Sustainable Airport Solutions

Winter Management Toolkit

GSA


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TRF Winter Management Toolkit

Green Sustainable Airports (GSA)

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1 Introduction

Winter conditions require comprehensive and continuous airport de-icing operations to ensure safe movements of aircraft and vehicles on grounds. Frozen contaminants and frost on the airfield cause loss of traction between aircraft wheels and airfield surfaces. Snow and ice on aircraft surfaces compromise aircraft ability to obtain sufficient lift for departures or damage aircraft.

Applied airport de-icing and anti-icing products include fluids and solids with multiple chemical components, which are expensive in use and polluting surface water by contaminated run-off.

Depending on climate and weather conditions, frequency and intensity of required winter operations vary significantly between airports. Some airports are rarely engaged in de-icing activities beyond aircraft frost removal, whereas other airports often cope with frequent and heavy snow or ice storms that necessitate both aircraft and pavement anti-icing and de-icing. Substantial variability among weeks or seasons at individual airports might occur as weather patterns shift and affect the necessity for de-icing activity. Therefore, the intensity of required de-icing activities varies both among airports and among de-icing seasons at individual airports.

Together with five regional airports from Denmark, Germany, Netherlands, Belgium and United Kingdom Sandefjord Airport Torp setup the EU-funded INTERREG project “Green Sustainable Airports” (GSA). Subject and rationale of the project cooperation is to develop eco-efficient and cost-saving solutions for better and more sustainable airport operations.

Based on its extensive experience in winter management Sandefjord Airport Torp is mandated to develop and compile solutions to:

- Ensure more efficient use of de-icing fluids and solids
- Substitute chemicals by alternate procedures and substance
- Reduce environmental impact from contaminated run-off

The winter management toolkit comprises a set of 17 commented and recommended measures in the area of:

- Airport pavement de-icing
- Aircraft de-icing and
- Run-off treatment

These are considered to improve winter management practices in terms of efficiency, costs, quality, safety and reduced environmental impact.

2 Analysis and challenges in winter management

2.1 As-is analysis

Sandefjord Airport Torp conducted an initial baseline study [1] on fundamentals in winter management and current winter management practices at associated GSA airports as:

- BLL - Billund Airport (Denmark)
- BRE - Bremen Airport (Germany)
- GRQ - Groningen Airport Eelde (The Netherlands)
- KJK - Kortrijk Airport (Belgium)
- SEN - Southend Airport (United Kingdom)

Identified performance data and information per airport is displayed in the Figure 1 below. Particularly strong winter conditions at Sandefjord Airport Torp and Billund Airport require high efforts for overall airport and aircraft de-icing, where at other GSA mild winter conditions prevail. As GSA 'frontrunners' in winter management Sandefjord Airport Torp and Billund are most active partners in developing more sustainable solutions.

