APPENDIX B

Deicer Treatment Technology Fact Sheets

The following Deicer Treatment Technology Fact Sheets update the information in the previously published *ACRP Fact Sheets: Deicer Treatment Technologies,* which was supplemental to *ACRP Report 99: Guidance for Treatment of Airport Stormwater Containing Deicers*.

- Deicer Treatment Technology Fact Sheet 101, Activated Sludge (Updated).
- Deicer Treatment Technology Fact Sheet 102, Aerated Gravel Beds (Updated)
- Deicer Treatment Technology Fact Sheet 103, Aerated Lagoons (Updated)
- Deicer Treatment Technology Fact Sheet 104, Anaerobic Fluidized Bed Reactor (Updated)
- Deicer Treatment Technology Fact Sheet 105, Distillation (Updated)
- Deicer Treatment Technology Fact Sheet 106, Mechanical Vapor Recompression (Updated)
- Deicer Treatment Technology Fact Sheet 107, Moving Bed Biofilm Reactor (Updated)
- Deicer Treatment Technology Fact Sheet 108, Natural Treatment Systems (Updated)
- Deicer Treatment Technology Fact Sheet 109, Public Wastewater Treatment Facilities (Updated)
- Deicer Treatment Technology Fact Sheet 110, Private Off-Site Recycling Facilities (Updated)
- Deicer Treatment Technology Fact Sheet 111, Reverse Osmosis (Updated)

Appendix B is supplemental to *ACRP Research Report 257: Guide for Treatment of Airport Stormwater Containing Deicers: Update* (ACRP Project 02-96, "Update ACRP Report 99: Guidance for Treatment of Airport Stormwater Containing Dicers"). The full report can be found by searching for *ACRP Research Report 257* on the National Academies Press website (nap.nationalacademies.org)

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Table B-1 lists the types of information found in each fact sheet and a description of their contents.

Table B-1. Fact sheet organization.

FACT SHEET SECTION	CONTENT DESCRIPTION
Process Description	A brief overview of the deicer treatment technology, including the method of deicer removal or treatment, process flow charts, typical process requirements, and general operational information.
Advantages	Conditions where treatment technology may be favorable.
Disadvantages	Conditions where the treatment technology may be unfavorable.
Required Support Systems	Summary of the component parts necessary to operate the treatment technology.
Potential Application Situations	Summary of the situations for which each technology is most appropriately applied.
Current Airport Applications	Airports presently using the treatment technology.
Process Selection Criteria	Information on typical ranges for concentrations and flows as well as performance expectations and siting.
Implementation Considerations	Information gathered from previous applications of the technology to assist with implementation of the technology at other airports.
Cost Considerations	Presentation of the preliminary planning-level rough order-of-magnitude capital and O&M 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.

FACT SHEET 101

Activated Sludge

1. Treatment Technology Description

Process Description

Activated sludge normally involves two-unit processes: an aerobic bioreactor (aeration basin) and a solids separation process. Soluble compounds in the influent are transformed into bacteria in the bioreactor and subsequently removed in the following solids separation process. A portion of the separated bacteria is returned to the bioreactor as Return Activated Sludge to maintain a stable bacteria population in the bioreactor. The bacteria removed for solids disposal are discharged as Waste Activated Sludge that is normally dewatered prior to disposal.

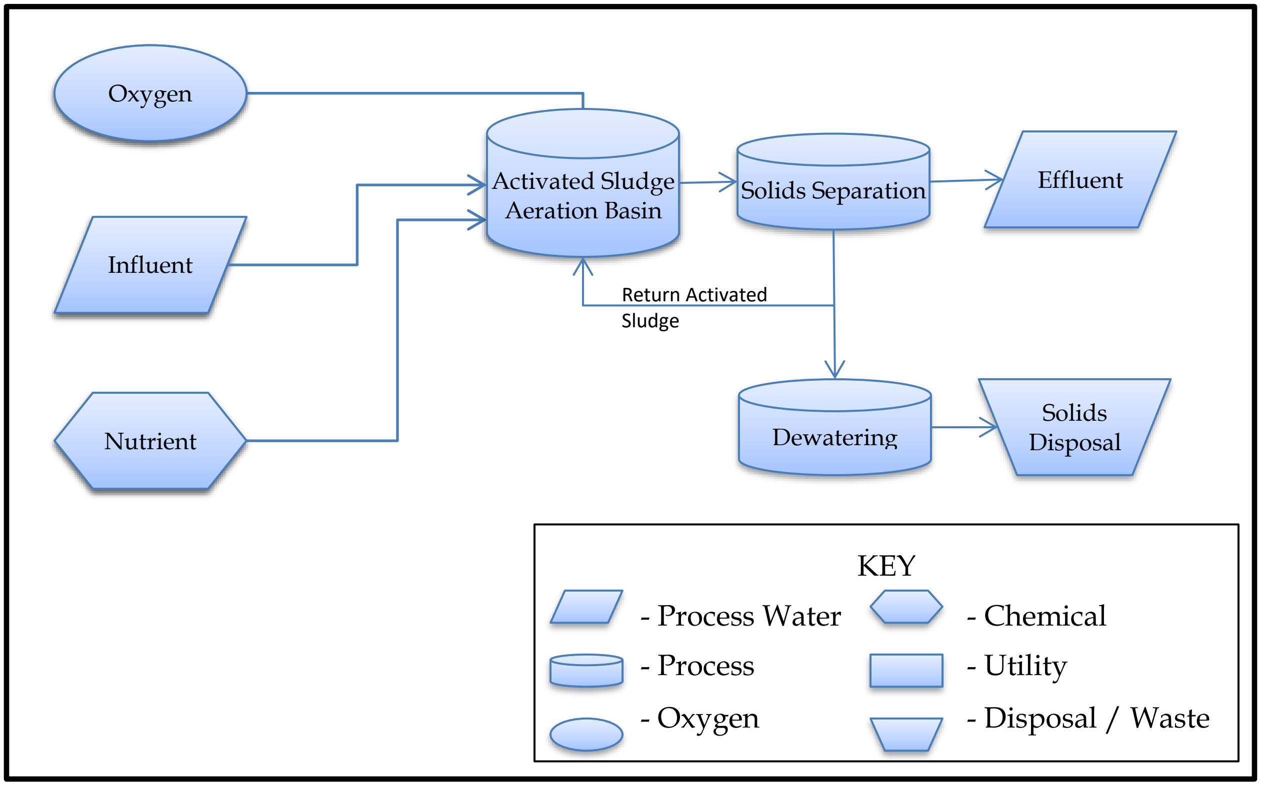

Figure 1: Activated sludge process flow chart.

Although activated sludge is used in many municipal and industrial wastewater treatment plants, the differences between deicer-impacted stormwater and other wastewater, listed below, require that the technology be adapted for deicer treatment.

- Highly variable flow and BOD_5 concentration
- Generally higher BOD_5 concentration
- Lower temperature
- Lack of nutrients

Municipal-activated sludge plants typically use flow rate as the primary basis-of-design parameter because the BOD_5 concentrations and flow rates of sanitary wastewater are relatively consistent. The BOD_5 concentration of airport stormwater may be 5 to 200 times greater than the BOD_5 concentration in sanitary wastewater. Flow rates from collected deicer-impacted stormwater can vary similarly.

While a traditional activated sludge system with large aeration basins has some capability to absorb variation in flows and BOD_5 mass loading, the operation of an activated sludge system is optimized if storage and equalization upstream of treatment and/or if mass loading rates into treatment are controlled to minimize variation. Equalization and load control promote a less variable and healthier bacterial population, which aids in the consistency of effluent quality. It also reduces the likelihood of upsets that can impact treatment.

Most municipal-activated sludge plants have influent temperatures between 50 and 86 degrees Fahrenheit (10-30 deg. C), which is a suitable range for the growth of bacteria. Airport storm water containing deicer is typically much colder – normally below 50 degrees Fahrenheit (10 deg. C). Since the bacteria grow slower in colder temperatures, the aeration basins for deicer systems typically need to be upsized to account for the slower rate of treatment.

The wastewater entering a municipal POTW with an activated sludge system typically has sufficient (and sometimes excess) nutrients. Deicer-impacted stormwater is virtually devoid of nutrients. Nutrients are essential to support the large biological population in activated sludge systems. Nutrients similar to fertilizer (nitrogen, phosphorous, and other compounds) must be added to the influent entering activated sludge aeration basins to stimulate the new bacterial growth. The nutrient addition rates are normally paced with the BOD_5 loading rates. Adding enough nutrients to allow bacterial growth without producing nutrient concentration in the treated effluent that exceeds permit limits is one of the principal challenges of operating an activated sludge system to treat deicer. Frequent monitoring of effluent nutrient concentrations and frequent addition of nutrients is required.

Cold weather, lack of nutrients, or other factors that upset the bacteria in the aeration basin may cause the growth of types of bacteria that do not settle well and are therefore not removed sufficiently in the clarifier. When this occurs, biomass (i.e., treatment capacity) is lost from the system and the effluent will contain a high concentration of suspended solids.

In the aeration basin, bacteria must be well mixed and supplied with sufficient oxygen. The mixing and oxygen are generally supplied by the same source: either mechanical mixers or aerators at the bottom of the basin.

Because the activated sludge process converts the deicer compounds primarily to new bacteria cells, the treatment system generates excess bacteria (sludge) as a waste product. The sludge has a very high concentration of water. To reduce the volume and weight of the sludge being disposed, a dewatering process is typically included with activated sludge processes. The high volume of sludge to process from an activated sludge system is one of the principal disadvantages of this technology.

The activated sludge process needs a bacterial population in the aeration basin to begin treatment. Therefore, at initial startup, the process must be seeded with an appropriate biological population. At the end of the deicing season, if the deicer, oxygen, and/or nutrients are shut off, the bacterial population will begin to die off. The die-off will reduce the amount of biomass, which reduces the treatment capacity. In addition, the die-off will release nitrogen and phosphorous back into the effluent and provisions may be needed to control the ammonia and orthophosphate concentrations in the effluent during this period.

At the start of each successive deicing season, the biological population needs to be re-established. With an activated sludge technology, it may be necessary to reseed the aeration basins with an outside source from another wastewater treatment plant. If that source is a municipal sludge, it may take some time for the bacterial population to acclimate to the treatment of deicer constituents. It is also possible to take steps to manage the biological population during the summer such that some fraction of the bacteria survives, thereby eliminating the need for reseeding. Steps to help the population survive over the summer include adding a carbon source (food) and continuing aeration.

Figure 2: Activated sludge aeration basin (courtesy CVG Airport).

Advantages

1. Well-understood process with a long history for municipal wastewater treatment and readily available operator pool.
2. Biogrowth is rapid such that capacity increases quickly (relative to other processes) from a seed.
3. Able to achieve very low effluent concentrations, in the range of less than 30 mg BOD_5/L.
4. Able to treat two to three times more BOD_5 load per acre of land than an aerated gravel bed treatment system or aerated lagoon system.

Disadvantages

1. High operating costs
   a. Utility costs for aeration.
   b. High nutrient demand (compared to other biological systems).
   c. High volume of biological solids in treated effluent that must be settled and dewatered prior to disposal.
2. Settling issues during biological upsets.
3. Likely need to reseed each season or keep a biological seed active over the summer.
4. Increased ammonia and phosphorous concentrations in effluent at end of treatment season.

Required Support Systems

1. Aeration System

   a. The aeration system provides oxygen for the aerobic bacteria and mixing. Aeration system sizing dictates the mass loading rate of the system.
   b. The equipment can be either surface mixers or blowers and an air-piping network.
2. Nutrient Feed System
   a. Provide nutrients, mixing and storage tanks and metering system typically paced to treatment capacity.
   b. The equipment typically includes mixing/storage tanks and metering pumps.
3. Sludge Handling System
   a. Reduces sludge volume and costs for disposal, typically clarifier sludge concentrations of 0.5% to 1% are increased to 8% to 20% solids concentration reducing the volume by a factor of 6 to 10.
   b. Equipment may include digesters, centrifuges, belt presses, or filter presses.
4. Analytical System
   a. Routine measurement of influent flows and concentrations for BOD_5 and nutrients are required to determine system loading, nutrient, and aeration requirements.
   b. Equipment may include online monitors or analytical test kits.

Variant Systems

Extended Aeration Activated Sludge is a variation of the standard activated sludge process. It uses a larger aeration basin to provide extended hydraulic and solids retention times. This provides somewhat more protection against the variation in influent flows and mass loads common with deicing applications.

Sequencing Batch Reactors (SBRs) incorporate the aeration basin and clarification step into one tank. A “fill and draw” methodology where treatment occurs in steps is used. One potential issue that could arise with SBR systems relates to the difficulty in optimizing the solids settling phase since solids removal does not occur in a distinct unit process.

Membrane BioReactors (MBRs) are also a variant of the activated sludge process. At the discharge end of the aeration basin, membranes are used to filter the effluent and keep the bacteria in the basin. There are no clarifiers in the MBR system, and the bacteria can be maintained at a higher concentration. This results in a smaller footprint for the basin. However, membrane installation costs, maintenance, and replacement costs may make this technology economically infeasible. MBRs are especially affected by cold temperatures as the high viscosity water slows down the flow rates through the membranes, resulting in the need for more membranes and a higher system cost. The membranes may also be subject to fouling from the bacteria, significantly affecting flow rates and effectiveness.

While SBRs and MBRs are commonly used in municipal and industrial wastewater treatment, they have seen little to no application for treatment of deicer because of concerns over operational upsets and performance in cold temperatures.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

The activated sludge process is typically applied where BOD_5 influent concentrations are less than 10,000 mg/L. The activated sludge process can achieve BOD_5 concentrations less than 30 mg/L when sized and operated properly. There are few inherent limitations on flow rate through an activated sludge system, provided the aeration basins and solids separation processes are large enough to meet the design flow rates. This combination of characteristics makes activated sludge best suited to treatment of more dilute, high-volume flows, such as runoff from airfield areas.

Current Airport Applications of Activated Sludge Technology

Cincinnati-Northern Kentucky Airport (CVG)

Nashville International Airport (BNA)

Process Selection Criteria

Table 1. Activated Sludge System Process Selection Criteria

Parameter	Consideration	Description
Preferred Influent BOD_5 Mass Loading Range	No limit	No inherent minimum or maximum mass loading limits. Aeration basin volume/footprint directly proportional to the required BOD_5 mass load.
Preferred Influent BOD_5 Concentration Range	100 to 10,000 mg/L BOD_5	At higher concentrations, dissolved oxygen may be subject to localized drops at the aeration basin influent.
Preferred Influent Flow Range	Varies	The maximum flow rate capacity is a situation-specific determination based on maximum mass load, lower limits of BOD_5 concentrations, and system hydraulics.
Typical Effluent Concentrations	<30 mg/L BOD_5 < 1 mg/L PG > 100 mg/L TSS	Effluent concentrations are consistent in practice. Effluent BOD_5 concentrations are not necessarily directly proportional to influent BOD_5 concentrations. TSS concentrations are prior to clarification. Post clarification TSS is < 30 mg/L.
Typical Range of Required Footprint	1 to 4 acres	Footprint represents range for aeration basins. The other supporting equipment requires additional acreage.
Typical Building / Equipment Height	< 20 ft.	Building will house sludge-handling equipment and blowers.
Pretreatment Needs	Fuel, Trash, Solids	Typically, upstream oil-water separator, trash removal, and not routing construction sediment to aeration basins.
Post-Treatment TSS Processing	Operations	Solids removal, typically with a clarifier, is needed. Sludge dewatering and potential digestion are also needed.
Utility Requirements	Operations	Requires electrical and water utility connections.
Open Water Surface	Bird attraction	Aeration basins and clarifiers typically have open water surfaces that can attract birds if not mixed and aerated.
Implementation Time	Scheduling	Design and construction typically require 20 to 38 months.
Staffing	Operations	Treatment plant operation is typically performed by 3-4 experienced wastewater treatment operators.
Time Required for Design and Construction	Planning, Design, Construction	Design and construction typically require 14 to 20 months.

Implementation Considerations for Activated Sludge Systems

The following represent the considerations typically most important when considering potential implementation of the activated sludge technology.

1. *Activated Sludge is a fit for airports with low-moderate* BOD_5 *concentrations and larger flow volumes.*
   Airports that have larger collection areas because of at-gate or stand deicing typically have larger stormwater volumes and lower BOD_5 concentrations than airports using only deicing pads.

2. *Activated Sludge can potentially achieve low effluent* BOD_5 *concentrations.*
   BOD_5 and PG concentrations of less than 30 mg/L are potentially achievable but the actual effluent BOD_5 that can be achieved is dependent on many factors. The treatment system operates most efficiently when it receives a constant load (pounds per day) of deicer. The treatment system can handle some variation in concentration by adjusting the flow rate to provide the constant load. Physical limitations in load removal are associated with maximum oxygen transfer efficiency of the aeration system, wastewater temperature, nutrient ratios, and residual dissolved oxygen.

3. *Activated Sludge footprint is relatively small.*
   The activated sludge system has a smaller footprint than aerated lagoons and aerated gravel beds but a larger footprint than MBBRs of equivalent capacity.

4. *Activated Sludge operation is somewhat affected by variability in deicing conditions.*
   Unlike the aerated gravel bed system but like the MBBR and aerated lagoon systems, the activated sludge operations and performance may be negatively affected in situations where steady deicer loads and flows are not available.

5. *Activated Sludge produces a sludge load as a byproduct that must be managed.*
   Unlike the aerated gravel bed but like MBBR systems, the activated sludge system produces waste biological solids that need to be removed from the effluent stream, dewatered, and disposed of off-site.

6. *Typical and minimum stormwater temperature*
   This information is used by the treatment system designer to adjust the size of the treatment system.

7. *Range of* BOD_5 *concentrations*
   The treatment system operates most efficiently when it receives a constant load (pounds per day) of deicer. The treatment system can handle some variation in concentration by adjusting the flow rate to provide the constant load. However, there may be physical limitations on the range of flows that can be delivered without causing hydraulic upset in the system.

8. *Solids Management*
   The amount of sludge produced, and the desired disposal solids percent will dictate the sludge handling method.

9. *'Over-Summering' of the Sludge*
   Since most of the biomass will not survive through the summer, the method for restarting the treatment must be considered. Feeding deicer in the summer to keep the bacterial population alive is not necessary. Operators should experiment with the risks and benefits of waiting until runoff with deicer is available. If it is determined that starting up the system with added deicer is necessary, it is recommended that this process be delayed until late fall to minimize the potentially high cost of

starting too soon. Thoughtful use of storage capacity to facilitate this process can be a significant benefit.

Cost Considerations

Accurate capital costs for activated sludge systems need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the activated sludge system.
- Need to utilize solids settling, dewatering, and disposal processes.
- Needs for storage, pumping, conveyance, and pretreatment outside of core activated sludge process.
- Site characteristics (e.g., site clearing, soil contamination, soil geotechnical characteristics, seismic requirements, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent-activated sludge system needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using activated sludge systems are almost always unreliable as estimates for activated sludge systems at a new site because of differences in the above elements.

Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates[1].

AACE Class	ANSI Classification	Typical Use	Project Definition	Expected Range of Accuracy: Low Expected Actual Cost	Expected Range of Accuracy: High Expected Actual Cost	Other Terms
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

***Figure 3. AACE and ANSI cost estimation classes*[1]**

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core activated sludge system treatment components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process.

The costs in Figure 4 include only the "core" activated sludge system treatment components:

- Aeration basins
- Blower and aeration systems
- Nutrient supply system
- Clarifier
- Return sludge pumping and piping
- Electrical, instrumentation, and controls for the systems above
- Basic utility building
- Basic site preparation

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring.
- Influent flow systems (pump stations, conveyance piping to treatment system).
- Spent deicer storage.
- Pretreatment and post-treatment systems (e.g., oil-water separation, sediment removal beyond those included above).

[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

- Utilities from external supply to treatment building.
- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage.

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at the conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core activated sludge units are reflected in the preliminary planning capital cost curve shown in Figure 4. The shaded areas represent application of a 20% contingency in both directions. The costs should be only used for guidance in treatment technology selection and not for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

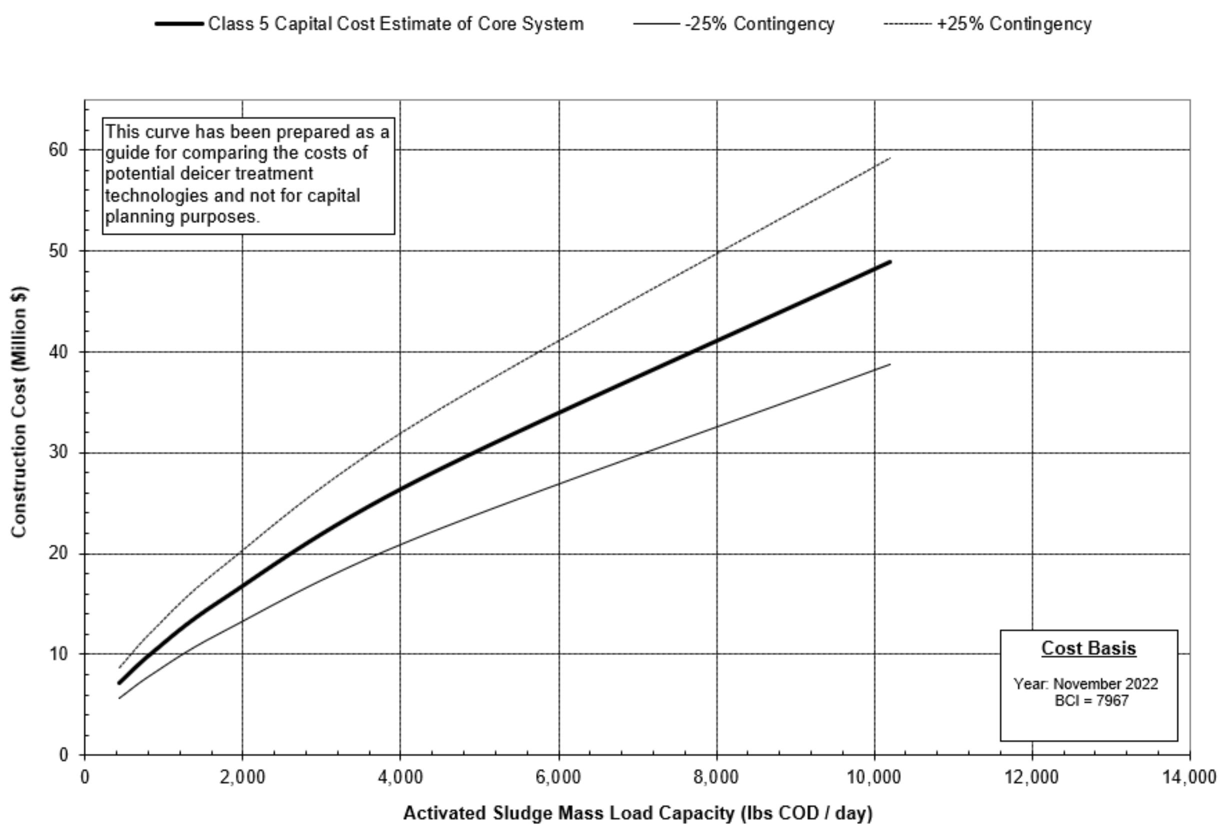

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core activated sludge units are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for an activated sludge system include:

- Electricity (especially from blowers)
- Chemicals (nutrients)

- Solids disposal
- Laboratory analyses
- Labor (three operators)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

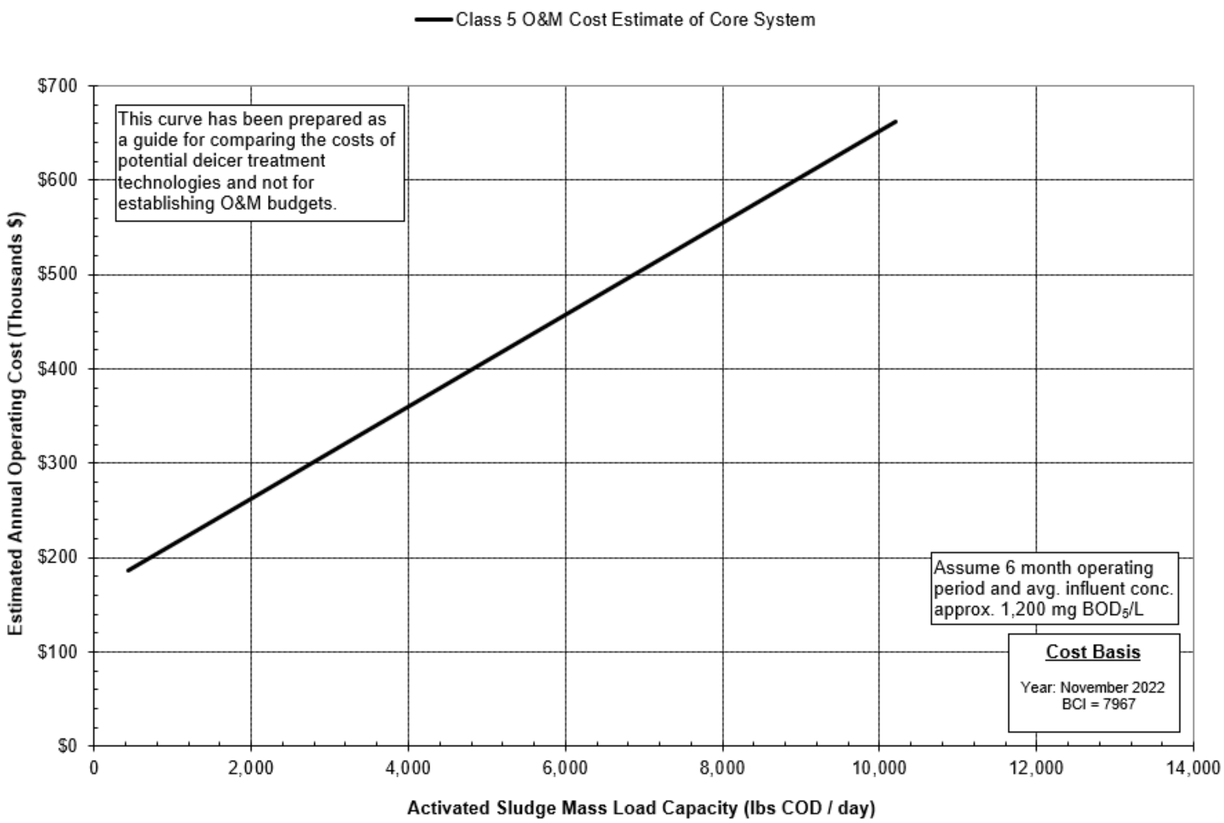

Figure 5: Preliminary planning O&M cost curve.

