Guidance for Treatment of Airport Stormwater Containing Deicers

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 99

Guidance for Treatment of Airport Stormwater Containing Deicers

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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- New York City Department of Environmental Protection

FOREWORD

By Joseph D. Navarrete
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ACRP Report 99: Guidance for Treatment of Airport Stormwater Containing Deicers provides a step-by-step process for identifying, selecting, and implementing technologies to treat stormwater that has been affected by applied deicing materials. The guidebook addresses the processes for identifying the various drivers for deicer treatment and for evaluating the appropriateness of various treatment technologies to meet an airport's specific needs. The guidance also provides recommendations for the design, operation, and maintenance of each treatment technology.

At many airports, the impact of aircraft and pavement deicing materials on stormwater is significant enough that treatment is required to meet the limits of their stormwater discharge permits. Yet airport personnel may not have the expertise to select the most appropriate treatment methods to meet their unique situations. Moreover, there has been considerable industry uncertainty about the performance, cost, and appropriateness of various methods for specific treatment situations.

This research, led by Gresham, Smith and Partners, began with summarizing existing and emerging treatment technologies. Next, an inventory of current treatment technologies used at U.S., Canadian, and selected European airports was prepared. The research team then undertook a detailed performance assessment of the 11 most common technologies used at a variety of airports. To supplement the evaluation of field performance data, lab tests were conducted to observe how certain design and operational parameters affected biological treatment. Based on this research, the team developed the guidebook.

The guidebook is organized into six chapters, with the first chapter providing an introduction and overview. Chapter 2 defines the process for identifying deicer treatment needs and implementation constraints. Chapter 3 provides descriptions of existing deicer treatment technologies. Guidance for selecting appropriate deicer treatment technologies is provided in Chapter 4. Considerations for designing and implementing deicer treatment systems are provided in Chapter 5. Cost considerations, often a key factor in selecting an appropriate treatment technology, are summarized in Chapter 6.

The guidebook also provides helpful appendices that include descriptions of deicer treatment technologies used at major airports, a matrix of key characteristics for existing technologies, and summaries of 15 representative airport deicer treatment systems.

Detailed information on various deicer treatment technologies is provided in a series of fact sheets. These fact sheets describe key factors, such as how the technology works, conditions that may be favorable or unfavorable for using the technology, required support systems, airports where the technology is being used, and data to relate the mass load of deicer to be treated to order-of-magnitude costs.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Introduction

1.1 Background

To support safe operations, airport operators and tenants apply a variety of deicing and anti-icing chemicals (collectively called *deicers*) to aircraft and to airport paved surfaces. The mixed flows containing applied deicers and stormwater runoff must often be managed to mitigate potential environmental impacts to surface water and groundwater. The comprehensive, integrated systems for collecting, conveying, monitoring, storing, treating, and discharging stormwater affected by deicing are often called *deicer management systems* (Figure 1).

Deicer treatment is the component of a deicer management system that removes contaminants of concern from stormwater. Since the mid-1980s, the aviation industry has implemented various deicer treatment technologies. Based on changing airport infrastructure, flight operations, weather patterns, and regulatory compliance needs, implementation of new and enhanced deicer treatment systems is likely to be needed in the foreseeable future.

Deicer Treatment Technologies Featured in the Guidebook

Activated sludge
Aerated gravel beds
Aerated lagoons
Anaerobic fluidized bed reactors
Distillation
Mechanical vapor recompression
Moving bed biofilm reactors
Passive facultative technologies
Private off-site recycling systems
Public wastewater treatment systems
Reverse osmosis

1.2 Guidebook Purpose and Value to Aviation Industry

This guidebook is intended to provide the aviation industry with a reference to facilitate the implementation of deicer treatment technologies at individual airports. In gathering the information for its content, the research team assessed a wide cross section of airports representing many different deicer treatment approaches in the United States, Canada, and Europe. The first objective of the research was to accurately document the deicer treatment technologies that have been applied. Those efforts yielded a better understanding of deicer treatment technology performance and provided numerous lessons learned regarding applicability, performance, cost, and operational considerations. These in-the-field experiences were melded with theoretical understanding of deicer treatment and consolidated in this guidebook.

The guidebook can be used to help frame the deicer treatment component of the overall deicer management system implementation process for individual airports. In practice, however, use of the guidebook must be coupled with consideration of site-specific factors such as stormwater characteristics, permit limits, site infrastructure constraints, airport operational impacts, and costs.

Appropriate implementation of a deicer treatment system must be supplemented by engaged management of the treatment system by airport operators. Deicer treatment is often a unique

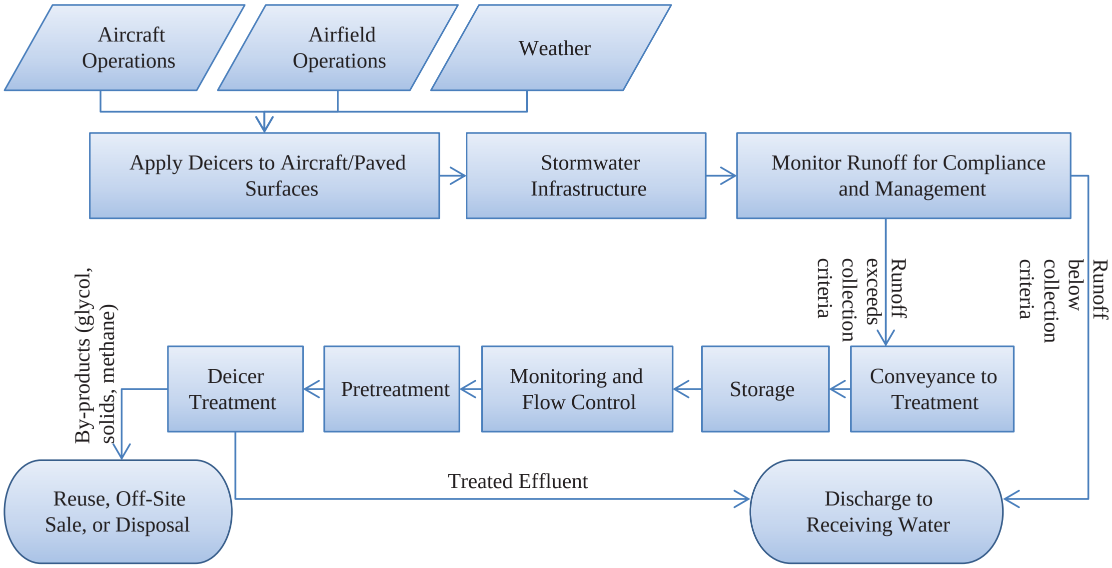


Figure 1. Schematic of potential deicer management system components.

operation for airports and in many ways is a foreign experience. It is also an operation that can be highly dynamic because of real-time dependencies on weather and airport operations. Inadequate management of deicer treatment operations can increase the risk of noncompliance and lead to excessive costs for even the most well-designed treatment system.

The need for a guidebook on deicer treatment is driven by several factors:

- An effective and reliable means of deicer treatment is critical to regulatory compliance.
- Improper selection, design, and management of deicer treatment systems can have significant short-term and long-term cost implications.
- Existing guidance on sizing, effectiveness, and costs of treatment technologies that is derived from treatment of other waters is not always appropriate to treatment of stormwater affected by deicer.
- The experiences and performance data on deicer treatment at individual airports have not been previously transmitted to the aviation industry in a collective manner.

It is envisioned that the aviation industry will find the following guidebook contents of value:

- *Summaries of airport deicer treatment experiences.* The airport summaries in this guidebook provide insight from the real-world experiences of airport operators.

Critical Actions for Engaged Management of Deicer Treatment Systems

1. Provide appropriate operational oversight
2. Facilitate timely maintenance
3. Understand treatment system limitations
4. Be attentive to treatment system needs
5. Coordinate treatment decisions with overall deicer management system operation

- *Treatment technology fact sheets.* Fact sheets for 11 deicer treatment technologies provide concise summaries of the function, features, and application of treatment technologies that have been applied at airports to help inform the technology implementation process.
- *Description of the information needed to establish a basis for selecting and designing treatment.* The guidebook discusses the types of information typically required to establish a basis for treatment technology selection and design.
- *Graphical relationships of technology cost and capacity.* The guidebook presents relationships between the quantities to be treated (pollutant mass loads) and order-of-magnitude capital and operational costs for 11 treatment technologies.
- *Methodologies for selecting one or more deicer treatment technologies.* Potential methodologies that can be used to help select treatment technologies are presented.
- *Insight on techniques for treatment technology design, construction, and operation.* The guidebook distills the collected experiences of the research team and aviation industry into guidance for designing, constructing, operating, and maintaining deicer treatment systems.

1.3 Guidebook Approach to Deicer Treatment Implementation

The guidebook provides a representation of the process an airport may follow for implementation of a deicer treatment system. It provides recommendations on methodologies to follow and on information frequently sought by those considering new or modified treatment systems.

In practice, the deicer treatment implementation process is customized to the individual situations and is often iterative in nature. The needs for site-specific information and assessment of technology applicability to the site go well beyond what is contained in this guidebook. The guidebook can, however, provide a framework and reference to help make the processes implemented at individual airports more effective and efficient.

For many airports, the processes for implementing deicer treatment and the remainder of the deicer management system run in parallel. The scope of this guidebook is focused on deicer treatment. However, because of the link between deicer treatment and the entire deicer management system, other deicer management system elements are referenced throughout the guidebook when there is a significant relationship to deicer treatment.

Recommended Process for Implementing Deicer Treatment

1. Establish the regulatory compliance drivers for treatment system implementation.
2. Characterize the stormwater to be treated.
3. Determine site and operational constraints for treatment implementation.
4. Identify potential deicer treatment technologies.
5. Perform technical and cost assessments to select the deicer treatment technologies.
6. Design and construct the treatment system as part of the overall deicer management system.
7. Actively manage the implemented treatment system.

Table 1. Guidebook structure.

Subject	Location
Guidance on Methodologies for Technology Selection and Implementation	**Main Guidebook Text**
• Introduction	Chapter 1
• Defining deicer treatment needs and implementation constraints	Chapter 2
• Identifying deicer treatment technology alternatives	Chapter 3
• Selecting deicer treatment technologies	Chapter 4
• Designing, constructing, and managing deicer treatment systems	Chapter 5
• Determining costs for deicer treatment	Chapter 6
Information on Individual Technology Characteristics and Capabilities	**Guidebook Appendices**
• Treatment technology use listed by airport	Appendix A
• Treatment technology characteristic matrix	Appendix B
• Instructions for using treatment technology fact sheets	Appendix C
• Airport treatment system summaries	Appendix D

1.4 Guidebook Structure

As shown in Table 1, the guidebook contains six chapters, with Chapters 2 through 6 representing steps in the process for approaching deicer treatment implementation. The emphasis of the appendices is on providing information on technology capabilities and application experiences.

Chapter 1: Introduction

Establishes the need, value, and use of the guidebook and provides general information on the current state of deicer treatment.

Chapter 2: Defining Deicer Treatment Needs and Implementation Constraints

An airport that requires new or enhanced deicer treatment must first define the need, objectives, and basis for the treatment technology selection and design. Chapter 2 discusses the characterization of regulatory constraints, stormwater to be treated, airport site features, and airport operational features that are required to establish the basis for treatment technology selection and design.

Chapter 3: Identifying Deicer Treatment Technologies

Chapter 3 presents information that categorizes and characterizes the deicer treatment technologies that have been applied in the industry.

Chapter 4: Selecting Deicing Treatment Technologies

Chapter 4 describes methodologies that airports can use to help select the specific treatment technology or technologies to be implemented. The elements of the recommended selection process include:

- Screening out technologies that are not feasible, and
- Comparative analysis of technologies based on consideration of site-specific criteria.

Chapter 5: Designing and Implementing Deicer Treatment Systems

Chapter 5 provides guidance, considerations, and lessons learned for the design, construction, and management of the deicer treatment systems in the context of the entire deicer management system.

Chapter 6: Determining Costs for Deicer Treatment

Chapter 6 provides guidance on determining costs for deicer treatment at various stages of implementation and cost considerations for various treatment technology categories.

Appendices

Appendix A provides a list of 106 airports and the deicer treatment technologies that they use. Appendix B provides a matrix of deicer treatment technologies and the parameters that are important to the treatment technology selection process. Appendix C contains instructions for using treatment technology fact sheets for the 11 types of technologies referenced in this guidebook. Appendix D summarizes how 15 selected airports from the United States, Canada, and Europe manage deicer treatment. The featured airport systems were selected to provide a broad representation of in-the-field performance of the technologies in the fact sheets. The types of information presented in the technology fact sheets and airport summaries are listed in the Deicer Treatment Technology Fact Sheet Contents and Airport Deicer Treatment System Summary Contents text boxes.

Throughout the guidebook, text boxes:

- Summarize key points from the guidebook text,
- Illustrate how specific airports have used deicer treatment, and
- Provide treatment tips, which are lessons learned and guidance on specific technical aspects of deicer treatment.

Deicer Treatment Technology Fact Sheet Contents

Process description
Advantages
Disadvantages
Required support systems
Current airport applications
Potential applications
Critical parameters for success
Order-of-magnitude costs

Airport Deicer Treatment System Summary Contents

Treatment technology category
Years operated
Deicer management system description
Technology selection considerations
Deicer treatment technology description
Treatment system performance
Cost assessment
Conclusions on performance
Lessons learned

1.5 Deicer Treatment Terminology

Based on feedback from the aviation industry during research for this guidebook, it is apparent that inconsistent use of deicer-treatment–related terminology can impede the technology's effective implementation. It is recommended that the stakeholders executing deicer treatment system implementation coordinate on defining a common understanding of treatment-related terms that will be used throughout the process. To help facilitate the use of consistent terminology, newly used terms in the guidebook are presented in italics. A full list of terms can found in the Glossary. Several key terms used in the guidebook are defined in the following.

Deicer Treatment Technology: *Treatment technology* is used in this guidebook to refer to a specific physical, chemical, or biological process whose primary purpose is removal of the primary deicer constituents from stormwater. In this guidebook, treatment technology categories include biological-based treatment systems located at airports, recycling-based systems located at airports, and off-site systems like publicly owned treatment works (POTWs) and privately run recycling operations. A primary goal of each category of treatment technology is the removal of primary deicer constituents from the stormwater that will ultimately be discharged to surface waters.

Deicer Treatment System: *Deicer treatment systems* are an integrated set of treatment technologies and support processes that are designed to work together to remove or degrade primary deicer constituents from airport stormwater runoff at a specific airport. The distinction between the terms *treatment technology* and *treatment system* is important in this guidebook. A *treatment* *technology* is a specific means for processing deicer whose essential elements can be applied to multiple airports. A *treatment system* is designed to operate at a specific airport. A treatment system can include one or more treatment technologies sized to the needs of the airport, plus the technology's required support systems (e.g., supporting processes that include piping, containment vessels, mechanical and electrical components, and instrumentation). Head-to-head comparisons of treatment system performance and cost among airports is often not of the apples-to-apples variety, even if the airports are using the same technology, because of the site-specific differences in stormwater characteristics, system capacity, and operating scheme.

For the purposes of this document, a *deicer treatment system* is a subset of the broader term *stormwater treatment system.* A *stormwater treatment system* can be any system or combination of technologies used to improve stormwater quality. Many controls and best management practices (BMPs) for treating constituents in typical airport stormwater runoff are not effective for treating deicers. Many deicer treatment technologies are not designed to treat contaminants such as oil and grease, sediment, and metals.

On-Site Deicer Treatment System: In this guidebook, an *on-site deicer treatment system* is a system that is located at or near an airport *and* is under the direct control of the operator of the airport. The primary function of an on-site deicer treatment system is the degradation, reduction, or recycling of primary deicer constituents in that airport's stormwater runoff. *Direct control* could include operation by airport staff or operation by outside firms contracted by the operator of the airport.

Off-Site Deicer Treatment System: In this guidebook, an *off-site deicer treatment system* is one located off of the airport site that is under the direct control of a non-airport entity and is designed to process wastewaters of multiple types or from multiple sources. Examples of off-site deicer treatment systems are:

- Municipal wastewater treatment plants (WWTPs, also known as POTWs),
- Privately owned wastewater treatment facilities, and
- Privately owned facilities that reclaim/recycle deicing chemical contained in stormwater.

Primary Deicer Constituents: In this guidebook, the term *primary deicer constituent* means the freezing-point–depressant chemicals in deicers that are the primary contributors to potential water quality issues. These includes propylene glycol, ethylene glycol, glycerin, acetate, formate, and urea.

Design Performance: The *design performance* of a treatment system is its treatment and processing capabilities as described in the system's basis of design. Some may refer to this as a "theoretical performance." As a subset of design performance, the term *design capacity* refers to the maximum flow rate of stormwater or mass loading rate of stormwater pollutants that can be processed by a deicer treatment system based on conditions in a projected design year or design circumstance. The design capacity serves as the basis for the sizing and design of the treatment facilities.

Actual Performance: *Actual performance* is the demonstrated performance of a deicer treatment system as calculated using analytical and process data collected during system operation.

A variety of parameters can be used to describe design and actual performance, including:

- *Ability to achieve design capacity.* The ability of a treatment system to demonstrate successful operation at or above its design flow rate or mass loading rates is a common measure of performance. Treatment systems are often sized to have capacity for a future deicing condition to accommodate potential airport operations growth.
- *Treatment efficiency*. Many airport operators calculate the treatment efficiency (also known as removal efficiency) as the percentage of influent pollutant mass load that is removed during

treatment. Treatment efficiency may be expressed for any specific pollutant. This serves as a long-term measure of the performance consistency. Treatment efficiency can be calculated from the following equation:

Treatment Efficiency = (Influent Mass Load – Effluent Mass Load)/(Influent Mass Load)

- *Pollutant effluent concentrations or effluent quality*. The ability of a treatment system to generate effluent at or below its design concentration targets for pollutant parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), propylene glycol (PG), or ethylene glycol (EG) is frequently used as a measure of performance. (Refer to Section 2.2 for definition and discussion of specific pollutant parameters.)
- *By-product concentrations and quantities.* The effectiveness of deicer recycling systems, in particular, is judged in part by the magnitude of the concentrated glycol concentration and the quantities of recycled product that can be reclaimed. For some biological treatment systems, the quantity of off-gas that can be captured and used for fuel is also used to assess performance. The quantity of biological solids that need to be disposed of is also a performance indicator.
- *Cost performance.* Both capital and operating/maintenance costs are important parameters in judging the performance of a treatment system.

1.6 Current Deicer Treatment Technology Applications

The research effort for this guidebook included collecting, assessing, and consolidating the experiences of those airports that have implemented deicer treatment systems. The research team gathered information from 106 airports that use deicer treatment technologies. The 106 airports are distributed throughout the United States, Canada, and Europe. The information was gathered from existing publicly available information, site visits to airports, phone discussions, and research team experience. A total of 155 deicer treatment technology applications were identified at 106 airports. The 155 technology applications and the 106 airports provide a large sampling of the technologies that have been applied, but do not represent all of the deicer treatment applications at all airports. From an evaluation of the 155 treatment applications, the research team identified 11 basic categories of deicer treatment technologies for inclusion in this guidebook. The primary criteria for inclusion of a technology in the list were:

- The technology has been applied to treat deicer-affected runoff in a full-scale system.
- The technology has characteristics that are reasonably distinct from other technologies in the list. Some closely related technologies were grouped into a single technology category.
- There has been enough experience with using the technology to make supportable conclusions regarding its applicability and effectiveness for deicer treatment.

Figure 2 illustrates the range of deicer treatment technology applications based on the information gathered in this research. As shown, approximately two-thirds of the technology applications involve treatment that is not on the airport site and not under airport control. This includes discharges to POTWs or recycling of deicer at private facilities not owned by the airport or municipality. As shown in Figure 3, approximately one-third of airports use more than one technology. Almost 50% of the airports that discharge to a POTW also have some type of on-site treatment. Figure 4 through Figure 7 show the distribution in the United States of the deicer treatment methods discussed in this guidebook: on-site biological, on-site physical treatment (generally recycling), off-site biological treatment (generally POTWs), and off-site physical treatment (generally recycling). Please refer to Appendix A for a complete list of the airports represented in these graphics. The individual treatment technologies are discussed in more detail in Chapter 2.

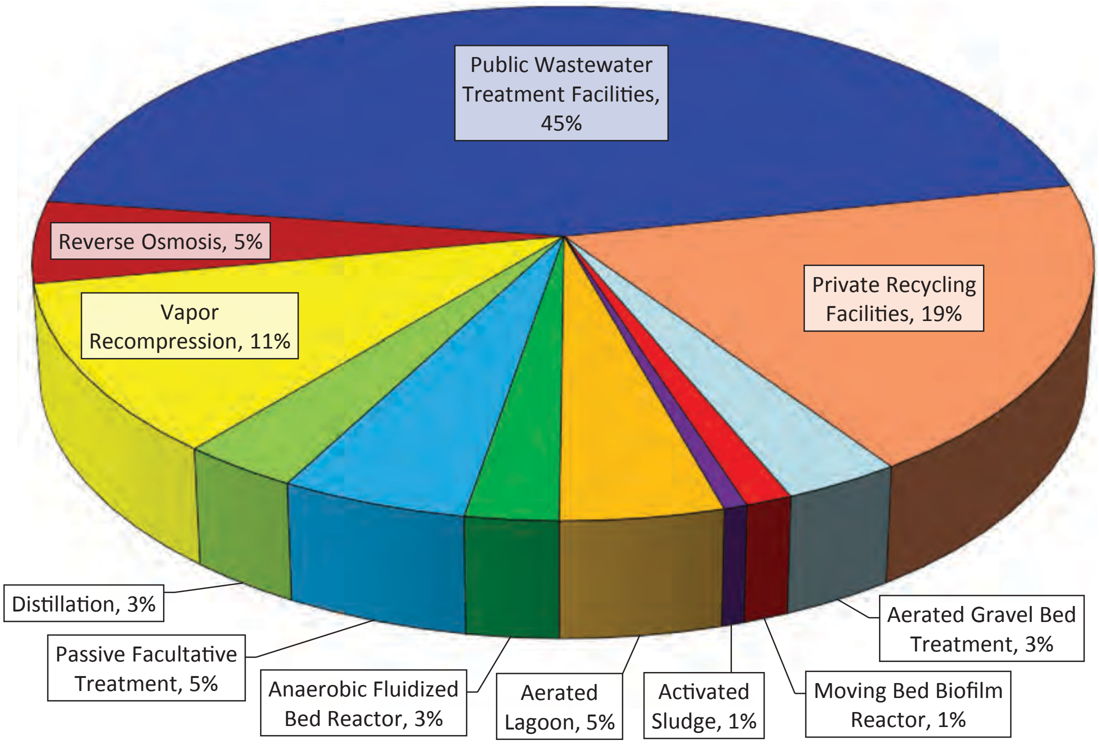


Figure 2. Deicer treatment technology use in assessed airports.

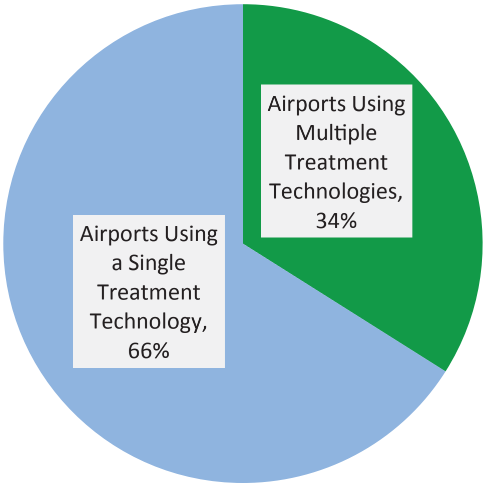
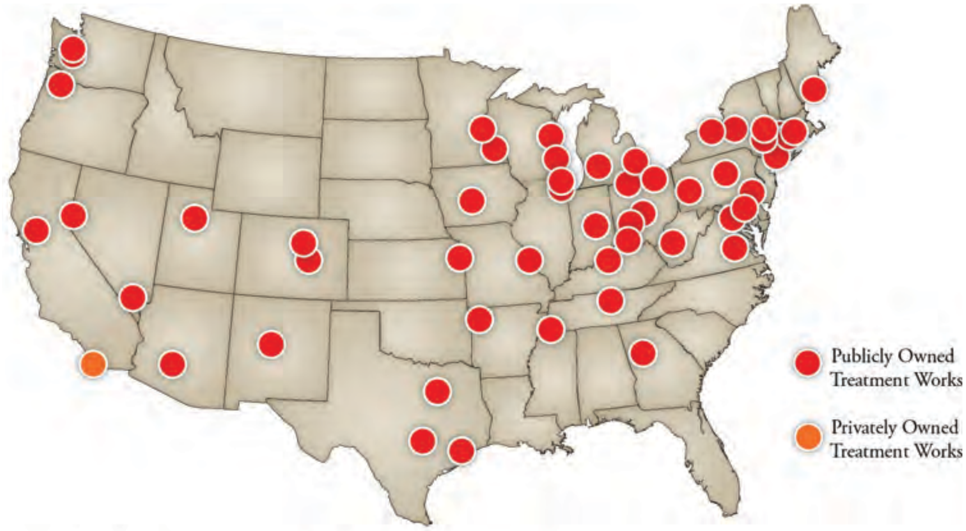
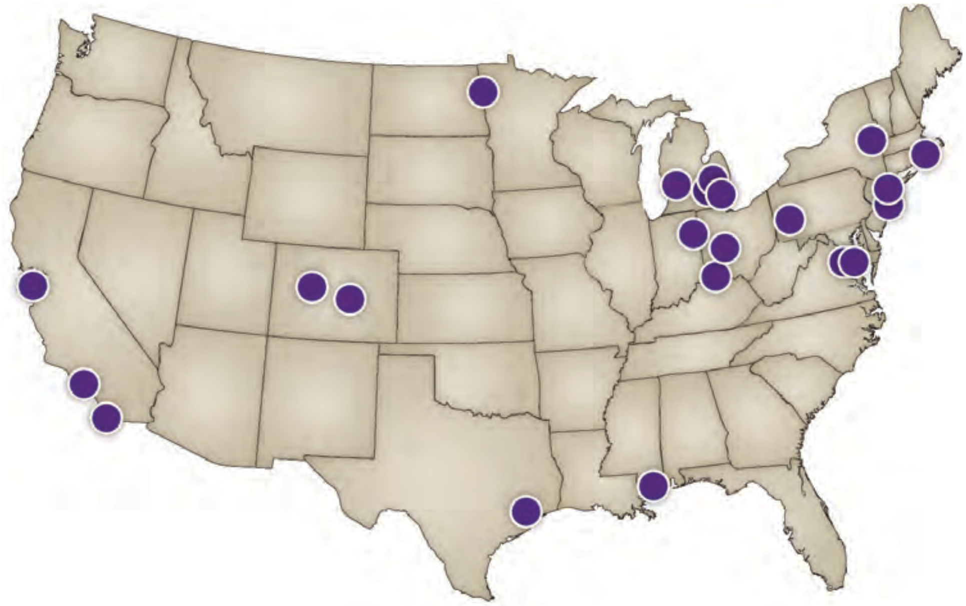


Figure 3. Airports using more than one treatment technology.



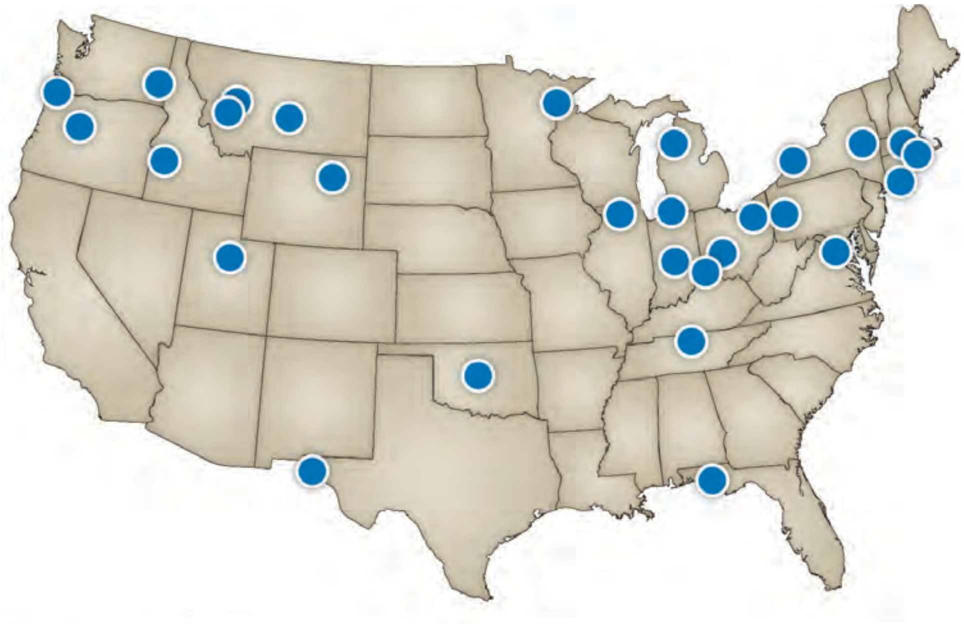
*Graphic may not represent a comprehensive list of all airports

Figure 4. U.S. airports using off-site biological treatment technologies.



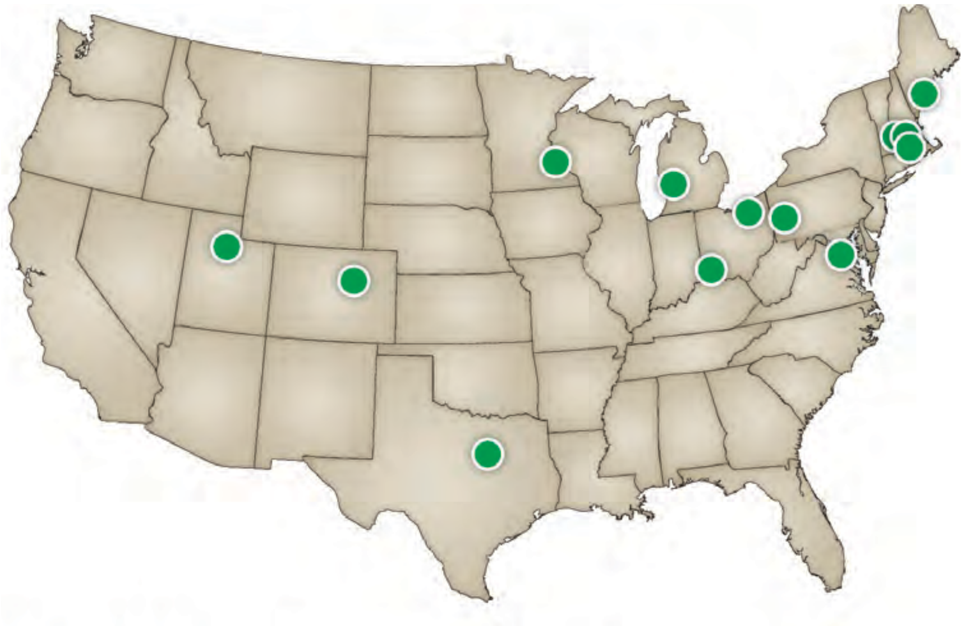
*Graphic may not represent a comprehensive list of all airports

Figure 5. U.S. airports using off-site recycling technologies.



*Graphic may not represent a comprehensive list of all airports

Figure 6. U.S. airports using on-site biological treatment technologies.



*Graphic may not represent a comprehensive list of all airports

Figure 7. U.S. airports using on-site physical treatment technologies for recycling.

CHAPTER 2

Defining Deicer Treatment Needs and Implementation Constraints

Deicer treatment systems are implemented primarily because the pollutants contained in the deicer-affected runoff are greater than the allowable pollutant in discharges to surface waters or groundwater.

When assessing what deicer treatment is needed (see Figure 8), the following must be determined by the airport:

- The type of deicer treatment technology(s).
- The capacity or size of treatment required.
- The role of treatment in the deicer management system.

To determine the specific deicer treatment needs, the following must first be defined:

1. Allowable pollutant discharges based on regulatory requirements (Section 2.1).
2. Characteristics of the stormwater affected by excess pollutants from deicing (Section 2.2).
3. Constraints to implementing treatment at the airport based on site characteristics and operational needs (Section 2.3).

In Section 2.4, example tables for documenting the results of this assessment are provided.

2.1 Allowable Pollutant Discharges

Almost all applications of deicer treatment technologies and their supporting systems are driven by the need to comply with environmental-based regulatory requirements. Typically, numeric limitations for commonly regulated deicing-related pollutants (e.g., BOD, PG) have the largest effect on treatment. Occasionally, other regulatory conditions can affect treatment technology implementation, including numeric limits for less common parameters, numeric ambient or receiving system conditions, narrative conditions, and receiving waters capacity limitations.

An analysis is necessary to find the limiting conditions for the existing permits and agreements that will govern the treatment requirements for a specific airport facility. Such an analysis may also need to incorporate assessment of potential new limits that will be imposed on the airport. An overview of the process for determining the governing limits is presented in Figure 9 and discussed in the following sections.

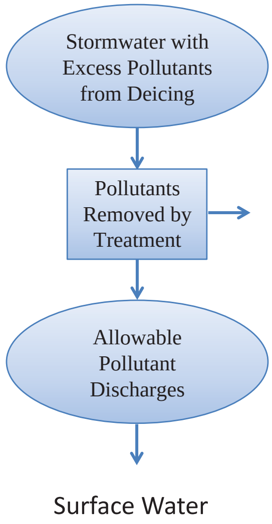


Figure 8. Quantifying treatment needs.

2.1.1 Identify Applicable Regulations and Agreements

Obtaining an understanding of the applicable regulations, permits, and agreements is the first step toward determining the allowable discharges that govern the basis of design for a treatment system. The criteria defining the allowable discharge could apply to untreated effluent discharged to an off-site location or treated effluent from a future on-site treatment system.

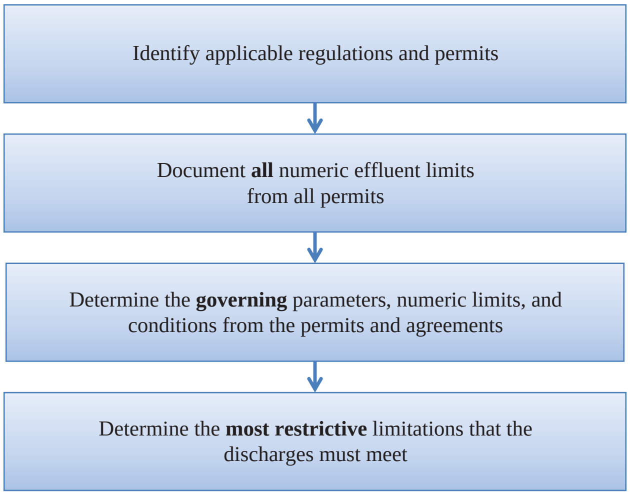


Figure 9. Steps in determining the discharge limitations that govern treatment needs.

2.1.1.1 Overview of Applicable U.S. Regulations

The federal Water Pollution Control Act amendments of 1972 and subsequent amendments, commonly known as the Clean Water Act (CWA), established the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Through Section 402 of the CWA, the National Pollutant Discharge Elimination System (NPDES) was created as a system for permitting point-source discharges to the waters of the United States. Point sources include treated wastewater from domestic, commercial, and industrial sources as well as stormwater contaminated with pollutants. The NPDES permit program generally requires that point-source dischargers of pollutants to waters of the United States (i.e., direct dischargers) obtain an NPDES permit or their state equivalent. The U.S. Environmental Protection Agency (EPA) has authorized regulatory agencies in most states to administer their NPDES programs, but there are four states[1] and the District of Columbia for which EPA retains this authority and issues NPDES permits to all direct dischargers.

Point sources may also discharge into collection (sewer) systems of other treatment facilities (instead of direct discharge under an NPDES permit). Such point sources are indirect dischargers. Airports may discharge either directly or indirectly—with appropriate regulatory permits in either case.

Airports that directly discharge deicer-affected stormwater runoff into surface waters are required to have one of two types of NPDES permit: either coverage under an applicable general NPDES permit, or an individual NPDES permit issued specifically for their facility. General NPDES permits cover many facilities that have similar operations or similar types of discharges, whereas individual NPDES permits are issued based on site-specific activities or discharges. General NPDES permits typically have requirements to implement BMPs to minimize pollution and may or may not have specific numeric effluent limitations. Individual NPDES permits typically have specific numeric effluent limitations for one or more pollutants, and they are usually required by the state agency or EPA based upon relative concern for potential violations of water quality standards. The agency will determine whether an airport will be required to obtain a general or individual NPDES permit.

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[1] Idaho, Massachusetts, New Hampshire, New Mexico, and the District of Columbia do not have approved state NPDES permit programs. NPDES permits in these states are issued by the respective EPA region.

Under the CWA, the effluent limits in NPDES permits are based on two principles: (1) all wastewater discharges must be treated with the best treatment technology economically achievable, regardless of the condition of the receiving water (which results in technology-based limits); and (2) more stringent effluent limits may be imposed if the technology-based limits do not prevent violations of water quality standards in the receiving water (which results in water-quality–based limits).

2.1.1.2 General NPDES Permits

General NPDES permits cover multiple facilities within a specific category, are issued by a state agency or the EPA, and are applicable only to dischargers within one state. Multiple facilities may be authorized to discharge under a single general permit. Many states have adapted general permits modeled after the EPA Multi-Sector General Permit.[2] Some states have their own version of a general permit applicable to industrial stormwater discharge, which, in general, has similar provisions and requirements.

General permits for stormwater discharges include requirements to implement BMPs, to prepare and implement a stormwater pollution prevention plan (SWPPP), and to perform monitoring of stormwater discharges, and may include effluent limitations or discharge benchmarks. The Multi-Sector General Permit has a section with sector-specific requirements that apply to air transportation facilities and, specifically, to discharges from airfield and aircraft deicing activities. Included in this permit are effluent monitoring benchmark concentrations for 5-day biochemical oxygen demand (BOD_5) (30 mg/L), COD (120 mg/L), ammonia (2.14 mg/L), and pH [6.0 – 9.0 s.u.(standard units)]. If benchmarks are exceeded, it is not a permit violation, although the airport would be required to implement additional practices to prevent further exceedances. In some states, failure to meet benchmarks results in the issuance of an individual NPDES permit.

2.1.1.3 Individual NPDES Permits and Effluent Limits

Individual NPDES permits are typically required when the state agency believes there is a reasonable potential for violation of water quality standards in the receiving water body as a result of the airport's stormwater discharges. As do general permits, a typical individual NPDES permit for an airport will include requirements that appropriate BMPs be implemented and that an SWPPP be prepared and implemented. An individual permit for an airport will also have effluent limits that are developed based on water quality considerations and may also include technology-based effluent limits. Effluent limits in individual NPDES permits are either water-quality–based limits (based on the water quality criteria and conditions of water bodies receiving the discharges) or technology-based limits (based on a treatment technology that is considered appropriate for dischargers in the same industrial category), as further described in the following.

> **Water-Quality–Based Limits:** Water-quality–based effluent limits are developed to ensure that the permitted discharge will not result in an exceedance of water quality criteria in the receiving water body. The limits are derived from existing upstream pollutant concentrations and the corresponding water quality criteria applicable downstream of the discharge. If water quality for one or more pollutants is not currently in attainment, then a total maximum daily load (TMDL) assessment for the entire watershed (or a portion) will be performed. The TMDL for each pollutant will determine an allowable allocation of pollutant loads to each point source (including the airport) and all nonpoint sources, and these load allocations will be used to derive the specific permit limit.
>
> **Technology-Based Limits:** Regulations under the CWA direct the EPA to develop treatment-technology–based effluent limits for groups of industrial facilities ("categories") that are similar in their activities or the nature of wastewater generated and that apply to all industries within the same category

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[2] "Multi-Sector General Permit for Stormwater Discharges Associated with Industrial Activity," U.S. EPA, 2008. http://cfpub.epa.gov/npdes/stormwater/msgp.cfm.

> regardless of their location in the United States. In 2012, the EPA published final technology-based effluent limitations guidelines (ELGs) and new source performance standards to control discharges of pollutants from airport deicing operations.[3] The requirements generally apply to wastewater associated with the deicing of airfield pavement at primary existing airports. The rule also establishes New Source Performance Standards (NSPSs) for wastewater discharges associated with aircraft deicing for a subset of new airports. The rule does not establish uniform, national requirements for aircraft deicing discharges at existing airports. Requirements will continue to be established in general permits, or for individual permits on a site-specific, best professional judgment basis by EPA or state permit writers, as appropriate. Existing and new primary airports with 1,000 or more annual jet departures (non-propeller aircraft) that generate wastewater associated with airfield pavement deicing are to use non–urea-containing deicers or, alternatively, meet a numeric effluent limitation for ammonia (14.7 mg/L) prior to any dilution or commingling with any non-deicing discharge. New airports, excluding airports in Alaska, with 10,000 annual departures located in cold climate zones are required to collect 60% of aircraft deicing fluid available for capture. Airports that discharge the collected aircraft deicing fluid directly to waters of the United States must also meet numeric discharge requirements for COD (271 mg/L daily maximum, 154 mg/L weekly average). These limits are based on the anaerobic fluidized bed reactor (AFBR) treatment technology representing best available technology economically achievable for deicer-runoff treatment, although an airport subject to these may use any alternative treatment technology. Technology-based limits applicable to an airport are integrated into the facility's NPDES permit by the governing agency's permit writer.

If both technology-based limits and water-quality–based limits are applicable for a given parameter, the most restrictive of the limits is incorporated into the permit.

2.1.1.4 MS4 Permits

Some airports, or portions of airports, may be regulated under rules for municipal separate storm sewer systems (MS4s). An MS4 is a conveyance or system of conveyances (including roads, catch basins, curbs, gutters, ditches, man-made channels, and storm drains) that is owned or operated by a public body, designed and used for collecting stormwater, is not a combined sewer, and is not part of a POTW. An entity designated as an MS4, such as a local municipality, may impose certain conditions on airport stormwater discharges within the municipality's MS4 service area, typically through conditions in the municipality's stormwater management plan. This may result in the need for additional monitoring and control of pollutants within the airport's drainage area.

Some airports may also be classified as MS4s themselves, which can result in the need to develop targets for reducing the quantities of particular pollutants in their discharges. Those pollutant reduction targets may result in the need for the airport to control deicer discharges beyond, or differently from, what is required in its individual or general industrial NPDES permit.

2.1.1.5 Industrial User Discharge Permits from POTWs

POTWs collect and treat wastewater from residential, commercial, and industrial sources. Generally, POTWs are designed to treat only domestic sewage and biodegradable commercial and industrial wastewater. POTWs are not necessarily capable of treating all pollutants discharged by industries. They are also not always capable of treating the full load of biodegradable wastes from industries. The undesirable effects of discharges from industries can be prevented by various management practices or treatment at the industrial facility (referred to as "pretreatment"). In order to protect the POTWs and avoid adverse impacts from industrial wastewater that could prevent full compliance with the POTW's NPDES permits, the EPA established the National Pretreatment Program [regulations are published in 40 Code of Federal Regulations (CFR) 403]. These regulations require that POTWs receiving industrial wastewater must develop and implement their own industrial pretreatment program. The POTW is established as the

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[3] "Effluent Limitations Guidelines and New Source Performance Standards for the Airport Deicing Category," 40 CFR Part 449, May 16, 2012.

Treatment Tips

Impact of Deicing ELG on Treatment Requirements

The U.S. EPA ELG for airport deicing operations did not establish uniform, national requirements for aircraft deicing discharges for existing U.S. airports.

For new airports exceeding a specified number of flight operations, effluent limits for COD are established for discharge directly to receiving waters.

The ELG does not specifically require that deicer-affected stormwater be treated or that any specific type of treatment technology be used.

Site-specific water-quality–based effluent limits will continue to be the primary regulatory drivers for deicer treatment in the United States.

control authority for implementation of its pretreatment program, much as a state agency is the control authority for its NPDES permit program.

A central requirement of pretreatment programs is the development of local limits applicable to discharges from industries, which will prevent interference with operation of the treatment processes or sludge use or disposal, and which will prevent pass-through of pollutants that could result in violation of NPDES permit limits or water quality criteria in the receiving water body. An airport is considered an industrial discharger by POTWs in the United States, and the airport stormwater discharges to the sanitary sewers are viewed similarly to wastewater discharges from manufacturing industrial facilities in terms of pollutant discharges. POTWs may also have concerns about the stormwater aspect of the discharges—specifically the volumes of stormwater that are processed by the POTW, and in some cases, POTW regulatory requirements regarding receipt of stormwater discharges may affect their ability to accept airport discharges of stormwater. With respect to the pollutant content of airport deicer-affected stormwater discharges, during development of local limits, the POTW treatment BOD capacity must be assessed, and loading or concentration discharge limits for BOD or COD may be established.

Under the POTW pretreatment program, all significant industrial dischargers, called industrial users (IUs), must obtain permits (or equivalent control mechanisms) to discharge to the POTW. These IU discharge permits include the local limits developed by the POTW, as well as effluent monitoring and reporting requirements. Each IU is responsible for determination of what level of pretreatment may be necessary to comply with the limits, and must design, install, and operate its pretreatment system in order to comply. IU discharge permits may also include other conditions and requirements relating to the discharge.

The discharge limits and other conditions in the IU permits are necessary to allow POTWs to comply with their own NPDES permit requirements. Each POTW (municipality, county, or local authority) establishes its own local sewer use ordinance that defines requirements for obtaining a user permit and appropriate discharge requirements and conditions. As discussed in Chapter 6, the entity issuing IU permits will establish a cost structure for the allowable discharges. The cost structure might include fees based on flow volume, as well as surcharge fees for parameters such as BOD, COD, total suspended solids (TSS), and ammonia-nitrogen (NH_3-N). The surcharges are applied when discharge concentrations exceed a predetermined threshold concentration or mass load amount.

Treatment Tips

Regulatory Considerations for Airports Discharging to POTWs

When establishing limits for potential airport deicer-impacted stormwater discharges to sanitary sewers, the POTW's primary consideration is the measures necessary to protect the POTW from violating its own NPDES permit limits or exceeding receiving stream water-quality criteria.

Industrial user permit limits are therefore set to ensure that the airport discharges:

1. Do not exceed the POTW hydraulic capacity, BOD load treatment capacity, or solids handling capacity.
2. Do not compromise POTW treatment operations.

2.1.1.6 Applying for Discharge Permits

The airport must submit an application for the appropriate discharge permit to the control authority: either the state agency or EPA for an NPDES permit, or the local POTW for an IU discharge permit. In some cases, the application will be for modification of an existing permit. Each control authority has specific application procedures and permit application forms. These are often available from the control authority's website, although it is highly recommended that the airport call or meet with the appropriate contact person(s) to discuss application requirements and verify understanding of specific information required.

Both NPDES permits and IU discharge permits are issued with an effective duration of not more than 5 years and must be renewed prior to expiration. The permitting control authority (either state agency/EPA or the POTW) establishes procedures and application forms for renewal of the discharge permit. NPDES permits (both individual and general) require that the permit holder submit the permit renewal application at least 180 days prior to the permit expiration date. Local IU discharge permit renewal requirements and procedures vary from one POTW pretreatment program to another, and the program contact should be consulted for specific details.

2.1.1.7 Agreements with Private Entities

For some airports, deicer-affected stormwater is conveyed or trucked to privately owned off-site facilities for processing. Typically, the off-site facilities are glycol recycling operations, but some airports also use private wastewater treatment facilities. The airports, or entities representing the airports, will establish agreements with these facilities that establish the terms of the disposal. These terms could place restrictions on the quantities, lower or upper concentrations, or timing of the material transfer, which could in turn affect pretreatment or storage needs at the airport. In a typical arrangement with a private entity, stormwater containing aircraft deicing fluid (ADF) is collected at the airport, temporarily held in storage tanks, and transported to the off-site, privately owned treatment facility. In some cases, the airport can transport the collected fluid without any on-site treatment. In other situations, some partial treatment of the collected ADF at the airport is necessary to reduce water content so that overall volume can be reduced. The airport, as generator of the collected ADF, must ensure that proper chain of custody is completed, and it also assumes liability for the waste not being treated in accordance with all local, state, and federal requirements.

Common Limiting Parameters Driving Treatment Performance Needs	**Less-Common Limiting Parameters Driving Treatment Performance Needs**
Treated effluent BOD, COD, PG concentrations	Effluent total suspended solids
Treated effluent BOD and COD loads	Effluent total dissolved solids
Treated effluent nutrient concentrations (N, P)	Effluent temperature
Stormwater flow rates	Stream or groundwater temperature
Stormwater volume	Groundwater depth
	Receiving stream flow rate
	Time of day or year
	POTW short-term capacity
	Presence of nuisance growth
	pH

2.1.2 Documenting All Applicable Limits and Conditions from Permits and Agreements

NPDES permits regulating discharges to surface waters, IU permits regulating discharges to sanitary sewers, and other permits may trigger the need for an airport to monitor stormwater discharges and to meet effluent limitations. Privately run facilities that accept deicer-affected stormwater for treatment or recycling may establish limits on the characteristics and quantity of the stormwater. In addition, the regulatory permits and agreements with private entities may place restrictions on the timing or conditions under which discharges can occur. The limits contained in the permits and agreements provide airport operators with their initial drivers for considering treatment. As a first step in understanding the governing limits for treated effluent, the parameters from the various permits that potentially govern discharges to on-site treatment systems or off-site entities should be documented.

The many limits, timescale of applicability (e.g., daily maximum, monthly average), points of compliance, monitoring requirements, and associated conditions should be documented in a comprehensive matrix covering all applicable permits and agreements. This will serve as the basis for determining which of the conditions from the permits govern compliance, as discussed in Section 2.1.3.

2.1.3 Determining the Governing Conditions from Permits and Agreements

Not all limits contained in the permits directly affect the selection of treatment technology and the design of the treatment system. Analysis of the permits and agreements is needed to define the parameters and limits that will govern design conditions. The *governing conditions* are essentially the most restrictive effective limits and the limits that help define the extent of the required treatment. A variety of permit features may affect the governing conditions for treatment, including:

- Limits for the same parameters may be found in multiple permits, causing issues with conflicts and overlaps.
- A given parameter may be limited in multiple ways. A common example is having BOD_5 limits for both concentration and mass loading.

- Parameters might be limited on multiple timescales (e.g., maximum and monthly average).
- A permit may contain limits for related parameters, such as BOD_5, COD, and PG. Frequently, only one of the related parameters provides the governing limits.

It is also necessary to consider the circumstances and ambient conditions under which NPDES limits apply. For example:

- The point of compliance for a treated effluent may not be at treatment facility discharge, but at a downstream point where the treated effluent has mixed with other stormwater discharges.
- In addition to other permitting requirements, new outfalls necessary for discharge of treated effluent to surface waters could trigger waste-load allocation and anti-degradation analyses requirements, with the result being newly regulated parameters or outfall-specific effluent limits.
- Discharges to surface waters might be restricted during dry weather conditions.
- The permit monitoring requirements may not align with the monitoring needed for treatment system process control.
- Limits for summertime discharges may be more restrictive than wintertime discharges. This can affect airports that treat down stored loads well past the end of the deicing season.

Conditions in IU permits from POTWs, such as those in the following, must be assessed:

- Allowable loadings for BOD_5 may vary with time or condition.
- Restrictions can be placed on discharges to the sanitary sewer during wet weather conditions.
- The monitoring performed by the POTW may not synchronize well with the monitoring performed by the airport for the type of sample, type of analyses, location, or number of samples used to calculate allowable discharges and fees.
- The POTW may impose restrictions on flow rates because of POTW treatment plant or sanitary sewer capacity limitations.

Some examples of specific types of restrictions from actual POTW IU discharge permits are shown in the "Examples of Types of Airport Discharge Limitations in POTW Discharge Permits" text box. The specific combination of discharge restrictions and limits will be unique to each airport and POTW.

Potential considerations in establishing limiting conditions in agreements with private entities for off-site recycling are listed in the following bullets. These conditions may be

Examples of Types of Airport Discharge Limitations in POTW Discharge Permits

- Daily maximum BOD_5 (or COD) load .... pounds per day (lbs/day)
- Daily maximum BOD_5 increase from prior day .... lbs/day
- Daily maximum BOD_5 (or COD) concentration .... milligrams per liter (mg/L)
- Daily maximum flow .... million gallons per day (mgd)
- Daily flow rate .... distributed uniformly over 24-hr period
- Discharge not permitted when POTW influent (or specified sewer) flow rate is greater than .... mgd
- Acclimation period (start of discharge season)
  - Maximum initial discharge .... lbs/day
  - Maximum daily increase .... lbs/day

Treatment Tips

Establishing Governing Conditions Affecting Treatment

1. Not all effluent limits affect treatment technology selection and design.
2. Establishing the governing limits that drive treatment may require consideration of multiple deicing conditions, receiving waters conditions, and interactive effects of multiple regulated parameters.
3. Potential changes in permit conditions that may occur during the life cycle of the treatment system or discharge should be considered, to the extent possible.

integrated into the contracts between the airport and the firm managing recycling operations at the airport.

- Minimum glycol concentration requirements.
- Treatment and storage capacities at the off-site facility that dictate the volumes that can be shipped and treated per day, per week, or per month.
- Requirements associated with non-glycol constituents.

The analyses for determining the governing limits associated with permits and agreements specific to treatment have to be site-specific and are an important part of the technology selection and system design process. Calculations may be needed to assess the governing limits under various conditions. An example is provided in the "Example for Establishing Governing Limits from Permits and Agreements" text box.

2.2 Characterizing Stormwater to be Treated

Prior to selecting a deicer treatment technology, the questions of what to treat and how much to treat have to be answered. This requires characterizing the stormwater to be treated on-site or discharged off-site for treatment. This section provides information and guidance on the stormwater characterization process.

2.2.1 Water Quality and Quantity Parameters

Water quality of both the deicer-affected runoff and the receiving streams is largely described in terms of the laboratory analyses used to quantify potential pollutants.

As illustrated in Figure 10, water quality analyses associated with deicing typically fall into four major categories: organics, solids, nutrients, and physical properties. The most typical deicing-related water quality analysis parameters associated with each category are also shown in the figure.

Many of the water quality issues created by deicing are associated with the presence of the primary deicer constituents in stormwater. In this guidebook, the term *primary deicer constituents* refers to the chemicals in aircraft and airfield deicers that serve as freezing-point depressants. The most common primary deicer constituents are propylene glycol, ethylene glycol, glycerin, sodium acetate, sodium formate, potassium acetate, and urea. While the deicer-affected runoff contains other constituents (most typically, deicing fluid chemical additives and non-deicing pollutants), the primary deicer constituents, especially in aircraft

Example for Establishing Governing Limits from Permits and Agreements

An airport has an NPDES permit with concentration and mass loading limits for BOD_5 and concentration limits for PG (shown below). The treated effluent will potentially mix with stormwater runoff from other areas of the airport prior to the NPDES compliance point. The average flow rate discharged from the potential treatment system is 100 gpm. The airport must assess the question: What are the governing limitations for the treatment facility effluent?

Parameter	Permit Concentration Limit	Permit Mass Loading Limit	Is Treated Effluent Mixed with Other Stormwater?
BOD_5	100 mg/L	50 lbs/day	Yes
PG	30 mg/L	No	No

At first glance, the limiting conditions for concentration, flow, and load may seem straightforward. Further examination reveals more information about the effective limiting conditions that will govern the treatment design:

1. The potential mixing of the treated effluent with stormwater from other sources prior to the compliance point could result in higher BOD_5 and PG concentration targets for the treated effluent than are indicated by the permit limits. However, the stormwater flows from other areas are likely to be variable and potentially could be zero (e.g., in an extended dry period). The airport will need to decide if the mixing can be relied upon for dilution. If not, no benefits to the allowable effluent concentrations from mixing should be assumed in treatment system design.
2. At a flow rate of 100 gpm for a treated discharge, the maximum BOD_5 concentration that could be discharged is only 41 mg/L without exceeding the 50-lbs/day mass loading limit (mass loading rate/flow rate $*$ conversion factor = concentration). Hence, at that flow rate, the BOD loading rate is the governing limit, which translates into an effective maximum BOD_5 concentration of 41 mg/L. This concentration is lower than the 100-mg/L limit in the permit, and 41 mg/L becomes the effective concentration limit at high flow rates. At lower flow rates, the effective BOD_5 limit would be higher until the point where the 100-mg/L limit becomes most restrictive. As a result of the effective BOD concentration limit being affected by the mass loading limit, the treatment plant in this example would need to be designed to reach a much lower target for treated effluent concentration.
3. Since 1 mg/L of PG is approximately 1 mg/L of BOD_5, and the PG limit is lower than the BOD_5 limit, PG could be the governing limit, depending on the technology that is used.
4. The governing limits are not necessarily the design points—to account for unknowns in measurement error, equipment functioning, response times, and so forth, the design points are typically set to a more restrictive value to provide a margin of safety.

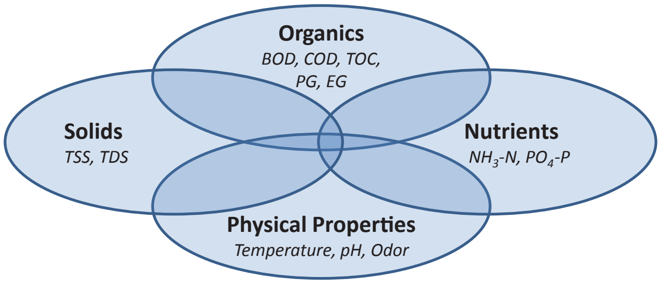


Figure 10. Primary analysis-based water quality parameters associated with deicer treatment.

deicers, are most often the principal drivers for selecting, sizing, and operating deicer treatment technologies and systems.

The primary deicer constituents can directly contribute to the presence of organics, nutrients, solids, and physical properties, as shown in Figure 11.

The water quality parameters shown in Figure 10 and Figure 11 and the associated analyses are described in detail in *ACRP Report 72: Guidebook for Selecting Methods to Monitor Airport and Aircraft Deicing Materials.* A summary of the parameters most commonly associated with deicer treatment is provided in the following.

Propylene Glycol, Ethylene Glycol, and Glycerin

PG is the freezing-point depressant most frequently used in aircraft deicers in the United States, while EG is widely used in Canada. Aircraft deicing fluids that include glycerin as a contributing freezing-point depressant are now available, although their use is not currently widespread.

Both PG and EG can be isolated in on-site and off-site deicer recycling technologies and reused in other products, providing some potential payback to offset processing costs. No known glycerin recycling operations exist for deicing operations. Many airports that use recycling technologies have moved toward arrangements where those applying deicer at the airport use only EG- or PG-based aircraft deicers to maximize the value that can be obtained from the recycling operation. Higher concentrations of both EG and PG result in a more cost-effective overall recycling process, and there is no known limitation on the maximum EG or PG concentration that can be recycled. No technological limitations exist for the minimum EG or PG concentration that

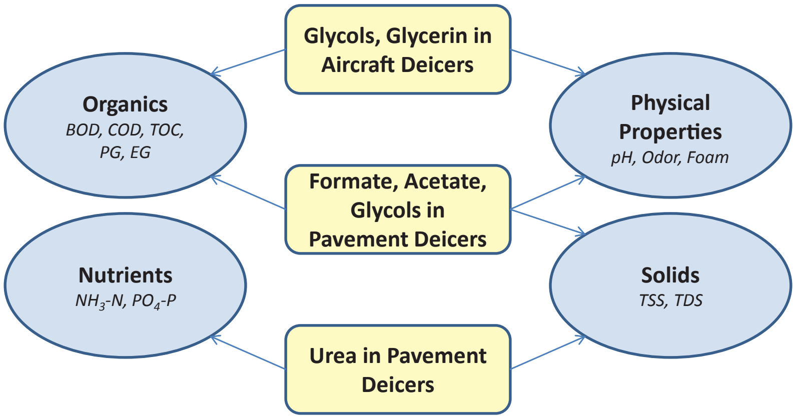


Figure 11. Relationships between deicer constituents and water quality parameters.

can be recycled by the typically used recycling technologies; however, the economics of recycling are affected at lower concentrations because of the increased volumes of water that need to be processed. A general rule of thumb is that minimum EG or PG concentrations of 1% are needed to make recycling economical.

From a biological treatment perspective, EG, PG, and glycerin are all similar chemical compounds and are highly biodegradable. All commonly used biological treatment technologies should successfully treat each chemical if designed and operated properly. The oxygen demands of the chemicals do differ. PG and glycerin carry similar oxygen demands and both have oxygen demands that are higher than that of EG. As a result, biological systems that treat PG and glycerin require larger capacities than systems that treat the equivalent volume of EG. Biological treatment systems can treat a mix of PG, EG, and glycerin without great difficulty, although bacterial populations that are acclimated predominantly to one or the other may take time to acclimate to a new mixture. This may result in short-term decreases in treatment efficiency when the relative concentrations of the constituents change.

In most biological treatment systems, the potential toxic effects of PG, EG, and glycerin on the bacteria are not a limiting factor in treatment. While potential toxic effects of these chemicals to a biological treatment system cannot be ruled out, from a practical sense, it is far more likely that limitations from factors such as oxygen supply, temperature, nutrient supply, extent of bacterial population, and operational variability will affect treatment before toxicity has an effect. In practice, biological treatment systems have demonstrated the ability to treat PG-based runoff with concentrations as high as 50,000 mg/L for anaerobic conditions and 15,000 mg/L for aerobic conditions. The laboratory testing associated with this guidebook did not reveal any inhibitory impacts for aerobic or anaerobic treatment at concentrations less than 7,000 mg/L (the maximum concentration tested). Field performance data on EG-only biological treatment systems are not readily available, but it is likely the maximum toxicity-based EG concentrations are somewhat less than the maximum PG or glycerin toxicity-based concentrations. If toxicity from PG, EG, or glycerin is a concern for the feasibility of biological treatment in unique cases, a pilot study to assess the toxicity is recommended.

Acetates and Formates from Pavement Deicing Materials

The organic portions of potassium acetate, sodium formate, and potassium formate are the acetates and formates. These organics carry an oxygen demand that may be high enough to require treatment. Like the glycols and glycerin in aircraft deicers, the acetates and formates are relatively simple organic molecules and are readily biodegradable.

There are no known operations for recycling acetates and formates. If these chemicals are contained in runoff to be proposed for recycling of glycols, the acetates and formates will typically be separated into the dilute stream and contribute to the BOD that needs to be removed.

If treatment for pavement deicers is necessary, it will be biological in nature. The BOD, COD, and TOC associated with these organics are generally lower than for the aircraft deicers, and often the pavement deicers are applied less frequently. As such, the impact of the pavement deicers to the sizing of biological deicer treatment systems is typically less significant than the impact from aircraft deicers.

While the acetates and formates in pavement deicer materials are biodegradable, their degradation rates can differ from glycols and glycerin. As a result, in treatment systems with biology that is not acclimated to acetates or formates, differences in treatment efficiency can be observed if there are spikes in the presence of these compounds. The performance changes are not typically significant enough to completely disrupt operations, but some adjustments to operational parameters, including potentially short-term reductions in throughput, may be necessary until the bacterial population can acclimate to the different chemicals.

Biochemical Oxygen Demand: BOD is the quantity of oxygen required when organic and nitrogen-based compounds in stormwater are biologically oxidized by bacteria. The BOD concentration is used as a measure of the total concentrations of biodegradable compounds in the sample.

Most often, when the term BOD is used in the aviation industry, it is in reference to the 5-day BOD laboratory test (BOD_5), which is often a required monitoring parameter in NPDES permits. A total BOD analysis will measure both the carbonaceous and nitrogenous contributors to the oxygen demand. The carbonaceous aspect of BOD (CBOD) in deicer-affected stormwater is primarily associated with the organics from glycols, glycerin, acetate, and formate. In addition, those organic compounds may biodegrade in the stormwater during collection and storage and result in breakdown products that also contribute to BOD. For example, PG can anaerobically degrade in storage tanks to produce compounds such as propionates. Propionate compounds derived from PG will not be measured as PG in a lab test, but they will be measured as BOD. The nitrogenous aspect of the BOD in deicer-affected stormwater is associated with nitrogen compounds in urea. With urea mostly taken out of use for deicing, for all practical purposes, the total BOD of a typical airport stormwater sample equals the CBOD.

Since BOD is a measure of the organics that are biodegradable in deicer-affected stormwater, BOD is also the most direct measure of the extent of biological treatment that is necessary. Biological treatment systems are often sized based on BOD load. The mix of constituents contributing to the BOD can also be a factor in biological treatment system performance if the bacterial population becomes predominantly acclimated to a particular chemical.

Treatment Tips

Parameters Driving Treatment

Most often, it is the quantities of BOD, PG, or EG in aircraft deicers and the volume of water to process that drive the selection of treatment technology and capacity of the treatment system.

Many NPDES permits have BOD_5 limits, necessitating BOD measurement in the treated effluent for both biological- and recycling-based systems. (The dilute streams from evaporation and membrane filtration processes for recycling contain concentrations of BOD that may trigger the need for additional treatment to meet compliance criteria.)

Chemical Oxygen Demand: COD is the quantity of oxygen required when an organic compound is chemically oxidized to its ultimate breakdown products (usually carbon dioxide and water). It is a measurement of all the chemicals in the stormwater that can be oxidized. The COD concentration is used as a surrogate measure of the total concentration of all organic compounds in the sample, whether they are biodegradable or not.

COD analyses usually result in higher laboratory concentrations than BOD_5 analyses because (a) more stormwater constituents can be chemically oxidized than biologically oxidized, and (b) the BOD_5 test may not completely measure all of the biodegradable compounds in the sample because the test is limited to 5 days. However, because deicer-affected stormwater samples tend to be dominated by the primary deicer constituent in aircraft deicers (e.g., propylene glycol), there is often a strong correlation between COD and BOD_5 in untreated deicer-affected stormwater. This may not be the case if there is a significant impact from pavement deicers in the mix. The correlation between COD and BOD_5 in treated deicer-affected stormwater effluent may not be as strong because the nonbiodegradable compounds in treated effluent are a higher percentage of the total organics remaining after treatment. Typically, the COD-to-BOD_5 ratio in treated effluent is significantly higher than the COD-to-BOD_5 ratio in the untreated influent.

COD is an attractive and frequently used alternative to BOD_5 for process control in many airport deicer treatment systems because COD analyses results can be obtained in less than 3 hours, as opposed to at least a 5-day wait time for the BOD_5 analysis. BOD_5 analyses are also subject to inaccuracies from factors such as interfering constituents, non-acclimated biological seed, and improper test dilutions. COD analyses are not affected by these conditions.

Total Organic Carbon: TOC monitoring methods measure the amount of carbon dioxide produced when the organic carbon in a water sample is oxidized (thermally, chemically, or by ultraviolet light). TOC concentration is a measure of the total concentration of organic carbon compounds in a sample. TOC is used by some airports in lieu of using COD or BOD to characterize the total concentration or load of deicer constituents to be treated. Most often, TOC is used when online TOC monitors are used to take real-time measurements from flowing stormwater samples. Online monitors can reduce the time to obtain an analytical result to a range of 5 to 10 min. Like COD, TOC generally correlates well to BOD_5 in untreated deicer-affected stormwater that is dominated by aircraft deicers.