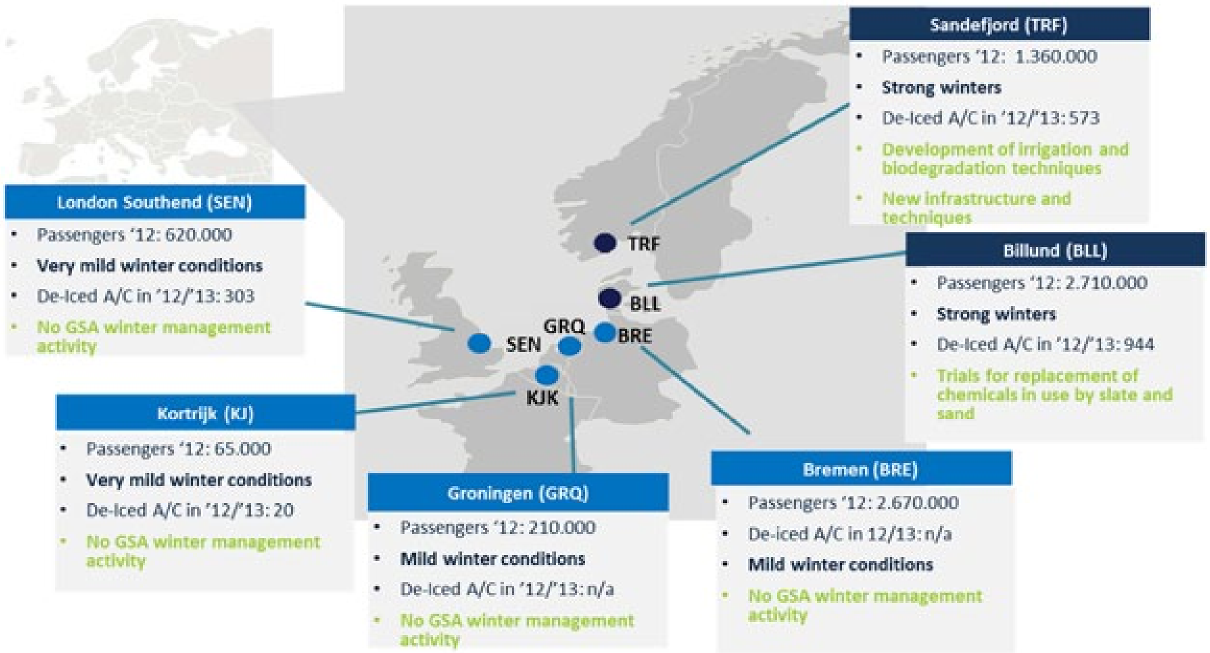

Figure 1: Winter management at GSA partner airports

The baseline study on sustainable de-icing and anti-icing practices focusses on the areas of airport pavement de-icing, aircraft de-icing and run-off treatment as input for the development of the winter management toolkit [1]. A summary on the defined areas is provided within the following sections.

2.1.1 Airport pavement de-Icing

Preventing and clearing snow and ice accumulation on runways and airport areas is one of the most important and challenging winter management activities. While pavement de-icing several priorities of airport stakeholders must be accounted simultaneously [2]:

- Constant safety of flight movements
- Compliance with environmental regulations
- Compatibility with aircraft components and airport infrastructure

While winter conditions airport operators are responsible to take adequate measures to maintain acceptable conditions for safe aircraft operations. Before undertaking action available data on weather conditions, forecasts, temperatures and precipitation is analysed and complemented by a friction test (as required in ICAO Annex 14, A6 [3]). The measurement of the friction co-efficient provides uniformity in the method of assessing and reporting runway friction conditions. Adequate measures need to be taken, if the runway is contaminated and the friction situation is not acceptable. The term “adequate measures” therefore covers all de-icing and anti-icing procedures. For runway and pavement de-icing, besides mechanical clearing, de-icing fluids and solids may be used to re-establish safe conditions.

The assessment of available pavement de-icing practices revealed that mainly the following chemical runway de-icers are used by airport operators:

- Aviform L50 (fluid)
- Clearway 1 (fluid)
- Cryotech E36 (fluid)
- Aviform (solid)

According to available performance data Aviform L50 is the most applied de-icing fluid, while Aviform solid is predominantly used at considered GSA airports [1].

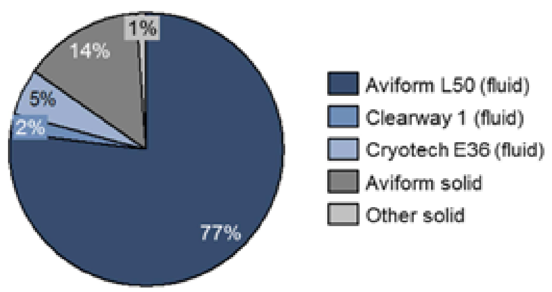

Figure 2: Usage of airport pavement de-icers at GSA airport in percent

All de-icing chemicals are ranked as environmentally compatible, which refers to their oxygen consumption and their degree of biodegradability. However, only ADDCON’s Aviform products are awarded with environmental labels (“Blue Angel” and “Nordic Swan”).

2.1.2 Aircraft de-icing and anti-icing

The purpose of aircraft de-icing is to remove ice and snow from control surfaces (wings, rudders and fuselages). Ice, snow or frost can significantly reduce aerodynamic performance due to disturbance of the air flow. In addition, ice can block aircraft flaps and may damage to the engine.

Aircraft de-icing and anti-icing procedures are performed at stands or dedicated de-icing areas (pads or platforms) to provide an aerodynamically clean aircraft. Contaminated aircraft surfaces are de-iced at the time prior dispatch. When aircraft surfaces may risk contamination at the time of dispatch, anti-icing service is required. When de-icing and anti-icing is necessary, the procedure may be performed in one or two steps. The selection of a one-step procedure respectively two-step procedure depends upon weather conditions, available equipment, available de-icing fluids and hold-over time to be achieved [4].

Generally, all stakeholders perform procedures and use aircraft de-icing and anti-icing fluids according to minimum requirements defined by Association of European Airlines (AEA) and any additional requirements from customer airlines [4].

Aircraft de-icing and anti-icing fluids come in a variety of types and consist of ethylene glycol (toxic) or propylene glycol (less toxic), along with other ingredients such as thickening agents, surfactants (wetting agents), corrosion inhibitors, and coloured UV-sensitive dye [6].

These must meet industry requirements of the applicable performance specification including the derivation of holdover time. Four different types of aircraft de-icing and anti-icing fluids are available, which are further specified in Table 1.