FACT SHEET 102

Aerated Gravel Beds

1. Treatment Technology Description

Process Description

The aerated gravel bed is a hybrid system that employs facets of engineered wetlands and aerated lagoons. The system is biological in nature and relies on aerobic bacteria to degrade glycols and other deicer compounds, including pavement deicers. From a wastewater treatment perspective, the system is a lightly loaded, aerobic, submerged, attached growth system. The main components of the system are shown in Figure 1.

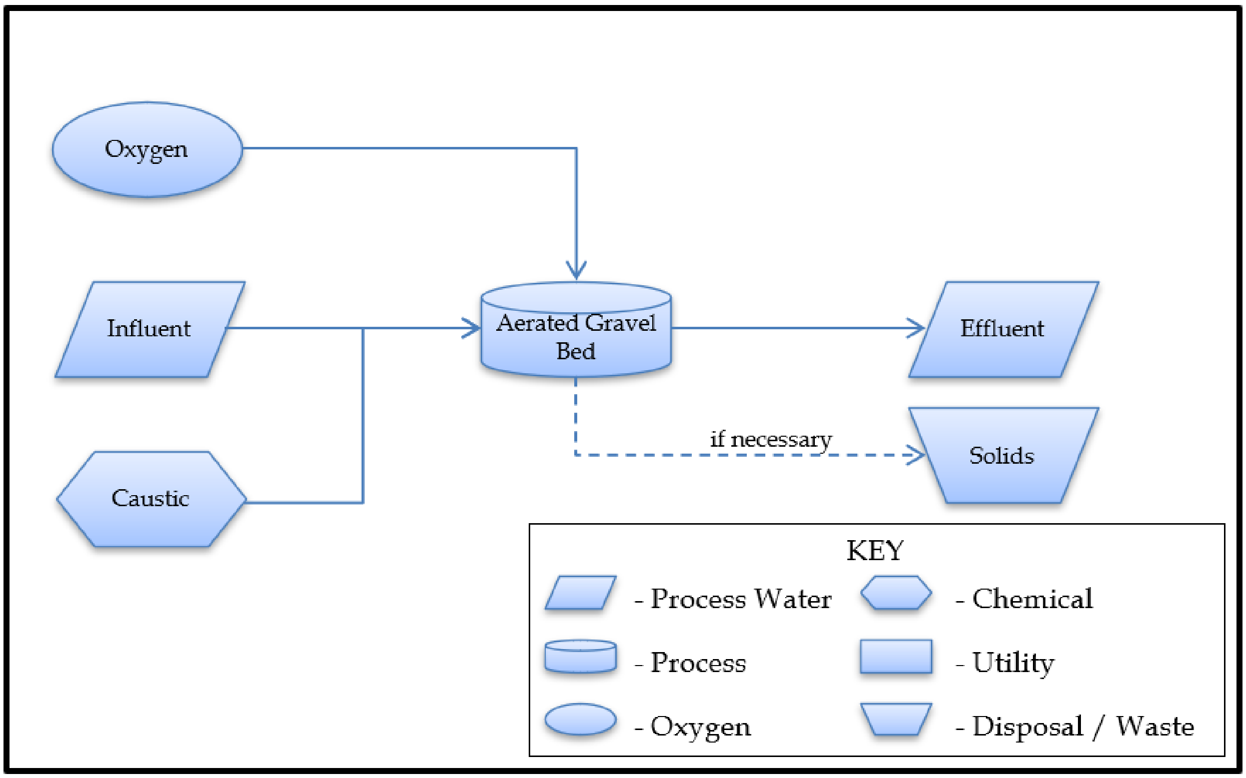

Figure 1. Aerated gravel bed process flow chart.

In an aerated gravel bed system, influent flow is pumped uniformly over the top of the beds through a distribution system. The water discharged from the distribution system travels downward through the gravel bed and is captured in collection lines on the floor of the basin. The collection lines are connected to an effluent hydraulic control structure that controls the elevation of the water in the bed. The water level is maintained to keep gravel submerged and prevent exposed water on the surface. Aeration lines cover the bed floor and supply air bubbles to the water, which maintains aerobic conditions for the bacteria. The treatment bed is lined with an impermeable liner, like those used for aerated lagoons.

The volumetric mass loading capacity to the AGB units (lbs BOD_5/ft3/day) is intentionally limited to a maximum value in the design process to prevent excessive growth of bacterial film and prevent clogging of the gravel with biomass. Assuming a constant depth of gravel, this results in the footprint for the AGB system being directly proportional to BOD_5 mass load that is required to be treated for a particular application.

Like many other biological deicer treatment systems, the AGB system is best operated in BOD_5 mass load-driven fashion with operators deciding on the mass loading rate and flow rates adjusted upward or downward based on BOD_5 concentrations in the influent (i.e., large volumes can be treated when pollutant concentrations are low; however only low volumes can be treated with high concentrations).

The aeration system includes blowers, manifolds, diffusers, airflow monitoring, pressure gauges, and distribution control valves. Blowers are normally positive displacement, rotary-lobe-type blowers. The diffusers are normally coarse bubbles that employ drip tubing or slotted hard piping to uniformly distribute air over the floor of a bed.

The treatment process depends on a resident bacterial population for treatment. Visually the bacteria appear as a very thin film on the aggregate. At the start of the deicing season, some bacteria will be present in the beds or incidentally brought in with the runoff to be treated. To date, not AGB units have required seeding of bacteria from an external source. As the system is started up each deicing season, the bacterial population will grow in response to a food supply (deicers), nutrients added to the influent, and oxygen. During the winter as long as sufficient deicer is available to treat, the bacterial population will reach a steady state, typically at the maximum design treatment mass load capacity. Some bacteria will die off during the season as part of the natural bacterial cycles and begin to be digested in the beds. The light mass loading of the AGBs in combination with the digestion in the beds results in low Total Suspended Solids (TSS) concentrations in the effluent and therefore typically no need for an external solids (sludge) removal process (if NPDES TSS limits are very low (<20 mg/L) some solids removal may be necessary). This is one of the major advantages of the AGB. At the end of the deicer season, when the deicer, oxygen, and/or nutrients are shutoff, the bacterial population will begin to die off at a fast rate. The die-off will reduce the amount of biomass, which reduces the treatment capacity. If controlled correctly, the shutoff process will not produce large TSS concentrations in the effluent. Some biomass will typically be available at the beginning of the next deicer season and approximately a one-week startup period is typically required to regain the treatment capacity.

A photo of the aerated gravel bed system at the Buffalo Niagara International Airport during its installation is shown in Figure 2.

Figure 2. Aerated gravel bed at Buffalo Niagara International Airport (courtesy Mark Liner).

Advantages

1. Relatively straightforward operation, including automatic operation of pumps and manual operation of blowers.
2. Aerated, attached growth bacteria are suitable for achieving biological treatment during cold temperatures.
3. Ability to achieve low propylene glycol and BOD effluent concentrations.
4. Consistent and predictable performance over a wide range of influent concentrations, if loading into the treatment system is controlled.
5. Typically, no need for an external biological solids settling or sludge removal system, unless the airport's NPDES or Industrial User permit has very low TSS limits (e.g., < 20 mg/L).
6. Underground construction allows installation on unused airside land.
7. Able to handle a wide range of influent concentrations. Concentrations greater than 10,000 mg/L BOD_5 can be accommodated in conjunction with periodic flow distribution dosing protocols.

Disadvantage

1. Requires a larger land area per pound of BOD_5 treated compared to other treatment technologies.
2. Influent concentrations greater than 10,000 mg/L BOD_5 result in relatively low water volumes treated.

3. Overloading of system by operating about the maximum BOD_5 mass loading rates may result in biological plugging of gravel beds.
4. Challenge in perfectly matching nutrient feed amounts to nutrient needs at the start of season. Excessive nutrient deficiencies (nitrogen or phosphorus) can affect performance and potentially change the nature of the bacterial population.
5. Cost of system is linear with size, and there are minimal economies of scale.
6. A goal of the system is to keep the water levels below the top of the gravel surface to prevent the AGBs from becoming a hazardous wildlife attractant and to reduce typical deicer odors. This results in the need for 6 to 12 inches of unused gravel at the top of the beds to account for fluctuation in water levels during operation.
7. All the water and air piping are buried in the gravel. While there are no moving parts buried in the gravel bed, should there be a need to repair piping, the gravel will need to be removed (with proper design and construction, this is an unlikely need).

Required Support Systems

1. Aeration System
    a. The aeration system provides air uniformly over the floor of the beds. Aeration system sizing dictates the treatment rate (in pounds per day) of the system.
    b. The equipment typically includes blowers and an air-piping network to supply diffusers on a bed’s floor.
2. Influent Dosing System
    a. The influent dosing system distributes influent flow uniformly over the top of the beds. Daily volumes pumped to the beds must be adjusted according to influent concentrations.
    b. The equipment includes pumps and piping distribution network.
    c. The dosing system must provide a means for routine cleanout of accumulated debris.
3. Nutrient Feed System
    a. Nutrient solution is paced into influent relative to the load of organics to account for nutrient deficiency. Online analytical equipment is required to determine exact concentrations of organics (glycol etc.) in the influent.
    b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider.
    c. The equipment typically includes mixing/storage tanks and metering pumps.
4. Analytical System
    a. Routine measurement of influent flows and concentrations is required to determine system loading, nutrient, and aeration requirements.
    b. Equipment may include online monitors or analytical test kits.

Variant Systems

The Reciprocating Subsurface Treatment System process is a variation of the aerated gravel bed. Rather than blowing air into the bottom of the gravel bed, bacteria is supplied oxygen by exposure to air. Reciprocating subsurface systems are designed in cell pairs and water is pumped in a batch from one cell to the pair. The biofilm on the gravel or other media is temporarily exposed to air, and the water is pumped back and the alternate cell is exposed to air. The advantages to this system over the supplied air gravel bed are the lack of air piping buried in the soil and lower operating costs. The primary disadvantage is the limits on treatment capacity under certain conditions when sufficient oxygen from the atmosphere cannot be drawn into the lower levels of the gravel bed.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

Aerated Gravel Beds are best suited for situations with runoff glycol concentrations less than 10,000 mg BOD_5/L, although they can treat higher concentrations if the periodicity of dosing to the AGB units is adjusted. The primary concern with high concentrations is not the concentrations themselves but the challenges with obtaining even distribution of flows in the AGB beds if flow rates into the beds are not sustained.

The AGB system provides more stable operation than suspended growth systems like activated sludge and aerated lagoons with similar performance but requires more land area.

Current Applications of Aerated Gravel Bed Technology

Buffalo Niagara International Airport (BUF)

Heathrow International Airport (LHR)

Edmonton International Airport (YEG)

Long Island MacArthur Airport (ISP)

Wilmington Air Park (ILN)

Confidential U.S Airport

Calgary International Airport (YYC)

Process Selection Criteria

Table 1. Aerated gravel bed process selection criteria.

Parameter	Consideration	Description
Preferred Influent BOD_5 Mass Loading Range	No limit	No inherent minimum or maximum mass loading limits. AGB volume/footprint directly proportional to the required BOD_5 mass load and is often limited by available area at the airport.
Preferred Influent BOD_5 Concentration Range	100 to 10,000 mg BOD_5/L	Can treat a wide variety of concentrations because flow is adjusted with influent concentrations to achieve steady loads.
Preferred Influent Flow Range	Varies	The maximum flow rate capacity is a situation-specific determination based on maximum mass load, lower limits of BOD_5 concentrations, and system hydraulics.
Typical Effluent Concentrations	<30 mg/L BOD_5 < 1 mg/L PG < 20 mg/L TSS	Effluent concentrations are very consistent in practice. Effluent BOD_5 concentrations are not necessarily directly proportional to influent BOD_5 concentrations.
Typical Range of Required Footprint	0.5 to 10 acres	Bigger systems ok if space is available. Required footprint directly proportional to required treatment BOD_5 mass load.
Typical Building / Equipment Height	< 20 ft.	A 3,000 to 5,000 ft2 building is typically recommended for housing blowers, nutrient feed, electrical, and controls.
Pretreatment Needs	Fuel, Trash, Solids	Typically, upstream oil-water separator, trash removal, and not routing construction sediment to AGBs.
Post-Treatment Processing	Operations	Typically, no post-AGB treatment processes are needed. Site-specific exceptions driven by permit conditions may include TSS removal if limits are less than 15 to 20 mg/L, aeration to increase dissolved oxygen, and pH adjustment.

Parameter	Consideration	Description
Utility Requirements	Operations	Requires electrical and water utility connections.
Open Water Surface	Bird attraction	Aerated gravel bed surface does not have open water.
Implementation Time	Scheduling	Design and construction typically require 18 to 36 months.
Staffing	Operations	Treatment plant operations are typically performed by 2-3 experienced wastewater treatment operators.

Implementation Considerations for Aerated Gravel Bed Systems

The following represent the considerations typically most important when considering potential selection on the aerated gravel bed technology.

1. *Aerated Gravel Bed is a good fit for airports with low-moderate BOD_5 concentrations and larger flow volumes but can be applied in other situations.*
   Airports that have larger collection areas because of at-gate or stand deicing typically have larger stormwater volumes and lower BOD_5 concentrations than airports using only deicing pads.

2. *Aerated Gravel Bed can potentially achieve low effluent BOD_5 concentrations.*
   BOD_5 of less than 30 mg/L is typically achievable with proper design and operation, but the situation-specific effluent BOD_5 concentrations are dependent on many factors. The treatment system operates most efficiently when it receives a constant BOD_5 mass load (pounds per day). The treatment system can handle some variation in concentration by adjusting the flow rate to provide a constant load. Physical limitations in load removal for a given sized AGB are associated with maximum oxygen transfer efficiency of the aeration system, wastewater temperature, nutrient ratios, and residual dissolved oxygen.

3. *Aerated Gravel Bed is relatively unaffected by variability in deicing conditions.*
   Unlike the activated sludge and MBBR systems, the large treatment area and lightly loaded operational approach of the aerated gravel bed system results in a more robust treatment technology that isolates the AGB cells from day-to-day variations of deicing.

4. *Aerated Gravel Bed produces little to no sludge load as a byproduct that must be managed.*
   Unlike the activated sludge and MBBR systems, the aerated gravel bed produces little to no bacterial solids because of its light-loading process approach. As a result, permanent unit processes for settling and dewatering sludge are not needed.

5. *Aerated Gravel Bed operation is less complex.*
   The aerated gravel bed is less complex operationally than the MBBR and activated sludge systems and can run for some periods unattended.

6. *Aerated Gravel Bed requires a larger available footprint for equivalent treatment.*
   The aerated gravel bed requires 2 to 3 times the acreage of activated sludge or MBBR system for an equivalent mass loading.

Cost Considerations

Accurate capital costs for aerated gravel bed systems need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the aerated gravel bed system.
- Site-specific needs for storage, pumping, conveyance, pretreatment, or posttreatment processes outside of core aerated gravel bed process.
- Site characteristics (e.g., site clearing, soil contamination, soil geotechnical characteristics, seismic requirements, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent aerated gravel bed system needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using aerated gravel bed systems are almost always unreliable as estimates for aerated gravel bed systems at a new site because of differences in the above elements.

Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates[1].

				Expected Range of Accuracy		
AACE Class	ANSI Classification	Typical Use	Project Definition	Low Expected Actual Cost	High Expected Actual Cost	Other Terms
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Figure 3. AACE and ANSI cost estimation classes.[2]

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core aerated gravel bed system treatment components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process.

The costs in Figure 4 include only the “core” aerated gravel bed treatment components:

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[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

- Gravel-filled and lined treatment cells
- Blower and aeration systems
- Nutrient supply system
- Pumping and piping systems
- Electrical, instrumentation, and controls for the systems above
- Basic utility building
- Basic site preparation

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring.
- Influent flow systems (pump stations, conveyance piping to treatment system).
- Spent deicer storage.
- Pretreatment and post-treatment systems (e.g., oil-water separation, sediment removal, sludge processing).
- Utilities from external supply to treatment building.
- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage.

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at the conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core AGB units are reflected in the preliminary planning capital cost curve shown in Figure 4. The lighter lines represent application of a 20% contingency in both directions. The costs should be only used for guidance in treatment technology selection and not for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

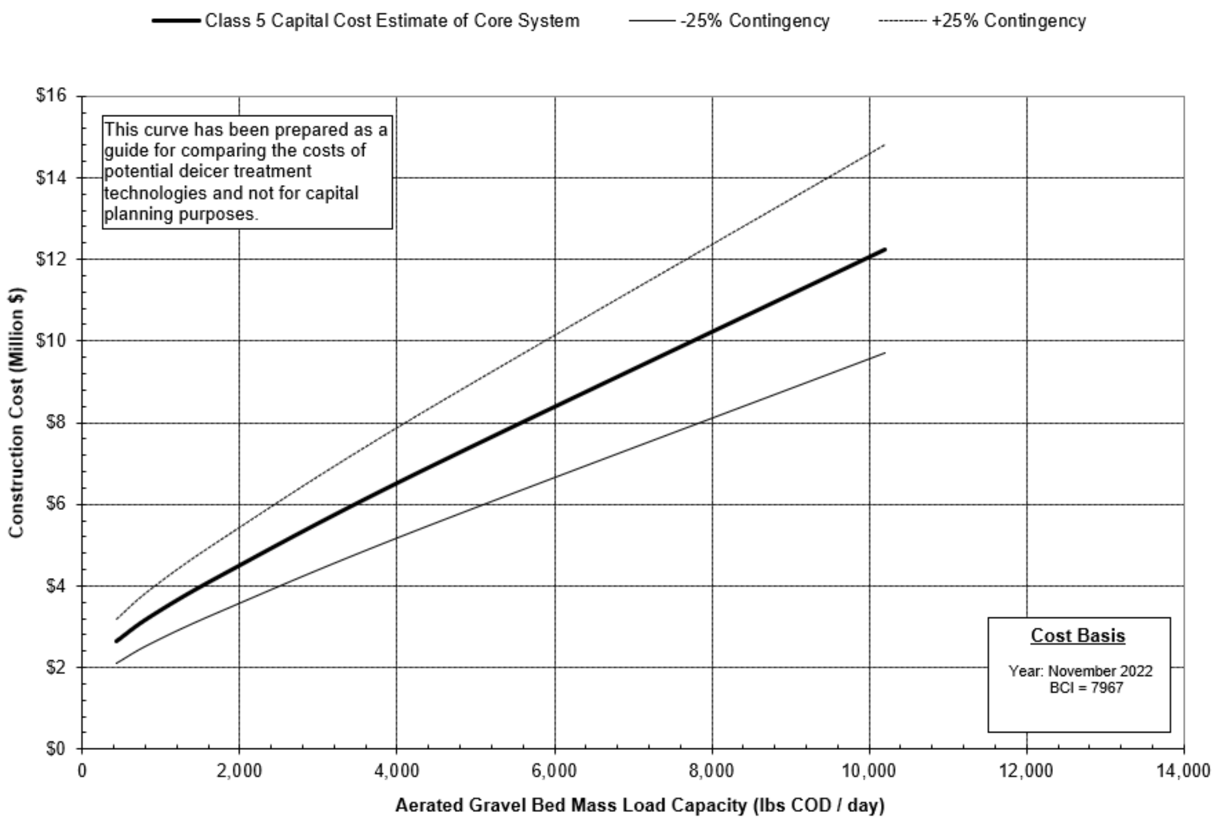

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core AGB units are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for an aerated gravel bed system include:

- Electricity (especially from blowers)
- Chemicals (nutrients)
- Laboratory analyses
- Labor (two operators)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

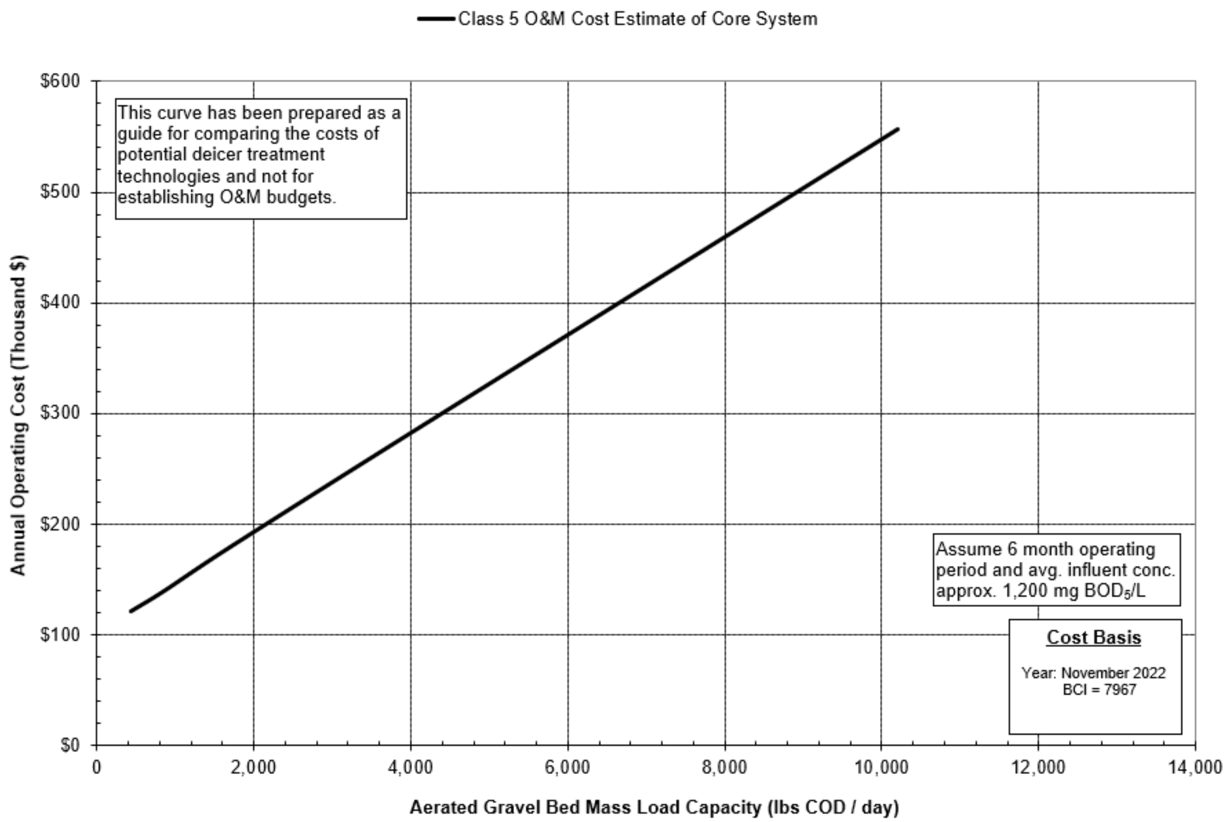

Figure 5. Preliminary planning O&M cost curve.

FACT SHEET 103

Aerated Lagoons

On-Site
Biological Treatment
Aerobic

1. Treatment Technology Description

Process Description

Aerated lagoons are earthen basins that employ mechanical aeration systems to deliver oxygen to the lagoon water. The aeration equipment can be floating splash or aspirator-type units or submerged diffusers. Floating (or "suspended") bacteria are responsible for the removal of organic contaminants (i.e., glycol) and design of the process requires the creation of a stable environment suitable for their growth. Water levels in the lagoon are kept at approximately the same elevation by a hydraulic control structure (i.e., weir) on the outlet. Accumulated solids on the floor of the lagoon must be periodically dredged.

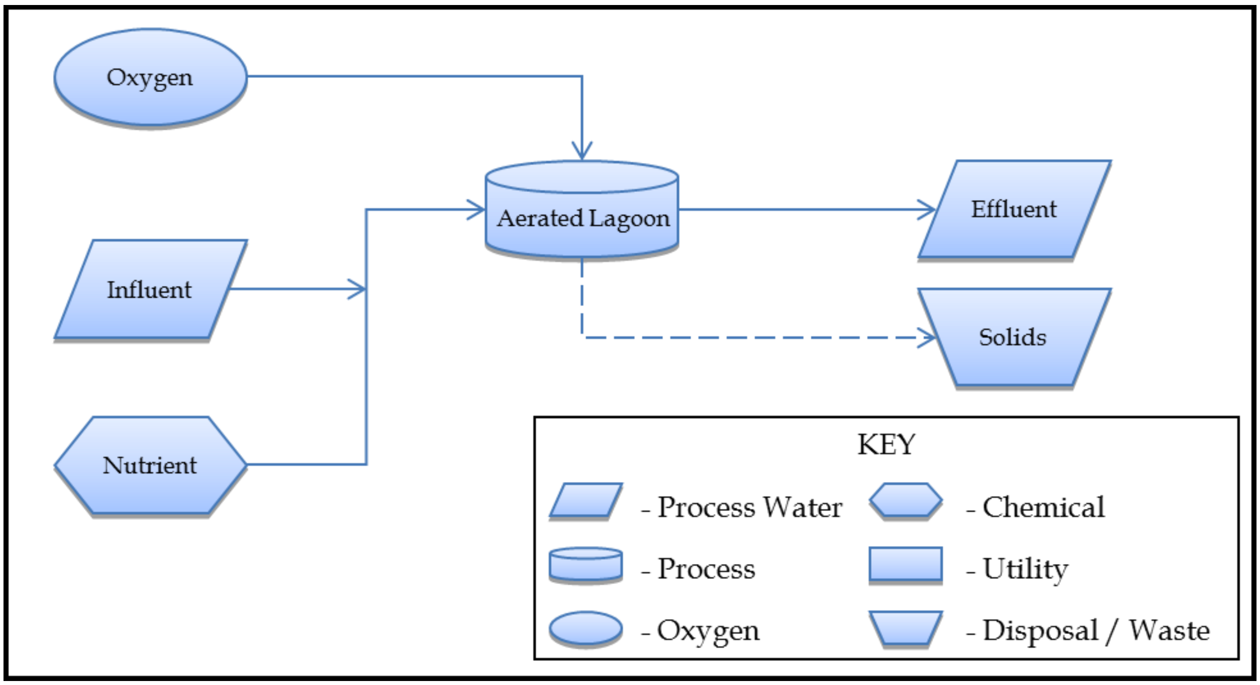

Figure 1. Aerated lagoon process flow chart.

