 ≤ operations < 425,000 per year
- Category C: 100,000 ≤ operations < 210,000 per year
- Category D: 50,000 ≤ operations < 100,000 per year
- Category E: 10,000 ≤ operations < 50,000 per year.

EPA divided snowfall data into four subcategories (8):

- Category 1: 60 inches ≤ snowfall < 120 inches per year
- Category 2: 30 inches ≤ snowfall < 60 inches per year
- Category 3: 15 inches ≤ snowfall < 30 inches per year
- Category 4: 1 inch ≤ snowfall < 15 inches per year.

Table 14-4 presents airports with the potential for significant deicing/anti-icing operations classified by operations, snowfall, and FAA size definition. Of the 212 airports that meet the operations and snowfall criteria, data for only 211 of these airports are contained in the ACAIS database. Therefore, Tables 14-4 and 14-5 are based on the 211 airports that meet both of EPA's criteria and are also in the ACAIS database.

Table 14-4 is organized so that the uppermost left cell contains the largest airports by operations classification and the largest average annual snowfall, while the lowermost right cell (excluding the subtotal row and column) contains the smallest airports with the least average annual snowfall. The classification by hub status is included because of the importance of large and medium hubs in the U.S. air transportation system. For example, based on the averages presented in Tables 14-1 and 14-2, the single large hub with "A" level operations and a minimum of 60 inches of snow probably accounts for more operations and passenger enplanements than the combined operations and enplanements of the 17 nonhub and noncommercial service airports that also average at least 60 inches of snow. A total of 21 large hubs (of 30 total) and 23 medium hubs (of 40 total) meet the snowfall and operations criteria.

Table 14-5 compares EPA's classification system with FAA's size classification for the 211 airports contained in both the ACAIS and NPIAS databases. Air carrier operations decline from 74% of non-GA operations in the highest operations category to 19% in the lowest operations category. As carriers fly the largest aircraft and are less likely to cancel flights due to weather, these operations may generate the most ADF use. While airplane operations decrease dramatically with airport size, carrier enplanements decrease much less dramatically since carriers use larger aircraft than air taxis. In the highest operations category, carrier enplanements account for 95% of average enplanements, while in the lowest operations category, they account for 78 percent. Finally, the number of GA operations increases as airport size decreases; in the largest category, GA operations are a fraction of non-GA operations (less than 8%), while at the smallest airports, GA operations are 264% of non-GA operations.

14.1.1.3 Analytic Issues and Evaluation of Data Availability

ACAIS data (enplanements and gross landed weight of cargo) are made available to the public approximately one year after the CY for which they are collected (e.g., the FAA finished compiling ACAIS data for CY 1997 by the end of October 1998, and reports based on that data were available on the Internet in December 1998). Components of the ACAIS database have also recently been made available in electronic format (Excel spreadsheet) at the FAA web site. Operations data are not currently available at the FAA web site and must be requested directly from the FAA. The FAA can provide data in electronic format to other government agencies if requested to do so, and in greater detail than is posted on the Internet (1).

The primary issues for airport activity data are data consistency and coverage. Databases used for this industry profile were generated by the FAA for its own internal purposes; therefore, not all databases contain data for all airports. For example, the 1997 ACAIS enplanement database contains data for 1,715 airports, while the operations database contains data for 449. Data for almost 1,300 airports in the enplanements database are not in the operations database while 31 airports in the operations database are not in the enplanements database. Furthermore, the number of airports with data in the enplanements database ranges from 1,703 to 1,909 between 1993 and 1997. It is not apparent why these inconsistencies exist. Presumably, a single request to the FAA for all necessary data will result in a single database containing all relevant information. If such a database cannot be obtained, care will be required not to overlook airports with potentially significant deicing/anti-icing operations not contained in the operations database. For example, by using regression analysis on available operations, enplanement and cargo-only service, EPA identified a handful of airports having a high probability of more than 10,000 non-GA operations per year that were not contained in the operations database. Such an analysis may be necessary to ensure that no airports are overlooked.

14.1.2 Airport Financial Management and Accounting

Section 14.1.2.1 presents an overview of the major features of airport financial management, followed by a discussion of data availability for airport financial analysis in Section 14.1.2.2 with a profile of airport finances based on the limited information that is available. Finally, Section 14.1.2.3 presents issues identified during the analysis of airport financial data, including the ability of an airport to pass costs through to airlines.

14.1.2.1 Overview

Airport financial management is fundamentally different from most other business enterprises, because many airports (including most large commercial airports) have traditionally used a *residual-cost* approach to finances. Under this approach, the airlines as a group assume the financial risk of running the airport by agreeing to pay any costs of running the airport not paid by other nonairline users. Under the alternative *compensatory* approach, the airport assumes the financial risk; airlines pay rates set equal to their estimated cost of using the facility. Using the compensatory approach, there is no guarantee the airport will cover costs; however, the airport can keep any surplus of revenues over cost and accumulate capital for future development. Many airports may combine the two approaches (9).

Airport financial statements are difficult to compare between airports and with other businesses due to differences in the size and objective of different airports, the type of airport ownership (e.g., private or public), financial approaches to operations, and legal restrictions on airport finances. For example, because most airports use a residual-cost approach, they receive sufficient revenues from airlines to pay the cost of capital investment and are unlikely to account for depreciation on assets the way most businesses do. Also, airports are legally prevented from using their revenues for nonairport purposes.[6] Therefore, airport financial

[6] Except in specific legal agreements signed prior to the 1982 law prohibiting such practices. Therefore, a few airport owners, such as the Port Authority of New York, still legally use airport revenues to subsidize nonairport activities. Periodic questions of “revenue diversion” do arise, the most notorious being the claim by the City of Los Angeles that it

statements do not meet the standards of Generally Accepted Accounting Principals (GAAP), and an airport's revenue surplus or loss is not equivalent to profit or loss (10).

Typical airport operating statements include the following categories (9):

- Operating revenues and operating expenditures on key "cost centers":
  - -- Airfield area (e.g., runways, taxiways, aprons),
  - -- Terminal area concessions (e.g., food and beverage services, travel services such as car rentals, specialty shops, personal services, amusements, advertising, outside concessions such as terminal parking, ground transportation, hotels),
  - -- Airline leased areas (e.g., ground equipment rentals, offices, ticket counters, cargo terminals, hangers, operations and maintenance areas),
  - -- Other leased areas (e.g., fixed-based operators (FBOs), freight forwarders, government offices, businesses in airport industrial parks, equipment and cargo Terminals rented by nonairline users), and
  - -- other operating revenues and expenditures.

- Nonoperating revenues (e.g., grants-in-aid (AIP), interest on investments, subsidies by government, leasing of properties not related to operations);

- General and administrative expenses (e.g., expenses of overhead services: accounting, legal, planning, public relations); at some airports (such as small municipal airports), these expenses, including policing and firefighting expenses, may appear in the governing authority's budget, not the airport budget;

- Nonoperating expenses (e.g., interest on outstanding debt, contributions to government); and

- Depreciation.

Under a residual-cost approach, the airport determines costs and revenues from each general operational area above, and airlines' fees are set by the anticipated revenue shortfall. Any surplus is returned to airlines in the form of lower fees the following year; any loss would be made up in

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was owed almost $90 million by the Los Angeles Department of Airports for alleged unreimbursed capital and operating expenses relating to the sale of airport property (11).

higher fees the following year. Both terminal and landing fees, or landing fees only, may be adjusted by the airport[7].

The compensatory approach may determine fees according to the actual cost of running the airport, or by market value. The latter is especially common for terminal concessions. A growing trend has been for airports to use a mix of the residual-cost and compensatory approaches. For example, an airport may operate terminal concessions using a compensatory approach that permits the airport to keep surpluses from concession rents and fees, while it runs air-side operations using the residual-cost approach.

The financial and operational relationship between airlines and airport is defined in the *airport-use agreement*. This document specifies how the risks and responsibilities of running the airport will be shared, how rates for using facilities and services are calculated, and how frequently these rates and fees may be adjusted.

One consequence of the residual-cost approach is that tenants at such airports tend to have very long-term leases (20 to 30 years) to assure the airport of revenue to finance capital expenditures. In this case, airlines typically have a *majority-in-interest* clause in the airport-use agreement. This clause gives airlines that represent most traffic at the airport the right to review and veto or defer any capital projects that would significantly increase the fees they pay. Airports using a compensatory approach to finance are not legally required to allow airlines to review capital improvement projects, but most do.

The post-deregulation trend in airport financial management has been towards (9):

- Shorter-term contracts of 5 years or less to new tenants or renewal of existing leases when they expire to permit greater flexibility in adjusting pricing, investment policy, and space allocation.

[7] Wells (9) claims that airports such as Los Angeles and Honolulu have approached "negative" landing fees in recent years due to overall operating surpluses.

- Greater use of the compensatory approach instead of the residual-cost approach with modification or elimination of majority-in-interest clauses.

- Maximization of revenues through more frequent adjustment of fees, competitive bidding for concessionaires' contracts, and greater emphasis on marketing and developing properties (e.g., airport industrial parks). Perhaps the most important new source of revenues at large airports is the collection of passenger facility charges (PFCs).

In the rapidly changing environment of the air transportation industry since deregulation and the burgeoning growth of air travel, airports seem more confident of their ability to be financially self-sustaining without residual-cost agreements by more aggressively pursuing all forms of revenues. For example, revenues from concession operations at hub airports (of all sizes) may account for one-third of total airport revenues; at some airports, concession revenues exceed airline revenues (9). On the other hand, deregulation has made airport finances somewhat more risky because airlines can reduce or discontinue service to an airport with little warning.

14.1.2.2 Airport Financial Data

Consistent data on airport financial conditions are not readily available. One source of data on airport operating revenues is the American Association of Airport Executives' (AAAE) Survey of Airport Rates and Charges, 1997-1998 (12). Because of the way this survey was administered, EPA cannot draw statistically reliable inferences from the survey results. However, more than 50% of large, medium, and small hubs (by FAA definition) responded to the survey, as well as over 220 nonhub and GA airports. Tables 14-6 and 14-7 summarize the results of this survey. Because the survey was voluntary, not all respondents answered all questions; EPA summarized the data for only those airports that provided complete operating revenue and expense data.[8]

Table 14-6 indicates the type of operating agreements used by responding airports. Although residual-cost agreements have historically been the most common type of operating

[8] In addition, EPA could not ensure the consistency or accuracy of the data contained in the survey.

agreement, the number of airports currently using compensatory or hybrid residual-cost/compensatory agreements exceeds the number of residual-cost agreement airports in all airport categories except medium hubs.

Table 14-7 summarizes operating revenues by major source, operating expenses, and government subsidies, by FAA airport definition. Average operating revenues for large hubs are five times those of the next largest airport type – medium hubs – while average large hub enplanements are approximately three times the average medium hub enplanements (see Table 14-1). Airline and air cargo revenues as a percentage of operating revenues diminish with airport size, while FBO and GA revenues as a percentage of operating revenues are inversely related to airport size. Parking and concessions are extremely important sources of airport operating revenues for all except GA airports.[9] Finally, operating expenses exceed operating revenues for GA airports, making them more reliant on government subsidies than any other class of airport.

The AAAE survey provides data on overall operating expenses, but not the source of those expenses. Nor does the AAAE survey provide information on capital expenditures. EPA used its airport mini-questionnaires to focus on these issues. Nine airports were sent mini-questionnaires; in addition, one airport voluntarily responded. Because of the small sample size, these results cannot be considered statistically significant; however, it is the only current source of information on expenses available to EPA.[10] To minimize burden to the respondent, airports were allowed to use “best professional judgement,” and therefore all answers should be considered approximate (13).

Table 14-8 characterizes airport expenditures by three key cost centers (airfield, terminal, and hanger areas), general and administrative (G&A) costs, debt service, and

[9] For the large, medium, and small hubs as a group that responded to the AAAE survey, parking fees comprised almost 41% of parking and concession revenues, exceeding airline landing fees as a source of revenue.

[10] The FAA utilized AAAE data from 1992 to characterize capital expenditures in its most recent NPIAS (6). As noted below, the FAA recently started systematically collecting airport financial statements. This information is not publicly available in electronic format suitable for data analysis, and airport expenses are not characterized by cost center (e.g., airside, terminals), but by cost type (e.g., labor, utilities, insurance).

depreciation; enplanement and operations data are also included to indicate relative airport size. With the exception of Airport #1, airfield operating and maintenance accounts for a range of 13% to 32% of all airport expenditure.[11] For large and medium hubs terminal expenditures are higher than airfield expenditures. This is presumably due to the passenger service at large and medium hubs. With one notable exception, larger airports are willing to incur more debt than smaller airports.

14.1.2.3 Analytic Issues and Evaluation of Data Availability

Little systematic analysis has apparently been done on airport finances. The AAAE Survey of Rates and Charges contains the largest readily available source of airport financial data. However, the AAAE Survey does not provide sufficient data for economic and financial impact analysis. First, coverage is incomplete. Second, because of the way the survey was administered, statistical estimates based on the responses are not reliable. Third, the responses do not deal with airport operating expenses or capital expenditures. AAAE has apparently performed some survey work of capital expenditures. The data cited by the FAA in the NPIAS are dated (1992).

Commercial service airports have recently been legally required to submit annual financial statements to the FAA. These financial statements are available for 1996 and 1997 on the Internet; in addition, the FAA will make an electronic version of these statements available to other federal agencies.[12] These financial statements are the best source of publicly available information to systematically analyze and summarize (e.g., for the industry profile) airport financial information. However, there are a few drawbacks to using this data source. It does not contain non-commercial service airports, and therefore does not include airports such as

[11] Airport #1 is a new airport, which may account for some of the apparent anomalies in its responses. For example, new facilities presumably require less maintenance, hence the low expenditures on the airfield and terminals relative to other airports, but may have relatively high debt to pay for them.

[12] These financial statements are available at http://www.faa.gov/arp/arphome; choose “Browse by Topic” from the menu and select “Financial Reports.” Each year’s reports are contained in a single PDF file that can be searched by the airport’s location ID. Further detail is available for the “other” category, but only in hard copy at the FAA (10).

Rickenbacker, OH or Willow Run, MI that may have significant cargo-only operations. While these files contain detailed information on airport revenue sources, airport expense information is much less detailed, and probably not adequate for economic and financial impact modeling. Finally, because airports are not required to submit audited data, and because different airports may use different accounting bases (e.g., cash vs. accrual) for their reports, these summary financial statements may not be directly comparable between airports (14).

Airport to Airline Cost Pass-Through

A significant question concerning airport finances also cannot be answered by the information provided in the FAA files: what percentage of cost increases are typically passed through to airlines in the form of higher fees? At residual-cost airports, the airlines are legally responsible to cover the costs of the airport; this suggests that airports pass 100% of costs through to airlines. Airline representatives have stated that costs on airports, FBOs, and the FAA are all passed through to the airlines. Furthermore, according to the industry, landing fees – the most likely vehicle for passing through airport costs – are a significant factor in determining the level of airline service provided to cities; an increase in landing fees can cause an airline to reduce or halt service to the airport (15).

Landing fees account for roughly 2% to 3% of overall airline operating costs (9). ATA comments that although landing fees are a relatively small percentage of airline operating costs, airport costs, including landing fees, are one of the most rapidly rising components of costs. According to ATA, any cost component is of great concern to the industry if it is increasing, regardless of the level of the cost (15). Furthermore, many airline operating costs are difficult for airlines to directly control in the short run. For example, jet fuel prices are determined by market forces. Similarly, labor costs are generally determined through multiyear union contracts. Airlines therefore have incentive to control any component of operating cost over which they have leverage, including landing fees (16). Although landing fees comprise a relatively small percentage of overall operating costs, a substantial increase in landing fees can significantly affect airline operating costs. If, for example, Boston's Logan Airport increased its landing fees by

$0.50 per 1,000 pounds (a 22% increase), the landing fees paid by U.S. Airways, Logan's most frequent user, would increase by approximately $1.6 million per year (12, 17, 18).

The small sample of airports visited or surveyed by EPA provide mixed evidence on the issue of cost pass-through. Five of 10 respondents to the EPA airport minisurvey indicated that they would anticipate passing through to commercial air carriers at least 90% of any cost increase caused by improving wastewater treatment systems. One airport indicated that 100% of such costs would be passed through on a special assessment to commercial carriers, and two other airports anticipated other fee increases that would significantly impact commercial carriers. A ninth airport stated that it would pass through 100% of these costs, but would not specify on whom it would raise fees. One of these nine airports indicated that although it was likely to pass through 100% of hypothetical compliance costs to airlines, in practice its ability to do so may be limited by fixed escalator clauses in its airport-use agreements (13).

However, airports do not uniformly believe that all costs can be passed through to commercial air carriers. Of the airports EPA visited, Chicago O'Hare expressed a strong preference for increasing revenues through concessions and other sources rather than increasing landing fees (16). Nearby General Mitchell International stated that the proximity of Chicago O'Hare places makes it difficult to increase revenues through increased landing fees; if General Mitchell increases its landing fees, it risks losing a significant portion of its passenger service to Chicago O'Hare (19). Airports that use a compensatory approach to financial management may consult airlines before undertaking capital improvements, even though they are not required to and the airline is not legally responsible for project costs. Salt Lake City International, for example, negotiated an increase in landing fees of $0.01 per 1,000 pounds with airlines that offset the costs of recycling aircraft deicing fluid; a $0.01 increase in landing fees increased the cost of landing a Boeing 747F by less than $7.00 (20). Finally, the tenth surveyed airport indicated it would not pass through any proposed wastewater treatment costs.

Perhaps the most important long-run determinant of the financial health of an airport is the demand to visit the city or region served by the airport. If the airport is a "terminal," people are going to that city. If an airport is a "hub," people are only going there to get somewhere else. Thus, terminal ("origin-destination demand") airports fare better than airline operational hub-and-spoke ("connecting demand") airports in the bond market. Passenger enplanements are an indicator of demand for service to an airport (and therefore revenues). If an airline using an airport as an operational hub pulls out at short notice (which it can since deregulation), passenger enplanements will probably drop significantly. In such cases, airports may risk significant losses in revenues and financial stability by increasing landing fees. Smaller airports face the same problem; if the costs of serving the airport rise too much, the airport risks losing its airline service. Thus, cost pass-through may vary according to the specific circumstances of individual airports.

14.1.3 Airport Ownership and Management

Section 14.1.3.1 presents an overview of major patterns of airport ownership and management, followed by a discussion of data availability and analytical issues in Section 14.1.3.2.

14.1.3.1 Overview

Different types of airport ownership affect decision-making at the airport, and the airport's access to funds for financing capital improvements. Typical ownership structures include:

- Municipal/county government: airport is owned by city/county and run as a department of that entity and managed by that entity's board of directors (e.g., city council); sometimes there may be a separate airport commission or advisory board. Policy decisions are made in the context of the wider city plan and the airport has no independent authority to issue bonds (9).

- Multipurpose port authority: legally chartered institutions operating a variety of publicly owned facilities such as airports, harbors, toll roads, and bridges. The authority typically has considerable decision-making autonomy from city/state government including the authority to issue debt in the form of revenue bonds (9).

- Single-purpose airport authority: similar to a port authority but only runs airport (or airports); like a port authority, it can issue debt, but typically has a narrower revenue base to operate from (9).

- State-operated airports: typically run by the state's Department of Transportation that can issue general obligation or revenue bonds. The state may also raise revenues through aviation fuel taxes. Only a handful of large-/medium-sized commercial airports are run by states: Alaska, Connecticut, Hawaii, Maryland, Rhode Island. The federal government owns one airport: Pomona Airport, Atlantic City, NJ (9).

- Private ownership: privately owned and operated, these airports are typically, but not exclusively, small GA airports (9); ABX, for example, is privately owned and operated by Airborne Express, which uses it as their operational cargo hub.