Different types of aircraft de-icing fluid are applied depending on [1]:

- Weather conditions (temperature, humidity, snow, frost, ice contaminants)
- Applied de-icing procedure (1-step vs. 2-step procedure)
- Availability of different de-icing fluids (type I – type IV)
- Availability of equipment
- Required hold-over times

Adverse impacts on the environment by run-off from aircraft de-icing need to be considered. When de-icing fluids swept away by storm water run-off and discharged to natural waterways chemical components can dissolve oxygen levels, increase nutrient concentration, threaten aquatic life, reduce diversity and further contaminates ground water [5].

Type	Characteristics
Type I De-Icing Fluids	Primarily used for de-icing
	Low viscosity
	"non-thickened"
	Provide only short-term protection due to quick flow-off of surfaces
	Often used for two-step de-icing / anti-icing procedure (since it does not offer any significant anti-icing holdover protection) -> Type II or Type IV applied afterwards
Type II De-Icing / Anti-Icing Fluids	Type II fluids can be used for de-icing purposes and extended for anti-icing holdover protection and can be used in a variety of ways
	Unheated and undiluted (or diluted) for anti-icing
	Heated and undiluted for de-icing / anti-icing as a one step process
	Diluted with water and heated for de-icing / anti-icing as a one step process
	Diluted with water and heated as the de-icing stage in a two-step process, when used with the unheated and undiluted fluid
	"pseudo plastic" (contains a thickening agent to prevent fluid from flow-off
Type III De-Icing / Anti-Icing Fluids	Compromise between type I and type II fluids
	Intended to be used on slower aircraft with a rotation speed of less than 100 knots
	Mainly used in regional and business aviation markets
	Have anti-icing capabilities (longer holdover performance than type I fluids)
	Excellent shear stability allows the use in simple type I de-icing trucks, reducing the high investment required in complex Type II / IV compatible equipment
Type IV De-Icing / Anti-icing Fluids	Type IV fluids offer maximum anti-icing holdover protection, but can also be used for de-icing purposes and can be used in the following way:
	Unheated and undiluted (or diluted) for anti-icing
	Heated and undiluted for de-icing / anti-icing as a one step process
	Diluted with water and heated for de-icing / anti-icing as a one step process
	Diluted with water and heated as the de-icing stage in a two-step process, when used with the unheated and undiluted fluid as step two.

Table 1: Characteristics of aircraft de-icing fluids

2.1.3 Run-off treatment

Preference for aviation's winter maintenance practices is given to de-icing and anti-icing with approved chemicals and additives to prevent the bonding of ice and snow on pavement and aircraft surfaces. As de-icing products are consisting on urea, glycol, acetates and formates owing environmental adverse impact comprehensive run-off treatment is an important objective for airports. In case of rain and snow, the de-icing fluids are flushed into sewage systems and might endanger the local ecosystem, when discharged into natural waterways (e.g. depleted oxygen levels can threaten aquatic life) [5].

Generally, environmentally harmful run-off is subject of regulation and requires airport operators to ensure full compliance by not exceeding defined thresholds for water pollution.

The baseline analysis showed a comprehensive set of measures and techniques including:

- Continuous monitoring of water pollution
- Run-off collection, separation by contamination levels and storage in ponds and tanks
- Run-off treatment by controlled discharge, irrigation and recovery in waste disposal facilities
- Irrigation of run-off on grasslands for biodegradation in summer

Corresponding to the amount of aircraft de-icing operations the considered airports apply different approaches to mitigate negative impact on water and environment by contaminated run-off. The following Table 2 provides a summary of applied measures and procedures at GSA airports [1].

	TRF	BLL	BRE	KJK	SEN	GRQ
Monitoring Water Pollution	✓	✓	✓	✗	✓	✗
Run-Off Collection	✓	✓	✗	✗	✓	✗
Run-Off treatment	✓	✓	✗	✗	✓	✗
Run-Off irrigation	(✓)	✗	✗	✗	✗	✗

Table 2: Run-off treatment at GSA airports

Generally, high volumes of run-off at northern airports as Sandefjord Torp (TRF) and Billund BLL) require extensive efforts to control and dispose contaminated effluents, whereas at airports facing mild winter conditions less activities are observed. However, as regulation is expected to tighten over the coming years more airports will be challenged to introduce comprehensive procedures for more sustainable run-off treatment.

2.2 Challenges in winter management

Airport and aircraft de-icing activities are essential activities in maintaining the aviation industry's safe winter operations. However, at the same time winter management operations are associated with intense application of environmental harmful de-icing chemicals, high costs, processes and safety requirements. Before developing the winter management toolkit Sandefjord Airport Torp drafted a compilation of industry challenges.

The results are derived by multiple expert interviews, expert workshops and a double-stage survey of GSA partner airports (please see Table 3 below) [1].