A number of aerated lagoon configurations exist. Low-energy "partial mix" lagoons are relatively large and aerated only to meet oxygen demands. Bacterial solids generated during treatment are left to settle on the lagoon floor. Other "complete mix" lagoons provide substantially more mixing energy to create conditions in which solids are uniform across the entire basin. This type of lagoon is usually followed by a "settling cell" that functions as a solids separation step in the process. The settling cell is sized to accommodate the sedimentation, storage, and digestion of bacterial solids.

Performance of aerated lagoon systems for treating deicing runoff is mixed. The suspended aerobic bacteria responsible for treatment readily degrade glycols under favorable conditions. In most cases, the lack of performance is likely due to insufficient nutrients, insufficient hydraulic residence time, and failure of bacteria to adapt quickly to cold temperatures. Oxygen requirements for deicing treatment systems can be high and equipment suppliers should be consulted with respect to the proper sizing of aeration equipment. Aerated lagoons are related to the activated sludge technology. However aerated lagoons are less efficient per unit volume than activated sludge systems, although they are easier to operate. Despite the relative ease of operation, aerated lagoons do require controls and operator attention. The perceived lack of attention needed for aerated lagoons operation is a contributing factor in their variable success in treating deicer-laden runoff.

Some airports do not use aerated lagoons for continuous treatment but provide enough storage capacity for all collected runoff to be stored until the warm weather season is encountered. In warmer temperatures, aeration, and nutrient feed are started to initiate treatment.

Figure 2. Aerated lagoons with aspirators (left) and submerged diffusers (right) (courtesy of Mark Liner).

Advantages

1. Relatively straightforward operation with automatic operation of aeration equipment.
2. Simple construction with simple mechanical equipment.
3. Large water volume provides dilution (equalization) of influent.
4. Lower cost the other biological treatment systems.
5. Design by civil engineers and constructed by civil contractors.

Disadvantages

1. Potentially requires larger volumes and land areas per pound of BOD_5 treated than activated sludge, AFBR, or MBBR treatment systems.
2. Less control over performance and lower ability to adapt to changing conditions than biological treatment technologies like MBBR, AFBR, activated sludge, and aerated gravel beds.
3. Providing the appropriate amounts of nutrient can be a challenge and nutrient deficiencies will result in suboptimal performance.
4. The large open water surfaces can be a hazardous wildlife attractant. Measures must be taken to reduce the risk.
5. Suspended bacteria can be “washed out” during peak flow events, causing upsets.
6. Bacterial activity slows in cold temperatures and other measures must be employed to maintain treatment levels.

7. Additional treatment processes may be required to achieve low effluent levels.
8. Overcoming perception that aerated lagoons require no or little control, monitoring, or operator attention.

Required Support Systems

1. Aeration System
    a. Aeration system must be suitable for application and deliver the required amount of oxygen and mixing.
    b. The equipment can be either surface mixers or blowers and an air-piping network.
2. Nutrient Feed System
    a. Nutrient solution must be paced into influent relative to the load of organics to account for nutrient deficiency. Analytical equipment may be required to determine exact concentrations of organics (glycol etc.) in the influent.
    b. Nutrient solution must be prepared on-site by airport staff or sourced from a third-party provider.
    c. The equipment typically includes mixing/storage tanks and metering pumps.
3. Analytical System
    a. Routine measurement of influent flows and concentrations are required to determine system loading, nutrient, and aeration requirements.
    b. Equipment may include online monitors or analytical test kits.
4. Flow Control System
    a. The aeration lagoon technology, if operated on a continuous basis during the winter, should have a flow control system that allows management of influent BOD_5 loads to help maintain steady biomass concentrations.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

Aerated Lagoons are best suited for systems with concentrations less than 0.4% (4,000 mg/L) BOD_5, higher effluent limits, large land areas, and the ability to hold water during the coldest conditions.

Current Airport Applications of Aerated Lagoon Technology

Duluth International Airport (DLH)

Chicago Rockford International Airport (RFD)

London Gatwick Airport (LGW)

London Heathrow Airport (LHR)

Technology Selection Criteria

Table 1. Aerated lagoon system process selection criteria.

Parameter	Consideration	Description
Maximum Influent BOD_5 Concentration	~4,000 mg BOD_5/L	Higher concentrations and loads may require very large areas because of low bacterial populations.
Typical Effluent Concentrations	<100 mg/L BOD_5	Effluent concentrations are very consistent in practice.

Parameter	Consideration	Description
Process Flow Rates	No limits	Flow rates are changed in response to BOD_5 concentrations to maintain a steady BOD_5 mass loading rate.
Typical Area (Footprint)	5 to 15 acres	Majority of footprint is open aerated lagoon.
Typical Building / Equipment Height	< 20 ft.	Building will house nutrient system and electrical, controls, and monitoring equipment.
Presence of Influent Flow Fuels	Requires upstream fuel removal	Free-product fuel spills will inhibit or kill growth; dissolved fuel components will be partially treated.
Post-Treatment TSS Processing	Operations	Difficulty in settling biological solids may be experienced in cold weather.
Utility Requirements	Planning, Design & Operations	Requires electrical connections.
Accessibility	Operations	Accessibility is required for delivery of nutrient chemicals and sludge removal.
Open Water Surface	Bird attraction	Aeration basins typically open water.
Temperature	Ambient	Cold temperatures may affect performance more than activated sludge, aerated gravel bed, and MBBR because of lower density of bacterial population.
Treatment Plant Operation Needs	Operations	Treatment plant operation is typically performed by 2-3 experienced wastewater treatment operators.
Time Required for Design and Construction	Planning, Design, Construction	Design and construction typically require 6 to 12 months.

Implementation Considerations for Aerated Lagoon Systems

The following represent the considerations typically most important when implementing aerated lagoon technology.

1. *Aerated Lagoon is a fit primarily for airports with low-moderate BOD_5 concentrations and moderate flow volumes.*
   Airports that have larger collection areas because of at-gate or stand deicing typically have larger stormwater volumes and lower BOD_5 concentrations than airports using only deicing pads. For large flow rates and large BOD_5 loads, very large lagoon sizes are needed to achieve treatment.

2. *Aerated Lagoon can potentially achieve moderate effluent BOD_5 concentrations but has less potential to treat high BOD_5 loads effectively and less potential to achieve low BOD_5 effluent when loads spike.*
   Effluent BOD_5 concentrations of less than 100 mg/L are potentially achievable for lighter loads but the actual effluent BOD_5 that can be achieved is dependent on many factors. The treatment system operates most efficiently when it receives a constant load (pounds per day) of deicer. However, it generally cannot treat high load and high-concentration flows as well as MBBR, activated sludge, or aerated gravel bed systems.

3. *Aerated Lagoon footprint is large.*
   For an equivalent load to treat, the aerated lagoon system is larger than activated sludge and MBBR systems.

4. *Aerated Lagoon operation is more sensitive to variability in deicing conditions.*
   While aerated lagoon operations can be simpler than other biological treatment technologies, they also have fewer options for adapting to changing conditions (variable concentrations, loads,

temperatures, flows) than other technologies and as a result, are more subject to performance impacts from that variability.

5. *Aerated Lagoon sludge must be managed.*
   Aerated lagoons may have TSS in the effluent that needs to be settled but will accumulate solids on the bottom of the lagoon that ultimately need to be removed and disposed of off-site.

Cost Considerations

Accurate capital costs for aerated lagoon systems need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the aerated lagoon system.
- Need to utilize solids settling, dewatering, and disposal processes.
- Needs for storage, pumping, conveyance, and pretreatment outside of core aerated lagoon process.
- Site characteristics (e.g., site clearing, soil contamination, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent system needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using aerated lagoon systems are almost always unreliable as estimates for aerated lagoon systems at a new site because of differences in the above elements. Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates.

				Expected Range of Accuracy		
AACE Class	ANSI Classification	Typical Use	Project Definition	Low Expected Actual Cost	High Expected Actual Cost	Other Terms
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Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Figure 3. AACE and ANSI cost estimation classes.[3]

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core aerated gravel bed system treatment components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process.

The costs in Figure 4 include only the "core" aerated lagoon treatment components:

- Earthen lined lagoon
- Blower and aeration systems
- Nutrient supply system
- Pumping and piping systems
- Electrical, instrumentation, and controls for the systems above
- Basic utility buildings
- Basic site preparation

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring.
- Influent flow systems (pump stations, conveyance piping to treatment system).
- Spent deicer storage.
- Pretreatment and post-treatment systems (e.g., oil-water separation, sediment removal, clarification, sludge processing).
- Utilities from external supply to treatment building.

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[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage.

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core aerated lagoon units are reflected in the preliminary planning capital cost curve shown in Figure 4. The shaded areas represent application of a 20% continency in both directions. The costs should be only used for guidance in treatment technology selection and not for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

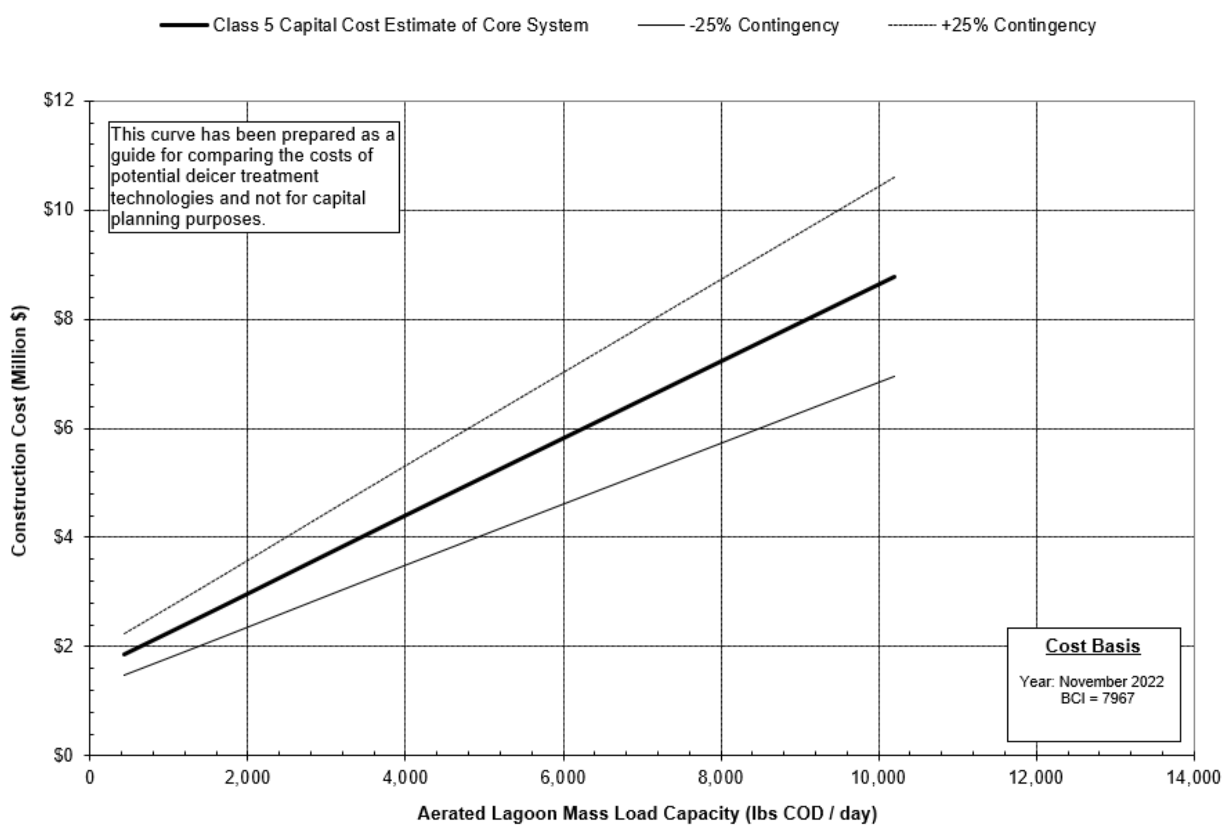

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core aerated lagoon units are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for an aerated lagoon system include:

- Electricity (especially from blowers)
- Chemicals (nutrients)
- Laboratory analyses
- Labor (one operator)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

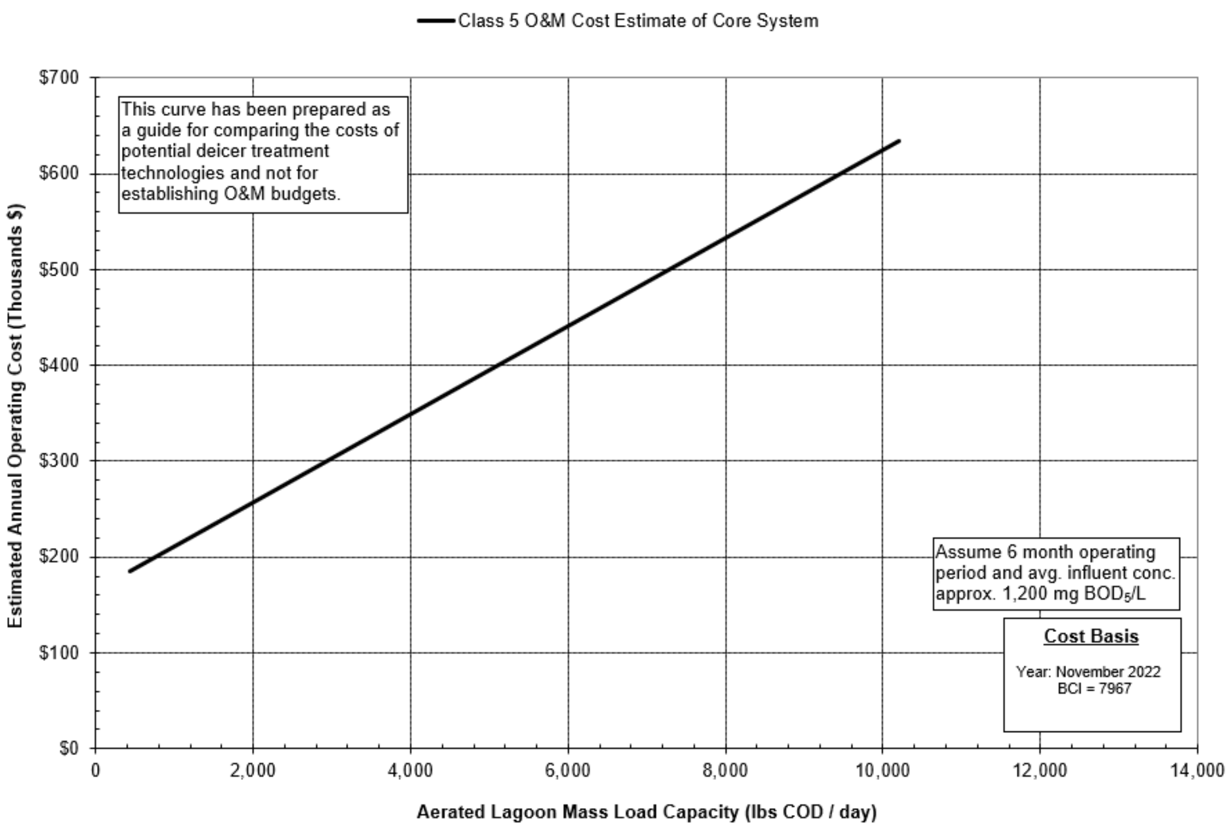

Figure 5. Preliminary planning O&M cost curve.

FACT SHEET 104

Anaerobic Fluidized Bed Reactor

1. Treatment Technology Description

Process Description

Anaerobic fluidized bed reactors (AFBRs) use anaerobic bacteria to convert the deicer compounds into methane and ultimately carbon dioxide, producing high-quality treated water that can be discharged to surface waters or sanitary sewers. Treatment usually occurs in an enclosed stainless steel reactor tank designed specifically for the process. Inside the reactor, anaerobic bacteria attach themselves to an activated carbon media that is 'fluidized' by pumping water into the bottom of the tank and up through the media bed. The fluidization separates the carbon particles in the water column and allows the entire surface of the media to be covered with bacteria. The fluidization loop flow rates are 5 to 20 times larger than the influent flow rate to minimize reactor size and cost. The tank is heated to approximately 90°F, to optimize anaerobic bacteria effectiveness. Nutrients are fed to stimulate bacterial cell growth, with caustic added to keep the pH balanced. Treated water flows through a pipe out of the top of the reactor, along with some of the carbon media and biological solids, into a second tank. The media flowing out of the reactor are settled in the second tank and returned to the reactor, with wasted biological solids in the effluent stream removed in a separate process.

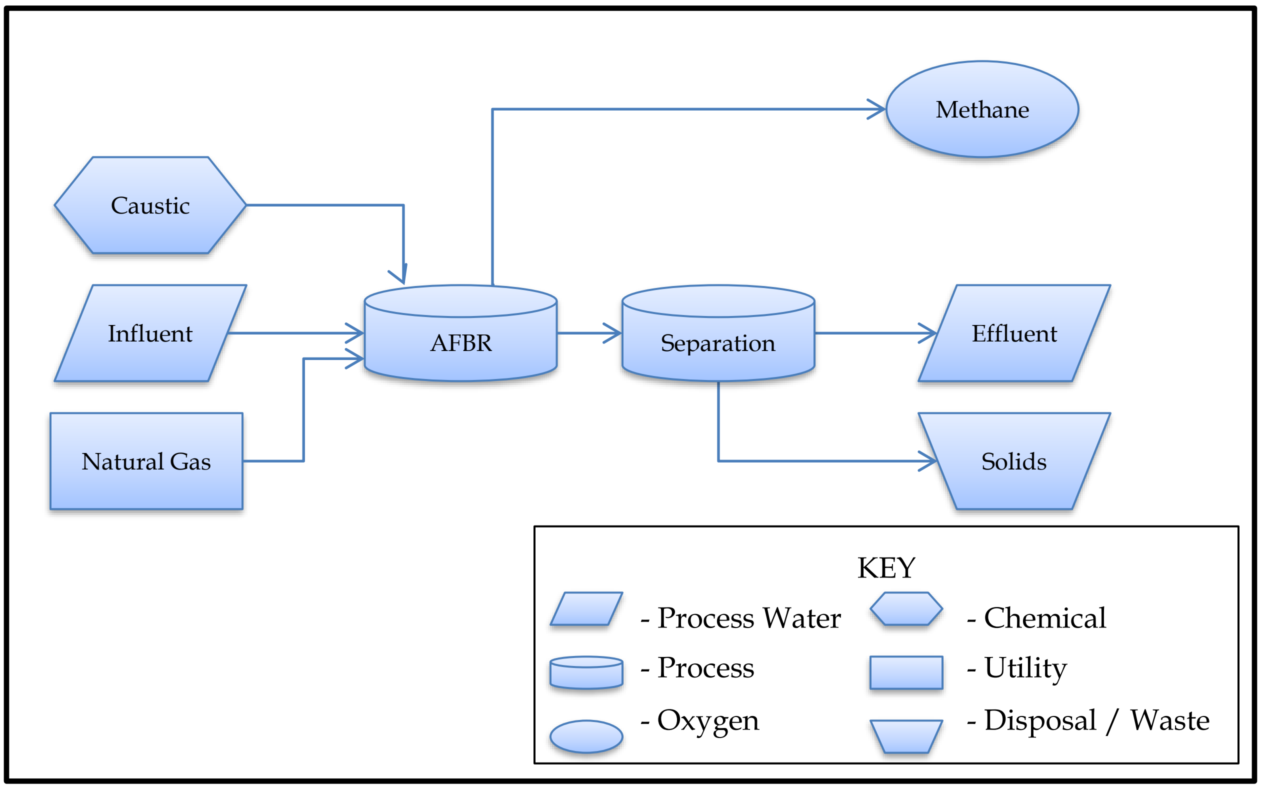

Figure 1. AFBR process flow chart.

Key characteristics of the AFBR are summarized below.

Off-gas Collection and Reuse to Isolate AFBR from Weather Conditions

Anaerobic bacteria have an optimum temperature range of approximately 90°F to 95°F. Treatment effectiveness is significantly reduced below approximately 80°F. Water to be treated must be heated to achieve this optimum temperature.

Anaerobic bacteria produce methane as the primary byproduct of treatment. The methane can be captured from the reactor and reused in the process as a fuel source for water heating. A natural gas boiler with a hot water process loop is typically used to burn the methane. Hot water from the boiler is passed through a heat exchanger to raise the temperature of the influent water. Depending on the efficiency of the heat exchangers, the heat lost by the reactors, and other heat demands of the boiler system, the lowest deicer concentration that is capable of self-sustained heating (without supplementing the methane with natural gas) is between 1,000 and 2,400 mg BOD_5/L. In a typical deicing season, the methane produced in the reactor provides enough fuel to heat the water for the season, except during the seasonal startup period when methane production is lower. Excess methane can also be captured for other beneficial reuses (e.g., heating the building) and/or routed to a flare to meet safety requirements and reduce greenhouse gas emissions.

The heating of the water essentially isolates the treatment system from the winter conditions, resulting in treatment not being affected by day-to-day variation in deicing conditions.

Low Solids Productions

Anaerobic bacteria are slow-growing microorganisms, which is advantageous for deicer treatment. The slow growth means less sludge from dead biological solids is produced than most aerobic biological treatment technologies, reducing the need and cost for solids settling, dewatering, and disposal.

If the AFBR effluent is discharged directly to surface water, a solids removal process will generally be required to remove Total Suspended Solids (TSS) for the remaining bacteria. Anaerobic bacteria are nearly the same density as water and because they may still be producing methane gas, they tend to float. Therefore, Dissolved Air Flotation (DAF) processes are often used to remove the solids from treated effluent.

High-Performance Effectiveness from Controlled and Steady Production

The influent flow rate for the AFBR is typically controlled to provide a constant mass load of BOD_5 during the treatment process. Flow rates are designed to vary as influent BOD_5 concentrations vary to keep a steady mass loading rate (steady lbs BOD_5/day). Flow rates can vary from a few gallons per minute for very high-concentration flows to between 50 to 200 gallons per minute depending on the treatment system capacity. The steady mass loading rate, combined with slow growth of bacteria, optimal operating temperatures, and isolation from weather conditions create a treatment process that is extremely consistent, with BOD_5 and glycol removal rates over 98%.

Seasonal Startup

The process needs a bacterial population to begin treatment. Therefore, the process must be seeded with an appropriate biological population at the first startup. The biological seed is typically obtained from another anaerobic system that treats wastewater high in sugar or alcohol content. In subsequent seasons, the slow-growing biomass will also die off slowly over the summer, when treatment is not occurring, resulting in some biomass in the reactor surviving to the next deicing season. Typically, 25 to 35 percent of the biomass survives to the next season, resulting in no need to reseed reactors with bacteria at the start of each season.

Figure 2. AFBR equipment at Akron-Canton Airport.

Advantages

1. Oxygen is not required, reducing operating costs.
2. Biogrowth is slow so sludge wasting is lower than activated sludge process or similar aerobic treatment processes.
3. Able to achieve relatively low effluent concentrations and steady and predictable operations.

Disadvantages

1. Slow-growth bacteria do not allow rapid increases in treatment capacity in the earliest portions of the startup periods.
2. Requires a flare to burn off excess methane.
3. System must be enclosed to prevent oxygen from entering the process.

The maximum flow rates that can be treated by an AFBR tend to be lower than the maximum flow rates achievable in aerobic systems because of practical constraints on maximum AFBR reactor size and the associated recirculation flow loop. While the lower flow rates are perfectly suitable for airports with lower volume, higher concentration runoff (e.g., runoff collected from deicing pads), those airports that collect high runoff volumes (e.g., airports with gate deicing and no flow segregation to isolate high concentrations) may find the lower flow capacity of the AFBR systems a disadvantage.

Required Support Systems

1. Chemical feed system
    a. Provide nutrients typically paced to treatment capacity.
    b. The system equipment typically includes mixing/storage tanks and metering pumps.
2. Sludge handling system
    a. Typically, required to meet discharge requirements to surface waters.
    b. The equipment typically includes Dissolved Air Flotation (DAF) and mechanical dewatering equipment.
3. Influent heating
    a. Boiler required to maintain approximately 85-90°F temperature.
4. Biogas handling
    a. Anaerobic treatment produces biogas containing methane. Biogas equipment is typically installed to remove water vapor prior to flare and boiler.

Variant Systems

Upflow Anaerobic Sludge Bed (USABs) is a variant on the AFBR process. These systems do not use a carbon media on which to grow the sludge bed. USABs rely on growing anaerobic bacteria in granules that are the correct size to fluidize. Breakdown of the granules during process shutdown or upsets makes control challenging.

Anaerobic Membrane BioReactor (AnMBR) is also a variant on the AFBR process. Anaerobic bacteria in an AnMBR system are contained in a tank and the effluent is forced through a membrane. The process footprint is smaller than an AFBR, but operation and maintenance costs are increased because of the system pressure and periodic membrane replacement.

These variants have been used for general wastewater treatment, but not for deicer treatment to date.

2. Information Supporting Technology Selection and Implementation

Potential Applications Situations

The AFBR process is best suited to high-concentration water, such as deicing pad runoff or collected stormwater from systems that segregate runoff into high-concentration fractions using online monitoring and diversion systems. The process is also capable of achieving relatively low effluent concentrations.