The recent trend for airports is to use independent authorities. Airports often outgrow political jurisdictions and impact surrounding communities both negatively and positively. Independent authorities allow the airport to spread the tax burden to other communities that benefit from that airport. (Note that government subsidies are much more important for smaller airports, especially as a percentage of operating costs; no large hubs, for example, are subsidized – see Table 14-7). Such authorities also allow smaller, more specialized, on-the-scene decision-making organizations somewhat insulated from politics. In addition to delegating management to an independent authority, that authority may further delegate airport management to a private contractor (21).

Table 14-9 summarizes ownership patterns found among airports responding to the AAAE Survey of Rates and Charges. The majority of respondents are municipally owned, a pattern that holds for all airport hub classes. Furthermore, "multigovernment" airports are typically airports with joint ownership by multiple municipalities. Thus, airport ownership by cities is dominant among AAAE survey respondents.

14.1.3.2 Analytic Issues and Evaluation of Data Availability

Two issues arise out of differences in airport ownership. The first is related to financial accounting. A municipal airport run by a department of the municipal government may account for costs in a significantly different way than other airports. Specifically, many costs of the airport such as accounting, legal, public relations, even policing and firefighting may be attributed to other city departments, not the airport. Thus, its financial position may be more difficult to analyze than an airport run by an independent authority.

The second issue is based on the lack of information available concerning privately owned airports. They are not required to submit financial summary statements to the FAA. Also, private ownership may affect airport access to funds for capital improvement; a significant portion of capital for publicly owned airports is raised through the municipal bond market. However, most, but not all, privately owned airports are relatively small GA airports (3) and are unlikely to perform many deicing operations.

14.1.4 Financing Capital Improvements

Section 14.1.4.1 profiles major sources of capital funding for airports and their relative importance in the system. Section 14.1.4.2 discusses data availability and analytic issues concerning airport capital financing.

14.1.4.1 Overview

In general, airports rely on the following sources of funds to finance capital improvements:

- Federal funding through the FAA AIP: funding comes from the Airport and Airway Trust Fund with revenues raised from taxes on airfares and airfreight waybills, surcharges on international flights originating in U.S., taxes on aviation gas and jet fuel, and registration fees on aircraft. Almost

50% of AIP funds are “apportioned” to airports by formula for use on any project meeting the guidelines for AIP-funded projects. The remaining funds are distributed at the FAA’s discretion for specifically approved projects. Most AIP funding goes for runways, taxiways, aprons, runway lighting and navigational aids; it may be used for building deicing pads and purchasing snow removal equipment (22). AIP funding may not be used to build hangers, parking facilities, or most terminal development (3). All NPIAS airports are eligible for AIP funds (2). AIP grants accounted for 20% of airport capital expenditures in 1996 (23).

- FAA-authorized Passenger Facility Charges (PFCs): the FAA authorizes commercial airports to impose PFCs for funding certain types of capital improvements similar to those eligible for AIP funds. Airports may charge $1, $2, or $3 per enplaned passenger and passengers may be charged PFCs no more than twice on each leg of a round-trip journey.[13] Airports must notify airlines of intention to charge the PFC and present to them its capital plan and financing strategy. Large and medium-sized hubs that use PFCs must give up AIP funds ($0.50 of AIP funds for every $1.00 of PFCs collected up to a maximum of 50% of their AIP apportionment); half of the relinquished AIP funds go into a discretionary fund earmarked for small airports (22). PFCs accounted for 16% of 1996 airport capital funding (23).

- State funding: this varies widely by state; Alaska and Hawaii provide considerable assistance while other states (e.g., New Hampshire) provide minimal assistance. Funding comes from state fuel taxes, aircraft, airport, and pilot registration fees, and general funds. State funding accounted for 4% of airport capital expenditure in 1996 (23).

- Bond market: although some city and states may fund airport expansion with general obligation bonds, or self-liquidating general obligation bonds, more typically airports use tax-exempt general revenue bonds. Typically airport revenue bonds have 25 to 30 year terms. Tax-exempt bonds are by far the single most important source of airport capital, accounting for 58% of 1996 funding (23).

[13] The FAA has proposed raising the maximum PFC charge. While endorsed by airports, this measure is opposed by airlines on the grounds that: (1) it helps most those airports that least need help (i.e., large airports with large levels of enplanements), (2) because projects funded with PFCs do not have to meet airline approval, they believe many unnecessary projects are funded, and (3) PFCs increase the cost of air travel and therefore decrease the quantity of air travel demanded (24, 15). Airports argue that incumbent airlines frequently oppose airport expansion in order to restrict airline competition (25).

- Airport revenues: capital improvements funded directly from airport revenue streams, whether airside or landside. Airport revenues accounted for 2% of capital funding in 1996 (23).

In addition:

- Airport may lease airport-owned land to a private individual or company who finances improvements (e.g., airlines that build their own terminal on airport property out of airline funds (9)).

Table 14-10 characterizes airport capital expenditure, and the sources of funding for that capital expenditure, for recipients of EPA's airport minisurvey. Small and nonhub capital expenditure is significantly smaller than large and medium hubs. Furthermore, while capital spending at small and nonhubs is primarily funded through AIP grants and PFCs, a large percentage of large and medium hub capital expenditures is financed through bonds. With one exception, all airports surveyed charge the maximum PFC ($3 per passenger), and that single exception has applied for permission to charge PFCs starting in the year 2000. Finally, most of these airports do not have a majority-in-interest clause in the airport-use agreement; a majority-in-interest clause requires airline approval of capital improvement projects.

An FAA study released in 1996 evaluated the airport access to funding for capital improvements and the effectiveness of the AIP program (26). Some key points of this evaluation are:

- From 1985 through 1995, AIP funded 14% capital spending at large commercial airports, 28% at medium-sized commercial airports, and 41% at small airports (including relievers and GA).

- PFCs are generating roughly $1 billion per year, 50% of which is concentrated at the 10 largest enplaning airports. PFCs are an important source of revenue for funding bond issues. Airports may be obligating the revenue stream from PFCs 10 to 15 years into the future (15).

- Airports tend to perform at least as well as any other borrowers in the municipal bond market. Of the 995 airport bond issued between 1985 and

1995, all but one were rated "investment grade" (48% of large airport bond issues and over 65% of medium and small airport bond issues by volume were rated AAA). The airport industry has never defaulted on a bond issue.

- The tax exempt status of municipal bonds saves airports approximately 2% in interest costs (estimated at $1 billion per year).

The report concluded:

"The nation's commercial airports today do not face systemic or widespread obstacles to finding willing investors, financing debt-service reserve funds, obtaining bond insurance and other debt guarantees, and generally exercising leveraging strategies that foster airport development."

Although the report found no systemic problems:

"At large and medium-sized airports, where major airlines exert significant influence over the scope and timing of investment, near-term financial realities facing airline management can create divergent airport-airline perspectives on the appropriate timing and scope of capital improvements due to their immediate implications for landing fees and other airline costs. . . . At small airports there is evidence of financial barriers to the desired level of development of terminal and land-side facilities."

These financial barriers were deemed to be caused by insufficient revenues to cover bond issues or a lack of state or local aid.

While a General Accounting Office (GAO) analysis of airport capital funding generally concurred with FAA's conclusions, it was not as confident as FAA about the overall availability of capital funding for airports (23). GAO projected a $4 billion per year shortfall of capital funds for airport improvements, although this conclusion must be qualified because the $4 billion figure was based on planned capital expenditure and was not prioritized by need. GAO noted that on a percentage basis, the shortfall was more significant for small airports rather than large and medium hubs. GAO also found that small airports are most dependent on government funding for capital projects.

14.1.4.2 Analytic Issues and Evaluation of Data Availability

The issue of capital availability will be important if EPA decides to proceed with development of an effluent guideline regulation for airport deicing operations. Due to the size of airports, and the level of construction necessary to withstand heavy usage, airside capital projects are potentially quite expensive, and the availability of capital funding could be of concern. FAA airport financial statements provide substantial data for characterizing sources of capital funding of the industry. However, the problem of local financial barriers to raising capital may become an important component of any impact analysis necessary to develop an effluent guideline.

In addition, airports, especially smaller airports, tend to rely heavily of government funds, such as AIP grants, to pay for capital improvements. The availability of AIP and PFC funds for use in meeting an effluent guideline may be difficult to determine. AIP funding is determined each year and Congress generally limits distribution of AIP funds to a lower level than authorized (26). Discretionary AIP funds are granted for specific projects only. Although PFCs may be a more predictable long-run source of revenues for capital improvements, airports may be “earmarking” projects to be funded by PFCs well into the future (15). Also, note that PFC funds provide little capital for airports with relatively small enplanements.

Should EPA move forward with a deicing effluent guidelines regulation, it is unlikely that airports could reasonably anticipate financing much capital expenditure to meet those regulations through AIP or PFC sources. This is due to both the limited availability of AIP funds and the tendency for AIP and PFC funds to be earmarked for specific projects. Combined with the perceived shortfall of capital funds for airport improvements, airports might only be able to meet such a regulation by postponing other capital projects. Thus, availability of capital may be a crucial issue in analyzing potential impacts of an effluent guideline regulation on airport deicing operations.

14.2 Airlines

Civil aviation can be divided into two groups: air carriers, and GA. Air carriers are defined as a company or other organization that carries passengers or cargo for hire or compensation by air; GA constitutes all other civil aviation (27).

Aircraft utilized by air carriers are distinguished from GA aircraft by the size, frequency and intensity of use. Table 14-11 displays some comparisons between selected types of GA and air carrier aircraft. Although there exist 21 times as many fixed-wing GA aircraft as air carrier aircraft, 75% of GA aircraft are single-engine piston aircraft, and each GA aircraft operates less than one-fifth as many hours per year as the average air carrier aircraft. Although the number of GA twin-engine turbojets outnumbers air carrier twin-engine turbojets, the latter are typically much larger (i.e., Boeing 737s and Douglas DC-9s/McDonnell Douglas MD-80s and MD-90s, carrying a minimum of 100 passengers). GA twin-engine turbojets tend to be much smaller aircrafts such as Learjets, carrying less than 20 passengers, flying as corporate/executive aircraft. Because GA aircraft are unlikely to fly in weather bad enough to require deicing – or if they do deice, they are likely to need relatively small quantities of deicing fluids – the remainder of this section will focus on air carriers.

14.2.1 Types of Air Carriers

Section 14.2.1.1 presents an overview of U.S. air carriers, major definitions, and a profile based on traffic statistics. Section 14.2.2.2 discusses data availability.

14.2.1.1 Overview

Air carriers can be divided into separate categories using two classification systems. The first classification system is primarily based on aircraft size. Air carriers must, in general, obtain a "fitness" certificate (covering economic and financial criteria) from the U.S. Department of Transportation (DOT) and an "operating" certificate (covering safety, training and other operating issues) from the FAA. Aircraft size is a primary determinant of the type of certificate airlines require from each agency. Air carriers may be classified as (28):

- Large certificated carriers: fly aircraft capable of carrying a minimum of 61 passengers, or payload capacity of 18,000 pounds, or conduct international operations. Large certificated carriers require a Section 401 fitness certificate from DOT, and a Part 121 operating certificate from FAA.

- Small certificated carriers: fly aircraft that carry less than 61 passengers, have a payload capacity of less than 18,000 pounds, and do not conduct international operations. Small certificated carriers also require a Section 401 fitness certificate from DOT, and a Part 121 or a Part 135 operating certificate from the FAA.[14]

- Commuter carriers: defined as air taxis that have a published service schedule of at least five round trips per week between at least two places. Commuters register with DOT under Section 298, but do not require a fitness certificate. They also need a Part 121 or a Part 135 operating certificate from the FAA.[15]

One significant factor about the definitions above is that DOT reporting requirements vary according to the above definitions. Large certificated carriers must report monthly traffic statistics and quarterly financial statistics to DOT's Bureau of Transportation Statistics (BTS); these statistics are regularly published. Small certificated carriers and commuters report scheduled service only on a quarterly basis, and, although they do report financial statistics, those are not published due to a confidentiality agreement.

Large certificated air carriers are also characterized by annual revenues. Airline classification by revenues include (29):

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[14] Part 121 operating certificates are required for aircraft carrying more than nine passengers, more than 7,500 pounds payload, or for turbojet aircraft regardless of passenger capacity. Part 135 operating certificates are required for aircraft carrying nine or fewer passengers, or less than 7,500 pounds payload. Prior to 1996, Part 135 certificates were required for aircraft carrying 30 or fewer passengers.

[15] For EPA's purposes, small certificated and commuter airlines are essentially identical. They offer the same type of service and operate the same type of aircraft. Small certificated air carriers are basically commuter airlines that chose to get certificated rather than registered because: (1) certificated airlines have a better chance of obtaining lucrative mail contracts in Alaska than do registered air carriers, or (2) bankruptcy laws – no longer in effect – made it easier for banks to recover capital from bankrupt certificated carriers compared to registered carriers (28).

- Major airlines: annual revenues greater than $1 billion;
- National airlines: annual revenues greater than $100 million, but less than $1 billion;
- Large regional airlines: annual revenues greater than $20 million, but less than $100 million; and
- Medium regional airlines: annual revenues greater than zero, but less than $20 million.

Although DOT does not report small certificated/commuter airline data according to revenue classification, some private publications might.

National and regional airlines tend to focus their service in particular regions of the country – a market "niche" strategy where the niche is defined by the geographic region served. Major airlines generally provide nationwide and often worldwide service. The primary difference between national and regional large certificated carriers is the scale of service as indicated by the level of revenues earned. Small certificated carriers/commuter airlines generally follow the same regional marketing strategy, and are distinguished from large certificated regionals more by the size of the aircraft flown than the type of service provided (30). Appendix D presents a list, by revenue classification, of EPA's estimate of U.S. airlines in operation as of June 1998, along with their key financial and traffic statistics, where available.

National and regional airlines often provide "feeder" services to major airlines by carrying passengers from smaller airports not served by major airlines to the major airlines' operational hubs. Through "code-sharing" agreements, the regional airlines can schedule such feeder flights under the major airline's scheduling code. The flight appears to be a "through" flight rather than a "connecting" flight, thus gaining a higher ranking in travel agents' computer reservation systems and therefore having a greater probability of being booked (30). The major airline gains by appearing to schedule service to more cities, while the regional airline gains by having its service appear to the traveler as being provided by a major airline. Through code-sharing agreements and non-code-shared feeder flights, major airlines and national/regional airlines often have more of a complementary relationship rather than a competitive relationship.

Table 14-12 presents summary traffic statistics by carrier type. A revenue passenger-mile (RPM) is defined as one revenue passenger transported one mile in revenue service and is a commonly used measure of the quantity of passenger service provided; an airline transporting one passenger 1,000 miles provides more service than an airline transporting one passenger 500 miles. Available seat-miles (ASM) is a commonly used measure of airline capacity: the number of seats available for revenue service multiplied by the number of miles those seats are flown. Load factor is a measure of the proportion of capacity actually used in revenue service, and is derived by dividing revenue passenger miles by available seat-miles (31).

As is the case for airports, the airline industry is dominated by a handful of very large entities. Thirteen major airlines (three of which provide only cargo service) account for 83% of passenger enplanements and 88% of cargo ton-miles. Flying larger aircraft over longer distances, as indicated by passengers per aircraft-mile and miles per passenger, major airlines account for over 90% of RPMs and ASMs.

14.2.1.2 Data Availability

BTS tracks a wide range of traffic and activity statistics on airlines at the level of the business entity (32). The BTS *Green Book* is published monthly and contains traffic statistics for all large certificated carriers. These data include key measures of airline capacity and capacity utilization, such as available seat-miles, revenue passenger-miles, passenger enplanements, passenger and cargo ton miles, aircraft departures and hours flown. Data are provided for both scheduled and unscheduled service, for each airline's entire route system, and domestic and international routes separately. Comparisons are provided between the latest month, the same month in the previous year, the latest 12 months in aggregate, and the previous 12 months.

The BTS *Blue Book* tracks activity for small certificated and commuter airlines (31). The *Blue Book* is published quarterly, and only scheduled service statistics are presented. Basic measures of airline capacity and capacity utilization, such as available seat-miles, revenue passenger-miles, passenger enplanements, passenger and cargo ton miles, aircraft departures and hours flown, are included; however, less detail is provided than in the *Green Book*. Comparisons are provided between the latest quarter, the same quarter in the previous year, the latest 12 months in aggregate, and the previous 12 months.

To determine airline service to individual airports, BTS also publishes Airport Activity Statistics for each calender year (18). BTS provides passenger, freight, mail, and cargo (cargo equals the sum of freight and mail) enplaned at each airport by each large certificated carrier. BTS also publishes scheduled and unscheduled aircraft departures for each airline at individual airports by aircraft type. BTS does not publish the destinations of passenger and cargo enplanements or aircraft departures, nor does it publish data for small certificated/commuter airlines, intrastate traffic, or foreign airlines.

14.2.2 Air Carrier Finances

Section 14.2.2.1 profiles the air transportation industry based on financial characteristics. Section 14.2.2.2 summarizes availability of key data necessary for analyzing airline finances.

14.2.2.1 Overview

Table 14-13 presents air carrier financial statistics by carrier type for the 12-month period ending June 30, 1998 (29). Major carriers account for over 85% of total air carrier passenger revenues, operating revenues, and operating expenses, and almost 95% of operating profit. As a group, only major carriers and small certificated carriers earned positive net income in this period (operating profits minus tax and interest payments).

Although in the aggregate, approximately 72% of total operating revenues are earned from passenger service, for specific airlines this average figure is deceptive. Table 14-14 presents 1997 passenger revenues, cargo revenues, and total operating revenues for selected ATA members. Table 14-14 also includes the number of aircraft owned and full-time-equivalent employees to provide nonrevenue size comparisons. Airlines are clearly divided among those providing both passenger and cargo service, but earning the majority of their revenues from passenger service (a minimum of 82% among the nonrandom sample displayed in this table), and cargo-only airlines that earn zero revenues from passenger service.

Operating profits presented in Table 14-13 for the airline industry are misleadingly high in the 12-month period ending in June 1998. Since deregulation in 1978, the airline industry has been notable for its low profit rate. Between 1978 and 1997, the industry's average net profit margin has been -0.1 percent (-1/10 of 1 percent). The record profits earned the last three years have been well below U.S. industry's average (15). Roughly 40% of the record profits earned in the last three years (approximately $2 billion out of 1997 net profits of $5 billion) have been directly attributable to low interest rates (resulting in significant savings on the cost of purchasing or leasing jet aircraft) and low jet fuel prices (which account for approximately 10% of industry operating costs).

Table 14-15 presents scheduled airlines' operating revenues, expenses, profits, net profits and profit margin for the period from 1982 to 1997 (33, 34). In only four of the 16 years did operating profit exceed 5 percent.[16] Moreover, in only one year did the airlines rate of return on investment exceed 12%; a 12% return on investment (pretax) is often considered a benchmark for the "normal" rate of return – that rate of return necessary to meet the opportunity cost of capital (35). If the opportunity cost of capital is not met, then in the long run, capital will flow out of the industry and the industry will contract.

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[16] Figures for 1992 include a one-time-only accounting loss due to changes in accounting procedures that affected all industries. However, these losses account for less than 50% of the operating loss for that year; hence, significant losses were still incurred in 1992 (35).

Although some of the low profit margin in the airline industry can be attributed to growing pains associated with relatively recent deregulation, the problem of low profits is most likely systemic in an industry like air transportation.[17] Economists typically measure industry competitiveness by the market share accounted for by the four or eight largest companies (4- or 8-firm concentration ratios) or an index such as the Herfindahl that measures the number of "effective competitors." Using such measures, the competitiveness of the airline industry has declined since deregulation due to mergers. However, air carriers do not really compete at the national level, but at the route level. As Morrison & Winston pointed out:

> "Four effective competitors at the national level can operate in two very different ways: with each having a monopoly share on one-quarter of the routes or with each having a one-quarter share on all routes. Although the number of airlines is the same either way, the second situation is obviously more competitive because more airlines serve each route. Thus fewer effective competitors at the national level does not necessarily mean that the industry is less competitive."