Challenges	Pavement De-Icing	Aircraft De-Icing	Run-Off Treatment
Inefficient use of chemical de-icing fluids and solids	✓	✓	✓
High prime costs for de-icing chemical	✓	✓	✗
Adverse environmental impact by glycol, urea and acetates as key component of de-icing chemicals	✓	✓	✗
Corrosion effects on aluminium and carbon-carbon composites by de-icing chemicals cause structural degradation to infrastr. and aircraft	✓	✓	✗
Conductivity of de-icing chemicals harm safety of apron workers when electric shocks occur	✓	✓	✗
Lack of stakeholder communication and process alignment leads to inefficiencies	✓	✓	✗
Unavailable winter management plan and documented procedures as input for staff training and instruction	✓	✓	✓
Limited availability of staff and unsteady staff training and knowledge exchange	✓	✓	✓
Exceeded hold-over times	✗	✓	✗
Request for "Special Treatment" by airlines	✗	✓	✗
Compliance with (future) environmental regulations (thresholds on water pollution levels)	✗	✗	✓
High efforts associated with disposal of contaminated run-off	✗	✗	✓

Table 3: Challenges in winter management

3 Winter management toolkit

The GSA Winter Management Toolkit provides an overview and recommendation on infra-structure measures, technologies and procedures in the areas of:

- Airport pavement de-icing
- Aircraft de-icing
- Eco-efficient run-off treatment

Based on experiences and knowledge, desktop research and workshop discussions with de-icing experts from Sandefjord Airport Torp and Billund Airport 17 proven and promising measures for more sustainable winter management have been selected [7][8].

All measures are introduced as fact sheets. These include high-level descriptions and evaluations. The recommendation is emphasized by a rating covering a three-part scale, where one snowflake is depicting a low rating and three snowflakes a high rating.

The GSA winter management toolkit is dedicated to regional airports in North-West Europe and designed for airport managers to compose an individual set of suitable measures as baseline for further assessments and initiation of improvement programmes.

3.1 Airport pavement de-icing

<table>
<tr><th colspan="2">3.1.1 Alternate pavement de-icing procedures</th><th>Rating ❄❄❄</th></tr>
<tr><th>Description</th><th colspan="2">Benefits</th></tr>
<tr><td rowspan="3">• Alternate de-icing procedures are proven to substitute chemicals by combinations of[7]:
◦ Intensive mechanical removal of contaminants
◦ Application of coarse sand and slate (max. 3,5mm)
◦ Removal of sand and slate on shoulder under dry conditions
◦ Intense use of blowers and sweepers to keep pavement dry and clean and maintain friction
• Provision of an updated winter management plan including proven local procedures applied for typical weather conditions
• Winter operations training programme and experience exchange for winter management staff
• Staff certification of staff on alternate de-icing procedures [8]
• Documentation procedures</td><td colspan="2">• More efficient use of de-icing chemicals reduce costs and environmental harmful run-off
• Improved safety for workers on the apron
• Reduction of corrosive and degrading side effects</td></tr>
<tr><th colspan="2">Conditions</th></tr>
<tr><td colspan="2">• Alternate pavement de-icing must enable sufficient friction
• Use of sand and granulates may block sewage systems
• Reliable information of weather conditions and local temperatures continuously required
• Extensive experience in de-icing required</td></tr>
<tr><td>Type: Procedure</td><td>Feasibility: Short-Term</td><td>References: TRF I BLL</td></tr>
</table>

Table 4: Alternate pavement de-icing procedures

3.1.2 Low-pressure de-icing sprayers	Rating ❄❄❄
Description	**Benefits**

• Low-pressure spraying technology enables a more accurate and efficient dosage of de-icing fluids
• De-icing liquid is pumped to the nozzles via a low pressure pumping system
• The nozzle-sprayers work with a minimum creation of swirl
• Maximum spraying width is approx. 24 meters
• New low-pressure sprayer technology successfully applied at TRF
	• Significant reduction in use of de-icing fluids compared to high-pressure spraying technology by:
	  ◦ Big drops reduce evaporation of applied chemicals
	  ◦ More effective distribution and more precise coverage
	• Significant cost reductions
	• Environmental benefits by less de-icing fluids used per de-icing event
	Conditions
	• Very positive business case for TRF
	• Transferability to other airports depends on saving potential in terms of de-icing fluid