Current Applications of Anaerobic Fluidized Bed Reactor Technology

Albany International Airport (ALB)	Akron-Canton Airport (CAK)
Portland International Airport (PDX)	T. F. Green Airport (PVD)

Technology Selection Criteria

Table 1. Anaerobic fluidized bed reactor process selection criteria.

Parameter	Consideration	Description
Preferred Influent BOD_5 Mass Loading Range	5,000 to 8,000 lbs BOD_5 per day	Maximum capacity is primarily limited by the practicality of constructing, transporting, and installing larger reactors.
Preferred Influent BOD_5 Concentration Range	Minimum of 1,400 mg BOD_5/L	Treatment can be performed below this concentration, but natural gas is required to supplement collected process biogas because of higher water content to evaporate. There is not an actual maximum BOD_5 concentration, but operations are more challenging at BOD_5 concentrations > 80,000 mg/L.
Preferred Influent Flow Range	10 to 200 gpm	Flow rates are changed in response to BOD_5 concentrations to maintain a steady BOD_5 loading rate.
Typical Effluent Concentrations	<50 mg/L BOD_5 < 1 mg/L PG	Effluent concentrations have been shown to be very consistent in practice.
Typical Range of Required Footprint	< 1 acre	Majority of footprint is process tanks.
Typical Building / Equipment Height	> 20 ft.	Reactors are over 35 feet in height but typically installed below the main floor of the treatment building.
Pretreatment Needs	Fuel, Trash, Solids, pH, temperature	Typically, upstream oil-water separator, trash removal, and not routing construction sediment to treatment. A constant adjustment to pH using caustic is also required because of acids produced in the anaerobic degradation. Temperature is maintained by burning collected biogas and natural gas if needed in a boiler and using heat exchangers to heat process water.
Post-Treatment Processing	Biological solids	Use of Dissolved Air Flotation or a similarly effective process is required to remove biological solids. Dewatering of solids is also required before disposal off-site.
Utility Requirements	Operations	Requires electrical, sewer, natural gas, and water utility connections.
Open Water Surface	Bird attraction	AFBR systems do not have open water.
Implementation Time	Scheduling	Design and construction typically require 18 to 36 months.
Staffing	Operations	Treatment plant operations are typically performed by two experienced wastewater treatment operators.

Implementation Considerations for AFBR

The following represent the considerations typically most important when considering implementation of the AFBR technology.

1. *AFBR is a fit for airports with high* BOD_5 *concentrations and lower flow volumes.*
Airports that use deicing pads where glycol recycling is not a feasible technology produce collected runoff that matches the concentration and flow processing rates of the AFBR.

2. *AFBR operation and performance have proven to be extremely consistent.*

The AFBR has nearly 20 years of demonstrated performance at multiple airports, with year-to-year and site-to-site performance data consistently showing BOD_5 and PG removals of 98% and greater.

3. AFBR operations are highly isolated from ongoing deicing operations.
Because of the collection of off-gas from treatment to heat the water and because anaerobic bacteria are more resistant to changes than aerobic bacteria, AFBR performance is highly robust and is minimally affected by current deicing conditions or weather.

4. AFBR operations are somewhat more complex than other treatment technologies
The AFBR has multiple unit processes that are needed to achieve treatment. Qualified operators are essential for good operation.

5. AFBR cost-benefit assessment changes at higher flow rates
The AFBR is suited to low stormwater volumes due to the lower flow rates that it can process. As flow rates increase and BOD_5 concentrations decrease, greater volumes of natural gas may be needed to supplement the collected off-gas from the reactors to achieve design temperatures.

Cost Considerations

Accurate capital costs for AFBRs need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the AFBR system.
- Need to utilize solids settling, dewatering, and disposal processes.
- Needs for storage, pumping, conveyance, and pretreatment processes outside of core AFBR process.
- Site characteristics (e.g., site clearing, soil contamination, soil geotechnical characteristics, seismic requirements, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent AFBR needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using AFBRs are almost always unreliable as estimates for AFBRs at a new site because of differences in the above elements.

Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates[1].

				Expected Range of Accuracy		
AACE Class	ANSI Classification	Typical Use	Project Definition	Low Expected Actual Cost	High Expected Actual Cost	Other Terms
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Figure 3. AACE and ANSI cost estimation classes. [1]

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core AFBR system treatment components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process.

The costs in Figure 4 include only the "core" AFBR treatment components:

- Reactors and solids separators
- Fluidization pumping system
- Nutrient supply system
- pH control system
- Biogas collection system
- Water heating system
- Instruments and PLC Controls
- Inside the building electrical
- Basic utility building
- Basic site preparation

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring
- Influent flow systems (pump stations, conveyance piping to reactor system)
- Spent deicer and stormwater storage
- Pretreatment system (e.g., oil-water separation, sediment removal)
- Biological solids removal, dewatering, storage, and disposal
- Utilities from external supply to treatment building

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[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core AFBR units are reflected in the preliminary planning capital cost curve shown in Figure 4. The lighter lines represent application of a 20% contingency in both directions. The costs should be only used for guidance in treatment technology selection and <u>not</u> for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

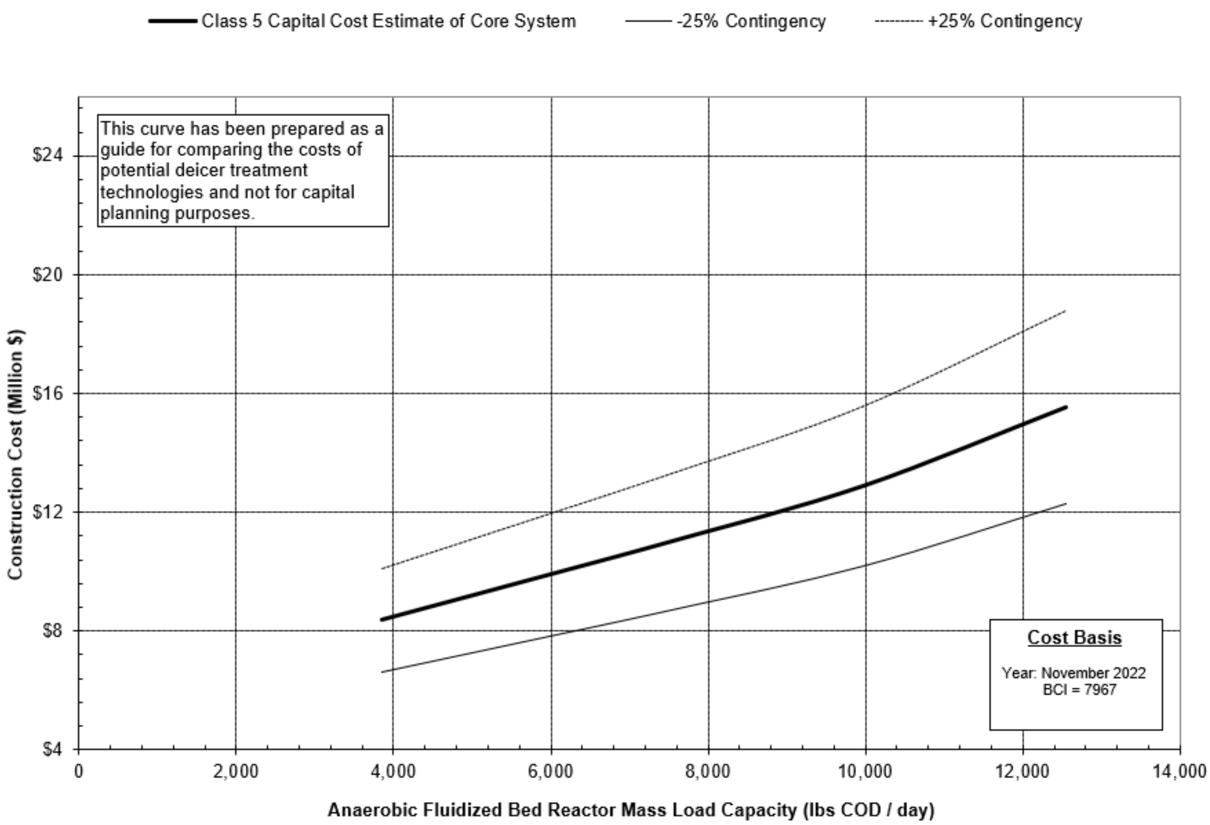

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core AFBR units are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for an AFBR system include:

- Electricity
- Natural gas usage to supplement captured biomass
- Solids disposal
- Chemicals (sodium hydroxide, nutrients)

- Laboratory analyses
- Labor (two operators)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Influent BOD_5 concentrations (affects biogas use and need for natural gas supplements)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

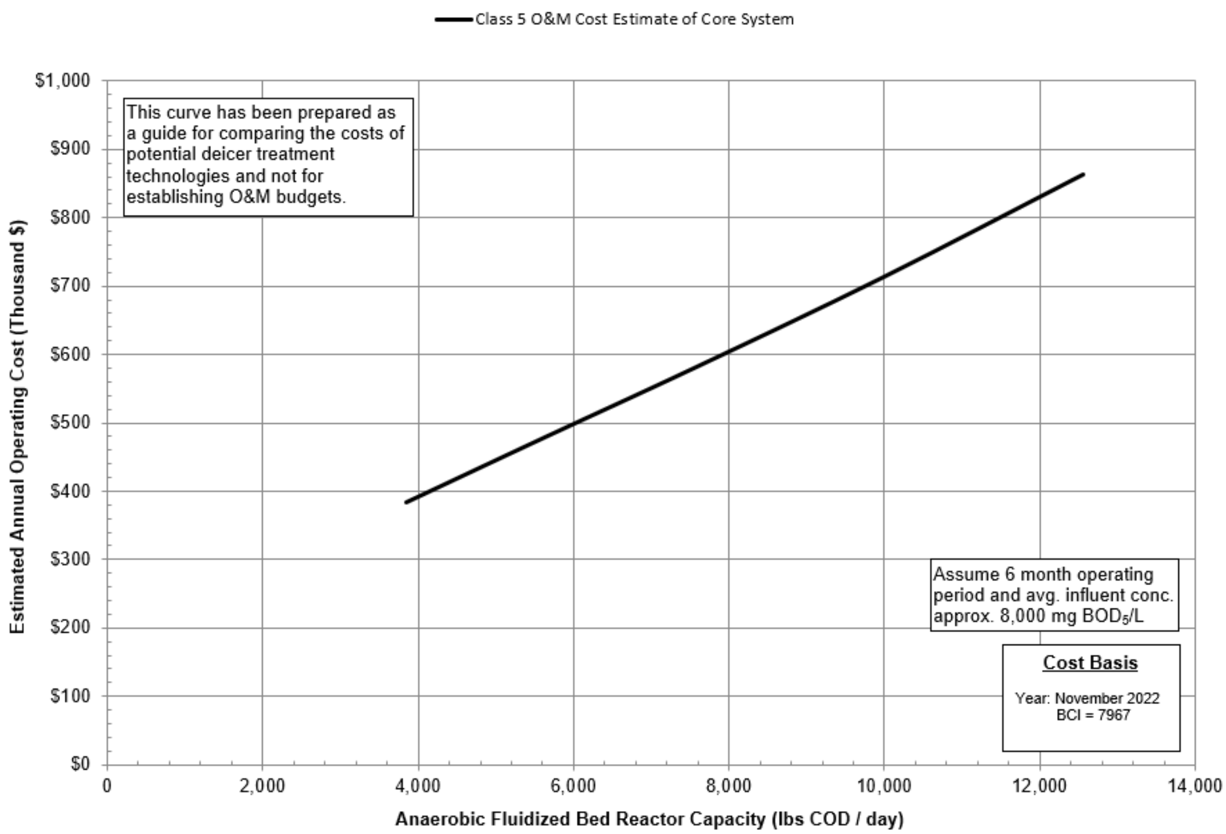

Figure 5. Preliminary planning O&M cost curve.

FACT SHEET 105

Distillation

On-Site
Physical Treatment
Evaporation

1. Treatment Technology Description

Process Description

Distillation is a physical treatment process where deicing-impacted stormwater is subjected to heat and/or pressure variations that cause evaporation. The distillation process separates the water from the organics in the deicing-impacted stormwater based on the different boiling points between these components. The water is brought to a boil, separates from the organics, and turns into a vapor. When the vapor cools, it condenses. The separated water stream is collected and discharged, while the concentrated organics from the deicing-impacted stormwater are captured for reuse.

In the case of Spent Aircraft Deicing Fluid (SADF) treatment with distillation, the main focus is to separate and reclaim either propylene or ethylene glycol, which is the primary component of aircraft deicing fluid. The concentrated product produced by distillation-based recycling systems has a higher concentration and in turn, a higher value than the glycol solutions produced by thermal vapor recompression, mechanical vapor recompression, and other evaporation-based systems. This is due to the ability of distillation systems to produce glycol product with concentrations as high as 99.9%

Distillation is energy-intensive, so it is generally not cost-effective to distill and recycle waste glycol solutions at low concentrations due to the energy requirements to evaporate large volumes of water. Depending on the configuration, glycol concentrations ranging from 30% to 60% are most commonly treated with distillation-based systems. As a result, distillation systems are normally used as a complementary technology to further concentrate glycols produced from MVR and other evaporator technologies. Most distillation systems designed for glycol applications use vacuum distillation to reduce pressure since the boiling point of the glycol/water mixture is lower at a lower external pressure. This results in the system using less energy to separate the glycol and water components.

Components of a typical distillation system include:

- Column(s) or towers
- Heat exchangers of various sizes and styles
- Heat transfer medium reboiler (Use of steam or heat medium fluid)
- Natural gas, oil, or electricity-based heat source and heating system
- Vacuum vessels (Water and Glycol)
- Chiller/Condenser
- Numerous pumps and motors
- Instrumentation: pressure, temperature, and flow transmitters and gauges
- PLC or equivalent controls
- Vacuum pump(s)
- Air compressor(s)

Distillation for the purpose of treating deicer-impacted stormwater is typically run continuously as opposed to batch processing. Depending on distillation manufacturer and design criteria single-stage, two-stage, or three-stage systems are typically used for glycol applications. The columns/towers used for each stage can be comprised of trays or packings to enhance the contact between vapor and liquid. With distillation being an energy-intensive separation method, the influent is usually preheated through heat exchangers (economizers) before entering the vacuum distillation towers. Heat exchangers can be horizontal or vertical and are typically of the “shell and tube” type. A reboiler is used to provide heat to the bottom of the distillation column(s). It boils the liquid from the bottom of a distillation column to generate vapors, which return to the column to drive the physical separation. The water vapors exit from the top of the columns and the heaviest products (the glycol and other organics) exit from the bottom of the column and are often called the “bottoms**.”** Distillation towers use reflux to achieve a more complete separation of products. Reflux refers to the portion of the condensed overhead liquid product from the column that is returned to the upper part of the tower. Inside the tower, the reflux liquid that flows downward provides cooling and condensation of the vapors moving upward, thereby increasing the efficiency of the distillation tower. Vapors produced from the distillation towers are condensed in a chiller or condenser.

Design variables include temperature, distillation column height, desired flow rates, and reflux ratio. Depending on distillation configuration, normally three output streams are produced.

1. The effluent product is a concentrated glycol-containing stream (>99% concentration) that can be sold as industrial glycol or possibly refined to be used as the glycol component in ADF.
2. The effluent distillate stream from distillation units contains glycol and BOD_5 that must be discharged to a POTW for further treatment.
3. The “bottoms”, or the residual waste produced from the system, is the last stream that contains the additives and contaminants that are removed from the spent deicing fluid waste. This material is normally trucked off-site for disposal.

Large distillation systems can be expensive to build on-site at an airport. 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 only a few airports that spray and recover enough ADF to justify the installation of a large on-site distillation system. Historically, spent ADF has been concentrated to a 30% to 60% glycol level on-site at an airport by recycling technologies, such as mechanical vapor recompression, and then this fluid is transported to a centralized distillation plant that serves a number of airports.

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 is appropriately permitted to do so.

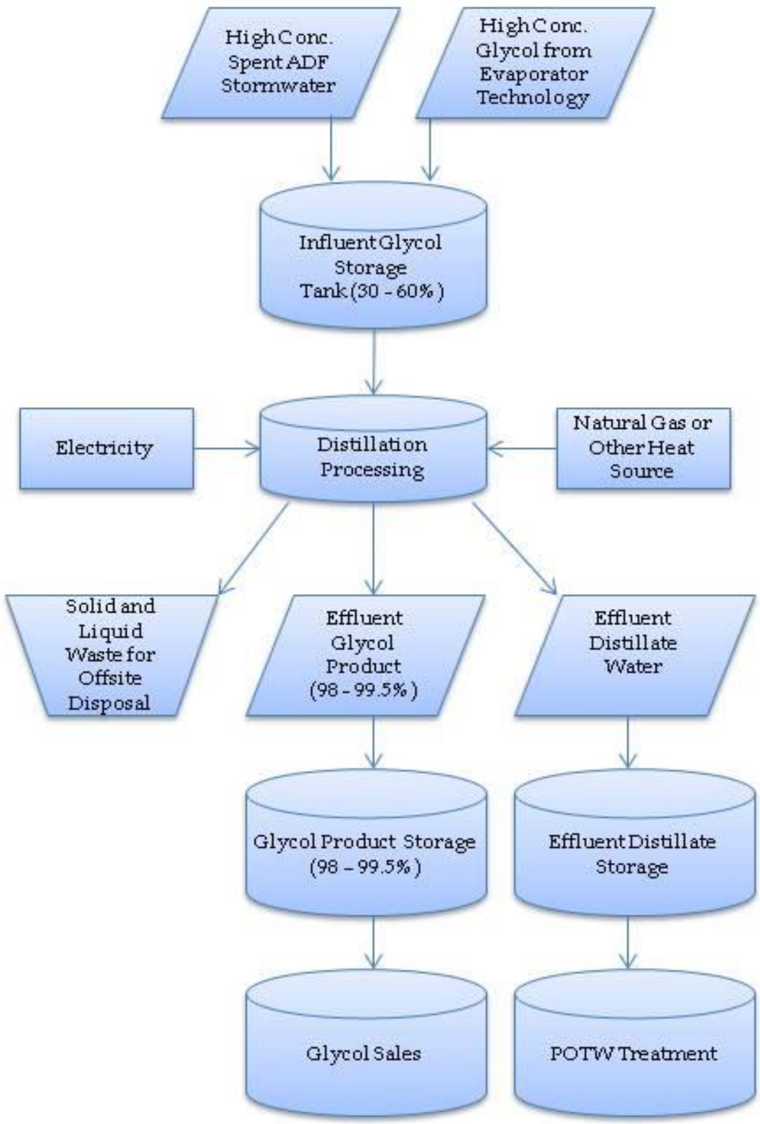

Figure 1. Distillation technology flow chart.

Figure 2. Distillation columns at Portland International Jetport (courtesy Inland Technologies).

Advantages

1. The higher the glycol content produced, the greater the value of the product for resale. Distillation systems have the capability to produce up to 99.9% propylene glycol (PG) concentration. The glycol reclaimed can be sold and the revenues generated can be used to offset operating expenses.
2. Distillation can be used in conjunction with other complementary technologies such as mechanical vapor recompression or other evaporator systems to improve the efficiency of recycling.
3. Due to recent advances in distillation technology, the quality of the glycol produced is acceptable for reuse as a feedstock for the on-site production of ADF at airports. This can provide substantial savings in logistics costs.

Disadvantages

1. A drawback of distillation is that it creates contaminated wash-down water and “bottoms waste” from the columns that cannot be discharged and must be treated further.
2. The distillate or condensate water stream that distillation produces contains BOD_5 concentrations that are usually above acceptable levels to discharge to stormwater, which requires airports to discharge these residual streams to POTWs for further treatment.
3. Distillation columns can be very large and tall. Height can be an issue at airports.
4. 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. Few airports spray and recover enough ADF to justify installation of an on-site distillation system.
5. Distillation is energy-intensive; therefore it is generally not cost-effective to distill and recycle waste glycol solutions at low concentrations.

Required Support Systems

1. Storage tanks
   a. Provide storage of the effluent streams until discharged or removed from the airport.
2. Other recycling technologies (typically)
   a. Distillation is normally used as a complementary technology to further concentrate glycols produced from MVR and other evaporator technologies
3. Filtration systems
   a. Adding filtration, such as use of activated carbon, to the distillation process, can decrease the amount of solids and particulate matter that normally would have accumulated in the heat exchangers. Without filtration, the system would be subject to frequent shutdowns and tedious maintenance to clean the exchangers.
4. “Bottoms” waste
   a. An off-site facility is usually required to dispose of the “bottoms waste.”

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

The distillation process is best suited to high-concentration water that typically has already been treated using RO and/or MVR processes to evaporate the large volumes of water associated with low concentrations. The process can produce PG sufficiently pure to be resold as industrial glycol, or further refined and used in ADF production. Several contaminated waste streams must be treated or discharged to a sanitary sewer – i.e., contaminated wash-down water and “bottoms waste.” The number of airports that have sufficiently high concentrations and sufficiently large volumes of collected glycol to make construction and operation of on-site distillation systems is relatively small.

Current Airport Applications of Distillation Technology

Denver International Airport (DEN)

Salt Lake City International Airport (SLC)

Portland International Jetport (PWM)

Halifax Stanfield International Airport (YHZ)

Calgary International Airport (YYC)

Technology Selection Criteria

Table 1. Distillation Process selection criteria.

Parameter	Consideration	Description
Minimum Influent PG, EG, BOD_5 Conc.	Approx. 300,000 mg PG/L	Treatment can be performed below this concentration; however, energy demands rise in relation to products recovered.
Typical Area (Footprint)	< 1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical Building /	> 40 ft	Equipment can be installed in building height ranging from 20 to 50 ft depending on type of distillation system and height of columns.

Parameter	Consideration	Description
Equipment Height		
Open Water Surface	No open water	All treatment occurs in enclosed tanks.
Reliance on Other Entities	Risk management	Effluent water produced must be sent to a POTW or further treated for discharge to stormwater. Reclaimed glycol is usually shipped off-site by a third-party vendor for sale. Small amount of "bottoms waste" is generated by maintenance activities.
Influent Contaminants	Operations impacts	Free-product fuels spills will contaminate PG stream Metals will concentrate in wastewater stream. Grit removal and screening are required before process feed.
Utility Requirements	Planning, Design & Operations	Requires electrical, natural gas, and water utility connections.
Accessibility	Operations	Off-site access is required for removal of PG product stream and loading to tanker trucks.
Treatment Plant Operation Needs	Operations	Treatment plant operation is typically performed by 3-4 experienced process operators present during operations.
Time Required for Design and Construction	Planning, Design & Construction	Design and construction typically require 18 to 24 months

Implementation Considerations for Distillation Systems

1. *Distillation almost always must be coupled with other technologies that more economically evaporate water or separate water and glycol at lower concentrations.*
2. *High-grade components should be incorporated into system design.*

   There can be incompatibility issues between the feed/effluent mixture and the tube material composition in heat exchangers, which can lead to early tube failures.
3. *Amount of ADF used at the airport and the amount of glycol that can be reclaimed.*

   The larger volume of glycol that can be recycled, the more cost-effective distillation treatment systems become. A significant annual glycol use is needed to justify distillation.
4. *Average concentration of spent ADF*

   Distillation systems are not typically installed unless other complementary technologies are used on-site to provide ideal glycol concentrations in the range of 30% to 60%.
5. *Effluent Discharge*

   A POTW outlet or other treatment equipment such as membranes is required to discharge the effluent water produced by the distillation system if discharge permits are stringent.

Cost Considerations

The cost structure for use of glycol recycling-based technologies for managing spent deicer is fundamentally different than for biological treatment systems for the following reasons:

- Capital costs are often a combination of airport-provided capital and equipment leased by the recycling vendors to the airports in the overarching contracts between the airports and recycling vendors.
- The capital and operating costs are dependent on which combinations of the typical recycling processes are applied (MVR, RO, distillation).
- The number of units required at a given site is dependent on both initial PG concentrations and flows that need to be processed.
- The operating costs are affected by the payback (or lack thereof) from resale or reuse of the recovered glycol product.
- The payback or costs are strongly affected by both the concentration of PG in the collected runoff and the amount of reclaimed product.
- The distance of the airport from a regional recycling facility affects transportation costs.
- The need for pretreatment, solids handling, and distillate discharge outside of core process is highly site-specific.

Capital costs, operating costs, fees, and payback obtained from other airports using recycling systems are almost always unreliable as estimates for distillation systems at a new site because of differences in the above elements.

For the reasons above, the capital and O&M costs for the recycling technologies (MVR, RO, distillation) need to be developed on a situation-specific basis. Providing specific cost ranges for these technologies similar to what was provided for the biological treatment technology fact sheets is not appropriate as reliable guidance for this document.

FACT SHEET 106

Mechanical Vapor Recompression

1. Treatment Technology Description

Process Description

Mechanical Vapor Recompression (MVR) is a type of evaporation technology that can be used to remove Spent Aircraft Deicing Fluid (SADF) from stormwater. It is a physical process where deicing-impacted stormwater is heated, the water is evaporated and subsequently, the fluid is separated into a stream of distilled water and a stream of concentrated spent deicing fluid. This technology is typically used to reclaim concentrated glycol, the primary component of ADF. MVR systems are typically designed to handle influent concentrations of glycol from 0.5% to 30+%. The glycol product that is produced has value and can be further refined or sold.