Although lower than its peak in 1985, competition has clearly increased at the route level since deregulation, leading to a decline in average air fares, and an increase in air travel (35).[18]

Two features of the airline industry are the key contributors to low profit margins: low marginal costs on established service, and few barriers to entry. On an already scheduled flight, the cost of flying one additional passenger is very low (e.g., the cost of flying 121 passengers, instead of 120 passengers, on an already scheduled flight): incremental fuel costs, food costs, travel agents' commissions, and similar costs. Because marginal costs are so low, and because the opportunity cost of flying with empty seats is high (i.e., an empty seat on a flight represents an opportunity foregone to earn revenue from that seat on that flight), there is a lot of

[17] Some financial problems can be attributed to airlines learning to operate in an entirely new, highly competitive market environment, such as dealings with labor unions in an environment where costs cannot simply be passed on to customers through regulated fares, the startup of many low-cost airlines (e.g. People's Express), a wave of mergers (e.g., Frank Lorenzo and Texas Air), and a shake-out of weaker airlines exposed to competition (e.g., Eastern, Pan Am, (36)).

[18] This view is not shared by all economists; see Shepherd & Brock (37), for example, for a less optimistic view of the degree of airline competitiveness. Also, competition may be restricted on certain routes due to "slot" restrictions at airports or the dominating presence of a single airline at an airport ("fortress hubs"); this issue is discussed in more detail in Section 14.2.4.4.

pressure in the air transportation industry to keep air fares low. Essentially, if an airline can sell a seat above marginal cost, the airline will earn more net revenue than if it flew with an empty seat, even if that price does not cover average cost of providing that seat (i.e., total cost of the flight divided by the number of seats on the flight (38)).

Low marginal cost is not, by itself, sufficient to keep profits low. If barriers exist that prevent other airlines from entering a market, the incumbent airline is not necessarily driven to offer fares as low as marginal cost. However, in many – but not all – airline markets, few barriers to entry exist; it is relatively easy and inexpensive for existing airlines to switch aircraft from one route to another.[19] The existence of a second airline, or more, in a market provides the competitive impetus to drive air fares down towards marginal cost (38). Fare wars have been common in the airline industry since deregulation, often driven by airlines struggling to stay afloat financially, and willing to fly below average total cost if it will generate some positive cash flow (i.e., revenues exceed operating costs, but not full costs (36)).

One result of this downward pressure on prices has been that airlines have become extremely aggressive cost cutters.[20] Airlines are concerned with any cost component exhibiting rapid growth, regardless of the relative size of that cost component (15). Much investment in new aircraft, for example, is geared towards cost reductions: a Boeing 757 provides 40 more seats, uses 20% less fuel, and requires a two-person cockpit crew instead of three compared to a Boeing 727 (15).

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[19] Crandall argues that in addition to low barriers to entry for existing airlines to enter a market, there are few barriers to entry to the air transportation industry as a whole. New airlines can be started relatively cheaply to compete with existing airlines (e.g., without having to hire unionized labor, new airlines can start business with a significant cost advantage over existing airlines because labor costs comprise up to 45% of operating costs). Crandall argues further that there are barriers to exit: the high cost of leaving the airline industry causes airlines to stay in business even when they are consistently losing money. Such airlines become some of the most aggressive price cutters in order to generate any kind of positive cash flow (38).

[20] Robert Crandall, the legendary CEO of American Airlines, has been quoted as saying that one of his proudest achievements at AA was saving the company $50,000 per year by reducing the number of cherry tomatoes in the in-flight salads from three to two.

Table 14-16 presents cost indices and cost components as a percentage of total operating costs (39). Labor, fuel, and aircraft costs are the three largest cost components, accounting for over 55% of airline operating costs. Landing fees comprised 2% of operating costs in 1997. However, note that landing fees did grow 68% between 1985 and 1992 – approximately 8% per year; this period of rapid growth probably accounts for the attention airlines have paid to landing fees in recent years.

14.2.2.2 Data Availability

A wealth of financial data is available at the business entity level for large certificated carriers in the Bureau of Transportation Statistics (BTS) *Yellow Book* (29). The *Yellow Book* is published quarterly and contains detailed income statements and balance sheets for each large certificated carrier. Income statements are presented system-wide as well as separately for domestic and international service. Comparisons are provided between the latest quarter, the same quarter in the previous year, the latest 12 months in aggregate, and the previous 12 months. DOT also publishes the Airline Quarterly Financial Review for major airlines (40); however, this information is available in the *Yellow Book* and *Green Book*.[21]

BTS does not publish financial data for small certificated/commuter airlines. BTS does collect income data on passenger service revenues, operating revenues, operating expenses, and net income for each airline in this category biannually. However, individual airline data are kept confidential for three years, and only group data are presented in the *Yellow Book*.[22]

[21] Although the Airline Quarterly Financial Review does contain financial ratios for major carriers not contained in the *Yellow Book*, the *Yellow Book* contains data that can be used to calculate important financial ratios.

[22] BTS did indicate that this small certificated/commuter airline income data may be available to other government agencies under certain circumstances (28).

14.2.3 Airline Deicing Costs

Airlines do not, in general, track deicing costs at the corporate level. In addition, while deicing costs may be tracked by the airline at individual airports, not all costs are directly attributed to deicing operations. Thus, for example, labor used for deicing aircraft may not be tracked as such, as labor may be tracked simply by hours, not by task. Similarly, while a certain percentage of airport landing fees and other charges are properly attributable to both the direct operating costs (e.g., vacuum trucks, wastewater treatment operations), and capital costs (e.g., deicing pads, drains, retention ponds) of ADF collection and disposal, the exact percentage of those fees attributable to deicing may be difficult to infer. All deicing costs cited in this section have been estimated by airlines, some with the assistance of ATA (41).

The methodology used for estimating deicing costs followed the following procedure. Five major airlines each provided ATA estimates of their deicing costs at a single airport for the three most recent deicing seasons (October to May of the following year). Airports were selected to provide a spectrum of weather and operational conditions. ATA used these airline specific costs to provide a breakdown of deicing costs into major components. Using figures on aircraft operations by the airline reporting for a specific airport, and total operations at that airport during each deicing season, costs were extrapolated from the individual airline to the entire airport. Finally, each airport's deicing cost per departure was regressed on three different measures of weather severity at each airport during the deicing season.[23] By using the same measures of weather conditions, the regression equations were used to estimate the deicing cost per departure at 236 other airports at which air carriers maintain air service. These costs were then aggregated using scheduled aircraft departures at each airport to estimate total airline deicing costs for the three deicing seasons (41).

The largest cost of airline deicing operations is the delays caused to each carrier's schedule. Costs of delay measure the direct operational costs of delay to the airlines, but not the

[23] ATA used heating degree days (an engineering index of heating fuel requirements), the number of days with temperatures below 32° F, and inches of snow.

opportunity cost of passengers' time on the delayed aircraft (42). Labor and operating costs comprise the second largest component, accounting for 28.5% of deicing costs. The third largest component of deicing costs is materials, primarily ADF. Finally, capital costs comprise 5.7% of deicing costs; these only include capital costs incurred by airlines, but not those incurred by airports. Therefore, ATA believes that the capital costs of deicing operations incurred by airlines are most likely understated in its study. Furthermore, ATA-member airlines estimate that deicing costs per aircraft have increased by 20% to 25% over the last five years due to rising ADF prices, increased use of more expensive anti-icing fluids, regulatory compliance costs, and increased wages and equipment costs (41).

The importance of the cost of delays to the airline industry can be observed in the fact that many operational decisions concerning deicing are made on the basis of how they will impact on-time performance. For example, a carrier's operational preference for gate/apron deicing as opposed to central deicing pad deicing, where both types of deicing are available, will depend on which is less likely to cause delays; it may be more difficult to coordinate activities of several carriers at a common-use centralized deicing pad without causing delays. Similarly, the decision by a carrier to provide its own deicing services at an airport as opposed to using another airline's or an FBO's services may hinge on how it will affect on-time performance (41).

Table 14-17 presents the measures of weather severity and deicing costs for the five airports selected by ATA.[24] Two points are apparent from this table: (1) the wide range of deicing costs per departure at different airports, and (2) the difficulty of easily characterizing those costs. Excluding Airport C with its semi-desert climate and relatively minimal deicing costs, deicing costs per departure at the remaining airports range from \$84 to \$640. With relatively basic measures of weather severity, costs differ substantially between deicing seasons at one airport, and between airports. For example, by all three measures of weather, the deicing season was more severe at Airport E in the 1998-99 season than airport B, yet per departure deicing costs were 73% higher at Airport B than Airport E. Similarly, at Airport A, the 1996-97 deicing

[24] In addition to key operational characteristics, ATA described important features of each airport's glycol collection system.

season was more severe than the 1998-99 season, yet per departure costs were 20% higher in the 1998-99 season. Finally, the deicing costs of cargo-only operations at Airport D are significantly higher than the other airports.[25]

EPA also received separate estimates of deicing costs from regional airlines. Minisurveys to regional airlines provided estimates of cost per aircraft deiced ranging from $320 to $360 at Northeastern, Midatlantic, and Midwestern regional airports. Although these costs appear somewhat higher than the estimates provided by ATA (with the exception of Airport D with cargo-only service), ATA's estimates include aircraft departures that did not receive deicing.[26] With that qualification, EPA considers the regional airline estimates similar to those provided by ATA for similar region airports (43).

Regional airline estimates of the percentage of costs accounted for by different components of deicing operations are not directly comparable to ATA estimates. Regional airlines provided estimates of the direct cost of deicing operations that excluded such items as the cost of delays, and the estimated increase in landing fees attributable to deicing operations. However, it can be noted that whereas ATA estimated that the percentage of costs attributable to labor (28.5%) were of roughly the same magnitude as costs attributable to materials (24.7%), regional airlines attributed a significantly larger percentage of direct deicing costs to materials (43). The reason for these differences are not immediately apparent.

Regional airlines also provided estimates for the price of some ethylene and propylene glycol-based deicing fluids. For Type I ethylene glycol-based fluids, the price was

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[25] Cargo aircraft spend significantly longer periods of time on the ground, typically only "cycling once" per day (compared to a passenger aircraft that might have several take-off/landing cycles per day. Thus, a cargo-only aircraft may land in the morning, be deiced and anti-iced, then need deicing again before departing that night (42).

[26] Regional airline respondents to the EPA minisurvey estimated a range of 35 to 50 deicing episodes in the 1997-98 deicing season; assuming a 150-day deicing season (e.g., from mid-October through mid-April), these airlines were undertaking deicing operations of varying intensity every three to four days (note that some episodes may have lasted more than one day). Presumably deicing operations were less frequent in October and April, and more frequent in January and February. Northwest Airlines indicates that it deices aircraft almost daily at its Minneapolis hub during the October to April "deicing season."

estimated in the $4.70 to $5.00 per gallon range; propylene glycol-based Type I fluids were somewhat more expensive in the $5.00 to $5.30 per gallon range. For Type II ethylene glycol-based anti-icing fluids, the price was estimated in the $6.15 to $6.30 range. For Type IV propylene-glycol based anti-icing fluids, the price was estimated in the $7.45 to $7.60 range (43).

As discussed in detail above, ATA extrapolated deicing costs at 236 other U.S. airports at which air carriers maintain operations using the airport-specific deicing costs per deicing season operation and the three measures of weather severity. Table 14-18 summarizes ATA's estimates of U.S. national air carrier deicing costs. Estimates of national deicing costs range from a low of $437 million in the 1997-98 deicing season (measured using days less than 32° F), to a high of $549 million in the 1996-97 deicing season (measured using HDD).[27] National deicing costs averaged well under 1% of total national operating costs for these three deicing seasons. However, because of the small profit margins in the air transportation industry, deicing costs ranged from 9% to almost 20% of net industry profits in the same time period.

14.2.4 Air Transportation Industry Trends

Following is a brief discussion of some trends that may significantly impact the air transportation industry, and its deicing operations, over the next few years.

14.2.4.1 Projected Industry Growth

Between 1998 and 2009, the FAA projects that the demand for air transportation services, as measured by domestic passenger enplanements, will grow faster than that projected for U.S. Gross Domestic Product (GDP), 3.5% compared to 2.3% for GDP. For the 2010 to 2020 period, both air travel demand and GDP growth is projected to slow, to 2.9% and 1.9%

[27] ATA argued that estimates based on snowfall underestimate the true national costs of deicing because zero snowfall implies zero deicing costs, yet airlines do incur deicing costs even with zero or minimal snow, as can be seen in Table 14-17.

respectively (44).[28] Boeing projects somewhat slower growth for North American air transportation (approximately 2.9%) while Airbus forecasts significantly slower growth (approximately 2.2%) than the FAA between 1998 and 2017 (45, 46).

Of particular interest is that regional and commuter airline growth is forecast to exceed large commercial airline growth, approximately 5.5% compared to 3.5% for large airlines, between 1998 and 2009. Also, because the demand for air travel is expected to grow faster than air carrier fleets during the forecast period, air carriers are expected to accommodate some of the increased demand through higher load factors and more intensive utilization of existing aircraft (44, 45).[29] To the extent that increased passenger demand is accommodated through more intensive utilization of existing aircraft, rather than using fewer aircraft with larger passenger capacity, more flight operations will be required to meet the increased demand for air transportation. Total operations and deicing operations would then be expected to grow more quickly with projected passenger demand, rather than more slowly with projected aircraft fleet size. ATA notes, however, that historically operations have grown more slowly than passenger demand.

14.2.4.2 Regional Jets

Regional jets (RJs) are smaller jet aircraft with seating capacities ranging from 32 seats to approximately 100 seats. RJs are largely being ordered by regional and commuter airlines, both to replace existing turboprop aircraft in their fleets, and to expand their fleets. RJs should result in increased service on smaller routes now generally served by turboprops. RJs offer lower operating costs per ASM than turboprops, resulting in lower cost service on smaller routes (15, 45). RJs are especially competitive on “long thin” routes. Comair, for example, estimates that it can break even operating an RJ on such a route with 21 passengers; if its affiliate Delta

[28] Air transportation growth projections are largely dependent on GDP growth projections; the FAA based its projections on an average of DRI/McGraw-Hill’s and The WEFA Group’s forecasts.

[29] Although Boeing sees little growth in average aircraft capacity, the FAA expects average aircraft capacity to grow by approximately two seats per year, from 142.6 seats to 166.6 seats in 2009.

operates a Boeing 737 on the same route, the larger aircraft would require 81 passengers to break even (47). Perhaps as importantly, RJs are more popular with the public because they are perceived as safer and more comfortable than turboprops; one commuter airline's research suggested demand on some of their routes would grow by perhaps 20% simply due to the "turboprop avoidance factor" (47).

The importance of RJs is reflected in the faster growth for regional and commuter airlines projected by FAA. The combination of lower operating costs (an increase in supply), and increased demand on routes serviced with RJs could result in significantly increased air transportation service to smaller airports. This could have two implications for aircraft deicing. First, due to the increasing demand for service by small aircraft, the number of deicing operations will grow more quickly than overall passenger demand because smaller aircraft will carry fewer passengers per flight. (Note that because smaller aircraft require less deicing fluid than larger aircraft, the total volume of ADF-contaminated wastewater generated may not increase significantly.) Second, because the comparative advantage of RJ aircraft is in serving smaller airports with insufficient traffic to justify larger aircraft, more deicing operations will be undertaken at these smaller airports than is currently performed.

14.2.4.3 Free Flight

Free Flight is a concept that will reduce pilots' reliance on air traffic controllers under most conditions, allowing them to choose the most efficient and economical route for their flight. Potentially this is an important development because delays due to inefficiency in the current Air Traffic Control system imposes significant costs on airlines (48). By decentralizing decision-making, and devolving that responsibility, in most circumstances, from the air traffic controller to the pilot, Free Flight should result in lower operating costs through reduction in delays and reduced fuel usage. For example, American Airlines was able to reduce fuel costs by $2.2 million in one year through the use of "negotiated wind routes;" other limited tests of the concept show substantial fuel savings for participants (49).

Due to decreased reliance on air traffic controllers, Free Flight may also allow air traffic capacity to expand more quickly than the air traffic control system, also saving the air transportation system significant infrastructure costs. Note that Free Flight will not increase capacity at airports; airport constraints and slot controls may cause bottlenecks in the system, decreasing the potential benefit of Free Flight. Free Flight is being implemented slowly, and in discrete steps; not all technology needed for full implementation of Free Flight has yet been developed (49). However, to the extent that Free Flight is able to lower airlines' operating costs, the resulting increase in air transportation supply could cause air traffic to grow more quickly than projected over the next 20 years.

14.2.4.4 Competitive Issues

A major issue in the air transportation industry is the degree of competition existing in the industry and the role of the government in fostering competition. Although economists may disagree over how competitive the industry is at the present time, most economists do agree that deregulation has, in general, caused air fares to fall and the quantity demanded of air transportation to increase (35, 37, 50, 51, 52, 53). In general, this has been caused by increased competition, both between existing airlines now able to compete head-to-head on routes of their choice, as well as through the entrance of new airlines into the industry undercutting the fares of existing airlines.

Although the benefits to consumers of deregulation have been large, and to most economists, indisputable, on a handful of routes competition has remained restricted. Fares on such routes have found to be significantly higher than comparable routes between other cities (52, 53). Airlines argue that these fare differentials are a result of traveler preferences on those routes, especially due to business travelers' willingness to pay a premium for frequent and nonstop service (53). Industry critics argue that the fare differentials are a result of factors minimizing competition at these airports including: (1) the dominant market position of a major airline at one of the airports, usually an operational hub (so-called "fortress hubs"), and (2) restricted access to an airport because of a lack of available gates at the airport ("gate-constrained") or FAA-mandated limitations on landing slots ("slot-constrained" (34, 53, 54)). GAO has identified six airports as gate-constrained: Charlotte, Cincinnati, Detroit, Minneapolis, Newark, and Pittsburgh, and four more as slot-constrained: Chicago O'Hare, LaGuardia, Kennedy, and Ronald Reagan Washington National (52). The FAA is examining ways of reducing gate and slot constraints at airports.

Evidence concerning a potential "hub premium" at such airports is mixed. Large hub premiums have been found in highly publicized studies by Borenstein and by the GAO; however, these studies appear to be badly flawed (35, 55). Morrison and Winston found a small but significant hub premium, and confirmed this result after adjusting GAO's study for methodological errors. On the other hand, a recent study by Gordon and Jenkins found a small but significant "hub <u>discount</u>" (55).

Other explanations of high fares have focused on allegations of anticompetitive behavior of incumbent airlines. Incumbent airlines have engaged in a variety of business practices, such as the use of frequent flier miles, bias in computer reservation systems, special bonus commissions to travel agents reaching certain goals for bookings on a specific airline, and codesharing alliances that can potentially provide them with a competitive advantage, especially against startup airlines. It should be noted that many of these business practices, including the previously discussed hub-and-spoke route systems, frequent flier programs, and computer reservation systems have benefited consumers as well as served as tools of inter-airline competition (53).

Of particular concern to some industry observers are allegations that incumbent airlines have engaged in predatory pricing behavior to drive new entrants out of markets. In short, incumbents have been accused of drastically cutting fares, perhaps even below costs, and dramatically increasing service on certain routes to a level with which new entrants cannot compete. After the new entrants are forced from the market, incumbents quickly revert to previous fare and service levels (52, 56). The U.S. Justice Department recently sued American Airlines for such antitrust violations, and is probing Delta and Northwest Airlines as well (57).

Concerns of anticompetitive behavior have been particularly prevalent in some quarters due to the failure rate of low-fare startups – point-to-point low-cost airlines, such as People's Express that try to emulate Southwest Airline's operating philosophy (36). The DOT believes that the success of airline deregulation has largely been due to low-fare startups (50). Incumbent airlines argue that the failure of low-fare airlines has been due to mismanagement (noting that the failure rate for new air carriers is virtually identical to the failure rate for new businesses of all types) and consumer preference for traditional airlines (15). Furthermore, incumbent airlines believe the decrease in new entrants is attributable to the slowdown in DOT approval of new airlines after the 1996 ValuJet crash (15, 48). Clearly, many of the low-fare airline failures – including People's Express – have been caused by their business shortcomings (53). However, there is concern among industry observers that anticompetitive behavior has also been responsible for a lack of competition in certain markets (53, 56).