Type: Technology / **Feasibility: Short-Term**	**References: TRF**

Table 5: Low-pressure de-icing sprayers

3.1.3 Mobile ice detection system for airports	Rating ❄❄
Description	**Benefits**
• Laser detectors measure ice layers for better decision-making on de-icing procedure and volume of de-icing fluids • Laser sensor technology equipped vehicles enable consistent screening of surfaces • Information on ice layer and friction can be transferred via link to the Airport Operation Control Center to support decision making • A trial run is carried out at Aarhus Airport [7] • Comparable solutions for black-ice detection on roads are available • Consistent and efficient ice warning system	• More reliable information on prevailing friction levels enables better decision making on best pavement de-icing / anti-icing action • Complementary to friction tests mobile ice detection systems improve overall airport safety • Mobile ice detection system for airports levers alternate de-icing procedures which may help to reduce environmental impact and save costs **Conditions** • Promising innovative and new technology require further testing and proof of applicability in daily operations • Unknown investment costs
Type: Technology / **Feasibility: Short-Term**	**References: Aarhus Airport**

Table 6: Mobile ice detection system for airports

3.1.4 Temperature sensors		Rating ❄❄
Description	**Benefits**	
• The runway temperature sensors enable precise measurement of the runway temperature • Temperature sensors enable accurate and live information on changed runway- and surface friction probabilities and trigger warnings • TRF is operating three temperature sensors embedded in the runway, linked to monitoring systems at the central command stand • In addition TRF continuously measures local temperatures (ground and air) around the airport by vehicles equipped with sensor technology	• Live information enable continuous and full transparency on temperature levels at the runway • Better decision making on runway and surface de-icing based on reliable and precise information • Overall safety improvement **Conditions** • Implementation of sensor technology require structural embedding into runway surface and constant maintenance • To explore full benefits from temperature sensors application need to be linked to airport monitoring systems • Temperature sensor are prerequisite for weather support de-icing decision systems	
Type: Technology	**Feasibility: Medium-Term**	**References: TRF**

Table 7: Temperature sensors

3.1.5 Weather support de-icing decision making system		Rating ❄❄
Description	**Benefits**	

• Weather support de-icing decision making systems are linked to various sensors to measure temperature, atmospheric pressure, dew point, wind speed and wind direction as well as snow gauge
• Weather support de-icing decision making systems enable prediction of friction levels, information and warnings
• Based on calculated values the weather support de-icing decision making systems provide recommendations on de-icing fluids, procedures and hold-over times
• IRIS: Avinor's Integrated Runway Information System enables continuous predicting and measuring of runway friction levels
	• Foresighted decision making improves overall safety
	• Selection of optimum de-icing procedure
	• More efficient use of chemicals used for de-icing associated with :
	  • Cost reductions
	  • Environmental benefits
	Conditions
	• Weather support de-icing decision making system relies on high number of various sensors, which may not be available
	• High investment costs (estimated by €300.000) associated with weather support de-icing decision making systems	

Type: Technology	**Feasibility: Medium-Term**	**References: OSL I Avinor**

Table 8: Weather support de-icing decision making system

3.2 Aircraft de-icing

<table>
<tr><th colspan="2">3.2.1 Aircraft De-icing platform</th><th>Rating ❄❄❄</th></tr>
<tr><td colspan="2">Description</td><td>Benefits</td></tr>
<tr><td colspan="2" rowspan="3">Bundling of aircraft de-icing and anti-icing operations on a dedicated de-icing platform or pad on a dedicated area in proximity to the runway
De-icing platform may be introduced temporarily fully installed on a dedicated area
Permanent de-icing platforms include storage tanks, shelter for de-icing equipment and staff and underground tanks to collect run-off
TRF operates a fully equipped central de-icing platform in proximity to the runway</td><td>Overall improvement of aircraft de-icing operations as services are concentrated at one pre-defined area close the runway
Higher predictability of hold-over times
Reduced amount of thickened fluids for anti-icing are required due to close proximity between departure point and runway
Simplified collection of contaminated run-off by glycol sweepers or tanks at permanent de-icing platform</td></tr>
<tr><td>Conditions</td></tr>
<tr><td>Permanent installation of a de-icing platform is associated with high investment costs for supply systems and underground tanks to collect run-off</td></tr>
<tr><td>Type: Infrastructure</td><td>Feasibility: Short (long)-Term</td><td>References: TRF I BLL I OSL</td></tr>
</table>

Table 9: De-icing platform

<table>
<tr><th colspan="2">3.2.2 Hangar storage</th><th>Rating ❄❄</th></tr>
<tr><td colspan="2">Description</td><td>Benefits</td></tr>
<tr><td colspan="2" rowspan="3">Keeping aircraft inside just prior to departure only Type IV fluid for aircraft anti-icing is required to keep ice and snow from building-up during taxiing from hangar parking to runway
Hangar storage is preventing ice and snow from accumulating on aircraft surfaces
Effectiveness depends on aircraft type, departure times, taxiing times, traffic mix as and hangar storage capacities
Reducing aircraft de-icing and anti-icing operations by Hangar storage is reported as successful practice from BLL [7]
Feasibility is proven for GAT and business aviation aircraft</td><td>Significant reduction of Type I de-icing fluids
Less glycol contaminated effluents
Cost savings when sufficient hangar capacities are available
Procedure can easily be implemented</td></tr>
<tr><td>Conditions</td></tr>
<tr><td>Sufficient hangar capacities are prerequisite for applying hangar storage
Hangar storage procedure for de-icing can be considered when developing business cases for of hangar capacities</td></tr>
<tr><td>Type: Procedure</td><td>Feasibility: Short-Term</td><td>References: BLL</td></tr>
</table>