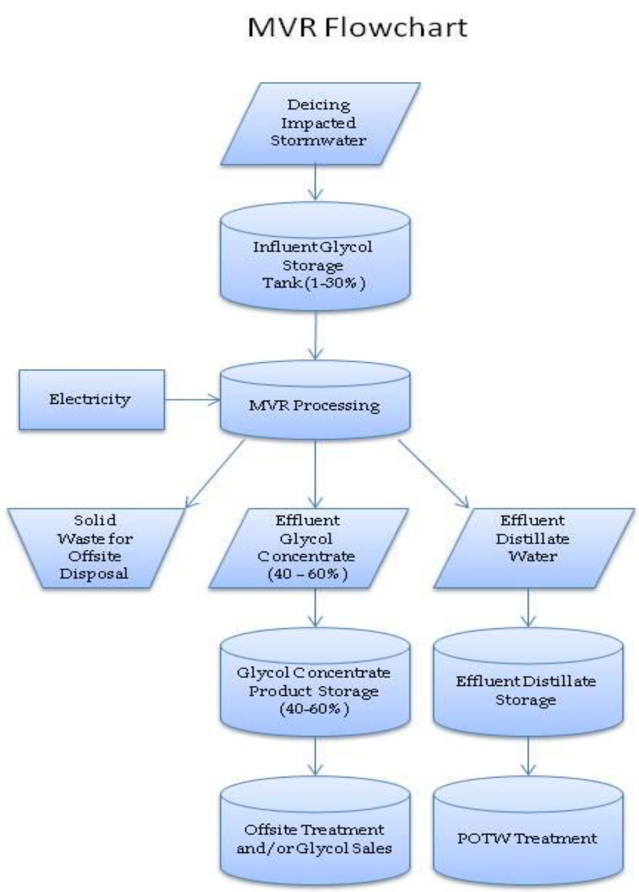

Figure 1. MVR flow chart.

An MVR system can be designed to handle input of water-ethylene or water-propylene glycol spent ADF mixtures up to 30% glycol concentration. The water is separated from the ADF stream based on the difference in boiling points between water and the type of glycol. MVR systems can be installed on-site at an airport or be part of an off-site centralized recycling facility. Manufacturers of this equipment offer MVR units that can be assembled and configured on steel skid units prior to delivery so that the units do not have to be constructed on-site. Scalability is easier as units can be added or removed to increase or decrease processing capacity. MVR technology can treat spent ADF streams with <1% glycol, but typically the economics are unfavorable at those percentages.

Most MVR units are designed to be operated with Programmable Logic Controllers (PLC) for ease of operation. At many airports MVR systems run twenty-four (24) hours per day and for seven (7) days per week, assuming there is a sufficient volume of fluid to process. Throughput flow rates vary according to the glycol concentration that is being fed through the system and are dependent on the quality of the feed. Spent ADF is usually contaminated with small amounts of mechanical impurities such as airfield contaminants, rust, sand, grit, and salt. The feed is typically stored in tanks prior to being treated and pumped through a filtration system before being sent to an MVR unit. Depending on the type of MVR system, the separation of water and glycol can occur in a primary heat exchanger or evaporator tank. The principal components of an MVR system are a heat exchanger, an evaporation tank, a cyclone, and a mechanically driven compressor or blower. Typically, the influent deicing-impacted stormwater is preheated in a heat exchanger and then the influent is evaporated in the evaporation tank. Following evaporation, the glycol/steam mixture enters a cyclone where steam separates from the recovered glycol product. The steam generated during this process is compressed and used as a heat source for the evaporation tank and heat exchanger. This minimizes energy requirements to supply constant heat to the system.

The distillate effluent produced from the MVR system contains low levels of propylene glycol and BOD_5 and is typically discharged to a POTW. The recovered glycol product stream is segregated into a separate storage tank. Typical concentrate products produced from MVR systems contain between 40% and 60% glycol.

Figure 2. MVR unit at Denver International Airport (courtesy of Inland Technologies).

Advantages

1. MVR systems can be designed to be modular, which means they can be installed in a relatively small footprint and additional units can be added if increased capacity is required.
2. MVR units with PLC systems can be adjusted while in operation to deal with varying influent concentrations caused by variability in precipitation-related deicing events.
3. MVR units can be used in conjunction with other complementary technologies such as membrane treatment systems and distillation to improve the efficiency of recycling.
4. The glycol reclaimed can be sold and the revenues generated can be used to offset operating expenses.

Disadvantages

1. 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 BOD_5 and glycol.

2. MVR units installed on-site are more economical the greater the volume of ADF sprayed at the airport, and more importantly, the greater the glycol that can be captured at the airport for recycling.
3. MVR heat exchangers require more maintenance and cleaning when dealing with spent ADF with higher concentrations of thickened fluids (i.e., Type IV fluids).

Required Support Systems

1. Storage tanks
    a. Provide storage of the effluent streams until discharged or removed from the airport.

2. Filtration systems
    a. Filtration prior to MVR treatment reduces the frequency of downtime associated with maintenance to clean heat exchanger systems.
3. Other recycling technology
    a. Most glycol reclaimed from MVR systems is further refined through a distillation system to achieve higher glycol concentrations (i.e., 99%) to increase the value of the glycol product to be sold or used in ADF production.
    b. Scrubber and/or membrane systems can be added to MVR systems to further treat the distillate effluent if discharging to stormwater.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

MVR systems are applicable to situations where recycling of glycols is desired. The technology is limited (for economic reasons) to processing concentrations greater than 1% glycol. A contaminated waste stream must be treated or discharged to a sanitary sewer – i.e., a water stream contaminated with PG. The saleable PG concentration from MVR systems can be as high as 50% PG.

Current Applications of MVR Technology

Washington Dulles International Airport (IAD)	Portland International Jetport (PWM)
Bradley International Airport (BDL)	Denver International Airport (DEN)
Halifax International Airport (YHZ)	Toronto Pearson International Airport (YYZ)
St. John's International Airport (YYT)	Minneapolis−Saint Paul International Airport (MSP)
Cleveland Hopkins International Airport (CLE)	Pittsburgh International Airport (PIT)
Salt Lake City International Airport (SLC)	Ottawa International Airport (YOW)
Calgary International Airport (YYC)	Winnipeg International Airport (YWG)

Criteria Useful to Analysis of Treatment Technology Options

Table 1. Mechanical vapor recompression process selection criteria.

Technology Parameter	Value or Rating	Description
Minimum PG, EG, BOD_5 Conc.	Approx. 10,000 mg PG/L	Treatment can be performed below this concentration; however, energy demands rise in relation to products recovered.
Typical Area (Footprint)	< 1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical Building / Equipment Height	May be > 20 ft	Equipment can be installed in building heights ranging from 16 ft to 22 ft depending on MVR manufacturer.
Open Water Surface	No open water	All treatment occurs in enclosed tanks.
Reliance on Other Entities	Reliance	Effluent water produced must be sent to a POTW or further treated for discharge to stormwater. Reclaimed glycol is usually shipped off-site by a third-party vendor for sale. Small amount of non-hazardous solid waste is generated by maintenance activities.
Influent Contaminants	Operations impacts	Free-product fuels spills will contaminate PG stream
Utility Requirements	Planning, Design, & Operations	Requires electrical and water utility connections.
Accessibility	Operations	Off-site access is required for removal of PG product stream and loading to tanker trucks.
Treatment Plant Operation Needs		Treatment plant operation is typically performed by 3-4 experienced process operators present during operations.
Time Required for Design and Construction	Scheduling	Design and construction typically require 18 to 24 months for the permanent facility. Temporary/mobile facilities can be established in 6 to 9 months, including planning and permitting.

Implementation Considerations for MVR Systems

The following represent the considerations typically most important when considering the implementation of the MVR technology.

1. *Careful consideration of the amount of ADF used at the airport and more importantly the amount of glycol that can be reclaimed.*
   The larger volume of glycol that can be recycled, the more cost-effective MVR treatment systems become.

2. *Careful consideration must be given to the average concentration of spent ADF*
   MVR systems are not typically installed unless the glycol concentration in the spent ADF is at least 1%. These systems run more efficiently when glycol concentrations are ideally between 8% to 15%.

3. *Effluent Discharge*
   A POTW outlet or other treatment equipment such as membranes is required to discharge the effluent water produced by MVR systems.

Cost Considerations

The cost structure for use of glycol-recycling-based technologies for managing spent deicer is fundamentally different than for biological treatment systems for the following reasons:

- Capital costs are often a combination of airport-provided capital and equipment leased by the recycling vendors to the airports in the overarching contracts between the airports and recycling vendors.
- The capital and operating costs are dependent on which combinations of the typical recycling processes are applied (MVR, RO, distillation).
- The number of units required at a given site is dependent on both initial PG concentrations and flows that need to be processed.
- The operating costs are affected by the payback (or lack thereof) from resale or reuse of the recovered glycol product.
- The payback or costs are strongly affected by both the concentration of PG in the collected runoff and the amount of reclaimed product.
- The distance of the airport from a regional recycling facility affects transportation costs.
- The need for pretreatment, solids handling, and distillate discharge outside of core process is highly site-specific.

Capital costs, operating costs, fees, and payback obtained from other airports using recycling systems are almost always unreliable as estimates for distillation systems at a new site because of differences in the above elements.

For the reasons above, the capital and O&M costs for the recycling technologies (MVR, RO, distillation) need to be developed on a situation-specific basis. Providing specific cost ranges for these technologies similar to what was provided for the biological treatment technology fact sheets is not appropriate as reliable guidance for this document.

Moving Bed Biofilm Reactor

1. Treatment Technology Description

Process Description

The Moving Bed Biofilm Reactor (MBBR) is a fixed film biological treatment process in which biomass preferentially attaches itself to the surface of carriers (media), which are completely mixed or moving within each treatment reactor, basin, or tank. The biomass is composed of bacterial population(s) similar to those found in activated sludge systems; however, the MBBR process does not require sludge return from a clarifier, and as such, the ratio of volatile to total solids in an MBBR tends to be 0.95 or higher, while activated sludge systems normally carry a ratio of 0.75 or less.

Clarification of sloughed biomass (biological solids) may be accomplished using Dissolved Air Flotation (DAF) or gravity-settling basins. In an MBBR configuration, sludge is wasted directly from the DAF or clarifier and not typically returned [Figures 1 and 2]. Hybrid MBBR systems that include sludge return are referred to as integrated fixed film and activated sludge (IFAS) systems.

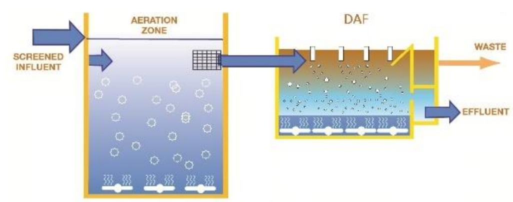

Figure 1. MBBR-DAF process flow chart

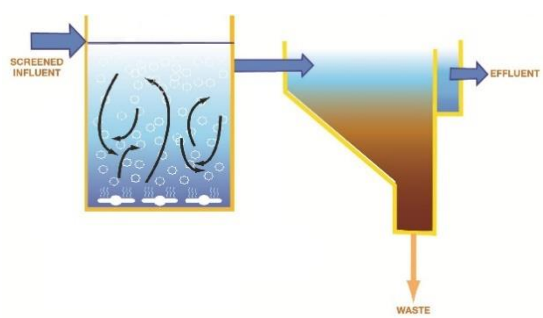

Figure 2. MBBR-clarifier process flow chart

The MBBR process has been implemented in full-scale systems since the late 1980s, with thousands of global installations. There are a number of biofilm carrier types, but they typically are constructed from HDPE, typically have a specific gravity of approximately 0.95 without biofilm attachment, and are typically neutrally buoyant with biofilm attachment (examples in Figure 3, below). The specific (protected) fixed film surface area [SSA] varies from supplier to supplier but typically ranges from 500 to

850 m^2 fixed film surface area per m^3 of biofilm carriers supplied (500-850 m^2/m^3 or 152 – 260 ft^2/ft^3). MBBRs are typically filled between 25 and 65 percent of the basin's empty bed operating volume.

The process is designed using surface area loading rate (SALR) criteria, given in mass of pollutant per day per unit fixed film surface area. The total fixed film area is calculated by dividing the design load of a given pollutant by the appropriate SALR. Once the area is determined, the volume of media required is calculated by dividing the total fixed film area required by the SSA. The MBBR reactor is sized by dividing the volume of media by the desired fill fraction (0.25 - 0.65).

The percent removal of any pollutant provided by one MBBR stage typically mimics a continuously stirred tank reactor (CSTR) with approximately 85-90% removal. Other factors such as hydraulic retention time, residual dissolved oxygen, and wastewater temperature play a part in actual removal efficiencies.

MBBRs may be operated in aerobic or anoxic modes for degradation of glycols and other deicing compounds.

- When the goal is to degrade glycols and other deicing compounds in stormwater runoff, an aerobic configuration is appropriate, and the number of stages (reactors operated in series) is determined by the percent BOD_5 reduction required.
- Anoxic MBBRs have been used at municipal wastewater treatment plants for total nitrogen removal, i.e., conversion of NO_3-N to N_2 gas, using carbon in the deicer as a food source in cellular reproduction and stripping O_2 required for respiration from the NO_3 molecules. The Gardermoen (Norway) and Blind Brook (NY, USA) wastewater treatment plants are examples. Refer to details in Chapter "Airport Summary 11 OSL (Oslo-NRWY)".
- The MBBR is a biological process that requires food, nutrients, and oxygen for respiration. At the end of the deicer season, when the deicer, oxygen, and/or nutrients are shut off, the bacterial population will begin to die off; however, a biofilm may remain attached and dormant for an extended period of time. The MBBR process has a relatively short assimilation period to establish heterotrophic biofilm (typically 1-4 weeks), a startup period would be required to regain the treatment capacity at the beginning of the following deicer season. Alternatively, a viable/similar food source (glycerol), nutrients, and aeration may be dosed to the MBBR during the off-season.

The MBBR process uses aerobic bacteria to degrade glycols and other deicing compounds. Influent is pumped into a large, open aeration tank. Oxygen is typically fed to the basin using blowers that pump air into a submerged grid that diffuses air across the floor of the reactor. Nutrients are fed to stimulate biological growth. Screens are installed on the discharge to retain the biofilm carriers in each MBBR stage. The main components of an MBBR system are shown in Figures 3 (various MBBR biofilm carrier makes/models) and 4 (typical MBBR tank/basin components and blowers).

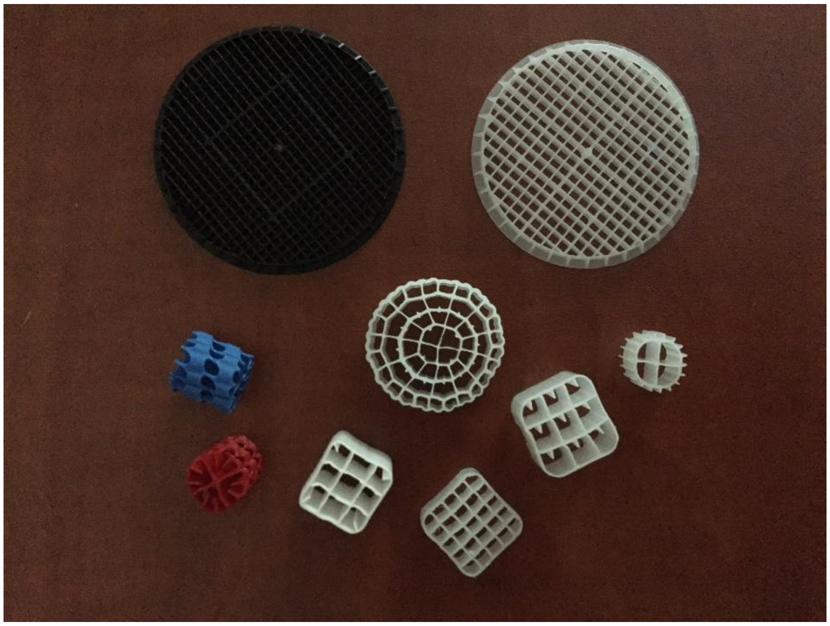

Figure 3. Various MBBR biofilm carrier media makes/models.

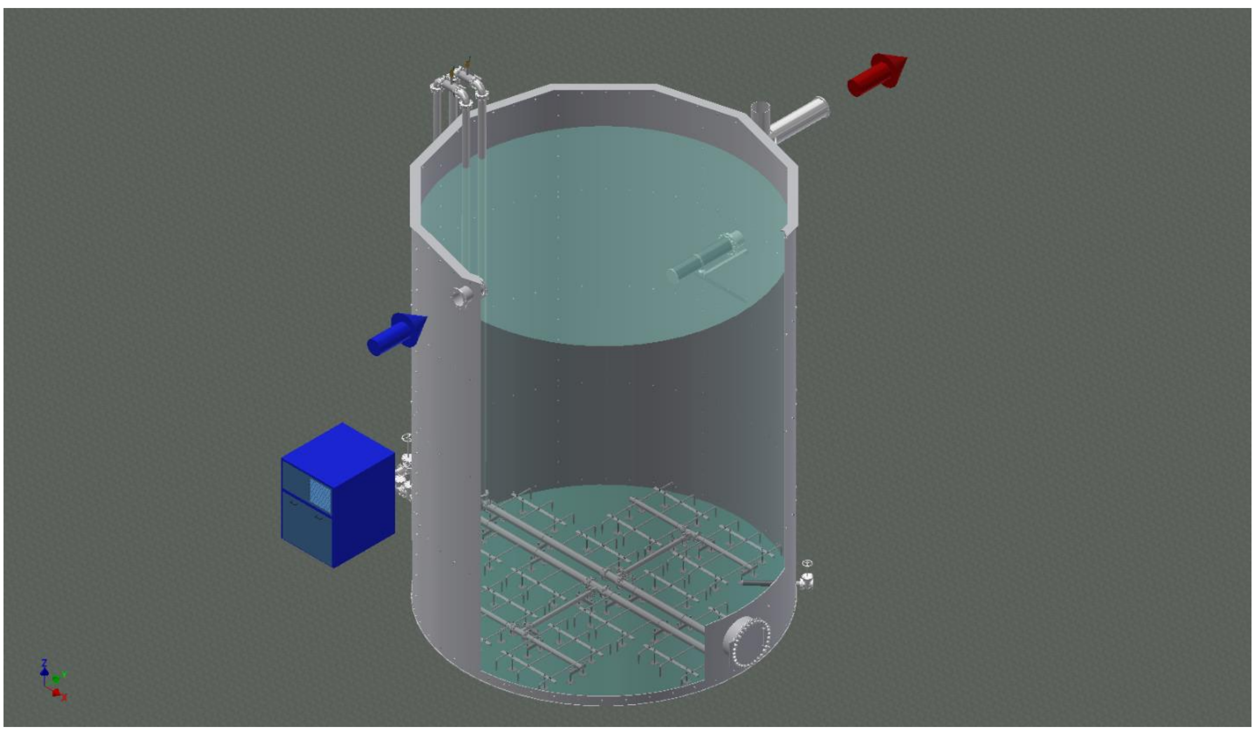

Figure 4. Typical MBBR tank/basin components and blowers.

Advantages

1. Attached growth bacteria are suitable for achieving biological treatment during cold temperatures.

2. The MBBR has a proven ability to achieve low propylene glycol and concentrations of less than 15 mg BOD_5/L. The percent pollutant removal required and the potential need for multiple MBBR stages must be evaluated by the designer.
3. Consistent and predictable performance over a wide range of influent concentrations, with influent load monitoring and control.
4. Operation requires nutrients, mixing, aeration, and operation/maintenance similar to other biological treatment processes such as activated sludge systems.

Disadvantages

1. As with any biological process, sludge (biomass) wasting and handling (thickening, dewatering, and/or disposal) is required.
2. Typically, biofilm carrier suppliers will guarantee carrier lifetime on the order of twenty (20) years, although designer/end-user should verify with supplier(s) when considering initial capital and long-term operational expenditures (CAPEX and OPEX, respectively).
3. With extended periods of seasonal dormancy, a startup/reseeding or off-season feeding process should be planned for each deicing season.

Required Support Systems

1. Aeration System
    a. The aeration system provides oxygen for the aerobic bacteria and mixing. Aeration system sizing dictates the treatment rate (in pounds per day) of the system. However, the mixing requirement may also be the limiting factor for the blower system.
    b. The equipment includes blowers, an air-piping manifold, and a diffused aeration grid or system.
2. Nutrient Feed System
    a. Provide nutrients paced to the MBBR loading rate.
    b. The equipment typically includes mixing/storage tanks and metering pumps.
3. Sludge Handling System
    a. Gravity Clarifier waste sludge typically ranges from 0.5-1% dry solids.
    b. DAF float (waste) typically ranges from 2-6% solids, requiring addition of coagulants and flocculants.
    c. Thickening and Dewatering processes may be incorporated into the design such that dry solids concentrations in waste sludge range from 8% to 20%, reducing the hauled sludge volume.
    d. Equipment may include digesters, centrifuges, belt presses, or filter presses.
4. Analytical System
    a. Routine measurements of influent flows and concentrations are required to determine system loading, nutrient, and aeration requirements.
    b. Equipment may include online monitors or analytical test kits.

Variant Systems

An Aerobic Fluidized Bed Reactor is a variation of the MBBR process. The media bed is typically housed in a vertical tank and the bed is fluidized by a flow loop. Pure oxygen is fed into the bottom of the tank. The effluent is then treated in a clarifier to remove the free-floating biofilm.

An Aerobic Fluidized Bed Reactor is currently in operation as the polishing treatment at the Albany Airport. It has been in operation since 2001.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

The MBBR process is best suited to low to moderate concentrations, high-volume flows, cold climates, and where available land is an issue. The process can achieve very low effluent concentrations. The MBBR has larger sludge handling requirements than AFBR and AGB technologies. Vendor supplying the media will typically assist with specifying and/or supplying the aeration system. The vendor may also have other proprietary equipment such as the screens to maintain the media in the basin.

Current Airport Applications of Moving Bed Biofilm Reactor Technology

Oslo Gardermoen Airport (OSL) London Heathrow Airport (LHR)

Technology Selection Criteria

Table 1. Moving Bed Biofilm Reactor Process Selection Criteria

Parameter	Consideration	Description
Preferred Influent BOD_5 Mass Loading Range	No limit	No inherent minimum or maximum mass loading limits. Number of reactors is directly proportional to the required BOD_5 mass load and is often limited by available area at the airport.
Preferred Influent BOD_5 Concentration Range	100 to 10,000 mg BOD_5/L	Can treat a wide variety of concentrations because flow is adjusted with influent concentrations to achieve steady loads.
Preferred Influent Flow Range	Varies	The maximum flow rate capacity is a situation-specific determination based on maximum mass load, lower limits of BOD_5 concentrations, and system hydraulics.
Typical Effluent Concentrations	<30 mg/L BOD_5 < 15 mg/L PG	Effluent concentrations have been shown to be very consistent in practice.
Typical Range of Required Footprint	2 to 4 acres	Majority of footprint is an open aeration tank with media.
Typical Building / Equipment Height	< 20 ft. <30 ft.	Building will typically house nutrient system and sludge handling equipment which can make the building slightly taller than 10 ft. Aerobic basins with side water depths of 15-30 feet optimize oxygen transfer efficiency.
Pretreatment Needs	Fuel, Trash, Solids	Typically, upstream oil-water separator, trash removal, and not routing construction sediment to MBBRs.
Post-Treatment TSS Processing	Operations	Removal of biological solids is required, along with subsequent dewatering and disposal.
Utility Requirements	Operations	Requires electrical and water utility connections.
Implementation Time	Scheduling	Design and construction typically require 18 to 36 months.

Parameter	Consideration	Description
Staffing	Operations	Treatment plant operations are typically performed by 2-3 experienced wastewater treatment operators.
Utility Requirements	Operations	Requires electrical and water utility connections.

Implementation Considerations for MBBR

The following represent the considerations typically most important when considering the potential implementation of the MBBR technology.

1. *MBBR is a fit for airports with low to moderate* BOD_5 *concentrations and larger flow volumes.*
   Airports that have larger collection areas because of at-gate or stand deicing typically have larger stormwater volumes and lower BOD_5 concentrations than airports using only deicing pads.

2. *MBBR can potentially achieve low effluent* BOD_5 *concentrations.*
   BOD_5 and PG concentrations of less than 15 mg/L are potentially achievable but the actual effluent BOD_5 that can be achieved is dependent on many factors. The treatment system operates most efficiently when it receives a constant load (pounds per day) of deicer. The treatment system can handle some variation in concentration by adjusting the flow rate to provide the constant load. Physical limitations in load removal are associated with maximum allowable SALR, maximum oxygen transfer efficiency of the aeration system, wastewater temperature, nutrient ratios, and residual dissolved oxygen.

3. *MBBR's footprint is relatively small.*
   The MBBR system has a somewhat smaller footprint than aerobic technologies such as activated sludge, aerated lagoons, and aerated gravel beds that might also be suitable for low to moderate BOD_5 concentrations and higher flow rates.

4. *MBBR operation is somewhat affected by variability in deicing conditions.*
   Unlike the aerated gravel bed system but like activated sludge and aerated lagoon systems, the MBBR operations and performance may be negatively affected in situations where steady deicer loads and flows are not available.

5. *MBBR produces a sludge load as a byproduct that must be managed.*
   Unlike the aerated gravel bed but like activated sludge systems, the MBBR system produces waste biological solids that need to be removed from the effluent stream, dewatered, and disposed of off-site.

Cost Considerations

Accurate capital costs for MBBRs need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the MBBR system.
- Need to utilize solids settling, dewatering, and disposal processes.
- Needs for storage, pumping, conveyance, and pretreatment processes outside of core MBBR process.

- Site characteristics (e.g., site clearing, soil contamination, soil geotechnical characteristics, seismic requirements, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent MBBR needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using MBBRs are almost always unreliable as estimates for MBBRs at a new site because of differences in the above elements.

Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates[1].

				Expected Range of Accuracy		
AACE Class	**ANSI Classification**	**Typical Use**	**Project Definition**	**Low Expected Actual Cost**	**High Expected Actual Cost**	**Other Terms**
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Figure 3. AACE and ANSI cost estimation classes[1]

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core MBBR treatment components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process.

The costs in Figure 4 include only the "core" MBBR treatment components:

- Aeration basins and blowers
- Solids removal system
- Pumping and conveyance systems
- Nutrient supply system

[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

- Instruments and PLC Controls
- Inside the building electrical
- Basic utility building

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring
- Influent flow systems (pump stations, conveyance piping to reactor system)
- Storage
- Pretreatment system (e.g., oil-water separation, sediment removal)
- Biological dewatering, storage, and disposal
- Utilities from external supply to treatment building
- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage.