In casual discussions on treatment, the terms BOD, COD, and TOC are sometimes used interchangeably. While relationships between the parameters can be established, the correlations can vary considerably based on multiple factors, including those identified in the "Treatment Tips – Correlations" text box. When sizing and operating treatment systems, it is therefore critical to establish site-specific relationships and understand that those relationships can vary with conditions.

Treatment Tips

Correlations

The correlations among BOD_5, COD, TOC, PG, and EG measurements may vary significantly with:

1. Relative contributions of aircraft and pavement deicers,
2. Concentration range,
3. Treated versus untreated runoff,
4. Relative presence of solids, and
5. Characteristics of the measuring instruments.

Understanding the basis and errors in correlations assumed in treatment system sizing and operations is critical for managing cost and compliance risk.

Ammonia: Ammonia-nitrogen exerts an oxygen demand that has a similar impact on receiving surface waters as do biodegradable organic compounds. This is defined as nitrogenous oxygen demand (NOD). The analytical parameter of total BOD is equal to the sum of CBOD and NOD. Ammonia is also toxic to aquatic life, and accordingly, water quality criteria are established at very low concentrations. Although most deicers do not include ammonia, urea used to deice pavement readily biodegrades in the environment to release ammonia. Many NPDES permits for municipal and industrial treatment plants include effluent limitations for ammonia. The ELG established by U.S.EPA requires that non–urea-containing deicers be used for pavement deicing, or that any discharge must meet an ammonia limitation. Because of water quality concerns about ammonia, most airports have replaced urea with use of alternative pavement deicers.

Nutrients: Nutrients are the typically inorganic stormwater constituents that can affect surface waters through formation of algal blooms, decreases in in-stream dissolved oxygen, addition of turbidity, and potentially toxic impacts on aquatic life. The nutrients of concern are certain forms of nitrogen and phosphorus. The NPDES permits of airports located near surface waters where excessive nutrients are a concern may contain limits or monitoring requirements for nutrients, most typically for total nitrogen (TN), total inorganic nitrogen (TIN), total phosphorus (TP), or orthophosphate (PO_4-P). Inorganic nitrogen in three forms can be a nutrient: ammonia-nitrogen (the same form that is both toxic to aquatic life and has an oxygen demand), nitrate nitrogen (NO_3), and nitrate (NO_2). Nutrient contributions from untreated deicer-affected stormwater are not typically a significant issue today because most airports have shifted away from urea use. However, nutrients are needed to support the functioning of biological treatment systems. Airport stormwater runoff typically does not contain significant nutrient concentrations because of the lack of nutrients present on airport surfaces and the lack of nutrient content in deicers. As a result, unlike municipal wastewater, airports operating deicer biological treatment systems need to add nutrients to the stormwater at treatment to support bacterial growth.

Solids: The pavement deicers used at airports are primarily chemical salts (inorganic cations and organic anions) and can contribute to high concentrations of total dissolved solids (TDS).

Excessive concentrations of TDS can potentially inhibit biological activity and could lead to scaling in physical treatment systems. Biological treatment systems will not remove TDS. The physical treatment systems used primarily for recycling may result in larger quantities of TDS segregated into the concentrate streams and less TDS in the dilute streams.

Total Suspended Solids: TSS associated with deicer-affected stormwater can arise from a variety of sources, and treatment support systems may need to be implemented to remove TSS. NPDES permits or user permits for sanitary discharges may limit TSS contained in stormwater discharges. TSS can be inorganic (e.g., sand, sediment) or organic (e.g., biomass, vegetative matter) in nature. The TSS contained in deicer-affected stormwater can lead to clogging in some biological treatment systems and can potentially damage equipment. TSS in the inflows to physical treatment systems such as membrane filtration and evaporation-based systems can cause fouling or damage to equipment. Biological treatment systems produce biological solids (measured as TSS) that may need to be wasted (sometimes referred to as biosolids or sludge).

If the TSS need to be removed for compliance purposes or for protection of the deicer treatment system, support systems for removing TSS before or after deicer treatment may be necessary. The removed solids are typically disposed of off-site. It may be economically beneficial to dewater the solids prior to transport.

pH: Deicer can affect pH in stormwater, but typically not enough to result in water quality issues. However, if deicer-affected stormwater is stored in tanks for long periods of time, especially in warm conditions, the pH may decrease to as low as 3 to 5. Some biological treatment systems, especially anaerobic systems, require integral pH control because of acids produced during the biodegradation of the organics. Typically, however, pH control for deicer-affected stormwater is not a significant consideration.

Temperature: While cold temperatures are not typically a water quality issue for deicer-affected stormwater discharges, low water temperatures have a significant impact on most biological treatment systems. Low temperatures can also affect the pressures needed in membrane filtration (reverse osmosis) systems and also lead to additional energy input for evaporation-based treatment systems. Cold temperatures have resulted in the need to adapt treatment system implementation through heating of the water, insulating systems from heat losses, storing stormwater until temperatures warm, or slowing down the throughput in treatment systems. Some NPDES permits for protected waters place limits on the maximum temperatures, and there may be a few select circumstances where operators need to observe the effluent temperature and manage discharges if treatment extends into warm months.

2.2.2 Water Quality and Quantity Characterization Methods

One of the critical yet challenging aspects of selecting treatment technologies and implementing deicer treatment systems is characterizing the stormwater quality and quantities to be treated. The nature of deicing, driven by variable weather conditions and airport operations, results in significant fluctuations in the flow rates, concentrations, and pollutant mass loadings over the course of time. That variability must be understood not only for the design of the treatment elements, but also to assess if control of the stormwater entering treatment is needed to attenuate peaks.

A detailed assessment of the methods for characterizing deicer-affected stormwater is beyond the scope of this document. Several other ACRP documents can be referenced to provide guidance, including:

ACRP Report 14: Deicing Planning Guidelines and Practices for Stormwater Management Systems
ACRP Report 72: Guidebook for Selecting Methods to Monitor Airport and Aircraft Deicing Materials
ACRP Report 81: Winter Design Storm Factor Determination for Airports

Treatment Tips

Determining the Parameters to Measure When Characterizing Deicer Treatment Needs

When determining the stormwater parameters to characterize, consider the following criteria:

- Parameters identified in permit limits and monitoring requirements.
- Parameters the potential treatment technologies typically use to define capacity and operations.
- Ability to collect sufficient samples at the appropriate runoff conditions.
- Time and cost to perform lab analyses.
- Feasibility and cost of collecting real-time data with portable and fixed online monitoring instruments.
- Ability to simulate the parameters in models instead of sampling and characterization.
- Risks associated with insufficient characterization.

Although detailed guidance on stormwater characterization analyses cannot be presented here, an overview of the stormwater characterization needs is provided because it is critical to effective selection and implementation of deicer treatment systems.

2.2.2.1 Defining the Water Quality and Quantity Parameters

An important step in characterizing stormwater for assessment of deicer treatment needs is to identify the water quality and quantity parameters applicable to your treatment situation. The parameter list will be partially driven by the applicable permit and agreement criteria, but other parameters that affect the ability of a treatment system to function may also be characterized. Typical characterizations that may be required for treatment-related assessments are shown in Table 2.

2.2.2.2 Considerations for Quantifying Stormwater Parameters

The process of quantifying the characteristics of deicer-affected stormwater is unique among wastewaters to be treated because of the variation in flow rates, deicer application quantities, and airport operations. Considerations when developing a characterization of the stormwater for implementing treatment include:

- Range of weather and deicing conditions assessed;
- Time-step for characterization of parameters (annual, monthly, daily, hourly);
- Timeframe for airport/deicing operations (current, future);
- Assumptions on flight schedule, fleet mix, and deicing locations;
- Handling of snow piling and snow melt processes;
- Data/assumptions on precipitation conditions; and
- Information/assumptions on stormwater conveyance infrastructure.

2.2.2.3 Methods for Quantifying Stormwater Parameters

The method by which the stormwater characteristics are quantified can have a significant impact on the results. Quantification methods are rooted in (1) sampling and analysis or (2) modeling. Simplified methods using few deicing events, large time periods between samples, and significant assumptions are less costly to use initially but often lack data on the critical conditions that often drive treatment sizing.

Table 2. Most common stormwater characterization parameters in deicer treatment.

Parameter	Characteristic	Treatment Technologies Where Parameter Is Important
BOD, COD, or TOC	Average loading rate Maximum concentration	Biological systems POTW discharges
PG or EG	Average and maximum concentrations	Biological systems
	Minimum concentration	Evaporation systems Membrane filtration systems Private recycling systems
NH_3-N	Average and maximum concentrations	Biological systems POTW discharge
TSS	Average and peak concentrations Average and peak loading rates	Evaporation systems Membrane filtration systems Private recycling systems
TDS	Average and peak concentrations	Biological systems Membrane filtration systems Evaporation systems
Flow rate	Average and peak flow rates	Biological systems Evaporation systems Membrane filtration systems Private recycling systems POTW discharges
Stormwater volume	Total per day and season	Evaporation systems Membrane filtration systems Private recycling systems POTW discharges
Water temperature	Minimum and average	Biological systems Membrane filtration systems Evaporation systems

More sophisticated modeling methods or extensive sampling requires additional up-front cost but can significantly reduce the risk that treatment is oversized (resulting in unnecessary cost) or undersized (resulting in more compliance risk). Each airport must decide the level of risk that it is able and willing to tolerate. As discussed in *ACRP Report 14,* the selected method should fit the situation being addressed and be consistent with the project goals and level of available data. As with any calculation method or model, the output from the model can only be as accurate as the input data and parameters used to drive it.

When making treatment decisions, stakeholders should be aware of how the characterization data were acquired. The extent that the data represent the variety of conditions, as well as the assumptions and errors implicit in the data, can affect the choice of treatment technology and the success of its long-term operation. For example, conservative assumptions necessitated by a lack of characterization data could result in significantly overestimating the concentration of PG that will be sent to an evaporation-based recycling treatment system. This could change the economics of recycling if the water to be evaporated is vastly different from what was assumed in design. As another example, if the BOD load to be treated in a biological system is underestimated, the system may be undersized. In an undersized system, an operator may be forced to load the system higher than its capacity under heavy deicing conditions, leading to higher effluent BOD concentrations or inhibition of the biological activity.

2.3 Evaluating the Airport Site Conditions and Constraints

Individual airports have specific site and operational characteristics that affect the feasibility and cost of implementing particular deicer treatment technologies. Evaluating those conditions and constraints prior to the evaluation of the technologies can streamline the deicer treatment technology selection process.

Treatment Tips

Understanding the Reliability of Your Stormwater Data

Airports report that insufficient or inaccurate characterization often has led directly to unanticipated treatment costs and noncompliance from overloaded treatment systems. Steps to take in understanding the reliability of your data include:

- Understand the method used to collect the data (sampling/analyses, real-time monitoring, model simulations);
- Verify that sample locations are representative;
- Document the accuracy of analytical methods;
- Verify the occurrence and potential errors of instrument calibration;
- Ensure that accurate correlations are used when relating parameters (e.g., BOD and PG);
- Review collected field data to exclude data affected by instrument malfunctions; and
- Understand timescales, limitations of applicability, assumptions, calibration, and accuracy of site representation in models—test model sensitivity if possible.

2.3.1 Siting Constraints

As part of the constraints analysis, an assessment of potential treatment system sites should be conducted. Siting considerations include:

- Proximity to collected and stored stormwater;
- Proximity to outfalls and sanitary sewers;
- Proximity to utilities, including power, water, and natural gas;
- Proximity to restricted airfield areas;
- Clashes with existing utilities;
- Presence of protected water resource land uses, such as wetlands;
- Stormwater management requirements;
- Geotechnical and hydrogeological characteristics;
- Presence of environmental contamination;
- Planned land uses such as may be found in the airport master plan; and
- Accessibility.

Considerations on potential site constraints are described in the following.

Available Land

Land is almost always at a premium at an airport. Deicer treatment systems typically require between 0.25 acres and 10 acres of land. Most treatment technologies have flexible configurations to allow adaptation to site features. From a siting analysis performed prior to selecting a treatment technology, the available area for a treatment system (and other deicer management features like storage) can be determined for use in the treatment technology screening analysis.

Height and Location Restrictions

A siting analysis should be incorporated into selecting an appropriate treatment technology and siting the treatment system for an airport. Each treatment system has unique operations that require a specific footprint or height that may exclude it from practical application based on various factors at an airport.

In addition to local construction regulations, construction at an airport is regulated by the FAA, primarily to mitigate hazards to aircraft operations. To reduce obstructions to airport operations, the FAA regulations generally specify minimum distances and maximum allowable heights for objects at or near an airport. FAA Advisory Circular (AC) 150/5370-2F states that any construction or alteration of objects that affects "navigable airspace" requires notification to the FAA.

The FAA defines navigable airspace in Federal Aviation Regulation (FAR) 77 with various imaginary surfaces. These imaginary surfaces are regions of space offset and sloped upwards from various airport features such as runways. The offsets and slopes are defined by the runway approach controls. Permanent structures or activities located outside the areas described by FAR 77 will not require notification to the FAA. However, FAR 77 states that a permanent structure or activity that breaks the imaginary surface defined within the regulation will require notification to the FAA and subsequent FAA approval. Typically notification is provided by submitting FAA Form 7460-1, "Notice of Proposed Construction or Alteration," to the appropriate FAA Airports Regional or District Office. Although the FAA may permit some objects and operations within the imaginary surfaces defined by FAR 77, there are areas in which FAA design criteria prohibit structures or activities. FAA AC 150/5300-13A (Airport Design) indicates the minimum offsets and maximum allowable heights that are permitted adjacent to airports for operations and permanent structures.

While these sources of information (AC 150/5370-2F, FAR 77, AC 150-5300-13A) provide sufficient information for determining siting criteria for a treatment system, it is important to coordinate with the appropriate FAA regulators throughout the selection and design processes of a treatment system.

As the airport considers treatment technology selection, the specific location, footprint, and height constraints driven by these FAA criteria for potential treatment system sites should be documented.

If a structure or operation necessary for a treatment system penetrates imaginary surfaces defined by FAR 77 or AC 150/5300-13A, then consider the following options:

1. Lower the height of the structure or operation.
2. Move the structure further away from the airport.
3. Use Airspace OMS software to determine a new location that is ideal for your needs.
4. Consider alternate treatment methods.

Environmental Conditions

Environmental conditions at potential treatment sites could affect the treatment technology selection process. An inventory of potentially affected environmental conditions should be performed, including evaluation of environmental resources, conditions, and permits (beyond those directly affecting the treated discharge), and should encompass the following:

- Potential water resource impacts (wetlands, streams, floodplains, groundwater, buffer zones),
- Limitations on air emissions,
- Restrictions on stormwater discharges associated with development,
- Presence of environmental contamination, and
- Willingness to go through the National Environmental Policy Act (NEPA) process (which may be triggered by some, but not all, treatment solutions).

It is possible that particular environmental restrictions may affect the viability of some deicer treatment technologies more than others. For example, significant environmental issues may eliminate any kind of on-site treatment. For additional information on potential water resources impacts, see *ACRP Report 53: A Handbook for Addressing Water Resource Issues Affecting Airport Development Planning.*

2.3.2 Operational Constraints

Limitations on Open-Water Surfaces

Some deicer treatment technologies, like activated sludge or aerated lagoons, are typically designed with open-water surfaces. Open-water surfaces can be wildlife attractants and provide reflectivity issues. Other treatment technologies, such as subsurface wetland treatment systems, may not have open-water surfaces but could attract wildlife. FAA AC 150/5200-33, "Hazardous Wildlife Attractants on or near Airports," defines minimum separation criteria between an airport's air operations area (AOA) and potential hazardous wildlife attractants, which would include stormwater management facilities with open-water surfaces. For facilities with open-water surfaces that do not comply with the proposed separation criteria, the FAA strongly recommends that these facilities be designed to eliminate permanent open-water surfaces and limit temporary ponding to a 48-hour period after the design storm. The AC also recommends additional design criteria for the BMPs to reduce their attractiveness to wildlife, including steep sides, rip-rap, narrow and linear shape, and no attractive vegetation. While modifications can sometimes be made in the design process to address the open-water surfaces or other wildlife attractant features in a deicer treatment system, the modifications can add cost. The airport and airline position on the acceptability of open water should be made clear prior to the treatment technology screening process.

Construction Interferences

In most cases, airports have found ways to work around the interferences with operations that could occur with construction of a treatment system. However, the airport should provide the treatment technology selection team with potentially constraining conditions, such as limitations on when runways can be closed, early in the project. These constraints could potentially rule out certain technologies in the screening process.

2.3.3 Other Constraints

Airport Policies and Management Interests

Airport policies on considerations such as staffing, reliance on outside agencies, taking on deicer treatment operations, and capital versus operating costs may play a role in deicer treatment selection. Some airports have clearly stated that they do not wish their deicer treatment operations to be dependent on the decisions and functions of outside entities like POTWs or private recycling firms. Understanding the airport's position on these issues helps to streamline the technology selection process.

Another frequently discussed factor is whether the airport wants to take on operational responsibilities for a potential treatment plant, contract out the operation, or have no responsibility for operations. This decision may be affected by the ease of obtaining maintenance support.

The allowable design and construction schedule can be a constraint. Many times, deicer treatment systems must be constructed within a compliance schedule within an individual permit. The time required to design and construct various treatment technologies varies. The airport should identify the timeframe available for design and construction early in the project. During the treatment technology screening phase, the times required for design and construction of the individual technologies can be determined and compared to the available schedule.

The ability to fund a treatment system's implementation is site-specific and often time-specific. Understanding what the available funds are for capital and operating expenses can be a factor that eliminates certain technologies. Also, the preference for expenditures of capital versus operating funds should be considered. Some treatment technologies (e.g., recycling) are more dependent on annual funding, while others (e.g., biological treatment systems) are more dependent on capital funds. Finally, available funding can limit the maximum treatment capacity that can be constructed. A lower capacity can result in increased risk resulting from extreme deicing conditions and in the need to expand the system sooner.

Aesthetics can sometimes play a factor in treatment technology decisions. Most often, accommodations for aesthetic preferences can be made in the design phases, but occasionally, aesthetic issues can be a cause for elimination of certain technologies during the technology screening phases.

The airport's position on these items should be identified in this phase of the work.

Stakeholder Buy-In

While the level of involvement varies from project to project, stakeholders such as private citizens, public interest groups, other local entities, regulatory agencies, airlines, and other tenants may have voices in the decisions on treatment technologies. Airports should identify potentially interested parties and assess the impact of their perspectives on the technology selection, cost, sizing, and siting.

2.4 Worksheets for Documenting Treatment Needs and Constraints

This section provides example worksheets for documenting the findings from the analysis of treatment needs and constraints. The worksheets are:

- Criteria Worksheet for Allowable Pollutant Discharges (Section 2.4.1),
- Criteria Worksheet for Characteristics of Stormwater to be Treated (Section 2.4.2), and
- Criteria Worksheet for Airport Site and Operational Constraints (Section 2.4.3).

The criteria worksheets are intended as guidance for the parameters to be considered. When considering treatment technologies, a more detailed and nuanced consideration of allowable pollutant discharges, stormwater characteristics, site constraints, and operational constraints will also be needed to support the decision-making process.

2.4.1 Criteria Worksheet for Allowable Pollutant Discharges

The site-specific criteria governing the allowable pollutant discharges can be documented in a matrix or table similar to what is shown in Worksheet 1. The criteria worksheet should include:

1. Documentation of all limiting parameters, numeric limits, and conditions explicitly stated in the applicable permits, and

Worksheet 1. Example of criteria table of potential and governing limits for discharges.

Limiting Criteria	Limit Value and Units from Permit	Example Applicable Conditions	Is It a Governing Limit? (Yes/No)	Governing Criteria Value for Treatment Technology Basis of Selection
COD	_____mg/L	Daily maximum		_____mg/L
COD	_____lbs/day	Monthly average		_____lbs/day
BOD5	_____mg/L	Daily maximum		_____mg/L
BOD5	_____lbs/day	Monthly average		_____lbs/day
PG	_____mg/L	Daily maximum		_____mg/L
EG	_____mg/L	Daily maximum		_____mg/L
NH_3-N	_____mg/L	Daily maximum		_____mg/L
Phosphorus	_____mg/L	Daily maximum		_____mg/L
Flow Rate	_____gpm	Monitor		_____gpm
pH	_____s.u.	Range		_____s.u.
Dissolved Oxygen	_____mg/L	Minimum		_____mg/L
TSS	_____mg/L	Maximum		_____mg/L
TDS	_____mg/L	Maximum		_____mg/L
Temperature	_____°F	Maximum at any time		_____°F

2. Documentation of the governing parameters, numeric limits, and conditions obtained from a comprehensive analysis.

A criteria worksheet for potential and governing discharge limits associated with allowable pollutant discharges provides the following value:

1. A portion of the data necessary to calculate the required treatment capacity, and
2. Definition of the treated effluent quality that the selected treatment technologies will need to meet.

2.4.2 Criteria Worksheet for Characteristics of Stormwater to be Treated

The characteristics of the stormwater that requires treatment can be summarized in a criteria table similar to the one shown in Worksheet 2.

A criteria worksheet for untreated stormwater characteristics provides the following value:

1. Provides data necessary to calculate the required treatment capacity, and
2. Defines the range of influent characteristics that the selected treatment technologies will have to process.

A criteria worksheet will need to be supplemented with an understanding of how these parameter values change over time, the basis for how the information was derived, the frequency of occurrence, the assumptions underlying the analysis, and the limitations of the methods used to derive the information.

2.4.3 Criteria Worksheet for Airport Site and Operational Constraints

Assessing the potential site and operational constraint criteria associated with implementing a treatment technology is somewhat of an iterative process. Some constraints may be absolute. Other constraints are preferences that can be overcome with adequate design and funding. Worksheet 3 presents an example of a matrix that documents site and operational constraints that may affect treatment technology selection, sizing, and siting.

Worksheet 2. Example of criteria table of stormwater characteristics to be treated.

Criteria	Description	Example Criteria Value
Flow rate	Average, maximum, minimum	_____ gpm
BOD, COD mass loading rates	Average, maximum, minimum	_____ lbs/day
Maximum BOD, COD, EG, or PG concentration	Identify frequency of maximum condition	_____ mg/L
Minimum PG, EG, BOD concentration	Primarily a concern from an operating cost perspective	_____ mg/L
Stormwater temperature	Range	_____°F
TSS concentration	Identify range and form of TSS (sediment, sand, organic)	_____ mg/L
TDS concentration	Could be a factor if proportion of pavement deicers is high	_____ mg/L
Presence of fuel	Associated with the likelihood of a spill	Specify
Presence of metals	Associated with typical stormwater runoff	Specify
Presence of fouling and clogging materials	Specific materials that could cause fouling or precipitation on treatment system equipment, such as silica, inorganics with high hardness	Specify

Worksheet 3. Example criteria table of limiting site and operational conditions.

Criteria	**Limiting Criteria Value (Complete for Multiple Sites if Applicable)**
Land available for on-site treatment	1. Available 2. Not available
Maximum available footprint	Specify
Maximum height	Specify
Open water	1. Allowed 2. Not allowed
NEPA process	1. Willing to go through NEPA process 2. Not willing to go through NEPA process
Water resource impacts	1. No impacts allowed 2. Willing to allow impacts for treatment system construction with appropriate permits
Site contamination	1. No contamination that limits on-site treatment facility construction 2. Contamination that eliminates on-site treatment construction 3. Contamination, but willing to remediate
Air emissions restrictions	1. No restrictions 2. Known restrictions (identify parameters and values)
Odors	1. Typically no odors 2. Potential for odors
Utility availability	3. Water, power, natural gas available 4. Specify utilities not available 5. Utilities available with significant added cost
Availability of surface water discharge	1. Receiving waters discharge point accessible 2. Receiving waters discharge point inaccessible 3. Receiving waters discharge point accessible with significant added cost
Availability of sanitary sewer for POTW discharge	1. Sanitary discharge point accessible 2. Sanitary discharge point inaccessible 3. Sanitary discharge point accessible with significant added cost
Groundwater conditions	1. Groundwater depth below surface
Treatment plant operations	1. Airport willing to operate on-site system 2. Airport willing to subcontract on-site system 3. Airport not willing to operate or subcontract on-site operation
Reliance on POTW to accept discharge	1. Airport willing to rely 2. Airport not willing to rely
Reliance on off-site recycling and market for recycled glycol	1. Airport willing to rely 2. Airport not willing to rely
Time available for design and construction	Specify
Maximum capital funding	Specify
Maximum annual operations and maintenance (O&M) funding	Specify
Preference to funding and capital or operating cost	1. Capital 2. Operating
Accessibility	1. Sites accessible to land-side vehicle traffic, including trucks 2. Sites not accessible
Ability to get regulatory approval	1. No concerns with eventual approval of technology 2. Potential concerns with eventual approval of technology
Aesthetic criteria	Specify
Construction constraints	Specify
Miscellaneous constraints	Specify

A criteria worksheet for airport site and operational constraints provides the following value:

1. A list of potential siting and operational considerations to promote discussion by stakeholders,
2. The data necessary to supporting the siting process, and
3. Characterization of the potential operating burden and constraints.

CHAPTER 3

Identifying Deicer Treatment Technologies

3.1 Classification System for Deicer Treatment

Many technologies are capable of removing deicers from stormwater. Classification of deicer treatment provides insight into the process of implementing deicer treatment systems. Figure 12 illustrates the classification system for deicer treatment technologies used in this guidebook.

The classification system is also shown in Table 3 with examples of airports that have implemented the various treatment technologies. Appendix A provides a more detailed list of airports reviewed in the guidebook and the treatment technologies that they use.

The classification system uses three categories to describe treatment: *method, process,* and *technology.* Characteristics associated with these categories are described in the following.

Method is a broad classification that identifies the type of treatment and its typical location. The type of treatment is described as physical or biological. The location is described as on-site or off-site. *On-site* refers to a treatment system that is directly controlled by the airport operator in a facility typically on or close to the airport. *Off-site* refers to a treatment system that is controlled by an entity other than the airport operator at an off-airport location. On-site biological treatment is a biological treatment system operated by the airport. On-site physical treatment is typically a recycling system operated by the airport. Off-site biological treatment is typically discharge to the sanitary sewer with treatment at the POTW. Off-site physical treatment is typically recycling at a privately operated facility.

Process refers to subcategories of physical and biological treatment that describe the fundamental elements of how the technology works, as summarized in the following.

1. *On-site biological treatment processes.* Biological processes have been used for over 100 years to treat contaminated water. All biological treatment systems are a combination of natural and engineered processes. Naturally occurring microorganisms, primarily bacteria, consume the organic contaminants in water as food. In all biological treatment systems, microorganisms (i.e., biomass) oxidize organic compounds contained in contaminated water, converting the compounds into simple end products and more biomass. End products can include carbon dioxide, methane, and water.

   While the essential treatment mechanism is natural for all biological treatment systems, various levels of engineering and control have been applied over the last century. The most prominent drivers for creating an engineered biological system are:

   - Reducing space requirements,
   - Improving treatment efficiency,
   - Providing better response to variations in influent characteristics and ambient conditions,

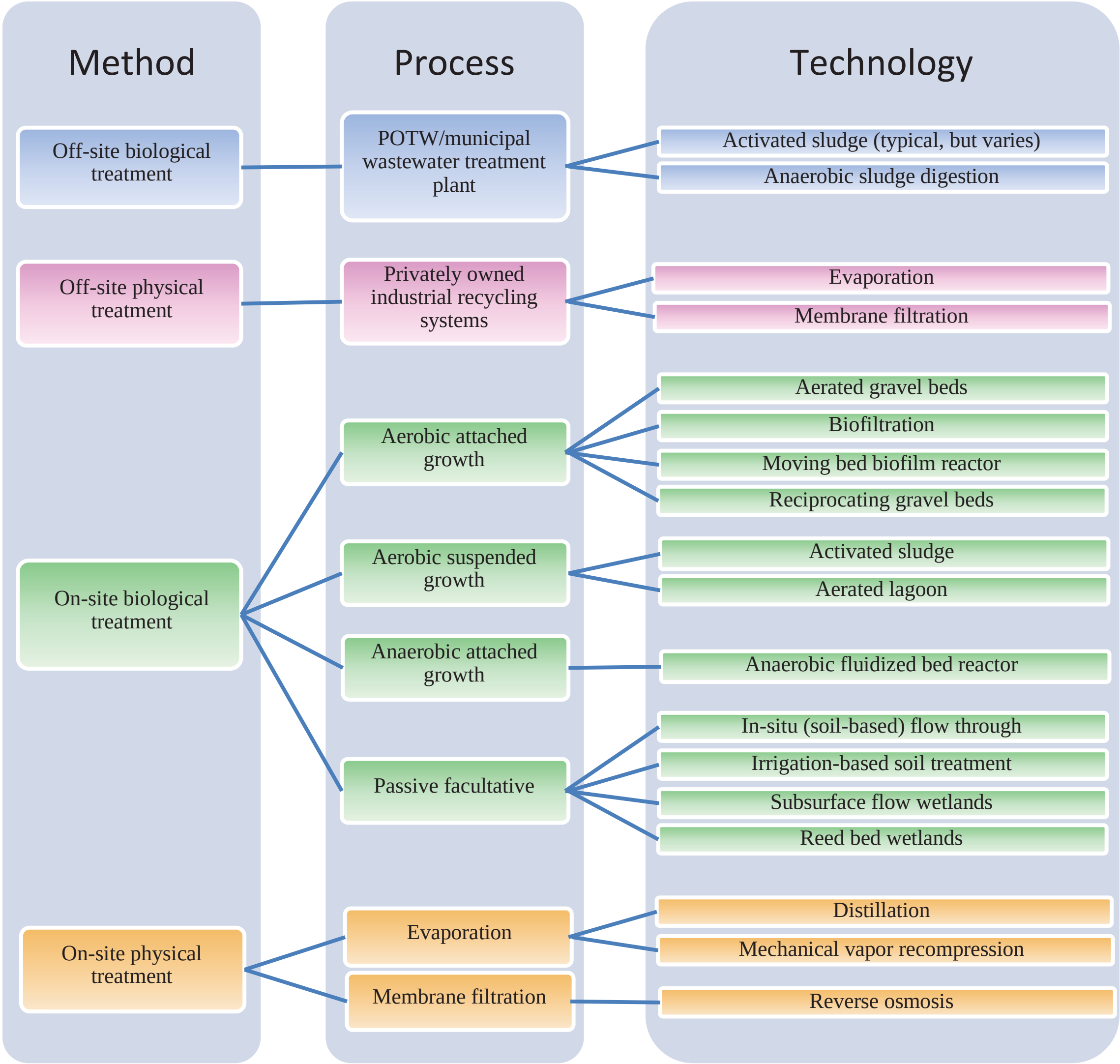


Figure 12. Deicer treatment classification system used in the guidebook.

- Providing a more predictable effluent quality, and
- Providing more consistent costs and operations.

All biological treatment systems are designed to create a contained environment that supports contact between the bacteria and the organic pollutants, allowing the living organisms to flourish and resulting in reduction of the concentrations of the oxygen-demanding pollutant (measured as BOD, COD, etc.). This contact can occur in flowing streams, soils via overland flow and infiltration, wetlands, or man-made structures. Biological treatment systems are generally engineered to contain naturally occurring treatment processes in a smaller, confined area to allow optimization of treatment effectiveness and efficiency. Even biological treatment systems that are sold as “natural treatment systems” require some degree of engineering and control. Deciding on a type of biological treatment, therefore, is not a choice between natural and engineered. Instead it is largely an exercise of understanding the trade-offs between space requirements, extent of engineering, level of control and operational requirements, and cost. Today, biological treatment is the principal treatment method used by municipalities worldwide to treat discharges to sanitary sewers. It is also used in many varied types of industrial-facility wastewater treatment.

Table 3. Proposed classification system deicer treatment as applied at airports.

Method	Process	Technology	Example Airport Using Technology*
Off-site biological treatment	Publicly owned treatment works/municipal wastewater treatment plant	Activated sludge (typical, but varies)	DTW
		Anaerobic sludge digestion	MKE
Off-site physical treatment	Privately owned industrial recycling systems	Evaporation and membrane filtration	PIT
On-site biological treatment	Aerobic attached growth	Moving bed biofilm reactor	OSL
		Aerated gravel beds	BUF
		Reciprocating gravel beds	ILN
		Biofiltration	CDG
	Aerobic suspended growth	Activated sludge	CVG
		Aerated lagoon	BNA
	Anaerobic attached growth	Anaerobic fluidized bed reactor	PDX
	Passive facultative	In-situ (soil-based) flow through	FRA
		Irrigation-based soil treatment	ZRH
		Subsurface flow wetlands	CEF
		Reed bed wetlands	LHR
On-site physical treatment	Evaporation	Mechanical vapor recompression	YYT
		Distillation	DEN
	Membrane filtration	Reverse osmosis	BDL

*See Acronyms and Abbreviations section for definition of airport codes.

Advantages to biological technologies for treatment of deicer-affected stormwater include:

- Compared to chemical oxidation and physical treatment technologies, biological treatment technologies generally have lower capital and operating costs, especially for stormwater with BOD_5 concentrations of less than 10,000 mg/L.
- They are better suited to treat mixtures of organic compounds (e.g., PG, EG, acetate, formate) in the stormwater than physical treatment technologies that isolate individual chemicals or types of chemical compounds. Biological technologies are therefore well suited to runoff that contains significant amounts of both ADF and pavement deicers.
- The primary deicer constituents in the stormwater are destroyed through conversion of the chemicals to cell mass and simpler chemicals, which is attractive for airports with PG and EG limits.
- If sized and operated properly, they can achieve low effluent concentrations.
- They are reasonably effective at treating waters with varying flow rates and mass loads.

Disadvantages to biological technologies for treatment of deicer-affected stormwater compared to physical treatment technologies include:

- Their effectiveness is dependent on keeping a population of microorganisms alive and healthy. With the variability in the deicing environment (flow rates, BOD loadings, temperatures), additional steps are frequently needed to control the influent loadings and create a consistent level of microorganism activity.
- Low water temperatures slow biological activity significantly. Low temperatures will often require operating at less than design capacity to achieve desired effluent quality.
- Deicer-impacted stormwater is generally devoid of the nutrients (forms of nitrogen, phosphorus, and micronutrients) that bacteria need for their metabolism and growth. Nutrients

can be effectively added, but in practice the regularity and extent of nutrient addition in some deicer treatment systems has been less than optimal.

- The health of the microorganisms is difficult to measure directly, so a variety of indirect measures are used. At times of unusual or upset conditions, relying on indirect measures can make troubleshooting more challenging.
- Some biological treatment technologies produce significant volumes of biological solids composed of microorganisms that are no longer needed or viable. These wasted biological solids must be processed and disposed of.

While the constituents in deicer-affected stormwater are generally highly biodegradable, the unique conditions of deicing have required that traditionally used biological wastewater treatment technologies be adapted for use in deicer treatment. For deicer-affected stormwater, four fundamental biological treatment processes have been used to date, as described in the following. The processes are defined by the biology type (aerobic and anaerobic) and the environment in which the bacteria grow (attached to inert media or suspended in water).

a. *Aerobic suspended-growth biological treatment.* An aerobic treatment process is primarily characterized by the supplying of oxygen to the water to promote the growth of aerobic bacteria. By-products from aerobic deicer treatment systems include additional biomass and carbon dioxide. *Suspended growth* refers to the fact that the aerobic bacteria are suspended in a reactor by the action of water or air. These types of systems are actively controlled using human operators or computers. Two aerobic suspended-growth technologies have been used at airports: activated sludge (see Fact Sheet 101) and aerated lagoons (see Fact Sheet 103). Both technologies have been used since the early part of the 20th century for general wastewater treatment.

b. *Aerobic attached-growth biological treatment.* An aerobic attached-growth process is characterized by aerobic bacteria growing on an inert media, such as gravel or plastic, contained in the treatment reactor that also receives an air supply. These types of systems are actively controlled using human operators or computers. By-products from aerobic deicer treatment systems include additional biomass and carbon dioxide. To date, the aerobic attached-growth technologies that have been used as a primary means to treat deicer from airports are the aerated gravel bed (see Fact Sheet 102) and the moving bed biofilm reactor (MBBR) (see Fact Sheet 107).

c. *Anaerobic attached-growth biological treatment.* An anaerobic treatment process uses anaerobic microorganisms living in the absence of oxygen to degrade the primary deicer constituents in the stormwater discharges. By-products from anaerobic treatment include additional biomass, methane, and carbon dioxide. The anaerobic bacteria are attached to an inert media in the treatment reactor, such as activated carbon. These types of systems are actively controlled using human operators and computers. The one anaerobic attached-growth process that has been used to treat deicer-affected stormwater is the AFBR (see Fact Sheet 104).

d. *Passive facultative biological treatment.* This category encompasses a wide variety of technologies that share the elements of employing facultative bacteria and minimal process control. A facultative process, as defined here, is one that typically features a mixture of bacteria that are capable of degrading deicing constituents regardless of the oxygen level in the stormwater. The bacteria include aerobic bacteria that can obtain oxygen from the atmosphere, anaerobic bacteria that live in areas without oxygen, and facultative bacteria that can live in areas with or without oxygen. *Passive* refers to a reduced level of operator and computer control and a reduced use of mechanical equipment. Due to low biological reaction rates, these systems are typically large in size—a slower pollutant processing rate by the bacteria means a larger number of bacteria are required to accomplish the same level of treatment. The lack of process control, however, restricts the conditions in which the systems will function adequately and generally results in fewer options for responding

Treatment Tips

Anaerobic Versus Aerobic Biological Deicer Treatment

	Anaerobic	Aerobic
Better effluent quality		√
Fewer nutrient requirements	√	
Less reactor volume/footprint	√	
Faster response at start-up		√
Less energy use	√	
Less sludge production	√	
Methane by-product may be used as fuel source	√	
Ability to treat at lower temperatures without heat addition		√
Less complex operation		√

to changing deicing conditions. This is most significant in regard to cold-weather operation, when low water temperatures reduce the efficacy of facultative treatment processes. A number of specific technologies that can be classified as passive facultative processes have been tested and implemented for treatment of airport stormwater, including subsurface flow wetlands, soil-based (sometimes called in-situ) systems where stormwater passes through soil as fed from irrigation or overland flow means, and non-aerated technologies where water is passed through a bed of gravel or other media. Fact Sheet 108 further discusses passive facultative processes.

2. *On-site physical treatment processes.* Physical treatment includes processes where the removal of deicer from stormwater is carried out through physical phenomena. Unlike biological treatment, physical treatment is not designed to change the pollutants chemically. It is designed to segregate the stormwater into a high pollutant concentration fraction (typically called a "concentrate stream") and a low-concentration fraction (typically called a "dilute stream"). Most often, physical treatment processes are employed in deicer treatment to achieve the benefit of a recyclable end product (concentrated glycol) in the process of reducing concentrations in the dilute stormwater stream that will ultimately be discharged to the environment. Additional processes may be required to treat the dilute streams from physical treatment systems that may contain several hundred mg/L of BOD. If the concentrated product is not recycled, it needs to be disposed of using an additional treatment process. To date, two primary physical treatment processes have been used for deicer-affected stormwater, as shown in the following.

   a. *Evaporation processes.* Evaporation processes use an applied energy source to heat the stormwater, evaporating the water and leaving behind a more concentrated fraction containing the bulk of the deicing chemicals. Two evaporation technologies have been used extensively in deicer treatment: mechanical vapor recompression (see Fact Sheet 106) and distillation (see Fact Sheet 105).
   b. *Membrane filtration processes.* Membrane filtration processes rely on a liquid being forced through a filter membrane with a high surface area. There are four basic pressure-driven membrane filtration processes for liquid separations. From smallest membrane openings to largest membrane openings, the four main technologies are reverse osmosis,

Treatment Tips

Biological Treatment for Degrading Deicers Versus Physical Treatment for Recycling Deicers

	Biological Treatment	Physical Treatment
Less pretreatment required	√	
Can produce saleable end product		√
Wider range of pollutants treated	√	
Better response start-up and shutdown sequences		√
Shorter start-up period		√
Less energy use	√	
Fewer odors		√
Less sludge production		√
Potential for off-gas to be used as fuel source	√	
Ability to treat at lower temperatures without heat addition		√
Ability to cost-effectively treat BOD <1% concentration	√	
Ability to cost-effectively treat BOD >1% concentration		√
Ability to cost-effectively treat deicer use <300,000 gal/year	√	
Ability to cost-effectively treat deicer use >300,000 gal/year		√
Ability to cost-effectively achieve low effluent concentrations	√	
Production of secondary waste stream requiring treatment	√	√

nanofiltration, ultrafiltration, and microfiltration. Reverse osmosis is the only membrane filtration technology that can separate glycol molecules from water. Other membrane filtration processes, especially ultrafiltration, may be used as a pretreatment step before reverse osmosis to remove larger particles. See Fact Sheet 111 for reverse osmosis.

3. *Off-site treatment at a publicly owned treatment facility.* In the United States and many other places, wastewater treatment plants operated by cities and other municipal entities are used to treat household sanitary sewage and polluted waters from commercial and industrial facilities. In the United States, these facilities are generally known as publicly owned treatment works. Elsewhere the facilities are more simply sewage treatment plants or municipal wastewater treatment plants. Most pollutant waters are conveyed to POTWs via sanitary sewer systems. Deicer-affected stormwater runoff that is discharged to the sanitary sewer is mixed with other wastewaters and passed through the entire treatment process.

Some airports have arranged for treatment of a concentrated stream of deicer-affected stormwater directly in the anaerobic digesters that POTWs operate to break down the biological solids generated from their treatment processes. This is beneficial to the POTWs because it provides an additional source for producing methane that the POTWs capture and use as a fuel source. A POTW could also use concentrated deicer as a carbon source for its denitrification process. Use of deicer in anaerobic digesters or the denitrification process requires a means for transporting, potentially storing, and metering the deicer into the process at the POTW.

Treatment Tips

On-Site Versus Off-Site Deicer Treatment

	On-Site Treatment	Off-Site Treatment
Storage needed	√	√
Control of discharges potentially needed	√	√
Lower risk in discharging collected water	√	
Lower operating cost	√	
Lower capital cost		√
Fewer airport operational interferences during construction		√
Fewer operators needed		√

See Fact Sheet 109 for public wastewater treatment facilities.

4. *Off-site treatment at a privately owned industrial recycling facility.* Some airports are located close enough to a privately operated glycol recycling facility that it is economical to transport the concentrated segments of the deicer-affected stormwater runoff for off-site recycling. The off-site facility typically uses multiple recycling technologies that may include membranes, mechanical vapor recompression, thermal vapor recompression, other evaporation systems, or distillation. By separating and reclaiming the glycol from the deicer-affected stormwater, the recycling provider can generate revenue from the sales of glycol. This arrangement can reduce the treatment equipment that would otherwise be installed at the airport site and eliminate the corresponding operating expenses.

3.2 Features of Existing Individual Deicer Treatment Technologies

In this section, the features of the 11 individual deicer treatment technologies defined in this guidebook are summarized. Guidebook users should reference the individual treatment technology fact sheets for more detailed information on the 11 technologies. Some specific variations of the technologies that have been implemented or tested are also discussed in this section in boxes entitled "Treatment Technology Example." Applications of the 11 deicer treatment technologies in Table 4 are discussed in the airport deicer treatment system summaries in Appendix D.

Table 4. Deicer treatment technologies featured in guidebook.

Fact Sheet No.	Treatment Technology	Sample of Airports Using the Technology (See Appendix D for Summaries)*
101	Activated sludge	CVG
102	Aerated gravel beds	BUF, LHR, YEG, ILN
103	Aerated lagoons	BNA
104	Anaerobic fluidized bed reactors	PDX, CAK, ALB
105	Distillation	DEN, ZRH
106	Mechanical vapor recompression	YHZ, DEN, CVG, BDL
107	Moving bed biofilm reactors	OSL
108	Passive facultative treatment systems	ZRH, CEF, YEG, LHR
109	Public wastewater treatment facilities	DTW, DEN, PDX, BNA
110	Private recycling facilities	DTW
111	Reverse osmosis	BDL

*See Acronyms and Abbreviations section for definition of airport codes.

3.2.1 Biological Treatment Technologies

3.2.1.1 Activated Sludge

Activated sludge is one of the oldest and most widely used suspended-growth biological treatment technologies to treat wastewater. The activated sludge process, as used for deicer treatment, has two main components: an aerated basin where most of the BOD reduction occurs and a clarifier where biological solids are separated. The key element of an activated sludge process is the recycling of the sludge from the clarifier back to the aeration basin to obtain an elevated concentration of bacteria in the aeration basin, allowing more efficient treatment.

Advantages of activated sludge compared to other treatment technologies include:

- It can obtain very low effluent BOD concentrations,
- It has a relatively small footprint, and
- It can process large volumes.

Disadvantages of activated sludge compared to other treatment technologies include:

- It typically has an open-water surface,
- It takes a high volume of biological solids (sludge) to process, and
- It can be negatively affected by cold temperatures.

The activated sludge technology is well suited to the following applications:

- Treatment of more dilute concentrations (typically <5,000-mg/L COD).
- Airports requiring treatment of high flow volumes.
- Airports in warmer climates.
- Airports with low effluent limits (<40-mg/L COD).

The specific variations on the activated sludge technology that have been applied for deicer treatment are summarized in the following.

- *Extended aeration activated sludge.* Extended aeration activated sludge is a slight variation on conventional activated sludge in which the activated sludge unit process is operated at a relatively long hydraulic retention time and increased biomass holding period.

  Advantages compared to other activated sludge variants include:

  – Lower sludge production,
  – Better ability to absorb shock loadings, and
  – Better ability to segregate BOD reduction and solids separation functions.

  Disadvantages compared to other activated sludge variants include:

  – Larger open-water surface and larger footprint, and
  – Challenges in maintaining healthy and sufficient biomass if deicer supply is variable.

  The extended aeration activated sludge technology is well suited for the following applications:

  – Airports with variation in influent stormwater characteristics.
  – Airports having a steady supply of deicer through the winter.
  – Airports needing to meet lower effluent limits for BOD.

- *Sequencing batch reactors (SBRs).* Unlike other variants of activated sludge, which operate in a continuous flow-through mode, SBR technology is essentially a batch mode process adapted to continuous-flow operation. An SBR system typically consists of at least two identically equipped tanks with a common, switchable inlet. Each tank operates separately in a fill-and-draw mode, whereby the tank goes through successive filling, reacting (aeration), and solids-separating steps. The switchable inlet for the tanks allows the system to operate in a flow-through mode, with raw wastewater (influent) continuously flowing into at least one tank while treated effluent can continuously flow out of at least one other tank. While one tank is in settle/decant mode, the other is aerating and filling. At the inlet is a section of the tank known as the bioselector. This consists of a series of walls or baffles that direct the flow either from side to side in the tank or under and over consecutive baffles. This helps to mix the incoming influent and the returned activated sludge (RAS), beginning the biological digestion process before the wastewater enters the main part of the tank.

Advantages of the SBR compared to other activated sludge variations include:

- Small footprint—all operations contained in a single tank, and
- Somewhat more resistant to cold temperatures because of less surface area for heat loss.

Disadvantages of the SBR compared to other activated sludge variations include:

- Higher degree of operator expertise required, and
- More difficulty in optimized individual treatment and settling functions.

The SBR activated sludge technology is well suited for the following applications:

- Airports with limited space, and
- Airports where low effluent concentrations are needed.

The airport summary in Appendix D for Cincinnati/Northern Kentucky International Airport features activated sludge treatment.

3.2.1.2 Aerated Gravel Beds

The aerated gravel bed is a treatment technology that combines key facets of engineered wetlands, trickling filters, and aerated lagoons. It achieves treatment using aerobic bacteria attached to gravel surfaces. The treatment capacity of an aerated gravel bed system is directly proportional to the surface area of the aerated gravel bed.

Specific variations on the aerated gravel bed technology that have been applied at airports include:

- Diffused air supply, and
- Reciprocating gravel beds.

Advantages of aerated gravel beds compared to other deicer treatment technologies include:

- Minimal requirements for solids processing in treated effluent,
- Less operationally complex than many other biological treatment systems, and
- No need to reseed at the start of each deicing season.

Disadvantages of aerated gravel beds compared to other deicer treatment technologies include:

- Larger footprint,
- Limited access to buried piping and equipment, and
- Potential for long-term fouling and clogging if mass load targets are exceeded.

The aerated gravel bed technology is well suited for the following applications:

- Airports with runoff having glycol concentrations less than 0.5% (5,000 mg/L).
- Airports with lower-concentration, higher flow rates to process, such as runoff from airfield areas.
- Airports with available land that want a less-complex treatment operation.

The following airport summaries in Appendix D feature some variation on aerated gravel beds:

- Buffalo Niagara International Airport.
- Wilmington Airpark.
- London Heathrow International Airport.
- Edmonton International Airport.

3.2.1.3 Aerated Lagoons

Aerated lagoons are earthen basins that employ mechanical aeration systems to deliver oxygen to the lagoon water. Aerated lagoons are best suited for airports that typically have concentrations of less than 0.5% (5,000 mg/L) glycol. An aerated lagoon treatment system may provide both treatment and equalization storage.

Specific variations of aerated lagoons that have been applied at airports include:

- Mechanical surface aeration,
- Facultative lagoons (without aeration), and
- Algal treatment systems.

Advantages of aerated lagoons compared to other deicer treatment technologies include:

- Lower cost, and
- Easier to operate than other biological treatment systems.

Disadvantages of aerated lagoons compared to other deicer treatment technologies include:

- Requires larger land area than activated sludge or similar technologies,
- Requires management of nutrient and BOD loadings for optimal performance,
- Loss of heat and performance in cold weather, and
- Odors, especially in early summer, and open-water issues.

The aerated lagoon technology is well suited for the following applications:

- Airports with large land areas available.
- Airports with less restrictive effluent limits.
- Airports with runoff with BOD concentrations of less than 5,000 mg/L.

The airport summary in Appendix D for Nashville International Airport features aerated lagoons.

A discussion of the experiences of other airports with aerated lagoons is found in the Treatment Technology Example: Aerated Lagoons text box.

3.2.1.4 Anaerobic Fluidized Bed Reactors

AFBR technology is an anaerobic biological process (i.e., does not require aeration or oxygen for the process) and is well suited for treatment of highly concentrated stormwater. In an AFBR, anaerobic bacteria grow on a media of activated carbon, sand, or other material housed in a reactor tank. This media bed is fluidized by forcing water into the bottom of the reactor. The AFBR system incorporates a process for separating and removing excess biological solids. The AFBR process is best suited to high-concentration water (~2,100-mg/L to 80,000-mg/L COD) and is also capable of achieving relatively low effluent concentrations (as low as 35 mg/L soluble COD after the biological solids removal in some systems).

Advantages of the AFBR compared to other deicer treatment technologies include:

- System is not subject to temperature fluctuations because the influent stormwater is heated using both heat reclaimed from the treated effluent and water heated by the burning of methane gas captured from the biological reactor and burned in a boiler,

Treatment Technology Example: Aerated Lagoons

Aerated lagoons are some of oldest biological treatment systems, both for wastewater in general and for deicer. Frequently, however, airports discovered that treatment efficiencies were often limited by cold temperatures, lack of nutrients, variations in flow and BOD loading, and lack of oxygen. As a result, some airports focused on using the lagoons for winter runoff storage, with treatment only occurring when temperatures were adequate for biological treatment. For example, Rockford International Airport stores runoff collected during the deicing season until April when it begins treating the collected stormwater. Syracuse International Airport (SYR) also observed that treatment was not optimized until summer. SYR altered its operation so that the aerated lagoon collected and stored runoff until treatment began in the summer. After successful operation of the aerated lagoon during the summer months for several seasons, the local POTW made enhancements that now permit SYR to discharge to the local POTW without on-site treatment.

- Excess methane gas captured from the treatment reactors can provide energy savings by use for heating the treatment building and other processes in need of heat,
- Resiliency to upsets caused by variation in stormwater characteristics,
- Effluent COD concentrations in a predictable range when operated as required,
- Low operating cost,
- Can be shut down for the summer months and restarted without seeding, and
- Because the anaerobic bacteria grow at a slower rate than aerobic bacteria in technologies like activated sludge and aerated lagoons, the quantities of biological solids generated in an AFBR are up to 10 times lower than the biological solids resulting from some aerobic treatment processes.

Disadvantages of the AFBR compared to other deicer treatment technologies include:

- More complex operation, with multiple support systems to manage together,
- The maximum flow rates that can be treated are limited by process constraints,
- Longer start-up periods due to the slower-growing bacteria,
- Longer and more complex construction,
- More equipment to maintain, and
- More process data to collect and assess.

The anaerobic fluidized bed reactor technology is well suited for the following applications:

- Treating lower-flow, higher-concentration, and high-load deicer-affected stormwater, such as runoff from deicing pads or runoff segregated by concentration using online monitors.
- Situations where low glycol concentrations in the effluent are required.
- Operations that can take advantage of excess methane production for use in reducing energy costs.
- Airports where the available space for treatment is limited.

The following airport summaries in Appendix D feature anaerobic fluidized bed reactors:

- Akron-Canton Airport.
- Portland International Airport.

3.2.1.5 Moving Bed Biofilm Reactors

The MBBR technology incorporates both activated sludge (suspended bacteria) and attached biological growth (fixed bacteria on media) in the treatment process. Aeration is provided to the tank to support activated sludge processes throughout the tank. The aeration also suspends media to promote attached biological growth. An MBBR can achieve low effluent concentrations and is typically best suited for systems that have low influent BOD concentrations (<5,000 mg/L). It can typically accommodate higher flow rates than systems like AFBRs and recycling-based technologies.

Advantages of MBBRs compared to other deicer treatment technologies include:

- Is a well-understood process with a readily available operator pool,
- Biogrowth is rapid, such that capacity increases quickly (relative to processes without media) from a seed, and
- Is able to achieve very low effluent concentrations, in the range of less than 30-mg BOD/L, when sufficient detention time is available and water temperatures are sufficiently high.

Disadvantages of MBBRs compared to other deicer treatment technologies include:

- High operating costs,
- Settling issues during biological upsets, and
- Must reseed each season or keep a biological seed active over the summer.

The moving bed biofilm reactor technology is well suited for the following applications:

- Low-to-moderate BOD concentrations (<5,000 mg/L) where very low effluent concentrations are required.

The airport summary in Appendix D for Oslo Gardermoen Airport (Norway) features MBBRs.

3.2.1.6 Passive Facultative Technologies

Passive facultative treatment (PFT) systems are designed to employ chemical, physical, and biological treatment mechanisms, but with minimal man-made power or equipment. The PFT category encompasses lagoons, wetlands, sand filters, and similar approaches that provide passive removal of glycols and other deicing compounds from contaminated stormwater. Some have labeled this broad category of technologies as "natural treatment systems." However, that label does not sufficiently distinguish treatment technologies and is potentially misleading because (a) all biological treatment technologies are based on use of natural, living microorganisms, and (b) all treatment technologies require some degree of engineering and control with man-made equipment, instruments, and structures. PFT systems tend to have a lesser degree of engineering and control. To successively function with less engineering and control, however, the PFT technologies require greater areas of land. The most successful PFT technology applications have required significant investments in testing, flow control, and monitoring.

Specific variations of passive facultative technologies that have been applied at airports include:

- Irrigation-fed soil (in-situ) treatment,
- Infiltration basins,
- Subsurface horizontal flow-through wetlands,
- Vertical flow wetlands, and
- Reed bed wetlands.

Advantages of passive facultative technologies compared to other deicer treatment technologies include:

- Potentially less operator involvement needed,
- Potentially lower cost,

- Less maintenance, and
- Can use land areas (such as infield areas for taxiways and runways) that are otherwise unusable for development.

Disadvantages of passive facultative technologies compared to other deicer treatment technologies include:

- Require large land areas,
- Performance of some systems can be uneven and subject to the effects of the variable stormwater influent, unless the influent loading to treatment is controlled, and
- More difficult to get effluent monitoring data, so performance of the systems is difficult to document.

Passive facultative technologies are well suited for the following applications:

- Airports with large land areas available.
- Airports with soil characteristics that allow the applied water to percolate in the soil while providing sufficient detention time for the bacteria in the soil/media to achieve treatment.
- Dilute runoff from runways and taxiways.

The following airport summaries in Appendix D feature passive facultative systems:

- Edmonton International Airport (original technology, since upgraded).
- London Heathrow International Airport (original technology, since upgraded).
- Westover Air Force Reserve Base.
- Zurich International Airport.

Examples of the experiences of other airports with PFTs are found in the Treatment Technology Example: Passive Facultative Systems text box.

3.2.2 Physical Treatment Technologies

3.2.2.1 Mechanical Vapor Recompression

Mechanical vapor recompression (MVR) is an evaporation process that uses compressors or blowers to increase the pressure of the vapors produced during evaporation, which allows for heat transfer back to the influent flow stream. MVR requires less energy input to achieve distillation than does thermal evaporation (distillation). The evaporation process allows the

Treatment Technology Example: Passive Facultative Systems

Washington Dulles International Airport (IAD) installed five non-aerated gravel bed biological treatment units as part of the construction of a new runway. The non-aerated gravel beds were designed to treat low-concentration fugitive deicing fluid in stormwater runoff from the new runway. Because the system is subsurface, it is less of a waterfowl attractant than a surface water treatment system. The non-aerated gravel bed at IAD does not use storage or nutrient addition. Performance of the non-aerated gravel bed system at IAD is not monitored.

Frankfurt Airport, Germany, uses a soil treatment system for low-concentration runoff from taxiways and runways. Runoff from the taxiways and runways is collected in slotted drains and treated by soil filters. This is a new system, and performance data should be available in the future.

deicer-affected stormwater to be separated into two separate effluent streams. The two streams consist of a higher-concentration glycol concentrate stream and a lower-concentration glycol distillate stream. The MVR is best suited for recovering glycol from systems that have influent concentrations of greater than 1% (10,000 mg/L) glycol.

Advantages of MVRs compared to other deicer treatment technologies include:

- Can lead to reclaiming of a recyclable product (in combination with other technologies to raise glycol concentrations to sufficient levels),
- Can be started and stopped quickly—no ramp-up time needed, and
- Can be easily expanded.

Disadvantages of MVRs compared to other deicer treatment technologies include:

- The distillate stream may require additional processing to reduce BOD concentrations to levels acceptable for discharge (depending on effluent limits),
- For airports with large collected volume, a large number of MVR units may be needed, and
- MVR heat exchangers require more maintenance and cleaning when dealing with spent ADF with higher concentrations of thickened fluids (i.e., Type IV fluids).

Mechanical vapor recompression technologies are well suited for the following applications:

- Airports using deicing pads, and
- Airports using glycol recovery vehicles.

The following airport summaries in Appendix D feature mechanical vapor recompression:

- Bradley International Airport.
- Cincinnati/Northern Kentucky International Airport.
- Denver International Airport.
- Halifax International Airport.

3.2.2.2 Distillation

Distillation is an evaporation process in which the influent is separated by vaporization and condensation into two streams. The two streams consist of a higher-concentration glycol concentrate stream and a lower-concentration glycol distillate stream. The distillate stream typically requires further treatment. Distillation is best suited for recovering glycol from systems that have influent concentrations of greater than 15% (150,000 mg/L) glycol.

Advantages of distillation compared to other deicer treatment technologies include:

- Produces product with concentrations high enough for recycle market to offset processing costs, and
- Reduces the costs of transportation of stormwater to off-site site facilities.

Disadvantages of distillation compared to other deicer treatment technologies include:

- Because of energy costs, distillation is only applicable to treatment of high-concentration streams.
- The distillation process creates contaminated wash-down water and bottoms waste (sludge) from the columns that cannot be discharged and must be treated further.
- The distillate or condensate water stream that distillation produces contains COD concentrations that are usually above acceptable levels to discharge to stormwater, which requires airports to discharge these residual streams to POTWs or other treatment systems for further treatment.
- Distillation columns can be very large and tall. Height can be an issue at airports.
- Large distillation systems can be expensive to build. A large volume of glycol needs to be reclaimed so that the glycol product can be sold to offset capital and operating expenses.

There are few airports that spray and recover enough ADF to justify installation of an on-site distillation system.

Distillation technologies applied at an airport are well suited for the following applications:

- High-concentration fractions from deicing pads or systems that segregate water by concentration.
- Treating concentrated discharges from MVRs or reverse osmosis systems.
- Due to recent advances in distillation technology, the quality of the glycol produced is acceptable for reuse as a feedstock for on-site production of ADF at airports. This can provide substantial savings in logistics costs.

However, distillation is energy-intensive; therefore, it is generally not cost-effective to distill and recycle waste glycol solutions at low concentrations.

The following airport summaries in Appendix D feature distillation:

- Denver International Airport.
- Zurich International Airport.

3.2.2.3 Reverse Osmosis (Membrane Filtration)

Reverse osmosis (RO) is a process where a semipermeable membrane is subjected to a pressurized influent stream. In natural osmosis, when two different concentrations of solutes are separated by a semipermeable membrane, the solvent (typically water) diffuses through the membrane from the lower-concentration side to the higher-concentration side. In RO, a high pressure is applied to the high-concentration side and the solvent (water) passes through the membrane to the lower-concentration side. The RO membrane pores are sized extremely small, thereby preventing individual molecules of the targeted constituents to pass through. The RO process creates two streams. The permeate stream is produced by water that passes through the RO membrane and contains relatively low glycol concentrations, while the concentrate stream contains much higher concentrations than the original stormwater influent. RO typically works best for recovering glycol from systems that have influent concentrations of greater than 1% (10,000 mg/L) glycol.

Advantages compared to other deicer treatment technologies include:

- RO units can be used in conjunction with other complementary recycling technologies, such as MVR systems, to increase the amount of glycol that can be reclaimed, and
- RO units can be designed to be modular, which means they can be installed on a relatively small footprint, and additional units can be added if increased capacity is required.

Disadvantages compared to other deicer treatment technologies include:

- Variability in influent deicer concentrations affects throughput. Generally, the higher the concentration of deicer in the stormwater, the slower the processing rate or the larger the RO pump required.
- The production rate is highly affected by temperature, with lower temperatures decreasing throughput.
- Desired effluent concentration of reject water affects influent processing rate and directly affects permeate quality for RO systems.
- Reverse osmosis units applied to stormwater treatment require some type of pretreatment or filtration ahead of the RO system in an effort to protect the membranes.
- To eliminate potential biological growth and scaling, membranes must be treated with biocide if the processing systems sit idle for extended periods.

RO technologies are best suited for the following applications:

- Situations where recycling is desired but collected concentrations are too low for MVR treatment to be economical.

- Other situations where recycling is desirable.
- Situations where it is desirable to create a more concentrated stream and a dilute stream for further processing.

The airport summary in Appendix D for Hartford International Airport features reverse osmosis.

3.3 Features of Emerging Treatment Technologies

Emerging deicer treatment technologies are considered those that have not been proven on a full-scale at an airport but merit potential consideration. If the history of deicer treatment is a guide, application of new technologies to deicer treatment will require a period of testing, trials, and adaptation that may evolve over several years.

The following categories of emerging technologies are discussed later in this section:

- Emerging biological technologies, and
- Emerging chemical treatment technologies.

In addition, enhancements to existing technologies are also discussed, including:

- Biological technologies,
- Physical treatment technologies, and
- POTW discharges.

3.3.1 Emerging Biological Technologies

3.3.1.1 Treatment in Algal Ponds

Biological treatment using micro-algae technology has been tested on deicer-affected stormwater. The technology uses elements of passive facultative lagoons and aerated lagoons, combined with the capability to harvest algae for sale on the market. Similar to other biological treatment technologies, the bacteria, not the algae, break down the deicer compounds. The technology uses the carbon dioxide by-product of the bacterial treatment to intentionally promote the growth of algae. Through photosynthesis, the algae in turn produce dissolved oxygen that can be used by the bacteria. To meet the oxygen demand needs in the stormwater, additional oxygen can be supplied through methods such as the use of paddle wheels. The algae are harvested and can be sold for products such as biofuels, plastics, and fertilizer.

Algal treatment has the following potential advantages for deicer treatment:

- Potential reduction in oxygen supply required due to the oxygen produced by the algae, and
- Potential development of an algae by-product that can be sold.

Algal treatment has the following potential disadvantages for deicer treatment:

- Treatment efficiency is not likely greater than other aerobic suspended-growth biological treatment systems,
- Possible large land area required if large BOD design capacity is required,
- Potential need to manipulate flows into treatment to optimize algae production, and
- Potential cold temperature impacts on biological treatment and algae production.

Most likely applications for algal treatment would be:

- Airports in warmer climates,
- Airports with available land, and
- Airports interested in reducing deicer treatment costs through sale of a by-product.

Treatment Technology Example:

Algal Treatment Pilot Test at Schiphol Amsterdam Airport (AMS)

(Photo Courtesy of AMS)

In 2009, AMS conducted a pilot-scale test of an algal treatment system. The pilot test was conducted in a raceway type of open, lined basin in which the water containing the deicer circulates around the basin to undergo treatment, and a paddle wheel is used to add oxygen. Treatment of deicer was provided by bacteria in the water. Algae are cultivated on top of the water. The objective at AMS was not only to break down the deicer but to produce an algae product that could be sold for use in other products. In the pilot testing, the airport was able to grow only the lowest-grade algae—suitable for bioenergy. The goal had been to produce algae that were suitable for sale as fertilizer. AMS tried a number of methods to improve the algae quality, especially in cold conditions, including use of waste building heat to warm the water and LED lighting. Although AMS considered the pilot test a success, they decided not to pursue a full-scale treatment system for a variety of reasons, including the amount of land needed to treat the full COD load that is collected. (Approximately 5 hectares would have been required.) AMS has subsequently moved toward design of an anaerobic-reactor–based technology.

Space requirements and the need to further optimize the balance between deicer treatment and algal production are potential impediments to the use of algal technology for deicer treatment. It is recommended that any airport considering algal treatment perform a pilot-scale test prior to design.

3.3.1.2 Membrane Bioreactors

A membrane bioreactor (MBR) is a variation of the suspended-growth activated sludge technology that incorporates membrane filtration instead of gravity settling to separate solids. The earliest MBRs were used for municipal wastewater treatment in 1997. Like a conventional activated sludge process, the MBR also uses an aeration basin with suspended biomass to treat the deicer. Unlike a conventional activated sludge process, the MBR uses membrane filter units to separate the biomass in the treated effluent from the water. The use of the membranes allows for better effluent quality and the ability to operate with higher concentrations of biomass in the aeration basin. The membranes can be internal or external to the aeration basin.

The MBR has the following potential advantages for deicer treatment:

- Produces a higher-quality effluent for discharge.
- The plant footprint is potentially 70% smaller than conventional aerated lagoons and activated sludge systems because of reduced aeration basin size and elimination of the clarifier. This potentially makes the system small enough to fit into a building, which provides benefits from a heat loss and open-water surface perspective.
- Better stability of biomass in the aeration basin and better removal efficiency because of the high biomass concentrations, which could provide improved response to variable stormwater characteristics.
- Elimination of the challenging biomass settling process.
- Lower biological solids production than conventional activated sludge.

The MBR has the following disadvantages for deicer treatment:

- Because of the effects of high water viscosity on the flow rate that can pass through the membranes and the fact that viscosity increases as temperature decreases, an MBR for treating cold deicer-affected stormwater will require a greater number of membranes. The costs of MBR systems are highly dependent on the number of membranes modules.
- More intensive and costly maintenance associated with membrane cleaning and replacement.
- The need for pretreatment to protect membranes.
- Potential limitations associated with oxygen transfer in the aeration basin.