Table 10: Hangar storage

3.2.3 Infrared de-icing hangar

Rating ❄

Description

- Infrared de-icing hangar are equipped with advanced technology to melt ice and snow contaminants on aircraft surface by heat waves
- For de-icing service aircraft taxi trough infrared de-icing hangar
- Before leaving the de-icing hangar anti-icing service still remains necessary
- Saving potential approx. 70% for aircraft de-icing fluid (Type I) per event [9]
- Installed infrared de-icing hangars are designed to serve all types of aircraft
- Approach is proven to be reliable in all weather conditions
- Infrared de-icing hangars are considered to enable a high throughput of aircraft at major airports
- Pilot run at OSL failed

Benefits

- Significant reductions in amount of de-icing fluids (Type I and Type II)
- Overall optimization of process flow at large and highly frequented airports with intense winter operations

Conditions

- Infrared de-icing hangar is not recommended to regional airports due to
  - Very high investment costs
  - High operational costs
  - Only limited benefits from process optimization as anti-icing services still remains necessary

Type: Infrastructure	Feasibility: Long-Term	References: OSL I JFK I ANC

Table 11: Infrared de-icing hangar

3.2.4 Prop-mix de-icing technology

Rating ❄❄❄

Description

- Prop-mix technology enables delivery of full controlled and optimized water and glycol mixture according to prevailing conditions
- Optimum mixture of water and aircraft de-icing fluids applicable for all weather conditions
- Full-automated control of water / glycol mixture improves overall safety at all times
- Introduction of prop-mix technology requires investments into new de-icing equipment
- 30% of Type I and Type II de-icing fluid wer saved at TRF since introducing prop-mix technology [8]

Benefits

- Prop-mix technology reduces the amount of de-icing fluids required for de-icing operations significantly
- Optimized composition of de-icing fluids enable significant savings in terms of costs and effluents
- Improved safety levels as composition of glycol and water gets electronically controlled

Conditions

- Implementation requires investment in new de-icing equipment to adopt prop-mix technology

Type: Technology	Feasibility: Short-Term	References: TRF

Table 12: Prop-mix de-icing technology

3.2.5 Ice detection system for aircraft		Rating ❄❄
Description	**Benefits**	
• Laser technology detectors enable constant measuring of ice layers on aircraft surface • As part of a larger on-board or ground – based system the laser detection systems determines surface conditions (dry, wet or icy) and provides recommendation to the pilot and de-icing company • Applying ice detection systems the required volume of de-icing fluid can be estimated according to measurement • According to FAA requirements US-based aircraft less than 60.000 pounds must be equipped with ice detection systems [10]	• Ice detection systems provides constant information on ice and snow layers as prerequisite for optimized and safe aircraft de-icing • Measurement supports de-icing agent to ensure most safe and efficient de-icing service **Conditions** • Ice detection systems are recommended to aircraft operator to constantly monitor ice and snow layers • No experience and reliable reference has been reported for ground-based ice detection systems	
Type: Technology	**Feasibility: Short-Term**	**References: FAA**

Table 13: Ice detection system for aircraft

3.2.6 Hot water aircraft de-icing		Rating ❄❄
Description	**Benefits**	

• Hot water aircraft de-icing covers distribution of hot water (> 60C degrees) over aircraft surface followed by anti-icing service
• Hot water aircraft de-icing only applicable when the ambient air temperature is above -2,8C degrees [6]
• Procedure also applicable with prop-mix technology
• Hot water aircraft de-icing is compliant to FAA requirements
• Hot water aircraft de-icing is successfully applied at TRF by well trained and experience staff when mild winter conditions prevail [8]
	• Hot water aircraft de-icing is an efficient alternate procedure to reduce use of Type I aircraft de-icing
	• Hot water aircraft de-icing reduce overall costs related to aircraft de-icing by saving de-icing fluids
	• Substitution of de-icing chemicals reduces water polluting run-off
	Conditions
	• Hot water aircraft de-icing is fully recommended but limited to:
	  • Mild winter conditions
	  • Very experienced and well trained staff	