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core MBBR units are reflected in the preliminary planning capital cost curve shown in Figure 4. The lighter lines represent application of a 20% contingency in both directions. The costs should be only used for guidance in treatment technology selection and <u>not</u> for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

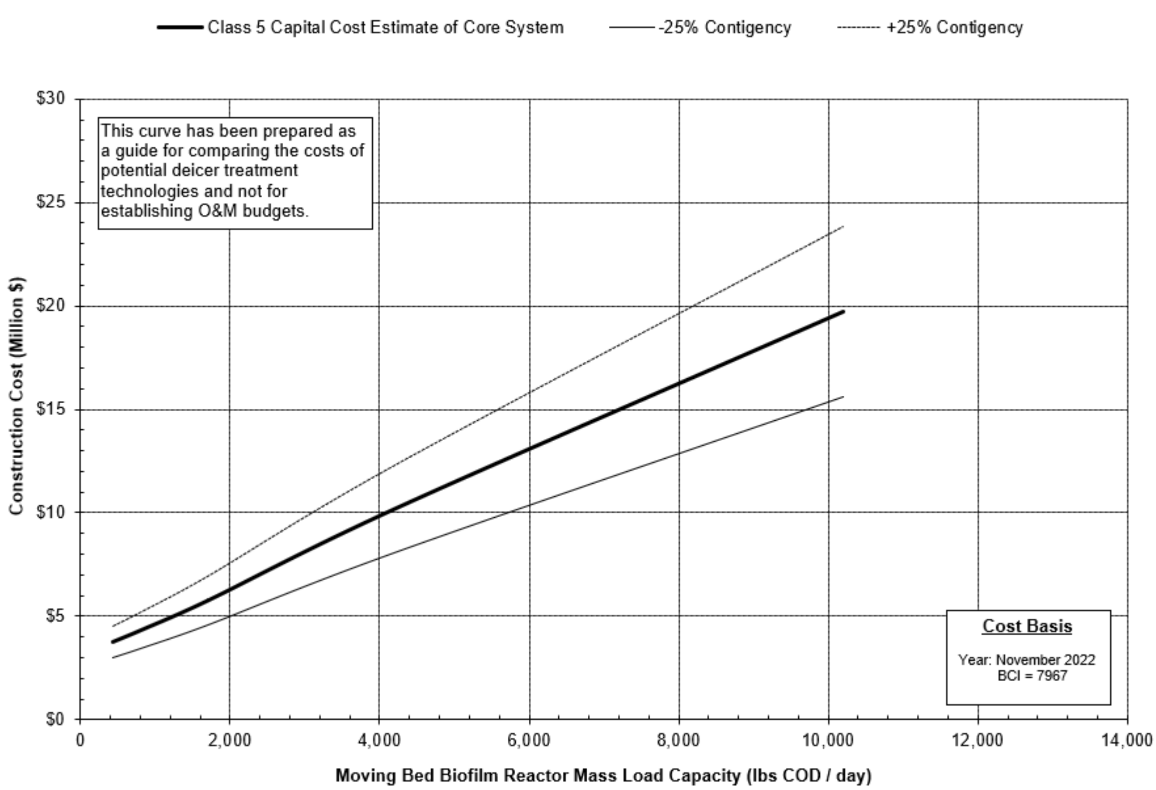

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core MBBR units are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for an MBBR include:

- Electricity (especially from blowers)
- Chemicals (nutrients)
- Laboratory analyses
- Labor (three operators)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

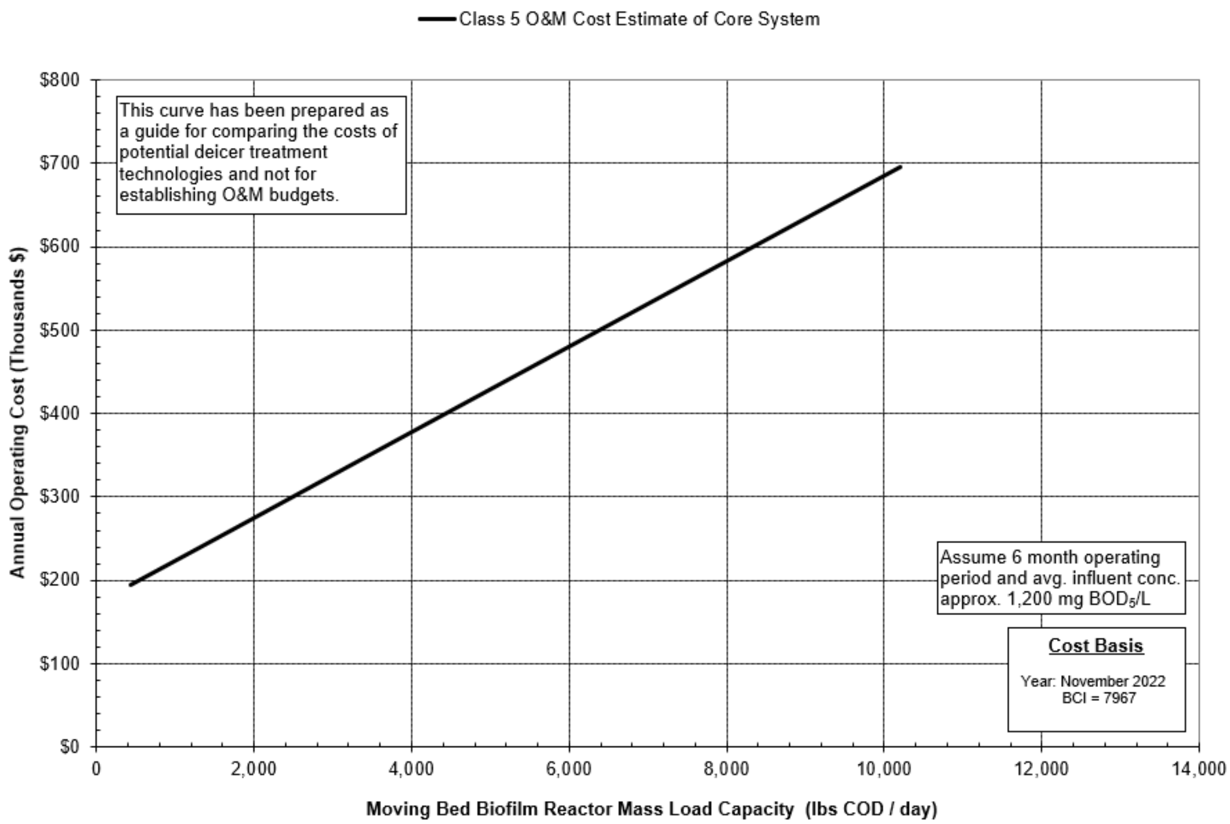

Figure 5: Preliminary planning O&M cost curve.

FACT SHEET 108

Natural Treatment Systems

1. Treatment Technology Description

Process Description

Wastewater treatment relies on chemical, physical, and biological mechanisms to remove pollutants. Natural Treatment Systems (NTSs) are designed to employ these same mechanisms but with minimal manmade power or equipment. The category encompasses lagoons, wetlands, sand filters, in situ soil treatment, and similar approaches that provide "passive" removal of glycols and other deicing compounds from contaminated stormwater. This broad category of technologies is sometimes labeled as "Passive Treatment Systems," although use of that terminology does not sufficiently differentiate these technologies from other biological treatment technologies.

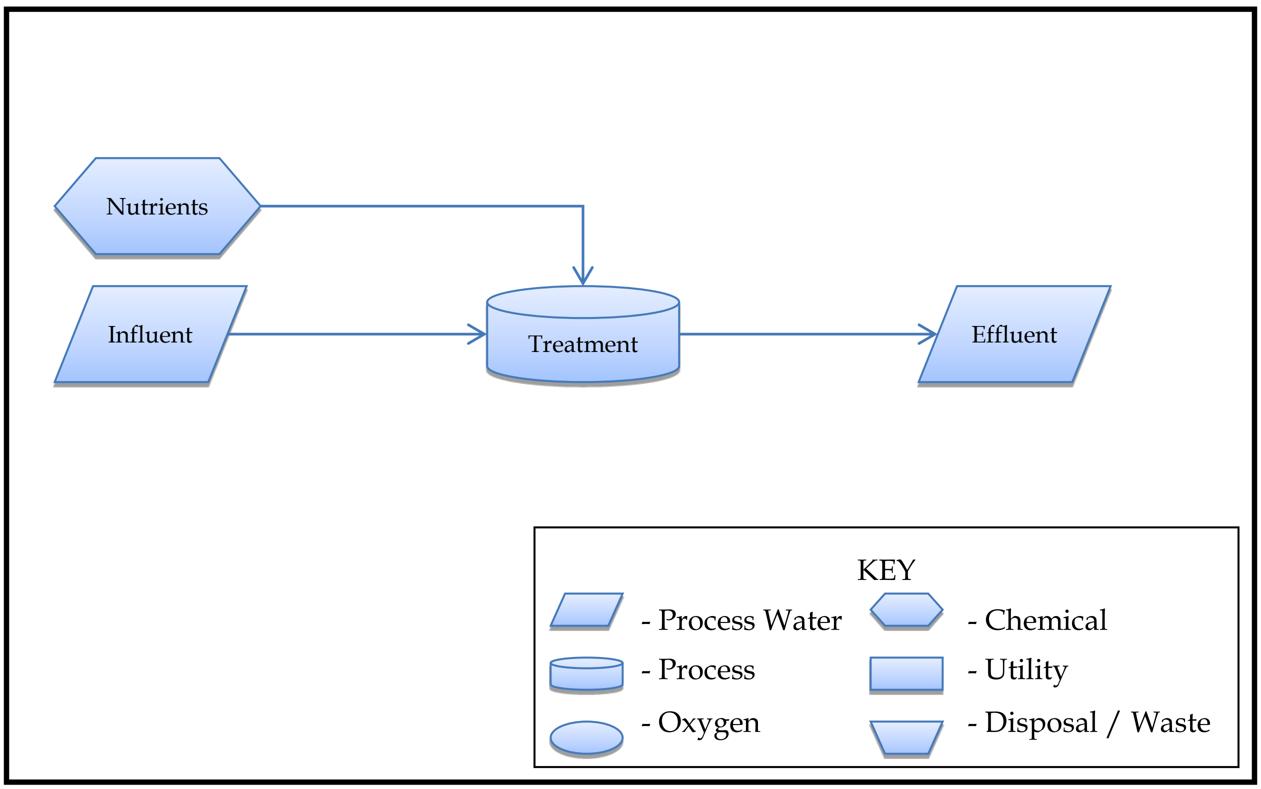

Figure 1. Natural treatment process flow chart.

The term "natural" refers to an emphasis on non-mechanical; these systems do not include mechanical aeration or other automated sub-systems that require regular attention. Mechanical components are typically limited to influent lift stations, hydraulic control structures, and monitoring. Chemical addition to provide nutrients may be necessary for many types of natural treatment systems, but others, especially lighted loaded systems designed to treat low concentrations, may be able to function without added nutrients.

NTSs are commonly used for domestic wastewater in smaller communities where land is relatively inexpensive. Properly sized facultative lagoons and treatment wetlands can provide reasonable treatment for organic compounds and suspended solids when flow rates and concentrations have minimal fluctuation.

The variable nature of deicing events and related runoff volumes introduces a challenge to employing NTSs at airports. Integrated into a stormwater collection system, NTS units provide capacity for removal of suspended solids, like runway grit, and biological glycol degradation. Performance, as measured by percent removal, is highly variable for these systems, and expectations of the level of treatment must be realistically set.

The most common NTS employed at airports is a facultative storage lagoon. In general, facultative lagoons store stormwater for controlled release. Concentrations of organics as measured by Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and glycol slowly decrease during the storage period. The rate of decrease is likely to be associated with water temperature, oxygen, and nutrient availability. This approach is reasonable for airports that choose to store contaminated stormwater and release it to sewage plants or as permitted, local waterways.

Figure 2. Facultative lagoon and treatment wetland at Edmonton International Airport

Although a number of NTSs have been installed to treat deicing fluid, few have provided strong evidence of stable performance. This can be due to several factors:

- Variability of flow and concentration
- Low water temperature and bacterial growth rate
- Nutrient deficiency
- Oxygen deficiency
- Poor design or operation

Any of these factors can disrupt the treatment process. A successful design must take into account each factor and consider how it will affect the expected performance of the system. Passive facultative systems such as the irrigation-based system at the Zurich International Airport, which have been well researched and tested– and which provide the required degree of control for limiting excessive loadings–- can be successful, especially when the systems are not overloaded with mass loads or BOD_5 concentrations higher than their capacity.

Advantages

1. Low labor, chemical, and electrical costs
2. Basic construction involving civil contractors (earthwork, precast concrete, etc.)

Disadvantages

1. Large areas required.
2. Significant limitations on the maximum BOD_5 mass loadings that can be treated and on the effluent BOD_5 concentrations that can be achieved.
3. For some technology variations, animal attractant aspects (i.e., open water) must be mitigated around airfield.
4. For some systems, treatment performance is highly variable, not well understood, often not predictable, and generally less effective than other treatment technologies.
5. Odors.

Required Support Systems

1. Hydraulic control structure to maintain appropriate water elevations and/or flow rates.
2. Routine ground maintenance to control vegetation and animals.

Variant Systems

Surface Flow and Subsurface Flow Wetlands are a variant of NTS. Subsurface wetlands are constructed as gravel beds through which the water to be treated flows. The organic loading of the systems is limited based on the oxygen that can be transferred between the air and water, resulting in systems needing to be very large to get equivalent treatment of other technologies. Treatment is carried out by aerobic bacteria.

Surface flow wetlands allow the water to flow across the surface. Degradation of organic chemicals is performed by aerobic bacteria either floating in the water or attached to the bottom sediment. Plants may be added to aid in transferring oxygen into the water, but do not perform any significant treatment.

Non-Aerated Lagoon is also a variant process. Non-aerated Lagoons, also called Facultative Ponds or Polishing Ponds in conventional wastewater treatment, rely on three zones: An aerobic zone at the surface of the pond; A facultative zone at the intermediate depth where either aerobic or anaerobic treatment can occur; an anaerobic zone at the bottom of the pond for the digestion of biological solids.

Algae growth may be encouraged in the pond to provide aeration. Algae are plants that give off dissolved oxygen as part of their respiration process. However, respiration only occurs during hours of sunlight, so the production of dissolved oxygen is limited.

An issue with the non-aerated lagoon for deicer treatment is that it can become unstable for two reasons:

1. The pond layers maintain the stratification mainly because of temperature. At cold temperatures, the densities of the colder bottom temperature and the warmer top temperature are not significantly different, and the layers may mix or invert.
2. In cold temperatures, the anaerobic treatment may slow down and accumulate a reservoir of untreated biosolids on the bottom. When the temperature warms up, there will be a sudden treatment demand that may cause the entire pond to become anaerobic.

In situ soil treatment is also a variant process. Water to be treated is sprayed onto the ground surface and allowed to infiltrate the ground. Bacteria in soil degrade the organic compounds. The organic loading rate is limited based on the oxygen transfer below ground. Since this transfer rate is low, the area required is typically large for deicer treatment systems.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

NTSs are best suited for airports with large land areas available, low BOD5 mass loads to treat, low BOD5 concentrations in collected stormwater, high limits for PG or BOD5 effluent concentrations, and the ability to test and monitor system performance. Several existing applications of the technologies are associated with runoff from runways and taxiways that may contain deicers.

Current Airport Applications of Natural Treatment Systems

Washington Dulles Airport (IAD) – Biological Treatment Unit

Toronto Pearson (YYZ) – Treatment Wetland

Zurich International Airport (ZRH) – Irrigation System

Frankfurt International Airport (FRA) – Media-Based Treatment

Gerald R. Ford International Airport (GRR)- Treatment Wetland

Technology Selection Criteria

Table 1. Natural treatment system process selection criteria.

Parameter	Consideration	Description
Preferred Influent BOD_5 Mass Loading Range	Low loadings	In practice, NTS are low-loading systems. While load limits are situation-specific, typically maximum loadings are at least an order of magnitude lower than systems like aerated gravel bed.
Preferred Influent BOD_5 Concentration Range	< 500 mg BOD_5/L	Peak influent concentrations depend somewhat on effluent limits but generally the bacteria in natural treatment systems because of oxygen limits at high concentrations.
Preferred Influent Flow Range	Varies	The maximum flow rate capacity is a situation-specific determination based on maximum mass load, lower limits of BOD_5 concentrations, and system hydraulics.
Typical Effluent Concentrations	Varies	NTS can take many forms, and effluent concentrations are situation-specific. For some NTS, effluent concentrations can be in hundreds or thousands of mg/L of BOD_5. Others can reach low concentrations if influent concentrations are less than 50 mg/L.
Typical Range of Required Footprint	>10 acres	Large areas are required for technology to be effective
Pretreatment Needs	Requires upstream fuel removal	Free-product fuel spills will inhibit or kill growth; dissolved fuel components will be partially treated.
Post-Treatment Processing	Operations	Typically, no post-treatment processes are used as the users are seeking a low-maintenance, simple system.
Utility Requirements	Operations	May require electrical connections.

Parameter	Consideration	Description
Open Water Surface	Bird attraction	Some natural treatment systems include open water.
Implementation Time	Ambient	6 – 16 months
Staffing	Operations	Varies by complexity, ranging from less than 1 to 4 FTE

Implementation Considerations for Natural Treatment Systems

The following represent the considerations typically most important when considering implementation of the natural treatment system technologies.

1. *Natural Treatment Systems are a fit for airports with low influent BOD_5 concentrations and flows.* Airports that have larger collection areas because of at-gate or stand deicing typically have larger stormwater volumes and lower BOD_5 concentrations than airports using only deicing pads.

2. *Unlike other treatment technologies NTS can take many forms and application to an individual situation typically has highly unique drivers and site conditions.* Care should be taken to fully understand performance needs, especially treated effluent concentrations for BOD_5 or PG.

3. *Natural Treatment Systems' performance capability is not as significant as other technologies.* In general, the various types of natural treatment systems do not have a great capability of removing BOD_5 and achieving low effluent concentrations.

4. *Natural Treatment Systems have lower operational and maintenance requirements.* Many natural treatment systems can operate passively, with limited operational oversight and occasional maintenance.

5. *Natural Treatment Systems generally require a larger available footprint for treatment.* Although the required area varies by application, in general significantly larger footprint is required for natural treatment systems to be effective.

Cost Considerations

Accurate capital costs for natural treatment systems need to be developed on a situation-specific basis. Factors that affect capital costs by situation include:

- Design capacity and size of the natural treatment system.
- Need to utilize solids settling, dewatering, and disposal processes.
- Needs for storage, pumping, conveyance, and pretreatment processes outside of core natural treatment process.
- Site characteristics (e.g., site clearing, soil contamination, earthwork needs).
- Utility needs (e.g., electric, gas, water, sewer, communications).
- Extent natural treatment system needs to be integrated into existing infrastructure.
- Current material costs including cost impacts of supply chain issues.

Capital costs obtained from other airports using natural treatment systems are almost always unreliable as estimates for natural treatment systems at a new site because of differences in the above elements.

Capital costs are best obtained from bid prices from construction contractors. If cost estimates are needed before bid prices are available, development of Opinions of Probable Capital Costs should be prepared by certified cost estimators following guidelines from the Association for the Advancement of Cost Engineering (AACE) and American National Standards Institute (ANSI). As shown in Table 3 below, Class 4 or 5 cost estimates can be prepared in the early planning stages to get budgetary planning estimates. Once construction documents are complete, Class 3 estimates can provide more definitive estimates[1].

AACE Class	ANSI Classification	Typical Use	Project Definition	Expected Range of Accuracy: Low Expected Actual Cost	Expected Range of Accuracy: High Expected Actual Cost	Other Terms
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Figure 3. AACE and ANSI cost estimation classes.[1]

To provide some guidance for early-stage comparison of treatment technology options, preliminary planning level cost benchmarks for the core natural treatment system components have been summarized in Figure 4 based on COD load to be treated using the AACE/ANSI Class 5 cost estimation process. These presented costs are highly subjective and site-specific analysis is strongly recommended because of the large variation in potential NTS forms.

Because of the wide variety of potential types of natural treatment systems and the variety of conditions under which they may be applied, it was necessary to set a baseline operating condition to perform the cost calculations presented below. The following conditions were assumed in the calculations. The numbers were based on a combination of engineering calculations and field data.

- Design Influent COD Concentration: 175 mg/L
- Design Effluent COD Concentration: 70 mg/L
- Cost per acre per pound of COD removed: $15,000
- COD load range limited to a maximum of 2,100 lbs per day removed (above this acreage for NTS because implausible)

[1] Table based on AACE International Recommended Practice No. 18R-97: *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries*. TCM Framework: 7.3 – Cost Estimating and Budgeting (Rev. March 6, 2019).

The costs in Figure 4 include only the “core” natural treatment system components:

- Earthwork, aggregate
- Nutrient supply system
- Electrical, instrumentation, and controls

The costs in Figure 4 exclude the following:

- Deicer application, collection, conveyance, monitoring
- Influent flow systems (pump stations, conveyance piping to reactor system)
- Storage
- Pretreatment system (e.g., oil-water separation, sediment removal)
- Biological solids removal, dewatering, storage, and disposal
- Utilities from external supply to treatment building
- Site-specific site work such as access roads, signage, lighting, access control, fencing, and stormwater drainage.

A 20 percent Uncertainty Contingency has been added to capital costs to reflect the detailed accuracy of the estimate. Typically, the expected accuracy, within the industry of an estimate at conceptual stage of a project ranges from between -20/-50% to +30/+100 % of the final cost of the project. Since site-specific conditions have not been considered, the actual site-specific cost may be outside of this range. All costs were developed based on pricing from November 2022.

The major capital cost items for the core natural treatment system units are reflected in the preliminary planning capital cost curve shown in Figure 4. The lighter lines represent application of a 20% contingency in both directions. The costs should be only used for guidance in treatment technology selection and not for establishing capital budgets. Capital planning budgets need to be developed on a situation-specific basis.

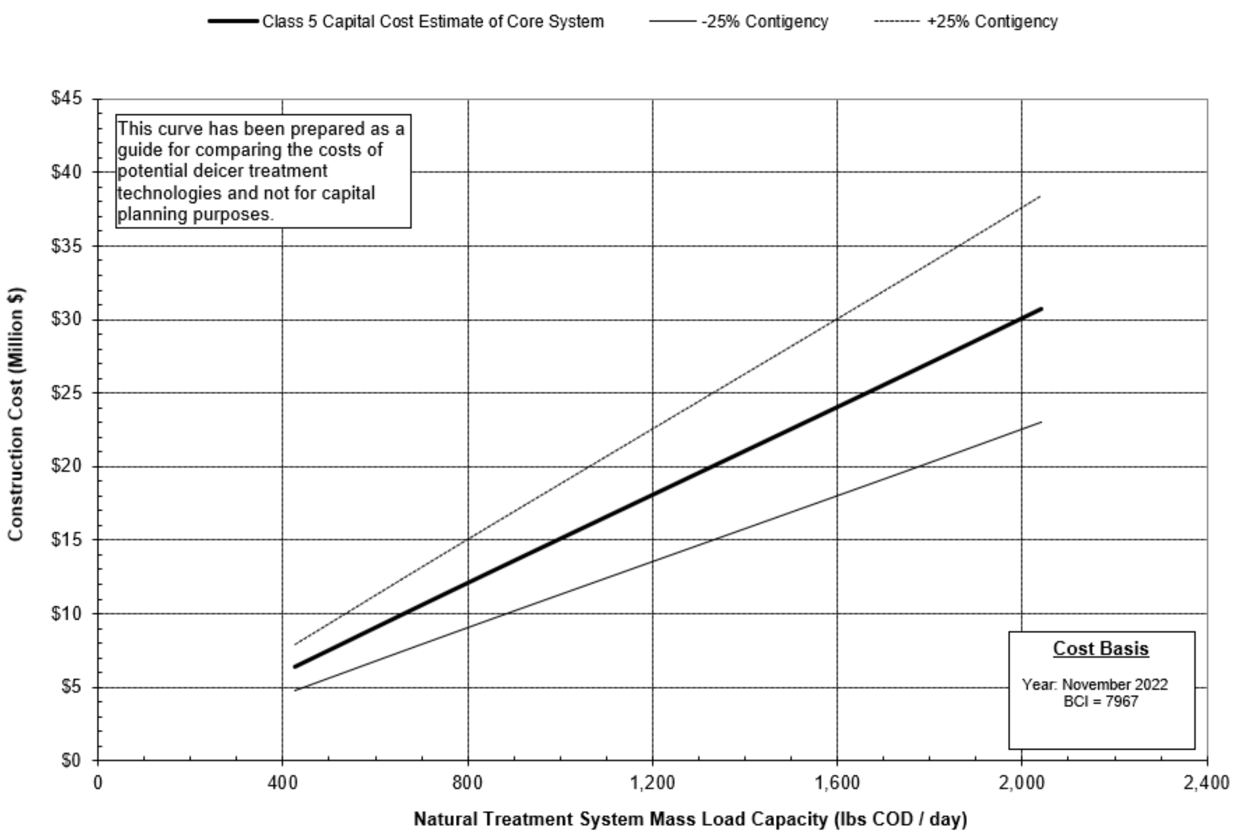

Figure 4. Preliminary planning capital cost curve.