The MBR technology has been considered by several airports, including PDX, CAK, and PIT, but based on the research survey results, it has not been installed on a full-scale or pilot-scale basis by an airport. Most likely applications would be:

- Airports needing effluent with very low BOD concentrations,
- Airports with space limitations, and
- Airports in warmer climates.

The airports in these instances would be willing to pay a somewhat higher cost to take advantage of the effluent quality and smaller space. It is recommended that any airport considering MBRs perform a pilot-scale test prior to design because of the lack of operating experience with MBRs treating deicer-containing stormwater.

3.3.1.3 Up-Flow Anaerobic Sludge Blanket Reactor

The up-flow anaerobic sludge blanket (UASB) reactor is a variation of the AFBR. The process was developed in the Netherlands in the late 1970s. This process has been used to treat wastewater at food processing plants and paper mills, and occasionally at municipal wastewater plants.

The process is essentially similar to the AFBR except that there is no inert media in the reactor. The anaerobic bacteria grow into granular shapes that stay fluidized in the reactor. If the granules shear and get too small or grow and get too large, the equilibrium keeping them suspended in the reactor is upset and they leave with the effluent. If the bed gets too large, some biological solids are wasted, as with a conventional wastewater treatment system.

The UASB has the potential advantage for deicer treatment of having a simpler biological solids wasting process than an AFBR.

The UASB has the following disadvantages for deicer treatment:

- System upset causes sludge blanket to be lost, and
- It is difficult to regrow sludge bed following process upset.

The issue with regrowing a sludge bed and the instability of the sludge bed will make the UASB a challenge to operate as a deicer treatment system.

UASBs have been used primarily in industries with high-strength wastewater such as breweries and food production facilities. The UASB has many similarities to the AFBR in terms of ability to treat high-strength wastewater efficiently, isolation from weather, and production of methane that can be used as a fuel source. Lack of media in the reactor can lead to a more unstable operation than an AFBR but may also offer more flexibility in design of the reactors than AFBRs. The most likely potential applications for a UASB are situations where they might offer an advantage over the AFBR, such as:

- Airports that are interested in anaerobic treatment but have height restrictions,
- Airports looking for a somewhat simpler biological solids wasting operation, and
- Airports that plan on operating year-round with another organic load source.

3.3.2 Emerging Enhancements to Existing Biological Treatment Systems

The evolution of biological treatment is more often about adaptations to existing technologies than use of new technologies. Operators of existing biological deicer treatment systems are continuing to make incremental improvements driven by their operating experience. Research is also being conducted on an academic level that may lead to improvements in existing technologies. Current research and incremental improvements for biological treatment systems relevant to deicer treatment include attempts to improve performance in the following areas relevant to deicer treatment:

- Stability of operations through improved process control.
- More efficient treatment with smaller footprints.
- Energy efficiency.

Potential enhancements to existing biological treatment systems that airports may consider include:

- Online monitoring of TOC, COD, nutrients, and dissolved oxygen coupled with computer controls to create more stable biological populations and maximize the use of the treatment system's capacity.
- Improved systems for aeration, including:
  - Jet aeration in suspended-growth systems (provides both mixing and aeration, potentially independently).
  - Pure oxygen addition.
- Activated carbon addition (provides physical adsorption of difficult-to-degrade compounds such as deicer additives).
- Addition of media-aerated basins to create a joint attached-growth–suspended-growth system to improve stability and treatment efficiency.
- Combining anaerobic systems that produce excess methane with aerobic systems that are heated by the methane to create a more efficient system.
- Automatic pacing of nutrient feed systems either paced to the deicer load or to the effluent nutrient concentration.

3.3.3 Emerging Chemical Treatment Technologies

Chemical treatment, where a chemical oxidant is used to break down the organic compounds in the stormwater, is a technology that has been successfully used to treat various types of wastewater. It is not necessarily an emerging technology for deicer treatment, but it could be an effective technology under the right circumstances. Chemical treatment, however, may not be able to compete with biological and physical treatment on a cost basis.

Chemicals could successfully be used to oxidize the organics in deicer-affected stormwater (like a large-scale version of COD analyses). However, it does not appear that chemical treatment is a good fit for deicer-affected stormwater because (a) the operating costs are greater than other technologies, and (b) it is difficult to correctly dose the chemical oxidant, resulting in either undertreating the stormwater or leaving a residual of the chemical oxidant in the stormwater. If chemical treatment were applied to deicer-affected stormwater, it would be most effective on high-concentration flows where the mass loadings were carefully controlled.

3.3.4 Emerging Enhancements to Physical Treatment Technologies

Distillation technology has advanced, and systems have now been developed so that smaller modular distillation systems can be installed at airports to make this process more cost-effective. In addition, the airport that hosts the modular system can serve as a centralized distillation outlet for other airports in the region if it has appropriate permits to do so.

3.3.5 Emerging Enhancements to POTW Discharges

The emerging opportunities associated with POTWs are situations where concentrated deicer could be trucked to the POTW plant and either injected into anaerobic sludge digesters or metered into the denitrification process as a carbon source. In both cases, the concentrated deicer could not be discharged to the sanitary sewer, but would need to be transported in batches from the airport to the POTW. Some equipment may need to be added at the POTW to support the operation. Since the addition of deicer in these two circumstances is potentially beneficial to the POTW, surcharge costs that would otherwise be applied for discharge into a sanitary sewer could be reduced.

Currently, most POTWs probably are not candidates for either of these situations. For anaerobic digestion of high-strength wastes (including concentrated deicer), the POTW would need to have the means of using the additional methane either to operate a generator to produce electricity for in-plant use or sale to the electric utility grid, or to clean and feed the excess methane into the natural gas utility distribution network. In the case of feed into denitrification, the POTW would have to include a separate denitrification process if the facility has NPDES permit limits for total nitrogen. At the current time, facilities with total nitrogen effluent limits are located with discharges into ocean or estuarine water bodies.

Treatment Tips: Testing of Emerging Technologies

Many of the deicer treatment technologies used at airports today were originally derived from technologies used to treat other types of contaminated water. The unique conditions of a deicer management environment, however, resulted in a period of adaptation. In particular, methods for managing the cold water temperatures, high degree of variability in constituent concentration and flow rate, high strength of the wastewater, and lack of nutrients needed to be developed, often on a trial-and-error basis. Experience with established deicer treatment technologies reveals the benefits of pilot testing wastewater technologies in a deicing environment before attempting on a full-scale basis. Some examples:

- A multi-year assessment was conducted on lab and pilot scales with the anaerobic fluidized bed treatment technology for the Albany International Airport. The testing allowed reactor heights, fluidization rates, treatment rates, solids production rates, and gas production rates to be established for design of a full-scale system.

- A 3-year pilot study of the reciprocating gravel bed technology at the Wilmington Air Park was conducted to set design degradation rates. It was also determined from this testing that addition of wetland plants to the gravel beds yielded no additional treatment compared to a gravel bed without plants.
- The Zurich International Airport conducted a 5-year testing program for their irrigation-based passive facultative treatment system. During that period, the parameters that needed to be controlled to achieve treatment goals were established, including monitoring and control based on groundwater levels, wind speed, water and air temperatures, and TOC concentrations.

Based on these experiences with extensive testing of existing deicer treatment technologies, it is recommended that potential implementation of emerging technologies undergo similar testing prior to full-scale application.

CHAPTER 4

Selecting Deicer Treatment Technologies

4.1 Overview of Alternatives Analysis Process

The process for selecting one or more deicer treatment technologies typically flows through an alternatives analysis. An alternatives analysis is a systematic comparison of the relative merits, constraints, and costs of alternatives. While a variety of alternatives analysis techniques can be applied, the methods presented here are drawn from direct experience with deicer treatment technology implementation. An overview of the deicer treatment technology selection method presented in this chapter is illustrated in Figure 13.

In the following sections, guidance is provided on the screening and comparative analysis methods. Details of the cost-assessment methodologies are presented in Chapter 6.

4.2 Techniques for Technology Screening Process

When considering potential deicer treatment technologies for new or enhanced treatment applications, it is typically not feasible to perform a detailed quantitative comparison of all potential technologies. As a result, execution of a screening (fatal-flaw) analysis to narrow the field to a small number of technologies is recommended. In a screening analysis, criteria that characterize the site-specific needs and constraints are compared to criteria for potential treatment technologies, as illustrated in Figure 14.

As shown in Figure 14, if the values of the criteria that characterize the airport's needs and constraints fall outside of the values for the same criteria associated with a specific technology, the technology is eliminated from consideration. The following steps in the screening process are recommended:

Step 1: Determine and document criteria describing airport's needs and constraints.
Step 2: Review treatment technology fact sheets and airport summaries (summaries in Appendix D).
Step 3: Gather information on technologies of interest from consultants, vendors, and other airports.
Step 4: Eliminate technologies by comparing site characterization and technology criteria values.
Step 5: Calculate order-of-magnitude capital, operating, and annualized costs for short list.
Step 6: Eliminate technologies by comparing costs to budgets.

Figure 15 illustrates this proposed screening process.

Not all parameters describing the airport's needs and constraints are suitable for use in a screening analysis. Criteria used in a screening analysis should be easily definable for both the airport site and the technologies that are being considered. Figure 16 provides examples of

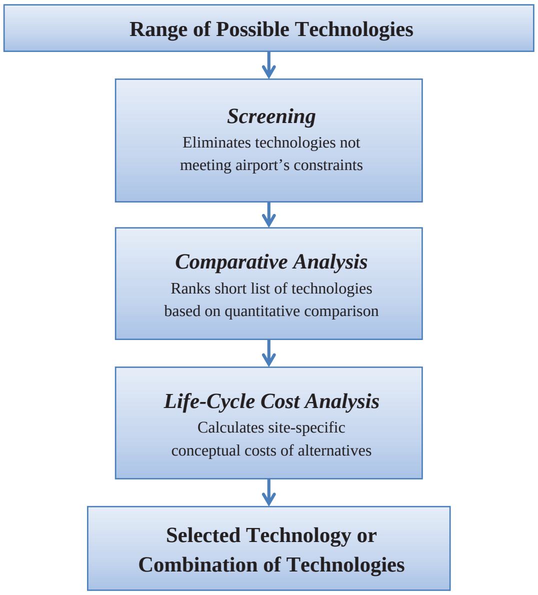


Figure 13. Deicer treatment technologies alternatives assessment method.

criteria that are often used in a screening analysis to eliminate deicer treatment technologies from further consideration.

Table 5 further defines a common set of screening criteria. Data on corresponding values for these criteria for individual treatment technologies are found in the treatment technology fact sheets.

Each screening step is briefly summarized in the following.

1. Determine and document criteria describing airport's needs and constraints.
   In the screening step, identify those criteria describing the airport's characteristics that can easily be used to rule out particular treatment technologies.

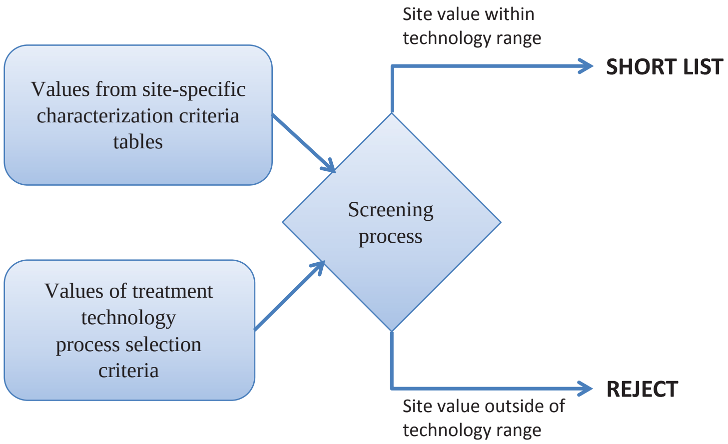


Figure 14. Overview of treatment technology screening process.

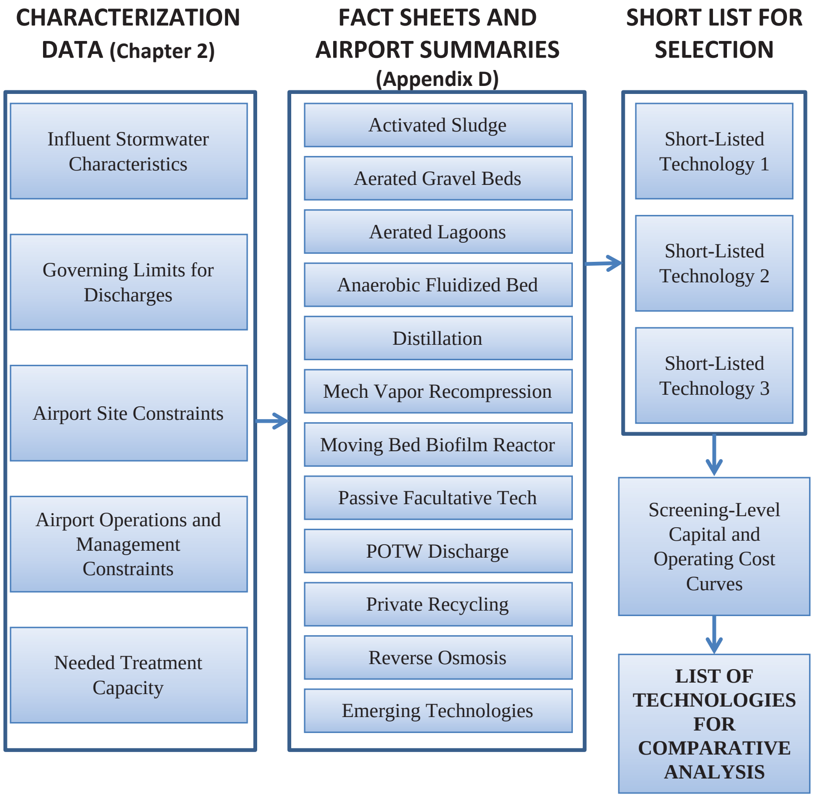


Figure 15. Details of proposed treatment technology screening process.

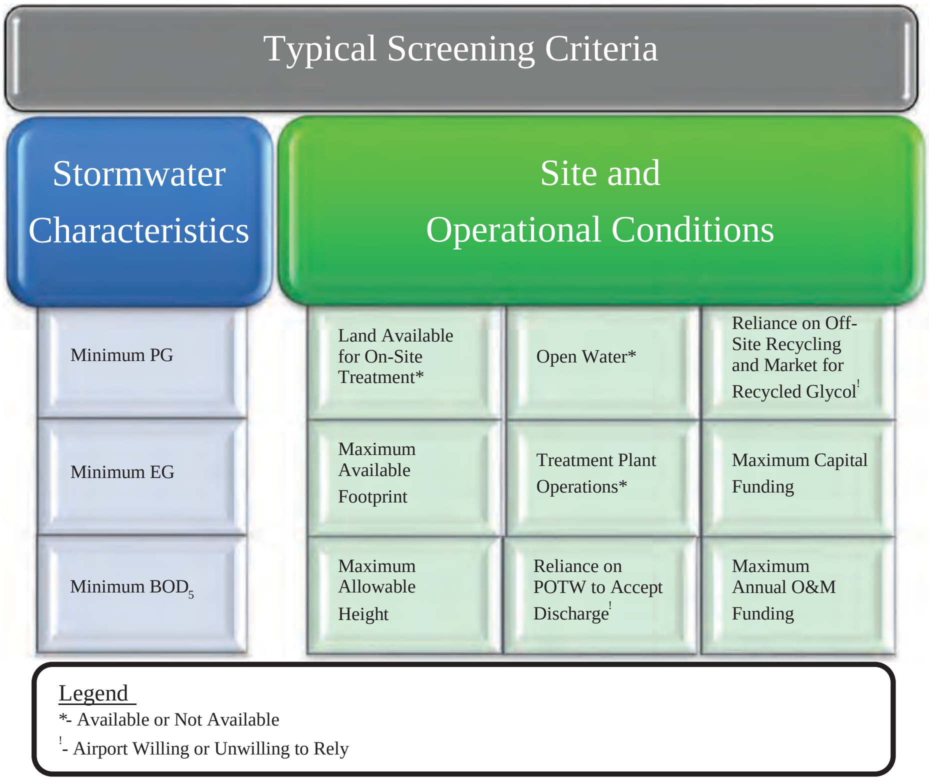


Figure 16. Criteria frequently used in deicer treatment technology screening analyses.

Table 5. Example treatment technology criteria list used in screening process.

Technology Criteria	Value or Rating	Description
Typical area (footprint)	1. <1 acre 2. >1 acre	Typical area required for the treatment facility. • Includes building, associated structures, parking, access. • Excludes storage structures, collection pump stations, deicer application areas.
Typical building/equipment height	1. <20 ft 2. >20 ft	Typical maximum height of the treatment facility. • Includes buildings and treatment-related structures. • Excludes storage tanks.
Reliance of disposal on outside entities	1. Reliance (describe) 2. No reliance	Is ability to discharge or dispose of flow streams typically dependent on the actions of an entity not under the airport's control? Examples: • Ability of POTW to accept discharge. • Ability to accept a recycled product.
Treatable stormwater constituent mix	1. Can be treated by technology 2. Can be treated by technology with additional process 3. Cannot be treated by technology	Applied to each constituent in stormwater that may need to be treated (for glycols, glycerin, acetate, formate, urea).
Minimum PG, EG, or BOD concentrations	1. >1% (10,000 mg/L) 2. >2,100, <10,000 mg/L 3. <2,100 mg/L	What is the range of influent concentrations where 90% of the collected concentrations in the deicer-affected stormwater fall?
Open-water surface	1. Open water 2. No open water	Core technology typically has or does not have open-water surface that might present wildlife attractant or reflectivity issues. Applied only to core treatment technology, not storage.

2. Review treatment technology fact sheets and airport summaries.
   The treatment technology fact sheets list typical values for criteria that describe the technology's performance and application. The airport summaries in Appendix D can also be used to provide context on the technology application by describing field experiences at the airports.
3. Gather information on technologies of interest from consultants, vendors, and other airports.
   Draw on the specific experiences of others to more specifically define criteria associated with particular technologies.
4. Eliminate technologies by comparing site characterization and technology criteria values.
   At the screening level, the comparison of characterization criteria values to technology criteria values results in a straightforward comparison—if the characterization criteria (i.e., your site's treatment needs and constraints) fall outside of the technology criteria (i.e., the technology's capabilities), then the technology should be eliminated from further consideration. Table 6 provides an example template that can be used to compare the criteria. A comparison table should be completed for each technology considered.
5. Calculate order-of-magnitude capital, operating, and annualized costs for short list.
   Within each treatment technology fact sheet, graphs are provided by which the order-of-magnitude capital and operating costs can be estimated from that mass loading capacity

Table 6. Example screening-level comparison table for technology: [name].

Criteria	Characterization Value	Technology Value	Do Criteria Eliminate the Technology?
Stormwater characteristics			
Site constraints			
Operational constraints			

Table 7. Example screening-level cost comparison table.

Treatment Technology	Order-of-Magnitude Capital Costs	Capital Cost Budget	Order-of-Magnitude Operating Costs	Annual Operating Cost Budget	Do Cost Criteria Eliminate the Technology?
Reverse osmosis					
AFBR					
MVR					

(see Chapter 5 for guidance on mass load determination and Chapter 6 for guidance on costs). These cost curves are provided to support the screening-level costs only and are based on a typical installation. They are based on the core elements of each technology and do not include other necessary components of the deicer management system. The costs also do not account for site-specific aspects of treatment system installation (e.g., decisions on treatment building size).

6. Eliminate technologies by comparing costs to budgets.
   The order-of-magnitude capital and operating costs can be compared to the airports' budgets for capital and annual costs to further eliminate potential deicer treatment technologies. An example cost comparison table is provided in Table 7. Please note that the capacity of the treatment system can also be used as a factor to fit treatment costs within the available budget. (Such a decision may sacrifice the ability to manage effects of extreme deicing conditions and require the system to be expanded at a sooner date.)

The result of the screening process is a short list of technologies that can be efficiently analyzed in more detail in the comparative analysis process.

4.3 Comparative Analysis Process for Assessing Alternatives

Use of a quantitative method to compare potentially applicable treatment technologies can be a great aid in the process of selecting deicer treatment technologies. Often when the choice is between two to four equally viable technologies, the differences between the technologies are complex and subtle. Use of a comparative analysis method can promote discussion and aid selection.

Comparative analyses typically use multiple criteria to compare alternatives and can incorporate systems for ranking or numerically rating alternatives. It is generally recommended that comparative analyses initially be performed without incorporation of cost into the comparisons, especially for those methods involving numeric scoring. The reasoning behind this recommendation is that cost as a criterion has the tendency to take precedence and outweigh other criteria. If cost is initially set aside, the importance of other criteria can be better explored. Cost can be integrated into the analysis after the other factors have been considered.

Potential methods for comparative analysis processes are summarized in the following. Please see the References section at the end of this guidebook for additional information on the processes described here.

1. *Analysis of alternatives to determine pros and cons.* This method is one of the simplest comparison methods to use for treatment technology selection. Typically in a pro/con analysis, there is an evaluation of criteria that considers how the deicer treatment technology will be used within the airport's specific deicer management system to meet the airport's goals. Pros and cons are developed for each treatment technology alternative. The lists of the pros and cons for each alternative are compared directly to one another, and a somewhat qualitative assessment

is made. The alternative with the strongest pros and weakest cons is preferred. Decisions are often made through iterative discussion and analysis. The process may be supported by analyses conducted by treatment technology experts. Users may want to weight the relative importance of each criteria category.

Features of the pro/con method include:

- It is the fastest and simplest method,
- It is familiar to users and allows for written analysis of complex topics,
- It has difficulty quantitatively demonstrating the basis for the choice, and
- It does not easily assess the relative and interactive effects of criteria.

2. *Weighted-sum scoring.* In the weighted-sum scoring method, weights are assigned to various selection criteria categories based on the relative importance of the criteria, and values are assigned to the individual criteria for each alternative. To accurately use this process, all criteria values must be in the same units, or total scores will be meaningless. Depending on the criterion, the assessment may be objective (factual) with respect to some commonly shared and understood scale of measurement (e.g., money), or it can be subjective (judgmental), reflecting the subjective assessment of the evaluator.

   Features of the weighted-sum ranking method include:

   - It provides simple numeric means of ranking alternatives,
   - It promotes discussion of relative importance of criteria,
   - It provides limited comparison of alternatives directly to each other, and
   - It uses criteria weighting that is somewhat arbitrary.

3. *Analytical hierarchy process.* The analytic hierarchy process (AHP) is one of several quantitative selection processes that are based on head-to-head or pair-wise comparisons of criteria against each other. In the AHP process, subjective assessments of the relative importance of criteria to the success of the deicer treatment alternative are made. The method assumes that evaluators are more capable of making judgments of relative importance between two choices than absolute judgments among all choices. The pair-wise comparisons are used to quantify the most promising alternatives. The AHP process can be executed with individual decision makers providing their own evaluation or in a collaborative fashion as a group. The AHP has proven to be very good for framing the discussion of alternatives, identifying key criteria, understanding the relative importance of criteria, providing a structure for discussion and consensus, and providing some quantitative guidance for the decision-making process.

   Features of the analytical hierarchy process include:

   - Adds a high level of quantification to selection to help demonstrate basis for choice,
   - Is more complex mathematically,
   - Promotes discussion of relative importance of criteria,
   - Promotes discussion of all alternatives against each other,
   - Breaks the evaluation down into small steps,
   - Promotes comprehensive discussion, and
   - Uses a weighting of criteria that is somewhat arbitrary but allows for more precise determination than other methods.

4.4 Testing of Assumptions

Regardless of the screening and selection method used to determine the treatment technology alternative that is preferred, assumptions were likely made during the course of the analysis. To the extent possible, those assumptions should be tested for the selected technology. If a model is used for any portion of the evaluation, sensitivity analyses are an excellent method for testing the significance and developing a level of confidence in the assumptions. In a sensitivity analysis, a series or range of values is assigned to parameters of interest, and the results of the calculations are reviewed to determine if the assumed values have a significant impact on the results. If the outcome is determined to be sensitive to the assumed parameter, the assumption should be revisited. Sensitivity analyses are particularly valuable for establishing the design capacity of the selected treatment technology.

4.5 Value Engineering

Value engineering is a systematic method to improve the value of selected alternatives by examining methods by which the same or better results can be achieved for the same or lower cost. *Value* is defined as the ratio of function to cost. Value can therefore be increased by either improving the outcome (e.g., more treatment capacity for the same cost) or reducing the cost (for the same capacity). In a value engineering exercise, the objective is not to sacrifice the basic functions as a consequence of pursuing value improvements.

CHAPTER 5

Designing and Implementing Deicer Treatment Systems

General considerations for deicer treatment system design and implementation are discussed in this chapter.

5.1 Sizing the Treatment System

The *basis of design* for a treatment system provides information that is needed to complete the design and cost estimates for the selected deicer management system. A basis of design typically includes the following:

- Treatment capacity needed.
- Number and type of treatment units.
- Sizes of supporting equipment.
- Quantities of materials needed and generated (e.g., chemical, solids, biogas).
- Expected performance (e.g., BOD removal efficiency).
- Design condition (e.g., design event, design season).

Establishing the required treatment system size or capacity is a key aspect of developing the treatment system basis of design because of its effect on cost, footprint, and performance. Considerations for determining the design treatment capacity are provided in the remainder of this section.

5.1.1 Understanding Treatment Capacity Parameters

The capacity of a treatment system can be described using a number of different parameters, including:

- Design flow rate,
- Concentration range, and
- Mass loading rate.

Ensuring that the project team understands these parameters, how they relate to each other, and that the appropriate parameters are applied to each treatment technology is important to the treatment implementation process.

5.1.1.1 Definition of Treatment Capacity Terms and their Relationships

Concentration. Concentration is the mass per unit volume, most often expressed in mg/L, of a single chemical constituent (e.g., PG, EG) or aggregate measurement parameter (e.g., BOD, COD, TOC) in stormwater.

Flow Rate. The flow rate of water is the volume conveyed or processed per unit time, typically expressed as gallons per minute (gpm), million gallons per day (mgd), liters per minute, or cubic meters per day.

Treatment Tips

Relationship of Treatment Capacity Parameters

Understanding the relationships among mass loading rate, flow rate, and concentration in treatment system design and operation is essential.

Determining which parameter will be used to control plant operations should be done early in the treatment design process.

Mass Loading Rate. The mass loading rate refers to the mass of stormwater constituents conveyed, processed, or treated per unit of time, expressed typically in pounds per day (lbs/day) or kilograms per day (kg/day). Mass loading rates (mass per unit of time) are calculated by multiplying the flow rate (volume per time) by the concentration (mass per unit of volume) of a given parameter:

$$\text{Mass Loading Rate (lbs/day)} = \text{Flow Rate (gpm)} \times \text{Concentration (mg/L)} \times 0.0120$$

As seen from this equation, if the flow rates entering a treatment system are kept at a constant rate, changes in pollutant concentration result in an equivalent change in mass loading rate. Keeping the mass loading rate constant, a recommended operating condition for many treatment systems, requires changing the flow rate to adapt to the changing concentrations typical of deicing. If both flow rate and concentration fluctuate independently, such as has been the case with uncontrolled deicer management operations, the mass loading rate may be highly variable. Treatment performance in an uncontrolled system is likely to suffer.

5.1.1.2 Treatment Capacity Parameters Used with Various Technologies

The capacities of recycling technologies, like reverse osmosis and mechanical vapor recompression, are typically described in terms of flow rate and the number of treatment units. The number of units required depends on the volume that must be processed, the PG or EG concentration, and the frequency of maintenance. Lower concentrations of PG or EG mean more water to separate from the glycol and a higher number of treatment units. *Mass loading rate* is not a term that is often directly used when considering recycling technologies, although a higher mass load to process will produce a larger volume of concentrated glycol product to sell.

For biological treatment technologies, mass loading rate is most often the proper means of characterizing treatment system capacity. This is because the treatment system capacity is directly related to the mass of bacteria maintained in the treatment reactors. The mass of bacteria, in turn, is directly related to the mass of food (BOD) supplied to the system. Consideration of how to manage mass loading rate in a biological treatment system is important because a fluctuating BOD mass loading rate results in an unstable bacterial population. Unstable populations make the treatment system prone to poor treatment efficiency (e.g., when a spike load of deicer is applied to a low bacterial population, higher effluent BOD concentrations may result). Unstable bacterial populations also result in less than the full capacity of the system being used. Flow rates for biological treatment systems primarily affect the detention time, or the time that the BOD in the water is exposed to the bacteria. Unless the flow rate entering a biological treatment system is relatively constant, defining treatment system capacity strictly by concentration is not appropriate.

Many of the most recently implemented biological deicer treatment systems, such as AFBRs and aerated gravel beds, are designed to maintain a near-constant mass loading rate by monitoring concentrations of BOD, TOC, or COD and adjusting flow rates in response. Higher measured concentrations result in the need to reduce flow rates to maintain a constant loading rate and vice versa. The allowable mass loading may be linked to temperature or the onset of excessive bacterial growth that could cause clogging.

These types of constant-load operations often use a greater percentage of their available treatment capacity in comparison to uncontrolled situations. They are also less prone to upsets from variable deicing conditions. If a biological treatment system's loading rate is controlled, the variation in the pollutant concentration is not a particularly important operational parameter if the system is operated within design conditions.

5.1.2 Calculating Required Mass Loading Treatment Capacity

A mass balance provides the basic means of approximating the required mass loading rate that must be removed to meet governing discharge criteria, as shown in simplified form in the following equation:

$$L_{\text{treatment}} = L_{\text{stormwater}} - L_{\text{discharge}}$$

Where:

$L_{\text{treatment}}$ = Approximate mass loading rate of treatment system (lbs/day),
$L_{\text{stormwater}}$ = Mass loading rate of untreated stormwater water (lbs/day), and
$L_{\text{discharge}}$ = Allowable mass loading rate of discharged stormwater (lbs/day).

To obtain an order-of-magnitude approximation of the mass load that needs to be removed by treatment for use in establishing costs during the alternative analysis process, $L_{\text{treatment}}$ and $L_{\text{stormwater}}$ can be calculated for average conditions. Care must be taken, however, to understand the source of the calculated values. Many deicer treatment systems in the early history of deicer management were sized based on limited stormwater sampling data and flow data. They subsequently proved to be undersized because the variety of flows and concentrations were not well understood.

In practice today, dynamic models that simulate deicer application conditions, stormwater runoff and routing, and deicer management measures are used to assess a broader array of potential conditions. Models can capture variation in deicing under much shorter time steps than is the case with calculations based on average calculations. The treatment capacities needed under more extreme conditions can be better understood in this way. In many instances, extreme deicing and runoff conditions dictate the required system capacity in terms of treated mass loading rate, flow rate, and storage capacity.

Dynamic models are typically devised to jointly simulate the characteristics of the stormwater runoff, the required treatment mass loading rate, and the required storage volume. The optimal balance between storage volume and the treatment mass loading rate required to meet the governing discharge conditions for a variety of deicing circumstances is assessed in an iterative fashion. The assumptions associated with the model development and simulations should be well documented. In many cases, sensitivity analyses can be used to understand the potential impacts of model simulations. The advantage to including the storage volume in a dynamic model is that the effects of equalization and attenuation of concentrations can more readily be understood and the required volumetric limit can be determined in one step.

The nature of deicing, with unpredictable weather conditions and uncertain future flight activity, makes it impossible to quantify a true worst-case condition. Attempts to project true worst-case deicing have shown that the worst of conditions tend to be true outliers that occur

Treatment Tips

Design Capacity

A simple mass balance can be used to get an order-of-magnitude approximation of the BOD mass loading rate that needs to be removed by treatment.

Model simulations are used to more accurately account for the treatment mass loading and flow rates needed for the more extreme conditions.

Site-specific factors like adjustments for low temperature, storage capacity, and future design conditions can affect the design treatment capacity.

extremely rarely. The design capacities needed to manage worst-case conditions can be several times larger, for example, than the design treatment capacities needed to fully manage 90% of the deicing events. As a result, worst-case design basis is defined by the airport in coordination with the regulatory authorities.

The required treatment system design capacity is not typically a distinguishing criterion for the treatment technology selection phase, except as it relates to costs and space requirements. The size and number of units for virtually any treatment technology can be adapted to meet the required treatment capacity. In other words, it is rare that a treatment technology could be eliminated from consideration based on the inability to size the technology to the required capacity. The required treatment capacity, however, does have a direct bearing on capital and operating costs.

The required design capacity is frequently affected by a number of site-specific factors, which are discussed in the following.

Design capacity may need to be **increased** to account for the following:

- *Cold temperatures.* Cold-weather treatment inefficiencies that cannot be managed by other means.
- *Influent variation.* Insufficient storage or control of influent flow and loadings results in the need to add capacity to treatment.
- *Effluent quality.* The system should have enough capacity to ensure that capacity is not the limiting factor in achieving the desired effluent quality.
- *Expansion.* The future year to which the treatment facility is designed to operate can have a significant effect on the design capacity.

Design capacity could be **decreased** based on design decisions on other components of the deicer management system, including:

- *More storage.* Increased storage capacity coupled with using more of the non-deicing season to operate the treatment plant will decrease the needed treatment capacity.
- *Multiple treatment technologies.* Use of multiple treatment technologies could reduce the total required design capacity and the cost of the primary deicer treatment technology. For example, discharge of loads to a POTW during rare extreme deicing conditions could allow the maximum capacity needed for an activated sludge plant to be decreased.
- *Monitoring and control.* Monitoring and control of the flow rates and BOD concentrations entering treatment to attenuate peaks could decrease the maximum treatment capacity needed.

These conditions affecting design capacity are further discussed in the following.

5.1.2.1 Effect of Temperature on Design Capacity

The cold temperatures characteristic of deicer-affected stormwater may affect treatment in multiple ways:

- Decreased levels of microbial activity reduce the mass of BOD that can be treated in a biological system per unit mass of bacteria.
- Increased water viscosity reduces flow rates through membrane systems.
- Chemical nutrients do not dissolve as readily.
- More energy input is required for evaporation-based systems.

For biological treatment, it is well established in theory and in practice that without implementing measures to adapt to cold temperatures, treatment effectiveness will suffer. As part of the research for this guidebook, the effect of water temperature on degradation rates for both aerobic and anaerobic systems was assessed using a lab-scale biological respirometer. Biological seeds from actively functioning full-scale deicer treatment systems were used for the analyses. Tests were conducted at a variety of PG concentrations and temperatures.

The results of the testing under aerobic conditions are shown in Figure 17. The *y*-axis represents the rate of off-gas production in the respirometer, which corresponds to the degree of biological activity (higher values = higher degradation rate and better treatment). The *x*-axis is PG concentration. As shown, the degradation rates at 36°F were approximately half of the rates at 41°F and over five times less than the degradation rates above 48°F. The relationships were similar over a PG range of between 100 mg/L and 7,000 mg/L, indicating no relationship between concentration versus temperature, and degradation rate within that range.

Not surprisingly, the temperature effects for anaerobic bacteria are even more pronounced (Figure 18). For anaerobic treatment, little or no degradation was observed below 60°F. There were marked differences in degradation rates between 75°F and 85°F. The PG concentration within the range tested (100 mg/L to 8,000 mg/L) did not change the basic temperature effects.

The temperature data from the lab testing aligned with results observed in the field. Anaerobic systems like the AFBR are specifically designed to function between 85°F and 90°F because that is where the anaerobic bacteria function best. Many aerobic systems, especially those that do not take specific measures to help counter the temperature effects, have seen significant decreases in

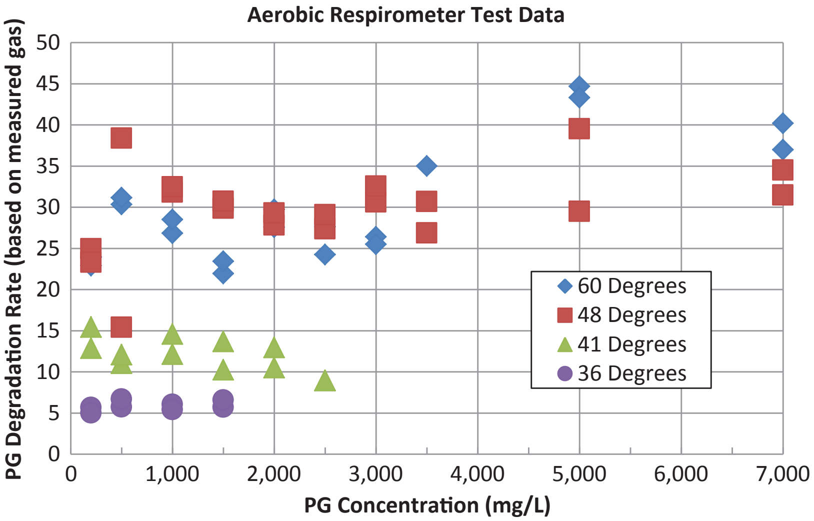


Figure 17. Relationship of water temperature and aerobic degradation rates.

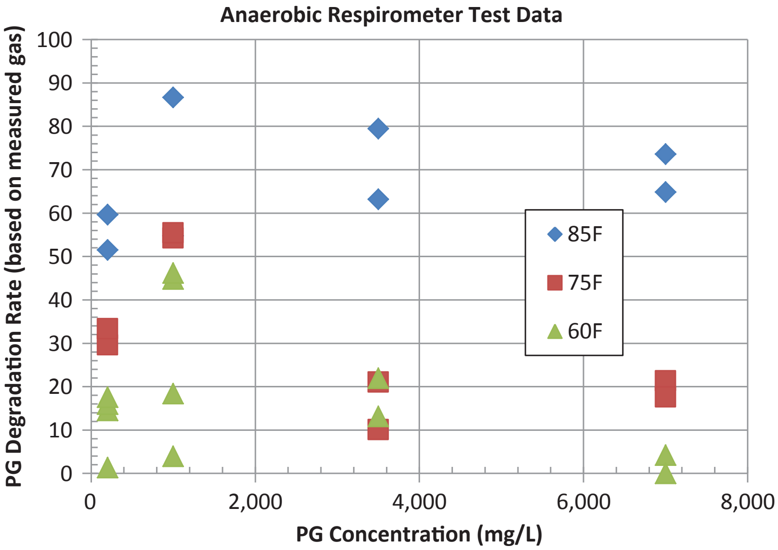


Figure 18. Relationship of water temperature and anaerobic degradation rates.

performance during the coldest months. During the coldest period for many northern airports, the water temperatures are frequently less than 41°F when the stormwater enters the treatment system.

Within a biological treatment system, the activity of the microorganisms actually releases energy. The extent to which water temperatures increase or decrease within a treatment system depends on the energy losses and gains. Factors in the heat balance include:

- Local climate conditions (ambient air temperature, wind speed, solar heating),
- Exposure of the treatment unit water surface to the air,
- Insulation from the ground,
- Insulation of tank walls,
- Reactor surface area, and
- Heat loss (evaporative cooling) from surface aeration or blowers.

Without taking steps in design and operation to counteract the cold temperatures and subsequent effects on treatment, the treatment efficiency of a biological treatment will suffer. A number of measures can be taken to address temperature effects on treatment capacity, including:

- Storage and flow control.
  - Holding water collected during winter in storage until temperatures increase (has net impact of increasing storage requirements).
  - Reducing mass loading rates during cold periods (has net impact of increasing storage requirements and running the treatment system for a longer period in a season).
  - Some systems have evidence that reducing mass loading rates prior to cold periods helps the bacterial population recover faster when the temperatures warm.
  - Reducing the volume of water that is collected from the runoff (e.g., with deicing pads) to reduce the volume of water that has to be heated.
- Heat management.
  - Insulation of potential heat loss surfaces to better take advantage of heat generated by the biological activity.

  - Providing external source of heat.
    - Heat exchange with hot water source fueled by:
      - Methane captured from anaerobic systems.
      - Natural gas.
    - Heat exchange between effluent and influent flows if the effluent has higher temperatures from the treatment process.
    - Geothermal heat.
    - Mixing with warmer wastewater such as sanitary sewage.
    - Treatment units contained in a heated building.
- Bacterial population management.
  - Increasing the biomass concentrations in the treatment reactors prior to cold weather. An increase in the number of bacteria can at least partially offset reduced treatment rates per unit mass of bacteria. This is primarily a strategy for short-term management.
- Increased reactor capacity.
  - Building in larger treatment capacity provides more opportunity to maintain a larger biomass population prior to treatment. However, a larger reactor can also make it more difficult to sustain the biomass during periods when the amount of deicer available to treat is low.

The specific measures that can be employed depend on the specific treatment technology characteristics as well as local infrastructure and resources.

5.1.2.2 Effect of Effluent Quality Targets on Design Capacity

A number of factors can affect the effluent pollutant concentrations for BOD, COD, PG, and EG that can be achieved by treatment:

- It is generally thought that anaerobic treatment results in higher effluent concentrations for BOD and COD than aerobic treatment, although the difference may not necessarily be as significant for deicer-affected stormwater as it is for other wastewaters.
- For a given flow rate, higher influent concentrations may result in higher effluent concentrations if the treatment system does not have enough treatment load capacity.
- A lack of nutrients or other essential conditions necessary during certain times for biological treatment will result in higher concentrations.
- When there are an insufficient number of membrane units in a reverse osmosis system, it will be unable to reduce the concentration of the dilute stream.

When considering treatment capacity, the capacity should be large enough that it is not a limiting factor in achieving effluent limits. Understanding that variable conditions will occur, it is good practice to design with a safety factor in treatment capacity that can provide a buffer against those variations and allow target effluent concentrations to be met more frequently.

5.1.2.3 Effect of Storage Volume on Design Capacity

In the process flow schematic of many deicer management systems, storage is located between the collection system and the treatment system. Storage is most typically viewed as a means of capturing large runoff events. Storage structures also provide an equalization function, where some of the variation in deicer concentrations in the collected runoff can be attenuated. Storage capacity is related to treatment capacity. Both are related to how long an on-site treatment system runs during a deicing season. As shown in the Treatment Examples: Balance Between Storage and Treatment at Portland International Airport text box, higher storage volumes generally allow lower treatment capacity. The trade-off does require longer running time for the treatment system into the warm months.

The maximum degree that storage can be increased in this scenario is typically bounded by the practical value in being able to drain the storage structure by the start of the next deicing

Treatment Examples
Achievable Effluent Quality at Akron–Canton Airport (CAK)

It is a generally accepted view, derived primarily from experience with municipal and industrial wastewater, that achievable effluent COD concentrations from anaerobic treatment systems are substantially higher than achievable effluent concentrations from aerobic treatment systems. Several years of operating data from the CAK's AFBR treatment system were reviewed in this research to further define the low range of anaerobic deicer treatment effluent quality. The conclusions indicate that anaerobic deicer treatment can achieve COD effluent concentrations significantly lower than previously thought, although not as low as some aerobic systems.

The CAK AFBR system includes two anaerobic reactors running in parallel, where the vast majority of the COD is removed, and a dissolved air flotation system for removal of biological solids. For the 2008–2009 and 2009–2010 deicing seasons, the CAK AFBR ran for a total of 296 days (excluding the start-up periods) at average COD mass loadings 15% higher than the system design capacity (3,400-lbs COD/day). Over those two seasons, the treated effluent averaged 151-mg/L soluble COD (i.e., COD without solids) directly from the anaerobic reactor and averaged 39-mg/L soluble COD in the effluent from the dissolved air flotation unit that is integral to the anaerobic treatment system. (PG concentrations were non-detectable in lab analyses, and no BOD analyses were conducted.) During this period, the system removed 99.77% of the influent COD load. See the airport summary for CAK in Appendix D for graphs showing the range of effluent concentrations in the 2009–2010 season.

It is theorized that the ability of the CAK system to achieve lower concentrations than thought with anaerobic treatment may be related to the vast majority of COD being derived from soluble glycols rather than more difficult to degrade soluble and insoluble COD found in municipal and industrial wastewater.

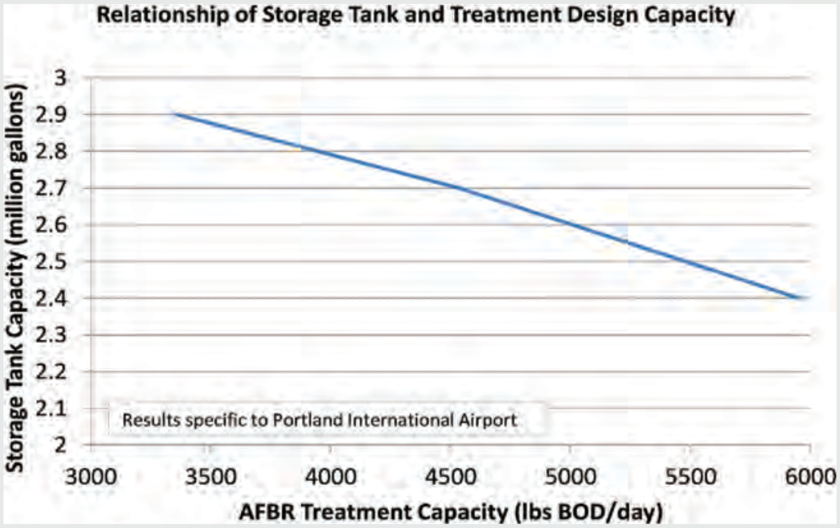
season. The inability to treat all water before the start of the deicing season could lead to several issues, including:

- Degradation of the stormwater stored in the tanks, in particular over warm weather months. For a recycling system, extended storage means loss of glycol product because of the degradation. For biological treatment systems, extended storage may cause treatability issues because the biology may not be sufficiently acclimated to the breakdown products of the primary deicer constituents.
- Breakdown of the deicer into volatile fatty acids during warm weather decreases the pH to as low as 3 to 5.
- Starting the season with water in storage could lead to a cascading effect where the treatment facility cannot catch up, and alternative means of disposal of the tank contents becomes necessary.
- Operations staff members, who often have other responsibilities, are needed to tend to the treatment facility for a longer period during the year.

The relative costs of storage capacity and treatment capacity need to be weighed. Storage can also require a greater footprint than some treatment technologies, which could be an issue in situations

Treatment Examples

Balance Between Storage and Treatment at Portland International Airport (PDX)



In the process of determining the required design mass loading capacity and design storage capacity for the PDX deicing system enhancement, a model was used to simulate the various combinations of storage and treatment capacity that would meet compliance objectives for discharges to surface waters. As shown in the graph, various combinations of storage and treatment would be able to meet the objectives. Once the storage–treatment capacity curve was determined, combined costs for storage and treatment were calculated to find the minimum cost point.

where space is at a premium. The primary advantage to storage is that there is significantly less operational burden and cost to operate a storage structure compared to treatment. It is also often easier to add storage than to expand treatment capacity in response to airport growth.

5.1.2.4 Effects on System Influent Control on Design Mass Loading Rate

Even with the partial equalizing effects of storage prior to treatment, most facilities experience significant periods of variability of deicer concentrations routed from storage to treatment. Biological treatment systems function best when the mass loading rate in the treatment influent is relatively constant because the bacterial populations tune themselves to the quantities of BOD to be treated. An increasing number of airports are finding that controlling the mass loading rate entering the treatment systems helps to stabilize operations and provide for more predictable effluent quality.

Control of mass loading rates can be achieved by monitoring concentrations, typically of COD or TOC, at least once a day and making adjustments to the flow rate. The control can mostly be manual in nature (grab samples, on-site lab tests, manual flow adjustments) or more computer controlled (online monitoring, changing of flow rates through automatic valves or variable frequency drives on pumps).

The level of control is related to the needed treatment capacity because the system can be designed for a lower mass loading capacity if the peak concentrations are dampened (Figure 19).

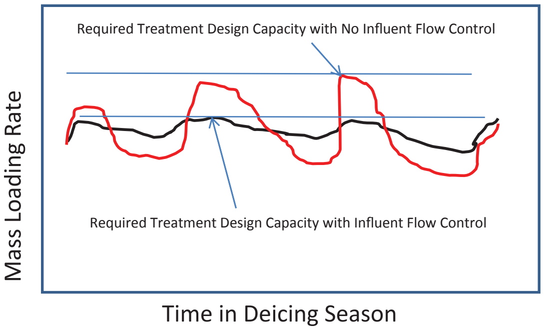


Figure 19. Accounting for effects of flow control on maximum required capacity.

5.1.2.5 Effects of Using Multiple Treatment Technologies on Design Mass Loading Rate

Many airports use multiple treatment technologies within a single treatment system. Frequently, the collected runoff is segregated into fractions based on PG, BOD, COD, or TOC concentration. Treatment technologies that best align with the individual fractions are selected.

Using multiple treatment technologies may allow the capacities of the individual technologies to be reduced because of the additional flexibility gained in managing flows during variable conditions. At times, the features of multiple technologies can be used in a complementary way to help reduce design capacity. In that scenario, the treatment technologies would be applied to the fraction of the collected stormwater stream that is optimal for their conditions. For example, if an AFBR and aerated lagoon were used in combination, the excess biogas captured from the AFBR could be used to heat water entering the aerated lagoon, thus improving the lagoon's cold-weather efficiency.

5.1.2.6 Allowances for Variation in Weather Conditions

An important design point for the treatment plant capacity (as well as storage) is the extent to which the systems are sized for the most extreme conditions. Most often this is represented as a "design event," "design storm," or "design season." The basis-of-design decision for sizing based on weather conditions is typically something that needs to be discussed with regulators. No specific regulatory standard exists in the United States for setting a design event or design season for deicer management. Treatment situations in some other industries, such as the design storms associated with combined sewer overflows, do have design standards. The basis-of-design condition can have significant consequences. For example, past modeling studies have shown that the treatment capacity needed for a 50-year-recurrence design season can be 1.5 to 2 times larger than the capacity needed for a 10-year-recurrence season. *ACRP Report 81: Winter Design Storm Factor Determination for Airports* discusses design storm methodologies.

5.1.2.7 Allowances for Future Growth and Expansion

Airports will typically design their storage and treatment systems to have the capacity needed at some future date. In most cases, this means having allowances in capacity for future growth in airport operations. Deicer application volumes at a future date driven by changes in future operations can be subject to many variables, so it is important to have a thorough and agreed-upon understanding of the assumptions for future conditions. Most airports will design for a point in time between 10 and 20 years in the future.

If the treatment capacity is designed for a point in the future, the system may have excess capacity in the short-term. Operating at a lower capacity than designed may have an impact on the treatment system's short-term performance (positive or negative).

5.1.2.8 Use of Modular Systems to Split Required Design Capacity

Many times, treatment systems are constructed as multiple smaller units rather than one large unit. Using multiple smaller units offers a number of advantages, including:

- Ability to run the system in series or parallel mode,
- Ability to have one or more treatment units offline for maintenance while continuing operations,
- Operational costs managed by only operating enough units to meet the current treatment demand,
- Better process control (e.g., more efficient mixing),
- Easier expansion to meet future demand, and
- Better effluent quality often achieved than with single, larger treatment unit.

As a result, the basis of design for many treatment systems provides the capacity of individual units and the number of units to reach the required treatment capacity.

5.1.3 Design Concentrations and Flow Rates

Conventional thinking for municipal and industrial wastewater treatment is that design concentration and design flow rate are defining design parameters for biological treatment system sizing. However, the huge variability in BOD concentrations and flow rates in deicer-affected stormwater result in the need for a different perspective on the significance of the terms "design concentration" and "design flow rate." In most situations with biological treatment of deicers, the need to control the mass loading rates resulting from the variability in deicer-affected stormwater results in there being relatively little significance to the term "design concentration." In a facility where mass loading rates are controlled, the fluctuation in concentrations does not really affect the biomass population in the treatment system or the treatment efficiency. Design flow rates are somewhat more important because of the impact on pump and pipe sizes, although the design flow rates are less a selected design point than a consequence of the selected mass loading rate and the BOD concentrations in the influent flow.

For recycling-based systems, design concentrations are important because they relate to the volume of water that must be evaporated. Therefore, for them to be economical, it is important that minimum thresholds for PG concentration be met (typically 1% or greater for reverse osmosis and MVR recycling technologies). Design flow rates for recycling systems typically affect the number of treatment units (MVR or reverse osmosis) that are required.

5.1.4 Relationship of Design Capacity, Cost, and Risk

When final treatment capacity decisions are made, it is important to understand the risks associated with the selected capacity. The decision may be made to construct a smaller system (usually because of insufficient funds) or oversize the system (usually to account for future growth or to add a greater degree of certainty of compliance). There are identifiable risks associated with undersizing or oversizing treatment, including:

- Undersizing a treatment system can potentially result in:
  - Performance risk from added stress on the treatment process if the system has to be overloaded to avoid overtopping storage during heavy deicing periods.
  - Compliance risk if the treatment system cannot process all stored volume within a calendar season.
  - Planning and development risk if there is insufficient capacity to accommodate future growth at the airport.

- Oversizing a treatment system can potentially result in:
  - Unnecessary capital and operating costs.
  - Compliance risk because of the difficultly in maintaining a continuous and stable treatment operation.
  - Compliance risk because of greater challenges with seasonal start-ups.

Finding the sweet spot for selecting the right treatment system size is one of the greater challenges in treatment system design. Over much of the range of potential treatment capacities, there is a direct relationship between the treatment system capacity (cost) and the probability of an effluent exceedance. Generally, increasing the treatment system capacity will decrease the risk of noncompliance, at least until the point where continuous treatment facility operation cannot be achieved. Eventually, a point of diminishing returns is reached where additional investment in treatment capacity yields smaller reductions in the risk of noncompliance. Therefore, the decision-making team should consider both the benefits and costs of potential design capacity points.

5.2 Treatment Support System Design

In this guidebook, *treatment support system* is defined as a unique process that is typically required to allow the primary treatment system process to function appropriately. Five categories of support systems are discussed in the following in general terms. Specific discussion of the support systems needed for each technology can be found in the treatment technology fact sheets.

5.2.1 Pretreatment

Some deicer treatment systems may require pretreatment of the deicer-affected stormwater prior to the stormwater entering the primary treatment process. The pretreatment is typically needed to modify the characteristics of the stormwater to either protect the primary treatment process or make it more effective. Typical pretreatment processes that may be applied include:

- Removal of large debris (through screening),
- Removal of grit (through sedimentation),
- Removal of TSS (through settling or flotation),
- Increase in water temperature (typically using heat exchangers),
- Adjustment of pH (through chemical addition),
- Addition of chemicals to reduce likelihood of biofouling, and
- Removal of oils, grease, and other petroleum products (through oil–water separator).

The physical treatment processes for recycling tend to be more sensitive to stormwater contamination from non-deicer constituents because of the potential fouling of the treatment structures, which hurts processing efficiency and increases maintenance costs. Therefore, these technologies have evolved to include multistep pretreatment operations that protect the primary treatment units and allow them to function optimally. In some cases, certain pretreatment processes can be combined, such as pretreatment units that remove large debris, TSS, and oil and grease.

The presence of dissolved solids (measured as TDS) in stormwater can be a particularly problematic issue. At times, the presence of pavement deicers can cause very high spikes in TDS concentrations. High TDS concentrations can negatively affect both biological and physical treatment systems. It can be difficult to treat deicer-affected stormwater to remove TDS. Biological systems will not remove dissolved solids. The effect of TDS and the need for pretreatment are usually mitigated through storage and equalization prior to treatment. While the peak TDS concentration during events of heavy pavement deicer use and low runoff volumes can be high, the dilution provided during the remainder of the time usually reduces average TDS concentrations in storage to avoid treatment impacts. However, the effect of TDS on deicer treatment systems has not been well-studied. If more significant TDS removal is needed, pretreatment processes such as chemical softening, ion exchange, and reverse osmosis can be used to remove certain constituents contributing to TDS.

5.2.2 Nutrient Management

Nutrient addition is an essential component to biological treatment. The microorganisms performing the treatment need nutrients for new cell synthesis. There is significant evidence that lack of nutrients in biological deicer treatment systems will severely restrict, if not inhibit, treatment of deicers because not enough new cells can grow and use the deicer constituents. Lab testing performed for this research, for example, indicated that withholding nutrients can decrease the treatment rate by as much as 40% in a short period (1 week). This effect will be continued as long as an insufficient nutrient concentration exists in the system.

While some wastewaters, such as sanitary wastewater, contain sufficient nutrients, deicer-affected stormwater does not. As a result, nutrients need to be added to most biological deicer treatment systems. The need for nutrients and their absence from deicer-affected stormwater mean that biological deicer treatment technologies need a support system for storing, mixing, and metering nutrients into stormwater prior to or within the primary biological treatment process. Deicer-treatment plant operators coming from a sanitary wastewater treatment background must adapt to the idea that nutrients are essential and that regular additions must be made. One of the more complex job functions for deicer system operators is the balancing of nutrient additions such that enough nutrients are added to adequately support the bacteria without overloading the stormwater to the point that effluent limits in permits (if present) for ammonia-nitrogen or phosphorus are exceeded. This can be especially difficult if the COD load to be treated fluctuates.

Often, nutrients in biological deicer treatment systems that need to be added continuously are classified as *macronutrients.* Nutrients that only need to be added on an occasional basis are classified as *micronutrients.* Nitrogen and phosphorus are almost always macronutrients. Other nutrients that may need to be added include:

- Sulfur,
- Iron,
- Magnesium,
- Potassium,
- Calcium,
- Sodium, and
- Small amounts of additional minerals for anaerobic bacteria.

Most often, nitrogen and phosphorus are the most critical nutrients to add. In anaerobic systems, sulfur is also critical and therefore considered a macronutrient requiring continuous feeding.

Deicer-affected stormwater also often has insufficient amounts of other nutrients. While these nutrients do not have to be added in the same quantities as nitrogen and phosphorus, their absence can negatively affect deicer treatment in a biological system.

Nutrient additions are typically paced to the organic (COD) load to reduce the likelihood of overfeeding or underfeeding of the biomass. Typically, the nutrients come in solid form and are mixed into solutions for larger systems. For smaller systems, prepurchased chemical solutions may be economical. A typical

Treatment Tips

Nutrients in Biological Treatment

Understanding the role of nutrients in biological treatment is essential.

In most situations, nutrients must be added regularly for a biological deicer treatment system to function well.

nutrient feed system includes mixing/storage tanks, metering pumps, and tubing to the injection point.

Many of the existing biological deicer management systems have experienced instances of unintentional or accidental impacts from lack of nutrients. Lessons learned from nutrient management in biological deicer treatment systems include:

- At one airport, lack of phosphorus addition for an extended period resulting from inaccurate laboratory analysis of the treated effluent resulted in treatment efficiency dropping by over 50%. When the phosphorus began to be added again, treatment efficiencies returned to normal within days.
- Nutrient addition needs, especially for nitrogen, are especially great during the system start-up at the beginning of the deicing season. This appears to be true for many different types of biological technologies. Nitrogen loadings several times higher than the normal loading may be necessary for several weeks at start-up.
- One airport found that adding nutrients alone prior to the addition of BOD at the system start-up helped to speed up the overall start-up process.
- The dying bacteria in a biological treatment system, especially after a summer shutdown, will typically release significant quantities of nutrients back into the water. It may be difficult to achieve the correct nutrient balance during this period.

5.2.3 Biogas Management

The biological treatment systems using anaerobic processes produce methane, which can be captured and used as fuel. This includes the anaerobic fluidized bed reactor and the anaerobic digesters at POTWs. For AFBRs with influent COD concentrations of greater than 2,100 mg/L, the captured gas is enough to heat the incoming water for most of the deicing season once the start-up period is over. During the start-up period, natural gas is needed because the quantity of biomass in the treatment system is insufficient to generate the required methane.

Methane is the primary component of biogas from an anaerobic treatment system and is the primary component in natural gas. As such, any system with the potential to use natural gas may be able to use the methane captured from an anaerobic reactor if the gas handling and burning equipment is adequately configured for both. If enough methane is produced to meet the treated water heating demands, excess methane can be used to heat buildings or sand, melt snow, or produce electricity.

Treatment systems that produce biogas containing methane may have gas management support systems that contain the following components: sealed piping for gas collection, boilers for burning methane, temperature monitoring, heat exchangers, and flares for burning excess methane. Flares without visible flames can be used.

5.2.4 Monitoring and Control Systems

One of the emerging trends in wastewater treatment in general, but more specifically in deicer treatment, is using online control of various elements of the treatment process to improve efficiency and predictability and reduce capital costs through reductions in the size of storage and treatment. Control system components include:

1. Instruments for monitoring temperatures, pressures, flow rates, pollutant concentrations, pH, and water level;
2. Programmable logic controllers (PLCs) for receiving the instrument inputs, performing calculations, and outputting signals to start, stop, and adjust operating conditions for equipment such as pumps, blowers, and valves;

3. Programming loaded onto the PLC to provide the process logic and control mechanisms; and
4. Means for recording process data.

Together these components are typically called the supervisory control and data acquisition (SCADA) system. SCADA systems take some of the operating responsibilities from the operating staff for direct monitoring and control, but may increase operator requirements to manage and interpret data.

The finer degree of control provided by a SCADA system helps to reduce the variation in the process and helps the treatment system respond more quickly to changes in conditions. It also provides additional information on process performance to help assess ways to optimize the system and help troubleshooting.

In some situations, such as when a control system is applied to manage the influent mass loading to a treatment system, the finer degree of control has the net effect of reducing the required treatment or storage system capacity by reducing the need to size to peak conditions.

5.2.5 Post-Treatment Biological Solids Management

In any biological treatment system, new microorganisms are continually formed and old organisms die. If a steady population of microorganisms is to be maintained, the excess microorganisms must be removed. Microorganisms contained in the treated effluent must also be removed to meet effluent limits for TSS. The removed microorganisms are often called biological solids or sludge.

The required biological solids management system varies depending on several factors, including:

- The type of process used. Anaerobic processes produce quantities of biological solids that are approximately 10 times less than the biological solids produced by many aerobic processes because the anaerobic bacteria grow more slowly.
- How well the biological solids settle. Anaerobic processes may have biological solids that are more difficult to settle by gravity. As a result, processes like dissolved air flotation systems may be required.
- The degree of dewatering that is required. This depends to some extent on how the biological solids will be disposed of. If they are transported off-site, it is expensive to transport solids with a significant water content, and some dewatering on the site may be required.
- The disposal method for the solids.

The design and operational impacts of solids management should not be underestimated. In the design phase, the likely characteristics of the biological solids, as well as the quantities to be produced, should be carefully evaluated. If there is insufficient thought given or insufficient funds allocated to this phase of the system design, there may be significant operational costs and hassle.

5.3 Guidance on Deicer Treatment System Implementation

5.3.1 Construction and Commissioning

The time required for construction of a deicer treatment system can vary from several months to over a year. The construction time depends on:

- The complexity of the project, including the number of different systems that must be constructed,
- Where the construction is occurring (e.g., inside or outside secure areas),

- When the construction is started (construction of some elements may not be feasible in winter),
- Weather delays during construction,
- The degree to which components or unit processes come prepackaged,
- The extent to which existing infrastructure is used, and
- When funding is available.

For many airports, one of the primary construction considerations is minimizing interference with airport operations. A safety and phasing plan is often required to identify where and when the construction is occurring, in addition to haul routes and staging areas. Significant coordination between the contractor and owner is required to manage operational impacts.

The last step of construction is the process for checking out and testing the individual pieces of equipment and the instruments, as well as the checking out of the deicer treatment system as a whole. Inadequate testing of the constructed treatment system can have significant effects on consistency of operations, compliance risk, the ability to reach design capacities, and cost. The process for checking and testing the constructed treatment system can take the form of a formal commissioning process conducted by a third party or the design engineer and contractor working together to check out operation of the system as a whole. For complex deicer treatment systems, the commissioning process can take 6 to 12 weeks, but in most cases it is well worth the time and investment.

5.3.2 System Start-Up and the First Year of Operation

The system start-up and first year of operation make up a critical period. Because deicer treatment systems involve many pieces of equipment and instruments working together in a dynamic environment with changing stormwater conditions, some issues with design and construction only come to light when the system operates as a fully functional unit treating collected stormwater. In addition, the start-up and first year of operation are the period when operations and maintenance personnel first get hands-on experience in running the system. In the case of a biological treatment system, the start-up is also the period when the bacterial population is first established. Often, biological treatment systems require a source of seed to start the system. Aerobic systems require seed from another aerobic treatment system, and anaerobic systems require anaerobic seed. Obtaining a quality seed will speed the start-up process. A biological treatment system starting up for the first time can take 2 to 4 months to reach the full treatment capacity, with anaerobic systems expected to take longer than aerobic systems because anaerobic bacteria are slower growing.

As a result of these conditions, the start-up and first year are usually the most difficult period of operation for a deicer treatment system. In some cases, early performance of new systems is not representative of the system's long-term ability to treat. Effective design, efficient construction, operator training, and well-planned testing can reduce the likelihood of issues in the start-up period, but airport management should be aware that a breaking-in period for the treatment system is to be expected.

5.3.3 Long-Term Operations and Maintenance

Most deicer treatment systems require some attention from operators in order to perform adequately. Typical operator functions include:

- Making decisions on feeding of deicer-affected stormwater into treatment;
- Adding the correct amounts of the right nutrients to biological systems at the right times;
- Making process adjustments based on influent stormwater characteristics, effluent quality, and process monitoring data;

Owner/Operator Management Tips for Successful Treatment Systems

- Have design engineers demonstrate the relationship between cost and compliance risk.
- Document and understand the system's capacities and operational limitations.
- Hire and train qualified and engaged operators.
- Implement a monitoring system for appropriate parameters.
- Track and regularly assess system operational parameters.
- Implement a preventative maintenance system.
- Ensure that short-term maintenance support is available in a timely manner.

- Troubleshooting;
- Sampling, monitoring, and lab analysis;
- Data entry, review, and analysis;
- Performing maintenance;
- Aligning treatment system operation with the rest of the deicer management system; and
- Reporting to regulatory authorities.

It is not always required or essential to have licensed wastewater treatment operators for deicer treatment facilities, but training of the operators in the specifics of the treatment system operation is essential. It is generally recommended that operators begin work on the treatment system no later than the testing and commissioning phase at the end of construction. If other airports use similar technologies, training with operators of those facilities is recommended.

The number of operators required depends on the complexity of the deicer treatment system and other duties assigned to operators. Many deicer treatment systems can be run with one to two full-time operators. Choosing the right operators is critical.

The airport's management team also plays a critical role in successful deicer treatment. Managers should understand the basic system operations. An understanding of the capacities and limitations of the deicer treatment system based on system capabilities is also critical. This includes understanding what constituents can be treated, stormwater constituents than can affect system performance (e.g., presence of spilled fuel), the maximum treatment capacity, expected effluent quality, and expected treatment efficiency.

Since most deicer treatment systems include a variety of electromechanical equipment, a preventative maintenance program is a necessity. It is also critical to work out procedures with those performing maintenance to have fast maintenance response for system components in need of repair.

CHAPTER 6

Determining Costs for Deicer Treatment

For any given application of deicer treatment at an airport, there are likely at least two to three deicer treatment technologies that could provide the necessary degree of treatment and meet the airport's regulatory compliance objectives. As a result, in many cases, cost of treatment becomes a differentiating factor. Treatment costs often need to be assessed at various points in the deicer treatment implementation process, from initial screening of alternatives through ongoing operations. Airports and airlines should solicit thorough cost estimates and be aware of the many challenges involved in obtaining accurate costs. Frequently encountered cost issues are shown in Table 8.