The DOT has proposed guidelines indicating practices that it will consider potential anticompetitive behavior. Under these proposed guidelines, which it continues to study, DOT would investigate such practices and take action against the airline if necessary (56). ATA argues that the DOT's guidelines are vague and contradictory to established U.S. antitrust law; it perceives DOT's guidelines as a move towards re-regulating the airline industry (15). Other observers, while also concerned with anticompetitive behavior in the industry, share ATA's concern that DOT's guidelines are too vague and will result in unnecessary increased regulation; these observers agree with ATA that allegations of illegal anticompetitive behavior should remain within the purview of the U.S. Department of Justice (53).

There is little or no support among economists for significant re-regulation by DOT of airline competition, although they do express concern about a relatively limited number of issues (35, 53). Indeed, many economists would argue that the historically low rate of return earned in the airline industry is inconsistent with allegations of market power that can systematically generate substantial price markups over cost. However, the key point for the purpose of this study is that the airline industry is facing intense scrutiny on a number of high-profile, potentially volatile issues. It is possible that government agencies could respond to these issues by dramatically increasing regulatory oversight of airline competition. A fundamental change in the government's relationship with the air transportation industry could cause such significant changes to the structure and conduct of the industry that the state of the industry may appear, after a period of adjustment, quite different than reported in this profile.

14.2.5 Analytic Issues

Section 14.2.5 discusses three analytic issues EPA will face should it choose to go forward with an effluent guideline regulation for airport deicing operations. The impacts of a potential regulation are unlikely to be measurable in terms of facility closures; Section 14.2.5.1 describes how impacts are likely to be incurred in the airline industry, and how they might be analyzed. Section 14.5.2.2 revisits the issue of cost pass-through, this time, however, focusing on the pass-through of costs from airlines to their passengers. Finally, Section 14.2.5.3 briefly discusses how the compliance costs of a potential regulation may affect the decision to deice.

14.2.5.1 Assessing Potential Regulatory Impacts

In previous effluent guidelines efforts, EPA has typically relied on facility-level cash flow analysis to project regulatory impacts; this is not likely to be appropriate for the airport deicing operations industry. In manufacturing and many service industries, the cost of regulatory compliance is incurred by the facility, which may be able to recover some of its costs through increased price to customers. Facility-level impacts can be projected by analyzing the net impact on facility costs and revenues and comparing the result with some well-defined benchmark (e.g., is estimated post-regulatory cash flow greater than the facility's salvage value). In the airport deicing operations industry, the facility is the airport, but the product – air transportation services – is provided by intermediaries, the different airlines that use the airport.

The financial arrangements between airports and airlines mean that facility closures (e.g., airport closures) are unlikely to be an impact of effluent guidelines on the industry. Most commercial service airports, those most likely to be impacted by an effluent guideline regulation, charge rents and fees on a residual cost basis. Airlines are bound by contract with the airport to pay any airport operating costs in excess of revenues, typically in the form of higher landing fees. Because of this financial structure, airports do not earn a profit or loss in the traditional accounting definitions of those terms, nor are they likely to go bankrupt (Section 14.1.2). Airports may incur other impacts from such a regulation, as discussed below, but facility closure is unlikely to be one of them.

Effluent guidelines regulating the airport deicing operations industry would likely result in increased operating costs to airlines, whether indirectly in the form of increased landing fees at airports or directly as increased costs of deicing. Such increased operational costs are likely to be at least partially passed on to the ultimate customer – the airline passengers – in the form of higher ticket prices. ATA estimates that the overall price elasticity of demand for air transportation is approximately unit elastic (i.e., -1.0), thus a 1% increase in ticket prices will on average cause a 1% decrease in the quantity of air transportation demanded (15). However, this will vary on individual routes; on some routes where the typical passenger is flying for vacation purposes (i.e., relatively elastic demand), the impact may be larger, while on routes flown by business travelers (i.e., relatively inelastic demand), the impact may be much smaller, but measurable. In the airline industry, however, a 1% decrease in passenger demand translates into empty seats and lost revenues on existing flights – with little decrease in operating costs – not a 1% reduction in flights and operating costs (38). Because empty seats reduce revenues more than costs, airlines may respond to decreased demand by reducing service (e.g., providing less frequent service, or using a turboprop instead of a jet) or terminating service on certain routes.

The complexities of airline pricing policies are one aspect of the difficulty in assessing potential regulatory impacts. Airlines calculate the viability of a route by comparing per unit revenues (i.e., yield, equal to revenue per revenue passenger mile) with the per unit cost of providing that service (i.e., cost per available seat mile (15)).[30] There is a wide range of publicly

[30] Clarification by ATA of airline pricing policy is necessary to fill out the details of this analysis. At an EPA meeting with ATA, for example, airline representatives stated that airlines compare yield with cost per available seat mile. However, these cost and revenue measures, while closely related, do not share a common denominator and are therefore

available information that would enable EPA to estimate per unit revenues and costs for individual airlines. However, such overall system-wide data would not enable EPA to estimate route-specific impacts. Unit costs, for example, are largely a function of the type of service offered on that route, especially flight length and aircraft type (the choice of aircraft type is not completely independent of flight length). For example, one analyst estimates that United Airlines' unit costs on routes of 500 miles or less are 23% greater than its overall system-wide average (58).

With the exception of low-cost single-fare airlines such as Southwest, unit revenues are determined by the complex procedure known as yield management. An aircraft seat is a perishable good just like fresh produce – once an aircraft leaves the gate, that seat's earning potential is lost for good. The marginal cost of filling an aircraft seat is very low, comprised of incremental fuel burn, baggage handling, ticketing and other incremental costs (assuming the flight's departure is not dependent on whether that passenger is on it). Therefore, an airline has incentive to offer very low fares rather than fly with empty seats that represent a forgone opportunity to earn revenue. However, filling an entire aircraft with passengers paying such a low fare to avoid empty seats is neither desirable, nor will it cover the operating costs of the aircraft (38). Filling a seat with a low-fare passenger when it could have been filled by a passenger willing to pay a higher fare also represents a lost opportunity to earn revenue. "Yield management" is the complex way in which airlines determine how many blocks of seating on each flight to offer at each fare in order avoid the twin pitfalls of lost revenue-earning opportunities (i.e., in economic terms, airlines practice "price discrimination" (59)). Because of yield management, it would be difficult to reliably determine the "average fare" on a specific route without obtaining airline and route specific data on realized per unit revenues.

Other factors contribute to the complexity of yield management. Two routes of similar length (and presumably similar unit costs) may realize dramatically different average fares due to characteristics of the routes. As discussed above, perhaps the most important factor is the

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not directly comparable. In addition, while the discussion above is in the context of passenger airline service, even airlines offering primarily passenger service generate significant revenues from cargo service (15). Impacts on cargo service should be included in the economic analysis.

existence of or lack of competition on a route. It has been documented in numerous studies that average fares on routes without competition between major passenger airlines are substantially higher than average fares on routes with competition (15, 35, 50, 60). Second, the type of traffic on a route will affect average fares; the demand for vacation travel is much more price-elastic than business travel, which limits the ability of airlines to increase fares on routes dominated by vacationers (35, 59). Finally, airlines judge the viability of routes based on how they fit in their overall route structure. What is considered an acceptable spread between unit costs and revenues on one route may not be acceptable on another depending on the importance of the route within the overall scheme of the airline's system (39).

Other things constant, increased deicing costs, regardless of whether they are incurred indirectly through increased landing fees or directly through increased deicing costs, will decrease the airlines' margin between per unit cost and revenue. If a route is already operated on a slim margin, then the increased costs of deicing may be sufficient for an airline to reduce or terminate service (15); these are potentially the major impacts of an effluent guideline on the industry. In addition, passengers will most likely have to pay higher fares, in some cases for lower quality service (i.e., less frequent service, or a downgrade from jet to turboprop service). Finally, reduced or terminated service will indirectly affect airport revenues and employment even if the airport is unlikely to close. All these impacts would have to be evaluated.

To properly assess potential regulatory impacts, EPA would need airline-specific data concerning unit costs and revenues of routes using each airport, for each airline using that airport. To perform a systematic airport-specific modeling effort would likely require a very large data-collection effort. EPA identified 212 airports with potentially significant deicing/anti-icing operations. There are 13 major airlines, plus approximately another 85 national, regional, and small certificated/commuter airlines with thousands of routes.

One potential solution to this data problem would be to focus analysis on a small number of representative airports using the classification system based on operations and weather developed for this study. By focusing on a small number of airports, EPA could hopefully obtain more detailed information on airline routes using that airport (e.g., number of flights with yield and per unit cost figures and type of aircraft used – the larger the aircraft the higher the landing fee) to model impacts on airline service to that airport. Under this modeling strategy, EPA may also have to estimate incremental compliance costs at other airports on that route (i.e., some routes may incur increased compliance costs at both airports on a route, Boston-to-Chicago for example, while other routes would likely incur costs only at one end, Chicago-to-Orlando for example).[31]

An alternate approach to analyzing route costs and revenues may also be viable. DOT maintains databases containing data on passengers fares and distances by city origin-destination pairs that may be usable for determining airline route revenues. DOT does not maintain similar information for operating costs between city pairs; however, one article has been identified that estimates airline unit costs by length of flight based on DOT's Domestic Fare Structure Costing Program (Version 6) using publicly available information (58). This may provide EPA with a template for performing similar calculations. Note that neither the accuracy of this methodology nor the availability of DOT's cost model have yet been determined.

14.2.5.2 Airline-to-Passenger Cost Pass-Through

Cost pass-through (CPT) from airports to airlines is discussed in Section 14.1.2.3. However, a second form of CPT needs to be considered: CPT to airline passengers. This can take three forms: passengers may incur direct CPT from airports (e.g., increased parking fees or passenger facility charges), indirect CPT from airports through airlines (i.e., higher landing fees due to ADF collection, containment, or treatment leading to increased ticket prices), and airlines may directly incur higher deicing operation costs (e.g., higher ADF costs) that are also passed through to passengers in the form of higher ticket prices. The second and third types of CPT are analytically similar.

[31] An opinion article by Robert Bork in the *Wall Street Journal*, and the subsequent rejoinders by Gerald Smith and Alfred Kahn concerning the U.S. Justice Department's antitrust case against American Airlines illustrate the difficulty of accurately allocating costs among airline's routes (54, 61, 62).

Airports directly pass through capital costs to passengers in the form of passenger facility charges (PFCs). Because the PFC is collected as part of the ticket cost, the passenger probably does not distinguish between an increase in travel price caused by the PFC and an increase in travel price caused by an airline fare increase. However, if an airport incurs compliance costs that are not passed on to airlines in the form of higher landing fees, but instead pays for improvements through imposing or increasing PFCs, passengers still pay higher ticket prices.[32] Airports can also increase revenues through charges on concessions, parking, and other fees. Because passengers are better able to avoid paying these higher fees by choosing not to park at the airport or not buying items at airport concession stands, CPT from this source may be small. The link between these increased costs of air travel and demand for air travel has not been examined.[33]

CPT from the airlines to their passengers is conceptually easier to estimate. In a simple market transaction, CPT is determined by the relative price elasticity of supply and demand. However, airlines are able to charge different prices to different types of passengers precisely because different types of travelers have different price elasticities of demand. As previously mentioned, business travelers have fairly inelastic demand, which enables airlines to increase their fares more with little loss in travel. CPT for business travelers should therefore be larger than for vacation travelers with much more elastic demand. The difficulty in applying this to specific airline routes is that different routes are likely to carry different mixes of passengers thus affecting the CPT for that route.

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[32] As of calender year 1996, 54 of 71 large and medium hubs had already imposed PFCs (ACAIS, 1997); however, there has been discussion of increasing the maximum PFC to $4 or even $6 (63). Should this happen, incremental increases in PFCs – if they can be attributed to deicing operation costs, and not other capital programs – would be part of the regulatory impact on consumers.

[33] Compliance costs incurred by airports and not passed through to airlines in the form of higher landing fees may still have impacts, although they may be more difficult to assess. In general, many airports do not have sufficient access to capital to pay for existing improvement and expansion plans; by not passing compliance costs through to airlines, an airport probably is paying for improvements by postponing other capital improvements. The impact of postponed or displaced capital improvements may be difficult to assess, but nonetheless could still potentially result from airport deicing operations effluent guidelines. For example, a number of airports are facing capacity constraints; the potential impact of postponed airport expansion plans, such as slower growth and higher fares, could be substantial, even though they may be difficult to quantify.

An assumption of 100% CPT from airports to airlines and zero CPT from airlines to passengers would be the most tractable to model, and would probably be the most conservative assumption as well. The maximum PFC at one airport probably represents a small percentage of the average airfare, and the majority of significant airports have already imposed PFCs. Thus, any incremental CPT from airports directly to passengers due to compliance with deicing operations effluent guidelines is likely to be small. The calculation of CPT from airlines to passengers is highly problematic because the relevant price elasticity of demand to determine CPT is route specific; the overall price elasticity of demand estimated by ATA provides little guidance in this case. The drawback of assuming 100% CPT from airports to airlines and zero CPT from airlines to passengers is that almost all projected impacts would be incurred by airlines. Even if the total dollar value of projected regulatory impacts is no higher under alternative assumptions about CPT, the distribution of impacts among airports, airlines, and passengers would differ.

14.2.5.3 Incentives

Both the airlines and the FAA have expressed their opinion that any proposed EPA effluent guidelines regulating discharges from airport deicing operations must not affect aircraft safety (i.e., the decision to deice aircraft and how much fluid to use). They are concerned that effluent guidelines potentially limiting the discharges of wastewater containing deicing agents may increase the cost of deicing operations and create an incentive for airlines to find ways to decrease the quantity of deicing agents used and deicing operations performed. However, this is unlikely due to the large liability surrounding air safety. The liability lies with the airline to ensure that an increase in the cost of deicing does not affect a pilot's decision to deice and judgement as to whether sufficient deicing has been performed.

However, a likely scenario may be that any compliance costs would be passed on to the airlines in the form of higher landing fees on all flights, not just those flights requiring deicing.[34] There should be no incentive for airlines to change their deicing decisions under such a

[34] Note that at least one airport in Canada has implemented a deicing surcharge on all flights.

scenario. It is the cost of using the airport regardless of whether deicing is performed or not that would increase. This could lead to a reduction or termination of service at the airport (although the extent to which costs are spread over all landings at the airport may help to mitigate those impacts), but should not affect the deicing decision.

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Table 14-1

Passenger and Cargo Activity by FAA Airport Definition, 1997

Airport Type	FAA Airport Definitions Based on Percentage of National Boardings (Brd)	Number of Airports by Type	Passenger Activity				Cargo-Only Activity (a)	
			Total Boardings by Type	Average Boardings by Type	Maximum Boardings by Type	Minimum Boardings by Type	Number of Airports (b)	Total Gross Landed Weight of Cargo
Primary, Large Hub **% of total**	1% <= Brd	30	439,556,180 68.6%	14,651,873	33,249,963	6,467,195	28	53,580,799,092
Primary, Medium Hub **% of total**	0.25% <= Brd <1%	40	132,472,093 20.7%	3,311,802	6,318,523	1,634,578	29	53,966,253,749
Primary, Small Hub **% of total**	0.05% <= Brd < 0.25%	71	46,968,440 7.3%	661,527	1,553,700	324,521	34	19,371,974,805
Primary, Nonhub **% of total**	10,000 < Brd < 0.05%	276	21,191,850 3.3%	76,782	317,199	10,019	9	3,119,938,255
Nonprimary Commercial Service (c) **% of total**	2,500 <= Brd<= 10,000	112	550,755 0.1%	4,917	9,724	2,509	2	1,593,027,497
Noncommercial Service **% of total**	NA	1,186	824,388 0.1%	695	81,416	0	4	1,588,610,350
Total		**1,715**	**641,563,706**				**106**	**133,220,603,748**

(a) Data for "qualifying" airports only-those airports that land a minimum of 100 million pounds of cargo-only aircraft; other airports may land cargo-only aircraft. Gross landed weight cargo refers to the rated landing weight of the aircraft, not the weight of the cargo carried in the aircraft.
(b) Number of airports within FAA type landing at least 100 million pounds of cargo-only aircraft in addition to their passenger activities (e.g., there are 30 large hubs based on passenger activity; 28 of these large hubs also qualified as significant cargo-only airports).
(c) Noncommercial service airports reporting boarding activity in the ACAIS database; the NPIAS contains over 2,800 noncommercial service airports.
Source: Reference (4).

Table 14-2

Growth of Total and Average Enplanements at Commercial Service Airports by FAA Definition, 1993 - 1997

Passenger Enplanements						Enplanement Growth Rates					
Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1993**	**1994**	**1995**	**1996**	**1997**	**Average**
Total Boardings (a)	528,920,496	573,575,959	586,326,851	621,613,161	641,563,706	NA	8.4%	2.2%	6.0%	3.2%	5.3%
Total Enplanements **# of Airports**	527,984,216 566	572,608,645 575	585,347,291 566	620,410,923 540	640,739,318 529	NA	8.5%	2.2%	6.0%	3.3%	5.3%
Total Enplanements by Airport Type						**Growth Rates, Total Enplanements**					
Large Hub Primary **# of Airports**	341,729,124 27	380,292,229 29	393,110,251 29	418,425,819 29	439,556,180 30	NA	11.3%	3.4%	6.4%	5.0%	7.2%
Medium Hub Primary **# of Airports**	118,290,399 38	126,220,983 40	129,792,590 42	137,813,925 42	132,472,093 40	NA	6.7%	2.8%	6.2%	-3.9%	3.0%
Small Hub Primary **# of Airports**	49,045,057 83	44,941,969 71	41,489,614 67	43,807,189 70	46,968,440 71	NA	-8.4%	-7.7%	5.6%	7.2%	-1.1%
Nonhub Primary **# of Airports**	18,193,093 269	20,396,930 281	20,197,540 273	19,748,437 272	21,191,850 276	NA	12.1%	-1.0%	-2.2%	7.3%	4.1%
Nonprimary **# of Airports**	726,543 149	756,534 154	757,296 155	615,553 127	550,755 112	NA	4.1%	0.1%	-18.7%	-10.5%	-6.0%
Average Enplanements by Airport Type						**Growth rates, Average Enplanements**					
Large Hub Primary	12,656,634	13,113,525	13,555,526	14,428,477	14,651,873	NA	3.6%	3.4%	6.4%	1.5%	3.9%
Medium Hub Primary	3,112,905	3.155,525	3,090,300	3,281,284	3,311,802	NA	1.4%	-2.1%	6.2%	0.9%	1.6%
Small Hub Primary	590,904	632,985	619,248	625,817	661,527	NA	7.1%	-2.2%	1.1%	5.7%	3.0%
Nonhub Primary	67,632	72,587	73,984	72,605	76,782	NA	7.3%	1.9%	-1.9%	5.8%	3.4%
Nonprimary	4,876	4,913	4,886	4,847	4,917	NA	0.7%	-0.5%	-0.8%	1.5%	0.2%

(a) Total boardings include revenue passenger boardings at noncommercial service airports; the difference between total boardings and total enplanements is small.
Average emplanements for all commercial service airports are not included because in this case; when both the numerator and denominator change, the estimate of growth is both deceptive and irrelevant.
Source: Reference (4).