The major operational cost items for the core natural treatment systems are reflected in the preliminary planning operations Class 5 cost curve shown in Figure 5. The major operating cost items are labor, utilities, and nutrients for larger systems. Operations and maintenance costs for a natural treatment system include:

- Electricity (potentially for pumps)
- Chemicals (nutrients)
- Laboratory analyses
- Labor (one operator)

Situation-specific conditions that can affect operating costs include:

- Local utility rates
- Mass loading rates and flow rates (affects chemical use and power costs)
- Extent to which preventive maintenance is properly executed
- Repairs and replacements needed
- Solids disposal costs
- Length of operational time during the year
- Decisions to use more than the assumed number of operators

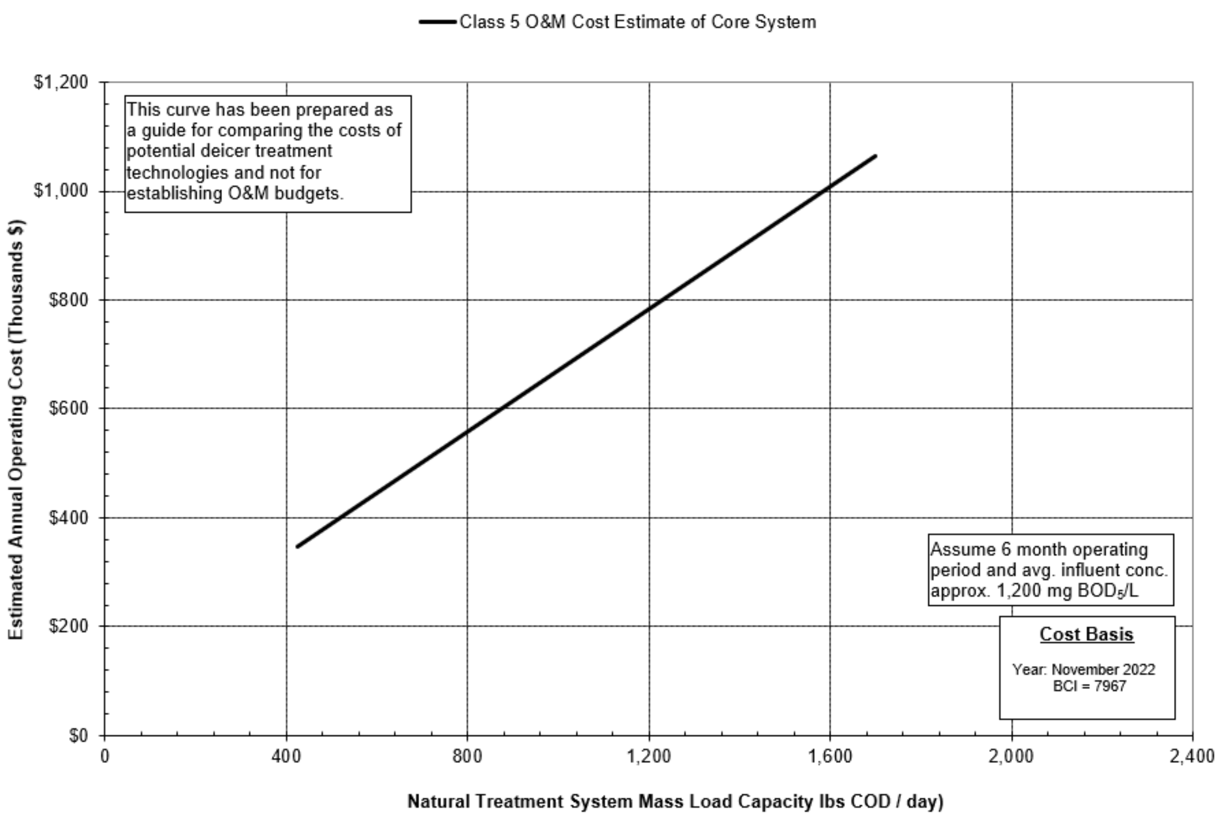

Figure 5. Preliminary planning O&M cost curve.

FACT SHEET 109

Public Wastewater Treatment Facilities

1. Treatment Technology Description

Process Description

Stormwater containing aircraft deicing fluid (ADF) can be collected at an airport and, if allowed by permit, discharged to a Publicly Owned Treatment Works (POTW) where it combines with other domestic and industrial wastewater and is treated by the POTW to remove pollutants from the wastewater. The POTW's treatment system biologically degrades organic pollutants present in the municipal wastewater, including the principal components of deicing fluids (glycols, acetates, formates). The POTW discharges its treated effluent in compliance with the conditions of an NPDES (National Pollutant Discharge Elimination System) permit issued by the state environmental control agency (or in some states, by the U.S. Environmental Protection Agency).

The airport must typically obtain an industrial user permit (or equivalent authorization) from the POTW to discharge stormwater containing deicers to the public sewer, as that discharge is considered an "industrial discharge" according to federal regulations. This permit contains various conditions, restrictions, and/or discharge limitations with which the airport must comply. The conditions may include restrictions on the volume or flow rate to be discharged, when the discharge may occur, maximum allowable BOD_5 concentration of pollutants that may be discharged, and/or maximum increase in discharge BOD_5 mass load from one day to the next.

The airport will also be required to pay user charges for the wastewater treatment service provided. The fees will typically include a charge based upon volume of stormwater discharged, plus a surcharge based upon the BOD_5 mass loading of pollutants. The surcharge provides payment to the POTW for the extra cost of treating high-strength organic pollutants in the airport stormwater.

Technology Considerations

POTWs provide biological treatment to remove organic pollutants from the wastewater they receive, including domestic sanitary wastewater and industrial process wastewater. If an airport discharges its deicer-contaminated stormwater to the public sewer system, it is combined with all other wastewater received by the POTW. The primary organic compounds used in deicers are highly biodegradable and can readily be treated by the POTW treatment system.

A principal consideration by the POTW is whether the treatment facility has adequate process capacity to treat the total loading of organic matter from all sources. Since deicer-contaminated stormwater frequently has a much higher BOD_5 concentration than domestic sanitary wastewater, it often becomes a significant fraction of the total organic loading to the POTW, even if its volumetric fraction is low. POTWs use aerobic biological treatment processes, which require oxygen to be transferred into the wastewater from the atmosphere. POTWs commonly use either large blowers or mechanical aerators to dissolve oxygen from air into the wastewater, so that the oxygen is available for bacterial degradation of the organic matter. Accordingly, the maximum oxygen transfer capability of the POTW's aeration system determines the maximum organic loading that can be treated.

The POTW has the right to not accept any discharges that may cause the POTW to potentially violate its own limits, whether the cause is excessive loading, inability to treat particular contaminants in the airport discharges, or disruptions to the POTWs treatment processes. At times, if a POTW has an issue in meeting its POTW requirements, it may temporarily or permanently limit discharges from multiple dischargers, even if the cause of the POTW upset cannot be directly attributed to an individual discharger.

A common issue with POTW treatment of airport deicer and stormwater discharges is challenges with settling of sludge after the initial biological treatment, often caused either by excessive BOD_5 loadings or lack of nutrients in the airport discharges. As a result, while the POTW can adequately treat the BOD_5, the resultant impacts on solids settling may cause the POTW to limit airport discharges under certain conditions.

The POTW's collection system (the network of sanitary sewers and pumping stations that convey raw wastewater to the treatment facility) must have the capacity to carry the airport stormwater in addition to its other wastewater flows, without resulting in backups or overflows. Accordingly, the POTW will determine what maximum discharge flow it can accept from the airport. It may be possible to construct additional conveyance capacity (e.g., a new gravity sewer from the airport into a larger existing sewer line, or perhaps a new force main and pump station from the airport). The capital cost of such new sewer would be paid by the airport, to the extent it provides service for the airport.

Figure 1 presents a simplified process flowchart for a public wastewater treatment facility, showing its basic treatment processes. Note that while airport stormwater would be discharged into the municipal sewer system and enter the POTW at the beginning of its process train, the waste deicer-impacted stormwater is only treated in the secondary (biological) treatment process as there is no need to remove solids in primary treatment.

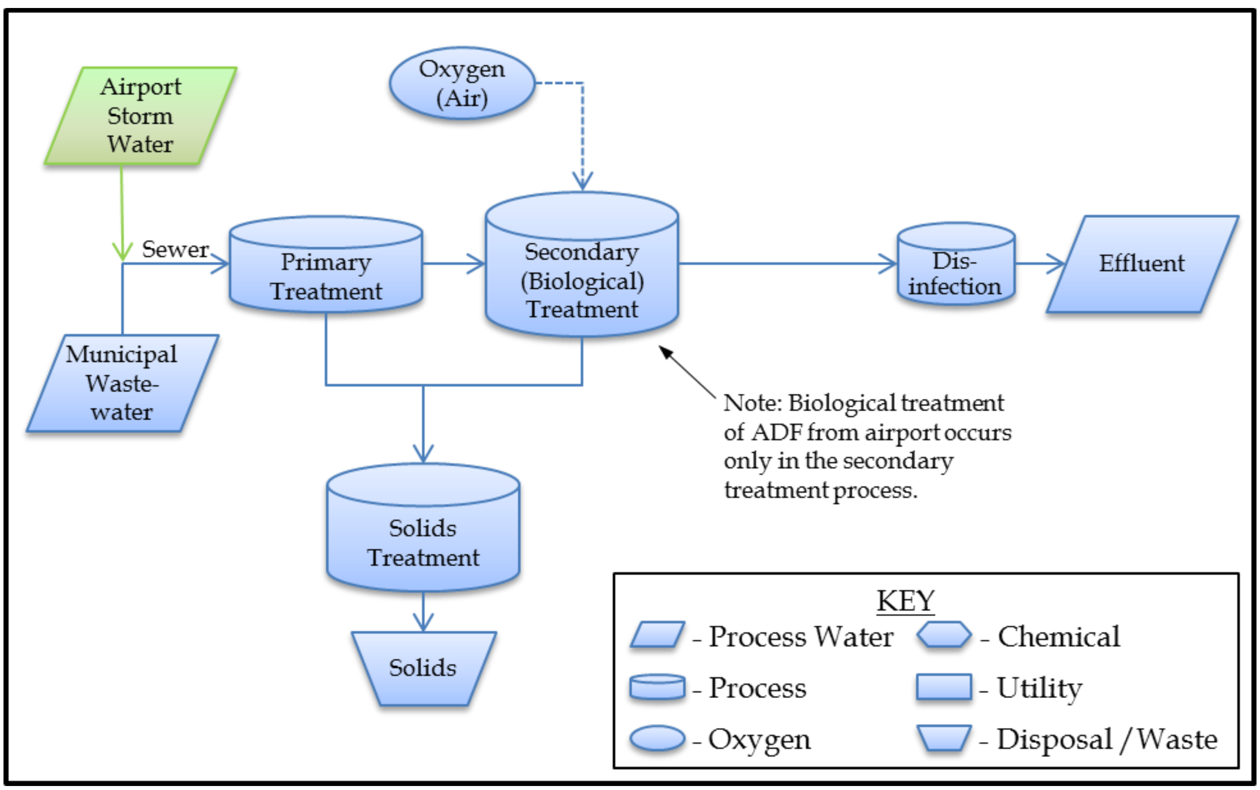

Figure 1. Off-site treatment: public wastewater treatment facility – process flow chart.

The POTW will place restrictions on the maximum allowable discharge of ADF stormwater based upon the following considerations:

1. Pollutant Loading:

   - Average discharge BOD_5 mass loading of organic pollutants must not exceed the long-term average biological treatment capacity of the POTW.
   - Instantaneous or short-term discharge mass loading of organic pollutants must not exceed the short-term maximum or peak biological treatment or solids settling capacity of the POTW.
   - Large/rapid swings in pollutant mass loading are difficult for the POTW to treat since bacterial population needs to be balanced with the organic loading, and it takes time for the biomass to grow or to be wasted.

2. Discharge Volume:

   - Discharge flow rate of airport stormwater (plus existing wastewater flow to the POTW) must not exceed at any time the hydraulic conveyance capacity of the public sewer, or the pumping capacity of any pump stations used to convey this plus other wastewater to the POTW. Otherwise, an overflow of wastewater would occur, including likely sewer backups into residences and commercial buildings.
   - Discharge flow rate of airport stormwater (plus existing wastewater flow to the POTW) must not exceed at any time the hydraulic capacity of the POTW treatment plant. Otherwise, this would result in untreated overflow or bypass of sewage at the POTW.
   - High flow rates or large flow rate swings cannot cause performance issues in POTW plant processes, including the solids settling processes.

Note that during periods of wet weather, when the volume of stormwater collected at the airport is likely to be greatest, the POTW will also be receiving its greatest flow rates because of wet weather inflow and infiltration into the sewer system. Accordingly, the airport's 'worst case' flow and loading will be a key factor for the POTW to determine allowable discharge.

To a degree, the airport controls the concentration of ADF in its stormwater. The way that ADF-contaminated stormwater is collected is a primary determinant of both volume and concentration. For example, if centralized deicing pads are used at the airport, the total mass of ADF collected for discharge will be contained within a smaller collection area than if decentralized deicing is performed at gates. Accordingly, the total mass of ADF will be combined with a smaller volume of precipitation, thereby producing a higher concentration.

Advantages

1. Capital investment on infrastructure at the airport should be considerably less than for a full on-site treatment system.
2. On-site operations at the airport are much more limited than for a full on-site treatment system.
3. Reduced need for trained operators or process control staff.

The risk of non-compliance is generally less for airports relying exclusively on POTW discharge for deicer treatment as opposed to on-site treatment with discharge to WOTUS or a combination of on-site treatment with discharge to WOTUS and POTW discharge. The lower compliance risk for POTW discharge is associated with sanitary sewer limits generally being less restrictive than NPDES limits, lack of impact from normal on-site treatment system performance variation, and lack of impact from on-site treatment maintenance issues.

Disadvantages

1. Requires permit from the control authority (usually issued by POTW, but in some cases by State agency or US EPA).
2. Must comply with permit conditions for discharge rate or volume, and/or discharge mass loading (typically, BOD_5).
3. Must pay discharge fees and surcharges to POTW.
4. May require on-site storage (to equalize high flows to comply with daily loading restrictions).
5. May require construction of additional sewer (may be gravity, or pumped force main) to connect to public collection system. Capital cost would be paid by airport.
6. May require some level of pretreatment on the airport site for reduction in pollutant concentrations for parameters such as TSS, pH, and BOD_5.

Required Support Systems

1. Discharge flow measurement, and likely some form of discharge flow rate control will be required.
2. Storage or equalization for excess stormwater (i.e., the amount exceeding POTW's restriction for volume or load) collected at the airport. The retained excess stormwater would then be discharged over a longer period following the stormwater collection event. Storage/equalization facilities would typically include enclosed tanks or large, open basin(s) – usually earthen construction with liner. A pumping system will likely be required to pump out of the storage basin(s).
3. Pumping may also be required if the airport's collection system cannot drain by gravity into the public sewer system.

Monitoring and Reporting Requirements

Monitoring and reporting requirements will be included in the airport's industrial user discharge permit from the POTW. Some POTWs perform all sampling and analyses, while others also require self-monitoring by the airport permit holder. If self-monitoring is required, the airport will likely have to collect 24-hour composite samples using automatic samplers. Samples would be sent by the airport to a contract laboratory for analyses of specified pollutants (including BOD_5). Some POTWs may accept or require continuous monitoring using an online organic compound analyzer, such as a Total Organic Carbon (TOC) monitor. Frequency of monitoring will be specified in the permit. Monitoring, whether performed by the POTW or the airport, may be required a few consecutive days on a monthly basis during deicing season but could be more frequent or even daily.

Discharge flow data and sampling analytical results (from the airport's contract laboratory) will have to be reported to the POTW, typically on a monthly or quarterly basis. The data forms the basis for the fee calculations.

Potential Alternative Uses of Spent Deicer at Public Wastewater Treatment Facilities

The discharge of airport stormwater to a public wastewater treatment facility simply provides off-site treatment of the deicer material contained in the stormwater. However, there are two specific circumstances in which the deicer in airport stormwater may be used beneficially as a resource for the POTW.

1. **Feed to Anaerobic Digester.** High-BOD_5 strength stormwater could be fed directly to the POTW's anaerobic digester thereby increasing biogas production. Some POTWs accept high-strength organic wastes as additional feed source for their anaerobic digesters and utilize the additional biogas generated for heating or other purposes.

For a POTW to be able to use high-strength ADF stormwater from an airport for this use, several conditions would have to exist:

(a) The POTW must have anaerobic digestion.
(b) There must be a practical means of conveying the ADF to the POTW.
(c) The Airport must separate, collect, and store concentrated ADF at the airport for conveyance to the POTW.

2. **Feed to Denitrification Process.** For POTWs that have total nitrogen removal requirements in their NPDES discharge permits, high-BOD_5 strength ADF could be fed directly to the denitrification reactor for use as an external carbon source. When biological denitrification is performed at a POTW, there must be a source of readily degradable organic matter (i.e., carbon source), which is not normally present in the wastewater at that point in the process train. This is commonly provided by chemical addition of purchased methanol (or other readily degradable organic compound) to the denitrification reactor. The potential use of propylene or ethylene glycol from the deicers would substitute for some of the purchased methanol, thereby reducing the cost for the POTW.

   For a POTW to be able to use high-strength deicer from an airport as a carbon source for denitrification, several conditions would have to exist:

   (a) The POTW must have a separate stage denitrification process that requires augmentation by addition of an external carbon source.
   (b) There must be a practical means of conveying the deicer and stormwater mix to the POTW, and likely storing the deicer at the POTW to meter it into the denitrification process.
   (c) The airport must separate, collect, and store concentrated deicer at the airport for conveyance to the POTW.

These possible alternative process uses for ADF stormwater at a POTW may only be feasible if most or all of the preceding conditions are met. In addition, from the POTW's perspective, accepting airport stormwater for either use would be less than ideal, since the 'resource' would only be available on a seasonal basis and there is likely to be significant daily variability in the quantity of ADF stormwater from the airport.

Figure 2 presents a simplified process flowchart for POTWs showing these two possible alternative process feed points.

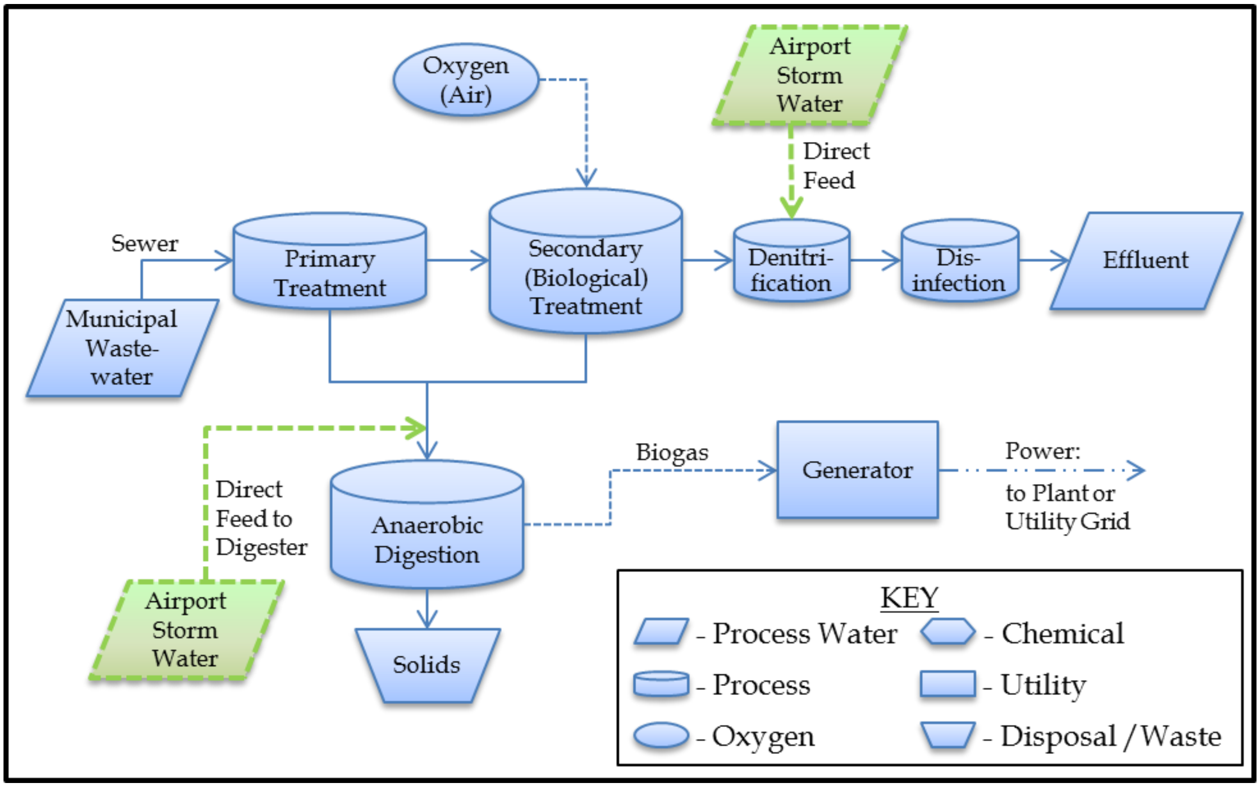

Figure 2. Alternative feeds to public wastewater treatment facility – process flow chart.

An additional possible alternative for an airport to utilize POTW discharge as a deicer treatment technology is an agreement between the airport and POTW to install additional infrastructure at the POTW to specifically support treatment of the airport dischargers. This could require a dedicated sewer pipeline between the airport and POTW or the ability to manage the airport impacts on the mixed flow to the POTW from the airport and other dischargers. New infrastructure that could be required to adapt to the airport dischargers in this scenario includes additional storage, additional secondary treatment capacity, and additional solids removal capacity along with pumps, piping, and controls. To make this alternative a viable option for both the airport and POTW, the following conditions would typically need to be addressed:

- POTW needs to have sufficient space available for added infrastructure.
- POTW needs to determine that adding capacity for the highly variable, seasonal discharges is compatible with their overall operation and long-term development plans.
- The POTW and the airport authority must come to an agreement on the financial terms, including airport support of the capital investment at the POTW, ongoing discharge fees, and maintenance costs.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations and Selection Criteria for POTW Discharge

An airport may consider discharge to a POTW as a viable deicer treatment option when the following conditions are met:

1. A connection to a sanitary sewer is available.

2. The sanitary has adequate hydraulic capacity to accept the airport's flow and the flows from other dischargers.
3. The POTW has sufficient volumetric, BOD5 treatment, and solids handling capacity to handle the airport's deicer-impacted stormwater discharge at the present time.
4. The POTW has provided information on their plans for future available capacity.
5. The POTW agrees to grant the airport an industrial user or similar permit to discharge.
6. The airport can meet POTW discharge permit limits for BOD5, TSS, and flow.
7. The airport can meet POTW discharge permit limits for other parameters such as PFAS compounds, metals, oil & grease, and pH.
8. The airport decides the risks of the POTW requiring the airport to reduce or cease discharges (because of the POTWs real-time need to protect its operation and meet its NPDES permit) are acceptable.
9. The economics of POTW discharge are acceptable to the airport compared to the economics of on-site treatment.

Current Applications of Discharge to Public Wastewater Treatment Facilities

Many airports utilize discharge to POTWs as a deicer treatment option, especially for higher flow, lower concentration discharges. This includes flows with concentrations higher than NPDES permit limits but lower concentrations that are treated on-site using other technologies. Airports with MVR and distillation systems also frequently discharge their distillate streams to POTWs. Below are a few examples of airports using POTW discharge.

Table 1. Airport POTW Discharge Examples

Airport	POTW	Application
Detroit (DTW)	Wayne County – Downriver WWTP	Lower concentration flows not collected for off-site recycling are discharged via sewer for wastewater treatment.
Dayton (DAY)	City of Dayton – AWT Plant	Flows not meeting NPDES limits are discharged via sewer for wastewater treatment.
Cleveland (CLE)	Northeast Ohio Reg. Sewer District – Southerly WWTC	Lower concentration flows not collected for the on-site evaporation system are discharged via sewer for wastewater treatment.
Milwaukee (MKE)	Milwaukee Metro. Sewerage Distr. – South Shore WRF	High-strength ADF hauled by truck, discharged to anaerobic digesters.
Dallas-Fort Worth (DFW)	Trinity River Authority, CRWS Plant	Runoff from aircraft deicing areas that meets POTW criteria for maximum influent BOD_5 concentration in their headworks.
Seattle-Tacoma International Airport (SEA)	King County South Treatment Plant	Runoff from industrial activity areas (aprons, deicing stands, fueling areas) is routed to storage, metered through DAF units, and metered to the sewer under maximum flow rate and BOD_5 load criteria.
... Numerous other examples of discharge to POTW for wastewater treatment		

Technology Selection Criteria

Airports should take the following steps when determining the appropriateness of a POTW discharge.

1. Identify local POTW and their Industrial Pretreatment Program coordinator or manager. Initiate preliminary discussion with POTW to determine whether they may potentially be willing to accept deicer-contaminated stormwater.
2. Review public records and determine what POTW limits and cost basis are applicable to any discharger.
3. Begin discussions with POTW about limits for BOD_5 that may be developed specifically for the airport discharge and share information on the POTW's basis for establishing those limits.
4. Hold discussions between the airport and POTW to determine if modifications to the POTW infrastructure may be needed or could be funded in lieu of new infrastructure at the airport.
5. Develop preliminary estimate of deicer-contaminated stormwater collection volume at the airport that needs to be discharged to the POTW and cannot be discharged to the surface waters. This should include estimates of deicing season total volume, maximum weekly volume, and maximum daily volume of stormwater. Review data from 'extreme' wet weather periods that occurred coincident with deicing activity.
6. Using available analytical data, calculate preliminary estimate of the range and average BOD_5 mass loadings for potential stormwater discharge to a POTW. Alternatively, consider developing a model of deicing activities to estimate stormwater volumes, BOD_5 concentrations, and BOD_5 loads over a range of weather and deicing conditions.

7. By comparing the range of volumes, BOD_5 load, and BOD_5 concentrations to the POTW limits, determine what, if any, additional infrastructure is needed at the airport to meet the POTW limits. This may include monitoring, pumping, conveyance, storage, and pretreatment to reduce quantities of various constituents, including BOD_5, TSS, metals, and PFAS.
8. Perform an economic analysis that includes the elements described in the cost section below.
9. Assess the POTW reducing discharge allowances either in the short-term or long-term.

Implementation Considerations for POTW Discharge

The following represent key considerations when implementing discharges to POTWs.

1. *POTW Discharge is appropriate for a wide range of flows and BOD_5 concentrations.*
   Because the airport discharges mix with other wastewater discharges upstream of the POTW, there typically is not any inherent limitation on BOD_5 concentrations or flows, unless the POTW mass load or flow capacity is impacted.

2. *Over the long-term POTW discharge is frequently the most cost-effective treatment, if available.*
   Many airports that can discharge to the POTW find that it has the lowest life-cycle costs.

3. *Selecting the POTW Discharge option may still require significant infrastructure at the airport.*
   In many situations, airports have had to install infrastructure to manage flows and store stormwater with deicer to meet POTW discharge limits, with the investment in that infrastructure being significant at times.

4. *Some level of operational support is needed for POTW Discharge*
   While exclusively relying on POTW discharge does not result in the need for on-site treatment, operators are needed to manage discharges of stormwater with deicer to the sanitary sewer.

5. *Relying only on POTW Discharge as the deicer treatment option always carries some risk.*
   When an airport relies exclusively on POTW discharge instead of on-site treatment, a real risk exists that the POTW can reduce allowable loadings in the future or even eliminate the ability to discharge without warning. Multiple airports have experienced both long-term and short-term restrictions on POTW discharges beyond the limits in their permits, which in some cases has led those airports to install on-site treatment systems.

Cost Considerations

Fees must be paid by airports to POTWs to cover the expenses incurred by the POTW to treat the airport discharges. The fees for off-site treatment and disposal of airport stormwater by a POTW will be paid as user charges to the POTW (typically a municipality or sewer authority) typically on a monthly or quarterly basis. The POTW likely has an existing user charge system, including surcharges for high-strength wastewater (which would apply to the high BOD_5 concentrations in airport stormwater). Costs are unique to each POTW entity based upon their specific circumstances and costs of providing service, including their capital debt service. Accordingly, a 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 cost of services. The rates are authorized by the local political entity with legal 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 may establish different rates for different classes of users.

One significant issue for the POTW is that the treatment capacity necessary to treat airport ADF 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.

Following is an example cost chart for airport stormwater discharge to a POTW. The example is based upon the 2012 sewer use rate schedule from the City of Columbus, Ohio. The charges shown in the chart would apply to any industrial user – and include a commodity (flow) charge and an extra strength BOD_5 surcharge. POTWs typically also have extra strength surcharges for suspended solids and ammonia nitrogen (or TKN), although deicer-impacted stormwater generally does not contain significant amounts of these pollutants. As is common with many POTWs, Columbus also has a monthly billing charge and a monthly industrial user charge that covers a proportional share of administration of the industrial pretreatment program. However, these fixed charges are minor in comparison with the flow and load charges.

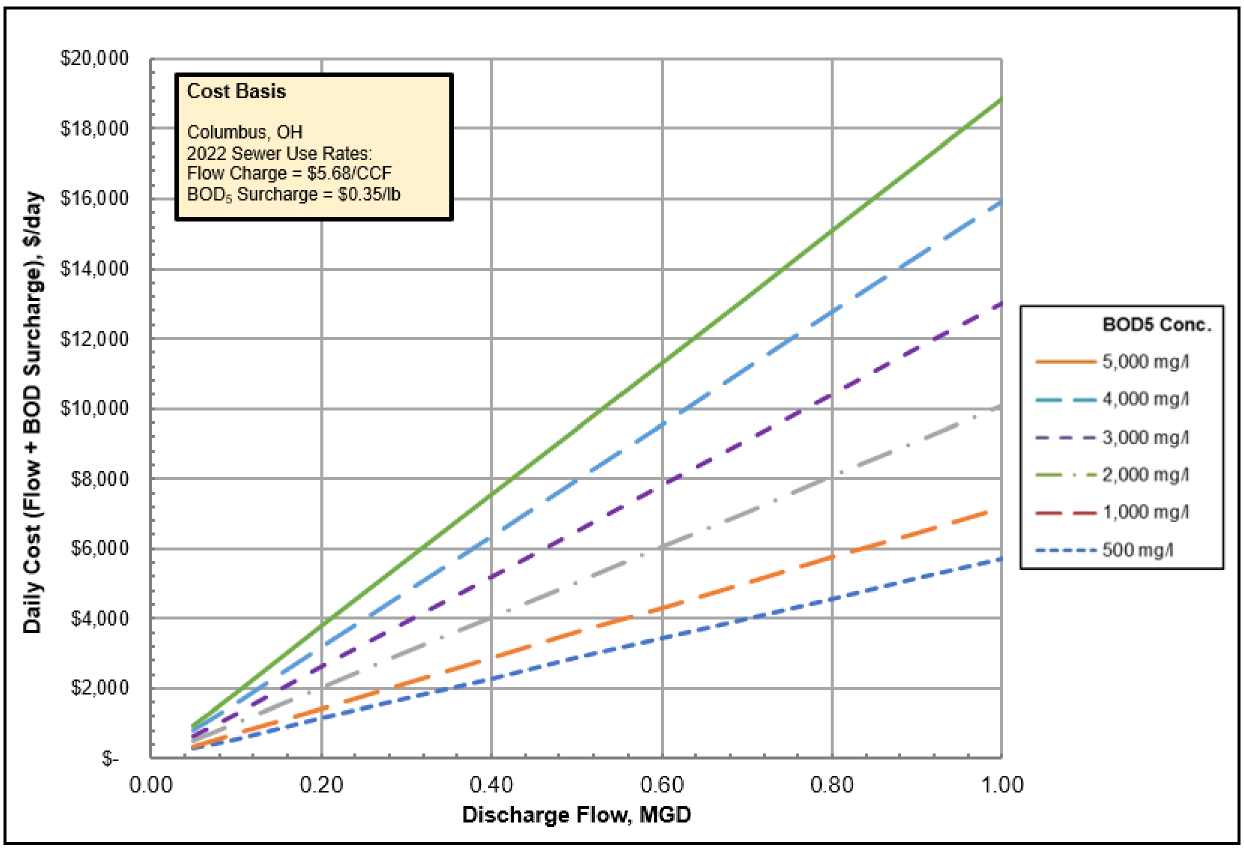

Figure 4. Example operating cost for airport stormwater discharge to POTW.

The fees paid by the airport to the POTW are often not the only costs incurred by the airport. The following represent other cost considerations:

- Capital costs for:

  - Diverting deicer-impacted stormwater to the airport area where POTW discharges occur (monitoring, pumping, conveyance)
  - Storage of deicer-impacted stormwater to absorb peak volume discharges such that the airport can meet volume or mass load restrictions for discharge to the sanitary sewer.
  - Pretreatment costs to reduce BOD_5 to acceptable levels prior to discharge to the sanitary
  - Pretreatment costs for treating other parameter to meet the airport's discharge permit (e.g., TSS removal, metals removal, fuel/oil removal, pH adjustment)

- Operations and maintenance costs for operating on-site diversion, storage, and pretreatment infrastructure, including utility, chemical, solids management, and labor costs.

A full life-cycle cost analysis should be performed by considering on-site capital infrastructure costs at the airport amortized over the life cycle of the infrastructure, yearly O&M costs, discharge fees for volume and BOD_5 surcharges, and any agreement on support of capital improvements at the POTW agreed upon to support treatment of the airport's discharges.

FACT SHEET 110

Private Off-Site Recycling Facilities

1. Treatment Technology Description

Process Description

Stormwater containing aircraft deicing fluid (ADF) is collected at an airport, temporarily held in storage tanks, and then can be transported to a privately owned and operated off-site recycling facility. The airport can ship this fluid without any treatment or partially treat the fluid on-site before shipping to remove some of the water content and reduce the overall volume to be treated by the third-party recycling provider.

Private recycling facilities are normally owned and operated by companies that specialize in the handling, processing, and reclamation of various industrial waste streams. These facilities normally comply with the effluent limitations established by EPA for the Centralized Waste Treatment Point Source Category. In general, this regulation includes wastewater discharge standards for facilities that treat or recover metal-bearing, oily, and organic wastes, wastewater, or used material received from off-site. These facilities typically have discharge permits issued by POTWs to discharge the effluent wastewater produced from recycling activities.

Private recycling facilities vary depending on the primary waste(s) that are treated on-site. For the recycling treatment centers that can handle deicing-impacted stormwater there are usually systems installed that can reclaim glycol, the main component of ADF. The technologies typically used can include membranes, mechanical vapor recompression, thermal vapor recompression, other evaporation systems, and distillation. By separating and reclaiming the glycol from the deicing-impacted stormwater, the recycling provider can generate revenue from the sales of glycol.

For smaller commercial airports and military installations that generate a low volume of Spent Aircraft Deicing Fluid (SADF), 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. In general, unless an airport generates in excess of 200,000 to 300,000 gallons of recovered deicing fluid feedstock (between 1-25% glycol concentrations) per year it is not cost-effective to install recycling equipment on-site. Many small airports can benefit from a regional recycling facility by avoiding 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 as these costs are consumed during a deicing season. The advantage to the airport is it does not have fixed expenses directly related to recycling and it only pays for the volume treated each season.

The operational cost of recycling is dependent on the concentration and the amount of the fluid to be recycled. Therefore, the private recycler may impose minimum limits on the amount and the deicer concentration that they will accept. Minimum concentrations of 30% PG for distillation or 1% PG for

MRV and reverse osmosis are typical economic limits. Rates may be negotiated that allow for a sliding scale based on the PG concentration and the volume to be treated.

For examples of the technologies used by private recycling facilities, see Fact Sheets for Distillation (10), Mechanical Vapor Recompression (9), and Reverse Osmosis (8).

Figure 1. Private recycling facility in Troy, Indiana.

Advantages

1. In many cases, each airport that uses a centralized recycling facility may only pay a price per gallon for transportation and recycling as these costs are consumed during a deicing season. The advantage to the airport is it does not have fixed expenses directly related to on-site recycling and it only pays for the volume treated each season.
2. Less spent ADF storage needs to be provided on-site at the airport since in most cases the off-site recycling facility can provide storage.
3. The recycling facility operator is required to secure and maintain all necessary permits to treat the spent ADF.

Disadvantages

1. The airport, as the generator of the spent ADF waste, must ensure proper chain of custody and assumes liability to ensure the waste is being treated in accordance with all local, state, and federal requirements.
2. With an off-site option, there is a disadvantage with unpredictable weather conditions during the winter that could halt transportation altogether and cause potential storage issues at the airport.
3. Staffing at the airport is required to manage accounting and logistics of fluid moved off-site.

Required Support Systems

1. Storage tanks for spent ADF must be installed at the airport to hold the fluid before it is trucked off-site. Depending on the location of the storage tanks, secondary containment or double-walled tanks may be required. Portable 20,000-gallon “Frac Tanks” are commonly used due to their convenient mobility and availability benefits.
2. Truck and/or railcar loading stations with metering and pumping systems need to be installed for the transfer of spent ADF from storage tanks for off-site shipping.

Monitoring and Reporting Requirements

Monitoring and reporting requirements will be included in the private recycling contract. Analyses will be required to comply with billing and process requirements. Each batch sent to the recycling facility may be required to be tested. Examples of analyses that may be required include PG or EG, BOD_5, TSS, pH, and TDS.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

Use of an off-site recycler depends upon several factors including proximity to the nearest off-site recycling facility, conditions imposed by the recyclers for the quality and quantity of the product, and economics.

Current Airport Applications of Private Off-Site Recycling Facilities

Demonstrated Systems: Many airports truck off-site to another airport facility that acts as the centralized deicing private recycler.

Technology Selection Criteria

Table 1. Private recycling facility process selection criteria.

Technology Parameter	Value or Rating	Description
Minimum PG, EG, BOD_5 Conc.	Either approx. 171,000 mg BOD_5/L if distillation process or approx. 5,700 mg BOD_5/L if MVR or RO process	Treatment can be performed below this concentration, however generally not economically feasible.
Typical Area (Footprint)	Not Applicable	Requires storage tanks.
Typical Building / Equipment Height	Not Applicable	No on-site infrastructure (other than storage tanks)
Open Water Surface	No open water	No on-site infrastructure
Reliance on Other Entities	Reliance	Relies on outside vendors for treatment.

Technology Parameter	Value or Rating	Description
Influent Contaminants	Operations impacts	Free-product fuel spills may cause batch to be rejected for treatment or increase cost. Metals may cause batch to be rejected for treatment or increase cost.
Susceptibility to Fouling and Clogging	Operations impacts	If there is a high TSS concentration, private recycler may add costs for solids removal and disposal.
Utility Requirements	Planning, Design & Operations	Requires electrical, natural gas, and water utility connections.
Accessibility	Operations	Accessibility to stored stormwater storage required for removal of stormwater by tanker trucks.
Treatment Plant Operation Needs	Operation	Staff use is primary for the deicer collection and storage operations.
Time Required for Design and Construction	Planning, Design & Construction	None, but time required for contract negotiation

Implementation Considerations for Off-Site Recycling Situations

1. *Amount of ADF used at the airport and the amount of glycol that can be reclaimed.*

   The larger volume of glycol that can be recycled, the more cost-effective recycling systems become. In general, unless an airport generates in excess of 200,000 to 300,000 gallons of recovered deicing fluid feedstock (between 1%-25% glycol concentrations) per year it is not cost-effective to install recycling equipment on-site.

2. *Average concentration of spent ADF*

   Private recycling systems are typically economically feasible above PG concentrations of approximately 1%.

3. *Effluent Discharge*

   A POTW outlet or other treatment equipment such as membranes is required to discharge the effluent water produced by the distillation system if discharge permits are stringent.

Cost Considerations

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 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 as these costs are consumed during a deicing season. The advantage to the airport is it does not have fixed expenses directly related to recycling and it only pays for the volume treated each season.

The itemized costs can be summarized as follows:

- Transportation costs (per gallon)
- Disposal cost (may be dependent on load concentration)
- Contaminant surcharges (if applicable)

FACT SHEET 111

Reverse Osmosis

1. Treatment Technology Description

Process Description

Reverse osmosis (RO) uses a semipermeable membrane, allowing the fluid that is being purified to pass through it while rejecting the contaminants that remain and allowing the membrane to continually clean itself. As some of the fluid passes through the membrane, the remaining fluid continues downstream, sweeping the rejected species away from the membranes. Reverse osmosis is capable of rejecting constituents of aqueous streams such as bacteria, salts, sugars, proteins, particles, *glycols,* and dyes.

RO can be used to remove spent glycols from stormwater. The concentrate stream is composed of deicer-impacted stormwater and is subjected to high pressures that promote the water molecules in the concentrate stream to pass through a semipermeable membrane to a dilute stream termed “permeate” which is near atmospheric pressure. Throughout this process, the deicing-impacted stormwater is concentrated into a stream termed “reject” or “concentrate” which can be recycled or disposed of. The dilute “permeate” stream can be discharged to stormwater, a POTW, or be used for other applications.

In applying RO units for spent glycol, the systems can be designed to serve two different purposes:

1. Treatment of SADF from 0.1% to 5% concentrations (1,000 to 48,600 mg/L BOD_5) to remove large volumes of water quickly from storage tanks at an airport to separate higher concentrations of glycol to be recycled or disposed of. This process “up-concentrates” the reject stream to concentrations anywhere from 2% to 10% glycol, depending on RO configuration and manufacturer. When the units are designed for a particular airport, as the concentration of glycol in stormwater increases, the driving force required to continue concentrating the fluid increases. As a result, the higher the concentration of spent deicing fluid in stormwater, the more pressure is required to force the fluid through the membrane and the larger the pump required on the RO system. It is important to note that using the RO for this application always requires some type of pretreatment or filtration ahead of the RO system in an effort to protect the RO membranes. Typically, this can be conducted by chemical pretreatment, nanofiltration or ultrafiltration, or a combination of these technologies.

2. Treatment of dilute streams of glycol from 0.01% to 1.5% concentrations (100 to 14,600 mg/L BOD_5) to “polish” the permeate stream for discharge to stormwater or airports with stringent POTW discharge requirements. Using the RO for this purpose can produce permeate streams with undetectable levels of BOD_5 or a desired level based on permitting requirements.

Reverse osmosis systems can be configured in multiple stages to accomplish both aforementioned purposes. Manufacturers of this equipment typically design and build RO unit(s) specific to each airport’s particular requirements. These units are assembled off-site and arrive at an airport on steel skid units whether for installation in a building or standalone containers for remote operations. Advanced RO systems can be operated with Programmable Logic Controllers (PLC) for ease of operation or be designed to run manually. Throughput flow rates vary according to glycol concentration and membrane configuration. Spirally wound desalination membranes are commonly used for spent ADF treatment, but there are other options depending on the RO manufacturer and type of system in use.

Each RO system usually requires separate influent feed storage, permeate, and reject concentrate stream tanks. Typical RO components include piping, control valves, canister filters, a pH adjustment system, high-pressure pump(s), membrane vessels, membranes, and control panel(s), and a washing system for backflushing the RO membrane when they foul from contaminants and begin to restrict flow.

Most RO membranes are pH sensitive, so caustic injection systems are installed and continually run while in operation to ensure the pH is maintained at an optimal level. RO systems are continually monitored for pressure readings and permeate quality to indicate when fouling is occurring, and the unit needs to be stopped for flushing. Pressures gradually climbing, coupled with increasing BOD_5 on the permeate discharge, are typical indications that an RO unit needs to be shut down for washes. The system is flushed with a mild cleaning solution to clean the membranes. Liquid waste is produced from the cleaning process and is typically hauled off-site for disposal at an appropriate treatment facility.

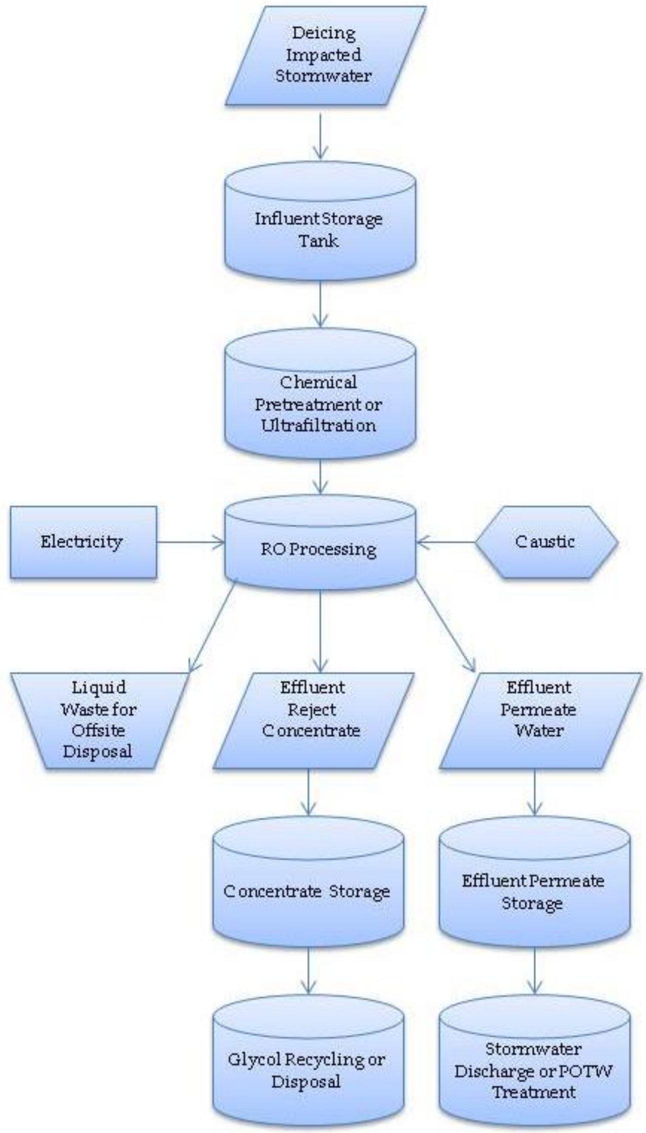

Figure 1. Reverse osmosis flow chart.

Figure 2. RO system at Bradley International Airport.

Advantages

1. Reverse osmosis systems can be an efficient means to quickly remove water from stormwater contaminated with aircraft deicing fluid, thus minimizing the volume to be treated or discharged.
2. RO units can be used in conjunction with other complimentary recycling technologies, such as MVR systems, to increase the amount of glycol that can be reclaimed from SADF.
3. RO units can be designed to be modular, which means they can be installed in a relatively small footprint and additional units can be added if increased capacity is required.

Disadvantages

1. 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.

2. Desired effluent concentration of reject affects influent processing rate and directly impacts permeate quality for RO systems. For example, the higher the reject concentration of glycol, the higher the glycol level in the permeate.
3. Reverse osmosis units usually always require some type of pretreatment or filtration ahead of the RO system to protect the membranes.
4. Flow rates through individual units are low, so using RO for higher volume, moderate concentration flows may not be economical.
5. Membranes must be treated with biocide if the processing systems sit idle for extended periods to eliminate potential biological growth.
6. The permeate stream from RO units will contain some concentrations of BOD_5 and other contaminants. While the concentrations may be low enough to discharge to surface water based

on some airport NPDES permits, in other cases the permeate needs to either be discharged to a sanitary sewer or treated with an on-site biological treatment system.

Required Support Systems

1. Storage tanks
   a. Provide storage of the effluent streams until discharge or removal from the airport.
2. Filtration systems
   a. Filtration prior to RO treatment is normally required to protect the membranes.
3. Other recycling technology
   a. Most glycol concentrates reclaimed from the RO systems require additional treatment equipment to recycle or a means of disposal.
   b. The liquid waste generated from the cleaning of the membranes is typically disposed of through an off-site treatment facility.
4. pH adjustment
   a. Normally pH adjustment systems and canister filters are installed on or before an RO unit.

2. Information Supporting Technology Selection and Implementation

Potential Application Situations

RO systems apply to situations where recycling of glycols is desired. The target application for an RO system is high volumes of low glycol percentage SADF, typically <2% average glycol percentage. The technology is limited, for economic reasons, to processing concentrations greater than 1% glycol. The water stream may have a concentration of PG in excess of local discharge limits and may require treatment or be discharged to a sanitary sewer. Saleable concentrated effluent product is 3 to 10% PG.

Current Applications of Reverse Osmosis Technology

Bradley International Airport (BDL)

Salt Lake City International Airport (SLC)

Dallas/Fort Worth International Airport (DFW)

Denver International Airport (DEN)

Portland International Jetport (PWM)

Pittsburgh International Airport (PIT)

Halifax Stanfield International Airport (YHZ)

Table 1: Reverse osmosis process selection criteria.

Technology Parameter	**Value or Rating**	**Description**
Minimum Influent PG, EG, BOD_5 Conc.	Approx. 6,000 mg BOD_5/L	Treatment can be performed below this concentration; however, energy demands rise in relation to products recovered.
Typical Area (Footprint)	< 1 acre	Includes building, associated structures, equipment, parking, access, and required storage tanks.
Typical Building / Equipment Height	< 20 ft	Equipment can be installed in building heights ranging from 12 ft to 16 ft depending on RO manufacturer.
Open Water Surface	No open water	All treatment occurs in enclosed tanks.
Reliance on Other Entities	Reliance	If a permit cannot be secured for stormwater discharges, then the effluent permeate must be sent to a POTW for discharge. Reclaimed glycol is usually treated by additional recycling systems on-site or off-site. Small amounts of liquid waste are generated by maintenance activities, which must be sent off-site to a disposal facility.
Influent Contaminants	Operations impacts	Metals will foul RO membranes. Free-product fuel spills will contaminate PG stream. TSS and TDS solids in the influent are concentrated in the wastewater stream – grit removal before RO unit is required.
Utility Requirements	Operations	Requires electrical and water utility connections.
Accessibility	Operations	Off-site access is required for removal of PG product stream and loading to tanker trucks.
Treatment Plant Operation Needs	Operations	Treatment plant operation is typically performed by 3-4 experienced process operators present during operations.
Time Required for Design and Construction	Schedule	Design and construction typically require 18 to 24 months for the permanent facility. Temporary/mobile facilities can be established in 6 to 9 months, including design and construction.

Implementation Considerations for RO Systems

1. *Discharge permit is required for permeate stream.*
   Permeate stream can be discharged to surface water or a POTW depending on site-specific restrictions.

2. *Processing system must have adequate controls to maximize performance.*
   Processing throughput is impacted by temperature, turbidity, and pH. This must be monitored and controlled on an ongoing basis.

3. *Filtration systems prior to RO treatment are normally required.*
   For spent ADF to be treated directly from airport storage tanks, a chemical pretreatment system or ultrafiltration system must be used to prevent damage to the RO membranes.

4. *Careful consideration must be given to the average concentration of spent ADF*
   If concentrations are too low or too high, then the RO system may not be the most effective treatment technology. Collection system should facilitate the ability to segregate concentrations ideally suited for RO treatment.

Cost Considerations

The cost structure for use of glycol-recycling-based technologies for managing spent deicer is fundamentally different than for biological treatment systems for the following reasons:

- Capital costs are often a combination of airport-provided capital and equipment leased by the recycling vendors to the airports in the overarching contracts between the airports and recycling vendors.
- The capital and operating costs are dependent on which combinations of the typical recycling processes are applied (MVR, RO, distillation).
- The number of units required at a given site is dependent on both initial PG concentrations and flows that need to be processed.
- The operating costs are affected by the payback (or lack thereof) from resale or reuse of the recovered glycol product.
- The payback or costs are strongly affected by both the concentration of PG in the collected runoff and the amount of reclaimed product.
- The distance of the airport from a regional recycling facility affects transportation costs.
- The need for pretreatment, solids handling, and distillate discharge outside of core process is highly site-specific.

Capital costs, operating costs, fees, and payback obtained from other airports using recycling systems are almost always unreliable as estimates for distillation systems at a new site because of differences in the above elements.

For the reasons above, the capital and O&M costs for the recycling technologies (MVR, RO, distillation) need to be developed on a situation-specific basis. Providing specific cost ranges for these technologies similar to what was provided for the biological treatment technology fact sheets is not appropriate as reliable guidance for this document.