Cost-related considerations are presented in this chapter for various aspects of deicer treatment assessment, implementation, and operations processes.

6.1 Cost Information Reported by Airports

Cost information that was reported by airports during the research is provided in the airport deicer treatment system summaries contained in Appendix D. Where possible, notations have been made in these summaries to indicate the sources and limitations of the cost information. Great care should be exercised by guidebook users in drawing meaningful relationships between treatment costs at other airports and their airports. Such comparisons do not take into consideration the differences in system size, the costs of other deicer management system components, local economic conditions at the time of construction, and site infrastructure impacts.

6.2 Screening-Level Order-of-Magnitude Cost Curves

To facilitate cost assessments during the treatment technology selection phase, screening-level cost curves have been incorporated into the technology fact sheets. Cost curves are presented for capital and operations and maintenance costs. Examples are provided in Figure 20 and Figure 21. The purpose of these curves is to provide order-of-magnitude guidance during the treatment technology screening phase. These cost curves were derived from unit costs for treatment system components considering only the typical technology features that are essential to the technology's functions. Cost information from specific applications of the technologies at airports was consulted as a reference.

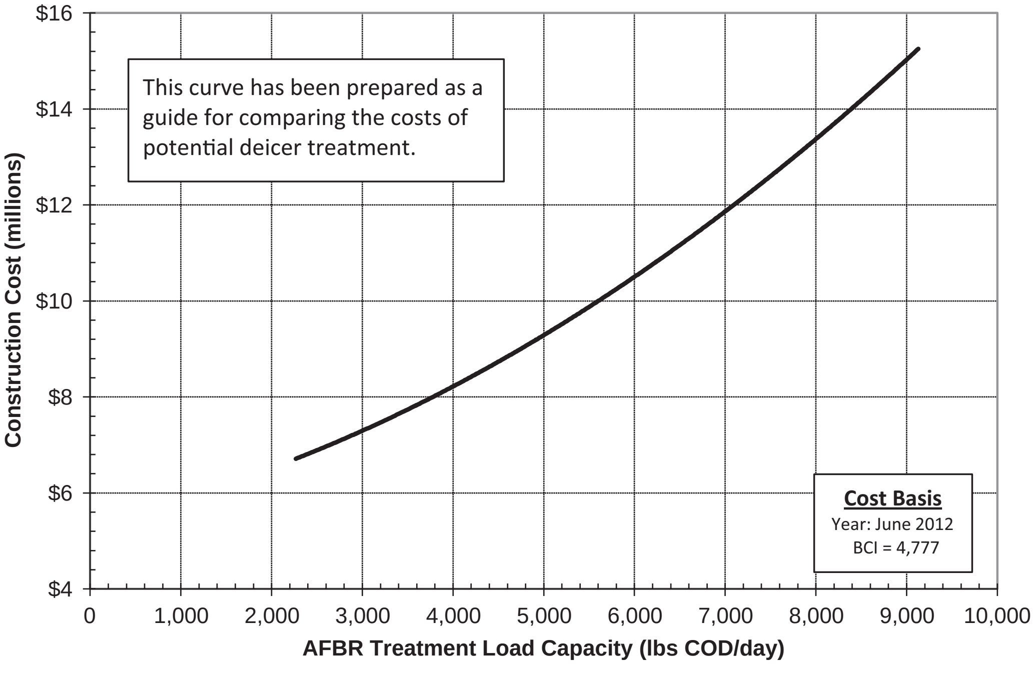
The screening-level cost curves in the fact sheets are not recommended for use in the final selection of the technology or in the design phase, but should only be used as a guide in comparing the costs of various technologies during the treatment screening process. Beyond the screening process, site-specific cost estimates should be prepared that take into consideration the nuances of the technology application

Table 8. Frequently encountered cost issues associated with deicer treatment.

Cost Issue	Impact
Often as-built treatment costs are not isolated from other deicer management costs.	As-built treatment cost numbers reported in numerous publications, including regulatory documents, may not be accurate.
Treatment costs are heavily dependent on the required size of the treatment system.	Head-to-head comparisons of multiple airports' treatment costs are not valid because sizes vary.
The airport's infrastructure and site conditions can affect treatment system cost.	Cost estimates early in the treatment implementation process often under-represent impacts of site-specific infrastructure that become associated with treatment.
Costs are often heavily affected by local economic conditions.	Local factors such as proximity to raw materials or off-site processing can affect which treatment alternatives are most appropriate.
The cost of treatment is directly related to the cost of other deicer management system components, especially storage.	Compare treatment alternatives on a common basis (either as part of the total deicer management system cost or using a common basis for the remainder of the deicer management system).
The relative proportion of capital versus operating costs can vary significantly among treatment technologies.	It may be difficult to compare the cost and value of potential technologies without a life-cycle–based cost estimate.
Projected annual costs are often underestimated.	Carefully consider all factors that may contribute to annual costs.

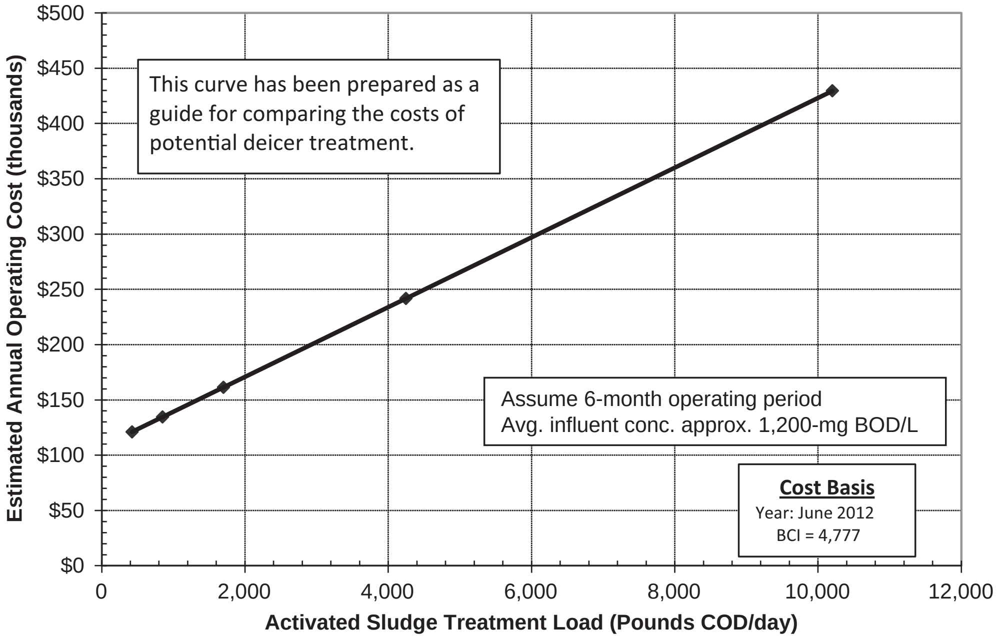
within the airport's specific deicer management system, site infrastructure, and site-specific design features.

The order-of-magnitude cost curves in the fact sheets were prepared for all technologies based on the pounds of COD per day that are required to be treated. Since all of the technologies have their individual differences, it may not be common practice to view costs primarily from the mass of COD to be treated. The cost guidance curves are presented as COD-load–dependent



Note: BCI = building cost index.

Figure 20. Example screening-level cost curve for capital cost of AFBR technology.



Note: BCI = building cost index.

Figure 21. Example screening-level cost curve for activated sludge operations.

to provide a common basis from which all technologies could be assessed. As technologies are evaluated in more detail during the treatment implementation process, the impact of other cost considerations, like impacts of flow rate, should be incorporated.

The costs in the graphs in Figures 3 and 4 of the fact sheets were calculated in 2012 dollars, based on Cleveland, OH, cost data. Since location affects the cost of construction, the order-of-magnitude costs from the fact sheet cost curves should be adjusted to your location. RS Means Building Construction Cost Data contains state indices that can be used to adjust the construction cost to the location of the treatment facility. This index is recognized in the industry and is commercially available. To adjust the cost data in the fact sheet graphs to a specific location, multiply the construction cost by the index that is specific to the project location and divide by the Cleveland, OH, index, which is 97.9. For example, assume the project has an estimated construction cost of $20 million, and the facility will be built in Fargo, ND. Fargo has a city index of 102.1. The adjusted construction cost for a facility to be constructed in Fargo would be:

$\$20 \text{ million} \times 102.1/97.9 = \$20.86 \text{ million}$

In addition, the year that the project will be built also affects the cost of construction. This is commonly referred to as construction escalation. *Engineering News Record*'s Construction Cost Index (ENR's CCI) provides a basis for adjusting costs. ENR's CCI is based on labor and material construction costs from 20 cities and is calculated monthly. This index allows for the comparison of costs from one year to another. Construction escalation can vary widely. A review of the yearly history of construction escalation for the last 5 years will be helpful in predicting future annual escalation. A conservative approach would be to use 2% per year beyond 2012.

The annual costs that are included in the fact sheet cost curves are also estimated in 2012 dollars. Just as the construction costs are adjusted for future years, the operating costs should be adjusted for future years to account for inflation. The Consumer Price Index (CPI) measures inflation by tracking price changes in goods and services from the purchaser's perspective. From 2007 to 2012, the CPI increased 2% per year. A conservative approach would be to use 2% per year beyond 2012 to adjust the operating costs to future years.

6.3 Site-Specific Cost Calculation Considerations

Considerations for calculating deicer treatment costs beyond the treatment technology screening phases are provided in the following.

6.3.1 Capital Cost Considerations

Typical capital cost categories to consider for deicer treatment include:

- Site investigation and land acquisition for treatment system site.
- Treatment system site work.
  - Clearing.
  - Excavation.
  - Fencing.
  - Pavement.
  - Site stormwater controls.
  - Demolition.
  - Relocating/rebuilding existing infrastructure to accommodate treatment.
- Treatment process costs.
  - Hydraulic control (pumps, pipes, valves, etc.) for system influent and process controls.
  - Treatment technology equipment and instrumentation.
  - Support system equipment and instrumentation.
  - Treated effluent discharge equipment and instrumentation.
  - Chemical and material storage.
- Utilities and controls.
  - Electrical and other utilities.
  - Monitoring system.
  - Computer control system.
  - Communication systems.
  - Security and safety systems.
- Building(s) to house the treatment technology and support systems.
- Soft costs for general conditions, permits, and bonding.
- General contractor profit and overhead.
- Design and construction contingency.
- Professional fees, which include engineering, legal, and construction administrative services.

6.3.2 Annual Cost Considerations

In addition to the cost of construction, the annual deicer treatment costs for each year of the project's lifetime should be determined. Those costs may vary, with costs during the start-up year likely to be higher, as construction and design related issues are worked out and as the operators learn the nuances of their particular system. Annual cost items to consider include:

- Operator labor costs;
- Maintenance repairs (labor and equipment);
- Preventative maintenance;
- Utilities fees (power, natural gas, water);
- Sanitary sewer discharge fees;
- Chemicals;

- Solids disposal;
- Monitoring, permitting, and compliance fees;
- Fees paid to consultants and contractors for operations and material handling;
- Payback from sale of recycled glycol; and
- Energy cost savings from methane captured from biological treatment and used as fuel.

6.3.3 Equivalent Annual Cost

A method frequently used to jointly assess capital and operating costs is calculation of the *equivalent annual cost.* In the equivalent annual cost calculation, the cost per year of owning and operating the treatment system over its entire life span is calculated. The annualized cost calculation is as follows:

Annualized Cost = (Capital Cost/$A_{t,r}$) + Annual Operating Cost

Where:

$A_{t,r} = (1 - 1/(1 + r)^t)/r$,
t = expected lifetime, typically 20 years, and
r = percentage cost of capital rate expected (finance rate).

Example:

If t is 20 years and r is 5%,
then $A_{t,r} = (1 - 1/(1 + 0.05)^{20})/0.05$, and
$A_{t,r} = 12.46$.

Therefore, Annualized Cost = Capital Cost/12.46 + Annual Operating Cost.

Use of equivalent annual cost will allow consideration of both capital and annual costs, allowing an easier head-to-head comparison of technologies that may be capital or annual cost-intensive to varying degrees.

6.3.4 Cost Assessments During the Alternatives Analysis Phase

Beyond the technology alternatives screening phase, where order-of-magnitude costs from the fact sheets can be used, site-specific cost estimates should be prepared for capital and operations and maintenance costs. When performing an alternatives analysis, it is important to compare the treatment technologies on a consistent design basis using the same basis-of-design capacity data, governing effluent criteria, stormwater characterization criteria, and, when applicable, the same site and operations criteria. It is also important to note that cost calculations during the alternatives analysis phase are typically not detailed enough to serve as engineering cost estimates, and contingencies as high as 40% may need to be applied.

6.3.5 Cost Assessments During the Design Phase

During the design phase, engineering cost estimates are typically developed at design milestones such as the 30%, 60%, 90%, and 100% design completion marks. The owner may ask for an engineer's cost estimate prior to the project bidding. The design phase cost estimates are typically completed by professional cost estimators with support from the engineering staff. The cost estimates prepared during design are based on individual items and their quantities associated with individual technical specifications. These estimates are based on the anticipated year of construction and are priced consistent with the geographic construction market. These estimates help to maintain the owner's budget and serve to predict the contractor's bid.

Treatment Tips

Estimating Treatment Costs

- Be aware of the risks in using cost data from other airports' treatment systems.
- Choose treatment size (capacity) carefully and realize that it is the most significant cost factor.
- Compare treatment technology alternative costs on a common basis with a clear understanding of how other deicer management system component costs are factored in.
- Consider using an equivalent annual cost approach that considers initial capital costs and the potentially variable annual operations and maintenance costs.

6.4 Technology-Specific Cost Considerations

6.4.1 Cost Considerations for On-Site Biological Treatment Technologies

On-site biological treatment systems typically have higher capital costs and lower operating costs than other deicer treatment technologies. Many times, biological treatment systems can rely on their core processes to reach the desired effluent concentrations, eliminating the need for additional polishing treatment processes.

Capital costs for biological systems typically include:

- Biological reactor (e.g., concrete basins, lined basins, earthen basins, and enclosed tanks);
- Storage tanks for water, chemicals, and solids;
- Pumps for stormwater conveyance, solids, chemicals, and sampling;
- Blowers for aeration (aerobic only);
- Equipment for process management (e.g., heat exchangers, pH adjustment, boilers, and air compressors);
- Piping for water, steam, air, chemicals, solids, and gas;
- Biological solids settling and solids dewatering equipment;
- Instrumentation for process monitoring;
- Computer control system;
- Lab equipment; and
- Buildings and associated structures, including maintenance support equipment.

There is often a balance between complexity, land requirements, and use of a building in biological treatment. Highly efficient technologies like the AFBR require more complex controls and a building to house the main treatment equipment, but they have small footprints. Less efficient technologies like aerated gravel beds have less complexity and do not require a building to house the entire treatment system, but they require significantly more land. Some technologies can operate with or without buildings, and use of a building is an operator preference. A building may help reduce the heat losses of some processes, prevent freezing of critical equipment, and provide space for a lab to monitor the treatment.

With anaerobic systems, the methane in the biogas generated by the biological degradation can be captured and burned as fuel to heat the influent water, isolating the system from weather effects. This isolation further reduces the needed treatment system footprint because accommodations do not have to be made in the sizing of the treatment system to account for cold weather.

The methane content in anaerobic digestion biogas typically ranges from 50% to 75%, whereas natural gas contains approximately 95% to 98% methane. Some modifications to burners may be necessary to burn biogas methane instead of natural gas, but systems are available that are capable of burning either fuel.

Handling of excess biological solids is an important cost consideration when comparing biological treatment technologies to each other. All biological technologies produce additional biological solids. For some technologies (aerated gravel beds and the related reciprocating gravel beds), the systems are operated with slow-growing bacteria, which minimizes the need to process biological solids. Other biological treatment technologies with faster growing bacteria and large capacities generate more solids and require a step for removing biological solids from the treated water, potentially followed by dewatering and disposal. The extent to which these steps are needed depends on the quantities generated and whether the POTW will accept discharges of solids (measured as TSS). If the POTWs will accept treated discharges containing solids, then the biological solids processing that is required is minimal. Arrangements could also be made for on-site digestion and on-site land application of biological solids to reduce biological solids processing costs. When comparing the quantities of biological solids to be produced, take note that aerobic treatment systems produce approximately 10 times more biological solids than anaerobic systems. On-site biological treatment technologies should have at least 20-year lifetimes. Many biological treatment facilities in other industries have lasted far longer.

The operating costs for biological treatment facilities for airport deicer stormwater are primarily associated with the following:

- Operators (typically one to two).
- Power for pump and blowers.
- Biological solids disposal.
- Chemicals for supplying nutrients and adjusting pH.
- Monitoring of system performance.
- Miscellaneous costs for natural gas, potable water for cleanup, and maintenance.

Significant maintenance costs should be anticipated for the electromechanical equipment (pumps, blowers, motors, controls, etc.). Systems that incorporate attached-growth (fixed-film) processes where the biofilm grows on a media provide good treatment efficiency, but the means for addressing potential solids buildup and clogging of the media should be understood. Some technologies have built-in means of removing solids (MBBR, AFBR), so clogging is not an issue. Consideration should be given to possible costs associated with future larger-scale unclogging of aerated gravel beds and passive facultative systems. Clogging in those systems can be managed with careful controls.

See the fact sheets for AFBRs, aerated gravel beds, aerated lagoons, MBBRs, and passive facultative treatments for additional details on biological technology costs.

6.4.2 Cost Considerations for Discharges to POTWs

POTWs will charge fees to all users (residential, commercial, and industrial) to offset their costs of treatment based on discharge volume and normal pollutant strength (as defined by the POTW for domestic sewage). POTWs may also establish additional fees applicable to IUs (i.e., the airport) only, which cover costs of the industrial pretreatment program administration and possibly costs of monitoring performed by the POTW pretreatment program staff. POTWs typically will also establish surcharges for extra-strength discharges to offset their additional treatment cost for discharges that exceed normal strength. Surcharges are typically established for BOD (or COD) and TSS, and often for ammonia. The surcharge cost is applied based on monitoring results for the amount of pollutant that exceeds the surcharge threshold concentration (i.e., the normal-strength concentration established by the POTW). Airport stormwater from aircraft deicing activities would typically exceed the surcharge concentration threshold for BOD/COD, but not for the others. Airport stormwater from airfield (pavement) deicing using urea-containing compounds would typically exceed the surcharge concentration threshold for ammonia/TKN as well as BOD/COD.

Costs are unique to each POTW based on its specific circumstances and costs of providing service, including capital debt service. Accordingly, comparison of POTW costs from other locales is not meaningful. The POTW's user charge structure and rates are typically developed based on an engineering/financial evaluation of the cost of services. The rates are authorized by the local political entity that has financial responsibility for the POTW (e.g., city, county, or separate wastewater/sewer agency or authority). It may be possible to negotiate a specific rate structure for the airport as a separate class of industrial user. The POTW must have uniform and equitable rates for all users within a class, but it may establish different rates for different classes of users.

The rates charged by POTWs are subject to change, and in recent years many POTWs have increased rates substantially to help cover the costs of required infrastructure changes associated with their own regulatory compliance, failing infrastructure, and growth. Some POTWs have increased rates by as much as 10% per year in the last 5 years, and even more when significant capital projects have been necessary to meet regulatory needs. Many POTWs are currently implementing costly long-term control plans to reduce wet weather pollutant discharges, and the associated costs are incorporated into discharge rates charged to all users. Airports interested in discharging to a POTW should not only negotiate current rates, but should take into consideration possible rate changes in the future. The POTW rate increases should be anticipated for the same period as the anticipated life span of potential on-site treatment systems that may be installed. For example, consider the case of an alternatives analysis featuring a choice between an on-site activated sludge treatment technology and a POTW discharge with no on-site treatment. If a 20-year life span for the on-site activated sludge system is used in calculating life-cycle costs, then rate increases associated with POTW discharges should also be considered over a 20-year period to get an apples-to-apples comparison of costs.

One significant issue from the POTW's perspective is that the treatment capacity necessary to treat deicer-affected stormwater is generally needed only during the deicing season and would be unused during the remainder of the year. While the variable portion of operating costs would not be incurred when this treatment capacity is unused, the fixed operating costs and capital debt service still must be paid continuously.

See Fact Sheet 109 for additional details on POTW costs.

6.4.3 Cost Considerations for On-Site and Off-Site Recycling

One of the 11 treatment technology options is discharge or transport of high-concentrate deicer to a privately run facility for completing the glycol recycling operation. Three other treatment technologies (mechanical vapor recompression, reverse osmosis, and distillation) are most frequently associated with on-site glycol recycling activities. For many recycling-based systems, airports will contract with vendors and pay ongoing fees. For these technologies, the capital costs are typically lower than for biological treatment systems, but operating costs are higher.

On-site recycling is more economical the greater the volume of ADF sprayed at the airport and, more importantly, the larger the volume of glycol that can be captured at the airport for recycling. The greater the volume reclaimed, the larger the volume of product that can be sold to generate revenues to offset capital and operating expenses. When compared to an off-site recycling option, a cost analysis can be conducted to determine if on-site recycling is a more economical option based on the distance to the off-site facility and the volumes of glycol generated from the airport.

The costs to transport and treat at an off-site location are compared to the capital investment for an on-site facility, recycling equipment, and operating expenses.

Following are considerations for determining costs for an on-site recycling facility:

- *Capital investment.* Even if recycling equipment is leased, there may be capital costs to the airport for buildings, piping, pumps, storage, and other elements fixed at the site.
- *Length of contract term or project.* If a recycling service provider invests in the manufacture of new equipment and incurs the up-front fees associated with installing and delivering recycling equipment, the fees will have to be recovered in a shorter time frame, usually driving up the cost to the airport.
- *Volume of glycol that can be reclaimed.* Volume captured is factored into the cost calculations to determine how much revenue can be generated from glycol sales to offset expenses. In addition, if higher volumes of glycol can be processed over a longer season, the unit price to recycle goes down. However, in the event of a light winter, the costs to treat at an on-site facility are more or less fixed. This means that whether the winter results in the collection of glycol-affected stormwater or not, an airport will incur the costs associated with this operational readiness.
- *The value of glycol.* Glycol prices fluctuate based on supply and demand. This risk must be factored in.
- *Permit limits and monitoring requirements.* In cases where there are permit limits for glycol for discharges to surface waters (e.g., less than 100-mg/L PG or EG), costs for treatment can rise because additional processing equipment, such as membrane technologies or two-stage processing, is needed to achieve lower effluent concentrations. Lab testing, analytical fees, and other operating costs can also vary based on permit requirements.
- *Utilities.* Costs for utilities are site specific and vary across the country.
- *Operations support overhead.* Generally, the larger the recycling processing site, the larger the base of core personnel that needs to be retained on an annual basis—even if the processing season is 7 to 8 months.

In general, if less than 200,000 to 300,000 of gallons of spent ADF with concentrations between 1% and 25% PG or EG are collected, then on-site recycling is not cost-effective, although off-site recycling may be an option. At greater volumes, the glycol transportation costs to the off-site facility can be excessive, and a number of benefits can be recognized with an on-site recycling option. Off-site recycling may be subject to unpredictable weather conditions affecting the ability to transport the glycol, resulting in potential storage issues at the airport. With on-site recycling, this issue can be avoided, and the staffing designated for the recycling operations can provide additional services that support effluent containment, collection, testing, reporting, and other airport functions.

Large-scale on-site recycling operations have the potential to reach a break-even point to cover expenses associated with glycol recovery, or in a best-case scenario, provide positive revenue generation. Also, if an airport installs on-site recycling capability, there may also be an opportunity for that airport to act as a centralized recycling facility for other airports in the area, assuming that outside fluids can be accepted. Treating spent ADF from other airports gives the host airport the ability to maximize facility resources and reduce the costs associated with its glycol recycling program.

For smaller commercial airports and military installations that generate a low volume of spent ADF, on-site recycling can be cost prohibitive. Trucking of fluid to an off-site recycling facility can be advantageous when considering the capital investment for a recycling facility, the processing equipment, and associated operating expenses. These costs can be avoided by providing on-site storage for spent ADF as a temporary measure to handle volumes generated from precipitation-related deicing events. After an event has subsided, the fluid can be trucked to a regional recycling center. Depending on the distance to the off-site facility and the volumes of glycol generated from the airport, a cost analysis can be conducted to determine if this option is the most economical. Many small airports can benefit from a regional recycling facility by avoiding the capital investment and fixed operating expenses. In many cases, each airport that uses a centralized recycling facility may only pay a price per gallon for transportation and recycling. The advantages to the airport are that it does not have fixed expenses directly related to recycling, and it only pays for the volume treated each season.

See the fact sheets for mechanical vapor recompression, distillation, reverse osmosis, and private recycling facilities for additional cost information.

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Glossary

Aerobic Biological Deicer Treatment—Biological treatment processes using aerobic (oxygen-consuming) microorganisms (primarily bacteria) for degrading the primary deicer constituents into smaller molecules. The purpose of aerobic treatment is to reduce the mass loads and concentrations of the primary deicer constituents in stormwater discharged to surface waters, groundwater, or the sanitary sewer. By-products from aerobic deicer treatment systems include wasted biomass and carbon dioxide.

Aerobic Mode—Operational mode for the biological respirometer used in the lab study that measures oxygen uptake by microorganisms as pollutants are consumed.

Aircraft Deicing Fluids—Deicers and anti-icers applied to aircraft; typically the primary deicer constituent is propylene glycol in the United States and ethylene glycol in Canada. Glycerin is the primary deicer constituent in a few products.

Ammonia-Nitrogen—The concentration of nitrogen contained in the compound ammonia in a water sample.

Anaerobic Biological Treatment—Biological treatment process using anaerobic microorganisms in the absence of oxygen for degrading the primary deicer constituents in stormwater discharges. By-products from anaerobic treatment include wasted biomass, methane, and carbon dioxide.

Anaerobic Mode—Operational mode for the biological respirometer used in the lab study that measures methane production by microorganisms as pollutants are consumed.

Attached Biological Growth Treatment—Treatment system where bacterial films form on inert media, such as activated carbon or plastic contained in a reactor.

Automatic Diversion System—Stormwater diversion system where a monitor is used to detect pollutant concentration, and an electronic system is used to control the diversion of stormwater based on the levels of pollutant detected by the monitor.

Biochemical Oxygen Demand (BOD)—The amount of oxygen used by bacteria to break down organic materials and organic nitrogen.

Biogas/Off-Gas—Gas, typically consisting of methane or carbon dioxide, produced from biological digestion of the primary deicer constituents in a treatment system.

Biological Inhibition—Decrease in biological activity as a result of environmental factors (e.g., temperature, decreased food source) or exposure to a toxic substance.

Bioreactor/Reactor/Reactor Vessel/Biological Reaction Vessel—Tank or basin containing microorganisms that are used to degrade pollutants from a sample stream.

Carbon Dioxide (CO_2)—A colorless, odorless gas produced as a by-product of aerobic biological treatment.

Chemical Oxygen Demand (COD)—The oxygen required for the chemical reaction with organic compounds in a sample.

Deicer—Either a liquid or dry chemical applied to melt ice or prevent ice from forming on a surface. In this guidebook, it can refer to either aircraft or pavement deicers or anti-icers.

Deicer Treatment—The process of removing deicing chemicals and their derivative products from stormwater.

Dissolved Oxygen (DO)—Oxygen that is dissolved in water.

Effluent Limits/Collection Efficiency—Any restriction on quantities, discharge rates, and concentrations of pollutants discharged from point sources.

Food Supply/Substrate/Pollutant—Substance consumed by bacteria that provides nutritional support for biological functioning.

Industrial Pretreatment Program—A program implemented by the POTW to prevent noncompliance or interference that may occur as a result of industrial-user wastewater discharges into the POTW sewer system. Pretreatment programs for POTWs are required under federal regulations establishing technology-based standards (effluent guidelines) for various industrial categories.

Industrial User—A nonresidential user that discharges non-sanitary, industrial-process wastewater into a POTW sewer. An industrial user must comply with the conditions of its discharge permit issued under the POTW's industrial pretreatment program.

Methane (CH_4)—A colorless, odorless, flammable gas produced as a by-product of anaerobic biological treatment.

Microbe/Microorganism/Biomass/Biomass Culture/Bacteria—The biological media used for treatment in a bioreactor.

National Pollutant Discharge Elimination System (NPDES)—U.S. EPA's program for permitting point-source discharges to waters of the United States.

Nutrients—Elements, including nitrogen and phosphorus, that are required for biological organisms to grow, and that may lead to excessive growth of algae and other nuisance plants in natural surface water systems.

Online Monitor—Permanently mounted devices designed to sample flow streams and analyze the samples on a regular basis without direct involvement of facility staff.

Pavement Deicer—Deicers applied to aircraft operations areas. The compounds are typically applied undiluted. The primary deicer constituents are sodium formate, sodium acetate, and potassium acetate.

Parameter—A parameter may be a chemical (e.g., ammonia), a physical characteristic (e.g., temperature or flow), or the result of analytical testing (e.g., biochemical oxygen demand).

pH—A measure of the acidity or alkalinity of a sample.

Primary Deicer Constituent—The primary freezing-point depressant constituents in deicers (propylene glycol, ethylene glycol, glycerin, acetate, formate, urea) that most often drive the need for deicer treatment.

Stormwater—Precipitation runoff, including rain and snowmelt.

Stormwater Monitoring—The act of obtaining a quantitative measurement of stormwater characteristics.

Surcharge Fee—Fee charged to an industrial user by a municipal treatment plant for wastewater with pollutant concentrations that exceed the typical concentration of sanitary wastewater.

Surrogate—A parameter that is measured in place of another parameter. A mathematical relationship exists between the two parameters such that the surrogate parameter's concentration can be used to estimate the desired parameter concentration.

Technology-Based Effluent Limit—Uniform national discharge limits established as part of the regulations established under the federal Clean Water Act. The limits are based on the ability of dischargers in the same industrial category to treat discharges.

Total Dissolved Solids (TDS)—Organic and inorganic solids that are able to be filtered in a sample.

Total Organic Carbon (TOC)—The measurement of carbon dioxide produced during the conversion of all organic carbon in a sample.

Total Suspended Solids (TSS)—A class of solids associated with particulates (i.e., sand or silt) that can cause sedimentation in a stream or block light, which will inhibit aquatic life. In analytical terms, organic and inorganic solids suspended in liquid, when filtered, remain on weighted glass-fiber filter paper.

Water-Quality–Based Effluent Limit—Discharge limits established as part of the NPDES program to protect the quality of the receiving water.

5-Day Biochemical Oxygen Demand (BOD_5)—The oxygen required for the biological degradation of organic compounds in a sample by bacteria and nutrients after 5 days.

Acronyms and Abbreviations

AC	Advisory Circular
ADF	Aircraft Deicing Fluid
AFBR	Anaerobic Fluidized Bed Reactor
AGB	Aerated Gravel Bed
AHP	Analytic Hierarchy Process
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
BOD_5	5-Day Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CPI	Consumer Price Index
CWA	Clean Water Act
DO	Dissolved Oxygen
EG	Ethylene Glycol
ELG	Effluent Limitation Guideline
EPA	Environmental Protection Agency
FAR	Federal Aviation Regulation
FWPCA	Federal Water Pollution Control Act
gpm	Gallons Per Minute
IU	Industrial User
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bioreactor
MGD	Million Gallons Per Day
mg/L	Milligrams Per Liter
MS4	Municipal Separate Storm Sewer System
MVR	Mechanical Vapor Recompression
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
PG	Propylene Glycol
PLC	Programmable Logic Controller
POTW	Publicly Owned Treatment Works
RAS	Return Activated Sludge
RO	Reverse Osmosis
SBR	Sequencing Batch Reactor
SCADA	Supervisory Control and Data Acquisition
s.u.	Standard Units
SWPPP	Stormwater Pollution Prevention Plan
TDS	Total Dissolved Solids

TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UASB	Up-Flow Anaerobic Sludge Bed
WWTP	Wastewater Treatment Plant

Airport Codes

ABQ	Albuquerque International Sunport
ADW	Andrews Air Force Base
ALB	Albany International Airport
AMS	Schiphol Airport
ANC	Ted Stevens Anchorage International Airport
ASE	Aspen/Pitkin County Airport/Sardy Field
ATL	Hartsfield–Jackson Atlanta International Airport
AUS	Austin–Bergstrom International Airport
AZO	Kalamazoo/Battle Creek International Airport
BDL	Bradley International Airport
BFI	Boeing Field/King County International Airport
BIL	Billings Logan International Airport
BNA	Nashville International Airport
BOI	Boise Air Terminal/Gowen Field
BTM	Bert Mooney Airport
BUF	Buffalo Niagara International Airport
BUR	Bob Hope Airport
BWI	Baltimore/Washington International Thurgood Marshall Airport
CAK	Akron–Canton Regional Airport
CDG	Paris Charles de Gaulle
CEF	Westover Air Reserve Base/Metropolitan Airport
CLE	Cleveland Hopkins International Airport
CMH	Port Columbus International Airport
COS	City Of Colorado Springs Municipal Airport
CRW	Yeager Airport
CVG	Cincinnati/Northern Kentucky International Airport
DAY	James M. Cox Dayton International Airport
DCA	Ronald Reagan Washington National Airport
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DLH	Duluth International Airport
DSM	Des Moines International Airport
DTW	Detroit Metropolitan Wayne County Airport
ELP	El Paso International Airport
EWR	Newark Liberty International Airport
FAI	Fairbanks International Airport
FNT	Bishop International Airport
FWA	Fort Wayne International Airport
GCC	Gillette–Campbell County Airport
GFK	Grand Forks International Airport
GPT	Gulfport–Biloxi International Airport
GRB	Austin Straubel International Airport
GRR	Gerald R. Ford International Airport

HFD	Hartford–Brainard Airport
HLN	Helena Regional Airport
HOU	William P. Hobby Airport
HPN	Westchester County Airport
IAD	Washington Dulles International Airport
IAH	George Bush Intercontinental/Houston Airport
ILN	Wilmington Air Park
IND	Indianapolis International Airport
IPT	Williamsport Regional Airport
ISP	Long Island MacArthur Airport
LAS	McCarran International Airport
LGW	Gatwick Airport
LHR	London Heathrow Airport
LWS	Lewiston-Nez Perce County Airport
MCI	Kansas City International Airport
MDW	Chicago Midway International Airport
MEM	Memphis International Airport
MKE	General Mitchell International Airport
MSP	Minneapolis–St. Paul Intl/Wold-Chamberlain Airport
MUC	Munich Franz Josef Strauss Airport
OKC	Will Rogers World Airport
ORD	Chicago O’Hare International Airport
OSL	Oslo Airport
PDX	Portland International Airport
PHL	Philadelphia International Airport
PHX	Phoenix Sky Harbor International Airport
PIT	Pittsburgh International Airport
PNS	Pensacola Gulf Coast Regional Airport
PVD	Theodore Francis Green State Airport
PWM	Portland International Jetport
RDM	Roberts Field
RFD	Chicago/Rockford International Airport
RIC	Richmond International Airport
RNO	Reno/Tahoe International Airport
ROC	Greater Rochester International Airport
RST	Rochester International Airport
SAN	San Diego International Airport
SBN	South Bend Regional Airport
SDF	Louisville International–Standiford Field
SEA	Seattle–Tacoma International Airport
SFO	San Francisco International Airport
SLC	Salt Lake City International Airport
SMF	Sacramento International Airport
STL	Lambert–St. Louis International Airport
SWF	Stewart International Airport
SYR	Syracuse Hancock International Airport
TOL	Toledo Express Airport
TVC	Cherry Capital Airport
WRI	McGuire Field Airport
XNA	Northwest Arkansas Regional Airport
YEG	Edmonton International Airport

YHZ	Halifax International Airport
YIP	Willow Run Airport
YMX	Mirabel Airport
YOW	Ottawa Macdonald Cartier International Airport
YQB	Quebec Jean Lesage International Airport
YQT	Thunder Bay International Airport
YTR	Canadian Forces Base Trenton Airport
YUL	Pierre Elliott Trudeau Airport
YVR	Vancouver International Airport
YWG	Winnipeg Airport
YYC	Calgary International Airport
YYT	St. John’s International Airport
YYZ	Pearson International Airport
ZRH	Zurich International Airport

APPENDIX A

Deicer Treatment Technologies By Airport

Using Appendix A

Appendix A provides a list of the treatment technologies used at 106 airports in the United States, Canada, and Europe. The list does not include all airports that have deicer treatment facilities. Some airports have multiple treatment technologies. Deicer use data are presented in a qualitative manner to provide perspective on the extent of deicer management at the airport.

Treatment technology use by airport.

Airport Code	Airport Name	City	State	Country	Category	Hub Size	Deicer Use	Treatment Technology	On-Site or Off-Site
ABQ	ALBUQUERQUE INTL SUNPORT	ALBUQUERQUE	NM	United States	P	M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
ADW	ANDREWS AFB	CAMP SPRINGS	MD	United States	GA	--		Industrial Recycling	Off-Site
ALB	ALBANY INTL	ALBANY	NY	United States	P	S	M	Anaerobic Fluidized Bed Reactor Publically Owned Treatment Works/Municipal Wastewater Treatment Plant In Situ Soil/Irrigation Treatment Industrial Recycling Aerobic Fluidized Bed Reactor	On-Site Off-Site On-Site Off-Site On-Site
AMS	SCHIPHOL	AMSTERDAM		Netherlands				Mechanical Vapor Recompression Algal Treatment	On-Site On-Site
ANC	TED STEVENS ANCHORAGE INTL	ANCHORAGE	AK	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
ASE	ASPEN-PITKIN CO/SARDY FIELD	ASPEN	CO	United States	P	N	S	Industrial Recycling	Off-Site
ATL	HARTSFIELD-JACKSON ATLANTA INTL	ATLANTA	GA	United States	P	L	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
AUS	AUSTIN-BERGSTROM INTL	AUSTIN	TX	United States	P	M	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
AZO	KALAMAZOO/BATTLE CREEK INTL	KALAMAZOO	MI	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
BDL	BRADLEY INTL	WINDSOR LOCKS	CT	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression Reverse Osmosis	Off-Site On-Site On-Site
BFI	BOEING FIELD/KING COUNTY INTL	SEATTLE	WA	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
BIL	BILLINGS LOGAN INTL	BILLINGS	MT	United States	P	S		Aerated Lagoon	On-Site
BNA	NASHVILLE INTL	NASHVILLE	TN	United States	P	M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Aerated Lagoon	Off-Site On-Site
BOI	BOISE AIR TERMINAL/GOWEN FLD	BOISE	ID	United States	P	S	M	Non-Aerated Lagoon	On-Site
BTM	BERT MOONEY	BUTTE	MT	United States	P	N	S	Non-Aerated Lagoon	On-Site
BUF	BUFFALO NIAGARA INTL	BUFFALO	NY	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Aerated Gravel Beds	Off-Site On-Site
BUR	BOB HOPE	BURBANK	CA	United States	P	M		Industrial Recycling	On-Site
BWI	BALTIMORE/WASHINGTON INTL THURGOOD MARSHALL	BALTIMORE	MD	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
CAK	AKRON-CANTON RGNL	AKRON	OH	United States	P	S	M	Anaerobic Fluidized Bed Reactor	On-Site
CEF	WESTOVER ARB/METROPOLITAN	SPRINGFIELD/CHICOPEE	MA	United States	GA	--		Constructed Subsurface Flow Wetlands	On-Site
CLE	CLEVELAND-HOPKINS INTL	CLEVELAND	OH	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression	Off-Site On-Site
CMH	PORT COLUMBUS INTL	COLUMBUS	OH	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site

COS	CITY OF COLORADO SPRINGS MUNI	COLORADO SPRINGS	CO	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Industrial Recycling	Off-Site Off-Site
CRW	YEAGER	CHARLESTON	WV	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
CVG	CINCINNATI/NORTHERN KENTUCKY INTL	COVINGTON	KY	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Activated Sludge Mechanical Vapor Recompression Industrial Recycling	Off-Site On-Site On-Site Off-Site
DAY	JAMES M COX DAYTON INTL	DAYTON	OH	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Industrial Recycling	Off-Site Off-Site
DCA	RONALD REAGAN WASHINGTON NATIONAL	WASHINGTON	DC	United States	P	L	M	Industrial Recycling	Off-Site
DEN	DENVER INTL	DENVER	CO	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Distillation Mechanical Vapor Recompression	Off-Site On-Site On-Site
DFW	DALLAS/FORT WORTH INTL	DALLAS-FORT WORTH	TX	United States	P	L	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Reverse Osmosis	Off-Site On-Site
DLH	DULUTH INTL	DULUTH	MN	United States	P	N	M	Aerated Lagoon	On-Site
DSM	DES MOINES INTL	DES MOINES	IA	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
DTW	DETROIT METROPOLITAN WAYNE COUNTY	DETROIT	MI	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Industrial Recycling	Off-Site Off-Site
ELP	EL PASO INTL	EL PASO	TX	United States	P	S	S	Non-Aerated Lagoon	On-Site
EWR	NEWARK LIBERTY INTL	NEWARK	NJ	United States	P	L	L	Industrial Recycling	Off-Site
FAI	FAIRBANKS INTL	FAIRBANKS	AK	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
FNT	BISHOP INTL	FLINT	MI	United States	P	S		Industrial Recycling	Off-Site
FWA	FORT WAYNE INTL	FORT WAYNE	IN	United States	P	N	M	Industrial Recycling	Off-Site
GCC	GILLETTE-CAMPBELL COUNTY	GILLETTE	WY	United States	P	N	S	Non-Aerated Lagoon	On-Site
GFK	GRAND FORKS INTL	GRAND FORKS	ND	United States	P	N	S	Industrial Recycling	Off-Site
GPT	GULFPORT-BILOXI INTL	GULFPORT	MS	United States	P	S	S	Industrial Recycling	Off-Site
GRB	AUSTIN STRAUBEL INTL	GREEN BAY	WI	United States	P	N	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
GRR	GERALD R. FORD INTL	GRAND RAPIDS	MI	United States	P	S	M	Thermal Vapor Recompression Industrial Recycling	 Off-Site
HFD	HARTFORD-BRAINARD	HARTFORD	CT	United States	GA	--		Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Reverse Osmosis	Off-Site On-Site

HLN	HELENA RGNL	HELENA	MT	United States	P	N	S	Non-Aerated Lagoon	On-Site
HOU	WILLIAM P HOBBY	HOUSTON	TX	United States	P	M	S	Industrial Recycling	Off-Site
HPN	WESTCHESTER COUNTY	WHITE PLAINS	NY	United States	P	S		Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
IAD	WASHINGTON DULLES INTL	WASHINGTON	DC	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								In Situ Soil/Irrigation Treatment	On-Site
								Mechanical Vapor Recompression	On-Site
IAH	GEORGE BUSH INTERCONTINENTAL/HOUSTON	HOUSTON	TX	United States	P	L	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
ILN	WILMINGTON AIR PARK	WILMINGTON	OH	United States	GA	--	L	Reciprocating Gravel Beds	On-Site
IND	INDIANAPOLIS INTL	INDIANAPOLIS	IN	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								Aerated Lagoon	On-Site
IPT	WILLIAMSPORT RGNL	WILLIAMSPORT	PA	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
ISP	LONG ISLAND MAC ARTHUR	NEW YORK	NY	United States	P	S	S	Aerated Gravel Beds	On-Site
LAS	MC CARRAN INTL	LAS VEGAS	NV	United States	P	L	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
LGW	GATWICK	LONDON		England				Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								Non-Aerated Lagoon	On-Site
LHR	LONDON HEATHROW	LONDON		England				Aerated Gravel Beds	On-Site
								Aerated Lagoon	On-Site
LWS	LEWISTON-NEZ PERCE COUNTY	LEWISTON	ID	United States	P	N	S	Non-Aerated Lagoon	On-Site
MCI	KANSAS CITY INTL	KANSAS CITY	MO	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
MDW	CHICAGO MIDWAY INTL	CHICAGO	IL	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
MEM	MEMPHIS INTL	MEMPHIS	TN	United States	P	M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
MKE	GENERAL MITCHELL INTL	MILWAUKEE	WI	United States	P	M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
MSP	MINNEAPOLIS-ST. PAUL INTL/WOLD-CHAMBERLAIN	MINNEAPOLIS	MN	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								Mechanical Vapor Recompression	On-Site
								Reverse Osmosis	On-Site
MUC	MUNICH FRANZ JOSEF STRAUSS	MUNICH		Germany				Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								In Situ Soil/Irrigation Treatment	On-Site
								Distillation	On-Site
OKC	WILL ROGERS WORLD	OKLAHOMA CITY	OK	United States	P	S	S	Aerated Lagoon	On-Site
ORD	CHICAGO O'HARE INTL	CHICAGO	IL	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
OSL	OSLO	OSLO		Norway				Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
								Moving Bed Biofilm Reactor	On-Site
								Industrial Recycling	Off-Site
PDX	PORTLAND INTL	PORTLAND	OR	United States	P	M	M	Anaerobic Fluidized Bed Reactor	On-Site
								Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site

PHL	PHILADELPHIA INTL	PHILADELPHIA	PA	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
PHX	PHOENIX SKY HARBOR INTL	PHOENIX	AZ	United States	P	L		Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
PIT	PITTSBURGH INTL	PITTSBURGH	PA	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Moving Bed Biofilm Reactor Reverse Osmosis Industrial Recycling	Off-Site On-Site On-Site Off-Site
PNS	PENSACOLA GULF COAST RGNL	PENSACOLA	FL	United States	P	S	S	Non-Aerated Lagoon	On-Site
PVD	THEODORE FRANCIS GREEN STATE	PROVIDENCE	RI	United States	P	M	M	Anaerobic Fluidized Bed Reactor Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression Reverse Osmosis Industrial Recycling	On-Site Off-Site On-Site On-Site Off-Site
PWM	PORTLAND INTL JETPORT	PORTLAND	ME	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Distillation Mechanical Vapor Recompression Reverse Osmosis	Off-Site On-Site On-Site On-Site
RDM	ROBERTS FIELD	REDMOND	OR	United States	P	N	S	Non-Aerated Lagoon	On-Site
RFD	CHICAGO/ROCKFORD INTL	CHICAGO/ROCKFORD	IL	United States	P	N	M	Aerated Lagoon	On-Site
RIC	RICHMOND INTL	RICHMOND	VA	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
RNO	RENO/TAHOE INTL	RENO	NV	United States	P	M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
ROC	GREATER ROCHESTER INTL	ROCHESTER	NY	United States	P	S	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
RST	ROCHESTER INTL	ROCHESTER	MN	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
SAN	SAN DIEGO INTL	SAN DIEGO	CA	United States	P	L		Industrial Wastewater Treatment Industrial Recycling	Off-Site Off-Site
SBN	SOUTH BEND RGNL	SOUTH BEND	IN	United States	P	N	S	Non-Aerated Lagoon	On-Site
SDF	LOUISVILLE INTL-STANDIFORD FIELD	LOUISVILLE	KY	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
SEA	SEATTLE-TACOMA INTL	SEATTLE	WA	United States	P	L	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
SFO	SAN FRANCISCO INTL	SAN FRANCISCO	CA	United States	P	L	S	Industrial Recycling	Off-Site
SLC	SALT LAKE CITY INTL	SALT LAKE CITY	UT	United States	P	L	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant In Situ Soil/Irrigation Treatment Distillation Mechanical Vapor Recompression Reverse Osmosis	Off-Site On-Site On-Site On-Site On-Site
SMF	SACRAMENTO INTL	SACRAMENTO	CA	United States	P	M		Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site

STL	LAMBERT-ST LOUIS INTL	ST LOUIS	MO	United States	P	M	L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
SWF	STEWART INTL	NEWBURGH	NY	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
SYR	SYRACUSE HANCOCK INTL	SYRACUSE	NY	United States	P	S	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
TOL	TOLEDO EXPRESS	TOLEDO	OH	United States	P	N	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
TVC	CHERRY CAPITAL	TRAVERSE CITY	MI	United States	P	N	S	Non-Aerated Lagoon	On-Site
WRI	MC GUIRE	WRIGHTSTOWN	NJ	United States	GA	--	M	Industrial Recycling	Off-Site
XNA	NORTHWEST ARKANSAS RGNL	FAYETTEVILLE/SPRINGDALE/	AR	United States	P	S	S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
YEG	EDMONTON INTERNATIONAL	EDMONTON		Canada		M	M	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Aerated Gravel Beds Constructed Subsurface Flow Wetlands	Off-Site On-Site On-Site
YHZ	HALIFAX INTERNATIONAL	HALIFAX		Canada			L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Distillation Mechanical Vapor Recompression	Off-Site On-Site On-Site
YIP	WILLOW RUN	DETROIT	MI	United States	GA	--	S	Industrial Recycling	Off-Site
YMX	MIRABEL	MONTREAL		Canada				Industrial Recycling	Off-Site
YOW	OTTAWA MACDONALD CARTIER INTERNATIONAL	OTTAWA		Canada			L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression Non-Aerated Lagoon	Off-Site On-Site On-Site
YQB	QUEBEC JEAN LESAGE INTERNATIONAL	QUEBEC CITY		Canada			M	Industrial Wastewater Treatment Industrial Recycling	Off-Site Off-Site
YQT	THUNDER BAY INTERNATIONAL	THUNDER BAY		Canada			S	Industrial Recycling	Off-Site
YTR	CANADIAN FORCES BASE TRENTON	TRENTON		Canada			S	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Industrial Recycling	Off-Site Off-Site
YUL	PIERRE ELLIOTT TRUDEAU	MONTREAL		Canada				Mechanical Vapor Recompression	On-Site
YVR	VANCOUVER INTERNATIONAL	RICHMOND		Canada			L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression	Off-Site On-Site
YWG	WINNIPEG	WINNIPEG		Canada			L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Industrial Recycling	Off-Site Off-Site
YYC	CALGARY INTERNATIONAL AIRPORT	CALGARY		Canada			L	Publically Owned Treatment Works/Municipal Wastewater Treatment Plant	Off-Site
YYT	ST. JOHN"S INTERNATIONAL	ST. JOHN"S		Canada			L	Mechanical Vapor Recompression	On-Site
YYZ	PEARSON INTERNATIONAL	TORONTO		Canada				Publically Owned Treatment Works/Municipal Wastewater Treatment Plant Mechanical Vapor Recompression Constructed Subsurface Flow Wetlands	Off-Site On-Site On-Site
ZRH	ZURICH INTERNATIONAL	ZURICH		Switzerland				Publically Owned Treatment Works/Municipal Wastewater Treatment Plant In Situ Soil/Irrigation Treatment	Off-Site On-Site

Notes: Category column: P = primary, GA = general aviation.
Hub size column: L = large hub, M = medium hub, S = small hub, and N = non-hub.
Deicer use column: H = high, greater than 200,000 gal/year, M = medium, less than 200,000 gal/yr but greater than 50,000 gal/yr, and L = low, less than 50,000 gal/yr.

APPENDIX B

Deicer Treatment Technology Characteristic Matrix

Using Appendix B Characteristics of Deicer Treatment Technologies Matrix

Appendix B lists the 11 categories of treatment technologies presented in the guidebook and a summary of the characteristics of those technologies for multiple criteria. The information in the matrix is a summary of the data provided in the fact sheets for the individual technologies.

When assessing the criteria associated with the specific deicer treatment technologies and comparing them to site-specific needs and characteristics, it is important to consider that the technology criteria values represent the potential capabilities of the technology based on the performance data for the technologies that was available to the research team. Many factors affect treatment performance, including:

- The composition of the remainder of the deicer management system;
- The degree of control, monitoring, and operational oversight applied at any given site;
- The capacity of the treatment system and how the system is operated in relation to that capacity;
- The extent to which proper maintenance is performed;
- The inherent variation in stormwater characteristics at a given airport and among airports;
- Ambient weather conditions; and
- Proper pretreatment to prepare the stormwater for the primary treatment system.

Therefore, the information provided in the Appendix B matrix is intended as guidance during technology selection and not as a guarantee of performance.

Deicer Treatment Technology Characteristic Matrix

Screening Value Parameter	Activated Sludge	Aerated Gravel Beds	Aerated Lagoons	Anaerobic Fluidized Bed Reactors	Distillation	Mechanical Vapor Recompression	Moving Bed Biofilm Reactors	Passive Facultative Treatment Systems	Public Wastewater Treatment Systems	Private Recycling Facilities	Reverse Osmosis
Treatment method	On-site biological	On-site biological	On-site biological	On-site biological	On-site physical	On-site physical	On-site biological	On-site biological	Off-site biological	Off-site physical	On-site physical
Most applicable influent concentration characteristics	Dilute stream[1]	Dilute stream	Dilute stream	Concentrated stream[2]	Highly concentrated stream[3]	Concentrated stream	Dilute stream	Dilute stream	Dilute stream	Concentrated stream	Concentrated stream
Typical minimum influent COD conc. (mg /L)	None	None	None	2,700	300,000	10,000	None	None	None	See MVR and distillation	10,000
Potential effluent COD conc. range (mg/L)[4]	10–30	50–100	30–100	40–100	8,000–15,000	50–1,000	10–30	10–100	Not applicable	Not applicable	10–1,000
Treatment by-products	Biomass and CO_2	Biomass and CO_2	Biomass and CO_2	Biomass, Methane and CO_2	High concentration glycol, distillate, and solids waste	Intermediate concentration glycol, distillate, and solids waste	Biomass and CO_2	Biomass and CO_2	Not applicable to the airport	Not applicable to the airport	Intermediate concentration glycol, distillate, and solids waste
Typical treatment area footprint	<1 acre	>1 acre	>1 acre	<1 acre	<1 acre	<1 acre	<1 acre	>1 acre	Not applicable	Not applicable	<1 acre
Typical treatment/ equipment height	<20 ft	<20 ft	<20 ft	>20 ft	>20 ft	>20 ft	<20 ft	<20 ft	Not applicable	Not applicable	<20 ft
Open water surface	Yes	No	Yes	No	No	No	Varies	Varies	No	No	No

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[1] Dilute stream = COD concentrations < 10,000 mg/l. Typical of deicer-affected stormwater from gate runoff, airfield runoff, and runoff segregated into low concentration fractions.

[2] Concentrated stream = Influent COD concentrations > 10,000 mg/L (1%) and < 300,000 mg/L (30%). Typical of deicer-affected stormwater from deicing pad runoff, GRV (glycol recovery vehicle) collection, and stormwater segregated from online monitoring.

[3] Highly concentrated stream = COD concentrations > 300,000 mg/L (30%). Typical of concentrate streams from MVR or reverse osmosis systems.

[4] "Potential effluent COD conc. range (mg/L)" represents the optimal potential performance based on review of existing treatment systems (when available). See the treatment technology fact sheets for additional details on the conditions used to determine the typical effluent concentrations. Results may vary based on individual circumstances.

APPENDIX C

Instructions for Using Treatment Technology Fact Sheets

Using the Fact Sheets

This report contains fact sheets for the 11 deicer treatment technologies referenced in the guidebook. The fact sheets contain the following categories of information.

Activated Sludge
Aerated Gravel Beds
Aerated Lagoons
Anaerobic Fluidized Bed Reactors
Distillation
Mechanical Vapor Recompression
Moving Bed Biofilm Reactors
Passive Facultative Treatment Systems
Public Wastewater Treatment Systems
Private Recycling Systems
Reverse Osmosis

FACT SHEET SECTION	CONTENT DESCRIPTION
Process Description	A brief overview of the deicer treatment technology, including the method of deicer removal or treatment, process flowcharts, typical process requirements, and general operational information.
Advantages	Favorable characteristics of the treatment technology.
Disadvantages	Unfavorable characteristics of the treatment technology.
Required Support Systems	Summary of the component parts necessary to operate the treatment technology.
Current Applications of the Technology	Airports presently using the treatment technology.
Variant Technologies	A brief discussion of treatment technologies that use components of the treatment technology with notable design or operational distinctions.
Potential Applications	Stormwater conditions for which the treatment technology is best suited.
Criteria Useful in Screening Analysis of Potential Treatment Technologies	Recommended conditions that may be used to determine whether the treatment technology is appropriate for a particular treatment system.
Criteria Useful in Comparative Analysis to Other Technologies	Recommended conditions that may be used to determine whether the treatment technology is preferable for a particular treatment system.
Technology-Specific Application Considerations	Additional information indicating criteria that may be pertinent to treatment technology screening or selection.
Costs	Presentation of the order-of-magnitude capital and operations and maintenance costs for the portion of the system associated with the treatment technology. The costs are based on the mass load of COD to be treated.

APPENDIX D

Airport Deicer Treatment System Summaries

Using Appendix D

Appendix D contains summaries of the deicer treatment experiences at 15 airports, listed in the following, that have used the 11 deicer treatment technologies referenced in the fact sheets.

Bradley International Airport (reverse osmosis)
Nashville International Airport (aerated lagoon)
Buffalo Niagara International Airport (aerated gravel bed)
Akron–Canton Airport (anaerobic fluidized bed reactor)
Westover Air Force Reserve Base (passive facultative treatment)
Cincinnati/Northern Kentucky Airport (activated sludge, mechanical vapor recompression)
Denver International Airport (mechanical vapor recompression, distillation, public wastewater treatment system)
Detroit Metropolitan International Airport (private off-site recycling, public wastewater treatment system)
Wilmington Airpark (aerated gravel beds)
London Heathrow (passive facultative treatment, aerated gravel beds)
Oslo Gardermoen (moving bed biofilm reactor)
Portland International Airport (anaerobic fluidized bed reactor, public wastewater treatment system)
Edmonton International Airport (passive facultative treatment, aerated gravel beds)
Halifax International Airport (mechanical vapor recompression)
Zurich International Airport (passive facultative biological treatment)

The Appendix D airport summaries contain the following categories of information.

SUMMARY SECTION	CONTENT DESCRIPTION
Treatment Technology Category	One or more of the 11 treatment technology categories for which treatment technology fact sheets are prepared.
Years Operated	The number of years that the treatment system has been operational.
Deicer Management System Description	A brief overview of the entire deicer management system used at the airport, including deicer collection, conveyance, storage, treatment, and disposal.
Deicer Treatment Technology Selection Considerations	Summary of the history of treatment technologies used at the airport, including a description of the considerations the airport used in selecting its current technology.

Deicer Treatment Technology Description	A technical description of the treatment technology as used at the airport, including sizing information and a description of the treatment technology's support systems.
Treatment System Performance	Numeric description of the design and actual performance of the treatment system at the airport.
Cost Assessment for Treatment System	Presentation of the capital and operations and maintenance costs for the portion of the system associated with the treatment technology. In some cases, capital costs for the treatment portion of the system were not specifically determined by the airport and costs for the broader deicer management system are presented.
Conclusions on Performance for Treatment System	A discussion of the treatment system performance in relation to its design intent.
Lessons Learned for Potential Implementation of Treatment System at Other Airports	Lessons learned from the operation of the system that may be applicable to others.

When assessing the actual performance of specific deicer treatment systems included in the airport summaries, an attempt was made by the research team to consider the numeric performance indicators in the context of the system operation conditions. It is recommended that guidebook users who seek out information from other airports' systems use similar caution. Many factors can affect treatment system performance on any given day or in any given season, and these conditions may be important for correctly interpreting operating data for the purposes of assessing a particular treatment technology's capabilities and suitability for other applications. Some of these factors are:

- Stormwater characteristics at the time of treatment (e.g., temperature, pH, nutrient content),
- Effluent limits the airport is trying to meet,
- Operational decisions on process settings,
- Maintenance issues,
- Whether the system is in the start-up portion of the season or in mid-season, and
- The actual loading or flow rate compared to the system load or flow rate capacity (i.e., if the treatment system is being underloaded or overloaded).

It is suggested that when an airport team uses information from other airport deicer treatment systems to supplement its own evaluation, the stakeholders should come to a common understanding of the basis for the performance assessments for the other airports' treatment systems.

Airport Treatment Summary No. 1

Airport:	Bradley International Airport—Windsor Locks, CT (BDL)
Treatment Technology:	Reverse Osmosis and Mechanical Vapor Recompression
Years Operated:	2006–2012 (Currently Operational)

Deicer Management System Description

The BDL deicer management system uses a passive and active collection system, collection basins, piping, pump stations, a recycling facility, and a POTW for discharging wastewater. The recycling facility uses RO and MVR treatment technologies. The passive and active collection system in place is used for the capture of spent aircraft deicing fluid. Deicing operations are conducted at the terminal gates, freight/remote parking areas, and the remote deicing facility (RDF). Active collection involves the use of glycol recovery vehicles (GRVs) at designated gate areas. Passive collection involves the use of dedicated glycol collection drainage systems for both the terminal gate areas and the RDF. Ultimately, all spent ADF captured is sent to two storage tanks (each with 1 million gallons of capacity) located at the on-site recycling facility. The two storage tanks act as the interim storage and feed reservoir for the glycol processing activities. Spent ADF is segregated according to glycol concentration. One storage tank is designated for high-concentration propylene glycol that is 4% and higher, while the other million-gallon tank is designated for low-concentration propylene glycol of less than 4%. All of the spent-ADF processing equipment is housed in two buildings. One building houses the MVR equipment, while the other houses the chemical pretreatment and membrane systems. The membrane systems include ultrafiltration (UF) and RO. The entire spent-ADF management system is operated to ensure that unpermitted levels of glycol do not enter the stormwater system and to comply with Consent Order #WC5727 that was issued in 1998 by the Connecticut Department of Environmental Protection. All wastewater generated from the on-site treatment systems is discharged to an off-site wastewater treatment plant called the Metropolitan District Poquonock Water Pollution Control Facility. Figure 1 demonstrates the deicer management system at BDL.

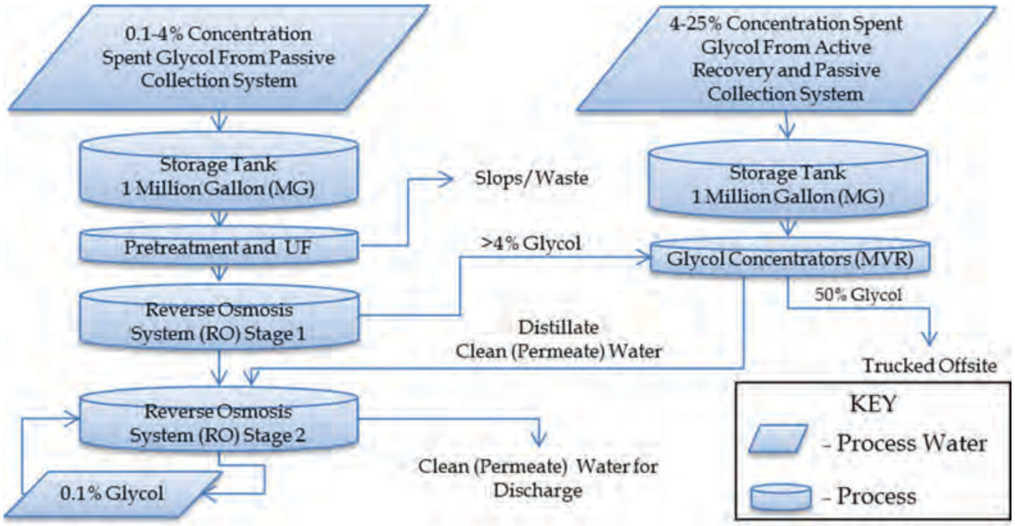

Figure 1. BDL spent-ADF management system process flow diagram.

Deicer Treatment Technology Selection Considerations

The on-site recycling system as a whole at BDL was designed, installed, and implemented to meet the following requirements:

- Compliance with federal and state environmental regulations, Connecticut Department of Energy and Environment orders, and wastewater discharge/pretreatment permits at the airport.
- On-site treatment that generated wastewater requires compliance with the following: maximum discharge of 288,000 gallons of wastewater per day, limitations of 125-mg/L propylene glycol, 200-mg/L BOD_5, 600-mg/L COD, a pH of 6.0–10.0, and 125-mg/L TSS.
- Equipment with the ability to conduct glycol processing at an average production/removal rate of 600,000 gallons per month when spent-ADF volumes are present. Minimum volume of 100,000 gallons in each of the high- and low-concentration storage tanks before systems have to be started.
- Empty storage tanks on or before September 1 each year.

The RO and MVR treatment technologies were specifically selected because:

- The combined technologies are able to handle fluctuating glycol concentrations in spent ADF that occur with each weather-related deicing event.
- The systems could be separated into two independent processing trains capable of recycling:
  - Propylene glycol of 0.1% to 4% concentration through the one tank.
  - Propylene glycol of greater than 4% concentration through the second tank.
- All glycol captured above 0.1% in concentration could be recycled.
- The glycol that is reclaimed from the system is sold, and the revenues generated are used to offset program costs to provide glycol management services.

Deicer Treatment Technology Description

The BDL treatment system employs both the RO and MVR treatment processes. The deicing treatment system was designed to operate both of these systems simultaneously. Descriptions of the MVR and RO treatment technologies can be found in Fact Sheet 106 and Fact Sheet 111, respectively. See Figure 2 for a photograph of the low-concentration processing building.

Figure 2. Low-concentration processing building.

Description of Support Systems

The support systems at BDL for the RO and MVR treatment technology are diversion and storage, pumping systems, chemical pretreatment, and a storage tank for the recycled glycol.

The passive system for ADF collection at BDL includes a diversion structure and pump station to move fluid from terminal areas to the recycling facility. Incorporated in this conveyance system is underground piping to allow testing of fluid so that spent ADF can be appropriately directed to recycling storage tanks based on glycol concentration. The main storage reservoirs for glycol recycling activities are two 1-million-gallon tanks.

A pretreatment system was installed prior to the UF and RO membrane systems to treat all diluted spent-ADF fluid. The constituents in the feed are analyzed to determine which chemical additives will perform best. In the pretreatment tank, chemical pretreatment is carried out to remove undesirable constituents from the waste fluid. The tank consists of a water-softening system and a mixed-reaction tank with pH control and chemical addition. After the influent is treated with the chemicals, it is transferred to a series of settlement tanks, where the chemically precipitated constituents of the waste stream are allowed to precipitate and settle. This material is removed from the system prior to passing from the pretreatment tank to the UF system. The UF system is used to remove constituents that may foul the RO membrane.

All recycled glycol at a 50% concentration is temporarily stored in two double-walled 20,000-gallon storage tanks. The 50% glycol is shipped to an off-site centralized distillation system where it is recycled to a 99%+ concentration before it is sold. All solid waste and membrane wash fluid is temporarily stored on-site and then shipped to an approved waste disposal facility

Key Treatment Sizing Parameters

See Table 1 through Table 3 for system sizing parameters.

Treatment System Performance

Although the RO and MVR systems operate simultaneously, they have different design requirements. Therefore, Table 4 and Table 5 reflect the design parameters for RO and MVR separately. The membrane systems were designed to meet the required removal rates in Table 4. The membrane systems were specifically configured to accomplish two tasks:

1. Treat influent streams with glycol concentrations from 0.1% to 4%
2. Treat all water produced from both MVR and membrane operations to ensure water quality levels meet sanitary discharge permit requirements.

Table 1. Treatment system size and capacity parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	1 million gallons 1 million gallons	2	2.0 million gallons
Treatment unit volume			
RO	1,060 ft³	1	1,060 ft³
MVR	980 ft³	4	3,920 ft³
Treatment unit dimensions			
RO	22-ft L x 6-ft W	1	Total area:
MVR	20-ft L x 6-ft W	4	612 ft^2
Treatment facility footprint	0.11-acre building 0.04-acre building	2	0.15 acres

Table 2. Additional system sizing parameters for RO (low-concentration treatment facility).