Type: Procedure	**Feasibility: Short-Term**	**References: TRF**

Table 14: Hot water aircraft de-icing

<table>
<tr><th colspan="2">3.2.7 Tempered steam aircraft de-icing</th><th>Rating ❄❄</th></tr>
<tr><td colspan="2">Description</td><td>Benefits</td></tr>
<tr><td colspan="2" rowspan="3">• Tempered steam aircraft de-icing is applied as option for non-glycol aircraft defrosting, gate de-icing, blade/fan de-icing or pre- de-icing tool
• Tempered steam aircraft de-icing technology reduces amount of chemical fluids needed for aircraft de-icing and anti-icing operations
• Moisture laden air applied to meld frozen contaminants from aircraft surfaces during gate de-icing or pre- de-icing events
• Tempered steam aircraft de-icing technology proven in trial-runs to reduce overall [11]:
  • operational time for de-icing
  • consumption of de-icing fluids
  • glycol contaminated effluents</td><td>• Tempered steam aircraft de-icing technology showed potential to reduce de-icing process times, costs and effluents from glycol
• Tempered steam technology enables more efficient use of de-icing fluids and reduces glycol contaminated run-off</td></tr>
<tr><td>Conditions</td></tr>
<tr><td>• Tempered steam aircraft de-icing technology has not achieved full marketability and has not be reported as fully compliant with safety requirements so far
• Reported experiences base on trial runs at Canadian airports and HEL [11]</td></tr>
<tr><td>Type: Technology</td><td>Feasibility: Long-Term</td><td>References: Canada I HEL</td></tr>
</table>

Table 15: Tempered steam aircraft de-icing

<table>
<tr><th colspan="2">3.2.8 Forced air de-icing system</th><th>Rating ❄</th></tr>
<tr><td colspan="2">Description</td><td>Benefits</td></tr>
<tr><td colspan="2" rowspan="3">• Forced air de-icing system delivers high-pressure air on aircraft surface to remove dry contaminants and powder snow [6].
• Optionally, aircraft de-icing fluid can be added to air steam to remove ice and wet snow
• Forced air de-icing systems are applied to:
  • Reduce time needed to clean aircraft from ice and snow
  • Reduce use of de-icing fluids
• Tests concluded, that forced air de-icing system did not reduce consumption of de-icing fluids, where wet snow and ice conditions dominantly prevail [8]</td><td>• Reduction of de-icing fluids needed to remove snow- and ice-layers from aircraft surfaces
• Decreased costs per snow and ice removal operation can be realized
• Reduction of contaminated run-off at parking areas</td></tr>
<tr><td>Conditions</td></tr>
<tr><td>• The solution has not be reported as effective for areas where rather wet winter conditions prevail
• Forced air de-icing systems can only be recommended for areas with rather dry winter conditions</td></tr>
<tr><td>Type: Technology</td><td>Feasibility: Long-Term</td><td>References: Ottawa Airport</td></tr>
</table>

Table 16: Forced air de-icing system

3.3 Run-off treatment

3.3.1 Glycol recovery sweepers	Rating ❄❄❄
Description	**Benefits**

• Glycol recovery sweepers are designed to vacuum run-off from aircraft de-icing areas, when drainage system and underground tank is not available
• The contaminated waste water is typically transported to an on-site storage facility
• Recovery sweepers are designed as multi-purpose vehicles also used for basic maintenance sweeping [6]
	• Flexible solution to collect contaminated run-off from aircraft de-icing pads:
	  • to ensure compliance with public regulation
	  • To avoid contamination of surface water when flowing into drainage system
	• Glycol recovery sweepers as multi-purpose vehicles for maintenance and cleaning activities
	Conditions
	• Glycol sweepers are fully recommended to airport operators as mobile and flexible solution for collecting run-off when providing aircraft de-icing services [8]
	• According to public regulations airports must control and separate contaminated run-off before the storm water is discharged to public sewage systems or other recipient

Type: Technology	**Feasibility: Short-Term** · **References: TRF**

Table 17: Glycol recovery sweepers

3.3.2 Containment pond and storage tanks	Rating ❄❄❄
Description	**Benefits**
• Providing storage for collected contaminated de-icing run-off prior to treatment (recovery plant and irrigation) or controlled discharge [5] • During detention, solids are allowed to settle and pollutant concentrations are equalized • Ponds and storage tanks contain microscopic bacteria used for biodegradation of active glycol components	• Key infrastructure to provide storage for collected run-off from aircraft de-icing before treatment or discharge **Conditions** • Ponds or tanks are prerequisite for sustainable run-off treatment • Ponds and storage tanks require larger areas for installation, where uncovered ponds may present a hazard by attracting wildlife
Type: Infrastructure	**Feasibility: Medium-Term** · **References: TRF I BLL**

Table 18: Containment pond and storage tanks

3.3.3 Storm water monitoring equipment		Rating ❄❄❄
Description	**Benefits**	
• Low-power water monitoring sensors measure constantly pollution level in storm water discharge and sewage systems • Performance data are send by data link to the connected environmental department of the airport • Monitoring technology associated with low investment and maintenance costs	• Provision of constant monitoring data on water pollution • Constant and reliable control of water pollution levels • Data measurement as baseline for environmental action to control and decrease water pollution **Conditions** • Airport management must ensure constant compliance with environmental regulations and thresholds on water pollution • Regulations on water pollution are expected to tighten over the upcoming years	
Type: Technology	**Feasibility: Short-Term**	**References: TRF I BLL**

Table 19: Storm water monitoring equipment

3.3.4 Eco-efficient run-off treatment		Rating ❄❄❄
Description	**Benefits**	

• Contaminated run-off is separated by the degree of pollution and stored in ponds and tanks separately, where:
  ◦ Heavily polluted run-off is stored in tanks before transported to local recovery plant(s)
  ◦ Medium-polluted run-off and water stored in tanks or ponds for irrigation on grassland in summer
  ◦ Low-polluted run-off stored in ponds for controlled discharge to creeks and sewage systems
• Proven practice at Zurich Airport and Oslo Airport [12]
• TRF is developing a local procedure to ensure eco-efficient run-off treatment [8]
	• Proven procedure to sustainably treat contaminated run-off from aircraft de-icing
	• Cost savings for disposal of medium polluted waste water by introducing irrigation techniques
	• Ensures full compliance with environmental regulations
	Conditions
	• Eco-efficient run-off treatment requires comprehensive infrastructure and equipment:
	  ◦ Containment ponds and tanks
	  ◦ Glycol sweeper(s)
	  ◦ Water monitoring system
	  ◦ Equipment for irrigation of polluted waste water	

Type: Procedure	**Feasibility: Long-Term**	**References: TRF I OSL I ZRH**

Table 20: Eco-efficient run-off treatment

4 Research report: De-icing and environment - Improving sustainability

Green Irrigation: Balancing ponds winter collection, operation spring, summer and autumn, intermittent irrigation, optimized addition nitrate (oxidizing agent) and phosphate, adapted perennial grass/vegetation, fixed irrigation system easy to maintain, automatic control of effluent, activation recirculation loop, control groundwater [13].

Figure 3: Balancing pond winter collection and green irrigation along taxiway

Willow Farm: Evapotranspiration, degradation and bioenergy, diverse solutions hydraulic loading and harvesting [13].

Figure 4: Willow harvesting (illustration, photo)

Emergency Ponds: balancing concentration runway deicer, oil trap, sedimentation precipitated iron and suspended solids, separates «treatment area» and stream, access vacuum vecicle/excavator for cleaning and emergency situations [13].

Figure 5: Emergency pond Rovebekken – to be expanded and optimized

Constructed wetlands: component of emergency ponds to improve treatment capacity, waterdepth 10-40 cm, wetland vegetation, permeable baffles to improve hydraulic efficiency [13].

Figure 6: Ditch with runoff from balancing pond – to be expanded as a constructed wetland

Dilution ponds: constructed for accumulation of clean water, built for flushing of streams (Rovebekken) when critical situations.

The comprehensive research report on "De-icing and Environment – Improving Sustain-ability" is prepared by Bioforsk and provided in Norwegian language [13].

5 Summary

Airport and aircraft de-icing activities are essential for maintaining the aviation industry's safe winter operations. Several priorities of airport stakeholders must be accounted simultaneously:

- Constant safety of flight movements
- Compliance with environmental regulations
- Compatibility with aircraft components and airport infrastructure

Significant efforts have been spend on developing alternative solutions for more eco-efficient de-icing procedures and run-off treatment. However, many approaches are not applicable to regional airports (e.g. infrared-facilities) as high investment costs and operational expenditures breaking the budget.

Together with regional airports from North-West Europe Sandefjord Airport Torp setup the EU-funded project "Green Sustainable Airports" (GSA) to develop more eco-efficient and cost-saving solutions for better and more sustainable airport operations. Sandefjord Airport Torp is mandated to develop a winter management toolkit to:

- leverage more efficient use of de-icing fluids and solids
- Substitute chemicals by alternate procedures and substance
- Reduce environmental impact from contaminated run-off

Based on experiences and knowledge, desktop research and workshop discussions with de-icing experts 17 measures have been compiled for airport managers to compose an individual set of suitable measures to improve winter management are regional airports.

The toolkit covers infrastructure measures, technologies and procedures in the areas of:

- Airport pavement de-icing
- Aircraft de-icing
- Eco-efficient run-off treatment

All measures are introduced as fact sheets, including high-level descriptions and re-commendation.

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