Table 14-3

Airport Flight Operations by FAA Airport Definition, 1997

Airport Type	Number of Airports by FAA Definition	Number of Airports Reporting Operations	Non-GA Operations Activity by Airport Definition				Average Operations by Aircraft Type and Airport Definition			
			Total Operations	Average Operations	Maximum Operations	Minimum Operations	Carrier	Air Taxi	Military	GA
Primary, Large Hub **% of total**	30	30	12,920,538 48.0%	430,685	847,901	209,827	306,706	119,661	4,317	44,424
Primary, Medium Hub **% of total**	40	40	5,592,685 20.8%	139,817	311,088	33,863	86,740	45,926	7,152	82,126
Primary, Small Hub **% of total**	71	70	3,967,527 14.7%	56,679	170,446	5,248	18,501	27,871	10,307	76,084
Primary, Nonhub **% of total**	276	157	3,423,075 12.7%	21,803	107,481	3,160	2,139	13,925	5,739	54,319
Nonprimary, Commercial Service **% of total**	112	11	171,669 0.6%	15,606	59,783	3,289	2,055	7,822	5,729	104,108
Noncommercial Service **% of total**	NA	110	830,379 3.1%	7,549	105,774	23	185	3,690	3,674	125,831
Total		418	26,905,873							

Based on 418 airports reporting operations data and contained in ACAIS database; operations data for the 4/1/97 - 3/31/98 time period, enplanements data for CY 1997.
Non-GA operations equals the sum of carrier, air taxi, and military operations.
Source: Reference (4, 7).

Table 14-4

Airports of Concern, by Operations, Snowfall, and FAA Size Definitions (a)

Snowfall Categorization	FAA Definition	Operations Categorization (b)					Subtotal by Snowfall
		Ops "A"	Ops "B"	Ops "C"	Ops "D"	Ops "E"	
60" <= snow < 120"	Large Hub	1	0	0	0	0	1
	Medium Hub	0	1	0	0	0	1
	Small Hub	0	0	2	8	3	13
	Nonhub	0	0	0	0	14	14
	Nonprimary	0	0	0	0	0	0
	Noncomm. Svc.	0	0	0	0	3	3
	Subtotal	1	1	2	8	20	32
30" <= snow < 60"	Large Hub	5	1	0	0	0	6
	Medium Hub	0	1	3	2	0	6
	Small Hub	0	0	0	4	8	12
	Nonhub	0	0	0	1	31	32
	Nonprimary	0	0	0	0	1	1
	Noncomm. Svc.	0	0	0	0	5	5
	Subtotal	5	2	3	7	45	62
15" <= snow < 30"	Large Hub	2	7	0	0	0	9
	Medium Hub	0	0	5	1	0	6
	Small Hub	0	0	0	3	7	10
	Nonhub	0	0	1	1	22	24
	Nonprimary	0	0	0	0	1	1
	Noncomm. Svc.	0	0	1	0	4	5
	Subtotal	2	7	7	5	34	55
1" <= snow < 15"	Large Hub	2	3	0	0	0	5
	Medium Hub	0	2	5	3	0	10
	Small Hub	0	0	0	7	7	14
	Nonhub	0	0	0	3	25	28
	Nonprimary	0	0	0	1	2	3
	Noncomm. Svc.	0	0	0	0	2	2
	Subtotal	2	5	5	14	36	62
Subtotal by Ops	Large Hub	10	11	0	0	0	21
	Medium Hub	0	4	13	6	0	23
	Small Hub	0	0	2	22	25	49
	Nonhub	0	0	1	5	92	98
	Nonprimary	0	0	0	1	4	5
	Noncomm. Svc.	0	0	1	0	14	15
	Subtotal	10	15	17	34	135	211

(a) EPA identified 212 airports of concern based on snowfall and aircraft operations criteria; this analysis is based on 211 airports for which operations, snowfall, and 1997 ACAIS enplanement data could be matched.
(b) Ops "A": 425,000 <= Ops < 850,000; Ops "B": 210,000 <= Ops < 425,000; Ops "C": 100,000 <= Ops < 210,000;
Ops "D": 50,000 <= Ops < 100,000; Ops "E": 10,000 <= Ops< 50,000.
Source: Reference (4, 7, 8).

Table 14-5

Airports with Potentially Significant Deicing Operations, by Operations and Enplanements (a)

Operations (Ops) Categorization	Number of Airports	Average Operations within Airport Ops Class: Non-GA Operations	Carrier Operations	Air Taxi Operations	GA Operations	Average Enplanements within Airport Class: All	Large Carrier	Commuter	Air Taxi
425,000 <= Ops < 850,000	10	567,680	417,349	147,917	43,510	19,296,737	18,303,408	438,088	98
210,000 <= Ops < 425,000	15	320,679	204,549	111,314	49,822	8,991,676	7,896,227	564,009	2,812
100,000 <= Ops < 210,000	17	144,138	71,601	59,534	54,223	2,574,169	2,431,328	124,987	11,571
50,000 <= Ops < 100,000	34	74,236	28,037	33,253	76,477	962,463	854,836	92,478	5,330
10,000 <= Ops < 50,000	135	24,685	4,749	14,037	65,254	168,282	131,397	36,679	189
Total Airports of Concern	211								

(a) EPA identified 212 airports with potentially significant deicing operations based on snowfall and aircraft operations criteria; this analysis is based on 211 airports for which operations, snowfall, and 1997 ACAIS enplanement data could be matched.
Source: Reference (4, 7).

Table 14-6

Airport Operating Agreements by Airport Type
AAAE Survey Respondents, 1997 - 1998

Airport Type	Number of Respondents by Type	Type of Agreement			
		Residual	Compensatory	Hybrid	Other
Large Hub	18	4	5	6	3
Medium Hub	28	14	5	8	2
Small Hub	53	17	16	16	4
Nonhub	96	11	48	20	17
General Aviation					
Total	**195**	**46**	**74**	**50**	**26**

Source: Reference (12).

Table 14-7

Airport Revenues by Airport Type for AAAE Survey Respondents, 1997 - 1998

Airport Type	Number of Respondents by Type	Average Airline and Air Cargo Revenues	Average FBO/GA Revenues	Average Total Other Revenues	Average Total Operating Revenues	Average Total Operating Expenses	Average Total Government Subsidy	Average Total Operating Income
Large Hub **% of total revenues**	15	$100,295,007 50%	$5,160,219 3%	$94,381,574 47%	$200,090,311	$106,506,742	$0	$93,583,569
Medium Hub **% of total revenues**	27	$14,969,744 39%	$1,840,125 5%	$19,497,502 51%	$38,039,780	$22,145,663	$177,642	$16,071,759
Small Hub **% of total revenues**	49	$3,295,032 41%	$842,245 10%	$4,304,924 53%	$8,117,894	$5,916,717	$338,164	$2,539,341
Nonhub **% of total revenues**	91	$418,198 27%	$358,565 23%	$735,206 47%	$1,551,172	$1,463,673	$221,324	$308,823
General Aviation **% of total revenues**	92	$37,554 4%	$506,232 58%	$264,471 31%	$865,988	$938,491	$218,829	$146,327
Total	274	$119,015,535	$8,707,385	$119,183,677	$248,665,145	$136,971,286	$955,959	$112,649,818

Source: Reference (12).

Table 14-8

Airport Expenditures for EPA Airport Mini-Questionnaire Recipients, 1997

	Large Hubs			Medium Hubs		Small Hubs	Primary Commercial Service Nonhubs			
	Airport #1	**Airport # 2**	**Airport # 3**	**Airport # 4**	**Airport # 5**	**Airport # 6**	**Airport # 7**	**Airport # 8**	**Airport # 9**	**Airport #10**
Enplanements	16,600,000	15,400,000	12,100,000	5,710,000	2,640,000	818,000	303,000	120,000	64,500	26,700
Non-GA Operations	476,000	445,000	381,000	278,000	214,000	67,000	41,800	21,500	13,400	44,400
Airfield Areas	4.0%	30.0%	13.0%	10.0%	22.6%	21.1%	32.0%	16.0%	3.2%	20.0%
Terminal Areas	16.0%	30.0%	32.0%	20.0%	24.8%	17.0%	20.0%	9.0%	5.9%	13.0%
Hangars, cargo facilities, and other areas	1.0%	(a)	1.0%	5.0%	3.2%	7.1%	7.0%	6.0%	1.2%	9.0%
General and Administrative	9.0%	20.0%	6.0%	24.0%	8.4%	12.6%	16.0%	20.0%	8.3%	20.0%
Other Agencies (b)	3.0%	0.0%	0.0%	6.0%	1.7%	10.5%	2.0%	0.0%	8.7%	0.0%
Debt Service	46.0%	20.0%	29.0%	35.0%	11.6%	13.0%	23.0%	0.0%	2.0%	0.0%
Depreciation	21.0%	(a)	18.0%	NA	27.7%	18.7%	0.0%	49.0%	6.6%	38.0%
Total	100.0%	100.0%	99.0%	100.0%	100.0%	100.0%	100.0%	100.0%	35.9%	100.0%

(a) Combined with previous answer.
(b) Payments to other agencies for services performed at airport (e.g., police, fire, accounting, legal).
Source: Reference (13).

Table 14-9

Airport Ownership by Airport Type
AAAE Survey Respondents, 1997 - 1998

Airport Type	Number of Respondents by Type	Type of Ownership			
		Municipal	Multi-government	Independent Authority	Other
Large Hub	18	10	4	2	2
Medium Hub	31	17	2	8	3
Small Hub	53	34	1	17	1
Nonhub	108	56	8	37	7
General Aviation	130	92	4	23	11
Total	340	209	19	87	24

Source: Reference (12)

Table 14-10

Airport Capital Expenditures for EPA Airport Minisurvey Recipients, 1997

	Large Hubs			Medium Hubs		Small Hubs	Primary Commercial Service Nonhubs			
	Airport #1	Airport #2	Airport #3	Airport #4	Airport #5	Airport #6	Airport #7	Airport #8	Airport #9	Airport #10
Enplanements	16,600,000	15,400,000	12,100,000	5,710,000	2,640,000	818,000	303,000	120,000	64,500	26,700
Non-GA Operations	476,000	445,000	381,000	278,000	214,000	67,000	41,800	21,500	13,400	44,400
Capital Expenditures	$55,423	$537,000	$109,153	$69,600,000	$28,125	$12,000	$2,756	$1,418	$1,452,196	$341
Airport Improvement Grants	25.7%	9.0%	19.5%	4.0%	14.4%	28.0%	67.0%	75.0%	89.3%	90.0%
Passenger Facility Charges	33.7%	40.0%	18.8%	13.0%	0.0%	15.0%	18.0%	10.0%	8.3%	5.0%
Other Government Grants	0.0%	0.0%	0.0%	0.0%	7.7%	0.0%	0.0%	10.0%	2.4%	0.0%
Bonds	33.1%	51.0%	40.9%	80.0%	60.1%	23.0%	0.0%	0.0%	0.0%	0.0%
Rates and Charges	7.5%	(c)	12.9%	3.0%	17.7%	28.0%	15.0%	5.0%	0.0%	5.0%
Other Revenue	0.0%	(c)	8.0%	0.0%	0.0%	6.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.1%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%
Majority-in-Interest Clause	No	No	Yes	Yes	Yes	No	No (b)	No	No	No

(a) Only airport in sample not charging a PFC, but has applied to start charging a PFC in 2000; all other airports in sample charge maximum PFC ($3).
(b) No majority-in-interest clause, but does have a contractual ceiling on capital expenditures.
(c) Combined with previous answer.

Source: Reference (13).

Table 14-11

Aircraft in Operation, Hours Flown, and Hours per Aircraft, Selected Aircraft Type, U.S. Air Carriers, and General Aviation, 1996

Aircraft Type	Number of Aircraft	Total Flight Hours	Hours per Aircraft
Air Carriers			
Total	7,478	14,784,409	1,977
4-Engine Turbojet % of Total	440 5.9%	934,572 6.3%	2,124
3-Engine Turbojet % of Total	1,212 16.2%	2,378,145 16.1%	1,962
2-Engine Turbojet (a) % of Total	3,270 43.7%	8,715,239 58.9%	2,665
2-Engine Turboprop % of Total	1,639 21.9%	2,602,374 17.6%	1,588
General Aviation (b)			
Total (Fixed-wing)	160,577	22,719,550	141
2-Engine Turbojet % of Total	3,971 2.5%	1,355,034 6.0%	341
2-Engine Turboprop % of Total	4,551 2.8%	1,243,572 5.5%	273
1-Engine Piston % of Total	150,980 94.0%	17,156,396 75.5%	114

(a)All but 216 air carrier twin engine turbojets carry a minimum of 100 passengers.
(b) Includes “on demand” air taxis, but excludes commuter aircraft; see text for further details.

Source: Reference (27).

Table 14-12

Air-Carrier Traffic Statistics by Carrier Type, June 1997 - June 1998

Carrier	Number	Passenger Enplanements (x 1,000)	Cargo Ton-miles (x 1,000)	Revenue Passenger-miles (x 1,000)	Available Seat-miles (x 1,000)	Load Factor (%)	Passengers per Aircraft-mile	Miles per Passenger
Major % of Total	13 9.0%	534,040 83.4%	18,491,148 87.7%	573,632,137 92.2%	807,270,192 91.2%	71.1%	112.6	1,074.1
National % of Total	28 19.4%	62,605 9.8%	2,390,465 11.3%	35,052,261 5.6%	53,843,361 6.1%	65.1%	63.2	559.9
Large Regional % of Total	15 10.4%	7,768 1.2%	199,559 0.9%	4,066,632 0.7%	6,490,996 0.7%	62.7%	46.0	523.5
Medium Regional (a) % of Total	88 61.1%	36,288 5.7%	13,937 0.1%	9,238,469 1.5%	17,886,124 2.0%	51.7%	16.4	254.6
Total	144 100%	640,701 100%	21,095,109 100%	621,989,499 100%	885,490,673 100%	70.2%	98.7	970.8

(a) Including small certificated carriers.
Source: Reference (31).

Table 14-13

Air-Carrier Financial Statistics by Carrier Type, June 1997 - June 1998

Carrier	Total Passenger Revenues (x $1,000,000)	Total Operating Revenues (x $1,000,000)	Total Operating Expenses (x $1,000,000)	Operating Profit (Loss) (x $1,000,000)	Operating Profit Margin (%)	Net Income(a) (x $1,000,000)	Net Profit Margin (%)
Major % of Total	$74,336.4 88.6%	$100,506.2 86.6%	$91,436.0 85.9%	$9,070.2 94.8%	9.0%	$5,821.6 101.5%	5.8%
National % of Total	$5,756.0 6.9%	$9,837.7 8.5%	$9,454.8 8.9%	$382.9 4.0%	3.9%	($16.7) -0.3%	-0.2%
Large Regional % of Total	$636.7 0.8%	$1,706.3 1.5%	$1,686.7 1.6%	$19.6 0.2%	1.1%	($56.5) -1.0%	-3.3%
Medium Regional % of Total	$62.5 0.1%	$286.5 0.2%	$317.8 0.3%	($31.3) -0.3%	-10.9%	($36.0) -0.6%	-12.6%
Small Certificated % of Total	$2,123.2 2.5%	$2,417.8 2.1%	$2,276.1 2.1%	$141.7 1.5%	5.9%	$41.5 0.7%	1.7%
Commuter % of Total	$1,029.8 1.2%	$1,267.3 1.1%	$1,278.4 1.2%	($11.1) -0.1%	-0.9%	($18.5) -0.3%	-1.5%
Total	$83,944.6 100.0%	$116,021.8 100.0%	$106,449.8 100.0%	$9,572.0 100.0%	8.3%	$5,735.4 100.0%	4.9%

(a) Operating profit calculates profit before tax and interest payments; net profits are calculated after taxes and interest.
Source: Reference (29).

Table 14-14

Passenger and Cargo Revenues for ATA Member Airlines, 1997 (x $1,000,000)

Airline	Number of Aircraft	Employees (FTEs)	Passenger Revenues	Cargo Revenues	Total Operating Revenues	% Passenger Revenues
Majors with Passenger Service						
Alaska	78	8,016	$1,256	$82	$1,457	86.2%
America West	103	10,195	$1,753	$51	$1,887	92.9%
American	641	80,321	$14,284	$678	$15,856	90.1%
Continental	388	31,705	$5,686	$205	$6,361	89.4%
Delta	559	62,934	$12,773	$588	$14,204	89.9%
Northwest	405	46,753	$8,722	$788	$9,984	87.4%
Southwest	261	23,749	$3,639	$95	$3,817	95.3%
Trans World	184	22,930	$2,924	$119	$3.328	87.9%
United	571	83,324	$15,069	$891	$17,335	86.9%
U.S. Airways	376	39,734	$7,112	$177	$8,501	83.7%
Majors with Cargo-only Service						
DHL	27	8,564	—	$664	$1,226	0.0%
Federal Express	581	105,649	—	$5,360	$12,730	0.0%
United Parcel Service (a)	214	4,349	—	$404	$1,863	0.0%
Nationals with Passenger Service						
Aloha	17	1,901	$195	$30	$233	83.7%
Hawaiian	22	2,357	$332	$20	$404	82.2%
Midwest Express	24	1,689	$273	$11	$310	88.0%
Nationals with Cargo-only Service						
Airborne Express	105	4,626	—	$890	$894	0.0%
Atlas (a)	19	592	—	$80	$401	0.0%
Emery (a)	77	967	—	$256	$262	0.0%
Evergreen (a)	20	429	—	$208	$256	0.0%
Polar Air Cargo	16	481	—	$288	$344	0.0%

Excludes members: American Trans Air and Reeve, due to data questions, and 3 non-U.S.-owned associate members.
(a) Includes nonscheduled service.

Source: Reference (34).

Table 14-15

Operating Revenues, Expenses, and Profits, 1982 - 1997
(in millions of dollars)

Year	Revenue Passenger Miles (x 1,000,000)	Total Op. Revenues	Total Op. Expenses	Total Op. Profits	Interest Expense	Net Profit	Operating Profit Margin	Net Profit Margin	Rate of Return on Investment
1982	259,644	$36,408	$37,141	($733)	$1,384	($916)	-2.0%	-2.5%	2.1%
1983	281,829	$38,954	$38,643	$310	$1,482	($188)	0.8%	-0.5%	6.0%
1984	305,116	$43,825	$41,674	$2,152	$1,540	$825	4.9%	1.9%	9.9%
1985	336,403	$46,664	$45,238	$1,426	$1,588	$863	3.1%	1.8%	9.6%
1986	366,546	$50,525	$49,202	$1,323	$1,693	($235)	2.6%	-0.5%	4.9%
1987	404,471	$56,986	$54,517	$2,469	$1,695	$593	4.3%	1.0%	7.2%
1988	423,302	$63,749	$60,312	$3,437	$1,846	$1,686	5.4%	2.6%	10.8%
1989	432,714	$69,316	$67,505	$1,811	$1,944	$128	2.6%	0.2%	6.3%
1990	457,926	$76,142	$78,054	($1,912)	$1,978	($3,921)	-2.5%	-5.1%	-6.0%
1991	447,955	$75,158	$76,943	($1,785)	$1,777	($1,940)	-2.4%	-2.6%	-0.5%
1992	478,554	$78,140	$80,585	($2,444)	$1,743	($4,791)	-3.1%	-6.1%	-9.3%
1993	489,684	$84,559	$83,121	$1,438	$2,027	($2,136)	1.7%	-2.5%	-0.4%
1994	519,382	$88,313	$85,600	$2,713	$2,347	($344)	3.1%	-0.4%	5.2%
1995	540,656	$94,578	$88,718	$5,860	$2,424	$2,314	6.2%	2.4%	11.9%
1996	578,663	$101,938	$95,729	$6,209	$1,981	$2,804	6.1%	2.8%	11.5%
1997	605,434	$109,535	$100,924	$8,611	$1,749	$5,195	7.9%	4.7%	14.9%

Notes: Federal Express began reporting as a section 401 carrier in 1986 and is included in 1986 and later years.
Excludes fresh start accounting extraordinary gains of Continental and Trans World in 1993.

Source: References (33,34).

Table 14-16

Airline Operating Costs, Selected Components, 1982 - 1997

	Labor			Fuel			Aircraft Fleet (a)			Interest			Insurance			Maintenance Material		
Year	Cost Index (1982=100)	Growth Rate	% Op. Expenses	Cost Index (1982=100)	Growth Rate	% Op. Expenses	Cost Index (1982=100)	Growth Rate	% Op. Expenses	Cost Index (1982=100)	Growth Rate	% Op. Expenses	Cost Index (1982=100)	Growth Rate	% Op. Expenses	Cost Index (1982=100)	Growth Rate	% Op. Expenses
1982	100.0	—	34.6%	100.0	—	27.5%	100.0	—	5.6%	100.0	—	4.0%	100.0	—	0.4%	100.0	—	2.0%
1983	107.7	7.7%	35.5%	88.3	-11.7%	24.7%	107.5	7.5%	6.1%	99.0	-1.0%	4.1%	95.7	-4.3%	0.4%	101.7	1.7%	2.1%
1984	108.4	0.6%	33.9%	84.6	-4.2%	24.0%	114.9	6.9%	6.4%	106.3	7.4%	3.9%	109.3	14.2%	0.5%	108.2	6.4%	2.3%
1985	110.6	2.0%	33.8%	79.6	-5.9%	22.3%	123.7	7.7%	6.8%	98.0	-7.8%	3.5%	155.3	42.1%	0.6%	119.9	10.8%	2.5%
1986	108.1	-2.3%	35.8%	55.5	-30.3%	15.5%	127.8	3.3%	7.4%	91.8	-6.3%	3.5%	212.0	36.5%	0.9%	147.7	23.2%	3.2%
1987	110.8	2.5%	34.7%	55.4	-0.2%	15.0%	135.1	5.7%	7.4%	88.7	-3.4%	3.2%	201.8	-4.8%	0.8%	153.1	3.7%	3.2%
1988	113.9	2.8%	34.2%	53.0	-4.3%	13.5%	146.9	8.7%	7.9%	91.9	3.6%	3.1%	151.7	-24.8%	0.6%	166.4	8.7%	3.3%
1989	117.4	3.1%	33.9%	59.7	12.6%	13.9%	162.2	10.4%	8.0%	99.4	8.2%	2.7%	114.5	-24.5%	0.4%	176.8	6.3%	3.2%
1990	123.0	4.8%	31.5%	77.2	29.3%	17.3%	177.0	9.1%	7.9%	96.0	-3.4%	2.6%	68.2	-40.4%	0.3%	190.5	7.7%	3.4%
1991	130.1	5.8%	32.4%	69.4	-10.1%	14.5%	187.1	5.7%	8.5%	81.4	-15.2%	2.4%	81.3	19.2%	0.3%	193.2	1.4%	3.3%
1992	136.5	4.9%	32.8%	65.0	-6.3%	13.5%	202.6	8.3%	9.0%	97.3	19.5%	2.2%	109.3	34.4%	0.4%	177.1	-8.3%	3.0%
1993	143.4	5.1%	33.3%	59.7	-8.2%	12.4%	208.0	2.7%	9.2%	81.2	-16.5%	2.6%	139.4	27.5%	0.5%	166.2	-6.2%	2.9%
1994	148.5	3.6%	34.1%	54.4	-8.9%	10.7%	217.5	4.6%	9.5%	87.6	7.9%	2.8%	110.8	-20.5%	0.7%	157.2	-5.4%	2.6%
1995	155.5	4.7%	34.4%	55.3	1.7%	11.5%	222.8	2.4%	9.5%	93.5	6.7%	3.0%	111.6	0.7%	0.7%	153.4	-2.4%	2.7%
1996	159.5	2.6%	33.6%	64.6	16.8%	13.0%	230.0	3.2%	9.6%	86.9	-7.1%	2.2%	111.5	-0.1%	0.7%	169.4	10.4%	2.9%
1997	162.4	1.8%	33.9%	62.7	-2.9%	12.5%	224.1	-2.6%	9.0%	72.1	-17.0%	1.8%	95.4	-14.4%	0.6%	191.2	12.9%	3.2%

(a) Passenger airlines only; includes lease, aircraft, and engine rentals, depreciation, and amortization.

Table 14-16 (Continued)

Year	Landing Fees			Traffic Commission			Communications			Advertising & Promotion			Passenger Meals			Composite Cost Index	
	Cost Index (1982= 100)	Growth Rate	% Op. Expenses	Cost Index (1982= 100)	Growth Rate	% Op. Expenses	Cost Index (1982= 100)	Growth Rate	% Op. Expenses	Cost Index (1982= 100)	Growth Rate	% Op. Expenses	Cost Index (1982= 100)	Growth Rate	% Op. Expenses	Cost Index (1982 = 100)	Growth Rate
1982	100.0	—	1.7%	100.0	—	5.9%	100.0	—	1.5%	100.0	—	2.2%	100.0	—	2.9%	100.0	—
1983	99.6	-0.4%	1.7%	104.4	4.4%	6.5%	98.7	-1.3%	1.5%	99.6	-0.4%	2.3%	101.4	1.4%	3.1%	101.1	1.1%
1984	101.0	1.4%	1.7%	113.9	9.1%	7.1%	98.4	-0.3%	1.5%	97.9	-1.7%	2.3%	104.7	3.3%	3.2%	102.5	1.4%
1985	99.9	-1.1%	1.6%	112.9	-0.9%	7.3%	96.6	-1.8%	1.6%	96.2	-1.7%	2.3%	98.9	-5.5%	3.2%	102.8	0.3%
1986	108.8	8.9%	1.8%	117.7	4.3%	8.1%	105.2	8.9%	1.8%	103.6	7.7%	2.5%	99.4	0.5%	3.4%	99.6	-3.1%
1987	117.7	8.2%	1.9%	126.3	7.3%	8.6%	98.2	-6.7%	1.6%	91.0	-12.2%	2.2%	102.5	3.1%	3.4%	101.9	2.3%
1988	124.8	6.0%	1.9%	145.4	15.1%	9.5%	109.0	11.0%	1.7%	97.1	6.7%	2.2%	108.6	6.0%	3.5%	105.9	3.9%
1989	130.5	4.6%	1.8%	157.7	8.5%	9.5%	111.8	2.6%	1.6%	103.2	6.3%	2.2%	118.8	9.4%	3.5%	112.3	6.0%
1990	139.0	6.5%	1.8%	169.2	7.3%	9.4%	111.2	-0.5%	1.4%	97.8	-5.2%	2.0%	128.4	8.1%	3.5%	122.6	9.2%
1991	153.4	10.4%	1.9%	188.1	11.2%	10.4%	116.6	4.9%	1.4%	89.9	-8.1%	1.8%	139.0	8.3%	3.8%	126.2	2.9%
1992	168.4	9.8%	2.1%	184.9	-1.7%	10.4%	124.5	6.8%	1.5%	81.1	-9.8%	1.7%	140.5	1.1%	3.9%	128.7	2.0%
1993	170.1	1.0%	2.1%	193.0	4.4%	10.9%	120.0	-3.6%	1.5%	72.4	-10.7%	1.5%	128.5	-8.5%	3.6%	130.5	1.4%
1994	171.6	0.9%	2.0%	163.3	-15.4%	9.6%	118.2	-1.5%	1.5%	69.7	-3.7%	1.5%	120.6	-6.1%	3.5%	129.9	-0.5%
1995	176.6	2.9%	2.2%	139.4	-14.6%	8.5%	116.0	-1.9%	1.5%	63.6	-8.8%	1.5%	110.9	-8.0%	3.3%	131.4	1.2%
1996	178.3	1.0%	2.1%	130.8	-6.2%	7.9%	114.8	-1.0%	1.5%	58.4	-8.2%	1.3%	104.0	-6.2%	3.1%	136.8	4.1%
1997	183.2	2.7%	2.0%	127.0	-2.9%	7.7%	110.4	-3.8%	1.4%	54.6	-6.5%	1.3%	102.9	-1.1%	3.1%	137.7	0.7%

Source: Reference (39).

Table 14-17

Estimated Deicing Costs and Weather Conditions at 5 Selected Airports

Airport and Airport Characteristics	Deicing Season	Heating Degree Days	Days < 32° F	Snowfall (inches)	Deicing Season Departures	Reported Deicing Cost	Reported Deicing Cost per Departure
Airport A							
Northern Tier	1996-97	7,966	165	73.6	88,964	$26,304,455	$296
241,436 departures, 1998	1997-98	6,536	105	50.3	90,334	$27,047,433	$299
11 Major Carriers	1998-99	6,599	91	56.5	60,670	$21,507,999	$355
Operational Hub							
Airport B							
Northeastern Tier	1996-97	4,468	28	12.9	69,253	$5,843,691	$84
234,732 departures, 1998	1997-98	3,989	7	0.8	76,410	$7,986,294	$105
7 Major Carriers	1998-99	4,110	25	12.5	81,037	$18,871,331	$233
Operational Hub							
Airport C							
Semi-desert Climate	1996-97	1,545	5	0	25,518	$166,211	$7
136,673 departures, 1998	1997-98	1,527	0	0	23,272	$148,712	$6
9 Major Carriers	1998-99	1,162	2	0	22,979	$182,253	$8
Not an Operational Hub							
Airport D							
Southeastern Tier	1996-97	4,109	27	5.3	30,111	$16,597,728	$551
86,002 departures, 1998	1997-98	3,850	19	22.8	26,424	$14,319,099	$542
8 Passenger/2 Cargo Airline	1998-99	3,580	27	13.3	21,202	$13,590,916	$641
Cargo Operational Hub							
Airport E							
Western Arid Climate	1996-97	4,798	34	63.3	56,575	NA	NA
182,667 departures, 1998	1997-98	5,060	37	65.2	54,949	$14,876,599	$271
8 Passenger Airlines	1998-99	5,027	36	31.2	52,855	$7,086,810	$134
Operational Hub							

Source: Reference (41).

Table 14-18

National Estimate of Total Deicing Costs at US Airports, 1997 - 1998

Deicing Season	Deicing Cost Based on:			Deicing Cost Characteristics				
	HDD	Days <32° F	Snowfall	Average (a)	Total Op. Costs	Deicing as % of Op. Costs	Net Profits	Deicing as % of Net Profits
1996-97	$548,974,570	$537,591,582	$411,725,552	$543,283,076	$95,729,000,000	0.57%	$2,804,000,000	19.38%
1997-98	$522,624,773	$437,407,901	$390,349,428	$480,016,337	$100,982,000,000	0.48%	$5,170,000,000	9.28%
1998-99	$506,479,210	$482,485,870	$415,862,888	$494,482,540	$104,034,000,000	0.48%	$4,894,000,000	10.10%

(a)Average for HDD and Days < 32° F; snowfall excluded from the estimate because zero snowfall implies zero deicing costs, yet airlines do incur deicing costs even with zero snowfall.

Source: Reference (41).

15.0 GLOSSARY

AAAE - American Association of Airport Executives.

ACAIS - Air Carrier Activity Information System database.

ACI - NA - Airports Council International - North America.

Acute Exposure - Exposure to a chemical for short amount of time relative to the test species lifespan. It is often contrasted with chronic exposure.

Additive - A component of aircraft deicing/anti-icing fluids. Chemical additives along with ethylene glycol or propylene glycol are necessary to meet various performance standards. Additives can include flame retardants and corrosion inhibitors, surfactants, dyes, pH buffers, and 1,4-dioxane.

ADF-Contaminated Wastewater -Wastewater, runoff, or storm water that has come in contact with or contains propylene and/or ethylene glycol-based deicing/anti-icing fluids.

Air Carrier - Airlines holding a certificate issued under section 401 of the Federal Aviation Act of 1958 that operate aircraft designed to have a maximum seating capacity of more than 60 seats or a maximum payload capacity of more than 18,000 pounds, or conduct international operations. The four types of air carriers are: majors, nationals, large regionals, and medium regionals.

Aircraft Deicing/Anti-icing Fluid (ADF) - Fluids that are applied to aircraft surfaces to remove and/or prevent snow and ice accumulation. They must be approved by the Society of Automotive Engineers (SAE) and typically contain either ethylene glycol or propylene glycol, together with a suite of chemical additives to meet various performance standards. There are three types of ADFs currently in use in the U.S.: Type I, Type II, and Type IV. Type I is a deicing fluid and Types II and IV are anti-icing fluids. ADFs are applied to ensure that the freezing point of any water on aircraft remains at a temperature not greater than 20°F below the ambient air or aircraft surface temperature, whichever is lower (FAA Advisory Circular No. 20-117). All deicing fluids must lower the freezing point of water to -18°F or lower when applied.

Aircraft Site Identification Database - A database that contains information for 3,957 facilities that potentially perform aircraft exterior cleaning and/or aircraft or pavement deicing/anti-icing operations.

Airline - A business defined by the type of service it offers, annual revenues, and the type of aircraft used. All federal safety requirements are pegged to aircraft size.

Airport Improvement Program (AIP) - A program administered by the FAA whereby federal funds are dispersed for projects that will maintain current airport infrastructure and increase the capacity of facilities in order to commodate growing passenger and cargo traffic.

Airport Matrix - An EPA database designed for this study containing current information on all aspects of airfield pavement and aircraft deicing for the airports for which detailed information were obtained from EPA site visits or questionnaires.

Air Taxi - An aircraft designed to have a maximum seating capacity of 60 seats or less or a maximum payload capacity of 18,000 pounds or less carrying passengers or cargo for hire or compensation. (See Air Carrier.)

AMIL - Anti-Icing Materials Laboratory located at the University of Quebec, Chicoutimi, Canada.

AMS - Aerospace Material Specification.

Anti-icing Operations - The prevention of the accumulation of frost, snow, or ice on aircraft or pavement. These operations are typically discussed with deicing operations. There are two types of deicing/anti-icing operations: dry-weather and wet-weather.

ARP - Aerospace Recommended Practice.

ATA - Air Transport Association.

Biochemical Oxygen Demand (BOD_5) - Five-day biochemical oxygen demand. A measure of biochemical decomposition of organic matter in a water sample. It is determined by measuring the dissolved oxygen consumed by microorganisms to oxidize the organic matter in a water sample under standard laboratory conditions of five days and 20°C (see Method 405.1). BOD_5 is not related to the oxygen requirements in chemical combustion.

BTS - Bureau of Transportation Safety.

Calcium Magnesium Acetate (CMA) - A solid runway deicer/anti-icer.

Canadian Environmental Protection Act (CEPA) - A Canadian federal statute that provides the authority for the establishment of the Part IV Glycol Guidelines in 1994 which included a voluntary guideline recommending discharge limitations for glycol at Canadian federal airports.

Canadian Water Quality Guidelines for Glycol - Established a voluntary guideline in 1997 recommending safe environmental levels from the discharge of glycols into the environment.

Carcinogen - A chemical capable of inducing cancer.

Cargo - Anything other than passengers, carried for hire, including both mail and freight.

Cargo Carrier - Airlines that primarily carry cargo using aircraft called "freighters." Freighters are essentially passenger aircraft with all or nearly all of the passenger seats removed.

CFR - Code of Federal Regulations, published by the U.S. Government Printing Office. A codification of the general and permanent rules published by the Federal Register by the Executive departments and agencies of the federal government.

Chemical Oxygen Demand (COD) - A nonconventional, bulk parameter that measures the oxygen-consuming capacity of refractory organic and inorganic matter present in water or wastewater. COD is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test (see Methods 410.1 through 401.4).

Chronic Exposure - Exposure to a chemical for a long duration, relative to the test species lifespan. It is often contrasted with acute exposure.

Civil Landing Area - FAA-approved landing site for aircraft, helicopters, or seaplanes. Civil landing areas are not associated with miliary areas.

Commercial Service Airports - Public airports receiving scheduled passenger service and having 2,500 or more enplaned passengers per year. There are 538 commercial service airports in the U.S.

CERCLA - Comprehensive Environmental Response, Compensation and Liability Act.

CWA - Clean Water Act. The Federal Water Pollution Control Act Amendments of 1972 (33 U.S.C. 1251 et seq.), as amended, inter alia, by the Clean Water Act of 1977 (Public Law 95-217) and the Water Quality Act of 1987 (Public Law 100-4).

Deicing Operations - The removal of frost, snow, or ice from aircraft or pavement. These operations are typically discussed with anti-icing operations. There are two types of deicing/anti-icing operations: dry-weather and wet-weather.

Developmental Toxicity - The occurrence of adverse effects on the developing organism that may result from exposure to a chemical prior to conception, during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at a point in the lifespan of the organism.

Direct Discharger - A facility that conveys or may convey untreated or facility-treated process wastewater or nonprocess wastewater directly into surface waters of the United States, such as rivers, lakes, or oceans. (See Surface Waters definition.)

Discharge - The conveyance of wastewater to: (1) United States surface waters such as rivers, lakes, and oceans, or (2) a publicly owned, federally owned, or other treatment works.

DO - Dissolved oxygen. The oxygen freely available in water, vital to fish and other aquatic life and for the prevention of odors. DO levels are considered a most important indicator of a water body's ability to support desirable aquatic life (see Methods 350.1 and 350.2).

Dry-Weather Deicing/Anti-icing - Also referred to as clear-ice deicing, may be performed whenever ambient temperatures are cold enough to form ice on aircraft wings (below 55°F). Dry-weather deicing/anti-icing is also used to defrost windshields and wingtips on commuter planes. May also be performed as necessary on some types of aircraft whose fuel tanks become super-cooled during high altitude flight, resulting in ice formation at lower altitudes and after landing. Dry-weather deicing is usually conducted throughout the entire deicing/anti-icing season.

EC - Environment Canada.

EC_{50} - The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the test organisms.

Effluent - Wastewater discharges.

Effluent Limitation - Any restriction, including schedules of compliance, established by a state or the Administrator on quantities, rates, and concentrations of chemical, physical, biological, and other constituents that are discharged from point sources into navigable waters, the waters of the contiguous zone, or the ocean. (CWA Sections 301(b) and 304(b).)

Enplanements - The number of passengers boarding a flight.

EPA - The U.S. Environmental Protection Agency.

Ethylene Glycol - A commonly used freezing point depressant in aircraft deicing/anti-icing fluids and pavement deicers.

FAA - Federal Aviation Administration.

FDA - Food and Drug Administration.

FIFRA - Federal Insecticide, Fungicide, Rodenticide Act.

Fixed-Based Operators (FBOs) - Companies that have contracts with the airport authority/airlines to conduct business operations on airport property.

FR - Federal Register, published by the U.S. Government Printing Office, Washington, D.C. A publication making available to the public regulations and legal notices issued by federal agencies.

Freight - All air cargo excluding mail.

GAO - General Accounting Office.

General Aviation (GA) Airports - Airports that do not receive commercial service, have at least 10 locally owned aircraft, and are at least 20 miles from the nearest NPIAS airport.

General Aviation Operations - Takeoffs and landings of all civil aircraft, except those classified as air carriers or air taxis.

Glycol-Contaminated Wastewater - Wastewater, runoff, or storm water that has come in contact with or contains propylene and/or ethylene glycol-based deicing/anti-icing fluids.

GRAS - Generally Recognized as Safe.

HAP - Hazardous Air Pollutant.

Hexane Extractable Material (HEM) - A method-defined parameter that measures the presence of relatively nonvolatile hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases, and related materials that are extractable in the solvent n-hexane (see Method 1664). HEM has replaced the freon-based oil and grease method.

Holdover Time - The period of time when ice or snow is prevented from adhering to the surface of an aircraft (i.e., the amount of time between application and takeoff).

Hubs - A term used by the FAA to identify very busy commercial service airports.

Immunological Toxicity - The occurrence of adverse health effects on the immune system that may result from exposure to chemicals.

Indirect Discharger - A facility that discharges or may discharge pollutants into a publicly owned treatment works (POTW).

ISO - International Standards Organization.

Isopropanol - A freezing point depressant that may be used in aircraft or pavement deicing/anti-icing fluids.

Large Regional Carrier - A type of air carrier with annual operating revenues between $20 million and $100 million.

LC_{50} - Concentration at which exposure for specific length of time is expected to cause death in 50% of a defined experimental population.

LD_{50} - The dose of a chemical that has been calculated to cause death in 50% of a defined experimental population.

Lethal Dose - The lowest does of a chemical introduced by a route other than inhalation that is expected to have caused death in humans or animals.

Lowest-Observed-Adverse-Effect Level (LOAEL) - The lowest dose of chemical in a study, or a group of studies, that produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Major Carrier - A type of air carrier with annual operating revenues greater than $1 billion.