Component/Parameter	Size/Description of Treatment Units	Number of Treatment Units	Total Value
Stormwater storage capacity (low-concentration PG tank)	1 million gallons	1	1 million gallons
Annual chemical pretreatment rate	7.956 million gallons	1	7.956 million gallons
Annual UF treatment rate		2	>10.5 million per year
Annual RO treatment rate	>10.5 million gallon	1	>10.5 million gallon
Support system dimensions:			
Chemical pretreatment:	9’8” L x 6’ W x 6’ H	1	
UF 1	11’L x 6’ W x 7’ H	1	
UF 2	9’ L x 7’ H x 5’ W	1	
Process tank	20’ L x 9’ H x 10’ W	6	10,800 ft^3
UF poly tank	4,000 gallons	1	4,000 gallons
RO poly tank	2,000 gallons	1	2,000 gallons
Treatment building footprint (RO building)	100’ W x 50’ L x 22’ H	1	5,000 ft^2
Wastewater discharge tanks	20’ L x 9’ H x 10’ W (13,000 gallons)	2	3,600 ft^3 (26,000) gallons

Table 5 summarizes the treatment design for a single MVR treatment unit. Typically, a treatment system that uses MVR technology would use sufficient MVR units to meet the needs of the airport system.

Additional design parameters for the RO treatment processes are provided in Table 6 and Table 7.

The MVR concentrators were designed to meet the required removal rates in Table 5. The primary function of these systems is to concentrate all collected spent glycol to a minimum of concentration of 50%. See Table 8 for additional MVR system design parameters.

Table 3. Additional system sizing parameters for MVR (high-concentration treatment facility).

Component/Parameter	Size/Description of Treatment Units	Number of Treatment Units or Capacity	Total Value
Stormwater storage capacity (high-concentration PG tank)	1 million gallons	1	1 million gallons
Annual MVR treatment rate	1.2 million gallons	4	4.8 million gallons
Support system dimensions:			
MVR feed tanks (spent-ADF storage)	13,000 gallons	2	26,000 gallons
Product storage tanks (recycled glycol)	20,000 gallons	2	40,000 gallons
MVR treatment unit dimensions	L = 20’, W = 6’, H= 8’2 with scrubber 22’H	4	
Treatment facility footprint (MVR building)	L= 60’, W= 32’, H = 22’	1	1,920 ft^2

Table 4. Design basis for RO system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 40 Not available 50	Gallons per minute
Design treatment load capacity	51,000* 30,000** 30,000	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	0~87,000* 0~50,000** 0~50,000	mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	50~450 Not available 0~1000	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency	99.5	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 5. Design basis for MVR system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 2 Not available 4	Gallons per minute
Design treatment load capacity	16,500*† 9,700** 9,700	lbs COD/d lbs BOD_5/day lbs PG/day
Design influent concentration - Range	17,000~459,000* 10,000~270,000** 10,000~270,000	mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	<50~1000 Not available <50~1000	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency	94.1~99.7	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].
† Data reflect absolute maximum. Typical maximum loads are 12,000-lbs COD/day.

Table 6. Additional design basis for UF system.

System Design Criteria	UF Unit #1	UF Unit #2
Influent flow rate range (gpm)	10 to 16	20 to 60
Influent glycol concentration range (% PG)	0%–5%	0%–5%
Influent temperature range (°F)	40 to 100	40 to 100
Influent TSS (NTU)	200	200
Influent pH	3 to 11	2 to 13
Effluent process fluid TSS (NTU)	<15 NTU	<40 NTU
Effluent process fluid flow rate range (gpm)	<16	<60
Effluent temperature range (°F)	40 to 100	40 to 100

Note: gpm = gallons per minute; NTU = nephelometric turbidity units.

Table 7. Additional design basis for RO system.

Number of stages	2
Constant flow or batch	Constant flow
Influent pressure range (psi)	575 to 625
Influent flow rate range for stage 1 (gpm)	<120
Influent glycol concentration range for stage 1	0% to 5%
Influent temperature range (°F)	40 to 100
Effluent stage 1 permeate (PG)	0% to 0.5%
Effluent stage 1 permeate (pH)	3 to 7
Effluent stage 1 permeate flow rate range (gpm)	40 to 50
Effluent stage 1 reject (PG)	1% to 5.0%
Effluent stage 1 reject (pH)	6 to 7
Effluent stage 1 reject flow rate range	7 to 15
Influent stage 2 flow rate range (gpm)	40 to 50
Effluent stage 2 permeate (PG)	0% to 0.1%
Effluent stage 2 permeate (pH)	6 to 7
Effluent stage 2 permeate (COD mg/L)	50 to 450
Effluent stage 2 permeate (TSS)	<10 NTU
Effluent stage 2 permeate flow rate range (gpm)	15 to 40
Effluent stage 2 reject (PG)	0.1% to 0.4 %
Effluent stage 2 reject (pH)	6 to 7
Effluent stage 2 reject (COD)	N/A
Effluent stage 2 reject (TSS)	<10 NTU
Effluent stage 2 reject flow rate range	18–25
Estimated of waste produced (per gal)	N/A
Temperature range requirement	40°F–100°F

Table 8. Additional design basis for MVR system.

Parameter	Single-Stage Production	Two-Stage Production	
		Stage 1	Stage 2
Influent flow rate range (gallons per hour)	150 to 200	170 to 230	130 to 170
Influent glycol concentration range (% glycol)	4 to 27	1 to 4	13 to 27
Influent temperature range (F or C)	Ambient	Ambient	Ambient
Number of effluent streams produced	2 streams–distillate and concentrate	2 streams–distillate and concentrate	2 streams–distillate and concentrate
Distillate effluent flow rate range (gallons per hour)	60 to 184	136 to 219	52 to 126
Distillate effluent water quality (COD range in mg/L)	<50 to 1,000	<50 to 1,000	<50 to 1,000
Distillate effluent water quality (pH range)	3 to 8	3 to 8	3 to 8
Concentrate effluent flow rate range (gallons per hour)	12 to 120	8.5 to 61	33 to 102
Concentrate effluent concentration (% glycol range)	50 to 55	15 to 20	50 to 55
Heat source	Electric-powered steam compression		
Control system	PLC		
Energy consumption information	0.4Kw per gal feed		
Estimate of waste to be produced	Sludge and solids negligible, and glycol in overheads less than 0.1%		
Anticipated frequency of maintenance activities	Duty cycle of 95% expected, depending on influent quality		
Footprint, dimensions, etc.	Each MVR unit is 20’ (L) x 6’ (W) x 8’ 2” (H), with scrubber 13’ (H) or 22’ (H)		
Other support systems	Feed preheater heat exchanger, electric air compressor, cold and hot filter systems, piping for feed, distillate, concentrate, and storage tanks for feed, distillate, and concentrate		

Table 9. Actual RO system performance.

Parameter	Value	Unit
Flow rates		Gallons per minute
- Minimum	0.3	
- Average	9.2	
- Maximum	31	
Actual COD treatment load rate		lbs/day
- Average	2,700*	
- Maximum	8,100*	
Actual BOD$_5$ treatment load rate		lbs/day
- Average	1,600**	
- Maximum	4,800**	
Actual PG treatment load rate		lbs/day
- Average	1,600	
- Maximum	4,800	
Influent COD concentration		mg/L
- Minimum	6,300*	
- Average	23,800*	
- Maximum	34,200*	
Influent BOD$_5$ concentration		mg/L
- Minimum	3,700**	
- Average	14,000**	
- Maximum	20,100**	
Influent PG concentration		mg/L
- Minimum	3,700	
- Average	14,000	
- Maximum	20,100	
Effluent COD Concentration		mg/L
- Minimum	5	
- Average	157	
- Maximum	430	
Effluent BOD$_5$ concentration		mg/L
- Minimum	2	
- Average	81	
- Maximum	230	
Effluent PG concentration		mg/L
- Minimum	1	
- Average	27	
- Maximum	120	
Treatment efficiency		% influent COD load treated
- Minimum	95.4	
- Average	99.0	
- Maximum	99.9	

*Data based on conversion: [COD] = 1.7 [BOD$_5$].
**Data based on conversion: [PG] = [BOD$_5$].

The information in Table 9 on actual system performance was derived from monthly average data collected at the facility between 2009 and 2012.

The information in Table 10 on actual system performance was derived from monthly average data collected at the facility between 2009 and 2012.

Cost Assessment for RO and MVR Treatment System

The Connecticut DOT paid for and installed the RO system, the low-concentration processing building, the two 1-million-gallon storage tanks, associated pumping stations, and the 11 process tanks.

The recycling vendor installed the chemical pretreatment system, the two UF units, the MVR building, four ADF concentrators, and two concentrate product storage tanks, and upgraded the RO system (state owned). The recycling vendor is responsible for the maintenance and operation of all equipment associated with the processing of spent ADF.

Table 10. Actual MVR system performance.

Parameter	Value	Unit
Flow rates - Minimum - Average - Maximum	 1.7 9.0 18	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 3,000* 13,000*	lbs/day
Actual BOD_5 treatment load rate - Average - Maximum	 1,800** 7,650**	lbs/day
Actual PG treatment load rate - Average - Maximum	 1,800 7,650	lbs/day
Influent COD concentration - Minimum - Average - Maximum	 45,900* 88,700* 178,500*	mg/L
Influent BOD_5 concentration - Minimum - Average - Maximum	 27,000** 52,000** 105,000**	mg/L
Influent PG concentration - Minimum - Average - Maximum	 27,000 52,000 105,000	mg/L
Effluent COD concentration*** - Minimum - Average - Maximum	 Not available Not available Not available	mg/L
Effluent BOD_5 concentration*** - Minimum - Average - Maximum	 Not available Not available Not available	mg/L
Effluent PG concentration*** - Minimum - Average - Maximum	 Not available Not available Not available	mg/L
Treatment efficiency*** - Minimum - Average - Maximum	 Not available Not available Not available	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].
***Effluent from the MVR is not monitored since it is sent to the RO treatment system.

Conclusions on Performance of BDL RO and MVR Treatment System

Influent Deicer Concentrations

The influent deicer concentration is a primary factor in the design and operation of RO and MVR treatment systems. While dilute concentrations of PG-affected stormwater can be treated by an RO/MVR treatment system, the RO/MVR treatment system performs better with higher influent deicer concentrations. Therefore, it is beneficial to operate the collection system in a manner that provides high influent deicer concentrations to the RO/MVR treatment process. Influent deicer concentrations of less than 40,000-mg PG/L are concentrated using the RO process. Concentrate from the RO process and influent deicer concentrations of greater than 40,000-mg PG/L are treated by the MVR. The RO/MVR treatment system at BDL has treated concentrations as low as 3,700-mg PG/L and as high as 105,000-mg PG/L. These concentrations fall well within the design concentrations of 0-mg to 270,000-mg PG/L.

To prevent fouling of the RO membrane, the RO process requires pretreatment of the influent deicing-affected stormwater by the UF processes. The UF systems are a very important part

Table 11. Actual BDL RO data for 2009–2010.

Stage 1	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Total or Average for Season**
Influent volume processed (gal)	20,273	75,812	625,786	602,007	300,774	1,326,694	141,721	0	139,206	29,738	**3,262,011**
Average influent glycol concentration (% PG)	0.40%	0.37%	0.75%	1.30%	1.30%	1.30%	1.30%	0	1.36%	1.40%	**1.17%**
Average influent (pH)	5.6	5.8	4.85	4.22	6.8	9.79	6.8	0	6.24	6.38	**5.6**
Average influent temperature (Fahrenheit)	65.8	71.5	60.77	60.18	58.8	66.36	76.2	0	76.11	85.00	**60.43**
Effluent volume of permeate produced (gal)	18,597	69,544	547,608	490,290	241,904	1,018,574	127,558	0	116,040	26,006	**2,656,121**
Average effluent permeate (pH)	5.65	8.33	7.07	7.48	8.60	9.56	7.53	0	7.93	6.18	**7.6**
Average effluent permeate (% PG)	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	0	<0.5%	<0.5%	**<0.5%**
Effluent volume of reject produced (gal)	1,676	6,268	78,178	111,717	58,870	308,120	14,163	0	23,166	3,732	**605,890**
Average effluent reject (% PG)	5.28%	5.86%	5.32%	5.30%	5.70%	5.64%	5.38%	0	0.00%	5.82%	**5.32%**
Stage 2											
Influent volume processed (gal)	18,597	69,544	547,608	490,290	241,904	1,018,574	127,558	0	116,040	26,006	**2,656,121**
Average influent glycol concentration (% PG)	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	0%	<0.5%	<0.5%	**<0.5%**
Average influent (pH)	5.65	8.33	7.07	7.48	8.6	9.56	7.53	0	7.93	6.18	**7.6**
Average influent temperature (Fahrenheit)	63	67.3	56.2	57.7	55.6	64	70.7	0	78.1	80.8	**65.9**
Effluent volume of permeate produced (gal) sanitary	9,287	42,807	325,140	297,524	137,577	639,978	82,057	0	68,937	16,205	**1,619,512**
Average effluent permeate (pH)	8.2	8.5	7.42	7.78	8.46	9.02	7.96	0	7.27	6.3	**7.9**
Average effluent permeate (PG ppm)	1	1	3.2	1	1	16.8	23	0	16	27	**9.7**
Average effluent permeate (BOD mg/L)	3	2	163	64.5	86.25	29	100	0	94.5	230	**74.8**
Average effluent permeate (COD mg/L)	230	290	88.3	5	130	44	107.5	0	110	320	**69.4**
Average effluent reject (% PG)	0.5%–1.0 %	0.5%–1.0 %	0.5% - 1.0 %	0.5%–1.0 %	0.5%–1.0 %	0.5%–1.0 %	0.5% - 1.0 %	0	0.5%–1.0 %	0.5%–1.0 %	**0.5%–1.0 %**
Effluent volume of reject produced (gal)	9,310	26,737	222,468	192,766	104,327	378,596	45,501	0	47,103	9,801	**1,036,609**
Overall ratio of pure PG removed by both stages	98.85%	98.47%	97.78%	99.62%	99.65%	93.77%	89.76%	0	94.17%	89.49%	**95.89%**
Average amount of waste produced month (gal)	5,000	5,000	10,000	15,000	0	15,000	10,000	10,000	5,000	5,000	**80,000**

Table 12. Actual BDL MVR data for 2009–2010 deicing season.

	9-28 to 10-25	10-26 to 11-22	11-23 to 12-20	12-21 to 1-17	1-18 to 02-14	2-15 to 03- 14	03-15 to 04-11	04-12 to 05-09	5-10 to 06-06	06-07 to 07-04	07-05 to 08-01	
Stage 1 (1/4 – MVRs)	**1 MVRs**	**2 MVRs**	**2 MVRs**	**3 MVRs**	**2 MVRs**	**4 MVRs**	**3 MVRs**	**1 MVRs**	**0 MVRs**	**1 MVRs**	**1 MVRs**	**Season Total**
Influent volume processed (gallons)	2,074	23,471	20,192	195,621	103,384	211,179	129,853	9,656		11,116	8,378	**714,924**
Average influent glycol concentration (%PG)	10.5	6.4	6.5	6.1	6.6	7.0	6.4	5.5		5.7	6.0	**6.51**
Volume of 100% PG in influent (gallons)	218	1,502	1,312	11,933	6,823	14,783	8,311	531		634	503	**46,549**
Average influent temperature (°C)	70	75	77	76	75	73	72	81		89	92	**78**
Average influent flow rate (gph)	296.3	357	421.0	584.5	379.2	897.6	562.1	205.4		138.5	209.5	**405**
Effluent volume of distillate produced (gallons)	1,289	18,598	15,478	152,504	79,417	152,595	100,023	7,297		8,869	5,792	**541,862**
Effluent volume of concentrate produced (gallons)	785	4,873	4,714	43,117	23,967	58,584	29,830	2,359		2,247	2,586	**173,062**
Average effluent concentration of concentrate (% PG)	24.4	23.3	24.0	23.5	25.3	24.2	26.9	23.0		22.3	20.0	**24.51**
Volume of 100% PG in concentrate (gallons)	192	1,135	1,131	10,132	6,064	14,177	8,024	543		501	517	**42,417**
Stage 2/Single Stage (1/4 MVRs)	**1 MVRs**	**3 MVRs**	**0 MVRs**	**2 MVRs**	**2 MVRs**	**2 MVRs**	**3 MVRs**	**1 MVRs**	**1 MVRs**	**1 MVRs**	**1 MVRs**	
Influent volume processed (gallons)	2,076	2,279		38,843	21,912	77,237	169,872	2,290	9,890	1,347	5,003	**314,509**
Average influent glycol concentration (%PG)	12.8	20.5		22.8	25.0	18.5	11.4	24.5	11.2	20.5	23.4	**15.67**
Volume of 100% PG in influent (gallons)	266	467		8,856	5,478	14,289	19,365	561	1,108	276	1,171	**49,282**
Average influent temperature (°C)	69	68		79	76	80	74	67	83	80	91	**73**
Average influent flow rate (gph)	143.2	483		301.6	317.6	366.6	597.8	229.0	133.2	244.9	178.7	**348**
Effluent volume of distillate produced (gallons)	1,545	1,479		23,160	12,725	48,476	121,754	1,074	7,098	778	2,755	**210,213**
Effluent volume of concentrate produced (gallons)	531	800		15,683	9,187	28,761	48,118	1,216	2,792	569	2,248	**104,296**
Average effluent concentration of concentrate (% PG)	52.5	52.5		54.5	55.5	48.8	37.8	53.0	43.0	52.2	51.5	**45.27**
Volume of 100% PG in concentrate (gallons)	279	420		8,547	5,099	14,035	18,189	644	1,201	297	1,158	**47,213**
% ratio of glycol produced versus infeed	104.9	89.9	0.0	96.5	93.1	98.2	93.9	114.9	108.4	107.6	98.9	**95.8**

Table 13. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost	Not provided	$3.4 million in 2006 RO: $150,000* UF: $300,000 MVR: $2,050,000 Subsystems:$900,000
Annual operating cost		
- Utilities	Not provided	Not provided
- Chemicals	Not provided	Not provided
- Analysis	Not provided	Not provided
- Material handling	Not provided	Not provided
Total operating cost	**Not provided**	**$500,000**

*Upgrade to existing system.

of the low-concentration treatment system. The processed fluid from the UF systems must be less than 200 NTU before being fed to the RO system. The temperature of the influent is closely monitored to maximize the flow rate through the membranes. Both UF systems are monitored continuously for influent temperature and show symptoms of fouling when flow rates fall below desired parameters. At that point the units are flushed with a mild cleaning solution to clean the membranes.

Flow Rate

The treated flow rate is not a parameter used to demonstrate performance of the BDL RO/MVR treatment system, but it is useful in interpreting other performance parameters and in establishing the potential range of treatment capabilities. It was anticipated that flow rates would average 40 gallons per minute (gpm) to 50 gpm through the RO treatment system and average 2 gpm to 3 gpm for the MVR treatment process. In practice, the flow rates have averaged 9.2 gpm for RO and 9.0 gpm for MVR. The lower-than-anticipated flow rates are a reflection of the system not operating continuously (i.e., 24 hours per day). Instead, the RO system operates only partial days since it can easily handle the volume being fed from both the UF and concentrator systems. The UF effluent output capacity, the MVR distillate output, and the overall availability of low-concentration spent ADF are the reverse osmosis system's limiting factors for the flow rate.

Treated Load Rate

The rate at which PG is removed from the system (treated load rate) is a key measure of the performance in RO and MVR technologies. This is because RO and MVR treatment processes are used to recover PG for reuse and recycling. Therefore, a high treatment load rate, such as at BDL, is an indicator that the system is recovering PG at a significant rate. Correspondingly, this demonstrates that the treatment system is meeting its design expectations.

The two-stage RO installed at BDL performs as intended. It has more than enough capacity to meet required processing removal rates. The RO does not run continuously (i.e., 24 hours per day) and runs only partial days since it can easily handle the volume fed from both the UF and concentrator systems. The RO was originally designed to handle up to 219,700 gallons per day, so 40,000 gallons to 60,000 gallons can easily be processed per day. Based on the historical operation of the system at BDL, it can be concluded that the system has performed for the needs of the airport, and its full potential has yet to be demonstrated.

Effluent Concentrations

The effluent PG concentration of the RO system effluent is a key performance indicator for removal efficiencies. The BDL RO and MVR were designed to concentrate the PG for recycling and reuse. By concentrating the PG into one stream, PG is removed from the distillate stream.

The distillate stream discharges or is sent through the RO treatment system again. The RO system is operated so that the distillate stream contains concentrations below the permitted concentration. The average PG concentration in the RO distillate stream has been 27 mg/L.

The MVR also has a concentrate and a distillate stream. However, the concentrate from the MVR is trucked off-site at BDL for PG reuse. The MVR distillate stream is sent back to the RO system for further treatment.

Treatment Efficiencies

Based on the data, the average influent concentration of glycol was approximately 10,400-mg PG/L during the 3-year span. The RO reject produced yielded glycol concentrations averaging 3% to 5%. This indicates that at least 50% of the glycol flowing through RO is removed and sent to the MVR systems for recycling. The remaining glycol that carries over in the Stage 1 permeate of the MVR eventually becomes Stage 2 influent and averages between 0.5% to 1% glycol. The remaining glycol is removed, and the fluid quality consistently meets all discharge requirements. Overall, the RO system 3-year data indicate a 92% average removal rate of glycol. The data suggest that the unit is capable of removing 99% of the glycol that is processed, but according to the recycling vendor, the unit is set to continually meet the permit requirements while maximizing flow rates and in turn maximizing removal rates to maximize spent-ADF storage capacity at any given time. For this reason, the main focus when adjusting parameters on the RO system is not to reclaim all glycol but to maximize production flow rates while maintaining permit compliance.

Cost

Cost is another key indicator of performance. High-volume seasons increase costs since more consumables are used and labor is extended into the summer to monitor equipment before shutdown. The costs also typically increase as influent has a higher concentration of TSS since these require more chemical pretreatment and typically more operational shutdowns for cleaning the system. If the treated fluid is very diluted and has glycol levels of less than 1% PG, then the system becomes less cost-effective since the volume of PG recovered per unit volume treated is typically lower.

Average annual operating costs of utilities, chemicals, analyses, and solids management are approximately $500,000 annually. The BDL system uses one full-time supervisor, two full-time operators, and seasonal operators as necessary for the system. Most maintenance activities at BDL are performed by the glycol recycling contractor as part of its duties.

A cost model developed in Task 5 of this research was used to relate required RO and MVR technology COD loading (lbs/day) to cost. Considerations from analysis of RO and MVR cost data application to the model include:

- Actual treatment capacity/RO volume compared to nominal design capacity.
- Effect of treatment efficiency on caustic demand.
- Chemical use data per pound of COD treated, which may vary with the concentration of influent soluble COD.
- Electrical costs per cubic foot of membrane, and
- Solids generation rates per pound of COD treated.

Lessons Learned for Potential Implementation of the RO and MVR Technology at Other Airports

Several factors have proven critical to effective and efficient performance in the RO and MVR systems at BDL. These factors are:

1. Adequate filtration methods prior to treatment;
2. Maintaining process variables such as temperature, turbidity, flow rate, and pressures at consistent set points;
3. The ability to adjust the UF/RO and MVR systems to respond to variability in influent glycol concentrations;
4. The ability to meet desired effluent concentrations, which affects influent processing rate;
5. The need to integrate daily preventative maintenance into operations in order to optimize equipment performance; and
6. The membrane systems should be treated with biocide when the processing systems sit idle for extended periods of time to eliminate potential biological growth.

The RO system is pH sensitive, so caustic injection systems continually run to ensure that the pH is maintained at an optimal level. The RO system is continually monitored for pressure readings and permeate quality. This gives an indication when fouling is occurring and the system needs to be stopped for flushing. Pressures gradually climbing, coupled with increasing COD on the permeate discharge, are typical indications that the RO unit needs to be shut down for washing. The system is flushed with a mild cleaning solution to clean the membranes. A small volume of waste is produced each year from slops disposal. The 3-year data indicate that the volume of wastewater generated by the system and trucked off-site is approximately 1% to 2% of the volume that is fed through the system.

By employing the use of both membrane and MVR technologies, Bradley International Airport is able to handle a large range of influent concentrations. This includes treatment of spent ADF of as low as 0.1% in concentration to as high as 25% in concentration. With the ability to use membrane systems, this also allows the airport to meet very stringent discharge limitations. By installing both types of recycling technologies, the airport was able to maintain a relatively small footprint with a significant amount of treatment capacity. All of the units installed are modular in design, and as a result, additional systems were able to be added in 2008 to meet an increase in volumes of spent ADF collected with the terminal gates being tied into the existing collection system. The type of technologies used at BDL could be effective for airports that generate a substantial volume of spent ADF at generally low concentrations.

Each MVR at BDL can be adjusted to produce a desired glycol concentration product. The MVR units produce two effluent streams, and the desired concentration set points in each effluent stream directly affect the performance of the concentrators. The glycol concentration is continually monitored to balance the parameters on the machine to increase the processing rate. The effluent glycol level is crucial since the recycling contractor has a goal to produce effluent with a concentration of 50% PG. At this level and higher, the contractor trucks the fluid off-site so that it can be distilled to the 99.1% and higher concentration level.

The second effluent stream produced from the MVR units is the distillate. This is the distilled water and is not continuously monitored since this fluid is sent to an interim storage tank where it is comingled with the other low-concentration spent ADF to be processed through the membrane systems. The quality of distillate is clean enough to be fed directly through the RO system. The RO system will remove any fugitive glycol to meet discharge permit levels. Based on the data, 94.6% of the glycol that was fed through the MVR systems was reclaimed. The remaining glycol was reclaimed through the RO system and the balance discharged through the effluent stream to the POTW.

Conclusions from operation of the RO and MVR at BDL that can be used by other airports considering this technology include:

1. The MVR technology is excellent for enabling recycling of the concentrated PG for offsetting costs.

2. The RO and MVR technologies are excellent for treating high propylene glycol concentrations.
3. The effluent concentrations can be minimized through optimizing turbidity, pressure, temperature, and pH.
4. The system performs very consistently and predictably once a constant concentration, pressure, temperature, and pH are obtained in the influent.
5. The system can start and stop as required with little impact to the influent loading rates or effluent concentrations.
6. Cost recovery from the recycled PG is dependent on the market value of PG and the amount of PG available for capture and recycling.
7. Sufficient ability to control flow rates is important, especially if influent concentrations are high, resulting in higher chemical dosing and maintenance.

Documents and Information Review in Development of Airport Summary

1. Bradley International Airport. Treatment System Operational Records, 2010.
2. Svedruzic, Michael and Arendt, Tim. *Deicer Treatment Options and Considerations for ELG,* 22 July 2010.

Airport Treatment Summary No. 2

Airport:	Nashville International Airport—Nashville, TN (BNA)
Treatment Technology:	Aerated Lagoon, POTW Discharge
Years Operated:	1997–2012 (Currently Operational)

Deicer Management System Description

At BNA, aircraft deicing fluid is applied primarily on dedicated deicing areas (pads). All stormwater runoff from the pads and runoff from selected non-deicing areas around the gates flows by gravity to the north and south storage ponds. The inclusion of non-deicing area runoff results in lower COD concentrations than would otherwise be expected from a deicing pad operation. Each storage pond has a pump station for conveying runoff to an aerated lagoon for treatment. The storage pond pumps are operated based only on the water level in the ponds; as a result, the influent flow rates to the aerated lagoon are variable and not controlled based on treatment system needs. Treated effluent from the aerated lagoon discharges to Sims Branch via an effluent weir at the north end of the lagoon. With permission from the POTW, the treated effluent can also be discharged to the sanitary sewer under special circumstances. Overflows from the storage ponds are conveyed to Sims Branch. Figure 1 shows a diagram of the system.

Deicer Treatment Technology Selection Considerations

In the early 1990s, the Metropolitan Nashville Airport Authority (MNAA) experienced issues with low dissolved oxygen and bacterial growth in Sims Branch as a result of discharge of deicer-affected stormwater. MNAA considered biological treatment as a potential treatment methodology, and in 1992 a treatability study was performed to assess the feasibility of treating the runoff with aerated lagoon and activated sludge technologies. The objectives of the study were to define treatment process design and sizing criteria and to assess potential system performance. The estimated effluent quality using the potential technologies was compared to anticipated effluent limitations for BOD and TSS. The treatability study was conducted at 9°C (48°F). The treatability evaluated a first-stage aerated lagoon technology with a 20-day hydraulic detention time, which was projected to achieve 97% removal efficiency at that temperature, plus a second-stage activated sludge technology with a 1-day detention time, which would achieve 96% removal efficiency and achieve the desired BOD effluent concentrations.

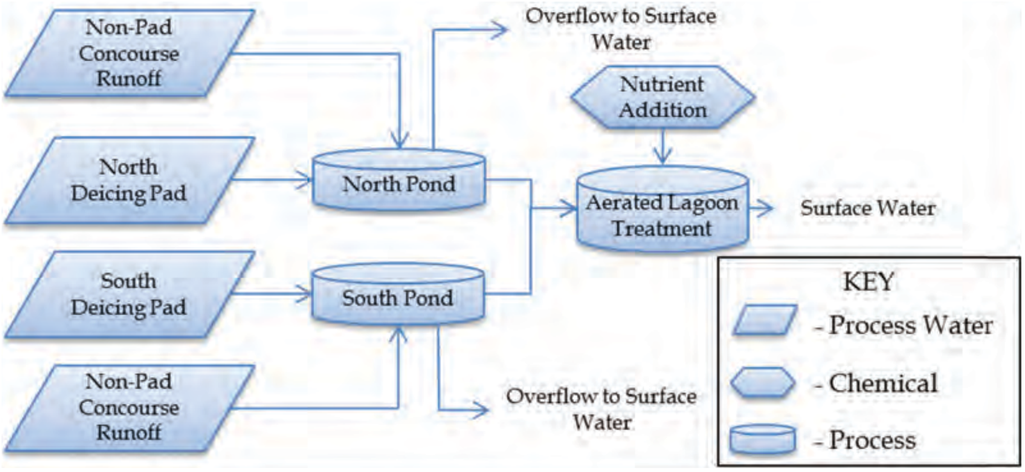

Figure 1. BNA deicing-affected stormwater management system.

Because of budgetary constraints, MNAA implemented the aerated lagoon technology but not the activated sludge system. A plan was also implemented to monitor performance of the aerated lagoon on an ongoing basis to assess the need to add the potential second-stage activated sludge treatment in the future. The activated sludge portion was ultimately not added, although later a system for recycling biosolids back into the aerated lagoon was implemented in an effort to boost system efficiency.

Deicer Treatment Technology Description

Aerated Lagoon

See the aerated lagoon fact sheet (Fact Sheet 103) for a description of the treatment technology used at BNA. The aerated lagoon at BNA (see Figure 2) is a lined structure, approximately 18 ft in depth at its deepest point. It was originally portioned into three sections of aerated treatment, with a final section for solids settling and sludge stabilization. A total of 13 surface aerators with draft tubes were used in the three aerated sections to provide mixing and oxygen transfer. At the present time, the liner-based baffles that segregated the basin into four sections are not in place, but MNAA plans to again segregate the basin in an upcoming system upgrade. Biological solids settle and partially degrade in the last section of the basin. Settled solids are removed occasionally, but typically no more than once per year. MNAA has experimented with several methods for removal of the solids from the basin, but the process of removing the solids without damaging the lagoon remains a challenge.

Description of Support Systems

Two ponds are located upstream of the treatment system for storage of stormwater runoff from the deicing pad and concourse areas. The capacity of the north pond is 1.09 million gallons, and the capacity of the south pond is 2.0 million gallons. The ponds are designed to hold runoff from the first flush, or up to 1.5 in. of rainfall. When the ponds are full, collected runoff will overflow at a weir in each pond and discharge directly to Sims Branch.

The north pond has two 125-gpm pumps. The south pond has two 250-gpm pumps. The maximum hydraulic retention time at average flows is 5 days for the north pond and 7 days for the south pond, although in practice water can stay in the ponds for much longer during dry periods.

Figure 2. BNA treatment system.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity North pond: South pond:	 1.09 million gallons 2 million gallons	2	3.09 million gallons
Treatment unit (lagoon) volume	5.75 million gallons	1	5.75 million gallons
Treatment unit (lagoon) dimensions Length Width at bottom Width at top of berm Depth Side slopes	 685 ft 35 ft 110 ft 18 ft 2.2 to 1	1	890,000 ft^3
Treatment facility footprint (treatment lagoon only)	2-acre total site	1	2 acres
Design biomass suspended solids concentrations in lagoon from treatability study	1,200 mg/L	3	N/A

Note: Data based on 1995 Operations and Maintenance Manual.

The system operators manually feed nutrients to supplement growth of the bacteria in the treatment system. Originally, solid nutrients were fed into the influent end of the lagoon until operators noted during lagoon maintenance that the solid nutrients were building up on the lagoon bottom, apparently due to a lack of dissolution in the water. The system operators now manually feed a liquid form of the nutrients.

Effluent from the settling section discharges over a two-sided V-notch weir. The baffles were removed from the lagoon in 2010 because of deteriorating condition and operational concerns with solids buildup in the aerated portions of the lagoon.

Key System Sizing Parameters (Original Design)

See Table 1 for system sizing parameters and Table 2 for other sizing parameters.

Treatment System Performance

Table 3 data on the intended design performance were derived from the 1995 BNA Operations Manual prepared for the original system design. Table 4 contains data on actual system performance.

Table 2. Additional system sizing parameters (original design for aerated lagoon).

Component/Parameter	Value	Unit
Treatment unit volume	4.5 (minimum) 5.75 (maximum)	Million gallons
Aeration system (when baffles in place): Cell 1 Cell 2 Cell 3 Cell 4	 6 4 3 0	Aerators
Hydraulic retention time at average flow	25	Days
Flow control baffle length	103	Feet
Storage pond design basis	1.5	Inches of rain
Aerated lagoon discharge weir length (v-notch)	35	Feet

Note: Data based on 1995 Operations and Maintenance Manual.

Table 3. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Average	130	Gallons per minute
Design treatment load capacity	15,800* 9,300 9,300**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	8,500~17,000 5,000~10,000 5,000~10,000**	mg COD/L mg BOD_5/L mg PG/L
Biomass suspended solids concentrations in lagoon	123	mg/L
Design effluent concentration (average)	578 167 Not provided	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency (average)	95	% influent COD load treated

Note: Design data based on 1995 Operations and Maintenance Manual and 1999 CDM Review of five MNAA environmental programs and response strategies. The design effluent concentrations shown were the intended design effluent if an activated sludge system were added for polishing. (The activated sludge system was not ultimately installed.)
*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Cost Assessment for the BNA Aerated Lagoon Treatment System

See Table 5 for treatment system costs.

Conclusions on Performance of BNA Aerated Lagoon System

Influent Deicer Concentrations

The influent concentration is variable and cannot be controlled in the system as it is operated today. As a result, fluctuations in concentration can affect treatment. The long detention times typical in the storage ponds help to dampen the range of influent concentrations sent to the treatment lagoon.

Table 4. Actual system performance.

Parameter	Value	Unit
Flow rates - Minimum - Maximum	70 244	Gallons per minute
Actual COD treatment load rate - Maximum	600	lbs/day
Influent COD concentration - Average - Maximum	800 3,000	mg/L
Effluent BOD_5 concentration	20–1,600	mg/L
Treatment efficiency	Not known, but estimated to be <50%	% influent COD load treated

Table 5. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost	Not available	$2.5M (approximate)
Annual operating cost	Not available	Not available

Flow Rate

The flow rates into the system fluctuate significantly, as different pumps from the ponds are activated, with flow rates fluctuating between 70 gpm and 244 gpm when the pumps are running. This fluctuation in flow rates may not have been accounted for in the original system treatability studies, which assumed a more steady-state operation.

Treated Load Rate

The deicer mass loading rate is likely highly variable as both flow rates and COD concentrations from the two storage ponds vary. Flow rates into the treatment system cannot presently be controlled. The COD loads that the system can treat are significantly lower than the design capability due to challenges in controlling mixed liquor suspended solids concentrations.

Effluent Concentrations

Effluent concentrations are highly variable, with numerous periods below 50 mg/L, but also with spikes into the hundreds of mg/L COD nearly every year as large deicing events occur. Over time, the treatment system has occasionally experienced effluent concentrations that exceed permit limits.

Treatment Efficiencies

The ability to calculate treatment efficiencies is limited by the fluctuation of the influent flows, influent COD concentrations, and to a lesser degree, variations in effluent flows and concentrations. As a result, insufficient data have been collected to calculate treatment efficiency with any accuracy. It is believed that the current ability to remove COD in treatment is limited by challenges in maintaining a viable biomass in the aerated lagoon.

Cost

Operational costs are not cumulatively tracked for the treatment system, but the airport is in the process of assisting in gathering data. Operating costs include power cost for the pumps and aerators, chemical cost for nutrient addition, analytical costs, and operator labor costs. One full-time operator is employed to operate the system.

Lessons Learned for Potential Implementation of the Aerated Lagoon Technology at Other Airports

The following factors have proven critical to effective and efficient performance of the performance of the BNA aerated lagoon:

1. Ability to maintain a healthy and sufficiently concentrated biomass.
2. Adapting to cold temperatures, leading to reduction to treatment performance.
3. Managing variable COD loadings, leading to reduction to treatment performance.
4. Ability to add nutrients regularly and sufficiently for biomass needs.
5. Ability to add sufficient aeration and achieve adequate mixing throughout extent of lagoon.
6. Separation of treatment from solids settling processes.
7. The large volume of stormwater that must be processed due to collection of runoff not affected by deicing activities.

Critical Performance Factors

Critical to the performance of the aerated lagoon is the ability to maintain a biomass population that is healthy, settles properly, is stable, and is present in sufficient quantities to meet the treatment needs. The lack of control of influent COD loading and the significant variations in loading make it difficult to sustain an appropriate biomass in the BNA system even with sufficient management of other factors. Other factors that may influence the biomass are appropriate nutrient loading, sufficient mixing, sufficient aeration, and control of returned sludge to bolster the biomass concentration. Appropriate addition of nutrients based on the influent load is one key to keeping the biomass healthy. Maintaining a low velocity through the lagoon will prevent the biomass from being washed out with the effluent. Reinstallation of the baffles that were removed several years ago could also help maintain the biomass, and addition of a solids removal system to remove solids from the effluent and pump them back into the system could also help maintain the population.

The temperature of the water in the system also has a significant impact on the performance of the system. Since it is exposed to the elements, it is very difficult to control the temperature in the lagoon. In Nashville, Tennessee, the climate is more temperate than at some other airports, although in many years water temperatures can drop below 40°F, which will significantly slow biomass growth.

Based on performance limitations, MNAA has initiated a new project to improve the existing treatment system that will include:

- Reduction in the volume of water from non-deicing area runoff;
- Online monitoring of TOC, flow rates, and temperature;
- Control of mass loading rates into the treatment system;
- New nutrient feed system;
- Upgraded aeration system;
- Segregation of the treatment and solids removal components;
- Solids removal system for biological solids; and
- Improved maintenance of existing equipment and infrastructure to reduce downtime.

Documents and Information Review in Development of Airport Summary

1. CDM. *BNA Deicer Management System Review Report*, 1998.
2. Nashville International Airport. Treatment System Operational Records, 2012.
3. Ogden. *BNA Deicer Treatment System Operations and Maintenance Manual*, 1995.
4. GS&P. *Feasibility Study Report for Improvements to Deicing Fluid Collection and Treatment Systems*, 2012.

Airport Treatment Summary No. 3

Airport: Buffalo Niagara International Airport—Buffalo, NY (BUF)

Treatment Technology: Aerated Gravel Bed

Years Operated: 2009–2012 (Currently Operational)

Deicer Management System Description

In 2009, BUF implemented a system for collection of deicer and on-site treatment of deicer prior to discharge to an adjacent stream, Scajaquada Creek. All stormwater from the southeast side of the airport, which includes the main terminal and air cargo, is captured and treated year round. There are 3 million gallons of equalization storage prior to treatment. The treatment system was installed in response to New York State SPDES permit limits on BOD_5 (30-mg/L), glycol, and flow rate (154 cubic feet per sec) discharges to Scajaquada Creek. On-site treatment consists of a subsurface aerated gravel bed located on the airside of the airport facility. Figure 1 shows a process flow diagram of the system.

Deicer Treatment Technology Selection Considerations

It was found that the sanitary sewer had limited hydraulic capacity (4-in. pipe was limiting), and on-site treatment with discharge to the surface waters was necessary to comply with the permit limits. Factors that were considered in the selection of the on-site aerated gravel bed treatment technology included:

1. Budget: 10 million USD available for construction.
2. Limited land was available.
3. A low-profile system was desired such that it could be placed on available land on the airside of the airport.

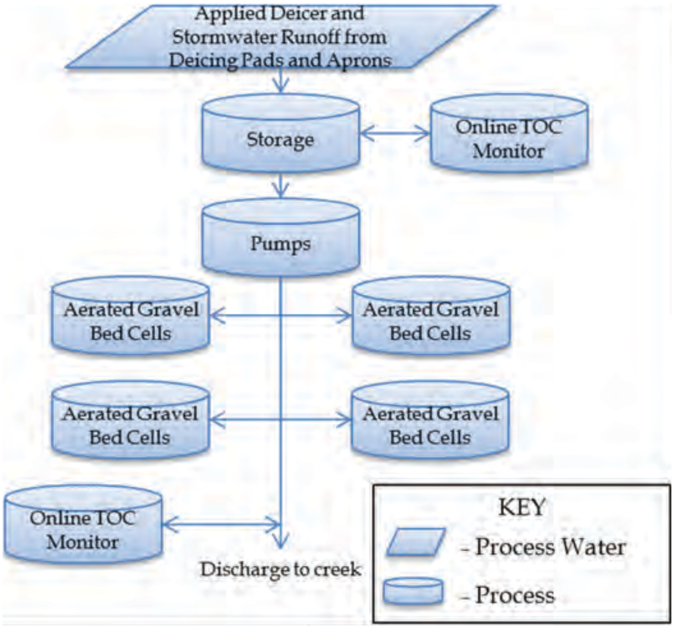

Figure 1. BUF deicer management system process flow diagram.

4. The treatment system needed to be retrofitted into the existing stormwater management system.
5. The nature of the weather and deicing at BUF resulted in high variability in flow and strength of water to be treated, which had to be controlled for effective treatment.

Treatability testing and pilot-scale testing were performed prior to design of the BUF aerated gravel bed system to establish technology capabilities and design parameters.

Deicer Treatment Technology Description

Description of Aerated Gravel Bed

BUF uses an aerated gravel bed treatment technology (see Fact Sheet 102 for technology details). The BUF aerated gravel bed uses a vertical flow configuration in which stormwater is uniformly distributed with infiltration chambers buried near the surface of the substrate over the gravel beds. The applied water percolates downward through the gravel substrate to an under-drain system. A relatively large gravel size, 1/2 in.–3/4 in. in diameter, provides a surface for growth of a bacterial biofilm. The biofilm grows during the deicing season and degrades in the summer when no deicer is applied. The BUF treatment system consists of four discrete gravel beds excavated from an existing open area near the airport's main runway. The gravel beds are vegetated with grasses growing in a mulch surface. The mulch surface helps to contain heat in the winter months within the bed. See Figure 2 for a photograph of the aerated gravel bed during construction.

Description of Support Systems

The aerated gravel bed at BUF includes the following support systems for the treatment system: aeration system, dosing system, nutrient feed system, and analytical system. The aeration system uses four blowers, a manifold system, and a forced bed aeration system.

The dosing system for supplying the deicer-affected stormwater to the treatment system includes four dosing pumps and a dosing tank. The objective of the dosing system is to provide a uniform mass loading to the treatment cells to stabilize the biological population and provide for efficient treatment. The dosing system is a means of counteracting the swings in deicer concentrations inherent in collected runoff during winter. The aerated gravel bed is monitored with influent and effluent TOC meters, an effluent ammonia meter, and four influent flow

Figure 2. Construction of the BUF aerated gravel bed.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	3,000,000 gallons	1	3,000,000 gallons
Treatment unit volume	0.70 million gallons	4	2.83 million gallons
Treatment unit dimensions	166-ft L x 300-ft W x 5-ft D	4	N/A
Treatment facility footprint	1.1 acres	4	4.5 acres

meters (1 meter per bed). The nutrient feed system uses three chemical feed pumps and one 500-gallon batch feed tank to supply nutrients to support the aerated gravel bed with pH.

Key System Sizing Parameters

Table 1 shows key sizing parameters.

Treatment System Performance

Table 2 indicates the intended design performance of the BUF system, and Table 3 shows actual system performance.

Table 4 provides field-measured weekly average performance data for the 2010–2011 deicing season. Monitoring to date indicates that influent $CBOD_5$ is roughly two times influent TOC values, and effluent $CBOD_5$ is roughly half of effluent TOC values.

Cost Assessment for the BUF Aerated Gravel Bed Treatment System

Table 5 shows the treatment system costs.

Conclusions on Performance of BUF Aerated Gravel Bed System

Influent Deicer Concentrations

The influent deicer concentration is not a direct operational factor in the aerated gravel bed treatment system. However, variations in the influent concentration affect the treatment loading rate operational limit. Influent TOC values range from 11 mg/L to 6,909 mg/L. These TOC values would correspond to roughly 22-mg/L to 13,818-mg/L influent for $CBOD_5$ using BUF sampling data. The concentrations indicate that the aerated gravel bed system is capable of treating concentrations as high as 130% of the design concentration maximum.

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Maximum	6,152	Gallons per minute
Design treatment load capacity	17,000* 10,000 10,000**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	Not provided	mg BOD_5/L
Design effluent concentration (average)	30 Not provided	mg BOD_5/L mg PG/L
Design treatment efficiency (average)	Not provided	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 3. Actual system performance.

Parameter	Value	Unit
Flow rates - Minimum - Average - Maximum	 187.5 402.8 1416.7	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 19,000* 72,000*	lbs/day
Actual BOD_5 treatment load rate - Average - Maximum	 11,200 42,400	lbs/day
Actual PG treatment load rate - Average - Maximum	 11,200** 42,400**	lbs/day
Influent COD concentration - Minimum - Maximum	 38* 23,500*	mg/L
Influent BOD_5 concentration - Minimum - Maximum	 22 13,818	mg/L
Influent PG concentration - Minimum - Maximum	 22** 13,818**	mg/L
Effluent BOD_5 concentration - Minimum - Average - Maximum	 25 73 178	mg/L
Treatment efficiency	Not provided	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Flow Rate

The flow rate is not a direct operational factor in the aerated gravel bed treatment system. However, the flow rate does vary based on the treatment loading rate and treatment system detention time.

Treated Load Rate

The aerated gravel bed system is designed and operated for 10,000-lbs BOD_5/day. The design treatment load rate of 10,000-lbs BOD_5/day is a limiting factor in the operation of the aerated gravel bed system. The system is loaded and monitored each day beginning at 8 a.m. The system continues to receive loads until the load limit of 10,000-lbs BOD_5/day is reached, at which time no additional influent is sent to the aerated gravel bed until 8 a.m. This batch loading system of feeding the aerated gravel bed works well due to the long detention time.

The system was able to withstand periodic high loadings that were four times design capacity.

Effluent Concentrations

Effluent TOC values range from 48 mg/L to 357 mg/L. This would correspond to roughly 24-mg/L to 179-mg/L effluent for $CBOD_5$ using BUF sampling data.

Treatment Efficiencies

Treatment efficiency was routinely above 90% for 2010–2011. Treatment performance ramped up quickly with an increase in TOC concentrations in the influent.

Cost

The extent of the aerated gravel bed system installed at BUF to date is a function of the available budget.

Table 4. BUF weekly performance data 2010–2011 season.

Date	Average Flow (gpd)	Average Load (lbs TOC/day)	Average Influent TOC (mg/L)	Average Effluent TOC (mg/L)
10/4/2010	1,046,362	640	74	54
10/11/2010	317,894	385	78	61
10/18/2010	543,039	108	18	56
10/25/2010	485,733	75	11	48
11/1/2010	331,446	119	13	53
11/8/2010	38,095	16	33	48
11/15/2010	695,874	814	132	54
11/22/2010	1,470,369	2,885	178	64
11/29/2010	988,104	6,270	458	211
12/6/2010	988,104	6,270	458	211
12/13/2010	827,512	5,567	1,731	116
12/20/2010	827,512	5,567	1,731	116
12/27/2010	248,767	19,335	1,828	163
1/3/2011	556,360	9,974	3,370	141
1/10/2011	41,714	4,804	6,714	122
1/17/2011	163,205	13,866	6,204	255
1/24/2011	38,889	4,587	6,909	138
1/31/2011	27,661	3,014	6,318	115
2/7/2011	46,886	4,572	4,670	134
2/14/2011	1,177,909	15,103	1,738	277
2/21/2011	122,705	3,287	1,400	142
2/28/2011	1,181,498	7,390	798	162
3/7/2011	2,039,782	21,232	581	357
3/14/2011	289,177	2,331	426	176
3/21/2011	656,285	11,993	1,392	318
3/28/2011	507,051	5,269	515	242
4/4/2011	527,261	2,032	294	142
4/11/2011	186,215	163	387	118
Maximum	**2,039,782**	**21,232**	**6,909**	**357**
Average	**584,693**	**5,631**	**1,731**	**146**
Minimum	**27,661**	**16**	**11**	**48**

Lessons Learned for Potential Implementation of the Aerated Gravel Bed Technology at Other Airports

The factors listed in the following have proven critical to effective and efficient performance in the BUF aerated gravel bed system:

1. Control of flow and TOC loading rates.
2. Management of nutrient loadings at start-up.
3. Routine clean out of dosing lines.
4. Adequate aeration through the use of forced bed aeration.
5. Use of plants has no effect on performance or treatment efficiency.

Table 5. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost*	$10M in 2008	$10M
Annual operating cost		Not provided

*Capital costs are for the treatment system only. Costs do not include site-specific costs for collection, storage, and discharge.

The system went online in spring of 2009 and performed as expected until late December 2009. In late December 2009, the formation of polysaccharides (slime) was observed within the treatment bed. To remedy the reduced treatment performance and remove the polysaccharides, the aeration and nutrient addition was increased. After 2 months, the system began operating at design performance. The nutrient addition levels have since increased to match a high rate of bacterial growth.

Since the aerated gravel bed went online in 2009, the sampling pumps burned out and required replacement and the SCADA system was upgraded to provide operator interface and off-site data access. Ammonia meter readings are erratic and the unit has undergone repeated troubleshooting.

It was determined that the influent dosing lines require regular cleaning to prevent clogging by floating debris (plastics). Regular cleaning of dosing lines is required to maximize flow through the system.

Conclusions from operation of the aerated gravel bed at BUF that can be used by other airports considering this technology include:

1. The AGB technology is excellent for isolating treatment from the effects of the weather and cold water temperatures because of heat generated in the cells during treatment.
2. The AGB technology is excellent for achieving effluent limits for propylene glycol and BOD concentrations. Some TOC remains, indicating that there are some organics that are not readily biodegradable.
3. The system performs very consistently and predictably over a wide range of influent concentrations because loading into the treatment system is controlled.
4. It is unclear as to the need to initially seed the system during start-up. Off-season operation at low concentrations appears to develop an acclimated culture prior to onset of the deicing season.
5. Providing sufficient nutrient balance is critical.
6. Sufficient ability to control flow rates is important, especially if influent concentrations are high, resulting in lower flow rates.
7. If treating high concentrations, such as is the case with flows from deicing pads, consider the potential impacts of the lower flow rates that are needed to maintain a consistent TOC loading, including effects on storage, effects on solids removal, and effects on effluent concentrations.

Documents and Information Review in Development of Airport Summary

1. BUF. Construction Drawings (Plans and Specs–2008).
2. BUF Weekly Reports 2010–2011 (summarized operating data).
3. Austin, D. C., Maciolek, D. J., Davis, B. M., Wallace, S. D., “Damköhler number design method to avoid clogging of subsurface flow constructed wetlands by heterotrophic biofilms.” *Water Science and Technology.* 56.3 (2007): 7–14.
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5. Kadlec, R. H., Wallace, S. D., *Treatment Wetlands,* Second Edition. Boca Raton, Florida: CRC Press, 2009. Print.
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Airport Treatment Summary No. 4

Airport: Akron–Canton Airport—North Canton, OH (CAK)

Treatment Technology: Anaerobic Fluidized Bed Reactor

Years Operated: 2007–2012 (Currently Operational)

Deicer Management System Description

In response to effluent limits for PG in its 2004 NPDES permit, CAK initiated a study to assess means for deicer application, runoff collection, conveyance, treatment, and disposal of aircraft deicer that would provide the ability to meet its permit limits for Outfall 003. The implemented deicer management system includes two deicing pads, gravity drainage from the pads to two storage tanks, an anaerobic fluidized bed reactor biological treatment system, and discharge of treated effluent to the existing detention basin upstream of Outfall 003. The discharge from Outfall 003 is to the city of Green municipal separate storm sewer, with subsequent discharge to Zimber Ditch, a regulated surface water. Operators have the ability to route diluted flows from the deicing pads around the treatment system directly to the Outfall 003 detention basin without treatment. Figure 1 shows a process flow diagram of the system.

Deicer Treatment Technology Selection Considerations

In its decision-making process, CAK placed a high premium on minimizing project costs to support its goal of being the local low-cost provider of air services. Since the capital portion of the treatment system installation was covered by a federal grant, decisions on treatment technologies were primarily driven by two factors: (1) minimizing annual operating and maintenance costs and (2) the ability to consistently and predictably achieve compliance with the NPDES permit effluent limits. Construction of the deicing pads was an important element in reducing costs because of the reduction in the volumes of water that would need to be stored, conveyed, and potentially heated. When considering treatment alternatives, CAK considered it important to minimize the footprint of the treatment operations to reduce expenditures associated with facility buildings.

Based on an assessment of a wide range of treatment options in 2005, it was determined that discharge to the local sanitary sewer (a POTW), recycling, and two types of on-site biological

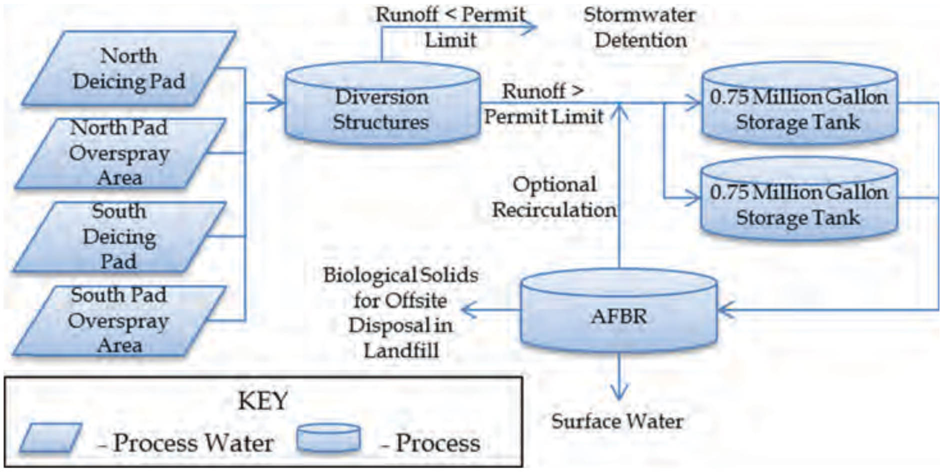


Figure 1. CAK deicing-affected stormwater management system.

treatment were the most applicable potential treatment and disposal options. The following conclusions on treatment technologies were reached before the AFBR technology was selected:

- POTW (sanitary) discharge was eliminated as a possible treatment and disposal technology due to insufficient capacity at two local wastewater treatment plants. The POTWs were not interested in modifying their plants to accommodate the increased seasonal loading.
- Treatment using membrane filtration or evaporation units, with ultimate transport of the moderately concentrated glycol off-site for recycling, was considered carefully, but was eliminated for several reasons:
  - The additional units needed to reach the PG concentrations in the dilute effluent stream drove up operating costs in relation to biological treatment.
  - CAK had concerns about relying on an outside entity for treatment services.
  - CAK preferred not to be dependent on potentially fluctuating market conditions for recycled glycol.
- Both aerobic and anaerobic biological treatment methods were considered. Since minimizing the treatment footprint was important, the aerobic membrane bioreactor system and the anaerobic fluidized bed reactor system were considered. The AFBR was selected over the MBR based on the following criteria:
  - Lower operating costs.
  - Built-in means for isolating the treatment effectiveness from weather concerns through the use of off-gassed methane as fuel to heat the runoff.
  - Proven success at another airport (Albany International).

Deicer Treatment Technology Description

Anaerobic Fluidized Bed Reactor

See the AFBR treatment technology fact sheet (Fact Sheet 104). Figure 2 shows reactor units used in the AFBR system.

Description of Support Systems

The AFBR at CAK includes the following support systems for the treatment reactor-separator unit: storage (two 750,000-gallon concrete tanks), influent pumping system, heat generation

Figure 2. Biological reactor units (at right) in the CAK AFBR system.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	750,000 gallons	2	1.5 million gallons
Treatment unit volume	2,500 ft³	2	5,000 ft³ 37,400 gallons
Treatment unit dimensions	Reactors: 10-ft diameter	2	N/A
Treatment facility footprint	0.1-acre building, 0.2-acre total site	1	0.2 acre

and exchange loop, chemical feed for nutrient addition and pH control, biogas handling, and biological solids removal and handling. Collected runoff water from the storage tanks is pumped at a flow rate set by the system operators to achieve a constant COD loading as influent COD concentrations change. The cold influent water is heated first by passing it by warm effluent water in a heat exchanger and then by passing it by hot water from a boiler in a second heat exchanger. The hot water is obtained by heating potable water in a boiler using biogas captured from the reactor. The biogas is approximately 70% methane and 30% carbon dioxide and is used similarly to natural gas. For the CAK system, the heating system burns exclusively self-generated biogas for the entire deicing season, except for initial yearly start-up when natural gas is used. Any excess biogas is burned in a flare external to the building. The AFBR technology requires addition of a base chemical (sodium hydroxide) to keep pH in the reactors neutral, as well as addition of various chemical nutrients to support growth of the bacteria. Biological solids exiting the reactor-separator unit with the treated effluent are removed with a dissolved air flotation clarifier. Treated effluent is discharged to CAK's Outfall 003 detention basin. Biological solids are disposed of in a landfill.

Key Treatment System Sizing Parameters

Table 1 shows system sizing parameters.

Treatment System Performance

The data in Table 2 on the intended design performance of the system were derived from the Engineering Report and Permit-to-Install Application to Ohio EPA.

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 5 20 50	Gallons per minute
Design treatment load capacity	3,400 2,000* 2,000**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	50~32,000 30~18,800* 30~18,800**	mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	340 200* <35	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency (average)	98%	% influent COD load treated

Design data based on 2006 Engineering Report. Design values based on two-reactor system.
*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

The information in Table 3 on actual system performance was derived from daily data collected at the facility between 2008 and 2011.

Table 4 presents performance data for each of the system's five operating seasons.

Figure 3 presents daily COD loading data for a typical season.

Figure 4 presents typical daily COD effluent concentrations from the AFBR reactor units. COD effluent concentrations are further reduced in the plant's dissolved air flotation solids removal unit.

Cost Assessment for the CAK AFBR Treatment System

See Table 5 for treatment system costs.

Conclusions on Performance of CAK AFBR System

Influent Deicer Concentrations

Influent deicer concentrations are not a parameter used to demonstrate performance of the CAK AFBR, but they are useful in interpreting other performance parameters and in establishing

Table 3. Actual system performance.

Parameter	Value	Unit
Flow rates		Gallons per minute
- Minimum	2.8	
- Average	5.9	
- Maximum	10.2	
Actual COD treatment load rate		lbs/day
- Average	3,715	
- Maximum	4,381	
Actual BOD_5 treatment load rate		lbs/day
- Average	2,185*	
- Maximum	2,580*	
Actual PG treatment load rate		lbs/day
- Average	2,185**	
- Maximum	2,580**	
Influent COD concentration		mg/L
- Minimum	34,065	
- Average	62,016	
- Maximum	85,775	
Influent BOD_5 concentration		mg/L
- Minimum	20,040	
- Average	36,480	
- Maximum	50,455	
Influent PG concentration		mg/L
- Minimum	20,040	
- Average	36,480	
- Maximum	50,455	
Effluent COD concentration		mg/L
- Minimum	36	
- Average	94	
- Maximum	280	
Effluent BOD_5 concentration	TBD	mg/L
Effluent PG concentration	Not detected	mg/L
Treatment efficiency	99.54%	% influent COD load treated

The following data was excluded from the data set used to assess performance documented in Table 3.

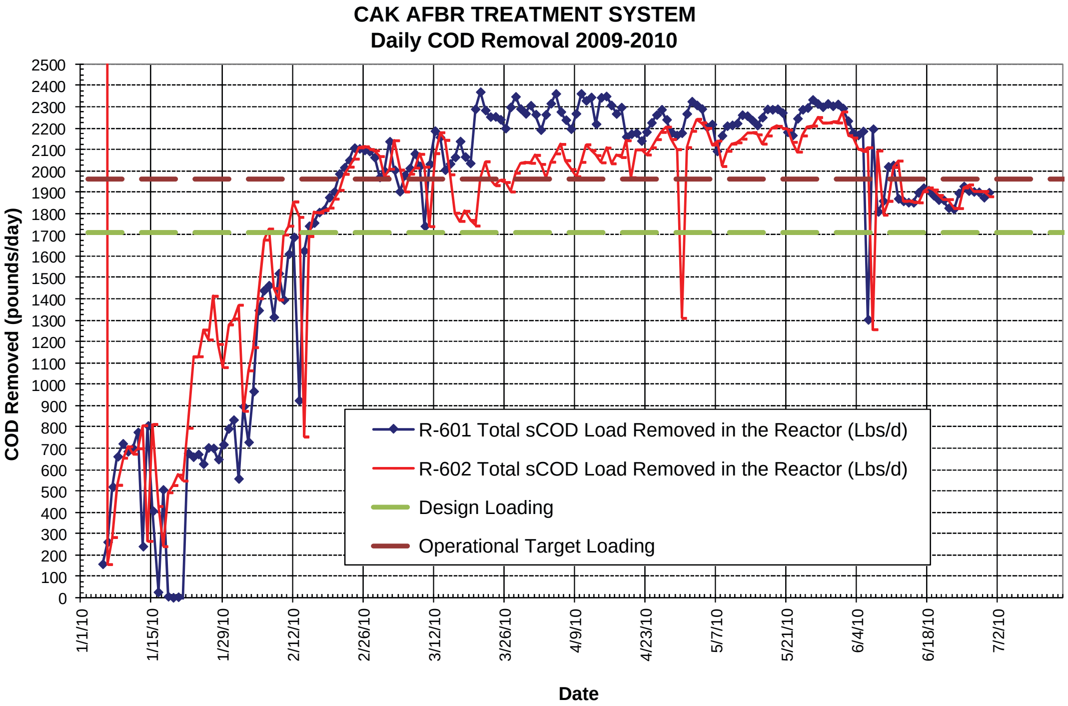
a. 2007–2008 season: data between system commissioning and introduction of suitable bioseed on 12/4/07; start-up period (12/4/07–1/11/08); data after 2/11/08 when phosphorus addition was stopped, resulting in reduced performance.
b. 2008–2009 season: period prior to 12/1/08 when phosphorus addition resumed; start-up period.
c. 2009–2010, 2010–2011 seasons: start-up periods.
d. 2011–2012 season: No data used as all deicer was used up in start-up period.

*Data based on conversion: [COD] = 1.7 [BOD_5].

**Data based on conversion: [PG] = [BOD_5].

Table 4. CAK season-by-season performance assessment.

Year	Unit 2	007–2008 (Start-up Season)	2008–2009	2009–2010	2010–2011	2011–2012
TREATMENT TIME						
Full season						
Treatment system start-up date		12/4/2007	12/1/2008	1/23/2010	1/11/2011	1/11/2012
Treatment system end date		7/24/2008	7/17/2009	6/30/2010	5/17/2011	2/17/2012
Treatment days – season	Days	233	228	158	126	37
Start-up period						
Start-up end date		1/11/2008	2/7/2009	2/14/2010	2/15/2011	2/17/2012
Treatment days – start-up	Days	38	68	22	35	37
Period for performance assessment						
Start date		12/24/2007	2/7/2009	2/14/2010	2/15/2011	1/11/2012
End date		2/11/2008	7/17/2009	6/30/2010	5/17/2011	2/17/2012
Treatment days – performance assessment	Days	49	160	136	91	37
Hydraulic retention time average	Days	3.7	7.3	5.0	5.6	8.2
TOTAL SYSTEM PERFORMANCE						
Flow rate maximum	gpm	14.7	7.1	10.7	8.3	9.6
Flow rate average	gpm	8.4	3.9	5.9	5.4	4.4
Flow rate minimum	gpm	4.6	0.9	2.8	3.1	1.4
Influent COD load maximum	lbs/day	4,727	4,156	4,597	4044	3236
Influent COD load average	lbs/day	3,390	3,654	4,151	3665	1648
Effluent COD load maximum	lbs/day	146	32	46	65	21
Effluent COD load average	lbs/day	34	8	10	14	3
Influent COD concentration maximum	mg/L	55,900	105,100	97,600	84,500	53,340
Influent COD concentration average	mg/L	39,195	84,129	64,382	60,359	33,783
Influent COD concentration minimum	mg/L	25,350	45,290	29,500	36,120	18,540
Reactor effluent COD concentration average	mg/L	288	162	141	231	62
Clarifier effluent COD concentration maximum	mg/L	475	105	190	351	28
Clarifier effluent COD concentration average	mg/L	176	41	37	128	5
Load removed	%	98.99%	99.77%	99.76%	99.62%	99.78%



Note: sCOD = soluble COD.

Figure 3. ***Typical season daily loading curve.***

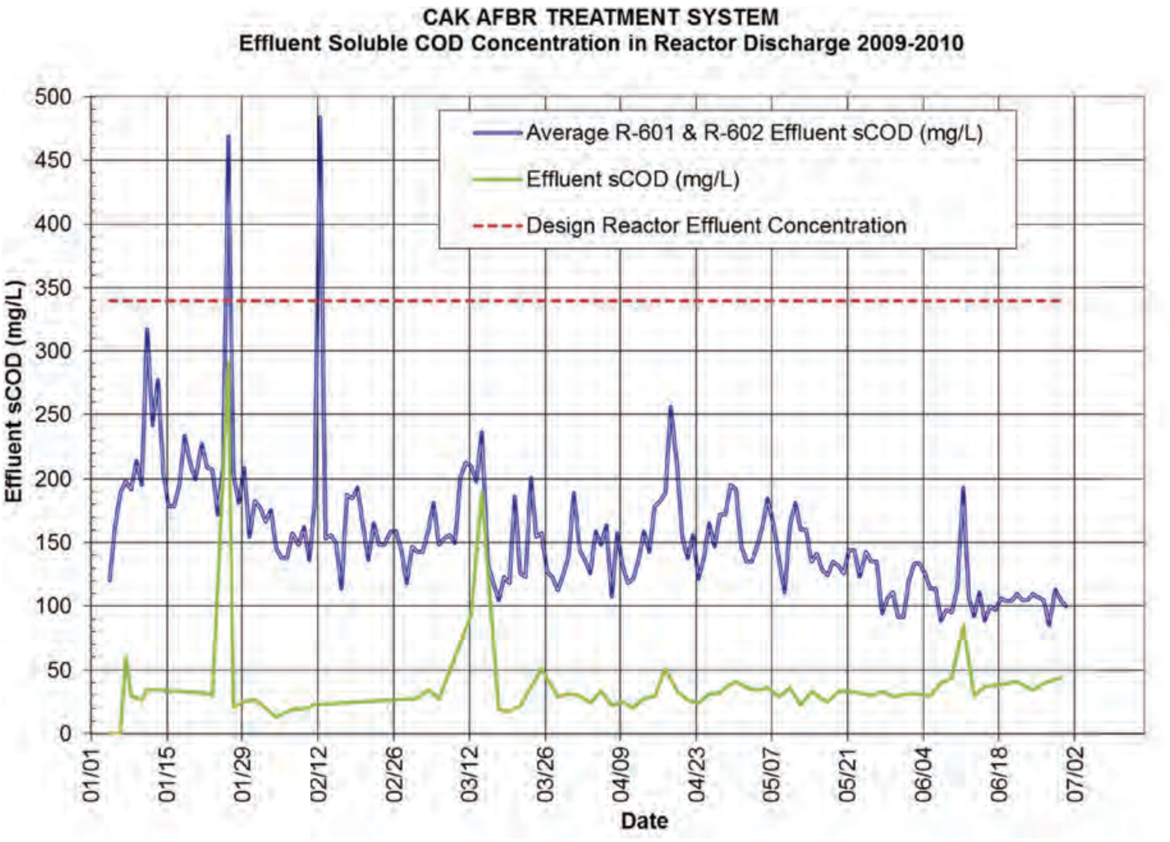


Figure 4. ***Typical season system effluent concentrations.***

Table 5. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost*	$3.2M in 2007	$3.2M $0.3M added in upgrades to solids and chemical handling since start-up from 2008 to 2011
Annual operating cost**		
- Utilities	$30,000	$35,000
- Chemicals	$38,000	$4,500
- Analysis	$2,000	$5,400
- Material handling	$9,000	$11,000
Total operating cost	$75,000	**$55,900**

Notes: Source of capital cost data: design (Engineering Report 2006), actual (airport cost records). Costs are for the treatment system and the building in which it is housed. Excluded are costs for deicing pads, storage tanks, and conveyance piping/structures external to treatment system. Source of operating cost data: design (Engineering Report 2006), actual (operating logs for quantities, vendor prices for material,utility records). Costs exclude the costs of the two system operators.
*Capital costs are for the treatment system only, including the building and basic building infrastructure. Costs do not include site-specific costs for collection, storage, and discharge.
**Operating costs do not include labor costs, but equate to approximately two full-time operators. Maintenance costs, which vary, are not included.

the potential range of treatment capabilities. Soluble influent PG and COD concentrations, as dictated by deicing activity and runoff volumes from the deicing pad, have been higher than projected primarily due to less rainfall in winter than anticipated. Average influent soluble COD concentrations have been 62,000 mg/L, and concentrations have been as high as 106,000 mg/L, compared to the 19,000 mg/L projected during conceptual design. Since the system is operated as a constant COD load system, there are no effects from the higher concentrations on treatment, other than the flow rate adjustments described in the following. There is some evidence that treatment removal efficiency (percentage of incoming COD load removed) is actually better at higher concentrations, possibly due to longer residence times. The operators simply reduce flow rates as influent concentrations rise to keep the constant COD loading that is desired.

Flow Rate

As with influent deicer concentrations, the treated flow rate is not a parameter used to demonstrate performance of the CAK AFBR, but it is useful in interpreting other performance parameters and in establishing the potential range of treatment capabilities. It was anticipated that flow rates would average 20 gpm through the treatment plant. In practice, the flow rates have averaged 5.9 gpm and have been consistently below 10 gpm. The lower-than-anticipated flow rates are a direct response to higher concentrations of COD from the deicing pad runoff and the operational goal of maintaining constant COD loading. System programming and set points were adjusted after the first year of operation to allow sufficient flow control at lower flow rates. The lower flow rates processed by the system have not had any negative effects on the ability to drain the storage tanks well before the next deicing season (The latest date for completion of treatment and emptying of tanks has been mid-July.)

Treated Load Rate

The rate at which soluble COD is removed from the system (treated load rate) is a key measure of performance of the AFBR system. Soluble COD is used to manage flow rate as opposed to total COD (soluble COD plus insoluble solids-based COD) because (a) the influent has very little COD from solids as primary deicer constituents are in a dissolved state in runoff, and (b) considering the COD from biological solids in the effluent does not provide a true indicator of treatment efficiency. COD from biological solids is managed through solids removal in the system's clarification unit. The soluble COD loading rate is the primary means by which the system is controlled and provides a good comparison of whether the treatment system meets its design expectations. The CAK AFBR system has been able to treat at a higher throughput than envisioned during design. In the 5 years of operation (not including yearly start-up periods), it has averaged 3,715-lbs soluble COD per day removed through treatment, which is higher than the 3,400-lbs COD/day design target. Operators have been typically running at approximately 18% above design capacity at 4,000-lbs COD/day during normal operational periods and have pushed system capacity as high as 4,440-lbs COD/day on occasion. At 4,440-lbs COD/day, the gas production from bacteria in the reactors begins to produce some instabilities in the biomass sludge layer in the reactor, so this loading (which is 30% higher than the design maximum loading) is viewed as the true system capacity. Based on these data, it can be concluded that the CAK AFBR system performed better than expected from a treated load capacity standpoint.

Effluent Concentrations

The effluent concentration of primary deicer constituents is another key performance indicator for the AFBR system. The CAK AFBR was designed primarily to reduce PG concentrations to meet the PG limits in the CAK NPDES permit. All PG measurements taken in the plant effluent have been below detection limits. Low or nonexistent PG concentrations were expected since PG degrades quickly and easily to other organic chemicals during biological treatment. The operators use soluble COD as the primary means of monitoring and controlling the plant. The next iteration of the NPDES permit will contain COD limits as well. Soluble COD concentrations in the effluent are obtained by measuring the COD of the filtrate from the TSS method. The anticipated average soluble COD effluent concentration from the AFBR facility at design was 340 mg/L. The average soluble COD concentration in practice for the plant as a whole has been 94 mg/L.

The vast majority of the soluble COD is removed in the treatment reactors. These units have averaged approximately 180-mg/L soluble COD in their effluent. The average soluble COD concentration is further reduced to 94 mg/L, on average over a 4-year period, as the treated water passes through a dissolved air flotation unit designed to remove suspended biological solids. In three of the five operating seasons, the total system soluble COD has averaged less than 40 mg/L for the entire season. The recent addition of the dissolved air flotation unit for removal of solids indicated that soluble effluent CODs averaged 5 mg/L in the unit effluent.

The operators have only taken occasional BOD_5 concentration measurements. A series of weekly effluent BOD_5 analyses were performed on the treated effluent in the 2011–2012 seasons as part of this study.

Both effluent COD concentrations (design 340 mg/L versus actual 180 mg/L in reactor effluent and 94 mg/L average in system effluent) and effluent PG concentrations (design <35 mg/L versus actual below detection limits) have been lower than anticipated at design, indicating that the CAK AFBR has outperformed its design conditions for effluent quality.

Treatment Efficiencies

The third key indicator of performance for AFBR systems is the percentage of the influent soluble COD load that is removed through treatment (i.e., treatment efficiency). The removal efficiency for COD has been higher than expected at 99.54% for the five operational seasons between 2008 and 2012, compared to the anticipated 98%.

Cost

Cost is another key indicator of performance. Capital costs following construction were within $0.1 million (3%) of the design cost estimates. Approximately $0.3 million in additional capital has been expended since start-up to upgrade the biological solids removal system, isolate the air compressor from the main building for noise control purposes, modify the sampling system, and provide better heat management in the building.

Average annual operating costs are approximately $55,900, including utilities, chemicals, analyses, and solids management. Overall operating costs have been approximately 30% ($20,000) lower than what was projected at design. Costs for labor were intentionally excluded from the cost calculation by the researchers because the means by which different airports account for labor costs vary. The CAK system uses two full-time operators. Maintenance costs are also not included in the annual operating cost calculation because (1) there were difficulties in obtaining consistent and all-inclusive maintenance operation from all airports, and (2) maintenance costs vary considerably by year and are influenced by the age of the system. Most maintenance activities at CAK are performed by system operators as part of their duties. The highest maintenance costs to date were in the first year following operation, when adjustments were made to the system.

Utility costs, primarily power, have been near what was projected at design. Chemical use costs have been lower than projected due to less caustic demand. The reduced caustic demand is related to higher treatment efficiency and consequent lower concentrations of breakdown products in the effluent. Lower concentrations of effluent breakdown products equates to less acid in the effluent, which reduces the caustic demand. The operators also found that purchasing chemicals in the summer months is less expensive; therefore, they get full seasonal loads of chemicals at that time of year. Biosolids generation rates and costs were approximately 25% higher than expected at design, resulting in higher costs than expected for solids disposal.

A cost model was developed in Task 5 of this research to relate required AFBR technology COD loading (lbs/day) to cost. Considerations from analysis of CAK cost data application to the model include:

- Actual treatment capacity/reactor volume compared to nominal design capacity,
- Effect of treatment efficiency on caustic demand,
- Chemical use data per pound of COD treated, which may vary with the concentration of influent soluble COD,
- Electrical costs per cubic foot of reactor, and
- Sludge and biogas generation rates per pound of COD treated.

Lessons Learned for Potential Implementation of the AFBR Technology at Other Airports

The following factors have proven critical to effective and efficient performance in the CAK AFBR:

1. Ability to adequately control flow and therefore COD loading rates.
2. Consistent nutrient loadings and understanding of differences in nutrient uptake at start-up versus standard operation.
3. Understanding which forms of phosphorus are and are not available to the anaerobic bacteria.
4. Adequate control of the reactor temperature.
5. Adequate control of the reactor pH.
6. Management of sludge bed levels in reactors.
7. Management of biological solids wasted from the reactors using dissolved air flotation, rather than reliance on gravity settling.

CAK experienced firsthand the importance of nutrient addition in keeping the biomass healthy and the treatment effectiveness high during the first year's start-up. During that period, phosphorus was left out of the nutrient mix for several months because it was found in the influent samples at sufficient concentrations. It was ultimately determined, however, that the phosphorous in the influent was not bio-available. The lack of bio-available phosphorus limited biomass growth and temporarily reduced the treatment capacity to approximately 25% of design capacity. Once phosphorus was added to the nutrient solutions, treatment rates reached 100% of design capacity and beyond within a matter of days.

Because the runoff entering the treatment system is heated with biogas generated from the biological reaction, the temperature of the influent runoff has had no effect on treatment performance. The pH is also controlled to near neutral for an optimized environment for the bacteria. Varying influent COD concentrations do not affect treatment because the mass loading of the COD into the reactor is controlled, which leads to a stable bacterial population.

The CAK AFBR has demonstrated the ability to treat non-PG constituents, including pavement deicer constituents (acetates, formates) and PG breakdown products (acetate, propionic acid, acetic acid). PG breakdown products were found in the storage tanks at CAK during the start-up season when the collected deicer had to be stored in the storage tanks while the treatment plant's construction was completed. Initially, it was thought the AFBR system had significant difficulty in treating those breakdown products; however, it was later determined that the lower treatment rates experienced during portions of the first year were due to the lack of bio-available phosphorus, as noted previously. If PG breakdown products or pavement deicer constituents form a majority of the COD in the runoff to be treated, however, the biology in the system may not be completely acclimated to that mix. Therefore, system operators are advised to more carefully monitor system effluent for volatile fatty acid concentrations and more closely control system influent loading. This is because the various types of bacteria in the reactors grow in proportion to the rate at which the PG is degraded when it is fed as the primary food source. If an intermediate compound, say propionic acid or acetic acid, is fed in significant concentration, the feed must be temporarily reduced so that the biological population can adjust its level to degrade the additional load.

Conclusions from operation of the AFBR at CAK that can be used by other airports considering this technology include:

1. The AFBR technology is excellent for isolating treatment from the effects of the weather and cold water temperatures.
2. The AFBR technology is excellent for achieving propylene glycol and BOD_5 concentrations that are near or below detection limits. Some COD remains, indicating that there are some organics that are not readily biodegradable. COD in the effluent can be minimized through biosolids removal from the effluent.
3. The system performs very consistently and predictably once a constant COD influent loading is achieved each year.
4. At initial start-up of the system after construction, acquisition of the appropriate type of healthy bioseed is critical. The bioseed must be obtained from a similar type of anaerobic operation. CAK has not had to obtain outside bioseed after the first year start-up. Enough anaerobic bacteria survive the 6- to 8-month shutdown period to start up the system each season.
5. At each year's plant start-up, 1 to 2 weeks are needed to restart the equipment, flush out dead biomass, and get system operational settings to desired levels before increases in COD loading rates can be made.
6. Based on historical data, the system has approximately 25% of its design capacity at the initial seasonal start-up. Approximately 40 days of continuous ramping up of COD loading are needed to get to design operational loadings. During that start-up time, treatment efficiencies remain over 99%, and effluent concentrations are sufficiently low to discharge.
7. Providing sufficient nutrient balance is critical.
8. Sufficient ability to control flow rates is important, especially if influent concentrations are high, resulting in lower flow rates.

9. If treating high concentrations, such as is the case with flows from deicing pads, consider the potential impacts of the lower flow rates that are needed to maintain a consistent COD loading, including effects on storage, effects on solids removal, and effects on effluent concentrations.
10. Due consideration of the means of removing and dewatering anaerobic biosolids from the AFBR is critical in design as that sludge has its own unique characteristics. Use of dissolved air flotation for biosolids removal from the treated effluent stream has proved the most successful method for CAK.

Documents and Information Review in Development of Airport Summary

1. CAK. Construction drawings (Plans and Specs, March 2006).
2. CAK. Operational and performance records. 2012.
3. Dvirka and Bartilucci. *Anaerobic Fluidized Bed Design Basis Report for Akron-Canton Regional Airport.* November 2005.
4. Facility Site Visit. 2012.
5. Gresham, Smith and Partners, Dvirka and Bartilucci. *Summary of Akron-Canton Airport Deicer Management System.* May 2006.
6. Gresham, Smith and Partners. *Conceptual Engineering and Analysis of On-Site Treatment Technologies.* May 2005.
7. McQueen, Rick. Akron-Canton Airport Deicer Management System Costs. 2007. E-mail.

Airport Treatment Summary No. 5

Airport: Westover Air Reserve Base—Chicopee, MA (CEF)

Treatment Technology: Passive Facultative Treatment (Subsurface Flow Wetland)

Years Operated: 2001–2012 (Currently Operational)

Deicer Management System Description

Winter stormwater is collected at Westover Air Reserve Base (CEF) in storm drains adjacent to the deicing areas. The stormwater is directed through a constructed subsurface wetland system for treatment prior to discharge to Cooley Brook south of the base. The subsurface wetland is planted with reeds and is considered a passive facultative treatment technology. The reeds planted in the wetland system are fully grown. The CEF wetland system is currently in operation. There is, however, no ongoing monitoring program of water quality or quantity. Figure 1 shows an aerial photograph of the wetland.

Deicer Treatment Technology Selection Considerations

The constructed subsurface wetland system was installed to demonstrate the efficacy of the technology with respect to treatment of stormwater from deicing activity. A principal consideration

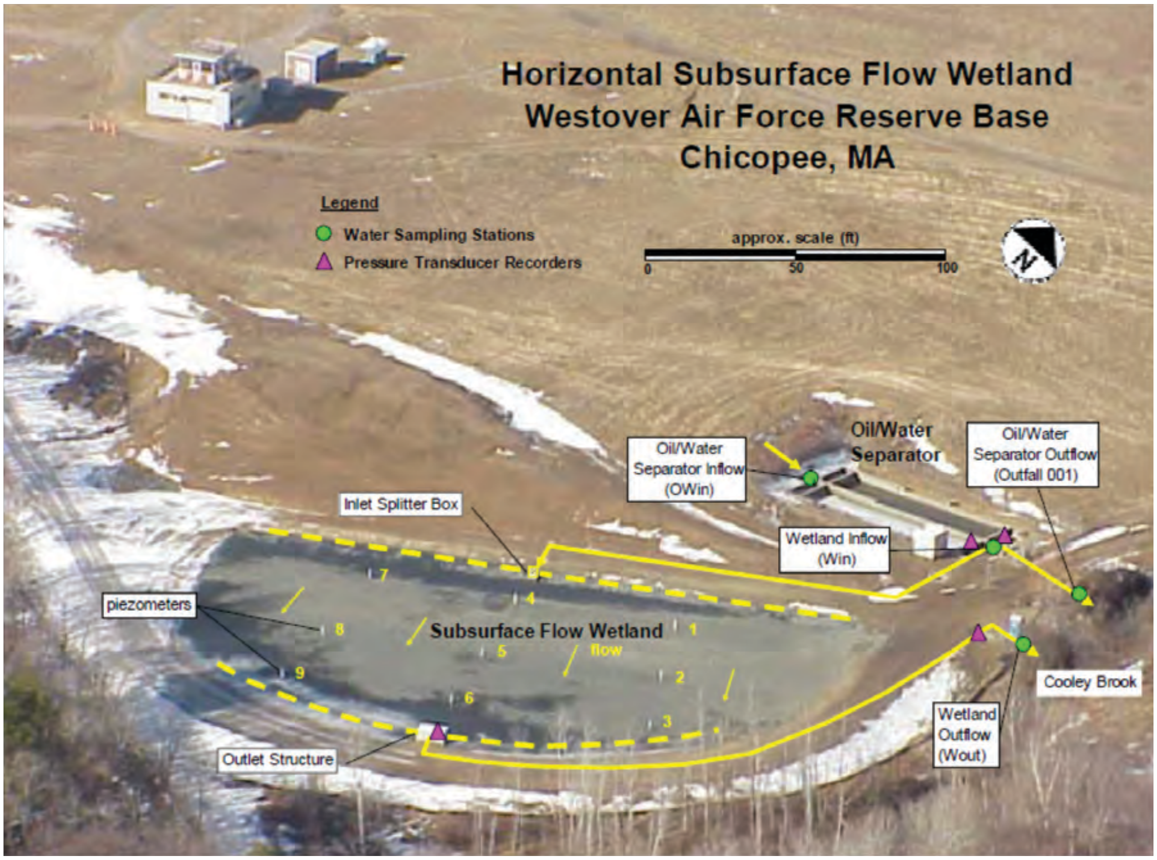


Figure 1. Aerial photograph of the horizontal subsurface flow wetland at the Westover Air Reserve Base, Chicopee, Massachusetts, from NAVFAC Technical Report TR-2251-ENV.

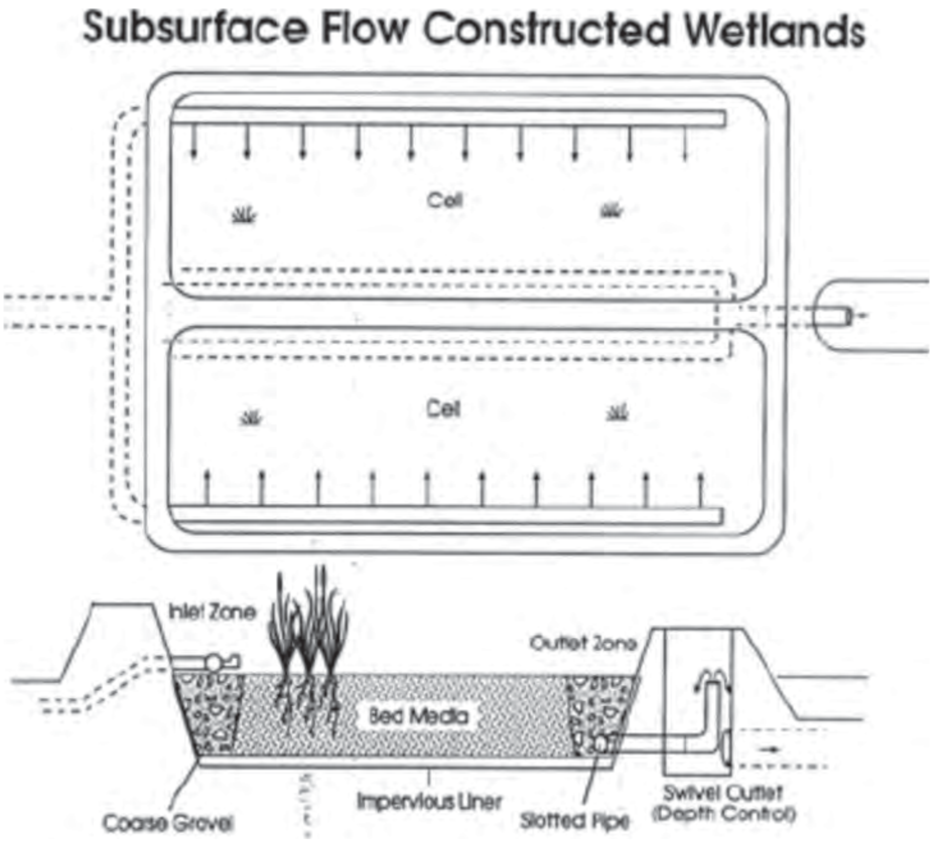


Figure 2. Plan and profile views of constructed subsurface wetland from NAVFAC Technical Report TR-2251-ENV.

for selecting a subsurface flow wetland (SSFW) system was limitation of free water surfaces to minimize attraction of birds and the potential threat to aircraft safety. A passive treatment technology was also desired—that is, one without pumps or other mechanical equipment.

Deicer Treatment Technology Description

Constructed Subsurface Flow Wetland

See the passive facultative treatment systems fact sheet (Fact Sheet 108). Figure 2 shows plan and profile views of the SSFW.

Description of Support Systems

The SSFW at CEF requires oil/water separation, uniform distribution on the front of the system, an aggregate bed, and collection drains on the downstream side. Water elevation is controlled to partially submerge the gravel. Stormwater is diverted to the constructed treatment wetland after the oil/water separator adjacent to the outfall. The influent enters a splitter structure that supplies two perforated inlet pipes on the front of the bed. The uniform distribution of stormwater is used to maintain equal distribution of the load through the entire SSFW system. The gravel bed serves as a medium for promoting anaerobic attached growth. The gravel layer is approximately 2-ft thick. The gravel bed is planted with reeds (phragmites) to assist in promoting growth of an attached biological treatment and as a means of exchanging nitrogen and phosphorous from the SSFW. Perforated outlet pipes on the opposite side collect the flow and discharge to the outflow structure.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	Not provided	Not provided	Not provided
Treatment unit volume	120,000 gal	1	120,000 gal
Treatment unit dimensions	0.6-acre x 2-ft deep	1	52,200 ft^3
Treatment facility footprint	0.6 acre total site	1	0.6 acre

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 0 70 280	Gallons per minute
Design treatment load capacity	200* 120 120**	lbs COD/day lbs BOD_5/day lbs PG/day
Design effluent concentration (average)	<30	mg BOD_5/L
Design treatment efficiency (average)	>80%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Key Treatment System Sizing Parameters[1]

See Table 1 for sizing parameters.

Treatment System Performance

The data in Table 2 presents the intended design performance of the system.

The data in Table 3 on actual performance of the treatment system are from the 2002–2003 season. Although the system still operates, performance data have not been collected in recent years. Table 4 shows analytical results, and Table 5 shows a summary of BOD loadings.

Cost Assessment for the CEF SSFW Treatment System

See Table 6 for treatment system costs.

Conclusions on Performance of CEF SSFW System

Influent Deicer Concentrations

Influent deicer concentrations are not a parameter used to demonstrate performance of the CEF SSFW since the system is slug loaded.

Flow Rate

The SSFW has a maximum flow rate that requires some flow to bypass the treatment system during events with high volumes. The flow rate is determined based on the hydraulic loading rate for the SSFW system.

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[1] From NAVFAC Technical Report TR-2251-ENV

Table 3. Actual system performance.

Parameter	Value	Unit
Flow rates		Gallons per minute
- Minimum	0	
- Average	118	
- Maximum	354	
Actual COD treatment load rate		
- Maximum	1,550	lbs/day
Actual BOD_5 treatment load rate		
- Maximum	910	lbs/day
Actual PG treatment load rate		lbs/day
- Average	2,185**	
- Maximum	2,580**	
Influent COD concentration		mg/L
- Minimum	100	
- Average	1,335	
- Maximum	23,100	
Influent BOD_5 concentration		mg/L
- Minimum	16	
- Average	2,226	
- Maximum	12,900	
Influent PG concentration		mg/L
- Minimum	16**	
- Average	2,226**	
- Maximum	12,900**	
Effluent BOD_5 concentration		mg/L
- Minimum	51	
- Average	2,094	
- Maximum	12,900	
Treatment efficiency	10~80%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 4. Summary of analytical results from the Westover subsurface flow constructed wetland, 2002–2003 deicing season.

Parameter	Units	Statistic	Wetland Inflow	Wetland Outflow
BOD	mg/L	Average	2,226	2,094
		Max	12,100	12,900
		Min	16.2	50.8
COD	mg/L	Average	1,883	1,335
		Max	37,900	23,100
		Min	3	100
MeBT	mg/L	Average	0.68	0.72
		Max	20.93	4.77
		Min	0.02	0.02
DO	%	Average	52.20	47.70
		Max	103.90	69.80
		Min	8.8	8.8
pH	SU	Average	7.58	9.54
		Max	8.95	13.92
		Min	5.61	6.54
Redox	mV	Average	391.00	172.00
		Max	596.00	518.00
		Min	235	-272
Temp	C	Average	17.30	18.90
		Max	26.80	32.70
		Min	10.8	12.1
Turbidity	NTU	Average	5.22	4.61
		Max	10.70	7.06
		Min	0.88	1.16

Table 5. Summary of BOD loadings from the Westover subsurface flow constructed wetland, 2002–2003 deicing season.

Parameter	Unit	Dec. 2002	Feb. 2003	Mar. 2003	Apr. 2003
SSFW inflow	(kg/d)	---	414	109	334
SSFW outflow	(kg/d)	---	360	113	264
SSFW removed	(kg/d)	---	54	-3	69
SSFW removed	(%)	---	13	-3	20.8
Bypass		---	26	130	122
Combined Outfall 001	(kg/d)	---	386	243	386

Treated Load Rate

The SSFW treatment system is not supported by a storage system. Therefore, the treatment load rates are slug loaded when a deicing event occurs. As a result, loading of the system was in excess of design due to the unrestricted flow, slug concentrations, and relatively small footprint. The observed treatment load rates were as low as baseline conditions and as high as 910-lbs BOD_5/day.

Effluent Concentrations

Effluent concentrations from the SSFW were highly variable and, therefore, demonstrate that the current treatment system at CEF does not produce consistent concentration reductions.

Treatment Efficiencies

Like effluent concentrations, the treatment efficiencies from the SSFW at CEF are inconsistent. Although treatment efficiencies as high as 80% were achieved, generally the removal of organics as measured by BOD were low and erratic. The range of treatment efficiencies indicates that the SSFW at CEF is not a viable treatment technology for application at other airports.

Cost

The SSFW has an attractively low capital cost of approximately $350,000/acre (2002 dollars). Additionally, the annual operating costs are negligible. However, when evaluating the cost per pound of COD removed, or cost per effluent limit exceedance, the SSFW treatment system quickly becomes an unattractive economic investment.

Lessons Learned for Potential Implementation of the SSFW Technology at Other Airports

Conclusions from operation of the SSFW at CEF that can be used by other airports considering this technology include:

1. Although some treatment removals were achieved, the demonstrated removals of less than 20% are far too low for practical and successful application.

Table 6. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost*	$286,000 in 2002	$326,000
Annual operating cost		
- Utilities	Not provided	$900
- Analysis	Not provided	$7,000
Total operating cost	**Not provided**	**$7,900**

*Capital costs are for the treatment system only, including the building and basic building infrastructure. Costs do not include site-specific costs for collection, storage, and discharge.

2. Treatment effectiveness might be improved by use of equalization up front to reduce slug loads.
3. No theoretical or empirical model provides guidance on the sizing criteria required to consistently achieve target effluent values.
4. The results corroborate results from the Wilmington Air Park passive subsurface treatment system pilot study performed from 1997 to 1999.

Although the passive treatment technology is attractive since the management and cost of this system would be minimal, the SSFW at CEF indicates that passive systems are not credible means of treating deicer-affected stormwater.

Documents and Information Review in Development of Airport Summary

1. Naval Facilities Engineering Command (NAVFAC). *Cost and Performance Report Enhanced Biological Attenuation of Aircraft Deicing Fluid Runoff Using Constructed Wetlands,* April 2005.
2. Jack Moriarty, Environmental Engineer of Westover Air Reserve Base. Personal Interview. February 1, 2012.
3. U.S. EPA. Federal Remediation Technologies Roundtable. Technology Cost and Performance Report Summary: Enhanced Biological Attenuation of Aircraft Deicing Fluid Runoff using Subsurface Flow Constructed Wetlands at the Westover Air Reserve Base, Chicopee, Massachusetts. 2005.

Airport Treatment Summary No. 6

Airport:	Cincinnati/Northern Kentucky International Airport—Kenton County, KY (CVG)
Treatment Technologies:	Activated Sludge, Mechanical Vapor Recompression
Years Operated:	2003–2012 (Currently Operational)

Deicer Management System Description

The Kenton County Airport Board (KCAB), operators of CVG, began to address deicer management issues in the early 1990s. At that time, local regulators made the airport aware of elevated BOD_5 concentrations in the airport's receiving streams. The regulator developed a TMDL for the receiving stream and subsequently incorporated effluent limitations in the airport's NPDES permit. Implementation of a deicer management system was initiated with the construction of deicing pads in the 1990s, which are still in use. Subsequent deicer management elements included construction of pump stations near the airport outfalls to collect stormwater from much of the airfield, storage tanks, mechanical vapor recompression for treatment of higher-concentration runoff from the deicing pads, a sequencing batch reactor system, an extended aeration activated sludge treatment system, and aeration of stormwater storage basins just upstream of the airport discharges to the surface waters. Currently, CVG operates the deicing management system so that concentrations of glycol of >1% are sent to the glycol processing recycling facility (GPRF), and concentrations of glycol of <1% are sent to the stormwater treatment plant (SWTP). The GPRF uses MVR treatment to concentrate spent aircraft deicing fluid. The SWTP uses biological activated sludge and support systems to remove glycol from the deicing-affected stormwater. The pump stations at the airport outfalls are designed to collect a maximum of 5.8 million gallons per day. Figure 1 shows a process flow diagram of the system, and Figure 2 shows an aerial view of the system.

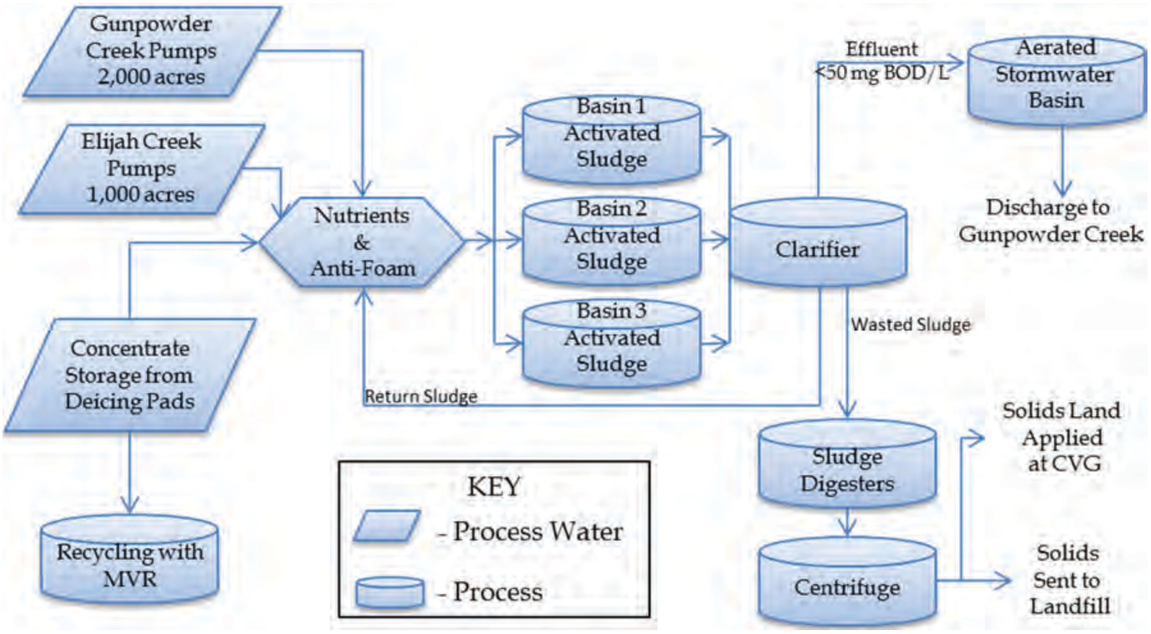

Figure 1. CVG deicing-affected stormwater management system process flow diagram.

Figure 2. Aerial photo of CVG activated sludge treatment system (Photo courtesy of KCAB).

Deicer Treatment Technology Selection Considerations

Deicer management at CVG has evolved over time to meet changing permit requirements, deicer use changes, and performance needs. The initial implementation consisted of deicing pads, storage, and subsequent recycling using mechanical vapor recompression, plus discharge of runoff from other areas of the airport to the local POTW. Deicer concentrations routed to the mechanical vapor recompression recycling system average approximately 6% propylene glycol concentration. The recycling system continues to operate today.

After the initial implementation of deicing pads and the recycling operation, aerators were installed in large ponds upstream of the receiving streams. The ponds had been designed primarily to manage the quantity and timing of stormwater discharges, and the aeration function was added after initial pond construction. The objective of adding aerators was to polish the water to reduce BOD_5 concentrations prior to discharge to the receiving streams. However, because of multiple influent sources and variable flow volumes entering the aerated basins, it has been difficult to characterize what effect the aeration is actually having on BOD_5 concentrations.

As the airport operations and deicer use changed over time, the local POTW began having issues with the BOD_5 load from airport deicers swamping the POTW's treatment capacity. This led KCAB to seek methods for on-site treatment of the deicer-affected flows from large portions of the airport rather than relying on a discharge to the POTW. One of the principal challenges that KCAB faced was the large drainage area that needed to be collected from to meet regulatory requirements, at least partially driven by concerns with biological nuisance growth in the streams. Collection of the stormwater necessitated installation of pump stations first for the discharges to Gunpowder Creek and later for the discharges to Elijah Creek. Finding appropriate and effective means to treat high flow volumes with highly variable BOD_5 concentrations is one of the more significant deicer management challenges that an airport can face. Several years of study were performed prior to selection and design of the initial biological treatment system.

The first phase of on-site treatment at the airport included installation of SBR-based aerobic biological treatment. The SBR technology is a variation on the activated sludge technology where the treatment is provided by aerobic bacteria suspended in a reactor. SBRs are operated in a fill-and-draw batch mode. Testing of the SBR technology was performed by KCAB and led to the design of a full-scale system with three SBR reactors. The SBRs were sized based on two key assumptions: (1) the deicer applied on aircraft was ethylene glycol based, and (2) only the collected flow from the Gunpowder Creek drainage areas would be treated. During the construction and initial operation of the SBR systems, the airlines switched to propylene-glycol–based deicers, and the Elijah Creek drainage area runoff was added to the volume that needed to be treated. Both of these changes led to a lack of capacity with the SBR units, and it was clear additional treatment capacity would be needed.

The second phase of biological treatment implementation at CVG led to installation of a treatment system based on extended aeration activated sludge treatment technology. The new system had a greater BOD_5 treatment capacity (30,000 lbs/day) and was designed as the principal means for degrading the deicer-affected stormwater. As part of the implementation of this system upgrade, the SBR units were converted into two sludge digesters and a sludge storage tank for the activated sludge system's effluent solids. The airport has progressively been improving the efficiency and effectiveness of the activated sludge treatment system, focusing in particular on ways to manage the high and variable volumes of deicer-affected runoff from the airport.

Deicer Treatment Technology Description

Activated Sludge Biological Treatment System

Fact Sheet 101 contains a general description of the activated sludge technology. This airport's particular activated sludge system is designed to promote an extended detention time for the deicer in the treatment system to help manage the variability in deicer loadings and create a more stable bacterial population than conventional activated sludge technology. The system is aerated using mechanical blowers supplying air through fine-bubble diffusers suspended from floating aeration chains in three aeration basins (see Figure 3). Air delivery to the basin can be

Figure 3. The airport's activated sludge treatment system aeration basins (Photo courtesy of KCAB).

reduced during periods of low loading while still maintaining the contact between the deicer and reducing the risk of solids settling out of the water. A clarifier for removal of solids is integral to the aerated basin unit. The CVG system is designed to treat a maximum of 30,000-lbs BOD/day over an extended period, although over short periods of less than 1 to 2 days, it can treat up to 45,000 lbs/day.

Mechanical Vapor Recompression

The concentrated deicer collected from the deicing pads at the airport is processed in mechanical vapor recompression units housed at the airport for the purpose of creating recycled propylene glycol. See Fact Sheet 106 for a description of this technology.

Description of Support Systems

CVG's deicer management system has 10 pump stations for collecting runoff from the airfield. The pump stations are designed to collect all flows up to the maximum capacity of the pumps, sending those flows to the activated sludge treatment system. Higher-concentrate deicer that is collected from the deicing pads is routed to three aboveground storage tanks totaling 8 million gallons in capacity. The deicer in the storage tanks can be routed to the MVR system or can be bled into the activated sludge treatment system to help sustain the biomass.

Chemical nutrients are added to the aeration basins in the activated sludge system to promote healthy growth of the microorganisms living in the activated sludge aeration basins. Adding sufficient nutrients is a key element of maintaining an effective biomass in the aeration basins and getting good treatment.

Blowers are used to supply air to the three aeration basins. The aeration of the three basins is independently controlled, and CVG may not always operate all of the basins.

The extended aeration activated sludge process produces biological solids. A portion of these are routed back into the aeration basin to help maintain a high level of mixed liquor suspended solids in the aeration basins. The remaining solids are wasted from the treatment system.

A clarifier integral to the aeration basin is used to settle biological solids contained in the treated effluent.

Management of the wasted sludge and the solids removed in the clarifier is a significant component of management of the treatment system. CVG has an advanced system for the dewatering and disposal of the biological solids. The dewatered solids are blended with soil and land applied on the airport property to save disposal costs.

Key System Sizing Parameters

Parameters that quantify the size and capacity of the key components of the airport's deicer management system related to treatment are provided in Tables 1 and 2.

Table 1. Key system sizing parameters.

Component/Parameter	Number of Units	Total Capacity
Activated sludge treatment unit volume	3	14 million gallons
Activated sludge aeration basin footprint	3	11 acres
Tanks for spent aircraft deicing fluid	2	6 million gallons
Mechanical vapor recompression system building footprint		3 acres

Table 2. Additional system sizing parameters.

Parameter	Value	Unit
Air delivery rate ranges - Activated sludge aeration basin 1 - Activate sludge aeration basins 2 and 3	 1,600–2,950 2,900–5,300	scfm
Total storage (three tanks)	8.0	Million gallons

Note: scfm = standard cubic feet per minute.

Table 3. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Average - Maximum	 3,470 5,200	Gallons per minute
Design treatment load capacity	61,200* 36,000 36,000**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	1220* 719.5 719.5**	mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	50 30	mg BOD_5/L mg TSS/L
Design treatment efficiency (average)	93%	% influent COD load treated

Design data courtesy of Parkson.
*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Treatment System Performance[2]

The data in Table 3 on the intended design performance of the activated sludge system were derived from airport records and publicly available presentations.

The information in Table 4 and Table 5 on actual system performance was derived from daily data collected at the facility for the 2011–2012 deicing season. The average TSS effluent concentration was 2 mg/L.

Cost Assessment for CVG's Activated Sludge Treatment System

Table 6 shows treatment system costs, and Table 7 shows improvement costs.

Conclusions on Performance of Airport's Activated Sludge System

Influent Deicer Concentrations

Concentrations of influent to the CVG extended aeration activated sludge treatment system average 1,300-mg/L COD, with a peak of 5,600 mg/L. While these are not unusual concentrations for deicer treatment, they are higher than what activated sludge systems experience in their typical municipal sanitary wastewater applications. The variability of concentrations at CVG is relatively significant compared to non-deicer applications. CVG does not have storage for the diluted stormwater collected from the drainage areas. The large potential capacity of the

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[2] Data from outlier periods of operation were excluded from the performance analysis, including data prior to installation of the activated sludge system, 2 weeks of a pump malfunction starting on February 12, 2010, and various periods with maintenance or operational issues. These outlier data represent periods where circumstances outside of the treatment technology operation affected the treatment results.

Table 4. Actual system performance.

Parameter	Value	Unit
Flow rates - Minimum - Average - Maximum	 278 1,950 4,700	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 20,000* 81,000*	lbs/day
Actual BOD_5 treatment load rate - Average - Maximum	 11,800 47,600	lbs/day
Actual PG treatment load rate - Average - Maximum	 11,800** 47,600**	lbs/day
Influent COD concentration - Minimum - Average - Maximum	 28 1,300 5,600	mg/L
Influent BOD_5 concentration - Minimum - Average - Maximum	 16* 760* 3,300*	mg/L
Influent PG concentration - Minimum - Average - Maximum	 16** 760** 3,300**	mg/L
Effluent COD concentration - Minimum - Average - Maximum	 1 16 81	mg/L
Treatment efficiency	98.7%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

aeration basins aids in managing the variable concentrations. Maintaining a constant and healthy biomass in response to variable concentrations can be challenging at times because flows into the treatment are not controlled.

Flow Rate

The activated sludge treatment system at the airport has treated flow rates of as high as 1,950 gpm. The system has the capacity to treat up to 7 mgd (approximately 4,700 gpm). KCAB indicated that there is additional hydraulic capacity available in its system.

Treated Load Rate

The CVG activated sludge technology has significant capacity to receive BOD loads while meeting water quality goals. This type of biological treatment technology is most efficient and effective where influent BOD loads do not vary significantly because a constant BOD load facilitates a less variable biomass population. During low deicing periods, the airport has had to

Table 5. Actual performance of treatment system support systems.

Parameter	Value
Number of collection pump stations	10
Nitrogen addition	130 gallons of urea ammonium nitrate per day (31% urea ammonium nitrate)
Phosphorus addition	22 gallons of phosphoric acid per day (75%)

Table 6. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost	Not provided	**SWTP (2001)** Pilot: $393,425 **SWTP (2005)** Engineering/design: $2,016,184 **SWTP (2007)** Gunpowder Creek: $9,627,798 **SWTP (2008)** Elijah Creek: $16,688,626 **SWTP Total: $28,726,033** **GPRF (2010)** Treatment system: $9,038,217 Capital improvements: $76,302 **GPRF (2011)** Rehabilitation of existing storage tanks: $1,315,978 **GPRF total: $10,561,595**
Annual operating cost*	$0.01/gal treated	$304,000

Source of capital cost data: Spent Aircraft Deicing Fluid Management System Letter Report (April 20, 2012).
*Operating costs based on 2008–2009 deicing season.

Table 7. Costs for improvements to the spent aircraft deicing fluid management system.

Completion	Project Description	Total Cost	Category
Dec 1993	Northwest Environmental Collection System	$1,591,378	C
Sep 2001	SWTP – Pilot Project	393,425	P
Dec 2002	South Detention Basin Closure	3,215,322	S
May 2003	Runway 36R Large Hold Pad and Deicing Recovery System	2,860,726	C
Dec 2003	Southwest Detention Facility – Land and Easements	4,100,151	S
Dec 2003	Southwest Detention Facility – Construction	3,072,641	S
Dec 2003	Deicing System Enhancements: Increase Storage Capacity	7,505,566	S
	South Airfield Glycol Dispensing/Storage Facility	1,447,076	
Oct 2005	SWTP – Instream Engineering/Design	2,016,184	P
Sep 2006	Deice Pad 8 Reconstruction	252,971	C
Jan 2007	SWTP – Gunpowder Creek	9,627,798	P
Jun 2008	SWTP – Elijah Creek	16,688,626	P
Jun 2008	Detention Facilities – Design	402,178	S/P
Jun 2008	Detention Facilities – All Other Costs	3,497,960	S/P
Sep 2008	Runway 17/35 (Future 18R/36L)-SWTP Elijah Creek	2,563,062	C
Sep 2008	Runway 17/35 (Future 18R/36L)-Gunpowder Creek	332,007	C
Sep 2010	GPRF – Instream Treatment	9,038,217	P
	GPRF – Misc. Cap Improvements	76,302	P
Sep 2011	Rehab Existing Glycol Concrete Storage Tanks	1,315,978	S
Grand Total – All Projects		$69,997,568	

Notes: Categories: C = collection; S = storage/containment; P = processing/treatment.

supplement the food (BOD) source to the treatment system to maintain an active biomass, resulting in additional costs incurred. Although the BOD load to the treatment system varies, the treatment system does operate at its 30,000-lbs/day limit at times.

Effluent Concentrations

The effluent concentrations achieved by the CVG treatment system routinely meet the water quality goals as long as the BOD load entering the system is not greater than the treatment capacity of the system. To mitigate for the risk of insufficient treatment capacity, the operators maintain a high biomass population and high treatment capacity through regular supplements of high-concentrate deicing pad runoff stored in the aboveground storage tanks.

Treatment Efficiency

The overall removal efficiency for COD has been over 98%, which has been sufficient to meet water quality goals. The actual treatment efficiency is similar to the treatment efficiency that was expected. Operational adjustments have been made to address unusual system conditions such as low temperature and excessive loading that can cause short-term decreases in treatment efficiency. Treatment in cold weather temperatures has not been a significant issue at CVG due to several factors, including (1) the large biological population that is maintained in the aeration basins and (2) heat generated from the biological degradation.

Cost

The capital costs for collection, storage, and treatment at the airport were approximately $70 million. The total costs for the SWTP and the GPRF were $39.3 million. The anticipated annual labor costs for the collection storage and treatment system were $0.01/gallon treated. Actual annual costs were approximately $304,000. Tables 6 and 7 provide additional information on the historical improvements at CVG and the associated capital costs.

Lessons Learned for Potential Implementation of the Activated Sludge Technology at Other Airports

The following parameters are critical to the success of the CVG activated sludge system:

1. Monitoring of influent characteristics.
2. Monitoring and management of nutrient loadings.
3. Maintaining sufficient and uniform dissolved oxygen concentrations.
4. Measuring and calculating food-to-microorganism ratios.
5. Avoiding spike loadings from storage.
6. Management of wasted and clarified biological solids.
7. Effectively managing the redevelopment of the biological population at the start of each new season.

General insights from the operation of this system that could be applied elsewhere include:

1. At CVG, the operators have experimented with various means of re-establishing the desired biological population for the start of the new deicing seasons. Experiments have included:
    a. Stopping treatment activity and reseeding the system in the fall with sludge from a local POTW.
    b. Keeping the system active the entire summer through the feeding of BOD sources, nutrients, and oxygen.
    c. Providing only aeration in the summer with no feeding of a BOD source or nutrients, followed by a fall start-up without seeding, initial introduction of nutrients, and minimal initial BOD sources. The operators feel this method works well.

2. It is necessary to add nutrients to the aeration basin on a regular basis. In the early years of operation, nutrient addition was less regular. The operators found that without nutrients, the health of the biological population decreases and treatment effectiveness decreases significantly. The operators have also noted that while concentrations of nutrients, in the form of total phosphorus and total nitrogen, are regularly measured in the treated effluent, the analytical tests on effluent samples measure both residual chemical concentration from added nutrients and nutrients released from dying bacteria. Since nutrients released from dying bacteria may not necessarily be in a form that can be absorbed by the living bacteria, the effluent nutrient measurements may overestimate the available nutrients. Therefore, while the operators try to maintain total phosphorus concentrations in the effluent of 1 mg/L and total nitrogen concentrations of 1–1.5 mg/L, they also add nutrients regularly even if residual concentrations are measured in the effluent characterization.
3. When the change was made from an EG-based deicer to a PG-based deicer, the biological treatment system reacted differently. It appears that treating the EG provided a somewhat more stable biological population.
4. During one season, due to a malfunction, the treatment system was significantly overloaded with propylene glycol, causing much of the biomass in the treatment system to die, greatly reducing the treatment capacity for a time. From this episode, it became apparent that:
    a. Once the bacteria population is lost, weeks may be required to regain full treatment capacity.
    b. The treatment system is resilient and flexible within a range of influent concentrations but not for all conditions.
    c. Appropriate monitoring and checks can be incorporated to quickly identify or prevent such operational issues.

Documents and Information Review in Development of Airport Summary

1. As-builts (record drawings).
2. Dietrich, Tom. *Facility from Site Visits.* 2011.
3. KCAB. Photographs. 2012.
4. CVG. Record drawings (plans and specs).
5. CVG. Operational logs and daily laboratory worksheets. 2012.
6. CVG. Airport correspondence and communications. 2011.
7. CVG. Treatment System Operation and Maintenance Manual.
8. CVG. Spent Aircraft Deicing Fluid Management System Letter Report by Leigh Fischer. April 20, 2012.
9. U.S. EPA. NPDES Permit No. KY0082864. 2005.

Airport Treatment Summary No. 7

Airport: Denver International Airport—Denver, CO (DEN)

Treatment Technology: Mechanical Vapor Recompression and Distillation

Years Operated: 2004–2012 (Currently Operational)

Deicer Management System Description

DEN is owned, operated, and maintained by the city and county of Denver (collectively, "the city"). The airport was built during the early 1990s and was specifically designed with infrastructure meant to reduce or control the potential for spent ADF to contribute pollutants to stormwater discharges. Deicer-affected stormwater is managed as part of DEN's airport deicing system (ADS). Components of the ADS include dedicated deicing pads, a deicing waste stormwater collection system, low-flow stormwater runoff diversion from the clean stormwater system into the deicing waste stormwater system, storage, a spent deicing fluid recycling plant, and discharge of lower-concentration runoff to the POTW. The city contracts with an operator to maintain, operate, and manage the ADS. Figure 1 shows a process flow diagram of the system.

Currently, full deicing at DEN is permitted on deicing pads and some aprons, while deicing on gates and concourses is limited. Each deicing area has a dedicated collection system that conveys stormwater runoff contaminated with ADF to temporary storage ponds or tanks. Conveyance of the runoff is managed through a system of valves and underground piping. Runoff is segregated based on glycol concentration for recycling (high concentration) and discharge to the POTW (low concentration), as described in the following.

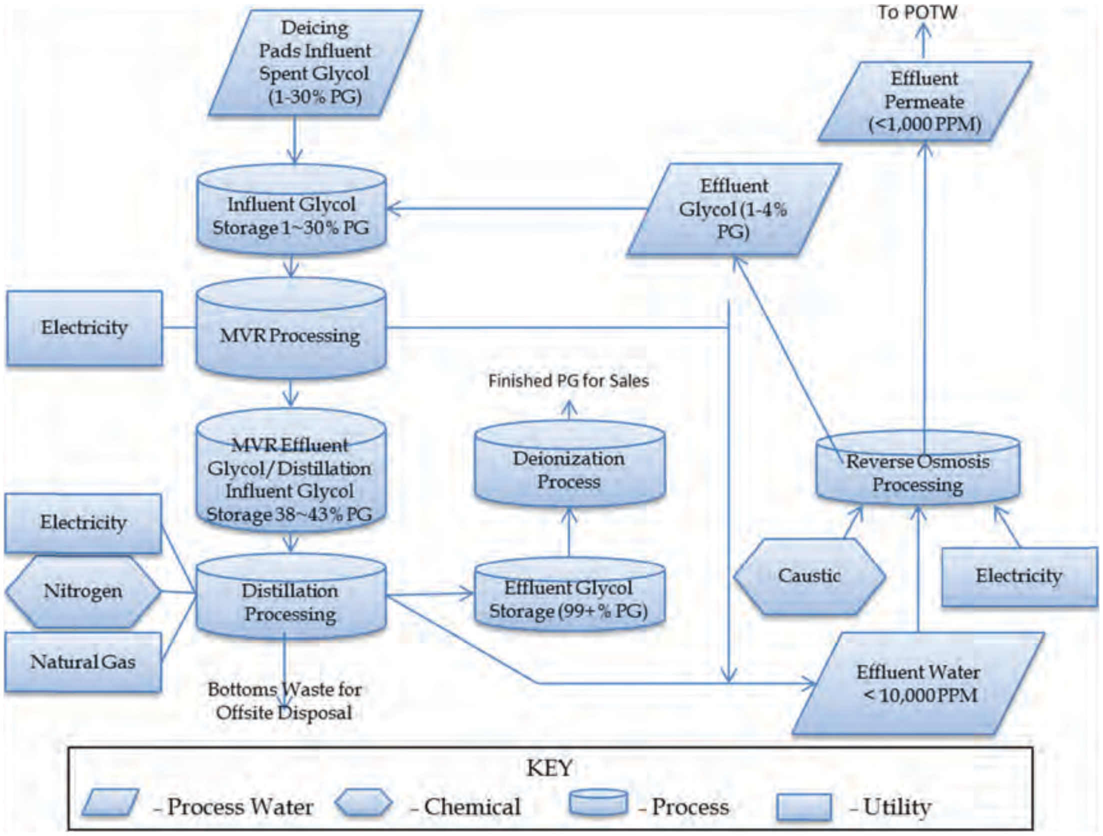

Figure 1. DEN deicing-affected stormwater management system.

Figure 2. Pond 003A at the glycol recycling facility.

High-concentrate runoff of greater than 1% concentration (10,000-mg/L PG) is managed for recycling-based treatment as follows. Deicer-affected runoff from the four central deicing pads is collected and conveyed to one of five 420,000-gallon storage tanks. In addition, a 4-million-gallon pond (Figure 2) can be used as contingency storage for high-concentrate runoff. Runoff from independent deicing pads is collected separately in storage tanks of 835,000 gallons and 420,000 gallons. Collected higher-concentrate runoff is conveyed from storage to the recycling plant via a pump and piping system or via truck. On deicing areas that are not part of the ADS, the operator uses a GRV in order to recover all fluids of over 1% glycol concentration. See Figure 3 for a photograph of the MVR building.

The recycling equipment includes eight MVR units (Figure 4) and a vacuum distillation system to produce 99%+ PG. The MVR systems in use at DEN are called "aircraft deicing fluid concentrators." Condensate from the MVR units and distillation systems contain BOD_5 concentrations that require monitoring and storage at the Western Airfield Diversion System (WADS) prior to metering to the Metro Wastewater Reclamation District's wastewater treatment plant, the local POTW. The residual waste, which contains additives and contaminants, removed from the deicing fluid by the vacuum distillation system is sent off-site for disposal at an approved waste handling facility. The 99%-PG product is sold.

Figure 3. MVR building.

Figure 4. MVR unit.

Lower-concentrate runoff from concourses and ramps of less than 10,000-mg/L PG is directed to lined retention ponds and sent to WADS for metering to the sanitary sewer system and subsequent treatment at the local POTW. The effluent discharge limitations to the POTW from recycling operations are:

- Daily maximum BOD load: 0.5 tons,
- Instantaneous maximum concentration COD: 2,500 mg/L, and
- Maximum daily flow volume: 0.288 mgd.

Deicer Treatment Technology Selection Considerations

As part of the original ADS system when the airport was constructed, the city built an on-site distillation plant to recycle spent ADF. Later, the city added a preconcentrator evaporator system, which was operated until 2004. Subsequently, MVR technology was installed at DEN to replace the preconcentrator system after the operator determined that the MVR technology was more energy efficient and economical than the preconcentrator system. Currently, both MVR and distillation technologies are used to recycle spent ADF at DEN. The current operator owns the MVR technology.

Based on high ADF usage and local climate characteristics, recycling systems were considered ideal treatment technologies for DEN. Spent ADF collected at DEN is generally higher in average propylene glycol concentration since the area's snow moisture content is typically low, and full deicing is only allowed on dedicated pads with collection capability. This yields a larger volume of spent ADF containing above-average glycol concentration that is considered ideally suited for recycling. Since the majority of captured spent ADF can be recycled, large volumes of propylene glycol can be reclaimed and sold in secondary industrial markets. This generates higher revenues related to the sale of recycled glycol, which offsets overall ADS management costs.

It is not economical to recycle runoff with PG concentrations of less than 10,000 mg/L due to the large water content that must be evaporated. This requires a separate treatment technology, which at this time is metering to the local POTW. DEN has a user permit for this discharge and pays fees based on volume and BOD load.

Deicer Treatment Technology Description

Descriptions of the vapor recompression and distillation treatment technologies can be found in Fact Sheet 106 and Fact Sheet 105, respectively. The MVR systems at DEN were designed to treat all spent ADF with glycol concentrations between 1% and 25% and concentrate to a minimum concentration of between 38% and 55% (Figure 4). The MVR concentrate glycol is routed into intermediate storage tanks and then sent through the distillation system (Figure 5), which generates a distillate of >99% PG. All ADF at DEN is PG-based.

Description of Support Systems

The deicer treatment technology at DEN includes support systems for the MVR and distillation systems such as influent filtration systems and effluent glycol polishing units.

Each ADF concentrator includes the following support systems: blowers, main plate heat exchanger, stainless-steel tanks and piping, and scrubber-absorber. The instrumentation includes pressure, temperature, and flow transmitters and gauges, and a control panel with PLC.

Stainless-steel hot filter vessels with 1-micron filter bags are used on each MVR prior to the feed entering the unit. This allows the influent to be filtered while it is hot in an effort to remove as much TSS as possible, thus maximizing production throughput and minimizing stoppages due to premature maintenance and cleaning requirements of the MVR heat exchangers.

Figure 5. Distillation columns.

An activated carbon filtration step was added to the influent of the distillation process to decrease the amount of solids and particulate matter that normally would build up in the heat exchangers and cause loss of heat exchange. Without this filtration step, the system would require frequent shutdowns to perform tedious maintenance. The overall positive result is an increase in performance and productivity of the distillation system.

The distillation system includes the following equipment:

- Numerous pumps and motors.
- Instrumentation: pressure, temperature, and flow transmitters and gauges.
- Control panel with PLC equipment.
- Various motor controllers.

The final step in the recycling process after the fluid has been sent through the MVR systems and distilled to 99%+ PG concentration is a product value-added step called "polishing." The glycol polisher is a carbon filtration, deionization, and demineralization process that was developed to remove trace airfield contaminants left in the 99% glycol after distillation.

An operator control room is located in the distillation facility. This room is equipped with a computer control station with an interactive system to monitor operating conditions. The automation system uses a PLC to provide the operator access to operating data and monitor alarms. This location serves as the main monitoring area where most of the system can be operated.

Key Treatment Sizing Parameters

Table 1 and Table 2 show size parameters for the system.

Treatment System Performance

Table 3 through Table 6 show system design performance information, and Table 7 and Table 8 show actual values.

Cost Assessment for Treatment System

The costs indicated in the following reflect the MVR and distillation treatment technologies. At DEN, the airport was responsible for the capital cost of the recycling building, facility infrastructure, ADF distribution system, ADF distribution tanks, collection piping, collection tanks, and distillation system, and the recycling/treatment equipment. The vendor operating the system was responsible for the capital costs of the MVR treatment units.

Table 1. Treatment system size and capacity parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Treatment unit dimensions			
MVR	6-ft L x 20-ft W	8	960 ft^2
Distillation	45-ft L x 40-ft W x 23-ft H	1	1,800 ft^2
Treatment facility footprint			
MVR	0.05-acre building	1	0.12 acres
Distillation	0.07-acre building (34-ft H)	1	

Table 2. Treatment support systems size and capacity parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Recycling system stormwater storage capacity	420,000 gallons 835,000 gallons 3,200,000 gallons	5 1 1	6.135 million gallons
Concentrated recycled product storage tanks	7 tanks; each tank is 12' D x 25' H	20,000 gallons each	140,000 gallons
Low-concentrate system (POTW discharge) stormwater storage	Ponds 001, 002, 004, 005 and 009	3.5–30 million gallons	60.5 million gallons

Table 3. Design basis for MVR system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 2 34 Not provided	Gallons per minute
Design treatment load capacity	16,500* 9,700** 9,700	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	17,000~459,000* 10,000~270,000** 10,000~270,000	mg COD/L mg BOD_5/L mg PG/L
Design concentrate (glycol) stream concentration - Range	35–55%	% PG
Design effluent (condensate) concentration - Range	<50~1000 Not available <50~1000	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency	94.1~99.7	% influent COD load removed

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 4. Design basis for distillation system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 9.7 10 12.5	Gallons per minute
Design treatment load capacity	107,100* 63,000** 63,000	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	646,000~714,000* 380,000~420,000** 380,000~420,000	mg COD/L mg BOD_5/L mg PG/L
Design concentrate (product) stream concentration - Range	99-99.5	% PG
Design effluent (condensate) Concentration*** Range	8,000~15,000 Not available 5,000~10,000	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency	Not provided	% influent COD load removed

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].
***Condensate from the distillation unit is sent to the MVR for additional treatment.

Table 5. Additional design basis for MVR system.

Parameter	Single-Stage Production	Two-Stage Production	
		Stage 1	Stage 2
Influent flow rate range (gallons per hour)	150 to 200	170 to 230	130 to 170
Influent glycol concentration range (% glycol)	4 to 27	1 to 4	13 to 27
Influent temperature range (F or C)	Ambient	Ambient	Ambient
Number of effluent streams produced	Two streams – distillate and concentrate	Two streams – distillate and concentrate	Two streams – distillate and concentrate
Distillate effluent flow rate range (gallons per hour)	60 to 184	136 to 219	52 to 126
Distillate effluent water quality (COD range in mg/L)	<50 to 1,000	<50 to 1,000	<50 to 1,000
Distillate effluent water quality (pH range)	3 to 8	3 to 8	3 to 8
Concentrate effluent flow rate range (gallons per hour)	12 to 120	8.5 to 61	33 to 102
Concentrate effluent concentration (% glycol range)	50 to 55	15 to 20	50 to 55
Heat source	Electric-powered steam compression		
Control system	PLC		
Energy consumption information	0.4Kw per gal feed		
Estimate of waste to be produced	Sludge and solids negligible and glycol in overheads less than 0.1%		
Anticipated frequency of maintenance activities	Duty cycle of 95% expected depending on influent quality		
Footprint, dimensions, etc.	Each MVR unit is 20’ (L) x 6’ (W) x 8’ 2” (H), with scrubber 13’ (H) or 22’ (H).		
Other support systems	Feed preheater heat exchanger, electric air compressor, cold and hot filter systems, piping for feed, distillate, concentrate, and storage tanks for feed, distillate, concentrate		

Note: DEN has eight MVR units installed.

Table 6. Additional design basis for distillation system performance.

Parameter	Value	Unit
Influent flow rate range	14,000 to 18,000	gpd
Influent flow rate average	9.7 to 12.5	gpm
Influent glycol concentration range*	38 to 42	% propylene glycol
Influent temperature range	40–50	°F
Number of effluent streams produced	2	Distillate and concentrate
Distillate effluent flow rate range	5.5 to 7.5	gpm
Distillate effluent water quality range (COD)	8,000 to 15,000	mg/L
Distillate effluent water quality range	0.5 to 1	% propylene glycol
Distillate effluent water quality	3 to 8	pH
Product effluent flow rate range	4 to 5	gpm
Product effluent glycol concentration	99–99.5	% propylene glycol

*Criteria provided based on design change in 2004. These are not the original specifications when the unit was built.

Table 7. Actual DEN MVR data for 2009–2010 deicing season.

	9-28 to 10-25	10-26 to 11-22	11-23 to 12-20	12-21 to 01-17	1-18 to 2-14	2-15 to 3- 14	3-15 to 4-11	4-12 to 5-9	5-10 to 6-6	6-7 to 7-4	7-5 to 8-1	8-2 to 8-29	08-30 to 9-26	Total or Avg for Season
Number of MVR units	6 MVRs	6 MVRs	6 MVRs	6 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	8 MVRs	
Influent vol processed (gallons)	570,777	542,268	555,587	586,543	832,951	723,507	704,000	750,366	804,766	770,043	800,906	766,551	716,590	**9,124,855**
Avg influent glycol concentration (% PG)	5.0	10.5	12.0	16.0	10.3	17.0	22.5	19.4	16.3	13.5	7.5	5.5	5.5	**12.4**
Vol of 100% PG in influent (gallons)	28,539	56,938	66,670	93,847	85,377	122,996	158,400	145,885	130,774	103,956	60,068	42,160	39,412	**1,135,024**
Avg influent temperature °C	65	64	61	61	62	67	69	66	72	75	77	76	74	**68**
Avg influent flow rate (GPH)*	972.5	845	855.1	903.9	1,431.7	1,121.3	1,150.8	1,163.6	1,270.0	1,204.7	1,228.7	1,180.9	1,132.4	**1,112**
Hours of operation	3,566	3,850	3,898	3,891	4,698	5,158	4,883	5,156	5,072	5,110	5,215	5,189	5,062	**60,748**
Duty cycle (%)**	94.0	95.0	97.0	97.0	97.0	96.0	91.0	96.0	94.0	95.0	97.0	97.0	94.0	**95**
Effluent vol of Distillate produced (gallons)	467,599	436,260	442,675	394,482	566,113	472,762	332,578	412,846	504,306	523,080	654,118	664,969	624,052	**6,495,840**
Avg effluent distillate per MVR (COD in mg/L)	6,044	6,516	4,981	4,201	5,592	4,070	3,085	3,779	4,241	6,478	6,906	6,298	6,079	**5,252**
Effluent vol of concentrate produced (gallons)	103,178	106,008	112,912	192,061	266,838	250,745	371,422	337,520	300,460	246,963	146,788	101,582	92,538	**2,629,015**
Avg effluent concentration of concentrate (% PG)	26.0	48.0	48.0	42.0	29.5	45.5	42.5	43.0	43.5	42.0	40.5	40.5	40.0	**41.1**
Vol of 100% PG in concentrate (gallons)	26,826	50,884	54,198	80,666	78,717	114,089	157,854	145,134	130,700	103,724	59,449	41,141	37,015	**1,080,397**
% ratio of glycol reclaimed vs. infeed	94.0	89.4	90.3	91.7	92.2	92.8	99.7	99.5	99.9	99.8	99.0	97.6	93.9	**95.2**

Data compiled per 28-day period while MVR systems were running. All treatment data provided by operational logs provided by Inland Technologies Int'l Ltd., DEN staff.
*Average flow rate of all machines running during this time period.
**Average % hours operation calculated by comparing how many hours the MVRs ran against theoretical hours possible for the time period the machines were running.
***Balance of PG discharged in distillate effluent to POTW.

Table 8. Actual DEN distillation data for 2009–2010 deicing season.