MCL - Maximum Concentration Level.

MEBT - 5-methyl-1H-benzotriazole or TTZ or tolyltriazole.

Medium Regional Carrier - A type of air carrier with annual operating revenues between $0 and $20 million.

Miliary Operations - All classes of military operations at FAA air traffic facilities.

MIL-SPEC - Military performance specifications for aircraft and pavement deicers/anti-icers. Similar to SAE performance specifications.

Mutagen - A substance that causes mutations (i.e., a change in the genetic material in a body cell).

NASA - National Aeronautics and Space Administration.

National Carrier - A type of air carrier with annual operating revenues between $100 million and $1 billion.

National Plan of Integrated Airport Systems (NPIAS) - A plan submitted to Congress in accordance with Section 47103 of Title 49 of the United States Code. Identifies airports that are important to national transportation, and, therefore, eligible to receive grants under the Airport Improvement Program (AIP). Does not apply to stand-alone military airports.

NOI - Notice of Intent.

Nondetect Value - A concentration-based measurement reported below the sample-specific detection limit that can reliably be measured by the analytical method for the pollutant.

No-Observed-Adverse-Effect Level (NOAEL) - The dose of chemical at which there were no statistically or biologically significant increases in frequency or severity of adverse effects seen between the exposed population and its appropriate control. Effects may be produced at this dose, but they are not considered adverse.

Nonprimary Commercial Service Airports - Commercial service airports with less than 10,000 annual enplanements. There are 125 nonprimary commercial airports in the U.S.

NPDES - The National Pollutant Discharge Elimination System authorized under Sec. 402 of the CWA. NPDES requires permits for discharge of pollutants from any point source into waters of the United States.

NRDC - Natural Resources Defense Council.

Octanol-Water Partition Coefficient (K_{ow}) - The equilibrium ratio of the concentrations of a chemical in n-octanol and water, in dilute solution.

OECD - Organization for Economic Cooperation and Development.

Operational Hub - See Section 14.0 - but used to describe airlines main airport for connections in the hub & spoke system.

Pollution Prevention - The use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, or other resources, as well as those practices that protect natural resources through conservation or more efficient use. Pollution prevention consists of source reduction, in-process recycle and reuse, and water conservation practices.

Potassium Acetate - A liquid runway deicer.

POTW - Publicly owned treatment works, as defined at 40 CFR 403.3(o).

Primary Commercial Airports - Commercial service airports with more than 10,000 annual enplanements. There are 413 primary commercial airports in the U.S.

Propylene Glycol - A commonly used freezing point depressant in aircraft deicing/anti-icing fluids.

RAA - Regional Airline Association.

Regional Carriers - Airlines whose services are generally limited to a single region of the country and have annual revenues of less than $100 million. These carriers are divided into three groups: large, medium, and small.

Reliever Airports - Included in the NPIAS. High-capacity general aviation airports in major metropolitan areas. There are 334 reliever airports in the U.S.

Reproductive Toxicity - The occurrence of adverse effects on the reproductive system that may result from exposure to a chemical.

RWIS - Road/Runway Weather Information System.

Screener Questionnaire - The EPA 1993 Screener Questionnaire for the Transportation Equipment Cleaning Industry.

SIC - Standard industrial classification. A numerical categorization system used by the U.S. Department of Commerce to catalogue economic activity. SIC codes refer to the products, or group of products, produced or distributed, or to services rendered by an operating establishment. SIC codes are used to group establishments by the economic activities in which they are engaged. SIC codes often denote a facility's primary, secondary, tertiary, etc. economic activities.

Silica Gel-Treated Hexane Extractable Material (SGT-HEM) - A method-defined parameter that measures the presence of mineral oils that are extractable in the solvent n-hexane and not adsorbed by silica gel (see Method 1664). SGT-HEM is also referred to as nonpolar material.

Small Regional Carrier - The largest segment of the regional airline business and mostly operate planes that have less than 30 seats. They are often called “commuters.” There is no revenue cut-off for this group.

SMI - Scientific Material International.

Society of Automotive Engineers (SAE) - A professional organization dedicated to improving safety and promoting new technologies in all sectors of the transportation industry through the development of engineering standards. The SAE Aerospace Council is responsible for developing standards for the aircraft industry and is organized into technical committees, each with its own area of specialization. The committee responsible for aircraft deicing and anti-icing issues is the G-12 Committee.

Sodium Acetate - A solid runway deicer.

Sodium Formate - A runway deicer typically applied in a pellet form and mixed with corrosion inhibitors to meet performance standards.

Storm Water - Storm water runoff, snow-melt runoff, and surface runoff and drainage.

Surface Waters - Waters including, but not limited to, oceans and all interstate and intrastate lakes, rivers, streams, mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, and natural ponds.

TECI - Transportation Equipment Cleaning Industry.

Teratogen - A chemical that causes structural defects that affect the development of an organism.

TMDL - Total Maximum Daily Load.

TOC - Total organic carbon. A measure of total organic content of wastewater. Unlike five-day biochemical oxygen demand (BOD_5) or chemical oxygen demand (COD), TOC is independent of the oxidation state of the organic matter and does not measure other organically bound elements, such as nitrogen and hydrogen, and inorganics that can contribute to the oxygen demand measured by BOD_5 and COD. TOC methods utilize heat and oxygen, ultraviolet irradiation, chemical oxidants, or combinations of these oxidants to convert organic carbon to carbon dioxide (CO_2). The CO_2 is then measured by various methods.

TOD - Total oxygen demand. A theoretical measure of the amount of oxygen required to break down a substance to its simplest parts. The COD of a substance may be used as a surrogate for the TOD.

TRI - Toxics Release Inventory.

TSCA - Toxic Substances Control Act.

TSS - Total suspended solids. A measure of the amount of particulate matter that is suspended in a water sample. The measure is obtained by filtering a water sample of known volume. The particulate material retained on the filter is then dried and weighed, see Method 160.2.

TTZ - Tolyltriazole or 5-methyl-1H-benzotriazole. A common additive in aircraft deicing/anti-icing fluids that is used as a corrosion inhibitor and flame retardant.

Type I ADFs - The most commonly used fluid. They are primarily used for aircraft deicing. They have the shortest holdover time of any type of fluid. Type I ADFs typically contain either ethylene glycol or propylene glycol, water, and additives.

Type II ADFs - Primarily used for aircraft anti-icing. They have a holdover time between Type I and Type IV fluids. They are typically composed of either ethylene glycol or propylene glycol, a small amount of thickener, water, and additives.

Type III ADFs - Designed for aircraft anti-icing for smaller, commuter aircraft. They have a holdover time between Type I and Type II fluids; however, they are believed to be obsolete.

Type IV ADFs - Primarily used for aircraft anti-icing. They have the longest holdover time of any type of fluid. They are typically composed of either ethylene glycol or propylene glycol, a small amount of thickener, water, and additives.

UCAR - A runway deicer manufactured by Union Carbide that contains urea, ethylene glycol, and water.

Urea - A runway deicer that is typically applied to pavement and runway areas in granular form.

U.S.C. - The United States Code.

USGS - United States Geological Survey.

VOCs - Volatile organic compounds. Any organic compound that participates in atmospheric photochemical reactions except those designated by EPA as having negligible photochemical reactivity.

Wet-Weather Deicing/Anti-icing - Occurs during storm events that include precipitation such as snow, sleet, or freezing rain.

WSDDM - Weather Support to Deicing Decision Making.

Appendix A

SELECT U.S. AIRPORT LOCATIONS

Appendix A

Select U.S. Airport Locations

Airport Code	Airport Name	Location
ILN	Airborne Air Park	Wilmington, OH
ALB	Albany International	Albany, NY
ANC	Anchorage International	Anchorage, AK
BWI	Baltimore/Washington International	Baltimore, MD
BIL	Billings Logan International	Billings, MT
BDL	Bradley International	Windsor Locks, CT (services Hartford, CT/ Springfield, MA
BUF	Buffalo International	Buffalo, NY
ORD	Chicago O'Hare International	Chicago, IL
CVG	Cincinnati/Northern Kentucky International	Covington/Cincinnati, KY/OH
CLE	Cleveland Hopkins International	Cleveland, OH
DFW	Dallas/Ft. Worth International	Dallas-Ft. Worth, TX
DAY	Dayton International	Dayton, OH
DIA	Denver International	Denver, CO
DSM	Des Moines International	Des Moines, IA
DTW	Detroit Metropolitan Wayne Country	Detroit, MI
DLH	Duluth International	Duluth, MN
MKE	General Mitchell International	Milwaukee, WI
RFD	Greater Rockford	Rockford, IL
MCI	Kansas City International	Kansas City, MO
MEI	Key Field (Meridian)	Meridian, MS
LGA	LaGuardia	New York, NY
STL	Lambert-St. Louis International	St. Louis, MO
BOS	Logan International	Boston, MA
SDF	Louisville International-Standiford Field	Louisville, KY
MSP	Minneapolis-St. Paul International	Minneapolis-St. Paul, MN
BNA	Nashville International	Nashville, TN
EWR	Newark International	Newark, NJ
PIT	Pittsburgh International	Pittsburgh, PA
PDX	Portland International	Portland, OR
RIC	Richmond International	Richmond, VA
DCA	Ronald Reagan Washington National	Arlington, VA (services Washington, DC)

Appendix A (Continued)

Airport Code	Airport Name	Location
SEA	Seattle-Tacoma International	Seattle, WA
SLC	Salt Lake City International	Salt Lake City, UT
SYR	Syracuse Hancock International	Syracuse, NY
PVD	T.F. Green	Providence, RI
ITH	Tomkins County	Ithaca, NY
HTS	Tri-State (Huntington)	Huntington, WV
HPN	Westchester County	White Plains, NY
IAD	Washington Dulles International	Chantilly, VA (services Washington DC)

Appendix B

MEAN ANNUAL SNOWFALL (THROUGH 1995) FOR SELECT U.S. CITIES

Appendix B

Mean Annual Snowfall (Through 1995) for Select U.S. Cities

City, State	Mean Annual Snowfall (in.)
VALDEZ, AK	325.8
MT. WASHINGTON, NH	253.9
YAKUTAT, AK	197.6
MARQUETTE, MI	130.6
SAULT STE. MARIE, MI	117.1
TALKEETNA, AK	115.0
SYRACUSE, NY	114.7
CARIBOU, ME	110.7
LANDER, WY	102.2
JUNEAU, AK	100.7
FLAGSTAFF, AZ	100.3
MUSKEGON, MI	97.9
MCGRATH, AK	94.2
BUFFALO, NY	91.8
ROCHESTER, NY	90.3
ERIE, PA.	86.5
ALPENA, MI	85.7
BINGHAMTON, NY	82.8
BETTLES,AK	82.5
CASPER, WY	79.1
DULUTH, MN	78.9
BURLINGTON, VT	78.0
KODIAK, AK	77.4
ELKINS, WV	76.7
HOUGHTON LAKE, MI	75.0
GRAND RAPIDS, MI	71.8
SHERIDAN, WY	71.7
SOUTH BEND, IN	70.9
PORTLAND, ME	70.8
ANCHORAGE, AK	70.0
FAIRBANKS, AK	69.5
WORCESTER, MA	67.6

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
INTERNATIONAL FALLS, MN	64.6
KALISPELL, MT	63.9
ALBANY, NY	63.8
CONCORD, NH	63.5
COLD BAY,AK	60.8
DENVER, CO	60.3
BECKLEY, WV	60.0
BLUE HILL, MA	59.5
NOME, AK	58.8
GREAT FALLS, MT	58.4
HOMER, AK	57.7
SALT LAKE CITY, UT	57.7
ST. PAUL ISLAND, AK	56.7
BILLINGS, MT	56.3
YOUNGSTOWN, OH	56.1
CLEVELAND, OH	55.7
CHEYENNE, WY	55.4
GULKANA,AK	50.7
MINNEAPOLIS-ST.PAUL, MN	49.5
SPOKANE, WA	49.5
BETHEL, AK	49.4
LANSING, MI	49.0
ANNETTE, AK	48.9
ELY, NV	48.9
ROCHESTER, MN	48.6
AVOCA, PA	48.1
HARTFORD, CT	47.9
KOTZEBUE, AK	47.6
AKRON, OH	47.4
MILWAUKEE, WI	47.2
HELENA, MT	47.0
GREEN BAY, WI	46.7
KING SALMON, AK	46.1
MISSOULA, MT	45.5

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
FLINT, MI	45.2
SAINT CLOUD, MN	44.9
MADISON, WI	43.9
BIG DELTA,AK	43.8
DUBUQUE,IA	43.6
PITTSBURGH, PA	43.5
POCATELLO, ID	42.7
BISMARCK, ND	42.7
LA CROSSE, WI	42.5
COLORADO SPRINGS, CO	42.3
MANSFIELD, OH	42.1
WILLIAMSPORT, PA	41.9
BOSTON, MA	41.7
SCOTTSBLUFF, NE	41.5
DETROIT, MI	41.3
BURNS,OR	41.3
HURON, SD	40.1
SIOUX FALLS, SD	40.1
WILLISTON, ND	39.5
RAPID CITY, SD	39.4
FARGO, ND	38.9
CHICAGO,IL	38.2
GOODLAND, KS	38.2
UNALAKLEET, AK	38.0
ELKO, NV	37.6
TOLEDO, OH	37.0
ABERDEEN, SD	36.5
ROCKFORD, IL	35.9
PROVIDENCE, RI	35.9
MIDDLETOWN/HARRISBURG INTL APT	35.0
ALAMOSA, CO	33.9
PUEBLO, CO	33.5
VALENTINE, NE	33.5
DES MOINES, IA	33.3

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
CHARLESTON, WV	33.1
FORT WAYNE, IN	32.8
WATERLOO, IA	32.3
ALLENTOWN, PA	32.1
SIOUX CITY, IA	31.7
OMAHA (NORTH), NE	31.2
GRAND ISLAND, NE	30.5
NORFOLK, NE	30.5
MOLINE, IL	30.4
NORTH PLATTE, NE	30.4
OMAHA EPPLEY AP, NE	29.8
NEW YORK C.PARK, NY	28.3
BARROW, AK	28.2
COLUMBUS, OH	27.9
GLASGOW, MT	27.7
DAYTON, OH	27.7
NEWARK, NJ	27.5
LINCOLN, NE	26.8
HUNTINGTON, WV	26.0
NEW YORK (LAGUARDIA AP), NY	25.8
BRIDGEPORT, CT	25.5
PEORIA, IL	24.8
GRAND JUNCTION, CO	24.7
RENO, NV	24.4
YAKIMA, WA	23.6
WINNEMUCCA, NV	23.5
GREATER CINCINNATI AP	23.4
SPRINGFIELD, IL	23.1
COLUMBIA, MO	23.1
INDIANAPOLIS, IN	22.9
NEW YORK (JFK AP), NY	22.9
JACKSON, KY	22.8
ROANOKE, VA	22.5
WASHINGTON DULLES AP, D.C.	22.3

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
CLAYTON, NM	22.0
CONCORDIA, KS	21.6
TOPEKA, KS	20.8
PHILADELPHIA, PA	20.8
BOISE, ID	20.7
ISLIP, NY	20.5
BALTIMORE, MD	20.4
WILMINGTON, DE	20.3
DODGE CITY, KS	19.9
KANSAS CITY, MO	19.9
ST. LOUIS, MO	19.5
PENDLETON, OR	17.7
LYNCHBURG, VA	17.7
SPRINGFIELD, MO	17.2
OLYMPIA, WA	16.8
WASHINGTON NAT'L AP, D.C.	16.4
LOUISVILLE, KY	16.1
LEWISTON, ID	15.8
LEXINGTON, KY	15.8
WICHITA, KS	15.7
ATLANTIC CITY AP, NJ	15.7
BRISTOL-JHNSN CTY-KNGSPRT,TN	15.4
AMARILLO, TX	15.0
ASHEVILLE, NC	14.9
RICHMOND, VA	13.7
EVANSVILLE, IN	13.6
QUILLAYUTE, WA	13.0
KNOXVILLE, TN	11.6
SEATTLE SEA-TAC AP, WA	11.3
ROSWELL, NM	11.1
ALBUQUERQUE, NM	10.8
PADUCAH KY	10.6
WINSLOW, AZ	10.5
NASHVILLE, TN	9.9

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
LUBBOCK, TX	9.9
OAK RIDGE,TN	9.5
TULSA, OK	9.4
OKLAHOMA CITY, OK	9.2
GREENSBORO-WNSTN-SALM-HGHPT,NC	8.5
WALLOPS ISLAND, VA	8.4
BISHOP, CA	8.2
NORFOLK, VA	7.4
MEDFORD, OR	7.2
RALEIGH, NC	6.9
SEATTLE C.O., WA	6.8
SALEM, OR	6.6
PORTLAND, OR	6.5
NORTH LITTLE ROCK, AR	6.3
EUGENE, OR	6.3
FORT SMITH, AR	6.2
GREENVILLE-SPARTANBURG AP, SC	5.9
WICHITA FALLS, TX	5.7
CHARLOTTE, NC	5.4
EL PASO, TX	5.3
LITTLE ROCK, AR	5.1
MEMPHIS, TN	5.1
ABILENE, TX	4.6
ASTORIA, OR	4.3
CHATTANOOGA, TN	4.3
MIDLAND-ODESSA, TX	4.2
REDDING, CA	2.9
TUPELO, MS	2.9
SAN ANGELO, TX	2.9
HUNTSVILLE, AL	2.7
DALLAS-FORT WORTH, TX	2.5
ATHENS, GA	2.4
ATLANTA, GA	2.0
CAPE HATTERAS, NC	1.9

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
WILMINGTON, NC	1.9
COLUMBIA, SC	1.7
BIRMINGHAM AP,AL	1.5
SHREVEPORT, LA	1.5
WACO, TX	1.4
TUCSON, AZ	1.2
MERIDIAN, MS	1.2
LAS VEGAS, NV	1.2
AUGUSTA,GA	1.1
MACON, GA	0.9
JACKSON, MS	0.9
AUSTIN, TX	0.9
DEL RIO, TX	0.9
CHARLESTON AP,SC	0.7
SAN ANTONIO, TX	0.7
COLUMBUS, GA	0.5
MOBILE, AL	0.4
MONTGOMERY, AL	0.4
SAVANNAH, GA	0.4
HOUSTON, TX	0.4
LAKE CHARLES, LA	0.3
PORT ARTHUR, TX	0.3
EUREKA, CA.	0.2
PENSACOLA, FL	0.2
BATON ROUGE, LA	0.2
NEW ORLEANS, LA	0.2
FRESNO, CA	0.1
VICTORIA, TX	0.1
SANTA BARBARA, CA	0
FORT MYERS, FL	0
KEY WEST, FL	0
MIAMI, FL	0
HILO, HI	0
HONOLULU,HI	0

Appendix B (Continued)

City, State	Mean Annual Snowfall (in.)
KAHULUI, HI	0
LIHUE, HI	0
GUAM, PC	0
KOROR, PC	0
KWAJALEIN, MARSHALL IS., PC	0
MAJURO, MARSHALL IS, PC	0
PAGO PAGO, AMER SAMOA, PC	0
POHNPEI, CAROLINE IS., PC	0
CHUUK, E. CAROLINE IS., PC	0
WAKE ISLAND, PC	0
YAP, W CAROLINE IS., PC	0

Source: National Oceanic Atmospheric Administration.

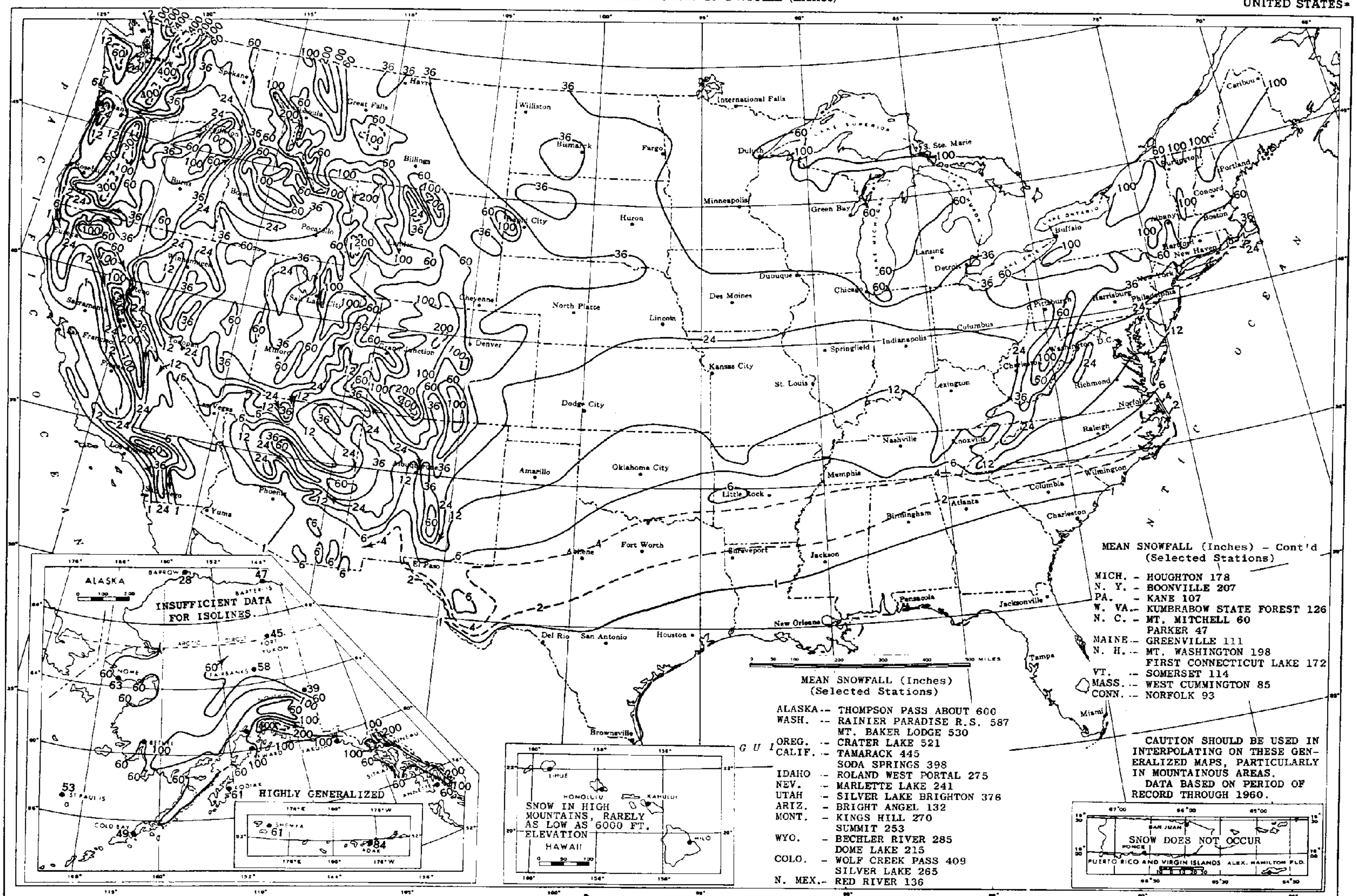
Appendix C

CLIMATE CONTOUR MAP OF THE U.S.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

MEAN ANNUAL TOTAL SNOWFALL (Inches)

CLIMATIC MAPS OF THE UNITED STATES*



Prepared by Office of Data Information

*Note.-- Formerly Sheet of the National Atlas of the United States

Revised 1966

Appendix D

SELECTED FINANCIAL AND SCHEDULED SERVICE TRAFFIC STATISTICS

U.S. Large Certificated Air Carriers, 1997 - 1998

Air Carrier	12 month period ending 6/30/98								
	Operating Revenues	Net Income	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000)	Cargo Ton-miles (x 1,000)	HQ State	Notes [3]
Majors									
Alaska	$1,527,189	$105,841	12,548	9,900,889	14,743,618	1,073,610	77,693		
America West	$1,938,366	$102,971	17,826	15,969,799	23,772,818	1,596,980	113,748		
American	$16,229,821	$1,017,980	81,192	107,640,234	154,188,327	10,764,023	2,053,551		
Continental	$6,870,111	$427,490	40,150	47,639,667	66,422,995	4,763,967	737,402		
Delta	$14,328,259	$1,000,505	104,050	101,056,563	139,995,366	10,105,656	1,744,996		
DHL Airways	$1,284,853	($32,962)	0	0	0	0	358,264		
Federal Express	$13,414,818	$441,887	0	0	0	0	6,518,002		
Northwest	$9,881,713	$536,386	54,506	72,408,489	97,219,704	7,240,849	2,226,434		
Southwest	$3,994,409	$376,467	57,286	29,935,657	45,978,282	2,993,566	131,828		
Trans World	$3,370,128	($60,897)	24,112	25,510,913	36,025,463	2,551,092	310,055		
United	$17,329,571	$924,935	84,500	121,683,332	170,943,723	12,168,333	2,972,682		
United Parcel	$1,842,455	($22,203)	0	0	0	0	895,094		
US Airways	$8,494,535	$1,003,208	57,869	41,051,381	56,773,242	4,105,139	349,414		
Nationals									
Air Transport Int'l	$117,749	$8,911	0	0	0	0	0	AR	NSS
Air Wisconsin	$155,265	$3,917	2,045	645,827	1,025,905	64,583	521	WI	
Air Trans [2]	$197,217	($3,407)	2,261	1,494,612	2,487,706	149,461	947	FL	
Valuejet	$183,424	($70,179)	2,339	1,203,597	2,392,198	120,396	2,153		
Aloha	$235,350	$6,526	5,312	734,974	1,112,337	73,498	9,416	HI	
American Eagle[3,4]	$645,073	$33,198	6,829	1,477,972	2,423,606	147,797	606	TX	
Flagship									
Simmons									
Wings West									
American Int'l.	$437,568	($17,166)	0	0	0	0	82,314	MI	
American Trans Air	$824,896	$28,663	3,776	5,259,538	7,163,577	525,954	0	IN	
Arrow	$89,363	($19,941)	0	0	0	0	96,540	FL	
Atlantic Southwest	$396,451	$57,804	3,876	976,055	1,818,538	97,605	611	GA	
Atlas	$392,674	$30,782	0	0	0	0	0	NY	NSS
Carnival	$63,299	($28,063)	971	1,052,291	1,554,150	105,229	1,525	FL	
Challenge Air Cargo	$134,928	$2,713	0	0	0	0	215,969	FL	
Continental Express [4]	$516,630	$50,918	5,261	1,358,487	2,355,329	135,849	536	TX	
Continental Micronesia	$670,352	($28,163)	2,432	4,206,328	6,178,542	420,633	134,949	HI	
Emery	$556,661	($7,389)	0	0	0	0	0	CA	NSS
Evergreen	$274,871	($4,172)	0	0	0	0	538,171	OR	
Executive [4]	$96,138	$4,142	1,446	276,806	463,382	27,681	10	PR	
Frontier	$155,474	($15,226)	1,348	1,104,154	1,945,860	110,415	5,262	CO	
Hawaiian	$409,838	$2,008	4,934	3,152,308	4,357,865	315,231	56,782	HI	

U.S. Large Certificated Air Carriers, 1997 - 1998 (Continued)

Air Carrier	12 month period ending 6/30/98								
	Operating Revenues	Net Income	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000)	Cargo Ton-miles (x 1,000)	HQ State	Notes [3]
Horizon Air [4]	$322,395	$10,688	3,930	980,848	1,590,185	98,085	3,469	WA	
Midway	$197,415	$13,471	1,538	842,662	1,300,572	84,266	763	NC	
Midwest Express	$333,483	$30,046	1,747	1,498,079	2,323,706	149,808	18,442	WI	
Polar Air Cargo	$337,239	($30,155)	0	0	0	0	1,113,913	CA	
Reno	$392,027	($12,791)	5,248	2,830,249	4,428,320	283,025	5,412	NV	
Southern Air	$124,336	($31,641)	0	0	0	0	0	OH	NSS
Sun Country	$245,899	($4,772)	0	0	0	0	0	MN	NSS
Tower	$487,212	($8,876)	1,459	3,920,610	5,162,146	392,061	97,895	NY	
Trans States	$211,165	$24,990	2,370	480,040	935,877	48,004	0	MO	
US Air Shuttle	$173,664	$5,987	1,516	302,491	685,793	30,249	294	NY	
World	$289,588	($4,359)	0	0	0	0	0	VA	NSS
Large Regionals									
Amerijet	$71,817	$4,033	0	0	0	0	97,520	FL	
Champion	$53,565	($26,456)	0	0	0	0	0	MN	NSS
Express One	$111,552	($1,910)	0	0	0	0	0	TX	NSS
Fine	$87,610	($6,575)	0	0	0	0	0	FL	NSS
Florida West	$64,267	$2,724	0	0	0	0	65,263	FL	
Gemini Air Cargo	$95,472	$11,488	0	0	0	0	0	DC	NSS
Kitty Hawk	$117,667	$7,701	0	0	0	0	0	TX	NSS
Kiwi	$73,447	($22,084)	609	558,891	988,784	55,889	914	NJ	Chap. 11
Mesaba	$303,270	$21,862	3,749	926,228	1,708,509	92,623	279	MN	
Miami Air	$78,399	$1,278	0	0	0	0	0	FL	NSS
North American	$60,665	$1,467	0	0	0	0	0	NY	NSS
Northern Air	$40,918	$4,112	0	0	0	0	17,890	AK	
Pan American	$38,264	($20,119)	333	538,284	795,823	53,828	9,615	FL	
Reeve	$29,827	($2,230)	57	35,607	83,619	3,561	4,002	AK	
Ryan Int'l.	$110,568	$4,547	0	0	0	0	0	KS	NSS
Spirit	$102,661	$3,909	1,088	871,324	1,109,572	87,132	0	MI	
Sun Pacific	$11,785	$287	0	0	0	0	0	AZ	NSS
TransMeridian	$29,682	($2,337)	0	0	0	0	0	GA	NSS
UFS	$57,689	$1,063	670	106,306	211,065	10,631	0	MO	
USA Jet	$76,188	$4,700	0	0	0	0	0	MI	NSS
Vanguard	$84,907	($17,411)	1,078	674,740	1,088,814	67,474	846	MO	
Zantop	$12,138	($1,892)	0	0	0	0	0	MI	NSS
Small Regionals									
Capital Cargo	$16,920	$375	0	0	0	0	0	FL	NSS
Casino Express	$15,692	($2,676)	205	201,846	239,369	20,184	0	NV	
Custom Air	$10,388	($146)	0	0	0	0	0	FL	

U.S. Large Certificated Air Carriers, 1997 - 1998 (Continued)

Air Carrier	12 month period ending 6/30/98								
	Operating Revenues	Net Income	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000)	Cargo Ton-miles (x 1,000)	HQ State	Notes [3]
Eastwind	$22,641	($8,684)	240	102,118	308,701	10,212	0	NC	
Falcon	$13,955	$1,265	0	0	0	0	0	FL	NSS
Lynden Air Cargo	$20,395	($5,761)	0	0	0	0	6,527	AK	
Nations Air	$6,724	$299	0	0	0	0	0	GA	NSS
Omni	$24,955	$1,141					0	OK	
Pace	$4,914	$256	0	0	0	0	0	NC	NSS
Panagra	$3,610	($1,071)	0	0	0	0	0	FL	NSS
Pro Air	$11,247	($18,849)	161	73,399	308,727	7,340	0	WA	
Renown	$8,599	($1,033)	0	0	0	0	0	CA	NSS
Sierra Pacific	$6,650	$631	0	0	0	0	0	AZ	NSS
Sunworld	$7,696	($914)	19	27,234	57,486	2,723	0	KY	PNSS
Tatonduk	$7,248	$1,127	NA	453	1,784	45	39	AK	
Tradewinds	$14,965	($665)	0	0	0	0	0	NC	6 mos.
Trans Continental	$22,719	$1,172	0	0	0	0	0	MI	NSS
Trans-Air-Link	$1,930	($220)	0	0	0	0	0	FL	NSS
Winair	$4,939	($1,150)	0	0	0	0	0	UT	6 mos.

[1] Notes: NSS: provided unscheduled services only.
Chap. 11: Kiwi Airlines filed for Chapter 11 bankruptcy protection 3/16/99.
6 mos.:financial data for 6 month period ending 6/30/98.
[2] Valujet merged with AirTran 3/98.
[3] Flagship, Simmons, and Wings West merged to become American Eagle, 6/1/98.
[4] Wholly owned subsidiary of a major air carrier.
Source: References (29, 32)

U.S. Small Certificated and Commuter Airlines, 1997 - 1998

Air Carrier	12 month period ending 6/30/98						
	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000	Cargo Ton-miles (x 1,000)	Code-Sharing [1]	HQ State
Fourth Quartile							
Comair	5,005,338	1,883,205	3,048,664	188,320,481		Y	OH
Mesa	4,151,202	1,044,158	1,856,093	104,415,813		Y	NM
Third Quartile							
Allegheny [3]	2,029,870	377,435	749,700	37,743,527	200,897	Y	PA
Piedmont [3]	2,906,282	585,507	1,026,577	58,550,692	285,102	Y	NC
Sky West	3,212,231	772,072	1,484,829	77,207,248		Y	UT
Second Quartile							
Atlantic Coast	1,854,888	584,279	1,085,484	58,427,900		Y	VA
Business Express	1,290,122	283,542	741,247	28,340,677	2,587	Y	NH
CC Air	776,663	141,304	254,142	14,130,398	1	Y	NC
Express Airlines I [3]	1,291,814	369,664	618,605	36,966,354		Y	TX
PSA [3]	1,190,126	393,392	611,206	39,239,146		Y	
Westair	1,467,951	231,378	391,277	23,137,785			CA
First Quartile							
Action	1,670	103	156	10,281			
Air Midwest	474,024	91,841	199,493	9,184,096			KS
Air Nevada	41,536	7,488	9,665	748,751			HI
Air St. Thomas	11,071	1,032	1,877	103,189			
Air Sunshine	26,860	3,278	7,449	327,750			
Air Vegas	117,528	21,425	29,581	2,142,549			
Alaska Seaplane Service	2,513	152	680	14,510	5,865		AK
Aloha Island	470,637	31,407	53,727	3,140,677		Y	
Alpine Air	6,129	1,056	4,744	105,640	3		
Astral Aviation	291,822	71,791	161,175	7,179,148	100,167		WI
Austin Express [2]	3,322	701	3,671	70,120	42		
Baker Aviation	17,840	1,352	5,256	135,229	97,590		AK
Bemidji	25	5	102	500	24,119		
Bering Air	45,699	6,178	15,602	617,784	243,102		AK
Big Sky	43,118	9,163	29,637	43,118	10,209		MT
Cape Air	388,348	21,212	41,717	2,121,183	8,464		
Cape Smythe Air	43,712	5,704	14,826	570,416	299,202		AK
Casino [2]	2,632	190,299	1,199,470	19,029,892			
Chautauqua	704,775	157,891	317,604	15,789,078	56,232	Y	
Coastal Air Transport	2,409	361	520	36,135	723		
Colgan Air	97,225	16,506	51,620	1,461,525	133,493	Y	
Commutair	630,827	117,374	271,088	11,737,425		Y	
Corporate Flight Management	160,177	37,189	86,824	3,718,930	1,322		

U.S. Small Certificated and Commuter Airlines, 1997 - 1998 (Continued)

Air Carrier	12 month period ending 6/30/98						
	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000	Cargo Ton-miles (x 1,000)	Code-Sharing [1]	HQ State
Eagle Canyon	199,079	35,834	50,227	3,583,422			NV
Ellis Air Taxi	400	52	200	4,175	1,441		
Era Aviation	418,640	51,950	104,071	5,195,049	385,973	Y	AK
Exec Express II	227,333	99,198	249,878	9,919,828	116,142	Y	TX
Flying Boat	35,413	3,180	5,213	318,004			
Forty-Mile Air	2,367	176	1,031	17,650	20,927		AK
Freedom Air	77,201	2,557	12,438	255,721	35,783		
Frontier Flying Service	37,548	9,471	26,572	947,058	476,619		AK
F.S. Air Service	1,203	152	772	15,168	10,253		AK
Grand Canyon Helicopters	1,156	70	113	6,960	77		
Grant Aviation	20,692	3,288	10,858	328,834	112,466		AK
Great Lakes Aviation	668,149	195,734	395,072	19,573,445		Y	
Gulf Air Taxi	242	23	108	1,644	1,198		
Gulfstream Int'l.	583,118	111,145	205,692	11,114,522	1,023,024	Y	
Hageland Aviation	54,098	5,171	15,364	517,134	285,006		AK
Haines	22,874	762	1,607	76,212	38,680		AK
Harbor	63,956	4,499	13,908	449,920	3,837	Y	
Iliamna Air Taxi	450	10	261	1,041	12,941		AK
Island Express	15,164	2,888	6,417	288,756	17,266		
Jim Air	860	144	629	14,425	27,635		AK
Katmai Air [2]	8,348	275	511	27,549	1,334		AK
Kenmore Air Harbor	51,974	4,155	7,730	415,515			
Larry's Flying Service	7,569	990	5,353	98,956	99,270		AK
Las Vegas	8,340	749	1,077	74,944	2,191		
L.A.B. Flying Service	32,966	2,215	3,477	221,480	99,285		AK
Merlin Express	52,216	15,423	42,272	1,542,263	116,986		
New England	25,031	426	958	25,031	559		
Olson Air Service	4,883	423	2,736	42,229	40,192		AK
Pacific Island	89,895	5,455	10,613	545,524	545,524		
Paradise Island	242,066	42,612	75,957	4,261,205			
Peninsula	179,334	45,976	99,724	4,597,570	320,674	Y	AK
Pine State	1,545	390	1,319	39,013	2		
Pro Air	160,602	73,399	308,727	7,339,767			WA
Promech	18,667	661	2,166	66,082	17,697		AK
Redwing	2,566	331	1,598	33,101			
Samoa Aviation	71,675	6,972	10,244	696,949	8,576		
Scenic	286,418	49,861	67,382	4,986,054			
Seaborne Aviation	63,275	2,385	3,637	238,547			AK

U.S. Small Certificated and Commuter Airlines, 1997 - 1998 (Continued)

Air Carrier	12 month period ending 6/30/98						
	Passenger Enplane-ments (x 1,000)	Revenue Passenger Miles (x 1,000)	Available Seat Miles (x 1,000)	Passenger Ton-miles (x 1,000	Cargo Ton-miles (x 1,000)	Code-Sharing [1]	HQ State
Skagway Air Service	10,099	803	1,711	80,292	15,849		AK
Southcentral Air	42,158	2,873	10,258	287,285	65,777		AK
Springdale Air	1,065	154	456	15,443	2,668		
Sunrise [2]	448	59	226	5,869			
Tanana Air Service	4,329	369	2,612	36,912	70,118		AK
Taquan Air Service	113,304	3,375	17,500	312,398	147,036		AK
Viesques Air Link	76,815	2,434	3,934	243,366			
Village Aviation	196	1	22	112	251		AK
Warbelow's Air Ventures	32,418	6,855	17,724	685,543	584,609		AK
Ward Air	43	1	9	96	25		
West Isle Air	26,436	1,029	2,602	102,925	976		
Wings of Alaska	29,234	1,414	4,454	141,358	35,725		AK
Wright Air Service	10,755	1,729	5,139	172,850	81,796		AK
Yute Air Alaska	74,223	5,804	17,410	580,351	237,778		AK

[1] Carrier has code-sharing arrangements with one or more major airlines;
source: RAA website: http:/www.raa.org/newsdesk/archive/Codeshare.htm.
[2] Carrier started service within 12 month period; less than full year's data provided.
[3] Wholly-owned subsidiary of a major air carrier.
Source: Reference (31)