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total or Avg for Season
Influent volume processed (gallons)	143,874	281,391	341,698	215,092	246,194	206,286	213,827	66,847	**1,715,209**
Average concentration of influent glycol (% PG)	42.00%	40.00%	41.00%	41.00%	40.00%	37.50%	35.00%	37.00%	**39.45%**
Volume of 100% PG in influent (gallons)	60,427	112,556	140,096	88,188	98,478	77,357	74,839	24,733	**676,675**
Average influent temperature (°F)	50	50	50	50	50	50	50	50	**50**
Average influent flow rate (GPH)	630	600	570	570	600	570	600	600	**592.5**
Average hours of operation (HPD)	24	24	24	23.5	24	24	24	23.5	**23.875**
Effluent volume of distillate produced (gallons)	86,661	164,601	201,305	146,981	142,674	120,550	131,610	45,355	**1,039,737**
Avg concentration of effluent distillate (% PG)	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.1%	**1.00%**
Average COD of effluent distillate (mg/L)	11,890	10,262	12,310	12,980	11,860	12,370	13,070	14,250	**8,624**
Effluent volume of product produced (gallons)	57,213	116,790	140,393	68,111	103,520	85,736	82,217	21,492	**675,472**
Avg concentration of effluent product (% PG)	99.2%	99.1%	99.2%	99.2%	99.2%	99.2%	99.2%	99.2%	**99.18%**
Volume of 100% PG in effluent product (gallons)	56,755	115,739	139,270	67,566	102,692	85,050	81,559	21,320	**669,951**
% ratio of glycol produced vs. glycol in feed*	93.92%	102.83%	99.41%	76.62%	104.28%	109.94%	108.98%	86.20%	**99.01%**

*Variability per month due to timing of when first and last processing data were recorded.

The installation cost of the recycling building, facility infrastructure, ADF distribution system, ADF distribution tanks, collection piping, collection tanks, and distillation system was $14.6 million. Details were not available to determine the capital costs associated only with recycling/treatment equipment associated with the distillation system. The MVR facility was installed at a cost of $1 million. The cost of eight MVR treatment units and associated support equipment was $2.8 million.

At DEN, the operating costs to recycle spent ADF are borne by the recycling vendor. The airport only covers capital replacement costs for the distillation system when the major components fail. The airport pays the operating costs to manage and discharge all spent ADF of less than 1% glycol concentration.

Table 9. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital Cost Collection system, treatment building, and distillation system	Not provided	$14.6M
Treatment building and system	Not provided	$2.8M
Annual Operating Cost		
- Utilities	Not provided	Not provided
- Chemicals	Not provided	Not provided
- Analysis	Not provided	Not provided
- Material handling	Not provided	Not provided
Total operating cost	**Not provided**	**$1.5M~2.0M**

*The annual operating costs are typically offset by the sale of the recovered PG.

Conclusions on Performance of DEN MVR and Distillation Treatment System

Influent Deicer Concentrations

Influent glycol concentration is a primary parameter used to demonstrate the performance of the MVR systems. With each deicing event, concentrations of spent ADF fluctuate. Collection during storm events can generate influent concentrations that range from 1% to 25% during any single deicing event. The MVRs are capable of handling these concentrations without any major setbacks.

The effluent from the MVR is the influent for the distillation treatment system. Therefore, the concentration of glycol influent sent to the distillation system is directly influenced by the glycol produced by the MVR systems. The distillation system was fed approximately 39% concentration glycol during the 2009–2010 and 2010–2011 deicing seasons and 45% during the 2011–2012 season. Per experimentation in previous years, where 8% to 20% glycol concentrations were fed through the distillation system, 99%+ product concentrations could not be achieved, and a greater quantity of natural gas was consumed. On average, with the unit being fed 39% to 45% glycol concentrations, the unit performs at 100% of redesign expectations.

Flow Rate

In an effort to sustain good flow rates, the MVR units are run 24 hours per day, 7 days per week. They have the ability to be adjusted based on influent PG. Based on analysis of the data, there is a clear correlation showing that PG concentration affects the processing rate. Over the course of the three seasons of data, the MVR systems processed at an average rate of 185 gpm. It appears the units perform best when influent concentrations are between 6.5% and 19.5% glycol. Individually, an MVR unit processed 2.3 gpm, which is 91.7% of the 2.5-gpm design specification. During the 2010–2011 deicing season, the MVR average was 19.9 gpm for all machines or 2.48 gpm individually, which equates to 99.3% of design. Adjustments are made on the PLC, and the influent and effluent streams are measured on an hourly basis. Operating flow rates between 2.6 gpm and 2.8 gpm are achievable per MVR unit, with influent concentrations of between 12% and 15%, but other factors such as quality of feed and desired product output also affect processing rate.

Treated Load Rate

The rate at which soluble or total COD is removed from the system is not a key measure of performance for the MVR system. The MVR units were designed to separate glycol from water.

Effluent Concentrations

Effluent wastewater generated from recycling activities at Denver International Airport is not allowed to be discharged to surface waters. The effluent streams produced by both the MVR and distillation systems are comingled and transferred to the WADS. In general, all low-concentration spent ADF (typically of less than 1%) captured from the dedicated collection system as well as the recycling facility wastewater is managed at WADS and then discharged to the Metro Wastewater Reclamation District's Central Treatment Plant (CTP). The airport's wastewater contribution permit with CTP defines a maximum allowable BOD load per day and an allowable monthly average. This typically ranges between 9 and 12 tons per day of BOD loading, depending on the time of year. On average, the airport manages and discharges 100 to 150 million gallons of low-concentration spent ADF to CTP.

The MVR units have the ability to produce up to 55% PG concentration. The units on average have produced concentrations between 39.6% and 42.5% PG. Influent processing flow rates tend to decrease the higher the concentration being achieved while the amount of PG produced per gallon in the effluent increases. In addition, the effluent concentration of the fluid being produced becomes the influent for the distillation system. The system operator indicated that the 40% concentration target rate is ideal to maximize the influent processing rate of the MVR so as to not jeopardize spent-ADF storage and is also considered an ideal concentration to maximize distillation processing rates.

The distillation system can be adjusted to produce a desired glycol concentration product. The higher the glycol content produced, the greater the value of the product for resale. The average concentration of effluent product made over the course of 3 years was 99.13% PG. Although the system has the ability to produce up to 99.5% PG concentration, the quality and color of the product can be jeopardized when exposed to additional heat. As a result, the operator of the facility maintains a 99.1% concentration target with specific product quality requirements.

Treatment Efficiencies

Based on the data, over 91.4% (or 93.1% with adjustment accounting for meter error) of the glycol that was fed through the MVR systems was reclaimed. The remaining balance of glycol was discharged through the effluent distillate stream to the POTW. At a peak, the ratio of glycol produced from the MVR for reuse compared to the amount of glycol fed through the system reached over 95.2% during the 2009–2010 season.

In an effort to increase the amount reclaimed from the MVR systems, adjustments can be made to the scrubber system on the MVR units to reduce the amount of glycol in the distillate stream. The issue is that influent processing rates have to be slowed down and each machine balanced individually for this to occur. Going forward, the recycling vendor has plans to install a reverse osmosis system after the MVR units to treat the distillate effluent and reclaim a larger percentage of the glycol.

Based on the 3 years of data, over 97.4% of the glycol that was fed through the distillation system was reclaimed for sales. The remaining balance of glycol was discharged through the effluent distillate stream to the POTW. As reported by the recycling vendor, 99% is considered typical, but there were maintenance issues experienced with some of the heat exchangers, which caused uncharacteristically high discharges of glycol in the effluent water for discharge to the POTW. The recycling vendor plans to install a reverse osmosis system after the distillation unit to treat the distillate effluent and reclaim a larger percentage of the glycol.

Cost

Prior to 2004, the city paid an annual fixed fee for a subcontractor to operate the entire ADS system. During this time, only 8% and higher glycol concentrations were removed from the airport's diversion system and recycled. The city incurred a significant expense to discharge all of the less than 8% concentration fluid to an off-site POTW. In addition, the city faced discharge restrictions and storage issues in managing all of the spent ADF that was not designated for recycling. In 2004, the MVR technology was introduced to recycle all spent ADF that was 1% or higher in propylene glycol concentration. The addition of this technology allowed the vendor to assume all costs to recycle the spent ADF. Denver is unique in that there is a large enough volume of ADF applied each year (approximately 1.4 million gallons) so that over 50% of that volume can be reclaimed from the system and processed to a final product to be sold in industrial markets. With this ability, the vendor can cover all expenses to recover and recycle the 1% and higher PG with the revenues generated by the sale of recycled glycol. The city does incur expenses if less than a predetermined amount of ADF is applied annually during a mild season in an effort to cover a portion of the subcontractor's costs that cannot be recouped with limited glycol volumes or if a major component needs replacement on the city-owned equipment. In addition, the city covers expenses to manage and discharge all of the fluid that is less than 1%

in glycol concentration. Overall, the recycling process saves a significant amount of money for the city each year. The city reported savings of $2 million during the 2009–2010 deicing season, $1 million of which was from disposal fees.[3]

Lessons Learned for Potential Implementation of the MVR and Distillation Technologies at Other Airports

The following factors have proven critical to the effective and efficient performance in the DEN MVR and distillation systems:

1. Influent glycol concentrations.
2. Quality of influent improved by mechanical filtration methods prior to treatment by both systems.
3. Desired effluent concentration of product produced affects influent processing rate.
4. Daily preventative maintenance is integrated into operations in order to optimize equipment performance.
5. Maintaining process variables such as temperature, flow rate, and pressures at consistent set points improves production rates.

The effluent concentrations in the distillate have spiked occasionally during the last three deicing seasons. The distillation system has experienced multiple heat exchanger tube failures due to the age of the components, the incompatibility between feed/effluent mixture, and the tube material composition. This caused the effluent (distillate) to entrap more and more residue from the decaying exchanger tubes, thus driving the overall COD levels higher, as the data indicate. At the same time, influent from the feed/steam heat exchangers will enter the distillate stream, bringing the 0.4% to 0.6% PG up to 1.0% to 1.2%. A combination of these two factors has caused the effluent being removed from distillation to be temporarily sent back through the MVR units in order to remove the remainder of glycol while the exchangers are replaced.

Conclusions from operation of the MVR and distillation systems at DEN that can be used by other airports considering these technologies include:

1. MVR technologies are very viable and most applicable with airports that generate spent-ADF concentrations of 1% and higher.
2. MVR technologies are modular, which means they can be installed in a relatively small footprint and can be adjusted to deal with varying influent concentrations.
3. MVR technologies are also scalable, and additional units can be added without the need to significantly expand infrastructure, as in the case of DEN, where three additional units have been added over the past 5 years to keep up with the airport's growth.
4. It is also important to note that MVR systems are typically installed at airports where there is an outlet for the effluent water produced such as a POTW or other type of system to treat low levels of COD and glycol.

Generally, MVR units are more economical the greater the volume of ADF sprayed at the airport and, more importantly, the more the glycol that can be captured at the airport for recycling. The greater the volume reclaimed, the larger the volume of product that can be sold to generate revenues to offset capital and operating expenses. If the volume is less than 200,000 to 300,000 gallons a year of influent that is greater than 1% glycol concentration, then another treatment technology may be more cost-effective than installation of an on-site MVR system.

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[3] Financial data provided from September 2011 edition of *Airport Improvement Magazine,* "Denver International Airport and Portland Jetport Stand Ready for New Glycol Regs."

There are few airports that spray and recover enough ADF to justify installation of an on-site distillation system. Although this model has been extremely successful in Denver, many airports could not generate enough glycol to offset the capital and operating expenses. Instead, many airports that have MVR or other recycling systems typically transport partially recycled glycol to centralized distillation plants. Technology has now been developed where modular distillation systems can be installed at smaller airports, and then that airport can serve as a centralized distillation outlet for other airports in the region.

Documents and Information Review in Development of Airport Summary

1. All treatment data provided by operational logs provided by DEN Inland Technologies staff.
2. Financial data provided from September 2011 edition of *Airport Improvement Magazine*, "Denver International Airport and Portland Jetport Stand Ready for New Glycol Regs."

Airport Treatment Summary No. 8

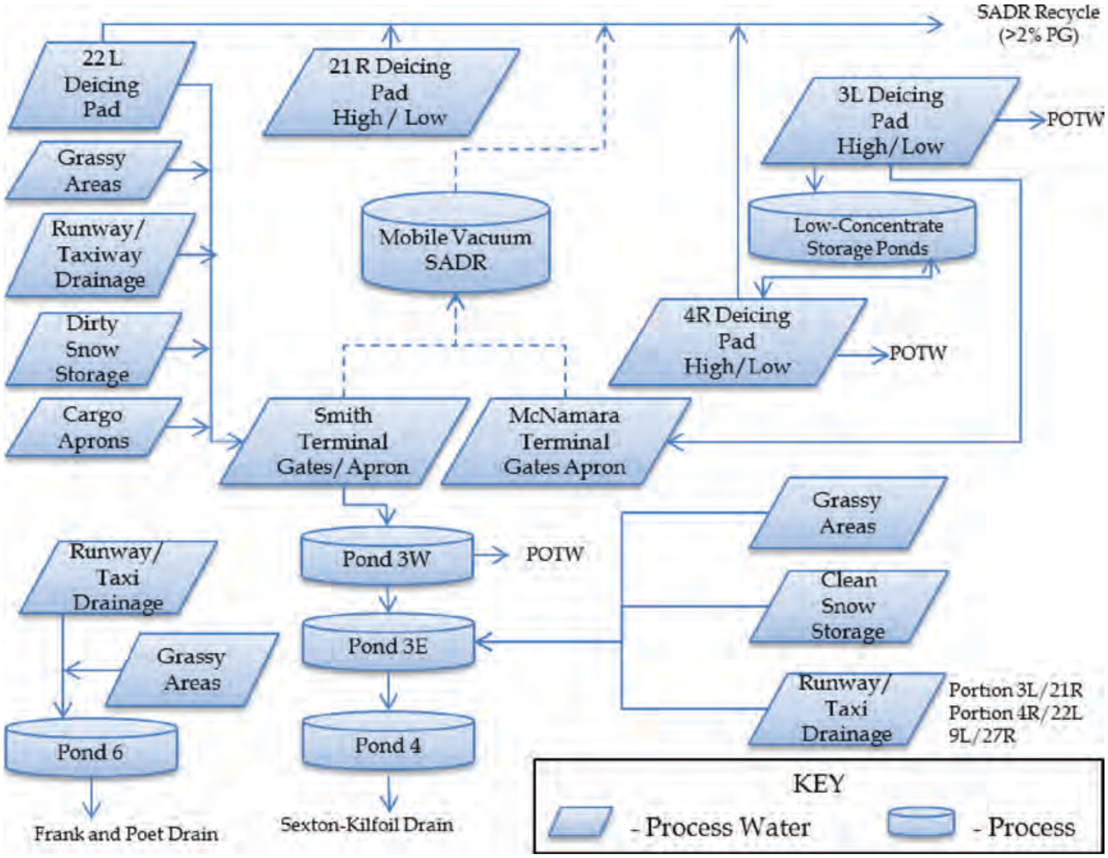
Airport:	Detroit Metropolitan International Airport—Detroit, MI (DTW)
Treatment Technology:	Industrial Recycling and POTW Discharge
Years Operated:	Early 1990s–2012 (Currently Operational)

Deicer Management System Description

In the early 1990s, DTW made efforts to reduce the PG load it sent to the local POTW. To reduce the load, DTW concentrated application of PG-based aircraft deicers onto several deicing pads. DTW contracted with a local private deicer management and recycling firm to manage all runoff with a concentration of greater than 2% PG from the deicing pads. In addition, DTW uses a GRV to collect high-concentration glycol from the gates from frost deicing activities or miscellaneous deicing activities beyond the pad areas. Since the late 1990s, DTW has been recycling runoff with PG concentrations of greater than 2%. Figure 1 shows a process flow diagram of the system.

Deicer Treatment Technology Selection Considerations

In the early 1990s, DTW realized that an improved deicer management program was necessary. The existing program of gate deicing, stormwater capture in ponds (several millions of gallons), and discharge to the local county-owned Downriver Wastewater Treatment Facility (WWTF) in



Note: SADR = spent aircraft deicing runoff.

Figure 1. DTW deicing-affected stormwater flow diagram.

Wyandotte, Michigan, experienced challenges. Gate deicing by tenants was affecting very large volumes of stormwater runoff, and occasional overflows of stormwater management ponds were occurring more and more often. Not only was DTW experiencing environmental challenges at the time, but the Wyandotte WWTF, a 50- to 60-million-gallon per day facility, was also experiencing treatment issues due to court-mandated construction projects. As a result, DTW's ability to discharge to the WWTF was at risk. To reduce this risk (i.e., the amount of high-concentration runoff being discharged to the WWTF), DTW embarked on a program to change how and where aircraft deicing was being performed.

DTW started working with tenants and developed a pad deicing operation. The pad deicing operation provided a much smaller area of pavement to be affected by aircraft deicer, resulting in a much higher concentration of stormwater runoff. This high-concentration runoff was a valuable commodity for DTW that could be handled by alternative means.

DTW contracted with a local deicer management and recycling firm to manage all runoff with a concentration of greater than 2% PG from the deicing pads.

DTW investigated other treatment processes for deicing-affected stormwater with concentrations of less than 2% PG, including on-site and off-site methods. DTW determined that a new force main connecting to the city of Detroit's WWTF would provide the needed improved compliance margin of safety. DTW constructed a new 5-mile-long force main that connected to the city of Detroit sanitary sewer system at a cost of approximately $11 million. This discharge location could accept up to 30,000 pounds per day with a flow limitation of 1 mgd. It too, however, is susceptible to precipitation events, and limits to DTW discharges can be imposed by the Detroit WWTF if inflows to the WWTF exceed 900 mgd.

Deicer Treatment Technology Description

Industrial Recycling

See the private recycling facilities fact sheet (Fact Sheet 110).

Description of Support Systems

The industrial recycling treatment system does not require the airport to maintain or operate support systems for treatment.

Key Treatment System Sizing Parameters

See Table 1 for sizing parameters.

Treatment System Performance

No normal basis-of-design treatment criteria were identified in the review of the project. Design data for the treatment system are not a parameter of concern for the airport since the deicing-affected stormwater is sent to a POTW or to an off-site industrial recycling facility.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	100 million gallons 106 million gallons 216 million gallons 70 million gallons 0.7 million gallons 0.75 million gallons	2	493 million gallons

Table 2. Costs for discharges to the POTW.

	BOD (lbs/day)	Flow (million ft^3)
Downriver WWTF	$0.271	$18.44
Detroit WWTF	$0.269	$10.69

No treatment performance data were routinely collected or readily available for review by the research team since the POTW or off-site recycler manages all treatment.

Cost Assessment for the DTW POTW Discharges and Recycling

The rates paid for discharge of deicer-affected stormwater to the POTW are shown in Table 2.

Cost terms of the contract for managing and recycling fluid from the deicing pads include:

- If greater than 600,000 gallons of fluid of greater than 2% PG are collected, DTW receives a $0.10/gallon rebate.
- If greater than 450,000 gallons and less than 600,000 gallons (2% PG) are collected, DTW breaks even and pays no fee and receives no rebate.
- If less than 450,000 gallons of 2% PG are collected, DTW pays $1.50 per gallon to the recycling firm.

Conclusions on Performance of DTW Deicer Treatment System

Influent Deicer Concentrations

At DTW, influent deicer concentrations are used to determine which treatment system receives deicer-affected stormwater. Concentrations of greater than 2% PG are sent to the industrial recycling treatment facility, and concentrations of less than 2% are sent to the POTW.

Flow Rate

The flow rate of the treatment systems is not a concern for DTW. However, the rates at which flows can be sent to the POTW are limited to the hydraulic limits of the pipe and delivery. The rate at which the industrial recycler removes deicing-affected stormwater is limited. At DTW, the industrial recycler removes deicing-affected stormwater by truck.

Treated Load Rate

The DTW discharges to POTWs capable of accepting up to 30,000-lbs BOD/day and 12,000~15,000 lbs BOD/day. Treatment load rate in excess of this limit must be stored on-site or will exact a fine from the POTW.

Effluent Concentrations

Effluent concentrations are not a concern for the airport since all deicing-affected stormwater is managed by a separate management facility.

Treatment Efficiencies

Treatment efficiencies are not a concern for the airport since all deicing-affected stormwater is managed by a separate management facility.

Cost

The deicer management firm contracted by the airport supplies all personnel, vehicles, frac-tanks, pumps, transportation, and recycling services as part of the contract. The runoff is taken to the firm's facility a few miles away from the airport for further processing and purification. The industrial recycling operation has been very economical for DTW since the contract provides for a payback to DTW depending on the volume of fluid collected.

Lessons Learned for Potential Implementation of the Industrial Recycling and POTW Technologies at Other Airports

Only the rate of sending flow from DTW to the industrial recycling system and the POTW are factors critical to the effective and efficient performance of deicing treatment. Other factors critical to the treatment of the deicing-affected stormwater are managed by the industrial recycling firm and POTW operator.

Although the industrial recycling worked well for several years for DTW, the winter of 2011–2012 had two significant changes at DTW that affected the treatment system. First, the largest airline tenant invested in a new ADF bulk blend-to-temperature system and six new deicer application trucks equipped with real-time blending to temperature capabilities. Second, a very mild winter greatly reduced the amount of deicer applied.

These events caused a significant shift in the volumes of water being recycled versus the volume of water being discharged to the WWTF. Significantly more water was being discharged to the WWTF, while less was being recycled. It also changed the economic model for the airport in that for the first time in several years, the airport was required to pay the industrial recycling firm for recycling services, rather than breaking even or receiving a rebate.

Through 2012, DTW has invested over $125 million in stormwater separation, storage, and support infrastructure and continues to investigate the impacts of recent changes on their compliance status and costs. DTW is considering its various contracts and may be investigating additional alternatives for disposal as future seasons reveal new challenges.

Conclusions from operation of the industrial recycling and use of the POTW at DTW that can be used by other airports considering these technologies include:

1. Industrial technologies are most applicable with airports that generate spent-ADF concentrations of 2% and higher.
2. A significant amount of spent PG is required to make industrial recycling profitable.
3. Changes to deicing operations can affect the economies associated with industrial recycling and POTW discharges.
4. POTWs have permit limits that may affect the flow, concentration, or load sent from an airport. Changes to these permit limits may require an airport to add a treatment technology or change operations.

Airport Treatment Summary No. 9

Airport:	Wilmington Air Park—Wilmington, OH (ILN)
Treatment Technology:	Reciprocating Aerated Gravel Bed
Years Operated:	2000–2009

Deicer Management System Description

From 1980 through 2009, ILN was operated as a hub for the cargo shipping and distribution businesses of Airborne Express and DHL, with a peak of 250 airport operations a day in 2007. The 2,200-acre ILN airport is a former military base with two 10,000-ft runways and over 200 acres of concrete ramps for parking, loading, and deicing of aircraft. During its peak years of operation, 200,000 to 300,000 gallons of pure PG-based aircraft deicer were applied each year. Three of the airport's 15 outfalls drain the main deicing areas and discharge stormwater to the airport's two receiving streams, Lytle Creek and Indian Run. These outfalls also discharge the majority of stormwater flow from the site. Outfall flow rates vary widely, from less than 50 gpm in dry weather conditions to over 150,000 gpm in wet weather. Figure 1 shows a process flow diagram of the system, and Figure 2 shows the system itself. Figure 3 shows the bacterial film used in the system.

In 1996, effluent limitations in a new NPDES stormwater discharge permit for the facility triggered the implementation of a deicer management system for collection, conveyance, storage, treatment, and discharge of deicer-affected stormwater from hundreds of acres of aircraft parking areas. Because of the vast deicing and collection area, the ILN deicer management system was designed as two separate systems, located on the north and south sides of the airport. Each system included collection of deicer-affected stormwater from existing airport outfalls, temporary storage in lined open basins, treatment of stormwater using the reciprocating aerated gravel bed technology, and discharge of treated effluent to the surface waters. DHL purchased the facility in 2003 and expanded airport operations. Additional conveyance and storage were added to the deicer management system in 2004 to account for the corresponding increased deicing operations. When DHL

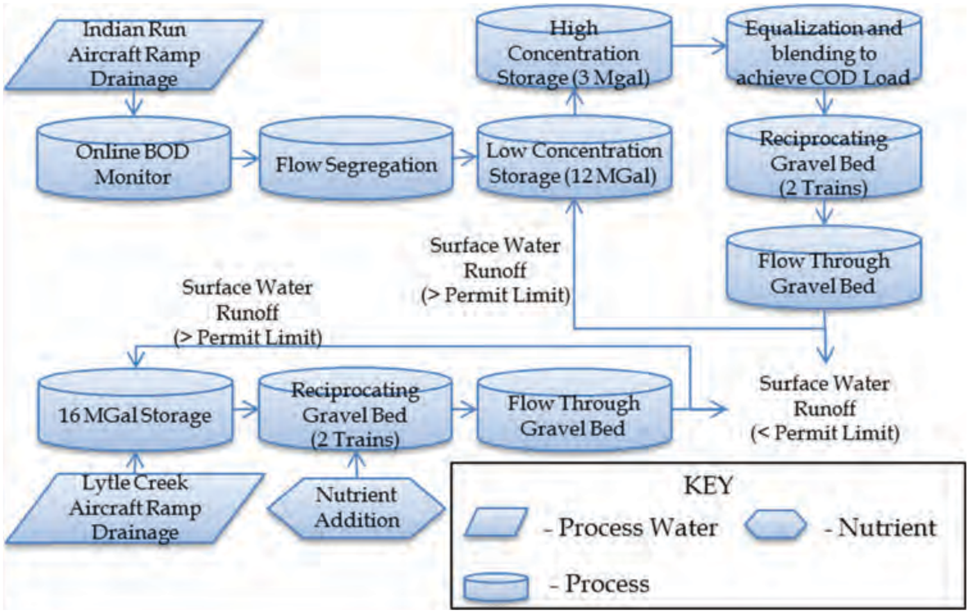


Figure 1. ILN deicer management system.

Figure 2. ILN reciprocating gravel bed system.

eliminated most of its domestic cargo operations and moved its international operations to the Cincinnati/Northern Kentucky Airport in 2009, the deicer management system was mothballed. Currently, there is an aircraft maintenance operation at ILN. Should aircraft deicing activities grow in the future, the deicer management system can be restarted.

Deicer Treatment Technology Selection Considerations

In 1995, ABX Air, owner of the airport at the time, began preliminary evaluation of alternative deicer management measures to achieve compliance with conditions in its NPDES permit. The initial work included evaluation of stormwater characteristics, evaluation of existing deicing practices, assessment of deicer collection methods, and evaluation of deicer disposal alternatives. A review of deicer application options resulted in ABX Air deciding that deicing on deicing pads was not a feasible operations scenario. As a result, runoff from over 800 acres of airfield surface

Figure 3. Example of bacterial film on reciprocating bed gravel.

had to be collected and managed. Being a cargo-only facility, each aircraft was deiced at its own unique location, once per day. This deicer application system led to vast quantities of highly variable deicer-affected stormwater runoff with wildly varying COD concentrations.

A series of preliminary assessments were conducted into means for collecting, storing, treating, and disposing of the runoff. The sheer quantity of stormwater, in addition to the huge COD load, made discharge to the POTW in the small town of Wilmington infeasible. Once it was determined that on-site treatment was necessary, several methods for treatment were considered. Recycling technologies were evaluated but were deemed not cost-effective because the volumes of water resulted in average concentrations too low for economical recycling. Several biological treatment options were considered, including AFBRs, trickling filters, and activated sludge. The volume of water to treat and the size range of COD concentrations led to size and cost challenges with the AFBR technology. More conventional biological technologies like activated sludge were considered to be overly affected by weather. After preliminary evaluation of conventional biological treatment processes, ABX pursued development of a subsurface, attached-growth gravel bed treatment system through implementation of a pilot study. From 1997 to 1999, two on-site biological treatment technologies were pilot tested: a traditional subsurface gravel bed wetland technology and a reciprocating gravel bed technology. The pilot-study results indicated that the constructed gravel bed wetland did not sufficiently degrade the deicer. The failure of the constructed wetland to treat sufficiently was associated with the lack of an aerobic environment to develop bacteria suitable for large treatment loads and with cold temperatures. It was also discovered that the addition of wetland plants provided no treatment value to either the constructed wetland or the reciprocating gravel bed system. The reciprocating subsurface gravel bed technology without plants was successfully pilot tested. The results of the pilot study were used to design and size two full-scale treatment systems at ILN that were based on the reciprocating technology.

Deicer Treatment Technology Description

Reciprocating Gravel Bed, a variant of Aerated Gravel Beds

See aerated gravel bed treatment technology fact sheet (Fact Sheet 102). The reciprocating gravel bed technology has been applied for treatment of various types of stormwater and wastewater applications, but ILN is the only deicer treatment application. The ILN gravel beds are constructed as a series of cell pairs in which water is pumped between the two gravel beds in the cell pair, alternately exposing one gravel bed to contaminated water in the cell for 30 to 60 minutes at a time and its partner cell to atmospheric oxygen for the same period. After the 30- to 60-minute period, water is pumped from the full gravel bed to the empty gravel bed, resulting in a reversal of the exposure to water and atmospheric oxygen. The benefit of this type of a system is the lack of a need for blowers and aeration piping buried in the gravel bed.

Description of Support Systems

The two reciprocating subsurface gravel bed systems at ILN each ultimately included over 14 million gallons in up-front storage, means for adding ammonia (for nitrogen) and phosphate to individual basin pairs at the pump stations, a Parshall flume for measuring effluent flow, a recirculation line back to storage for situations when effluent COD concentrations were too high, and a cascade aeration system to increase the dissolved oxygen concentrations in the treated effluent prior to discharge. The systems are controlled by SCADA systems, with a PLC that receives level and pump status data and turns the reciprocation pumps on and off to automatically create the system cycling. The SCADA system was also used to help segregate influent flow with COD concentrations that could be directly discharged to the streams from diluted runoff that needed to be treated and concentrated runoff that needed to be treated. The system did include a final gravel bed cell that did not reciprocate as potential means for capturing biosolids from the reciprocating cells. Discharge of biosolids from the reciprocating cells (as represented by TSS) was kept low during winter by carefully managing the growth of the bacterial films on the gravel and through summertime degradation of the dead biomass within the cells.

Key Treatment System Sizing Parameters

See Table 1 for sizing parameters.

Treatment System Performance

The data in Table 2 on the intended design performance of the system were derived from the 1998 Engineering Report associated with the Permit-to-Install Application to the Ohio EPA.

The information in Table 3 on actual system performance was derived from daily data collected at the facility between 2000 and 2009.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	15.8 million gallons 14.4 million gallons	2	30.2 million gallons
Treatment unit volume	4.8 million gallons 3.6 million gallons	2	8.4 million gallons
Treatment unit dimensions	6 acre x 7-ft D 3 acre x 7-ft D	2	1,180,000 ft^3 887,000 ft^3
Treatment facility footprint	6 acres 3 acres	2	9 acres

Note: Not including conventional flow-through gravel bed.

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Average - Maximum	 250 1,000	Gallons per minute
Design treatment load capacity	25,000 14,700*	lbs COD/day lbs BOD_5/day
Design influent concentration - Range	0~3,000 0~1,700*	mg COD/L mg BOD_5/L
Design effluent concentration (average)	270~690 160~410	mg COD/L mg BOD_5/L
Design treatment efficiency (average)	98%	% influent COD load treated

Loading is based on an average temperature of 41°F
*Data based on conversion: [COD] = 1.7 [BOD_5].

Table 3. Actual system performance.

Parameter	Value Lytle Creek System	Value Indian Run System	Unit
Flow rates - Average - Maximum	 439 1,967	 413 2,680	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 13,400 235,000	 17,100 584,000	lbs/day
Influent COD concentration - Average - Maximum	 2,160 22,000	 2,080 26,540	mg/L
Effluent COD concentration - Average - Maximum	 342 7,410	 323 10,600	mg/L
Treatment efficiency	87.7	85.5	% influent COD load treated

Table 4. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost*	$6M in 2000	$6.2M at construction, $0.6M added in 2004 for upgrades to control system and online monitoring
Annual operating cost**		
- Utilities	$40,000	$44,000
- Chemicals	$20,000	$24,000
- Analysis	$5,000	$4,000
- Material handling	0	0
Total operating cost	**$65,000**	**$72,000**

*Capital costs are for the two treatment systems combined, excluding collection, storage, and discharge support systems.

**Operating costs are for Lytle Creek and Indian Run systems combined. They do not include labor costs, but equate to approximately two full-time operators. Maintenance costs, which vary, are not included. Major maintenance items included liner repair, weeding of gravel beds once per year, and pump preventative maintenance and repair.

Cost Assessment for the ILN Reciprocating Gravel Bed System

See Table 4 for treatment system costs.

Conclusions on Performance of ILN Reciprocating Gravel Bed System

Influent Deicer Concentrations

Influent deicer concentrations, although monitored regularly, are not a primary control parameter used in managing the loading to the system. If the overall mass loading is kept within the load capacity of the system, it can treat a wide variety of COD concentrations within the capabilities of the system pumps.

Flow Rates

The system was controlled initially to a set flow rate for concentrated deicer and diluted deicer conditions. Later the methodology was changed to a mass-load–based control system such that influent flows were turned on and off to meet the system loading targets. Based on the growth of airport operations (and deicer applied) and initial underestimation of the effects of prolonged cold weather, the design flow rates (treatment capacity) were insufficient for treatment needs, and additional storage had to be added.

Treatment Load Rate

The nominal design system COD treatment capacity was based on a water temperature of 41°F. It was known from standard biological treatment theory and pilot-study results that treatment rates would increase with higher water temperatures and decrease with lower temperatures. When performance data from 2001 through 2009 are averaged for the water temperature range of 41°F +/– 2°F, the COD treatment rates measured in the field compared well to the design treatment rates. At temperatures lower than 38°F, treatment rates were lower than anticipated in comparison to the results from the pilot studies. The most significant factor was not short-term decreases in treatment rates from cold temperatures, but the effects from prolonged air temperatures below 20°F (and the corresponding decreases in water temperature). It was also determined that at temperatures greater than 60°F, treatment rates also decreased to some degree because biofilm growth on the gravel began to clog the gravel beds, resulting in shorter hydraulic detention times.

Effluent Concentrations

When operating at influent COD loading levels suitable for the temperature, effluent COD concentrations of less than 200 mg/L could be obtained for water temperatures greater than 40°F.

BOD concentrations of less than the detection limits of the BOD test could also be obtained. COD effluent concentrations rose when water temperatures were less than 40°F, especially when the system was overloaded.

Treatment Efficiencies

Over the course of most seasons, and over the 8 post–start-up years, the treatment efficiency (% of COD removed) was near 98%, very close to the design removal rates when temperatures were above 38°F. There were numerous instances where removal efficiency decreased for periods up to several weeks during the coldest portions of the winter, dropping average COD removal rates to near 85%. Most instances where treatment efficiency suffered were associated with the system being loaded beyond its treatment capacity for a given temperature. Through the course of operations, it was learned to decrease COD loadings in anticipation of extended stretches of cold weather. This allowed the system to recover more quickly when temperatures warmed.

Cost

The initial total cost of the deicer management system (collection, storage, treatment, discharge) was $11.5 million in 2000. $6.2 million of that total was associated with treatment. In 2004, $4 million in improvements were added, most of which was associated with additional storage. Direct additional costs for the treatment system were $600,000 for improvements to the treatment system controls. The increase in storage capacity was driven primarily by the decreased treatment rates at cold temperatures, which led to the need to hold more water during the middle portion of the deicing season.

The operating costs were near design basis projections. The system required two full-time operators, as initially determined. Electrical costs were maintained at planned levels (~$40,000 per year), and use of the reciprocation method likely resulted in significantly lower electrical costs than would have been the case if blowers were used to supply air. Chemical use costs for nutrients were somewhat higher than projected.

Lessons Learned for Potential Implementation of the Reciprocating Aerated Gravel Bed Technology at Other Airports

Factors that have proved to be critical to the performance of the reciprocating aerated gravel bed treatment technology at ILN are:

1. Ability to control COD loading rate to the system,
2. Adjustment of the COD loading rate based on water temperature,
3. Location of nutrient supply to treatment system, and
4. Ability to reduce shorter reciprocation cycle times, which has proven to improve performance.

The ILN treatment system performed as intended when the treatment system COD mass loading rates were within the system capacity. However, changes in operation at ILN, including the significant drop in operations and corresponding deicing operations, demonstrated the interdependency of treatment technology, deicing operations, deicing-affected stormwater collection, and storage.

Conclusions from operation of the reciprocating aerated gravel bed system at ILN that can be used by other airports considering this technology include:

1. The reciprocating aerated gravel bed technology was the first use of its kind for a deicer management system. Several years of experience reveal that that system can successfully treat large COD loads and volumes of runoff and produce, but loading of the COD and nutrients must be controlled such that a healthy biological population can be maintained.

2. At temperatures of less than 38°F, treatment rates were less than anticipated from the pilot studies. As the system operation evolved, it was learned that decreasing COD loading rates in anticipation of cold temperatures helped the system treatment rates rebound faster when temperatures warmed up.
3. Swings in air temperature had a somewhat larger negative effect on treatment rates than swings in water temperature, presumably because of the cold air drawn into the system in the reciprocation process. The effect was most pronounced when air temperatures were less than 20°F for prolonged periods.
4. A decrease in performance was also seen in the late spring in years when there was heavy deicer use because of the proliferation of bacterial colonies that thrived under warm temperatures and clogged air spaces between gravel cells, limiting the system hydraulic detention time. This biological growth can be managed by controlling COD loading rates at higher temperatures.
5. Effective tools for reducing the swings in treatment rates were installation of an online BOD monitor and implementation of a variable frequency drive on influent pumps in 2004, which allowed much better control and consistency of influent COD loading rates. When this system was implemented, the SCADA control system was programmed to maintain a constant COD loading rate with appropriate decreases in the COD loading rate with lower water temperatures.
6. The rates at which nutrients were added to the system had a significant effect on treatment rates, especially at the start of each season. Over time, the loading rates were adjusted to reduce the likelihood that nutrients were a limiting factor in performance.
7. Although it was never specifically quantified, it is likely that under certain conditions, the treatment was oxygen limited.
8. Over time, the gravel beds in the initial part of the treatment system became partially clogged with both inorganic sediment and biological solids. A challenge with this type of system is preventing the clogging from occurring by using pretreatment to remove inorganic solids and management of deicer loads to keep biological growth from being excessive.

Documents and Information Review in Development of Airport Summary

1. Permit-to-Install Applications to Ohio EPA for Wilmington Air Park Deicer Management System, 1998 and 2004.
2. Daily system operating logs.

Airport Treatment Summary No. 10

Airport:	London Heathrow International Airport—London, United Kingdom (LHR)
Treatment Technology:	Aerated Lagoon Aerated Gravel Beds Passive Facultative Treatment
Years Operated:	2001 to 2012 (Currently Operational)

Deicer Management System Description

LHR is divided into four main catchments, each served by a separate balancing reservoir, designated as northwestern, southwestern, eastern, and southern. Deicing operations drain to either the eastern or southern catchment. The system discharges to surface waters. The British Airports Authority (BAA) commissioned a reed bed treatment facility in 2001 at Mayfield Farm to treat deicing runoff from the southern catchment. Due to expansion of airfield operations, the existing facility was upgraded in 2010 to provide a significant increase in treatment capacity.

The 2010 treatment system at Mayfield Farm includes three major unit processes downstream of the main reservoir: the upgraded floating reed bed (a passive facultative technology), the balancing lagoon (an aerated lagoon), and the aerated gravel beds. During winter operations, as BOD meters detect elevated concentrations of BOD associated with deicing, stormwater flow is diverted to the main reservoir and is stored there before being pumped to the treatment system. Under normal operations, flow is pumped from the main reservoir so as to flow in series through each unit process until discharge. A schematic of the system is provided in Figure 1. Figure 2 and Figure 3 show photographs of the system.

Deicer Treatment Technology Selection Considerations

The reed bed treatment facility commissioned in 2001 at Mayfield Farm had a treatment capacity of 770 lbs of BOD_5. BAA decided to upgrade the treatment capacity in 2010. The upgrade included the reconfiguration of existing unit processes and installation of new aeration equipment and nutrient feed system.

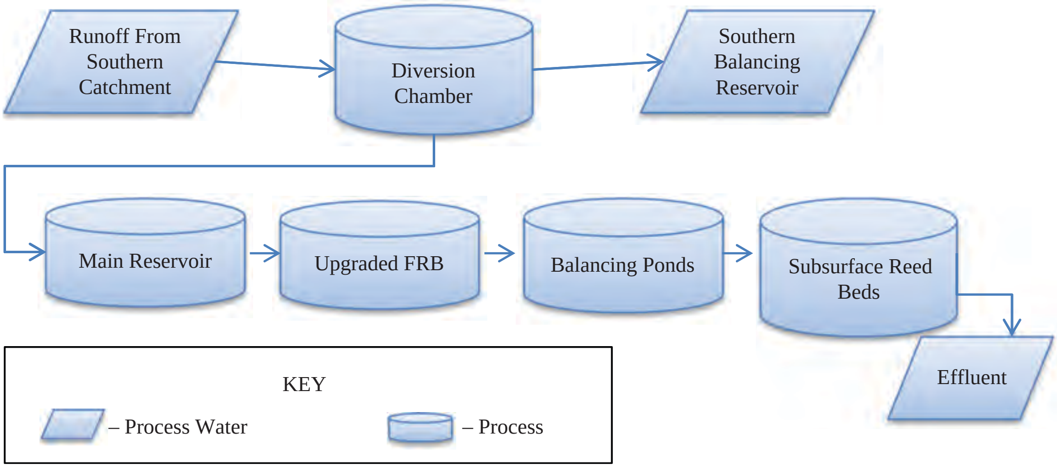


Figure 1. Mayfield Farm stormwater management system process flow diagram.

Figure 2. Retrofit of aerated gravel beds (reed beds).

The existing floating reed bed channels were transformed into aerated channels. The channels were designed using aerated lagoon practices. The first part of each channel was designed as a complete mix lagoon. The remainder of the channel was designed as a partial mix lagoon. Floating reed bed racks were retained in the partial mix zones to improve the sedimentation of the bacterial solids generated in the complete mix zone.

The balancing lagoon was added to provide process flexibility for the treatment train. The lagoon can be employed for either hydraulic equalization or as a middle process in the treatment train. It was designed as a partial mix aerated lagoon.

The final reed bed was upgraded to a planted aerated gravel bed (also known as an intensified or aerated wetland). The upgrade included addition of aeration tubing and the reconfiguration of the flow path in the beds from horizontal (left to right) to vertical (top to bottom).

The following considerations were factors in the selection of the upgrade design:

1. Ability to use existing infrastructure at Mayfield Farm.
2. Ability to quickly design and construct the system.

Figure 3. Aeration in main reservoir.

3. Results from an on-site pilot test that demonstrated the capacity of the system.
4. Need to comply with green-zone requirements for the project location.

Deicer Treatment Technology Description

The original treatment technology employed at LHR was a reed bed system classified for the purposes of this guidebook as a passive facultative treatment system (See Fact Sheet 108). The upgrade of the floating reed bed and balancing lagoon used aerated lagoon technology (See Fact Sheet 103). The aerated gravel bed technology is described in Fact Sheet 102. Aeration is also provided in the main reservoir.

Description of Support Systems

The upgrade of the LHR treatment system included the addition of aeration equipment, a nutrient feed system, and related electrical and instrumentation work. The main storage reservoir is equipped with floating aerators, which are used at the discretion of the operator.

A nutrient feed system has also been included into the re-engineering of the system. The nutrients are added at various points in the process to support bacterial growth. By adding supplemental nitrogen, phosphorus, and other micronutrients at the influent, the aerobic bacteria can properly grow and degrade the hydrocarbons in the carbon-rich stormwater from deicing operations. The nutrient solution is prepared off-site and delivered to a chemical storage tank at Mayfield Farm. The feed system consists of a storage tank and four feed pumps. Each feed pump supplies nutrient solution to a dedicated dosing point. The primary feed points are to the main reservoir and the influent of the upgraded floating reed beds.

Instrumentation for the system includes the collection and transfer of signals from blower panels, pumps, and online analytical equipment (online BOD meter, dissolved oxygen probe, phosphorus meter, and flow meter) to the existing SCADA system operated by BAA. The SCADA system is used to control the operation of motorized equipment (blowers, pumps, and valve actuators).

Key System Sizing Parameters

See Table 1 for sizing parameters.

Treatment System Performance

The data in Table 2 represent the intended design performance of the treatment system.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	7.92 million gallons	1	7.92 million gallons
Treatment unit volume		3	11 million gallons
Complete mix/partial mix channels	4.0 million gallons		
Balancing lagoon	5.2 million gallons		
Aerated gravel beds	1.8 million gallons		
Treatment unit dimensions	529,000 ft^3 706,000 ft^3 247,000 ft^3	3	1,482,000 ft^3
Treatment facility footprint			9.6 acres
Complete mix/partial mix channels	2.5 acres		
Balancing lagoon	2.0 acres		
Aerated gravel beds	5.1 acres		

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Average - Maximum	 634 1,270	Gallons per minute
Design treatment load capacity	13,000* 7,700 7,700**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration	1,000	mg BOD_5/L
Design effluent concentration (average)	30	mg BOD_5/L
Design treatment efficiency (average)	98%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

The facility has numerous online BOD meters that are used to monitor real-time values of BOD within the system. These data are logged, along with related flow rates.

The operation of the upgraded system began in February 2011. No monitoring data are available at this time.

Cost Assessment for the LHR Aerated Gravel Bed Treatment System

Table 3 shows treatment system costs.

Operational effort and cost consist primarily of management of pump, aeration, and nutrient feed systems. Biomass levels are monitored and managed as needed.

Conclusions on Performance of LHR Aerated Gravel Bed System

No performance data are currently available on which to make conclusions. Factors that are expected to be critical in the performance of the LHR aerated gravel bed system include:

1. The ability to provide adequate storage upstream of treatment,
2. Adequate nutrient dosing concentrations and dosing locations, and
3. The ability to properly operate aeration equipment.

Lessons Learned for Potential Implementation of the LHR Treatment Technologies at Other Airports

1. The treatment system site should be located far enough from runways that bird strikes are reduced.

Table 3. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital Cost 2001* 2011	 $30M** in 2001 $4.5M*** in 2011	 $27M** in 2001 Not available
Annual Operating Cost*** - Utilities - Chemicals - Analysis - Material handling	 Not provided Not provided Not provided Not provided	 Not provided Not provided Not provided Not provided
Total operating cost	**$250,000**	**Not provided**

*"Mayfield Farm Constructed Wetlands," Constructing Excellence (2006).
**Data based on conversion: $1.40 = £1.00
***Data based on conversion: $1.60 = £1.00

2. The nutrient dosing points around the system should be flexible and accessible.
3. The ability to take tanker truck deliveries to the treatment site was a major design challenge.
4. Nutrient solution is prepared off-site and shipped to a storage unit on-site since the ability to take tanker trucks to the treatment site was a major design challenge.
5. Preliminary testing demonstrated that aeration and nutrient addition greatly improved performance in comparison to unaerated beds without nutrient addition.
6. Aeration lines were plowed into the existing beds, which greatly lowered the cost of the project.

Document and Information Review in Development of Airport Summary

1. Naturally Wallace project fact sheet (http://naturallywallace.com/docs/NWC%20Mayfield%20Farm%204-1-11%20F2.pdf).
2. 2011 WETPOL presentation: Glycol Treatment at London's Heathrow Airport. BAA, ARM, and Naturally Wallace.
3. Naturally Wallace project files.

Airport Treatment Summary No. 11

Airport: Oslo Airport, Gardermoen—Oslo, Norway (OSL)

Treatment Technology: Moving Bed Biofilm Reactor

Years Operated: 1998–2012 (Currently Operational)

Deicer Management System Description

The new OSL opened in 1998. Currently, OSL services 22 million passengers per year and has anywhere from 6,000 to 12,000 annual deicing operations. The deicer collection system was constructed as part of the new airport in 1998. Components of the ADS include three dedicated deicing pads and an ADF-contaminated stormwater collection/retention system, including four retention basins with a total storage capacity of approximately 17 million gallons.

OSL has financed a moving bed bioreactor pretreatment unit based on the MBBR method used at the nearby municipal Gardermoen sewage treatment plant.

Environmental regulations limit the acceptable concentration of COD in the groundwater to 15-mg COD/L on airport property and 0.5-mg COD/L off airport property during spring/snow melting periods. The regulatory limit for deicing fluid concentration in surface waters outside airport property is 0.5-mg/L glycol, formate, or acetate.

All aircraft deicing at OSL is conducted on one of three remote deicing pads located next to runway entry points. Runoff from the pads, as well as from key taxiway/runway areas where deicing fluids generally drip from the aircraft, is collected in the ADF deicer management system. Figure 1 shows a process flow diagram of the system.

Runoff contaminated with runway deicer from approximately 124 acres of apron area is collected in a separate system to keep it separated from stormwater contaminated with glycol. This system includes two retention basins with 20 million gallons of capacity. However, due to ongoing airport extension, apron areas have been doubled, and three new retention basins have been constructed; thus, a total storage capacity of nearly 40 million gallons will be available from the 2012–2013 deicing season on.

Runoff from taxiways and runways is generally not collected but percolates into the soil alongside these areas. OSL monitors concentrations of COD in the groundwater to confirm natural attenuation of the deicing chemicals from these areas.

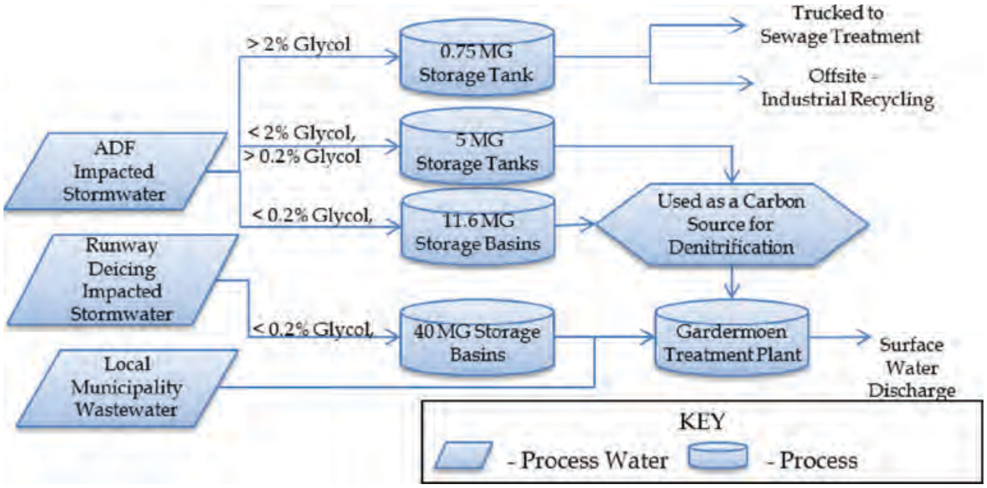


Figure 1. OSL deicing-affected stormwater management system process flow diagram.

Table 1. Treatment of aircraft deicing-affected stormwater at OSL.

Concentration	Collection and Treatment
More than 2% glycol	Recycled/reused in the glycol industry. Previously trucked to two different sewage treatment plants where it was used as a carbon source for the biological denitrification process (2004–2011).
Between 0.2% and 2% glycol	Sent to the Gardermoen sewage treatment plant as a carbon source for the denitrification process.
Less than 0.2% glycol	Sent to the Gardermoen sewage treatment plant for treatment as sewage.

Source: Per Espen Jahren, Water Management Systems. Oslo Airport, Norway.

Stormwater runoff containing ADF collected from the deicing pads and portions of the runways is separated into three separate storage tanks at each deicing pad based on deicer usage and weather conditions. These tanks contain collected runoff at three different concentration levels (Table 1). High-concentration runoff is pumped to a treatment plant where a concentrate suitable for trucking is produced. This concentrate is then transported to a chemical industrial facility in Germany for distillation into a pure glycol product. The medium- and low-concentration runoff is pumped to the storage basins prior to usage or treatment at the Gardermoen sewage treatment plant (Table 1).

Runoff containing runway deicer from the apron area is collected in two 9-million-gallon basins. Following collection, the contaminated stormwater is sent to Gardermoen sewage treatment plant for treatment in the ordinary MBBR train, mixed with sanitary wastewater. (COD varies from 100-mg to 400-mg COD/L.) The biomass in the MBBR has to be adapted to the runway deicer through a start-up procedure; thus initial capacity every new delivery period is low and then increases through buildup of specialized bacterial population.

Deicer Treatment Technology Selection Considerations

OSL is located on the largest unconfined aquifer in Norway. Consequently, strict regulations were introduced by the Norwegian pollution control authorities to minimize the environmental impact on the groundwater system. To mitigate impacts from deicing activities at the airport on the aquifer, the Norwegian pollution control authorities required OSL to not affect:

1. Groundwater balance,
2. Groundwater quality,
3. Natural erosion processes in the ravine system, or
4. Surrounding water resources.

During the planning phase of OSL, it was determined that the local wastewater treatment plant did not have the capacity to treat the combined wastewaters from the local municipalities of Ullensaker and Nannestad in addition to that from OSL. Therefore, in 1994, the Norwegian pollution control authorities concluded that a new semi-regional wastewater treatment plant should be built. During the planning process of the new wastewater treatment plant, testing demonstrated that the glycol in the runoff could be used as an external carbon source for biological denitrification as a substitute for the commonly used ethanol or methanol. Combining treatment of the wastewater and the deicer-contaminated stormwater into one treatment facility became a primary design focus.

The Gardermoen treatment plant was then constructed to treat wastewater from the surrounding municipalities of Ullensaker and Nannestad as well as sanitary wastewater from OSL. Deicer-contaminated stormwater from OSL is treated in the winter and spring seasons.

Deicer Treatment Technology Description

The OSL treatment system is unique with respect to process concept. Stormwater is segregated by COD concentrations, and the medium-concentration fraction and the low-concentration fraction are treated in distinctly different parts of the biological treatment plant. The treatment reduces the high-COD of ADF deicer runoff as well as runway deicer runoff to a very low level.

ADF-contaminated runoff containing less than 0.2% glycol is mixed with wastewater and sent through the pretreatment reactor prior to treatment in the ordinary MBBR train. The treatment plant includes an anoxic reactor for nitrogen removal, sludge removal (dissolved air floatation), and UV disinfection (summer only). ADF-contaminated runoff with glycol concentrations of between 0.2% and 2% is injected as a carbon source for the denitrification processes in the anoxic reactor of the MBBR train.

A more detailed description of the MBBR technology can be found in Fact Sheet 107. Figure 2 shows a process diagram for the MBBR.

The OSL deicer treatment system is unique compared to other airports because the biological treatment in the sanitary wastewater treatment plant is capable of treating large volumes of deicer-contaminated runoff from the airport. The mixing of stormwater and sanitary wastewaters is likely to have beneficial effects compared to treating stormwater alone because of the heat and nutrients supplied to the biological process from the sanitary wastewater, as well as creation of a more stable organic and hydraulic load and a more stable sludge volume and quality suitable for sludge dewatering and handling.

Key Treatment System Sizing Parameters

See Table 2 for system sizing parameters.

Sewage Treatment Plant System Performance

See Table 3 for designed system performance information.

The ADF applications at OSL are integrated into the deicing management system. The ADF applied at OSL is a Type I proportional mix and Type II ADF, mono propylene glycol only. The average ADF consumption is 290-lbs to 310-lbs glycol/aircraft (calculated as pure/100% glycol only).

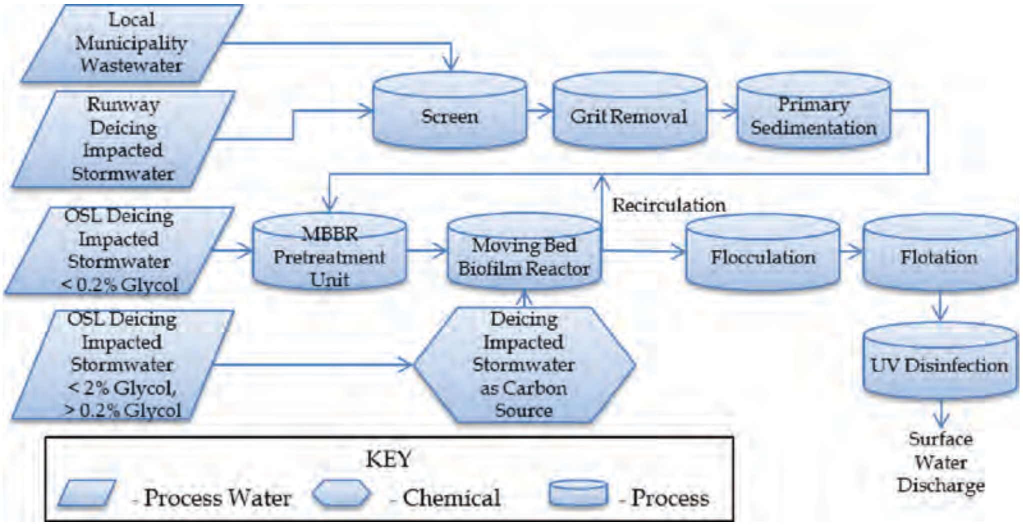


Figure 2. Gardermoen treatment plant, moving bed biofilm reactor process diagram.

Table 2. Key system sizing parameters.

Component/Parameter	Size/Capacity	Number of Units	Comments
ADF runoff storage capacity, for recycling	3,500 m^3 0.9 million gallons	One tank at each deicing pad and two connected buffer tanks	>2% glycol
ADF runoff storage capacity, carbon source for denitrification	19,000 m^3 5.0 million gallons	One tank at each pad and two buffer basins	<2%, >0.2 % glycol
ADF runoff storage capacity, for delivery to sanitary sewage treatment	44,000 m^3 11.6 million gallons	One tank at each pad and two buffer basins	<0.2% glycol
Runway deicer runoff capacity	75,000 m^3 (2012)/ 150,000 m^3 (2013). 19.8 million gallons/ 39.6 million gallons	Two basins (2012)/ five basins (2013)	Originally 2 x 9.2 million gallons. Under construction due to expansion: 3 x 6.6 million gallons.
ADF capacity in pretreatment unit	Max 9,900 lbs COD/day, max 26,400 gal/hour		
ADF consumption in denitrification unit	Approx. 280 tons glycol/year (470 tons COD/year)		
Runway deicer capacity	Max 2,200 lbs COD/day, max 1.31 mgd		Start-up capacity is approx. 220-lbs COD/day due to biomass adjustment to the deicer chemical.

Source: Per Espen Jahren, Water Management. Oslo Airport Norway.
Notes: Conversion factor: 1-kg glycol = 1.68-kg COD; U.S. gallon = 3.785 L.

The information in Table 4 on actual system performance was derived from facility data from the year 2000.

Conclusions on Performance of OSL MBBR System

Influent Deicer Concentrations

The collected deicer-contaminated stormwater sent to the fixed film portion of the MBBR contains less than 2,000-mg PG/L, or approximately 3,400-mg COD/L. Higher-concentration stormwater runoff is used as a carbon source for the denitrification process in the treatment

Table 3. Design basis for system performance.

Parameter	Value	Unit
Design flow rates		Gallons per minute
- Minimum		
- Average	540	
- Maximum	765	
Design treatment load capacity	12,000 7,100* 7,100**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	725 425* 425**	mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	33 10 0.5	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency (average)	95%	% influent COD load treated

Source: Kruger Kaldnes, Case Study: Gardermoen Waste Water Treatment Plant.
*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 4. Actual system performance.

Parameter	Value	Unit
Flow rates	Not available	Gallons per minute
Actual COD treatment load rate	Not available	lbs/day
Actual BOD_5 treatment load rate	Not available	lbs/day
Influent COD concentration - Average	559	mg/L
Influent BOD_5 concentration - Average	330*	mg/L
Effluent COD concentration - Average	25	mg/L
Effluent BOD_5 concentration - Average	3.2	mg/L
Treatment efficiency	96%	% influent COD load treated

Source: Van Haandel, A. C., and Van Der Lubbs, J. G. M. *Handbook of Biological Wastewater Treatment: Design and Optimisation of Activated Sludge Systems*. London: IWA Publishing, 2012.
*Data based on conversion: [COD] = 1.7 [BOD_5].

plant. Prior to treatment in the MBBR, the deicing-affected stormwater is mixed with the influent sanitary wastewater. Sanitary wastewater typically ranges between 250-mg and 800-mg COD/L.[4] Mixing the sanitary wastewater with the deicing-affected stormwater typically reduces combined concentration before treatment by the MBBR and dampens the peaks. Mixing the sanitary wastewater with the deicing-affected stormwater also increases the temperature of the deicing-affected stormwater and adds biological nutrients.

Flow Rate

Data on the operation and performance of the OSL MBBR were not available.

Treated Load Rate

Data on the operation and performance of the OSL MBBR were not available. However, the presence of sanitary wastewater sources provides a steady baseline mass loading that likely stabilizes the biological population, potentially making for a more robust system in the face of the more fluctuating deicer load contribution.

Effluent Concentrations

Approximately 3 days a year, OSL experiences discharges to their surface waters that exceed the regulatory limits. These exceedances are not necessarily related to the deicing component.

Treatment Efficiencies

The MBBR has demonstrated a 96% removal efficiency for COD.

Cost

The OSL MBBR treatment system is used to treat municipal wastewater as well as deicing-affected stormwater. Therefore, the capital and operating costs for the treatment of stormwater runoff at the municipal MBBR treatment plant are less than for a separate stormwater treatment system with the same capability.

Lessons Learned for Potential Implementation of the MBBR Technology at Other Airports

Conclusions drawn from the operation of the MBBR at OSL that can be used by other airports considering implementing this technology include:

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[4] Metcalf & Eddy. *Wastewater Engineering: Treatment and Reuse.* New York: McGraw Hill Publishing, 2003.

1. The MBBR technology is located in an enclosed facility, with the cold stormwater influent mixed into warm sanitary wastewater. This results in less treatment at cold temperatures compared to some other deicer treatment systems.
2. The MBBR technology typically has negligible effluent concentrations of BOD_5 (3.2 mg/L) and COD (25 mg/L), although the system may exceed regulatory limits as often as 3 times a year.
3. The municipal wastewater MBBR system is operated year round, treating deicer-contaminated stormwater from OSL in winter and spring. The year-round operation allows a healthy bacteria population capable of treating the seasonal stormwater runoff.
4. Nutrient balance is provided by the municipal wastewater.
5. Some municipal wastewater treatment plants are in need of sources of carbon to facilitate the process of removing nitrogen from wastewater (the denitrification process). Airports may want to engage local wastewater treatment authorities to assess if there is a need. If so, it could be a lower-cost method than other alternative off-site destruction methods for disposing of the concentrate. The biggest obstacles to using collected deicer-contaminated stormwater as a carbon source for denitrification are:
    a. The means of transportation and transportation costs from the airport to the treatment plant, since it cannot be discharged to the sanitary sewer system.
    b. The means of storage for the deicer at the treatment plant.
    c. The means of metering the deicer into the denitrification process, given the potentially changing deicer concentrations.
    d. Matching the quantity of carbon needed for denitrification with the quantity of deicer that is available. This can be problematic since the availability of deicer is variable.
    e. Large-volume storage facilities have to be available in order to provide even delivery to the sewage treatment plants.

Airport Treatment Summary No. 12

Airport:	Portland International Airport—Portland, OR (PDX)
Treatment Technology:	Anaerobic Fluidized Bed Reactor, POTW Discharge
Years Operated:	2011–2012 (currently operational)

Deicer Management System Description

In response to effluent limits for BOD_5 in its NPDES permit, the Port of Portland constructed an airport-wide deicer management system at PDX that came into operation during the 2002–2003 winter season. This deicer management system included concentrate deicer runoff collection, storage (2 million gallons), and discharge to the sanitary sewer along with diluted deicer runoff collection, storage (13 million gallons), and metered discharge to the receiving water according to the limits of the NPDES permit. In 2005, the port began consideration of additional deicer system enhancements to improve the performance of its existing system based on limitations in the receiving water's ability to assimilate the discharges under all necessary conditions, in addition to unforeseen limitations in the BOD load that could be discharged to the local POTW. In 2011, construction was completed on the enhancements to the deicer system, which included additional diluted deicer runoff storage (13 million gallons), additional concentrated deicer runoff storage (3 million gallons), a new outfall to the Columbia River, and an on-site AFBR treatment system. The treated effluent from the AFBR can be discharged to either the sanitary sewer or to the Columbia River if BOD load limitations in the NPDES permit allow. Figure 1 shows a process flow diagram of the system. Figure 2 shows the treatment facility site.

Deicer Treatment Technology Selection Considerations

The limits in the NPDES permit at PDX are dependent on flow rate in the receiving water (Columbia Slough) and are therefore variable. There are periods during which the limits to the Columbia Slough are so restrictive that no discharge of BOD_5 is allowed. The airport also has limitations on the daily load that they may discharge to the sanitary sewer. Lastly, the port may expand operations in the future as demand grows. These factors led the airport to decide that on-site treatment was necessary to effectively manage deicer runoff collected at the airport while maintaining compliance with the NPDES limits and the load limits for discharges to the sanitary sewer.

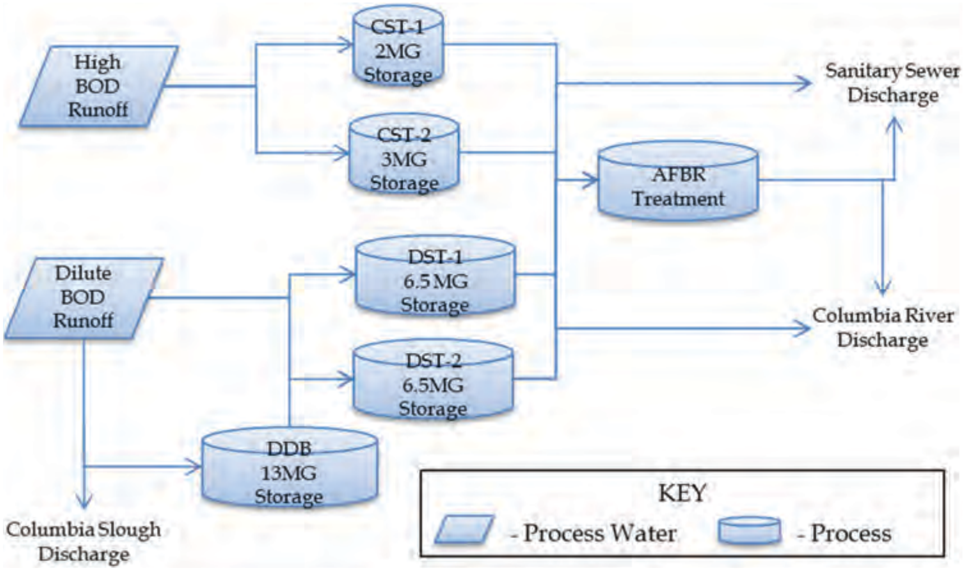

Figure 1. PDX deicer management system flow diagram.

Figure 2. PDX on-site treatment facility site.

A wide variety of deicer treatment technologies was considered for PDX. An AFBR treatment facility was chosen because of its proven ability to treat deicer-affected runoff, its ability to remove a high percentage of influent BOD_5, its ability to withstand the potential intermittent availability of deicer without needing to reseed the system, and because the system fit well into PDX's existing airport-wide deicer management system. The AFBR system was also chosen due to its ability to consistently and predictably achieve desired effluent concentrations despite the great potential for variability of flows and concentrations entering the concentrate storage tanks. An RO treatment system was considered, and a pilot system was installed at PDX during design of the system enhancements, but an overabundance in silica in the stormwater prevented the RO facility from becoming a viable alternative. An aerobic treatment system was also considered but was discarded due to a lesser ability to handle the intermittent nature of PDX deicer discharges without reseeding or addition of supplementary and costly sources of BOD_5 to keep the biology active.

Deicer Treatment Technology Description

AFBR

See the AFBR treatment technology fact sheet (Fact Sheet 104) for a general description of the AFBR technology. The PDX AFBR system generally follows this description. Figure 3 shows the biological reactor units in the system.

Figure 3. Biological reactor units in the PDX AFBR system.

Description of Support Systems

The AFBR at PDX includes the following support systems for the treatment reactor-separator unit: storage (one 2-million-gallon tank and one 3-million-gallon tank for concentrated deicer runoff), influent pumping system, heat generation and exchange loop, chemical feed for nutrient addition and pH control, biogas handling, and biological solids removal and handling. Collected runoff water from the storage tanks is pumped to a small holding tank near the treatment facility and then pumped at a flow rate set by the system operators to achieve a constant BOD_5 loading as influent BOD_5 concentrations change. The cold influent water is heated first by passing it by warm effluent water in a heat exchanger and then by passing it by hot water from a boiler in a second heat exchanger. The hot water is obtained by heating potable water in a boiler using biogas captured from the reactor. The biogas is approximately 77% methane and 23% carbon dioxide and is used similarly to natural gas. For the PDX system, the heating system burns self-generated biogas, except for initial yearly start-up when natural gas is used. Any excess biogas is burned in a flare external to the building. The AFBR technology requires addition of a base chemical (sodium hydroxide) to keep pH in the reactors neutral, as well as addition of various chemical nutrients to support growth of the bacteria. Biological solids exiting the reactor-separator unit with the treated effluent are removed with a dissolved air flotation clarifier under certain conditions. The treated effluent from the reactors can be routed to bypass the dissolved air flotation clarifier, with the biological solids discharged to the sanitary sewer. Biological solids that are removed from the effluent are disposed of in a landfill.

Key Treatment System Sizing Parameters

See Table 1 for system sizing parameters.

Treatment System Performance

The 2011–2012 season was the start-up year for the PDX AFBR. During the year, the AFBR system was fed both from deicer-affected stormwater, off-spec deicer that could no longer be used, and purchased glycol. The feeding of purchased glycol was only for the start-up season. The goal was to test the capacity and capabilities of the system by slowly increasing the COD loading to the AFBR reactors over time, with the further goal of reaching the design COD loading and assessing whether the COD removal target of 98% could be reached. Through the process, the mechanical and control functions of the system were assessed. Design performance targets are presented in Table 2. Actual performance data are presented in Table 3. Figure 4 and Figure 5 graph actual performance data.

Cost Assessment for the PDX AFBR Treatment System

Engineering cost estimates indicated that the treatment facility capital cost, including the equipment, instrumentation, treatment building, and site/civil features external to the building, would be $9 million to $10 million.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Treatment unit volume	29,000 gallons	2	58,000 gallons
Treatment unit dimensions	Reactors: 14-ft diameter	2	N/A
Treatment facility footprint	0.28-acre building*	1	0.28-acre building

*The 0.28-acre building footprint includes 0.06 acre storage and maintenance facility for GRVs.

Table 2. Design basis for PDX AFBR system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 5 35 200	Gallons per minute
Design treatment load capacity	11,500 6,700* 6,700**	lbs COD/day lbs BOD_5/day lbs PG/day
Design influent concentration - Range	 1,800~34,000 1,050~20,000* 1,050~20,000**	 mg COD/L mg BOD_5/L mg PG/L
Design effluent concentration (average)	<250 (after start-up) <150 <10	mg COD/L mg BOD_5/L mg PG/L
Design treatment efficiency (average)	98%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

Table 3. Actual system performance.

Parameter	Value	Unit
Flow rates - Minimum - Average - Maximum	 11 32 90	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 2,400 4,200	lbs/day
Actual BOD_5 treatment load rate - Average - Maximum	 1,400* 2,400*	lbs/day
Actual PG treatment load rate - Average - Maximum	 1,400** 2,400**	lbs/day
Influent COD concentration - Minimum - Average - Maximum	 2,000 14,500 52,500	mg/L
Influent BOD_5 concentration - Minimum - Average - Maximum	 1,200* 8,500* 30,800*	mg/L
Influent PG concentration - Minimum - Average - Maximum	 1,200** 8,500** 30,800**	mg/L
Effluent COD concentration - Minimum - Average - Maximum	 40 141 2,100	mg/L
Treatment efficiency	98.66%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

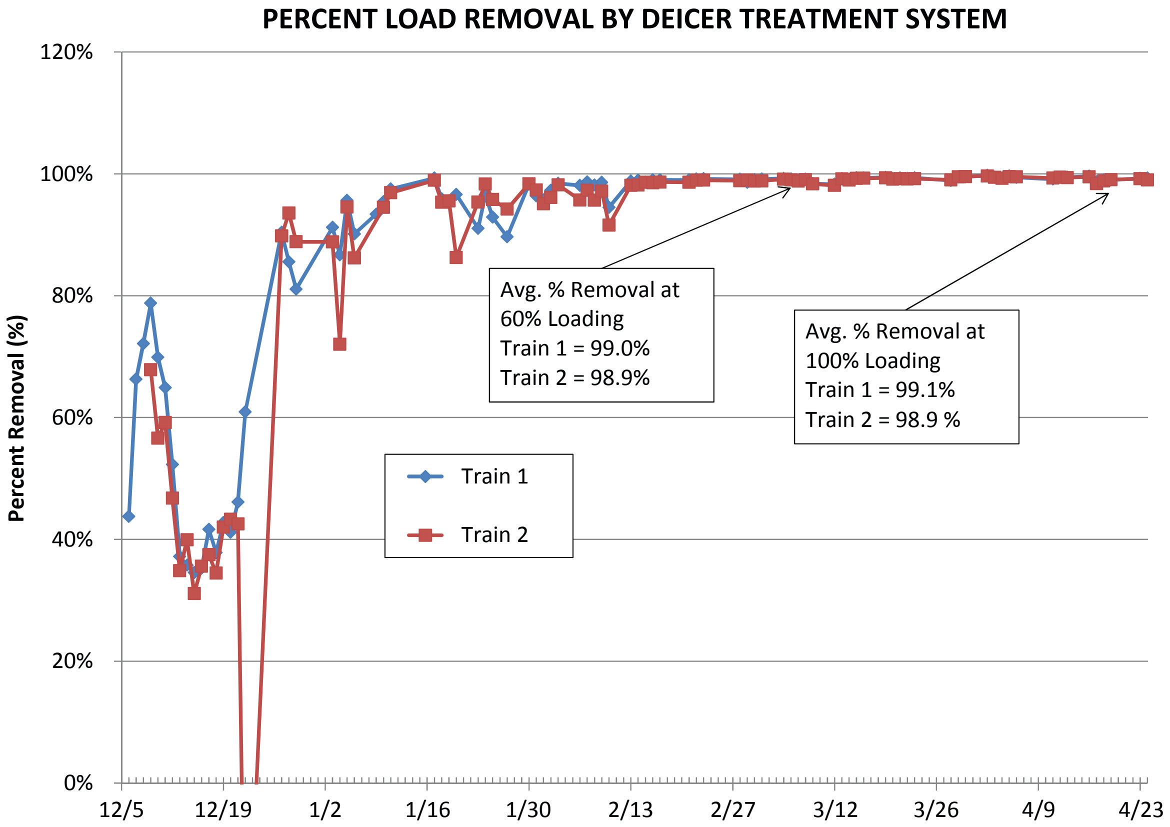

Figure 4. Actual system treatment efficiency performance.

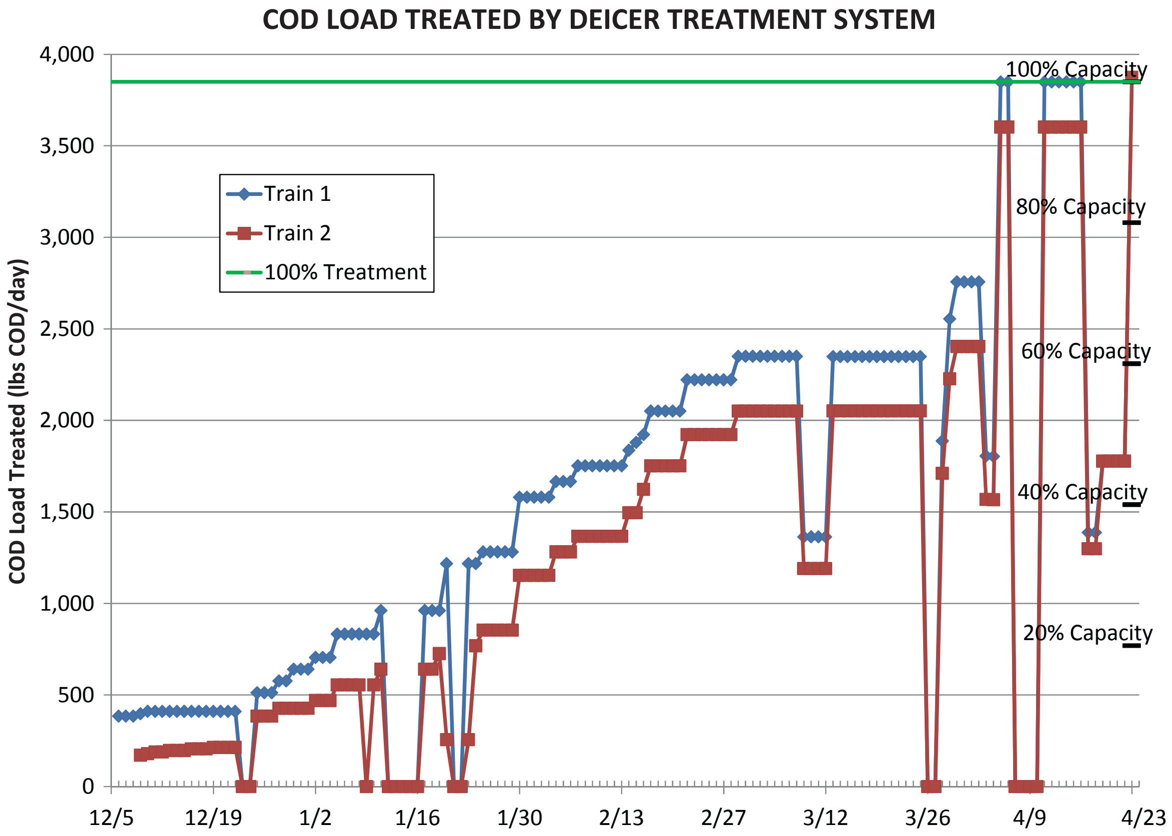

Figure 5. Actual system treated load performance.

Conclusions on Performance of PDX AFBR System

The conclusions presented here are based only on 2011–2012 data, which was the system's start-up season.

Influent Deicer Concentrations

Influent COD concentrations were higher than would be expected in subsequent seasons due to the times when the system was fed from off-spec and new glycol sources. During the times when the system ran from deicer-affected stormwater, the COD concentrations were in the range of what would typically be expected.

Flow Rate

During the start-up phase, flow rates were not representative of flow rates expected in the future when runoff collected from the apron areas will be treated.

Treated Load Rate

The PDX AFBR reached its COD loading target of 7,700 lbs COD per day.

Effluent Concentrations

The PDX AFBR effluent concentrations averaged 131 mg/L based on measurements once the system reached the 50% loading mark. The average effluent concentrations for both reactors were similar.

Treatment Efficiencies

The COD removal efficiency was 99%, exceeding the design target of 98%. The system was able to maintain that removal efficiency at loading rates that ranged from 25% to 100% of design loadings.

Lessons Learned for Potential Implementation of the PDX AFBR Technology at Other Airports

The following factors have proven critical to effective and efficient performance in the PDX AFBR:

1. Proper seeding of bacteria.
2. Achieving target fluidization rates for the pumps.
3. Providing the necessary caustic feed to achieve pH targets.
4. Achieving target reactor temperatures.
5. Step increases in COD loading during the first year.

Conclusions from operation of the AFBR at PDX that can be used by other airports considering this technology include:

1. At initial start-up of the system, acquisition of the appropriate type of healthy bioseed is critical. The bioseed must be obtained from a similar type of anaerobic operation.
2. Appropriate storage capacity and control of loading into the AFBR are important.
3. A well-planned and thorough commissioning of the system, including performance-based commissioning once bioseed is added, is critical to successful system implementation. This includes testing of the biogas handling system under field conditions.

Documents and Information Review in Development of Airport Summary

1. Portland International Airport Deicing Facility Enhancement Project Schematic Design Report (2008).
2. RO Concentrate Treatment Alternatives Plan for PDX Deicing System Enhancements Schematic Design (2007).
3. PDX Airport Deicer Treatment System operational logs (2011–2012).

Airport Treatment Summary No. 13

Airport:	Edmonton International Airport—Edmonton, Alberta (YEG)
Treatment Technology:	Passive Facultative Biological Treatment, Aerated Gravel Beds
Years Operated:	2001–2012 (Currently Operational)[5]

Deicer Management System Description

In the deicer management system at YEG, contaminated snow and ice is piled on the edge of pavement during the very cold winter months. During spring thaw, the contaminated snowmelt is diverted to a 90,000-m^3 (~24 million gallons) pond for storage. The stored contaminated snowmelt is pumped into a treatment system prior to discharge to the adjacent creek. From 2001 through 2011, YEG treated deicer-affected stormwater in a 12-bed wetland-based passive facultative system. Due to the nature of snowmelt in Edmonton, the system functioned as a batch treatment process with initial influent BOD_5 concentrations of approximately 600 mg/L when active treatment began in the spring. As each spring thaw continued, concentrations decreased notably. The system was upgraded in 2011 with the addition of an aerated gravel bed system to provide treatment of airfield runoff associated with deicing activity and meet Alberta Environment permit limits for discharge to a neighboring tributary to Whitemud Creek. Figure 1 shows the treatment system.

The original horizontal flow wetland-based design suffered from performance issues primarily related to a lack of hydraulic capacity. The influent pump was improperly sized to handle the range of static head. Moreover, the horizontal flow configuration of the media bed reduced the hydraulic throughput due to the hydraulic resistance of the gravel. In 2011, the system was upgraded with a new set of influent pumps and reconfigured to a vertical flow configuration to increase the hydraulic capacity. Aeration and nutrient addition were also included based on the projected design load. Two of the original six treatment cells were upgraded to aerated gravel beds.

The upgraded treatment system consists of two parallel trains. The first cell of each train is an aerated graved bed. The second cell is a surface flow wetland. The upgraded system is required

Figure 1. Photo of treatment system.

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[5] The YEG deicing-affected stormwater treatment system was upgraded from non-aerated gravel beds to aerated gravel beds in 2012.

Figure 2. Vertical flow distribution system.

to treat the full capacity of the storage pond within a 60-day time period once treatment starts in the spring, and to produce a high-quality effluent to protect the receiving stream.

Deicer Treatment Technology Selection Considerations

The primary considerations for the airport in selection of the upgraded treatment technology were low capital cost, a system that was compatible with existing systems, the ability to provide sufficient treatment load, and the ability to reliably meet effluent limits. YEG is located in a rural area with an abundance of land surrounding the airfield. A gun club pond and treatment system are located far away and present negligible bird strike hazards.

Deicer Treatment Technology Description

YEG uses a combination of passive facultative treatment (Fact Sheet 108) in the form of a horizontal subsurface wetland and aerated gravel beds (Fact Sheet 102). The flow distribution and aeration/collection piping are shown in Figure 2 and Figure 3, respectively.

Figure 3. Installation of drain and aeration lines.

Table 1. Key system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Capacity
Stormwater storage capacity	42 million gallons	1	42 million gallons
Treatment unit volume	140,000 gallons	2	280,000 gal
Treatment unit dimensions	141-ft L x 141-ft W x 3-ft $3^1/_3$-in. D	2	130,400 ft^3
Treatment facility footprint	0.45 acre per train 2.5 acre total site	2 1	2.5 acre

Description of Support Systems

Influent from the gun club pond is pumped into an aboveground splitter structure that divides flow between the trains. Influent pumps (two) have variable frequency drives. Water from the splitter structure flows by gravity to influent dosing, and nutrient addition lines lie atop the aerated gravel bed. Flow from the dosing line travels downward through the gravel to drains on the floor of the cells. A recirculation pump is installed in a sump prior to the effluent structure and is designed to provide water recirculation during seasonal start-up. Each recirculation pump is sized for 350 gpm. An irrigation propeller pump is used for the high flow, low head system.

Effluent from the aerated gravel bed flows by gravity to the constructed surface flow wetlands (second cell). Influent is distributed along the leading edge of the system and picked up in a drain line running along the opposite side. The water level in this cell is to be maintained at 1-ft water depth.

Key System Sizing Parameters

See Table 1 for system sizing parameters.

Treatment System Performance

See Table 2 for designed system performance information.

The upgraded system was started up in the spring of 2012. Deicer-affected stormwater enhanced with nutrients was gradually loaded into the system in a flow-through manner following a 2-week acclimation period in which effluent was recirculated. The system was able to treat the contents of the storage pond in 60 days while meeting regulatory effluent limits.

Figure 4 illustrates the decrease of COD over the sampling period.

Figure 4 shows a near linear decrease in COD concentrations over time at approximately 7-mg COD/L per hour (168-mg COD/L per day). It is expected that after all biodegradable contaminants are degraded, the COD values will level out to a practical floor representative of the

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Average - Maximum	 275 733	Gallons per minute
Design treatment load capacity	1,770* 1,040 1,040**	lbs COD/day lbs BOD_5/day lbs PG/day
Design effluent concentration (average)	100	mg PG/L
Design treatment efficiency (average)	98%	% influent COD load treated

*Data based on conversion: [COD] = 1.7 [BOD_5].
**Data based on conversion: [PG] = [BOD_5].

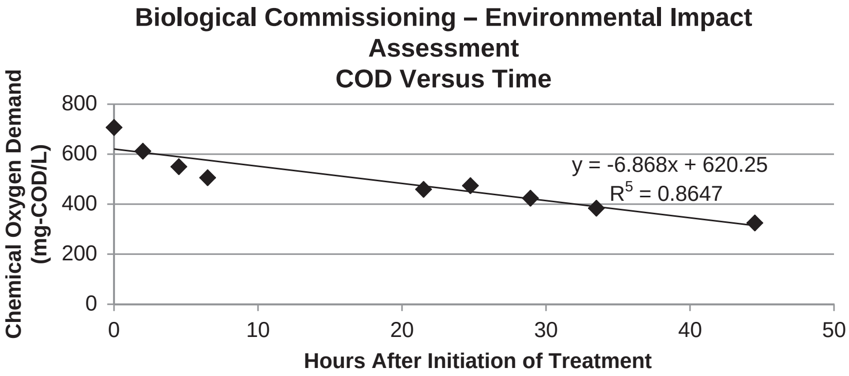

Figure 4. COD removal after initiation of treatment.

nonbiodegradable fraction of organics in the water. Figure 5 provides a visual confirmation of treatment after 24 hours of operation.

Cost Assessment for Treatment System

See Table 3 for treatment system costs.

Conclusions on Performance of YEG Aerated Gravel Bed System

Based on the initial start-up of the enhanced system in the spring of 2012, the addition of the aerated gravel beds met performance objectives.

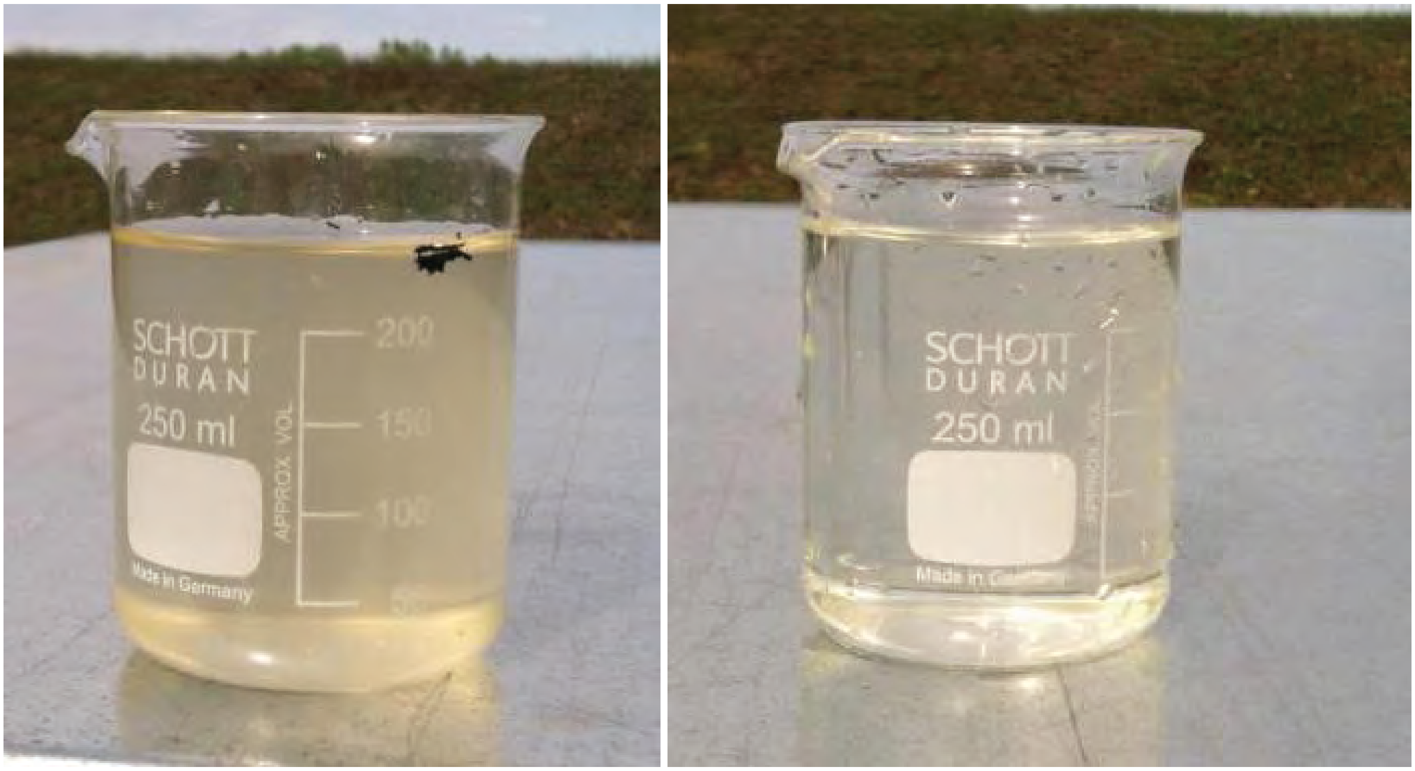

Figure 5. Influent (left) and effluent (right) samples after 24 hours of operation.

Table 3. Costs for the treatment system.

Cost Category	Projected at Initial Implementation	Actual
Capital cost*		
- Initial system	$2,000,000	$2,000,000
- Upgraded system	$3,000,000	$3,000,000
Annual operating cost	Not provided	Not provided

*Capital costs are for the treatment system only, including the building and basic building infrastructure. Costs do not include site-specific costs for collection, storage, and discharge.

Lessons Learned for Potential Implementation of the AFBR Technology at Other Airports

The following factors are anticipated to be critical to effective and efficient performance in the YEG aerated gravel bed system:

1. The ability to maintain a loading rate below 0.051-lbs BOD/ft^2/day.
2. The ability to provide upstream equalization from the beginning of the deicing season until spring thaw.
3. The ability to apply nutrients one time upstream of the treatment system was deemed the most cost-effective means to add nitrogen and phosphorus to the influent flow.
4. Presence of adequate material to operate effectively during extremely cold winters.
5. The ability to start up and shut down effectively since the system is uniquely designed to provide treatment of stormwater in the thaw period of the spring.

Documents and Information Review in Development of Airport Summary

1. Wetland treatment upgrade–construction drawings (Associated Eng., et al.)
2. Design Brief, February 2011(Associated Eng. and Naturally Wallace)
3. Naturally Wallace project files.

Airport Treatment Summary No. 14

Airport:	Halifax International Airport—Halifax, Nova Scotia (YHZ)
Treatment Technology:	Mechanical Vapor Recompression (MVR)
Years Operated:	2004–2012 (Currently Operational)

Deicer Management System Description

YHZ has both a passive and active collection system in place for the capture of spent aircraft deicing fluid. All ADF that is applied at YHZ is EG-based. Deicing operations are conducted at both the terminal gate areas and the remote deicing pad.

Active collection involves the use of GRVs on any area with deicing activity in order to maximize the collection of high-concentrate fluids as soon as possible.

Passive collection involves the use of a dedicated glycol collection drainage system for the deicing pad areas. These collection basins, piping, and pump stations allow conveyance of spent aircraft deicing fluid to on-site storage tanks adjacent to the deicing pads. The spent ADF captured by this passive system is sent to two storage tanks (each with 65,000 gallons of capacity), which are connected to the deicing pad pumping systems. The two large storage tanks act as the interim storage until the spent ADF is transferred via tanker truck to the glycol processing facility at YHZ.

All spent ADF that is collected is treated at an on-site recycling facility located at the Halifax International Airport. The glycol processing facility is owned and operated by a recycling subcontractor. This facility is on the airport, but it is located outside the airside secured area. Once transported to the processing facility, the collected ADF is segregated according to glycol concentration. The YHZ glycol recycling facility has two storage tanks with a combined volume of 950,000 U.S. gallons; these are used to store the low-concentration ethylene glycol (less than 10%). A third storage tank with a capacity of 66,000 U.S. gallons is designated for the collection of high-concentration ethylene glycol (more than 10%). The entire spent-ADF management system is operated by a subcontractor to ensure that unpermitted levels of glycol do not enter the sanitary sewer, via the airport wastewater flow, in order to comply with the Halifax Regional Municipality Wastewater Guidelines as directed by the Nova Scotia Department of Environment's 2004 permit approval. This coincides with the Canadian Environmental Protection Act, which requires that discharge of glycols into surface waters resulting from aircraft deicing and anti-icing activities at Canadian airports not exceed a concentration of 100 mg/L of ethylene glycol at the property lines.

The recycling equipment includes three mechanical vapor recompression units, one dissolved air floatation filtration system, and one distillate aerator. All wastewater generated from the on-site treatment systems is discharged to an off-site wastewater treatment plant called the Aerotech Park Wastewater Treatment Facility.

Deicer Treatment Technology Selection Considerations

In 2002, the aviation industry in Canada established a "National Contract" to ensure that the airline community met the guidelines for the discharge of effluent generated from deicing operations. The Halifax International Airport meets these terms by using a subcontractor to manage the drain management at the gate areas and the deicing pads to ensure all noncompliant fluids are collected and processed. The guideline for release to the environment is 100-mg/L ethylene glycol, as set under the Canadian Environmental Protection Act.

YHZ has deicing pads that consist of a pumping system that the airport owns and maintains. This is used to pump all high-volume fluids from the deicing pads into aboveground storage tanks beside the pads. With Halifax being in a maritime climate, there are many weather events that require the collection of rainwater until the 100-mg/L release point is met. This typically could result in a large volume of dilute spent ADF being collected, but GRVs are also used to vacuum the glycol directly off the surface. The fluids recovered by the GRVs are normally higher in concentration levels. By proactively cleaning the pad surfaces with this equipment, the overall volume of stormwater that has to be collected is reduced, and compliance levels can be met more quickly.

All the collected ADF, from the passive system on the deicing pads and from direct recovery on pads or gates with the recovery vehicles, is transferred to the glycol recycling facility at YHZ. The fluids from the passive system are transferred by tanker truck, while the glycol recovery vehicle offloads the fluid it collects directly into the appropriate tank located at the facility.

The Halifax site recycling system was designed, installed, and implemented to meet the following requirements:

1. Compliance with federal and provincial environmental regulations plus the existing municipal bylaws for wastewater discharge criteria.
2. On-site treatment that generates wastewater requires compliance with the following: limitations of 100-mg/L EG, 300-mg/L BOD_5, 1000-mg/L COD, 15-mg/L oil and grease (mineral/synthetic), and 300-mg/L TSS.
3. Ability to meet an average production/removal rate of 400,000 U.S. gallons per month when spent-ADF volumes are present.

Treatment technology was selected by the recycling contractor on the basis of being able to handle fluctuating glycol concentrations in spent ADF that occur with each weather-related deicing event. The analysis of factors included designing processing capability based on actual spent-ADF collection data from previous years. As part of the overall system, two independent processing trains were designed: one to recycle ethylene glycol of less than 10% concentration from the low-concentrate feed tanks, and another to process ethylene glycol of greater than 10% concentration from the high-concentrate feed tank. MVR was selected to treat both streams of concentrations because:

1. Alternative disposal options were limited and expensive (specifically, no off-site treatment facilities were in close proximity to the airport),
2. The MVR could handle anticipated fluctuations in glycol concentrations, and
3. The airport authority determined it was in its best interests to capture and recycle the glycol.

Equipment was sized to accommodate the 400,000-gallon/month removal rate and so that no additional storage tanks would be required for storage and processing of the collected fluids. The glycol that is reclaimed from the system is sold, and the revenues generated are used to offset program costs to provide glycol management services.

Deicer Treatment Technology Description

The YHZ treatment system employs the MVR treatment process. A description of the MVR treatment technology can be found in Fact Sheet 106. Figure 1 shows the recycling facility.

Description of Treatment Support Systems

The MVR at YHZ includes the following support systems: two low-concentrate tanks capable of storing a combined 846,000 gallons, one high-concentrate tank capable of storing 66,000 gallons, a filtration system, a dissolved air flotation (DAF) unit, a chemical feed system, blowers

Figure 1. YHZ glycol recycling facility.

with variable frequency drives, heat exchangers, a scrubber-absorber, electrical service, a control system, MVR maintenance, and solids disposal.

Filtration systems installed to treat influent on the MVR units are an integral part of the overall recycling system. The DAF unit is an effective and integral part of the recycling process. Stainless-steel hot filter vessels with 1-micron filter bags are also used on each MVR prior to the feed entering the unit, which allows the influent to be filtered while it is hot in an effort to remove as much TSS as possible. Each type of filtration method increases influent throughput production by minimizing stoppages due to premature maintenance and cleaning requirements of the MVR heat exchangers.

The DAF was designed as a support system to the MVR units to treat as much of the contaminants that make up TSS in the spent ADF as can be drawn out before the fluid is processed. Using the DAF increases production, and with less contamination of dirt in the MVR heat exchanger plates, the downtime for maintenance and cleaning is significantly reduced. The DAF adjusts the pH to a neutral level by reading and injecting caustic with a pumping system. With the fluid at neutral pH, a flocculent chemical is added. This fluid is then injected into the fluid-filled DAF unit along with air drawn in through the DAF pump. This mixture binds the contaminants (smaller than 1 micron) together to make larger particles that float with the air that was injected. These accumulated contaminants form a floating cake on the top of the fluids, which is skimmed off and disposed of. The fluids under the cake, now filtered by the DAF, are drawn in to the MVR units for processing. The concentrate is kept in tanks for interim storage until it can be trucked off the airport for sales into secondary markets.

The control system includes many warning and emergency controls that, in the event of any mechanical failure or fluid overflow situation, shut off the units automatically. These were installed to minimize manpower requirements so that in most cases the facility can be run with one person.

Heat exchanger plate changes are anticipated every 170,000 U.S. gallons on average. Downtime per shutdown is approximately 12 hours per machine for total maintenance.

Solids from processing in YHZ filters are dried and sent to a landfill. Tank sludge at season end is disposed of at an off-site treatment plant.

Key Treatment System Sizing Parameters

The recycling contractor leases the airport land for the glycol processing facility, as well as the airside tanks at YHZ. The contractor supplied and installed the tanks, building, recovery trucks, and processing equipment for the Halifax site. The airport authority supplies the deicing pad

Table 1. Key treatment system sizing parameters.

Component/Parameter	Size/Capacity of Treatment Units	Number of Treatment Units	Total Value
Stormwater storage capacity			
Low-concentrate storage	423,000 gallons	2	846,000 gal
Airfield storage	66,000 gallons	2	122,000 gal
High-concentrate storage	66,000 gallons	1	66,000 gal
Product storage volume	17,000 gallons	3	51,000 gal
Treatment unit dimensions			
MVR	20-ft L x 6-ft W x 8’2” H	3	
MVR with scrubber	20-ft L x 6-ft W x 22 H		
Treatment facility footprint			
MVR treatment building	0.11 acre	1	0.11 acre
Treatment building and storage tanks	4.94 acre	1	4.94 acre

Table 2. Stage 1 EG processing design basis (concentrator MVR systems).

Glycol Percentage	Min. Removal Rate per Month (Two concentrators)	Max. Removal Rate per Month (Three concentrators)
<10% and lower	225,000 gallons	458,000 gallons

Table 3. Stage 2 EG processing design basis (concentrator MVR systems).

Glycol Percentage	Min. Removal Rate per Month (One concentrator)	Max. Removal Rate per Month (Two concentrators)
>10% and higher	95,000 gallons	260,000 gallons

Table 4. Design basis for MVR system performance.

Parameter	Value	Unit
Design flow rates		Gallons per minute
- Minimum	2	
- Average	Not available	
- Maximum	4	
Design treatment load capacity	16,500*	lbs COD/day
	9,700**	lbs BOD_5/day
	9,700	lbs PG/day
Design influent concentration	13,000~351,000*	mg COD/L
- Range	5,000~135,000**	mg BOD_5/L
	10,000~270,000	mg PG/L
Design effluent concentration (average)	<50~1000	mg COD/L
	Not available	mg BOD_5/L
	<50~1000	mg PG/L
Target concentrate stream % EG	50	%
Design treatment efficiency	94.1~99.7	% influent COD load treated

*Data based on conversion: [EG] = 1.3 [COD].
**Data based on conversion: [EG] = 0.5 [BOD_5].

and pumping systems and owns the drain blocking devices used in the spent-ADF collection infrastructure. See Table 1 for treatment sizing parameters.

Treatment System Performance

The processing/disposal rate per month will vary based on the glycol percentage. A processing performance of 400,000 gallons per month was designed based on two stages, with the concentrator system running to achieve the performance indicated in Table 2 through Table 5.

The information in Table 6 on actual system performance was derived from monthly average data collected at the facility between 2009 and 2012.

Table 5. Additional design basis for MVR system.

Parameters	Single-Stage Production	Two-Stage Production	
		Stage 1	Stage 2
Influent flow rate range (gallons per hour)	150 to 200	170 to 230	130 to 170
Influent glycol concentration range (% glycol)	4 to 27	1 to 4	13 to 27
Influent temperature range (F or C)	Ambient	Ambient	Ambient
Number of effluent streams produced	2 streams–distillate and concentrate	2 streams–distillate and concentrate	2 streams–distillate and concentrate
Distillate effluent flow rate range (gallons per hour)	60 to 184	136 to 219	52 to 126
Distillate effluent water quality (COD range in mg/L)	<50 to 1,000	<50 to 1,000	<50 to 1,000
Distillate effluent water quality (mg/L COD)	<50 to 1,000	<50 to 1,000	<50 to 1,000
Distillate effluent water quality (pH range)	3 to 8	3 to 8	3 to 8
Concentrate effluent flow rate range (gallons per hour)	12 to 120	8.5 to 61	33 to 102
Concentrate effluent concentration (% glycol range)	50 to 55	15 to 20	50 to 55
Heat source	Electric-powered steam compression		
Control system	PLC		
Energy consumption information	0.4 Kw per gal feed		
Estimate of waste to be produced	Sludge and solids negligible and glycol in overheads less than 0.1%		
Footprint, dimensions, etc.	Each MVR unit is 20’ (L) x 6’ (W) x 8’ 2” (H), with scrubber 13’ (H) or 22’ (H)		
Other support systems	Feed pre heater heat exchanger, electric air compressor, cold and hot filter systems, piping for feed, distillate, concentrate, and storage tanks for feed, distillate, concentrate		

Notes: Specifications provided by Inland Technologies per design criteria for each MVR.
YHZ has three MVR units installed.

Table 6. Actual MVR system performance.

Parameter	Value	Unit
Flow rates - Minimum - Average - Maximum	 0.11 5.9 8.6	Gallons per minute
Actual EG treatment load rate - Average - Maximum	 695 1,180	lbs/day
Influent EG concentration - Minimum - Average - Maximum	 27,000 52,000 105,000	mg/L
Effluent COD concentration	<100 mg/L	mg/L
Effluent BOD_5 concentration	Not available	mg/L
Effluent EG concentration* - Average - Maximum	 27 70	mg/L
Treatment efficiency	99.66	% influent EG load treated

Values obtained from the monthly averages and totals in “Historical Data Assessment Based on Three Seasons of Data from 2009 Through 2012.”
*Values obtained from monthly sampling provided in “Historical Data Assessment Based on Three Seasons of Data from 2009 Through 2012.”

Table 7. Actual YHZ MVR data for 2009–2010 deicing season.

Stage 1	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total or Avg for Season**
Influent volume processed (liters)	285,258	962,200	1,071,267	1,048,233	1,256,418	1,157,428	547,684	**6,328,488**
Average influent glycol concentration (% EG)	6.9%	3.7%	4.6%	5.1%	4.3%	3.1%	1.5%	**4.2%**
Effluent volume of concentrate produced (liters)	83,328	266,124	334,766	332,045	349,691	270,055	106,638	**1,742,647**
Average effluent concentration of glycol produced (% EG)	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Stage 2								
Influent volume processed (liters)	0	294,078	289,742	356,237	380,658	235,500	212,223	**1,768,438**
Average influent glycol concentration (% EG)	0.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Volume of 100% EG in influent (liters)	0	41,171	40,564	49,873	53,292	32,970	29,711	**247,581**
Effluent volume of concentrate produced (liters)	0	60,535	75,403	89,617	101,056	52,072	50,935	**429,618**
Average effluent concentration of glycol produced (% EG)	0.0%	53.0%	50.5%	52.0%	54.6%	53.0%	53.0%	**52.7%**
Volume of 100% EG in glycol produced (liters)	0	32,084	38,079	46,601	55,177	27,598	26,996	**226,533**
Combined Discharges from Both Stages								
Total distillate discharged to sanitary (liters)	165,396	785,907	854,841	768,398	1,053,244	1,157,206	561,469	**5,346,461**
Average effluent concentration of distillate (mg/L EG)	<100	<100	<100	<100	<100	<100	<100	**<100**
% ratio of glycol reclaimed from Stage 2 vs. infeed	N/A	77.9%	93.9%	93.4%	103.5%	83.7%	90.9%	**91.5%**

Historical Data Assessment Based on Three Seasons of Data from 2009 Through 2012[6]

See Table 7 through Table 9 for actual MVR data at YHZ.

Cost Assessment for YHZ MVR Treatment System

The recycling contractor leases the airport land for the glycol processing facility as well as the airside tanks at YHZ. The contractor supplied and installed the tanks, building, recovery trucks, and processing equipment for the Halifax site. The airport authority supplies the deicing pad and pumping systems and owns the drain blocking devices used in the spent-ADF collection infrastructure. See Table 10 for treatment system costs.

Conclusions on Performance of YHZ Treatment System

Influent Deicer Concentrations and Flow Rate

The MVR units at YHZ are configured to conduct two-stage processing. Based on data from 2009–2012, influent glycol concentrations of the low-concentration EG stream ranged from 3.9% to

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[6] All treatment data provided by YHZ operational logs.

Table 8. Actual YHZ MVR data for 2010–2011 deicing season.

Stage 1	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total or Avg for Season
Influent volume processed (liters)	19,262	731,277	1,067,950	1,273,601	989,352	1,413,106	1,011,352	1,136,983	453,591	**8,096,474**
Average influent glycol concentration (% EG)	5.6%	5.5%	4.3%	4.3%	4.1%	3.2%	3.4%	3.4%	5.0%	**4.3%**
Effluent volume of concentrate produced (liters)	5,517	213,741	292,599	314,743	315,608	335,442	260,667	327,040	133,409	**2,198,766**
Average effluent concentration of glycol produced (% EG)	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Stage 2										
Influent volume processed (liters)	0	165,444	402,440	184,862	387,560	250,735	316,829	293,245	245,730	**2,246,845**
Average influent glycol concentration (% EG)	0.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Volume of 100% EG in influent (liters)	0	23,162	56,342	25,881	54,258	35,103	44,356	41,054	34,402	**314,558**
Effluent volume of concentrate produced (liters)	0	38,749	100,184	39,166	103,328	73,916	85,043	72,142	69,717	**582,245**
Average effluent concentration of glycol produced (% EG)	0.0%	54.2%	55.5%	52.7%	52.0%	52.0%	52.0%	52.7%	51.0%	**52.8%**
Volume of 100% EG in glycol produced (liters)	0	21,002	55,602	20,640	53,731	38,436	44,222	38,019	35,556	**307,208**
Combined Discharges from Both Stages										
Total effluent distillate discharged to sanitary (liters)	0	476,219	720,682	830,623	715,328	1,132,068	909,635	1,065,889	525,778	**6,376,222**
Average effluent concentration of distillate (mg/L EG)	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	**<100 mg/L**
% ratio of glycol reclaimed from Stage 2 vs. infeed	N/A	90.7%	98.7%	79.8%	99.0%	109.5%	99.7%	92.6%	103.4%	**97.7%**

4.3%. This low-percentage feed is processed by two of the MVR units to make a concentrated stream with an average concentration of 14%. This stream is then comingled with any other spent ADF that is collected that is over 10% EG concentration so that the third MVR unit is configured to process the high-concentration EG feed, which is brought up to 50% to 52% EG. Based on feedback from the recycling operator, the MVR up-stages the concentration of spent EG to increase flow rates through the MVR units. In reference to the data, it is apparent that each concentrator running Stage 1 can process at least double the amount of influent when compared to a concentrator running Stage 2, higher-concentration glycol. This is very beneficial since this technique removes water from storage tanks more quickly than single-stage processing and keeps adequate storage for future storm events.

Treated Load Rate

The rate at which soluble or total COD is removed from the system is not a key measure of performance for the MVR system.

Effluent Concentrations

Each MVR at YHZ can be adjusted to produce a desired glycol concentration product. The MVR units produce two effluent streams, and the desired concentration set points in each effluent stream directly affect the performance of the concentrators. The operators have the ability to

Table 9. Actual YHZ MVR data for 2011–2012 deicing season.

Stage 1	**November**	**December**	**January**	**February**	**March**	**April**	**Total or Avg for Season**
Influent volume processed (liters)	502,376	1,056,419	1,168,546	1,218,376	1,385,299	1,346,240	**6,677,256**
Average influent glycol concentration (% EG)	4.0%	2.9%	3.6%	3.9%	4.8%	4.4%	**3.9%**
Effluent volume of concentrate produced (liters)	120,730	200,061	277,204	292,074	433,171	385,922	**1,709,162**
Average effluent concentration of glycol produced (% EG)	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Stage 2							
Influent volume processed (liters)	0	219,335	294,294	251,748	512,606	440,452	**1,718,435**
Average influent glycol concentration (% EG)	0.0%	14.0%	14.0%	14.0%	14.0%	14.0%	**14.0%**
Volume of 100% EG in influent (liters)		30,707	41,201	35,245	71,765	61,663	**240,581**
Effluent volume of concentrate produced (liters)	0	54,835	74,691	67,084	132,377	107,773	**436,760**
Average effluent concentration of glycol produced (% EG)	0.0%	52.0%	53.0%	51.8%	52.8%	53.5%	**52.8%**
Volume of 100% EG in glycol produced (liters)	0	28,514	39,586	34,750	69,895	57,659	**230,404**
Combined Discharges from Both Stages							
Total effluent distillate discharged to sanitary (liters)	261,080	989,616	1,104,459	862,233	1,383,081	1,423,335	**6,023,804**
Average effluent concentration of distillate (mg/L EG)	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	<100 mg/L	**<100 mg/L**
% ratio of glycol reclaimed from Stage 2 vs. infeed	N/A	92.9%	96.1%	98.6%	97.4%	93.5%	**95.8%**

Table 10. Costs for the treatment system.

Cost Category	**Actual (Canadian $, 2003)**
Capital cost* Building and storage tanks Concentrators and support equipment **Total capital cost**	 $2M $1.15M $3.15M
Annual operating cost** - Utilities - Processing supplies - Analysis - Repair and maintenance, labor, tank cleaning, other **Total operating cost**	 $90,000 $23,000 $5,000 $312,000 **$ 430,000**

*Capital costs are for the treatment system only and do not include glycol collection infrastructure costs.
**Processing supplies include chemicals and filters.

adjust various parameters on each MVR via the PLC and can do so as conditions or influent characteristics change. In Stage 1 of the processing phase, the effluent glycol produced averaged 14% EG. This glycol concentration is continually monitored to balance the parameters on the machine to increase the processing rate of the low-concentration influent and to ensure that the effluent glycol produced is of a concentration that is ideal to feed Stage 2 of the processing. At Stage 2, the effluent glycol level is also crucial as the recycling contractor has a goal to produce a minimum of 50% EG. At this level and higher, the contractor is able to sell the glycol and generate revenue to offset the expenses of the recycling operation.

The second effluent stream produced from the MVR units is a distillate. This is the distilled water, which is continually monitored to ensure that glycol levels remain below 100-mg/L EG, and that BOD is below 300 mg/L to comply with the wastewater discharge permits. Based on the data, the MVR systems demonstrate that they are able to continually achieve distillate levels below the 100-mg/L requirement. BOD target concentrations are met through monitoring of COD concentrations and application of a site-specific correlation factor for COD to BOD. If the wastewater is not within the target concentration range, it can be sent through an aerator system prior to discharge.

Effluent Concentrations

The MVR has a concentrate and a distillate stream. However, the concentrate from the MVR is sold to vendors for EG reuse. The MVR distillate stream is sent back to the Aerotech Park Wastewater Treatment Facility for further treatment. Additionally, the distillate effluent EG concentrations have consistently been demonstrated to be below 100 mg/L.

Treatment Efficiencies

Based on the data, 95% of the glycol that was fed through the MVR systems was reclaimed. The remaining balance of glycol was discharged through the effluent distillate stream to the POTW or for handling as solid waste at an off-site disposal facility. At a peak, the ratio of glycol produced from the MVR for reuse compared to the amount of glycol fed through the system reached over 97.7% during the 2010–2011 season. Based on operator feedback, this ratio is based on the data provided and is only from meter readings.

Cost

Before an on-site recycling facility was established at YHZ, all spent ADF was trucked to an off-site disposal facility in Debert, Nova Scotia. With the increase in volumes of ADF being applied at YHZ and the increase in volumes collected of spent ADF, trucking off-site became almost unsustainable. An average season at YHZ could generate 240 tanker trailer loads that would have to be trucked off-site. In addition, the cost was significant since each load would experience a 4-hour turnaround and unpredictable weather conditions during the winter that could halt transportation altogether. This affected the availability of on-site storage to support deicing operations. With an on-site recycling facility, fluid is transferred quickly, and manpower requirements are reduced. The recycling contractor staff is used to conduct collection operations, recycling activities, and the management of wastewater discharges. The fluid is processed on-site, and adequate storage can be maintained for deicing operations.

Lessons Learned for Potential Implementation of the MVR Technology at Other Airports

The following factors have proven critical to the effective and efficient performance of the YHZ MVR system:

1. Variability in influent glycol concentrations and the ability to adjust the MVR systems to respond.

2. Quality of influent improved by filtration methods prior to treatment.
3. Desired effluent concentration of product produced affects influent processing rate.
4. Daily preventative maintenance is integrated into operations in order to optimize equipment performance.
5. Maintaining process variables such as temperature, flow rate, and pressures at consistent set points improves production rates.

Although the distillate effluent concentrations are low, additional treatment of the low-concentration distillate is typically necessary. The MVR treatment system may commonly be installed at airports where there is an outlet for the effluent water produced such as a POTW or other type of system to treat low levels of COD and glycol.

MVR units are more economical the greater the volume of ADF sprayed at the airport and, more importantly, the more glycol that can be captured at the airport for recycling. The greater the volume reclaimed, the larger the volume of product that can be sold to generate revenues to offset capital and operating expenses. Sale of the treated EG can reduce operational burdens and concerns associated with extensive trucking operations during winter weather events.

Conclusions from operation of the MVR at YHZ that can be used by other airports considering this technology include:

1. The MVR at YHZ requires additional treatment of the MVR distillate such as the use of a POTW or RO treatment system to be discharged to surface waters.
2. MVR heat exchangers require more maintenance and cleaning when dealing with ADF with higher concentrations of thickening agents, such as Type IV ADF.
3. The MVR technology can be effective for airports that consistently have variability in weather patterns and in influent concentrations.
4. The MVR can successfully conduct two-stage processing in an effort to efficiently remove large volumes of water in very diluted glycol concentration streams.
5. The MVR concentrators are modular, which means they can be installed in a relatively small footprint and can be adjusted to deal with varying influent concentrations or infrastructure needs.
6. If an airport generates a significant volume of spent ADF, then on-site recycling can be more cost-effective than transporting the fluid to an off-site facility.
7. Filtration systems are an integral part of the glycol recycling process with MVR technology.
8. The DAF system is a viable support technology to improve processing rates as well as other mechanical filtration methods to minimize equipment maintenance associated with heat exchanger plate fouling.

Airport Treatment Summary No. 15

Airport:	Zurich International Airport—Zurich, Switzerland (ZRH)
Treatment Technologies:	Passive Facultative Biological Treatment Distillation Treatment
Years Operated:	2002–2012 (Currently Operational)

Deicer Management System Description

ZRH is Switzerland's primary airport, transporting approximately 24 million passengers annually. The airport covers a total area of 800 ha (1,976 acres), including 250 ha (617 acres) of impervious area. Permit limits for stormwater discharges to the river Glatt require concentrations of less than 10-mg/L BOD_5 and less than 20-mg/L dissolved organic carbon (DOC). As a result, much of the deicer-affected runoff from the airport has to be collected for treatment at the airport.

In 2002, ZRH constructed a system for collecting, storing, and treating deicer-affected stormwater featuring passive, in-ground biological treatment. Testing of the system and establishment of operating parameters occurred over a 5-year period from 2002 to 2007. At present, two forms of passive facultative biological treatment technology, infiltration basins and spray irrigation-fed soil treatment, are used to treat low- and moderate-concentration fractions of runoff, respectively. The airport also uses distillation for treatment of high-concentration runoff to obtain a recyclable product.

In the ZRH deicer management system, represented schematically in Figure 1, approximately 70% of the aircraft deicer is applied on two central deicing pads, with most of the remainder applied at the terminal aprons. Runoff containing spent deicing fluid is collected from the deicing pads, terminal apron, remote deicing areas, and several taxiways. All but 250 hectares of

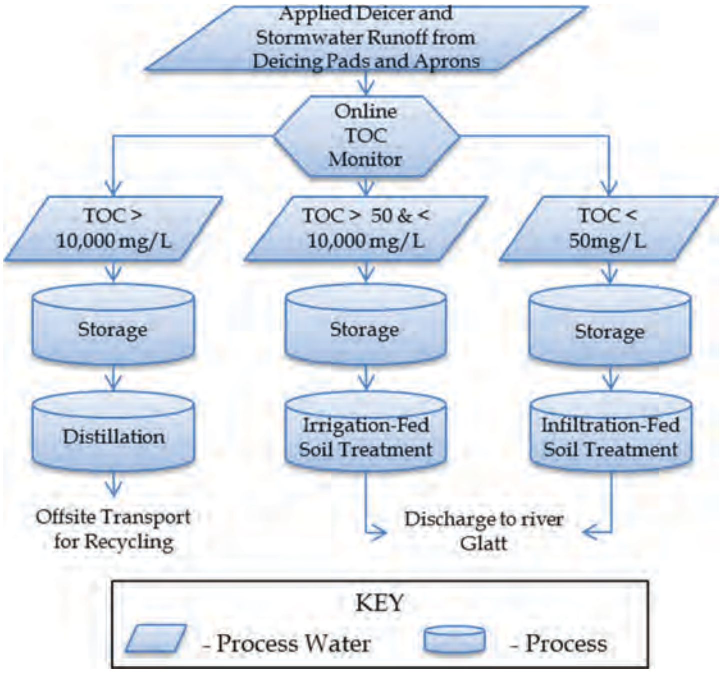

Figure 1. Zurich International Airport deicer management system.

airport surface area is currently collected. However, based on pressure from regulators, ZRH is planning to expand the area of runoff collected and treated. Currently, ZRH collects and treats 75% of the carbon contained in deicer-affected runoff. By the year 2015, this share is expected to be increased to 95%.

Online TOC meters at various locations are used to measure the concentration of the collected runoff. The runoff is diverted to one of three locations based on concentration, as shown in Figure 1. The runoff is stored in underground reservoirs prior to treatment and disposal. The airport has 5.3 million liters of storage tanks available for runoff.

Through over 5 years of pilot testing and monitoring, ZRH determined that a high degree of control of the quantities and timing of discharges to treatment are necessary to achieve the desired effluent quality.

Deicer Treatment Technology Selection Considerations

In the 1990s, the local Swiss canton (state) began pressuring the Zurich Airport Authority (ZAA) to meet cantonal concentration limits for discharges from ZRH to the river Glatt. To reduce impacts to the Glatt from deicing operations, a deicing task force, made up of the department of water protection and hydraulic engineering and Swissair, was created. The task force began evaluating treatment methods appropriate for reducing discharges from the airport to below the cantonal concentration limits.

ZRH evaluated discharge to the local POTW (Werdholzli), in-situ soil treatment, aerated gravel beds, and aerobic membrane bioreactors as potential treatment technologies. The passive biological methods included two alternatives: root (reed) bed wetland treatment and spray irrigation treatment.

Pilot studies were conducted for root bed sewage, spray irrigation, aerated gravel beds, and the aerobic membrane bioreactor. All of the treatment methods demonstrated the ability to reduce concentrations from deicing operations at ZRH to below the cantonal concentration limits. However:

1. The Werdholzli POTW treatment capacity was determined to be inadequate to treat the flows or loads from ZRH.
2. A reed bed wetland-based treatment system was tested and had some success, but it was determined not to be a desirable long-term option because of the following:
   a. It had odor issues.
   b. It was an obstacle to aviation activities.
   c. It required too much space.
   d. It required too much maintenance.
   e. The effectiveness of treatment depended greatly on starting conditions and other factors difficult to control.
   f. A large initial capital investment would be required.
   g. Maintenance costs were high.

The spray irrigation in-situ soil treatment technology tests demonstrated that the technology would require the lowest investment and lowest operational costs. Additionally, spray irrigation was selected because:

1. It is suitable for low concentrations,
2. ZRH has land available for irrigation, and
3. The ZRH climate is suitable for wintertime irrigation.

Figure 2. Surface of ZRH infiltration basin.

The spray irrigation system was tested from 2002 to 2007 as described in the following and has been operational since. The testing was performed to establish the parameters for controlling influent flows to the irrigation system based on ambient conditions.

ZRH also has a second passive facultative system described as infiltration basins (see Figure 2) that treat the lowest-concentration fraction of runoff (<50-mg/L TOC). Runoff for this system is supplied via piping rather than spray irrigation. In recent years, a distillation system was also added on-site to increase the concentration of runoff with greater than a 1% concentration.

Deicer Treatment Technology Description

The irrigation and infiltration fed treatment technologies below the ground surfaces at ZRH are classified as passive facultative biological treatment technologies in this guidebook. The systems are considered passive because there is no active control over the biological treatment that occurs in the soil and media in the in-ground systems (e.g., there is no aeration, nutrient addition, or mixing). There is, however, significant active control over the timing and degree to which the treatment areas are loaded with deicer-affected stormwater. The systems are classified as facultative because, without active aeration, it is reasonably likely that the bacteria degrading the deicer are a mix of bacteria types or bacteria that can function under both aerobic and anaerobic conditions. The focus of this summary is on the two biological technologies, although the basic parameters of the distillation system used to treat the bulk of the deicer loading are provided. General descriptions of the passive facultative technologies and distillation technologies are provided in Fact Sheet 108 and Fact Sheet 105, respectively. The specific applications of the technologies used at ZRH are described in the following.

1. *Infiltration Basins (for TOC < 50 mg/L)*

   The lowest-concentration portion of the runoff (<50-mg carbon/L) at ZRH is treated with a passive facultative treatment technology described by the airport as infiltration basins. The basins include a vegetated 30-cm top layer of humus (degraded organic material) on top of a sand and stone gravel layer. A liner is located under the gravel layer to seal the treatment units and prevent contamination of groundwater. Treated water is collected with a perforated pipe and discharged to the river Glatt. Approximately 47% of the total surface runoff volume and 0.3% of the total spent deicer mass load are treated in the infiltration basins.

2. *Spray Irrigation In-Situ Soil Treatment Technology (for TOC > 50 mg/L, <10,000 mg/L)*

   The spray irrigation in-situ soil treatment at ZRH is a highly controlled system for managing spraying of deicer-affected runoff to the soils based on ambient conditions and runoff characteristics. The irrigated areas cover approximately 21 hectares (51 acres). The irrigated areas are in the infield grass areas outside of the safety areas adjacent to the runways. The

Figure 3. ZRH irrigation system.

irrigation system (see Figure 3) requires a complex series of pumps, pipes, and approximately 700 pop-up sprinklers with heated heads to prevent the mechanism from freezing in winter. The irrigation pumps are fed from six reservoirs, which can hold a total of approximately 4,500 m^3 (~1.2 million gallons). The irrigation system can process approximately 25 liters per second

While irrigation could take place year round, due to relatively low storage capacity, irrigation is operated from October to April. The flow rates pumped through the irrigation system are controlled based on continuous measurement of several different parameters, including:

- Influent and effluent TOC concentration,
- Groundwater depth,
- Precipitation,
- Wind speed,
- Air temperature, and
- Soil temperature.

The airport has developed ranges for these ambient conditions that are acceptable to achieve the desired effluent quality. The system has TOC (DOC) load targets on an hourly, daily, and total load basis specific to irrigation areas that are not to be exceeded. Vegetation is also monitored. The procedure for monitoring and controlling flows to the irrigation system is largely automated. The monitored area is divided into four quadrants.

No irrigation can occur under the following conditions:

- Rainfall of over 0.2 cm per hour.
- Rainfall of over 1.5 cm per day.
- Air temperature of less than –15°C.
- Soil temperature of less than –2°C.
- Wind greater than 6 m/s.
- Groundwater less than 0.5 m below the surface.

Pollutants are degraded biologically primarily in an aerobic zone in the top 20 cm (8 in.) of the soil. Based on testing, degradation is most complete at a depth of 80 cm (32 in.). Treated water from the irrigation system passes through perforated pipe drains that were originally installed at the airport for reducing the airport groundwater elevations. Therefore, unlike some other in-situ–based soil treatment systems, ZRH has the opportunity to monitor the treated concentrations. This monitoring led to the understanding that the loadings of deicer-affected stormwater to the soil needed to be controlled based on the factors shown previously. The monitoring and control system helps to reduce the exposure of the treatment system to stressful conditions. The treated water is discharged to the river Glatt. The typical detention time in the soils associated with the irrigation system is 7 days.

Figure 4. ZRH distillation system.

The irrigation areas are located in the infield areas adjacent to runways and taxiways, although outside of the runway safety areas. Approximately 36% of the total surface runoff and 7% of the total spent deicer load are treated in the current irrigation system. ZRH is planning to collect an additional 77 hectares of area and treat it in a new irrigation area 25 hectares in size, which adds up to a total irrigation area of 45 hectares.

3. *Distillation*

Distillation (see Figure 4) is used for high-concentration spent deicing fluid collected from two deicing pads. The high-concentration portion of the collected runoff is processed with an on-site distillation treatment plan paid for and run by a deicing chemical company. If the average concentration is below 5% glycol, the distillation process is not economically reasonable because of electricity costs. Collected concentrations sent to the distillation system range from 5% to 10%. The distillation process produces a concentrated and a diluted stream. The concentrated stream from the distillation process contains an average of 60% glycol and is transported off-site by the operator for reuse. The diluted stream from this process is mixed back into the runoff storage system for treatment by the irrigation system. Approximately 5% of the total surface runoff volume and 37% of the total spent deicing fluid load is treated in the distillation system.

Key Sizing and Capacity Parameters

Table 1 shows the sizing basis for the irrigation- and infiltration-based biological treatment systems.

Table 1. Key system sizing parameters.

Component/Parameter	**Total Size/Capacity**
Stormwater storage capacity	1.325 million gallons
Current irrigation system footprint	21 ha (50 acres)
Planned expansion to irrigation system footprint	25 ha (60 acres)
Infiltration basins footprint	2.7 ha
Planned expansion to infiltration basin	1.9 ha

Table 2. Design basis for system performance.

Parameter	Value	Unit
Design flow rates - Minimum - Average - Maximum	 0 127* 1,500	Gallons per minute
Design treatment load capacity	8,900 ** 5,200*** 5,200**** 2,500	lbs COD/day lbs BOD_5/day lbs PG/day lbs TOC/day
Design influent concentration - Range	178~35,500 100~21,000*** 100~21,000**** 50~10,000	mg COD/L mg BOD_5/L mg PG/L mg TOC/L
Design effluent concentration (average)	<67***** <20	mg COD/L mg TOC/L
Design treatment efficiency (average)	Not provided	% influent COD load treated

*"Facts–Sheet Spray Irrigation System," Unique.
**[COD] = 3.55 [TOC] (theoretical PG stochiometric correlation for COD to TOC).
***Data based on conversion: [COD] = 1.7 [BOD_5].
****Data based on conversion: [PG] = [BOD_5].
*****Assumed effluent concentration correlation [COD] = 7.25 + 2.99 [TOC] [Dubber, D. and Gray, N. (2010). "Replacement of chemical oxygen demand (COD) with total organic carbon (TOC) for monitoring wastewater treatment performance to minimize disposal of toxic analytical waste." *Journal of Environmental Science and Health*, Part A, 45, 1595–1600].

Treatment System Performance

The data in Table 2 reflect the intended design performance of the ZRH in-situ soil/irrigation treatment system. Table 3 shows actual values.

Cost Assessment for the ZRH Irrigation Treatment System

Table 4 shows treatment system costs.

Table 3. Actual irrigation system performance.

Parameter	Value	Unit
Flow rates - Average	 396	Gallons per minute
Actual COD treatment load rate - Average - Maximum	 1,280 4,460	lbs/day
Effluent COD concentration - Average	 20~32	 mg/L
Effluent TOC concentration - Average	 4.4~8.3	 mg/L
Treatment efficiency	98.7%	% influent COD load treated

Table 4. Costs for the treatment system.

Cost Category	Value
Capital cost* - Existing system - Planned expansion of irrigation system	 25M CHF (Swiss Francs, approximately $31M in 2012) 35M CHF (~$43M) in 2012
Annual operating cost	1M CHF ($3.1M) in 2011

*Capital costs for the existing system are for the irrigation and infiltration basins' treatment units, plus the costs for the collection, piping, storage, and distribution systems for supplying the stormwater to the treatment units.

Conclusions on Performance of ZRH Irrigation System

Influent Deicer Concentrations

Like many biological treatment systems, while influent TOC concentrations are measured, the flow into the treatment systems is essentially controlled based on TOC mass loading rate rather than concentrations. If collected concentrations are high, the flow rate to the treatment areas is reduced.

Treated Load Rate

Published data from 2005 indicate carbon inputs into the soil of 4,622-kg carbon (2001–2002) and 17,120-kg carbon (2003–2004). During the same periods, irrigation areas were 3.5 ha and 16.7 ha, respectively. This yields loading rates of 132-g carbon/m^2 and 102-g carbon/m^2.

Effluent Concentrations

The most extensive testing of the irrigation system was performed between 2002 and 2007. During 2003–2004 deicing season, only five out of 834 samples exceeded the effluent limit of 20-mg/L DOC. The average DOC concentration of the treated water in the irrigation system in that season ranged from 4.4 mg/L to 8.3 mg/L, which is 1 mg/L to 3 mg/L above the natural DOC level.

Treatment Efficiencies

Treatment in the irrigation-fed system occurs as the infiltrating water passes through bacteria located primarily in the top 80 cm (32 in.) of the soil. Overall, approximately 98% of the applied organic carbon is removed by the bacteria, with 90% of the removal in the top 20 cm (8 in.).

Cost

Although the ZRH irrigation and infiltration basin systems are considered passive from a treatment standpoint, the capital cost for the entire system is high because of the extensive amount of monitoring, storage, pumping, and piping that is needed. ZRH had one advantage in cost that not all airports will have: a ready-made pipe drainage system in the soil of the irrigated areas that was installed originally to drain groundwater. The operation of the system incurs costs for monitoring, power, and operations.

Lessons Learned for Potential Implementation of the Irrigation Passive Biological Treatment Technology at Other Airports

The following factors have proven critical to effective and efficient performance in the ZRH irrigation:

1. Measurements at ZRH suggest that most treatment (90%) occurs in the first 20 cm (8 in.) of soil. The upper layers also are typically composed of more natural organics from plant degradation that may be supplying nutrient-rich soils for the bacteria.
2. The degree of saturation of the soils with water from precipitation or groundwater is important. A saturated top layer is not conducive to treatment.
3. Wind speed is a factor in determining the feasibility in using the irrigation system at any given time because of a desire to avoid irrigation on roads and taxiways.
4. Water, soil, and air temperature are all factors in performance, and ZRH has determined the ranges in which effective performance can be achieved. System input is affected by the temperatures.

Conclusions from operation of the irrigation-fed soil treatment technology at ZRH that can be used by other airports considering this technology include:

1. While there is no active control of the treatment elements such as oxygen supply and nutrient addition that is seen with other biological treatment systems, ZRH employs an extensive effort to control the timing of when the systems are fed with deicer-affected water, the mass loading rates, and the flow rates. The information used to control the influent flows is based on ongoing monitoring of ambient conditions, including real-time monitoring of multiple parameters. Therefore, while the treatment portion of the technology is passive, it would not meet performance criteria without a high active control of the loading of deicer-affected stormwater into the treatment areas.
2. ZRH spent 5 years performing extensive monitoring of the system performance and conditions that might affect performance. This resulted in the control system for the treatment system operation being based on field-collected data. Because of this extensive testing period, ZRH has developed a high degree of predictability for the treatment system performance.
3. Based on the measurements taken at ZRH, the passive biological treatment technologies are well suited for the higher-volume, lower-concentration fractions of the collected deicer-affected stormwater. At ZRH, a high percentage of runoff volume, but a relatively low percentage of the total spent deicer load, is treated in the passive biological treatment systems.
4. The hydraulic conductivity of silty soils would make getting sufficient detention time to get acceptable treatment more of a challenge.
5. Many passive biological treatment systems that use soil or media for treatment frequently have limited monitoring of influent pollutant concentrations and no means of measuring effluent concentrations. ZRH demonstrated that influent and effluent measurements are critical to achieving the desired treatment effectiveness.

Documents and Information Review in Development of Assessment

1. Jungo, E, Schob, P., Disposal of De-Icing Effluents by Irrigation.
2. Jungo, E., Schob, P (2006), Disposal of Zurich Airport's De-Icing Effluent by Irrigation, Water21.
3. Unique (2004), Treatment of De-Icing Sewage.
4. Unique (2005), Facts–Sheet Spray Irrigation System
5. Zurich Airport Annual Report (2011), Environmental Protection–Water and Wastewater.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation