An investigation of the feasibility of recycling deicing materials at Munich airport

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AN INVESTIGATION OF THE FEASIBILITY OF RECYCLING DEICING MATERIALS AT MUNICH AIRPORT

by

ALEXANDER HOFFMANN

A MASTER'S THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY OF LOUGHBOROUGH UNIVERSITY

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Abstract

The growing public awareness and sensitiveness towards environmental protection increases significantly the pressure upon the air transport industry to implement regulatory measures for the operation of both airports and aircraft. With regard to the feasibility of recycling deicing materials and the requirement to achieve compatibility between a deicing concept and a fluid recycling concept, many airports are isolated with insufficient guidelines for developing an appropriate decision making process. Regretably at present only informations exists, which deals with the dedicated issues and problems concerning aircraft deicing, airport deicing and the disposal of fluids. Also, differing international and national regulations concerning environmental protection have impeded the development of generic strategies. As Munich International Airport has implemented a specialized concept of aircraft/airport deicing and fluid recycling with the opening of the airport in 1992, the decision to investigate its operational, environmental and economic performance in this thesis was simple and obvious. However, aircraft/airport deicing is an international issue, which affects many airport and airlines around the world. Consequently, a generic strategy would be of general interest. Although the Munich case is the basis for this thesis, international operational aspects and environmental issues are also discussed with a view to drawing conclusions for the establishment of a generic strategy. The major conclusions concern the need to improve existing environmental legislation and to harmonize these legislative measures in order to achieve a general applicable international standard worldwide. There is no perfect alternative – no one solution to fit every size of airport. Differing international environmental regulations and standards concerning fluid disposal and environmental impact demand diversified investigations which subsequently may lead to totally different solutions for an individual airport operator. The recommendations and suggested generic strategies contained in this thesis are only to be seen as a guideline for any decision making process an airport operator may suddenly be confronted with.
In memorial to my father Dr. Max Hoffmann who continuously encouraged me over many years to undertake and complete my studies at Loughborough University.

To my dear wife Annette for her patient and caring support and understanding.
Abstract

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Note

This study represents the personal views of the author and does not necessarily represent the official view of Munich Airport. This applies especially for Chapter 6 - Case Study Of The Munich Aircraft Deicing And Fluid Recycling System. The decisions which lead to the general configuration and layout of the deicing facilities for aircraft as well as the construction and location of the fixed deicing facility were strongly influenced by political issues and differing corporate interests of the joint venture partners - Lufthansa and Munich Airport.

The references in the text have received a numerical form and are displayed in the attached Reference List.
Rationale For The Study

As the 21st century approaches, perhaps the most pressing challenge facing mankind is the preservation of the environment and its fragile ecosystem. International aviation, as a leader in technological and economic development, together with travel and tourism, has a major role to play in improving the quality of the environment. The United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, was held in Rio de Janeiro, Brazil, in June 1992. This important event was attended by representatives of over 80 countries and virtually all components of the United Nations system, including the International Civil Aviation Organization (ICAO), as well as by more than 30 intergovernmental organizations and a very large number of non governmental organizations. It was recognized that most of the responsibility for leading change will have to fall on national governments. Since emissions from the transport sector are one of the causes of atmospheric related problems, governments were charged with calling upon the transport community to undertake activities aimed at identifying and solving these problems.

The problems created by the increasing burden of air transport will become relatively worse if other major sources of pollution reduce their environmentally harmful practices significantly, as they are expected to, and in some cases have been legislated, to do. If this occurs, the share of environmental deterioration directly attributable to aviation will increase. Therefore, the aviation industry needs to demonstrate a trend opposite to that of other sources and, consequently, a great deal of pressure will be brought to bear should projects for increasing airport capacity need approval. The creation of a comprehensive and well-coordinated environmental management programme is a major task that must be undertaken as efficiently and cost-effectively as possible. The global nature of air transport and environmental issues must be dealt with on an international basis, not by local, inconsistent, and sometimes incompatible changes in technologies and regulations. Undoubtedly, an effective
industry-wide approach will benefit from the exchange of information and expertise and, as necessary, the pooling of resources for research and development aimed at solving common problems.

The aviation industry as a whole has no effective means of coordination and collaboration among all those who, together, make aviation a transport system: manufacturers, airlines, airport managements, government authorities, air traffic control, military and general aviation, municipal planners and a vast number of other organizations and individuals. Therefore, as a first step, a system must be developed that would foster a closer collaboration among these groups. This is one of the reasons the international aviation community has not made significant progress towards the maintenance of a more sustainable environment. Industry groups concerned with environmental issues focus primarily on aircraft noise and engine emissions. As a result of the sharply increased concern over environmental issues, ICAO has developed an ambitious programme aimed at addressing air and noise emission problems.

To date however, the operational area of airport ground activity, passenger, baggage, cargo and mail processing has received little attention. As well as being sources of aircraft noise and emissions, airports use large amounts of land, contribute to air and ground water pollution, produce vast amounts of waste, and consume excess energy. In general, aviation and airport users tend to be rather slow to participate in any cohesive meaningful energy and waste reduction strategies. Part of the problem is the fact that international regulations, combined with national laws and environmental protective measures, applicable and mandatory for all involved in the aviation business are missing.

The revised ICAO Annex 16 consists of two volumes and future updating and improvements are now the responsibility of the Committee on Aviation Environmental Protection (CAEP), which was established in 1986. Volume I contains provisions related to aircraft noise and describes the different aircraft type classifications, for each of which a noise evaluation measure has been standardized. Volume II contains provisions related to aircraft
engine emissions and describes the standards which prohibit the international venting of raw fuel to the atmosphere from all turbine engine powered aircraft. Furthermore standard limits for emissions of smoke, carbon monoxide, unburned hydrocarbons, etc., have been set here. Regretably, no comment is made here on further environmental protection measures like, for example, the mandatory use of recycling materials and fluids at airports.

It is clear that environmental objectives, like the establishing of basic guidelines and practices for use by the aviation industry worldwide in order to protect and improve the environment, should be incorporated as well as guidelines to help to conduct research on specific environmental issues to improve airline/airport performance and operating conditions. The Airports Council International (ACI) has produced a policy handbook with the title “Airports and the Environment” containing guidelines about environmental protective measures. One of the topics adressed in this handbook contains recommendations for the deicing and anti-icing of aircraft and the deicing and anti-icing of runways, taxiways, aircraft stands, pavements and other similar locations.

This thesis examines the requirements for the deicing of aircraft and aircraft movement areas at airports, the environmental impacts and the potentials for the collection and treatment (disposal or recycling) of aircraft deicing glycols and tarmac deicing fluids. The aims of the thesis are:

I. To assist airport operators in establishing appropriate design criteria for the development of an environmentally sensitive airports/aircraft deicing/anti-icing strategy.

II. To enable airport operators to establish a generic strategy, capable of incorporating specific airport unique issues into a decision making process.

III. To encourage airport operators to adapt and enforce environmental protective measures and to play increasingly an active and accountable role in the worldwide environmental protection issue.
IV. To assist airport operators to reduce or diminish risks and mistakes in design and operation considerations during the critical concept planning phase

The thesis is divided into nine substantive chapters. Chapter 1 explores the need for deicing and its consequences. Chapter 2 describes the methods of deicing aircraft and the technologies available. Chapter 3 focuses on the impact of deicing activities on the environment. Chapter 4 describes potentials for reducing the degree of environmental impact at airports. Chapter 5 examines the potentials for the recovery of aircraft deicing fluids. Chapter 6 presents the case study of the Munich aircraft deicing/fluid recycling concept. Chapter 7 defines objectives and performance levels of an ideal recycling system. Chapter 8 - Conclusions Part I - identifies appropriate design criteria for the development of an environmentally sensitive airport aircraft deicing/anti-icing strategy and already contains several recommendations. Finally, in Chapter 9 - Conclusions Part II - a approach is suggested to locate and identify factors necessary for developing a Generic Strategy applicable to all airports.
Chapter 1
The Need For Deicing Aircraft And Its Consequences

This chapter examines the need for deicing aircraft and explores its consequences. In the following, the relevant topics of Chapter 1 cover the general need for deicing aircraft and the problems associated with the aerodynamics of lift and drag in differing weather conditions during flight and ground turnaround. In detail, ground deicing and anti-icing operations at airports are pointed out to inform the reader of the operational difficulties an airport operator additionally encounters during icing conditions or snowfall within the aerodrome aircraft movement areas. Additionally, the problems of forecasting icing conditions at airports and the subsequent legal requirement for an airport operator to produce snow and ice control plans as well as feasible technical solutions and concepts are addressed. The conditions under which icing occurs are identified. The effects of fluids and procedures on the environment as well as the relative pollution strength of deicing chemicals and the subsequent contamination of aircraft movement areas and stormwater systems are explored. Finalizing Chapter 1 is a short historic review of deicing methods and the development of aircraft de-/anti-icing fluids.

In the United States as well as in Europe, by 1950 regulations were established by the Civil Aeronautics Board (CAB) and European national aviation authorities, prohibiting the take-off of aircraft with frost, snow, or ice adhering to wings, propellers, or control surfaces of the aircraft. These regulations still remain in effect (ref. nr. 5, 6 and 8). The basis of these regulations, which are commonly referred to as the clean aircraft concept, is the known degradation of aircraft performance and changes of aircraft flight characteristics when ice formations of any type are present. These effects are wide ranging, unpredictable, and dependent upon individual aircraft design. The magnitude of these changes is dependent upon many variables and is thus unpredictable, but these changes can be significant. Wind tunnel and flight tests indicate that ice, frost, or snow formations on the leading edge and upper surface of a wing, having the thickness and surface roughness similar to medium or coarse sandpaper, can reduce wing lift by as much as 30% and
increase drag by 40%. These changes in lift and drag significantly increase stall speed, reduce controllability and alter aircraft flight characteristics. Thicker or rougher ice accumulations in the form of frost, snow, or ice deposits can have increasing effects on lift, drag, stall speed, stability and control, but the primary influence is surface roughness on critical portions of an aerodynamic surface (compare with Figure 1-1).

**Figure 1-1:**

*Influence Of Surface Roughness On Aircraft Wing*

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It is therefore imperative that takeoff is not attempted unless it has been ascertained, as required by regulation, that all critical components of the aircraft are free from adhering snow, frost, or other ice formations. Most transport aircraft used in commercial transportation as well as some other aircraft types are certificated for flight in icing conditions. It is emphasized that rotorcraft and most small, general aviation fixed wing aircraft have not been certificated by the FAA for flight in icing conditions. Aircraft so certificated have been designed and demonstrated to have the capability of penetrating supercooled cloud icing conditions during their flight operation. This capability is provided either by ice protection equipment installed on critical surfaces (usually the leading edge) or demonstration that ice formed, under supercooled cloud icing conditions, on certain unprotected components will not significantly affect aircraft performance, stability and control. Ice, frost, or snow formed on these surfaces on the ground can have a totally
different effect on aircraft flight characteristics from ice formed in flight. Exposure to weather conditions on the ground that are conducive to ice formation can also cause accumulation of frost, snow, or ice on ice protected areas of the aircraft that are designed for in-flight use only and that are not designed for use during ground operation. Common practice developed by the North American and European aviation community over many years of operational experience (ref. nr. 1 and 7) is to deice an aircraft prior takeoff. Various techniques of ground deicing were also developed. The most modern of these techniques is the use of special deicing and anti-icing fluids to aid the ground deicing process and to provide a protective film of fluid to delay formations of frost, snow, or other ice. An airplane may be cleaned of ice formations (deiced) by any suitable manual method, by use of hot water, by use of special deicing fluids, or different mixtures of deicing fluids and water. The deicing and anti-icing process may be performed in one stage or multiple stage processes as desired depending upon prevailing conditions, concentration of fluids utilized, facilities available and deicing methods.

Recently, there has been a trend towards the use of off-gate deicing pads and engines-on deicing techniques as a means to reduce delays, and minimize glycol contamination. With the move to off-gate deicing, a new set of issues has been raised with respect to on-time-deicing, traffic flow management, equipment suitability for engines-on deicing and appropriate locations for deicing activities. Although at many airports a move has been made to off-gate/ramp locations to carry out precipitation deicing, it is still common at many airports, to remove hoarfrost at the gate, often well before the aircraft departure time. As concerns about the impact of deicing fluid on the environment continue, there will be persistent arguments to have all deicing operations performed at off-gate/ramp locations where the run-off deicing fluids can be properly collected and if possible recycled for further use.

Existing fleets of deicing vehicles are aging and becoming obsolete as new fluid technologies and deicing practices are introduced. The airline industry as well as airport operators are cognizant of the need for change, but the current competitive and recessionary climate favours near term solutions. Longer term approaches, however, are being tried at a number of airports.
Automated systems have been installed in Sweden, the United States and Europe. One-man enclosed cab trucks are being evaluated and used by operators in Europe and North America (ref. nr. 21). These technical innovations have all been introduced under the environment of central or remote facilities that are dedicated to the purpose of aircraft deicing.

The introduction of longer term approaches have held the promise of higher throughputs, improved environmental responsibility and reduced operating costs. The introduction of new practices, such as deicing with engines on, has the potential to decrease deicing times and increase throughput capacity. With automated equipment, there is the potential to improve throughput even further and to add consistency to the process that is not possible with the truck-based operation. Environmental response, and it’s related costs, can be improved under the use of centralized deicing facilities (ref. nr. 9, 31 and 32) through better containment methods and through the fact that the area of containment is significantly smaller than the catchment areas associated with the terminal aprons. The optimal technical and environmental protective solution is the use of high throughput, just in time centralized deicing facilities at locations with minimal runway access time. At Munich International Airport (ref. nr. 22) and at the New Denver International Airport (ref. nr. 30) deicing pads were incorporated into the takeoff positioning and line-up areas, designed to accommodate both deicing trucks or fixed technologies.

At existing airports the location and design of remote deicing facilities is often more difficult because of existing land use, airport zoning, and economic constraints. With the introduction of automated technologies, lower operational costs have been forecast through reduced labour costs and deicing time cycles. It should also be possible to reduce capital and operational costs through a decrease in vehicle requirements. However, because of the large number of involved participants in the deicing process like airlines, handling agents, deicing companies and airport authorities, the question will always be - how to determine and develop a generic strategy capable of assisting airport operators to define and describe an ideal aircraft deicing/fluid recycling concept for their specific operational needs and environmental compliance
Ground Deicing / Anti-icing Operations At Airports

When discussing the need for deicing aircraft, subsequently the need for ground deicing/anti-icing of runways, taxiways and aprons should also be pointed out. As modern jet aircraft can operate in icing conditions, airports also have to ensure safe operations of aircraft on ground roll during these adverse weather conditions (ref. nr. 36). Besides the mandatory duty of an airport operator to ensure safe operations of his aircraft traffic (ref.nr. 37), it is also necessary to offer continuous convenience to the traveller by maintaining regular air transport activities, and also to comply with the economic requirements imposed upon an airport operator nowadays. So the need for ground deicing/anti-icing is also, apart from the high safety aspect and standard in aviation, an economic and last but not least an environmental issue also.

Disruptions within the operational system of an airport can quickly accumulate into extensive operational delays, aircraft diversions and total airport closures for many hours. Besides the well known experiences the traveller encounters during such chaotic and unpleasant situations, like for example missing transfer connections, exhausting waiting intervals and over-night stops through cancellations, there exist even far more problems which affect aircraft/airport operators under these conditions and include:

- Disruptions in the aircraft rotation patterns resulting in further problems with airport curfew hours, exceeding of crew operating hours, missing compatibility with scheduling windows, operational malfunctioning of aircraft due to adverse weather impact.

- Airports facilities exceeding capacity due to grounded and delayed flights.

- Reduced aircraft movement rates within the runway systems thus further increase of the delay factor.

- Permanent runway and airport closures due to snow removal and deicing/anti-icing activities of the airport operator.

- Loss of revenue for aircraft movements and ground handling charges due to aircraft diversions may accumulate quickly.

- Additional costs to airlines due to bussing of passengers to/from other airports.
• Hotel accommodation costs for passengers of cancelled flights.
• Additional overnight stops of aircraft resulting in drastic changes in aircraft rotation plans of especially small and medium carriers as well as increased landing fees for diversion airports.

Thus, airports which during winterly weather situations experience these continuous operational problems due to a lack of efficient ground deicing/anti-icing and snow removal procedures suffer loss of revenues and, what is even more serious, lose their attractiveness for airlines. In the long term, such airports are bound to have a less attractive market position than other airport competitors. They may lose significant portions of their traffic resulting in an additional increasing loss of attractiveness for other carriers. So ground deicing/anti-icing and snow removal actions are mandatory operational requirements having to be performed by airport operators. This involves often significant investment and maintenance costs for specialized vehicles as well as the provision of manpower. Highly skilled staff for these airport safety sensitive jobs are required, which are expensive due to the limited requirement time, are hard to find and hard to integrate into the normal operational airport performance.

Conditions Under Which Icing Occurs

In conditions of freezing precipitation or high humidity when aircraft surface temperatures are near or below freezing and when it cannot be determined that snow or other ice crystal accumulations are not adhering and will blow off during initial stages of takeoff, surfaces should be anti-iced to inhibit the formation of ice prior to takeoff (ref. nr. 13 and 15). Critical surface temperatures under many circumstances are found in the vicinity of integral wing fuel tanks. When fuel temperatures are higher than ambient, critical surface temperatures will occur at other locations. Aircraft on the ground or in flight are susceptible to accumulation of ice formations under various atmospheric and operational conditions. Aircraft in flight can encounter a variety of atmospheric conditions that will individually or in combination produce ice formations on various components of the aircraft. These
conditions include the following weather situations according to meteorological definition:

**Supercooled Clouds**
Clouds containing water droplets (below 32° F) that have remained in a liquid state. Supercooled water droplets will freeze upon impact with another object. Water droplets can remain in the liquid state at ambient temperatures as low as -40° F. The rate of ice accretion on an aircraft component is dependent upon many factors such as droplet size, cloud liquid water content, ambient temperature, component size, shape and velocity.

**Ice Crystal Clouds**
Clouds existing usually at very cold temperatures where moisture has frozen to the solid or crystal state.

**Mixed Conditions**
Clouds at ambient temperatures below 32° F containing a mixture of ice crystals and supercooled water droplets.

**Freezing Rain And Drizzle**
Precipitation existing within clouds or below clouds at ambient temperatures below 32° F where rain droplets remain in the supercooled liquid state.

**Frozen Precipitation**
Aircraft on the ground, during ground storage or turnaround operations, are susceptible to many of the conditions that can be encountered in flight in addition to conditions peculiar to ground operations. These include, for example: Supercooled ground fog and ice clouds; Operation on ramps, taxiways, and runways containing moisture, slush, or snow; Blown snow from snow drifts, other aircraft, buildings, or other ground structures; Snow blown by ambient winds, other aircraft, or ground support equipment; Recirculated snow made airborne by engine, propeller, or rotor wash; Operation of jet engines in reverse thrust, reverse pitch propellers and helicopter rotor blades which are common causes for snow recirculation; Conditions of high relative humidity that may produce frost formations on aircraft surfaces having a temperature at or below the frost point. Frost accumulations are common
during overnight ground storage and after landing where aircraft surface temperatures remain cold following descent from higher altitudes. This is a common occurrence on lower wing surfaces in the vicinity of fuel cells; Frost formations can also occur on upper wing surfaces in contact with cold fuel.

When dealing with the issue of temperature, a clear distinction has to be made between ambient temperature and aircraft surface temperature. Ambient temperature depends on the geographical location of the airport, the seasonal time of the year, type of precipitation (snow, rain, ice) and other factors like wind, humidity or solar radiation. The ambient temperature at the ramp, gate, taxiway or runway may vary significantly from the temperature near the terminal area or the control tower. Additionally, ambient temperature may be steady, rising, or falling. Each of these variables can either independently or in combination influence the time of effectiveness and usage of aircraft deicing fluids. As discussed earlier, once the deicing process is completed, a thin film of deicing fluid remains on the surface and this film contains a mixture of ADF and water. The ratio of water to ADF is unknown and therefore the freezing point is unknown. Assume that a very rich mixture of fluid is uniformly added to the surface in a manner that most moisture is flushed away while realizing that some water will always remain in the solution. Also assume that the fluid film that remains is 80% ethylene glycol. Under these assumptions, the question then becomes "how much water must be added to this remaining film to cause the freeze point of the fluid to reach that of ambient temperature"? To answer this question, test results have shown that when ambient and surface temperature is 20° F the fluid film thickness on a surface sloped at an angle of 15° is at best (the most) 0.10mm deep. At 20° F a mixture of 16% ethylene glycol and 84% water will begin to crystalize.

Precipitation rates in snow conditions have been found to contain water in amounts up to 0.7 in/hr. A general rule of thumb, commonly used by meteorologists, is that the depth of snow is about 10 times the depth of melted snow. This rule of thumb, although useful for some purposes, could be misleading, since snow densities vary widely. Very dry snow can have the density of 30:1 (30cm of snow contains 1cm of water) and very wet
snow can have a density of 5:1. In snow conditions, the primary influence upon ADF life is the rate of addition of water and subsequent dilution of ADF fluid. If snow is falling at a rate of 1.5 cm/hr and if the water content of this snow is 0.1, then the rate of addition of water to the ADF fluid will be 0.15 mm/hr. If we assume that the falling snow contacts the aircraft surface and it melts and the water mixes thoroughly with the fluid contained in the film, the strength (glycol to water ratio) of 16% will be reached in a specific time. A snowfall rate of 1.5 cm/hr onto a wing having been coated with a very rich mixture, 100% ethylene glycol, at an ambient temperature of 20° F, crystallization may begin approximately in 25 minutes.

As snow contacts the upper surface of this film it melts and the water begins to mix with the ADF fluid. It is known that glycols are very soluble in water but it is also known that to assure a homogeneous fluid, the mixture must be agitated or stirred. So when a snowflake or other ice crystal, supercooled rain drop, or water in any form contacts the fluid film surface, a finite time is required for the water to mix with the fluid. During this time, the water remains somewhat in pure form or a weak aqueous solution of ADF. If during this process, before the water from a snowflake mixes with the fluid, another snowflake impacts on the surface, a portion of the snowflake may not melt immediately but will remain in ice-crystal form. Whether or not these ice crystals will bond to the aircraft surface depends upon many factors, such as: fluid film thickness, ADF fluid strength, surface temperature, ambient temperature and temperature of snow, rain, or ice crystals impacting on the surface.

If the ADF fluid film is sufficiently thick, these surface ice crystals may initially be localized on or near the surface or be floating on the surface. But as the process continues, water being added will gradually mix with the ADF fluid and, in time, the fluid in the surface film will reach an aqueous solution that will freeze (become slush) at the prevailing temperature and with time become frozen or adhere to the aircraft surface. As the quantity of slush increases, the viscosity of the surface film increases, requiring greater forces to cause the surface slush to be blown off the aircraft surfaces. Once the crystallization process begins, the chances of proper
blow-off during takeoff roll are minimal. In addition, once the crystallization process begins, the surface may be expected to be a rough texture which can adversely impair aircraft performance and flight characteristics.

Precipitation rates in freezing rain and drizzle conditions have been found to vary from about 0.3cm/hr to 0.5cm/hr. These conditions can occur at ambient temperatures between 32°F and approximately 12°F. Freezing rain and drizzle water droplets are in the supercooled liquid state and freeze upon impact with other objects. Because of the large size of freezing rain droplets the ice produced is usually glaze ice. When the aircraft surface is coated with a film of ADF fluid, freezing rain and drizzle droplets impacting on the fluid film will mix readily with ADF fluid, causing rapid dilution and under certain conditions can wash away the ADF fluid.

Airline operational experience indicates that ADF fluids are short lived in most freezing rain conditions (ref. nr. 14 and 16). In many instances, one side of the aircraft already deiced will begin to refreeze while the otherside is being deiced.

Aircraft surface temperature influences ADF-usage operation and consumption. Surface temperatures can be drastically different from ambient temperatures for many reasons: Solar radiation (cloudy day, sunny day etc.); temperature of fuel in fuel cells after refuelling on ground (specific airport); the type and location of fuel cells; fuel cold soaked during previous high altitude flight; quantity of fuel in fuel cells (tankering behaviour at specific airport); the source of fuel (above or below ground storage); time since refuelling; engine operation; APU operation; operation of subsystems or components that generate heat; and thickness of the skin, type of skins, and skin materials used. These are only a few of the many variables that can influence aircraft surface temperature.

Common practice accepted in the aviation industry is that if it can be determined that a small quantity of dry snow is not adhering to aircraft surfaces, it will blow off during the takeoff-roll and thereby not affect aircraft flight characteristics. This practice is well proven if one can ascertain that the snow is not adhering to critical surfaces. Dry snow at
cold ambient temperatures will not adhere to dry aircraft surfaces if surface temperatures are also very cold and will remain cold during start, taxi, and takeoff. However, operation of engines, or other equipment and many other factors may warm surface temperatures, causing melting or partial melting of snow and possibly cause freezing prior to the takeoff or during takeoff roll. Under certain conditions dry snow could adequately blow off of a dry cold spoiler or ailerons but not from large fuel tankage areas.

Solar radiation can significantly influence aircraft surface temperature. In conditions of heavy precipitation, solar radiation is usually slight. Generally, solar radiation will warm aircraft surfaces, but, in shadow areas, surface temperatures will be colder. Ambient wind blowing over an aircraft surface tends to remove heat from the surface at a more rapid rate rather than under calm conditions. Evaporation of liquids can cause surface temperatures to actually be lower than ambient. The rate of reduction of surface temperatures and the temperature depression is a function of many variables that make it impractical to estimate.

Aircraft operations on snow, slush, or wet ground surfaces can cause ice, snow or slush to be splashed or blown onto various aircraft surfaces. Jet engine exhaust (in forward or reverse thrust), jet engine vortices, prop or rotor wash, and taxi and takeoff operations can, through recirculation, blowing, or splashing, cause snow, ice particles or water to impact on various aircraft surfaces and freeze or adhere to these surfaces or further dilute ADF fluids. These occurrences are however somewhat predictable and should be expected during ground operations. The effect of these occurrences is unpredictable. If ice formations are anticipated, the clean aircraft concept must be implemented.
Predicting icing conditions at an airport, thus being able to produce reliable forecasts, is a difficult task and this problem area cannot be covered through general recommendations applicable at all airports, but more through the application of individual procedures and activities and thus taking account of specific airport criteria. As it is an airport’s mandatory and legal duty to prepare snow and ice control plans (ref. nr. 36 and 37), the general procedure is that forecasting, in some way or the other practicable under the specific airport criteria, is integrated into such snow and ice control plans. The legal requirement to produce snow and ice control plans is laid down in the ICAO Annex 14, Volume 1, Aerodrome Design and Operations (ref.nr. 37), as well as in detail (ref. nr. 36) in the Airport Services Manuals (ICAO Documentations). The day-to-day requirement for measuring the runway braking action under winter conditions must be determined by the authority having the responsibility of deciding whether the runway is fit for use. In most cases this is the responsibility of the airport authority. If the airport is open on a 24-hour basis, it will need to know the situation throughout this period. The airport operator has to inform the aerodrome users about the condition of the aircraft movement area and related facilities. Information on the condition of the movement area and the operational status of related facilities shall be provided by the airport operator to the appropriate aeronautical information service units, and similar information of operational significance to the air traffic services units, to enable those units to provide necessary information to arriving and departing aircraft. The information shall be kept up to date and changes in conditions reported without delay. The condition of the movement area and the operational status of related facilities shall be monitored and reports on matters of operational significance or affecting aircraft performance given. The information containing these status reports have been specified to satisfy the detailed specifications of the SNOWTAM and NOTAM promulgation requirements contained in ICAO Annex 15 (ref. nr. 38). In general these specifications state that, whenever a runway is affected by snow, slush or ice, and it has not been possible to clear the precipitant fully, the condition of the runway should be assessed, and the friction coefficient measured. For a modern turbo-jet transport aircraft, the difference in stopping distance on a
Dry runway, as compared with an ice-covered runway, can amount in extreme cases of poor braking action to an extra distance in the order of up to 900m. The airport snow and ice control plan contains all the duties and responsibilities to be performed and adhered to by the ATC-Services, Airport Duty Officer, Airport Snow Committee and the Airline Operators Committee (AOC). These plans ensure that even under adverse weather conditions, aircraft operations can be performed in a safe and orderly way as well as ensuring by definition clear competencies and the chain of command and responsibilities of the system users. Reliable forecasting of icing conditions at an airport is still one of the most demanding challenges an airport operator has to deal with. Forecasting weather situations is very complicated and still sometimes very unreliable, although technical progress is impressive. Weather forecasting for aviation purposes is even more demanding and requires advanced technical equipment and well trained and experienced staff to draw conclusions. All major airports thus utilize meteorological services (MET-Services) for forecasting activities and airport operational staff are trained to communicate continuously with MET-Services and to respond quickly to changes in weather. Although there is today less of a problem in forecasting snowstorms, freezing rain or continuous snow fall and precipitation, the forecasting of gradual increasing icing conditions and its unpredictable effects on the asphalt and concrete surfaces prior, between or after any main "precipitation attacks" on the airport, remains difficult. One of the major problems is to forecast accurately during drops in temperature, the gradual and airport locally differing development of such dangerous icing conditions and the in-advance required operational counter-measures to be implemented. In order to develop such an airport specific forecasting concept with the aim to help airport operations staff to predict such weather conditions, and to assist them to implement in advance preventive measures ensuring safe aircraft operation, the following additional issues have to be taken account of and addressed:

- Current weather factors (i.e. humidity, temperature, precipitation, wind)
- Current status of surface conditions on asphalt and concrete areas (i.e. wet, standing water, ice, compacted snow, etc.)
- Availability of response measures (manpower and snow removal equipment)
- Response time for the implementation of counter measures to inhibit a
decrease of operational safety within the movement area and to prevent
icing conditions

The implementation of anti-icing/deicing measures and thus especially the
spreading of anti-icing/deicing fluid has to be performed in a controlled way,
taking account of the presently existing status of surface conditions and
weather factors. Unnecessary spreading of anti-icing/deicing fluids will
significantly increase the environmental impact and the cost increase of these
operations. Reduced spreading of anti-icing/deicing fluids will in contrary
significantly degrade ground operational safety of aircraft within the aprons
and movement areas. Utilizing a computerized ground icing forecasting system
may be a promising course of action, especially for large airports with
extensive runway, taxiway and apron systems. For example, Munich
International Airport has implemented such a forecasting system in order to
preplan preventive and response measures during winter operations.
The system consists of a total of 39 sophisticated automatic sensor units
linked to a computer. The sensors are located within the two runway and
taxiway systems and the apron areas. The locations for the sensors have been
allocated according to the geographically most ice sensitive areas. The
sensors can register relevant meteorological data continuously and transmit it
to the main computer to be analysed. The sensor can register the following
meteorological data: Air temperature; Precipitation; Surface temperature of
cement/asphalt; Surface humidity; Surface freezing temperature forecast
according to status of existing tarmac condition. The computer software
enables not only an analysis of the present weather situation at the airport
and of the actual surface conditions of the cement/asphalt areas, but
additionally it is possible to determine in advance the development of icing
conditions. Additionally some of these sensors register relative humidity, air
pressure, wind direction and speed, in-depth temperature and height of
(snow)-contamination. The existing condition of the surface freezing
temperature, according to status of cement/asphalt and sprayed anti-
inging/deicing fluid can be registered as well as forecast when new fluid should
be spread to inhibit refreezing.
In critical icing conditions, by definition being a condition prior to icing occurring, the system produces a set of alarms to notify the responsible airport snow and ice control unit. The required measures can then be implemented before the icing condition actually appears. Thus anti-icing measures as well as following up snow removal operations can be launched with a "just in time" approach and individual controlled anti-icing deicing fluid spreading and consumption is possible.

Of major importance is the number of sensors installed at an airport site, as it is a fact that there can be a significant difference in the measured data at the distant measuring points. Temperatures may vary up to 2°C due to the immense distances within an airport compound. Action required in one airport area, at one or more sensor points, may not necessarily require actions at other areas or sensor points. Few measuring points may influence an observation to that extent, that any preventive anti-icing measure may be implemented far too late and situations elsewhere at the airport have already become worse. With such a system of forecasting, certainly only to be seen in addition to existing close cooperation with the airport's meteorological office, the uncertainty gap between actually developing icing (and snow/precipitation) conditions and "near miss situations" can be significantly reduced. Certainly it is out of the question that such a system can only function within an effective snow and ice control concept.

Relative Pollution Strength Of Deicing Chemicals

The only anti-icing and deicing fluid (ADF) chemicals certificated by the Society of Automotive Engineers (SAE) and approved by the FAA are ethylene or propylene glycol-based solutions, available in concentrated form (98% ethylene or 93% propylene glycol). In their concentrated form, the chemical oxygen demand (COD) of ethylene based ADF solutions is approximately $1.4 \times 10^6$ mg/l (98% ethylene glycol) and for propylene glycol based solutions $1.6 \times 10^6$ mg/l (93% propylene glycol).

The 5-day carbonaceous biochemical oxygen demand (BOD 5) for ethylene glycol ranges from 400,000 to 800,000 mg/l, while that of propylene glycol is
even higher approaching 1,000,000 mg/l. Just 250 gallons of these chemicals in their concentrated form has the same BOD 5 mass as one million gallons of domestic sewage (compare with Table 1-2). ADF deicing solutions, as applied to aircraft, are usually in a diluted form depending on desired effect. However, even in their diluted form (10% - 50%), the volume required to deice a typical large passenger jet is significant (approximately 750ltr. With a 20% propylene glycol dilution). It is now recognized that ADF’s pose a significant threat to the environment and yet their use is mandated to ensure the safety of passengers and crew members. Thus, airlines and airport managers have to search for an economical treatment alternative for the safe disposal of airport deicing fluids (ref. nr. 23).

Table 1-2:
Organic Concentrations Of Glycol-based Airport Deicing Fluids Compared To Domestic Wastewater

<table>
<thead>
<tr>
<th>Substance</th>
<th>Purity %</th>
<th>COD (mg/l)</th>
<th>COD (lb/gal)</th>
<th>BOD (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene glycol</td>
<td>93</td>
<td>1,600,000</td>
<td>13.53</td>
<td>900,000</td>
</tr>
<tr>
<td>Ethylene glycol</td>
<td>98</td>
<td>1,400,000</td>
<td>11.68</td>
<td>700,000</td>
</tr>
<tr>
<td>Domestic sewage</td>
<td>100</td>
<td>200 - 400</td>
<td>0.002</td>
<td>100 - 200</td>
</tr>
</tbody>
</table>

1 COD = Chemical Oxygen Demand
2 BOD = Biological Oxygen Demand

Effects On The Environment

Anti-icing/De-icing fluids (ADF) are vital in the prevention of ice and snow accumulation on aircraft wings and fuselage. Without the use of ADF, airplanes would be incapable of flight during winter conditions. ADF’s can lower the freezing point of any surface to which they are applied, thus preventing the accumulation of snow, ice and frost on aircraft surfaces. The de-icing and anti-icing fluids presently used consist mainly of Ethylene Glycol or mixtures of Ethylene Glycol, Diethylene Glycol, and Propylene Glycol as well as minor amounts of additives. These compounds have a freezing point approximately −6°C to −13°C below that of pure water. This ability to depress
The freezing point is the reason for the extensive use of glycol. A major drawback to using glycol-based ADF is the associated environmental hazard. Within the last decade, concerns have been raised that glycol-based ADF may be toxic and oxygen limiting to aquatic environments. Many toxicity studies express a common conclusion, that glycol causes damage at higher concentrations (i.e. >15000 mg/L). At low concentrations, the effect of glycol is minimal. In contrast, studies conducted on the oxygen limiting effects, expressed as biochemical oxygen demand (BOD), suggested that the environmental effects can occur at very low concentrations. At low levels (>200 mg/L) the BOD can be quite harmful to aquatic life. During the breakdown of glycol by microorganisms at temperatures >4°C, oxygen is removed from the surrounding environment and consumed by the microorganisms. Oxygen required during this breakdown process is expressed in mg/L and is proportional to glycol (Nutrient) in the water. Consequently, high glycol levels will result in high BOD levels.

The major source of toxicities within deicing fluid is thought to be the result of the additives to the glycol base. The additive package is property to each deicing fluid manufacturer (ref. nr. 3). All aircraft deicers in widespread use in North America and Europe today have formulations based on ethylene or propylene glycol. The composition and properties of glycol-based aircraft deicers have been grouped into general classes (ref. nr. 1 and 15) by the Association of European Airlines (AEA). Type I deicers are unthickened deicing/anti-icing fluids that are used to remove ice/snow and provide some protection against refreezing. AEA Type II deicers are thicker deicing/anti-icing fluids that provide greater protection against refreezing even under precipitation. The Type II deicers contain a polymeric ingredient which adheres firmly to the aircraft surfaces and protects them against icing while aircraft are standing; it then shears off the wings during takeoff. Deicing fluids may contain ethylene glycol or propylene glycol as the primary chemical, with diethylene glycol sometimes present as a minor constituent. AEA Type I Fluids which meet specifications for use in North America contain a minimum of 80% glycols by weight. The balance of the constitutes are primarily water along with a buffer, a wetting agent and an oxidation inhibitor. AEA Type II Fluids contain a minimum of 50% glycols by weight, with the balance being water and the polymer system for thickening.
The AEA Type I Fluids have been widely used in North America, while the AEA Type II Fluids have been common in Europe and only recently have been introduced to markets in the United States (ref.nr. 19). These types of deicing fluids have been identified as creating primary concern when released into the environment (environmental contamination). The acute and chronic aquatic toxicity of ethylene and propylene glycol is relatively low. The acute and chronic oral toxicity of the glycols to humans and terrestrial life is also relatively low. However, this is not to say that ethylene glycol does not pose an acute toxicity hazard under any scenario (ref.nr. 17). The ready availability around the home of ethylene glycol in its concentrated form as automotive anti-freeze has resulted in numerous accidental poisonings of children, as well as its use in suicide attempts. Presence of concentrated ethylene glycol in the environment as puddles of radiator boil-over may create a hazard to domestic animals and wildlife attracted to its sweet taste. Propylene glycol has even lower acute oral toxicity than ethylene glycol, but it may be somewhat more potent as a skin irritant and sensitizer. Under chronic exposure conditions, the glycols are also relatively low in toxicity to humans and animals. The glycols are not bioaccumulative in organisms, and are highly biodegradable under normal conditions in soil and aquatic systems and are, therefore, generally non-persistent in the environment. In principle, these are highly desirable traits for chemicals that enter the environment.

However, the biodegradation of glycols is so rapid and extremely oxygen demanding (ref. nr. 40) that it can deplete dissolved oxygen levels and threaten oxygen dependent aquatic life in receiving waters. Even with dilution and slower biological processes at winter time temperatures, this poses a hazard of oxygen depletion in waters receiving deicer-laden stormwater runoff. Reports of fish kills associated with deicer-laden runoff are rare. However, such events could easily go unobserved during winter time conditions. Two fish kill occurrences attributed to discharges of glycols from airports and subsequent ammonia formation have been reported in England. A fish kill linked to ethylene glycol was reported downstream from the stormwater discharge at Lambert Field, St. Louis, USA. Airport stormwater runoff in Pittsburgh (USA), Nashville (USA) and Anchorage (Alaska) have also resulted in impairment to aquatic communities.

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Temperate-zone airports with a high level of winter time operations use substantial amounts of deicing chemicals which are frequently released into the environment with little or no treatment (ref. nr. 20). There is ample evidence correlating the timing and volume of deicer use at airports and the degree of pollution of receiving streams. Such contamination has been measured in terms of glycol concentrations, biochemical oxygen demand, oxygen depletion, ammonia concentrations and aesthetic impacts.

An estimated 35 million gallons of aircraft deicing fluid (ADF) is used annually in the United States (ref. nr. 2). Based upon the percentage of glycol typically found in ADF and the percentage of ADF that falls to the pavement during application, an estimated 75 mill. lbs of glycol are released into the environment annually. A certain amount of ADF is also released to the runway when the aircraft takes off.

Runway Glycol Contamination

The amount of Type II deicing fluid released on to the runway is by no means insignificant, although when it is compared to the total amount of fluid sprayed onto an aircraft, it is much less. Still it may cause, depending upon the aircraft deicing techniques and the prevailing environmental regulations, significant problems at particular airports. Since ADF is applied in a spray form, some is lost to the atmosphere under windy conditions and some adheres to the aircraft surfaces. This indicates that a certain percentage of the ADF applied to the aircraft does not reach the storm sewer collection system. Additionally, depending on the aircraft deicing techniques, some of the ADF which does reach the apron remains in the snow as it accumulates on the apron. Snow lying on the apron areas is removed to the snowdumps. Thus, some ADF is removed with the snow and does not enter the apron collection system. The ADF accumulates in the snow mass at the snowdump and runs off during snowmelt events. The following summarizes the fate of aircraft deicing and anti-icing fluids after application and is to be seen as an average with minimum and maximum rates (compare with Table 1-3).
Table 1-3:
Deicing Fluid Fate After Application On Aircraft

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Minimum Rate (%)</th>
<th>Maximum Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhering To Aircraft</td>
<td>16&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>20&lt;sup&gt;(1)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Wind Dispersion</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>Entering Snowdump</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Dropping To Apron</td>
<td>50</td>
<td>70</td>
</tr>
</tbody>
</table>

<sup>(1)</sup>Applicable percentage of fluid (ADF Type I and II) from an average aircraft deicing operation affecting runway contamination rate and being released on to the runway.

The amount and type of ADF released on to the runway depends on the following criteria:

Type of deicing concept the airport has implemented:
- Decentralized deicing operations on the ramp with ADF Type II Fluids
- Centralized deicing operations on dedicated deicing areas with ADF Type II Fluids
- Centralized deicing operations on dedicated deicing areas with ADF Type I Fluids

Type of deicing techniques applied:
- Deicing with ADF Type I Fluid
- Deicing with ADF Type I Fluid and anti-icing with ADF Type II Fluid
- Deicing with ADF Type II Fluid
- Fluid application techniques (fluid minimization techniques)
- Type of equipment utilization

The ADF, consisting either of dilutions from Type I or Type II Fluids or a mixture of both, is gradually deposited from the origin point of aircraft deicing operation continuously onto the runway up to the final point shortly prior to where the aircraft commences the rotation phase. This is generally 1/3 of the runway distance. There it remains until, due to precipitation, it is either washed into the stormwater collection system or, during snow removal,
transferred to the runway adjacent areas. Most of the ADF dilution is collected immediately in the drains adjacent to the runways and subsequently enters the surface stormwater drainage system. It can be estimated that approximately 50% of the ADF deposited on to the runways is picked up during snow removal operations and spread by the snow blowers on to the bordering grassed areas.

Thus the airports have to deal with continuously differing ADF dilutions in both runway stormwater drainage systems (ref. nr. 32 and 33) and the soil of the runway adjacent grassed areas. The surface water run-off from the runways is usually controlled by drainage systems (storm-water sewerage) in combination with various treatment facilities, either on or off-site. Such systems will either direct the run-off into separate receptacles at the airport or mix them with other waste-water streams in a combined sewer system leading to a treatment facility. Modern systems are usually constructed to keep waste water and storm water separate, to allow operational flexibility and to ensure compatibility with modern public infrastructure.

Depending upon the prevailing environmental regulations at an airport in conjunction with off-airport disposal levels for sewage treatment plants, additional pre-treatment facilities may have to be installed, but controlled disposal and treatment is ensured. More complicated is the impact of ADF dilutions on the adjacent runway and taxiway grassed areas. There the danger exists, that these harmful dilutions will seep uncontrolled into the soil and subsequently into watersystems. The high levels of total phosphorus and BOD are the negative attributes of the aircraft deicing/anti-icing fluids. These high levels of contaminants are unacceptable and must be reduced in some way. However, the higher levels extend only to a distance of 10 to 50 m from the runway edge.

Munich Airport has implemented a system that collects contaminated waters from runway deicing operations (ref. nr. 28) into lined sand/gravel channels, where naturally occurring soil bacteria can break down the glycol before the water is released and seeps into the ground. Such a system is highly recommendable, as it can be installed also at a later time and also ensures that airports having to cope with very stringent environmental regulations concerning the protection of water systems are able to comply with these
standards on a long term basis. The Munich Airport concept has proven to be an efficient and reliable solution capable of complying also with future environmental standards. The ADF dilutions from the apron areas and the taxiways have the same fate as from the runways. The ADF dilutions from the deicing pads are caught in a system of channels surrounding the deicing areas. It is then collected for further reuse. Although impact on groundwaters have not been widely investigated, evidence suggests that porous soils and groundwater are also susceptible to contamination. Regulatory action is necessary to control the indiscriminate release of these contaminants in runoffs. Such actions should stress improved collection and treatment to address the concerns for dissolved oxygen depletion, toxicant levels and aesthetic effects. In the long term, possible solutions may also include increased reuse/recycling of deicer chemicals, and the development of alternative deicers which have a lower potential for environmental impacts.

History Of Deicing Methods

Ground deicing procedures have been under development, practically speaking, since the time of the invention of the aircraft. Early methods employed the use of hangars to avoid exposure to the elements or use of wing covers and covers for other critical components such as windshields, engine air intakes, pitot probes, etc. But these devices were useful only to reduce the extent of work required to remove frost, snow, or other ice formations from the aircraft. Various devices such as brooms, brushes, ropes, squeegees, fire hoses, or other devices were used to remove dry snow accumulations but caution had to be exercised to preclude damage to aircraft skins and other critical components. Common sense prevailed. Many of these manual methods are still used today for both small and large aircraft. As larger aircraft were introduced and the number of air carrier fleets and scheduled flights increased, more expeditious and less costly procedures were developed.

Thus freezing point depressing deicing fluids were introduced to prevent or retard the formation of frost during overnight storage, to assist in melting and removal of frost, snow, or other ice formations. Various methods of applying deicing fluids were utilized, such as mopping the fluid on the surface requiring
treatment, use of hand pumps attached to a supply tank and spreading the solution with a mop, brush or other suitable devices, to melt the ice to the extent that it could be removed in time by using manual means. These manual methods of deicing provided a capability, in clear weather, to clean an aircraft adequately to allow safe takeoff and flight. In inclement, cold weather conditions, however, the only alternative was to place the aircraft in a protected area such as a hangar to perform the cleaning process by whatever means were available. In freezing precipitation conditions, take-off had to be initiated almost immediately following removal from the protected area. Common practice developed was to clean the aircraft in the hangar and provide a protective coating of anti-icing fluid to protect the aircraft from ice or snow accumulation prior to takeoff.

Many of these techniques remain in use today, depending upon the local facilities and services that exist. However, most modern airports have traffic conditions and limitations of hangar space that, for the most part, preclude indoor ground deicing. Such airports usually have one or more fixed base operators who have the equipment, capability and experience to clean an aircraft and provide brief protection to allow a safe takeoff to be performed.

Many airlines have prepositioned ground deicing equipment for ramp deicing at major airports where icing conditions are prevalent such as in the United States (ref. nr. 13), Canada, and European Countries. Several manufacturers of various types of aircraft ground deicing equipment exist today to meet the ground support equipment demands of the aviation community. This ground support equipment varies in types from simple trailers hauling a 55 gal drum of aircraft deicing fluid with a wobble pump and mop to sophisticated equipment capable of heating and dispensing large quantities of water and deicing fluid and capable of elevating deicing personnel to heights necessary to have access to any area of the largest of today's aircraft (ref. nr. 31). This technology exists and it is believed that any demand for aircraft ground deicing can be readily met by the ground support equipment industry. Although modern and sophisticated ground support equipment exists (compare with Figures 1-4 and 1-5), cost considerations sometimes dictate a combination of removal methods.
For example, heavy accumulations of snow may be removed most cost effectively using brooms, brushes, ropes, fire hoses, etc. and other techniques followed by a final cleaning with aqueous solutions of deicing fluid. Again, common sense, experience, and foresight prevail to make the aircraft ground deicing process a cost effective and safe operation. With the rising cost of petroleum products, which are the primary base of most commonly used aircraft deicing fluids, the expense of fluid deicing has become a very significant parameter in the final decision process. A potential answer to the issue of expense has been developed in recent years, by using very hot water. Hot water alone may be effective for deicing at temperatures down to -7 C°; however, refreezing may be a problem unless followed by a
glycol spray. Deicing fluids are needed for deicing at all temperatures below -7°C. At all sub-zero temperatures, deicing fluids would be necessary to provide anti-icing prior to takeoff. Depending on the ambient temperature, deicer products are diluted with water to between 20 and 60 percent glycol by volume (50% appears common) to attain a lower freezing point than pure glycol and to be more cost-effective. The glycol solution is heated for deicing to 80-95°C and sprayed onto the aircraft.

History Of Aircraft De-/Anti-icing Fluids

The introduction of glycol based liquid deicers started around the year 1930. Pre 1930, mechanical methods (brushes, ropes and squeegees) were the only available alternative to clear aircraft wing areas from snow and ice deposits. Then the development of new fluids increased rapidly in speed and product diversity (compare with Table 1-6).

Table 1-6:

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Till 1945</td>
<td>Glycol deicing of allied bombers</td>
</tr>
<tr>
<td>1960</td>
<td>First introduction of thickened deicing fluids (Kilifrost ABC)</td>
</tr>
<tr>
<td>1970</td>
<td>Introduction of deicing fluid Hoechst Antifrogen EVS</td>
</tr>
<tr>
<td>1982</td>
<td>The Association of European Airlines (AEA) develop formal specifications for Type I and Type II fluids</td>
</tr>
<tr>
<td>1983</td>
<td>Introduction of the first AEA specifications for holdover time requirements for deicing fluids</td>
</tr>
<tr>
<td>1987</td>
<td>Introduction of new Type II, diethylene glycol based fluids</td>
</tr>
<tr>
<td>1990</td>
<td>Implementation of new regulations concerning aerodynamic acceptance requirement for deicing fluids</td>
</tr>
<tr>
<td>1993</td>
<td>Introduction of new Type II, propylene glycol based fluids, Type II fluids are used world-wide and are supported by full specifications from AEA, ISO and SAE</td>
</tr>
<tr>
<td>1995</td>
<td>Introduction of alternative Type II with improved holdover times</td>
</tr>
<tr>
<td>1996</td>
<td>New specification requirements for Type IV deicing fluids are set up</td>
</tr>
<tr>
<td>1996</td>
<td>Introduction of New Type IV, propylene glycol based fluids</td>
</tr>
</tbody>
</table>
Chapter 2
Methods of Deicing Aircraft

This chapter examines in more detail the methods of deicing aircraft and aircraft movement areas at an airport. It covers the following topics and informs in detail about operational deicing practices and procedures: The definition and description of an aircraft deicing facility is of importance to understand the influences of different facility layouts and subsequent applicable operational systems and their environmental impact performance. As differing deicing procedures and practices also influence the methods of fluid application, the industry has produced special deicing fluids to meet these demands. Health and safety issues for deicing personnel and deicing operators are adressed in order increase safety awareness for personnel, equipment and procedures. Finalizing Chapter 2 is a description of the available technologies and operating successes as well as operating constraints or limitations. Aircraft deicing facilities are recommended at airports where icing conditions are to be expected. This includes airports that serve aircraft that can develop frost or ice on critical surfaces even though the airport itself does not experience ground icing conditions.

Definition Of An Aircraft Deicing Facility

An aircraft deicing facility is a facility where frost, ice, or snow is removed (deicing) from the aircraft in order to provide clean surfaces and/or clean surfaces of the aircraft receive protection (anti-icing) against the formation of frost or ice and accumulation of snow or slush for a limited period of time (ref. nr. 11). Deicing facilities can be identified as being either centralized or remote. A centralized deicing facility is an aircraft deicing facility located at the terminal gates/aprons or along taxiways serving departure runways. A remote deicing facility is an aircraft deicing facility located along taxiways serving departure runways or near the departure end of runways.
Centralized Deicing Facilities

Centralized deicing facilities, where aircraft receive initial deicing/anti-icing treatment, can be constructed at numerous sites with increasing constraints towards departure runways. A terminal, for example, is a centralized deicing facility where the gates are the pads used for deicing/anti-icing operations. Gate areas that cannot meet storm water regulations but can adequately handle deicing/anti-icing demands of users and allow acceptable taxiing times to the departure runway under varying weather conditions, should, if practicable, be upgraded environmentally. For some airports, centralized deicing facilities at or adjacent to terminals can adequately meet the deicing/anti-icing demands of users and still allow acceptable taxiing times to the departure runways under varying weather conditions. Improvements to or expansion of these facilities at terminal gates should, if practicable, include apron drainage areas that collect glycol runoff for proper disposal or recycling. Centralized deicing facilities off-terminal are recommended when terminal deicing facilities (including apron facilities) experience excessive gate delays, taxiing times, or suffer from severe weather conditions conductive to aircraft icing conditions. Terminals whose deicing gates lack permanent environmental runoff structures are candidates for off-terminal deicing facilities when the construction cost for runoff mitigation is not cost effective.

Centralized deicing facilities (compare with Figures 2-1 and 2-2) have five main components: An aircraft deicing pad for the maneuvering of aircraft and mobile deicing vehicles; Bypass taxiing capability; Environmental runoff mitigation measure; Permanent or portable nighttime lighting system, and, but not necessarily, support facilities that may include one or more of the following: Storage tanks, transfer systems for aircraft deicing/anti-icing fluids, deicing crew shelters and fixed fluid applicators.

Remote deicing facilities allow aircraft to receive initial or additional deicing/anti-icing treatment. Siting remote facilities near departure
runways minimizes the taxiing time between treatment and takeoff. Such facilities also compensate for changing weather conditions when icing conditions or blowing snow are expected to occur along the taxi route taken by the aircraft to the departure runway (ref. nr. 11).

Remote deicing facilities located near departure runway ends or along taxiways are recommended when taxiing times from terminals or other centralized deicing facilities frequently exceed holdover times. These facilities can improve flow control by permitting retreatment of aircraft without having the aircraft return to a more distant treatment site. Remote deicing facilities have the following components (compare also with Figure 2-2): An aircraft deicing pad for the maneuvering of aircraft and mobile deicing vehicles; Bypass taxiing capability; Environmental runoff mitigation measures; Permanent or portable nighttime lighting system and storage tank, transfer system for aircraft deicing/anti-icing fluids. The primary factor for siting deicing facilities is taxiing time that begins with the start of the last step of the deicing/anti-icing treatment and ends with the takeoff clearance, such that the holdover times of the fluids are still in effect.

Figure 2-1:
Layout Of Centralized Aircraft Deicing Area (Off-Terminal Location)
The processing time to deice/anti-ice aircraft for the same weather conditions and fluids varies by aircraft type. In terms of design, narrow body aircraft are processed quicker than wide-body aircraft, and aircraft such as DC10s and Boeing 727s require additional processing time. In terms of fleet mix, airports with a high percentage of wide-body aircraft may need additional deicing pads to adequately maintain this particular fleet's departure demand. A balanced fleet mix may provide a means to increase a facility's deicing capacity by relating flow rates of common sized aircraft to specific deicing pads. The physical space required by deicing facilities depends to some degree on the fleet mix being served (compare with Figure 2-3).
For instance, airports serving a large variety of aircraft types and sizes require facilities more flexible and complex than those airports serving predominantly one class of aircraft. The latter case is more conducive to standardizing the design requirements of such a facility.

For these reasons, at many airports mixed methods of aircraft deicing are used, with the result, that different types of aircraft are deiced at different locations. An extreme example of such a mixed mode operation would be the deicing of regional propeller aircraft on the ramp parking stand and the deicing of jet aircraft on remote deicing areas near the runway (ref. nr. 29) with different deicing fluids and under different procedures.

Restrictions on deicing fluid usage can also impact on the siting of facilities. Though for the same weather conditions Type II fluids provide longer holdover times as compared to Type I fluids, they are restricted to aircraft with higher takeoff rotational speeds (e.g., 100kts or more as approved by airframe manufacturers). This restriction may necessitate siting a facility closer to the departure runway in order to serve restricted aircraft or have separate facilities for the two groups. Also, facility siting may have to take into account airports that are located in very cold climates since Type II Fluids have a lower temperature application limit.
An examination was made of the way in which airports in the United States and Europe perform deicing operations (ref. nr. 20) and what future measures will be taken to ensure improved operational conditions under adverse winter weather conditions (aircraft deicing) and improved environmental protection (glycol recollection).

Special deicing facilities are being constructed or already in use at 50 large airports in the United States and Canada, Scandinavia, Japan and northern Europe. The amount and type of facilities per airport ranges from one remote facility to a maximum of five remote facilities. Primary and secondary deicing is done on remote deicing facilities as well as on centralized deicing facilities. Deicing activities are conducted at gates (ramps), remote facilities or even both, as demonstrated in the Munich case. Some airports even deice at the runway threshold. For those airports which experience a deicing season, the "normal" range spans from September to June at the longest, to January through to March at the shortest. Major deicing events range from one per season up to more than 4,000 per season. The amount and types of fluids used varies widely and are used under different operational procedures. At some airports the glycol is collected and recovered; few airports recycle all or some portion of the glycol. The recovery systems are operated by the airport, air carriers, or a recycling contractor.

The disposal of deicing effluent is either treated and drained into sanitary sewers, allowed to drain into stormwater systems, allowed to evaporate and degrade, recycled totally or partially and/or handled as a hazardous material.

Environmentally sensitive features in the immediate vicinity of designated areas for aircraft deicing include creeks and small rivers, downstream ponds, drinking water supply, protected habitats, wetlands (freshwater) and wetlands (saltwater). All airports are affected at least by one Federal, Provincial/State or municipal law or regulation that directly impacts on their deicing procedures. Some restrictions are very severe, so that deicing fluids may be limited to only one type (Type I) or are restricted on
dioxane levels. The airports are, without exception, all liable for any contamination caused to stormwater, surface waters and ground water. Some airports are currently exempt from particular regulations, as the amount of deicing material used annually is below the minimum levels stipulated by the general regulations.

Current Operating Procedures And Practices

The current equipment most commonly used for applying deicing/anti-icing fluid is mobile open basket boom trucks operated by people. One person is the driver of the vehicle and manoeuvres the unit into the required positions around the aircraft's. The other member of the team stands in the open basket at the end of a boom and applies the fluid using a hose or spray gun. This technique is commonly known as a 'firehose application'. In most cases two vehicles are used per aircraft. Aircraft are normally deiced from wing tip to wing root with the fluid being directed towards the trailing edge. The tail section is deiced starting at the top of the vertical stabilizer and moving down to the horizontal stabilizer. The units position themselves so that the operator can work upwind of the aircraft, which helps to minimize the fluid being blown back on personnel or lost on the apron. Deicing crews are often comprised of ramp personnel who are reassigned from regular duties when the need arises or belong to a special company offering deicing services (e.g. at Munich Airport). Depending on the surface area of the aircraft being deiced, the distance from the applicator to the surface can vary from three to nine metres. For safety reasons associated with deicing personnel being exposed to noise and engine blast, aircraft are currently mostly deiced with engines shut down. The APU is left operational to restart the aircraft when the deicing is completed and personnel have moved out of range. The crew communicates with the pilot via VHF radio or interphone (wire cable to the cockpit). Deicing personnel receive in-depth training at the start of each deicing season and receive some refresher training during the course of the season. In some countries, deicing personnel require certification (ref. nr. 29) by the governmental aviation authorities (e.g. USA and Germany).
Depending on the type of accumulation on the surface of the aircraft and the type of aircraft, operational procedures employed in aircraft ground deicing and anti-icing vary. The general procedures used by aircraft operators are similar and are based on the procedures recommended by the aircraft manufacturers, which, in turn, may be based upon procedures recommended by the fluid manufacturer, the SAE and ISO. Deicing and anti-icing may be performed as a one-step or two-step process, depending on predetermined practices, prevailing weather conditions, concentration of fluids used, and available deicing equipment and facilities (ref. nr. 41).

The One-step Procedure is accomplished using a heated or, in some cases, an unheated glycol mixture. In this process, the residual glycol fluid film provides a very limited anti-icing protection. This protection can be enhanced by the use of cold fluids or by the use of techniques to cool heated fluid during the deicing process. A technique used commonly in the past is to spray on a final coat of deicing fluid using a very fine mist, applied in an arched trajectory so as to cool the fluid before contact with the aircraft surface. This produces a thicker fluid film which will have a slightly enhanced anti-icing effectiveness.

The Two-step Procedure involves both deicing and anti-icing. Deicing is accomplished with hot water or a hot mixture of glycol and water. The ambient weather conditions and the type of accumulation to be removed from the aircraft must be considered when determining which deicing fluid to use. The second (anti-icing) step involves applying a mixture of SAE or ISO Type II and water to the critical surfaces of the aircraft. When heated water alone is used in the deicing process, the second step must be performed before refreezing occurs, generally within three minutes after the beginning of the deicing step. An aircraft must be systematically deiced and anti-iced in weather conditions conducive to icing. Each aircraft surface requires a specific technique to achieve a clean aircraft. The wings are the main lifting surfaces of the aircraft and must be free of contaminants to operate efficiently. An accumulation of upperwing frost, snow, or ice changes the airflow characteristics over the wing, reducing its
lifting capabilities, increasing drag, increasing stall speed, and changing pitching moments. The weight increase is slight, and its effects are secondary to those caused by surface roughness. On most aircraft, the deicing of the wing begins at the leading edge wing tip, sweeping in the aft and inboard direction. The tail surfaces require the same kind of treatment. The fuselage is deiced and anti-iced from the top down. Deicing the top of the fuselage is especially important on aircraft with aft-mounted centreline and fuselage mounted engines. The ingestion of ice or snow into an engine may result in compressor stalls or damage to the engine. The radome or nose of the aircraft is deiced to eliminate snow or ice accumulations from being projected into the crew's field of vision during takeoff. This area also contains navigation and guidance equipment and the sensors have to be clear for proper operation.

Methods Of Fluid Application On Aircraft Surfaces

The application of deicing fluids on aircraft surfaces raises four major discussion points. These concern the type of fluids used, the systems operated, operating procedures and locations.

Fluid Type

There are two basic types of aircraft deicing/anti-icing fluids - Type I (unthickened) Fluids and Type II (thickened) Fluids. The following Table 2-4 summarizes the key features of each (ref. nr. 41):
Table 2-4:
Key Features Of Type I and Type II Fluids

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unthickened</td>
<td>At least 80% glycol</td>
<td>Thickened</td>
</tr>
<tr>
<td></td>
<td>Viscosity depends on temperature</td>
<td>At least 80% glycol</td>
</tr>
<tr>
<td></td>
<td>Limited anti-icing capability relative to holdover time</td>
<td>Viscosity depends on temperature and aerodynamic force acting on fluid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good anti-icing capability</td>
</tr>
</tbody>
</table>

Type I Fluids have a high glycol content (minimum 80%) and a relative low viscosity, except at very cold temperatures. Because the rate at which the fluid flows off the wing depends, among other things, on the fluid viscosity, a high viscosity fluid is likely to have larger aerodynamic effects than a low viscosity fluid. The viscosity of Type I fluids depends only on the temperature. The holdover time is relatively short for Type I fluids.

For many years ethylene-glycol-based Type I Fluids were the principal type of fluid used in the United States. However, because of an ethylene oxide shortage, nonethylene-glycol-based Type I Fluids were offered in the United States during the 1988/89 winter season.

Nonethylene-glycol-based Type I Fluids are also used in Europe because of environmental concerns. Propylene glycol is one of the most common nonethylene glycols.

Because taxi times are often much longer than the holdover times provided by Type I Fluids, Type II (thickened) deicing/anti-icing fluids were developed. These fluids have significantly longer holdover times than Type I Fluids. They have been used extensively in Europe for many years, and their use is increasing in the United States and in other countries, although these fluids cannot be recycled presently. At airports, where Type II Fluids are being used exclusively for aircraft deicing, the environmental impact is likely to be much higher, but this depends also on the deicing procedures and the location of the deicing areas (ref. nr. 24).
Anti-icing Treatment After Aircraft Arrival At The Gate

Especially during precipitation conditions an effective measure to protect aircraft against the formation of snow and ice on the wing surfaces is to spray these sensitive areas of the aircraft with small amounts of ADF Type II Fluid. The wing areas of most aircraft are very sensitive to the formation of ice (ref. nr. 25), due to the fact that fuel in the tanks is very cold and thus contributes to the formation of ice and snow. Especially aircraft with full fuel tanks are subject to frequent tankering (no fuelling during intermediate stops) at airports and often require intensive deicing activities prior take-off (ref. nr. 12). Also aircraft with longer turnaround times are much more vulnerable to the build-up and formation of snow and ice on their wings and stabilizers. Subsequently, any anti-icing pre-treatment at the gate shortly after the aircraft has landed will contribute to less fluid consumption during the off-gate deicing prior take-off. This special treatment may either be performed by the designated deicing operator or by the airline maintenance staff themselves, since at the gate the aircraft engines are shut down and access to the aircraft wing areas is easily possible.

In Munich this type of preventive anti-icing is performed for example by Swissair with their MD 80 aircraft. Small amounts of ADF Type II Fluid (30-50 ltr.) are sprayed onto the sensitive areas immediately after the aircraft has arrived at the gate. This prevents the build-up and formation of ice and snow during the turn-round of the aircraft and minimizes fluid consumption at the off-gate deicing areas prior to aircraft take-off. The stormwater drainage system of the ramp can easily cope with these amounts of ADF dilutions, as the airport operates a pre-treatment facility for these run-offs. At airports where considerable refuelling is being performed, due to low fuel prices, such measures may only be required in a reduced form under certain weather conditions, as the fuel from the airport refuelling system (or fuel farm) has a significantly higher temperature upon being transferred into the aircraft, then upon aircraft arrival from high flight levels (fuel temperature can be as low as -50° C).
A major problem is also the refreezing of slush on aircraft landing gear and underwing surfaces (flaps, slats, etc.) after having landed on a snow contaminated runway (ref. nr. 26). The removal of frozen slush accumulations in this area is very problematic and requires a lot of additional deicing fluid consumption for this one aircraft deicing event. Additional anti-icing pre-treatment of these aircraft areas upon arrival at the gate will subsequently reduce the risk of refreezing and thus effectively reduce increased consumption of deicing fluid prior aircraft departure from the gate (ref. nr. 27).

Operational Requirements

In developing operating requirements for assessing new technology, the following deficiencies in current practices must be addressed:

- Because aircraft must be deiced with engines off for safety purposes, the total time to deice an aircraft is extended significantly. It has been estimated by airlines that it costs them $50 for every minute an aircraft is standing still;
- The ability to verify with total confidence that the aircraft has been properly deiced is lacking. Verification is currently undertaken by a combination of the flight crew and the deicing personnel at the end of the boom. It must be noted however that the boom personnel are not close to the surface of the aircraft, must look at surfaces often through blowing snow, and must work under extreme conditions. Personnel get tired and there is the potential for error;
- Application of deicing fluids is totally at the discretion of the individual in the basket operating the spray gun. This results in a wide variance in the time taken to complete the processing as well as in the amount of fluid applied. Concerns have been raised about consistency of application and the most efficient application of fluid.
- The time taken to complete the process using current practices has been questioned in terms of negative impacts on holdover times.
Holdover time starts when the deicing fluid is first applied, which means that long processing times reduce the "window" that aircraft have to reach the threshold of the active runway.

- Gate and apron areas are often congested with vehicles and personnel. This congestion is multiplied in many types of deicing situation. This can have a negative impact on the ability of the deicing trucks to move into required positions around the aircraft, and

- as the current equipment is considered first generation technology and does not have the necessary refinements and mechanisms built in, the risk making contact with the surface of an airplane is addressed through the distance of application. As the fluid is applied anywhere from three to nine metres away from the surface, the issues of fluid heat loss and over-spray arise. It has been estimated that deicing fluid temperature drops 7°C for every metre it travels before contacting an aircraft surface.

Health And Safety Issues

The following health and safety issues are identified:

Of the two glycol-based deicing/anti-icing compounds, ethylene glycol (EG) is listed as a hazardous substance under the U.S. Environmental Protection Agency (EPA) regulations (ref. nr. 9). Also, in the 1990 amendment to the U.S. Clean Air Act, the U.S. Congress included EG in the list of hazardous air pollutants. EG poses potential threats to workers' health and to air and water quality. The concern with airport workers is possible exposure to anyone not wearing respiratory protection while EG-based deicing fluids are being sprayed. Such exposure can cause severe throat irritation, headache and nausea. In contrast, propylene glycol (PG) is not listed as a hazardous substance. In fact, PG is approved by the U.S. Food and Drug Administration (FDA) for use as an additive to food for human consumption. The FDA rates PG as generally recognized as safe and suitable for adding directly to food products when produced according to current good manufacturing practice. Due to its safer environmental and toxicological profile, PG predominates at European and U.S. airports for
deicing operations. A growing number of airports require the use of PG deicers exclusively. There have been questions raised about the long term impact of exposure to glycol on humans. As the current trucks use booms with open baskets on the end, there exists a potential health as well as safety risk:

- The major exposure possibilities are vapour inhalation, skin exposure and ingestion. In a deicing situation ingestion of significant amounts of liquid is highly improbable. The fluid temperatures involved would not be high enough to generate much vapour, and any which was generated would be dissipated rapidly. Deicing personnel are provided with adequate protective clothing to prevent skin exposure. It appears that the danger to deicing personnel from exposure to deicing fluid is very small.
- Exposure to vapors or aerosols of any glycol fluid may cause transitory irritation of the eyes. Exposure to ethylene glycol vapors in a poorly ventilated area may cause nose and throat irritations, headaches, nausea, vomiting, and dizziness.
- All glycols cause some irritation upon contact with the eyes or the skin.
- Glycol is extremely slippery, which increases the risk of equipment collision or personal injury on apron areas where glycol is sprayed or tracked.
- Deicing equipment on the apron increases the level of traffic which in turn increases the probability of accidents.
Technologies Available

An automatic deicing gantry structure carrying multiple spray nozzles on moveable arms has been developed by Kallax, a Swedish company (ref. nr. 28). The gantry is high and wide enough to span an aircraft and is mounted on mobile carriages (rails). In operation, the aircraft is parked under the gantry and stopped. The aircraft then remains stationary (with running engines) while the gantry slowly moves over it, spraying fluid according to the aircraft profile and weather conditions which have been pre-programmed into its control system. It is also possible to process propeller aircraft through this facility (compare with Figure 2-5).

Figure 2-5:
Layout Of Fixed Deicing Facility (Munich Airport)

These gantries have been installed at 4 airports so far, the most prominent being Munich. The automatic gantry system gives more consistent deicing performance than manually controlled spraying, and Kallax claims it to be a more economical way of deicing aircraft at a high rate than employing multiple boom trucks. Listed in the following Table 2-6 are the current performance specifications and capital costs of the gantry system.
Table 2-6: Technical Data And Design Features Of Gantry System:

<table>
<thead>
<tr>
<th>DIMENSIONS GANTRY</th>
<th>SPAN</th>
<th>70.85M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free height</td>
<td>20.90m</td>
</tr>
<tr>
<td></td>
<td>Total height</td>
<td>26.00m</td>
</tr>
</tbody>
</table>

Dimensions Deicing Pad
- For narrowbody a/c: 45 x 78m
- For widebody a/c: 110 x 71m

Travelling Speed
- Gantry: 0-60m/min
- Winches: 0-30m/min

STRUCTURE
- Weather station on top
- One operator cabin, one inspector cabin
- Floodlighting for 24-hour operations

Surfaces deiced:
- Wing/horizontal stabilizer
- Fuselage
- Vertical stabilizer

General specifications:
- Maximum handling of B747-400
- 100 - 200 spray nozzles
- 1m distance of fluid application from surface
- Nozzle flow consistent at 30ltr./min
- Fluid application temperature 90°C
- Amount of fluid is controlled by gantry speed
- Aircraft profiles stored on computer
- 6 deicing programmes available
- Aircraft guidance via beacon on gantry bridge and beacon located on the extended centreline

PROCESSING CAPABILITIES:
- FROST: 20 AIRCRAFT/HR.
- Light snow: 16 aircraft/hr.
- Heavy snow: 12 aircraft/hr.
- Freezing rain: 9 aircraft/hr

Current operations: Munich Airport, Germany
Several manufacturers now offer more sophisticated versions of the conventional boom truck deicer equipment. Significant improvements include one-man operation and enclosure for the sprayer operator. Enclosure not only improves the comfort level of the operator and protection from exposure to deicer spray, but allows deicing to be carried out with the engines running because the operator is protected from the engine intake and exhaust blasts and noise. Modern deicing trucks have precision control of the spray head, although a single spray per truck remains the norm, and can work closely to the profile of the aircraft, so improving the efficiency of the deicing process.

A Canadian company has developed a mobile robotic system which refuels and decontaminates fighter aircraft. This system is easily adaptable to deicing of aircraft. The system is an amalgamation of advanced boom-truck and robotic technology, and may offer a way to combine the expected advantages of robotics with complete freedom of deployment on the airport. However, the current version is designed for fighter aircraft only and would need to be enlarged considerably to deice widebody commercial aircraft. The advanced deicing boom trucks with one-man control operation are considerably more expensive than the simple trucks used at present.

The robotic system was designed to match the operating capabilities of the Kallax gantry in terms of processing time and fluid application. The main
components of the system which are required for each deicing pad are as follows:

- Four robots with spray booms and hydraulic operating system. A 10m spray boom is attached to the end of a telescopic boom. The spray boom will operate one to two metres from the aircraft surface being deiced. There is a separate set of nozzles for Type I and Type II fluids. The booms are able to access all critical surfaces and the process will be fully automatic. It is envisaged that the robots will be folded down when not in use. The height of the robot base is approximately 2.6 metres. The maximum height while in use has been estimated to be approximately 21.6 metres. This occurs when a B747-400 is being deiced.

- One operator station and one observer station. These fixed structures will have a height of fifteen metres, and will be located at the edge of the pad· approx. in the centre of the deicing pad. The stations will be equipped with video cameras, monitor, intercom and system stop controls. The operator station will also have a weather station, transceiver and system control equipment;

- Pilot guidance system. There will be a system to guide aircraft taxiing onto the deicing pad. The guidance and position controller will use a VME based vision system with cameras on both sides of the aircraft. The system will track the taxiing aircraft and will display graphic cues for centreline offset, rate and distance to stop.

- Pilot visual display. There will be a visual system to show the pilot what aircraft type and deicing/anti-icing programme the operator has selected.

- Environmental conditions. The system is designed to operate continuously for 20 hours under extreme conditions including 70 km/h winds, 12mm ice loading and a temperature of -40° C. The system is designed for a useful life of 20 years.

- Processing capability. The system will match the processing capability of the Kallax gantry. This is based on the premise that the required airside infrastructure is in place to allow aircraft to enter and exit the deicing pad quickly and efficiently.
Another method of deicing, recently installed at Pittsburgh (USA), is a manually operated stationary boom, which by virtue of its solid mounting to the ground can be considerably larger and possessed of a longer reach than a truck mounted boom. However, it is still not possible to span a whole aircraft with a single boom, and four units are required per aircraft (e.g. Paris CDG Airport).

The following conclusions can be drawn from the contents of Chapter 2: Aircraft deicing facilities have to incorporate a variety of general design features in order to assure safe, efficient and environmentally friendly deicing operations for aircraft. Depending on the location of aircraft deicing areas, different operational issues have to be specifically addressed. Operating procedures and practices for the deicing of aircraft may vary and depend upon individual airline, aircraft or airport requirements. The fluid application on aircraft surfaces depends also on type of fluid availability and fluid useage. In developing operating requirements for assessing new aircraft deicing technologies, deficiencies in current practices and deicing equipment have to be taken account of. Of importance are the health and safety issues of glycol-based deicing/anti-icing compounds for deicing operators, as they have significant influence upon operational practices. Closing this chapter is a description of the available technologies for the deicing of aircraft.
Chapter 3
Impact Of Deicing Activities On The Environment

This chapter examines in detail the factors which influence the degree of environmental impact. These factors are chosen by definition to include procedures, type of deicing agent and technical installations. The following factors will be addressed: The environmental Effects of ground deicing and relative pollution strength of glycols, the fate of aircraft deicing fluids after application as well as the sources and pathways for entering the environment; the impact of urea on runways and aircraft movement areas; the impact of tarmac deicing activities on the natural environment of an airport and examples of consumption of tarmac deicing fluids at chosen airports.

Very little attention has been given until recently to controlling the runoff of deicing chemicals to the surface drainage system. Usually, these chemicals are antifreeze and salts and are not looked upon as particularly harmful. Deicing operations are absolutely critical to the safety of aircraft and airport operation. However, the control, collection, and disposal of the deicing fluids will be extremely difficult to address. In most cases, this will involve a retrofit situation at existing airport facilities. The amount of airport/aircraft deicing performed varies by location, but the extent of deicing operations is widespread (ref. nr. 40).

Environmental Effects Of Ground Deicing And Relative Pollution Strength

Water pollution is caused by the direct or indirect discharge of substances into the aquatic environment resulting in the alteration of the quality or nature of water ecosystems, with subsequent detrimental effects on human health or animal and plant life (ref. nr. 31 and 32). Quantitative and qualitative influences of aviation on flowing and still
bodies of water can arise to varying extents from land modifications (diversion, drainage, and canalization as a result of space requirements of airfields), air traffic, and other activities on the airfield, such as aircraft maintenance, refuelling, accidental releases of chemicals (e.g., leaking underground storage tanks and spills), de-icing operations, and runway maintenance. Water pollution, if not controlled, can find its way into the drainage systems and, ultimately, into local rivers and streams. Such releases threaten the health of aquatic organisms, animals, and humans who rely on the receiving body of water as a water supply.

Health effects can result directly from physical contact with or ingestion of the contaminated water, or indirectly from contaminants transferred into irrigated crops and up through the food chain. Ground water also flows into surface waterways and is a source of drinking water or irrigation for some communities. Since ground water and soils are intrinsically linked, concern for water quality implies concern for soil quality. Soil acts as both a reservoir and a filter for water; therefore, its contamination or the general degradation of its physical or chemical structure can have far-reaching effects on human, animal, and plant life.

Responsibility for careful management of airport operations rests with the airport operator, the airport's tenants and users, and federal, provincial, state, and municipal governments. Increasing financial burdens and quality standards for effluents, reflecting the importance of water as a resource, mean that airport operators and users are under continuing pressure to improve performance in this area. Water pollution at airports is ultimately the result of poor ground operational procedures, which lead to uncontrolled releases or the generation of more polluted water than waste water/run-off water disposal systems can cope with.

Water is used at airports in relatively large quantities in the course of many routine airport activities. A great deal of time, expense, and manpower is spent in anti-icing and deicing operations, because safety requires that, for take-off, aircraft surfaces be free of snow and ice that could impede the aircraft's ability to gain lift. The bulk of deicing activity takes place in cold weather. However, design features unique to certain aircraft make it possible for ice to form on wings and other surfaces.
even when the air temperature is comfortably above freezing. As a consequence, deicing can be a year-round activity.

Deicing and anti-icing fluids are complex products which need to meet often conflicting requirements. Fluid design is a compromise between a number of factors, which include holdover performance, the aerodynamic flow-off properties, storage stability, stability during heating, pumping and spraying with deicing vehicles, compatibility with aircraft materials and environmental acceptability (ref. nr. 41).

Ethylene Glycol (EG) is listed as a hazardous pollutant (HAP) under the US Clean Air Act, regulated by the Comprehensive Environmental Response and Liability Act (CERCLA), controlled by Federal Underground Storage Tank Regulations. The exposure standards are regulated by the Occupational Safety and Health Act (OSHA). Diethylene Glycol (DEG) is equally as toxic as EG but not yet regulated. Propylene Glycol (PG) is approved for direct food use and generally regarded as safe. The toxicity data for Ethylene Glycol (EG) is for a human lethal oral dose to be 1.4 ml/kg. The toxicity data for Diethylene Glycol (DEG) is for a human lethal oral dose to be 1.0 ml/kg. The Elixir of Sulfanilamide Incident (DEG ingestion) in the US in the 1930's caused 105 fatalities. Propylene Glycol (PG) is in sharp distinction from EG and DEG and has a low order of toxicity. No system or organ has been identified as a target for oral lethal effects.

Glycols are used in a wide range of formulated products such as: aircraft deicing/anti-icing fluids (ADAF's), automobile coolants, and desiccants for the oil and gas industry. Besides toxicity data on glycols, information on the toxicological hazards of the formulated products containing glycols are necessary to evaluate the potential environmental impacts associated with their use and disposal. ADAF's were the only formulated products for which toxicity data are available. The available data strongly suggests that formulated deicing/anti-icing fluids are more toxic than pure glycols. Furthermore, it appears that additives, other than glycols, contribute substantially to the toxicity of these products. ADAF's are
typically classified into either Type I or Type II Fluids. The Type I solutions are composed primarily of glycols and water (e.g. 49%EG, 5%DEG, 44.5% water); however, there are also additives such as corrosion inhibitors (e.g. phosphates, nitrites, nitrates, borax, and silicates), wetting agents (e.g. nonionic and anionic surfactants), buffers, and dyes (e.g. azo dyes) which are added. Type II Fluids are more viscous anti-icing agents used to prevent ice from adhering to an aircraft while it waits to take off. Polymers are added to Type II Fluids to increase their adhesion to aircraft. Ethylene glycol exhibits relatively low acute and chronic toxicity to humans and laboratory animals. It has not been found to cause cancer or mutations; however, it is a teratogen. Indications exist that propylene glycol is less toxic than ethylene glycol. ADF mixtures also contain various types of additives in addition to glycols which constitute the primary component. These additives include precious metal corrosion inhibitors, rust inhibitors, thickening agents and surfactants. The following contaminants may also present in glycol based ADF: diethylene glycol, ethylene oxide, dioxane, and acetaldehyde (trace levels only). Dioxane and acetaldehyde are suspected carcinogens or teratogens. High concentrations of glycols (greater than 10,000 mg/l) are required to cause acute aquatic toxicological effects (Hartwell, et. al. 1993). Although the ethylene and propylene glycols in ADF have a low potential to exhibit aquatic toxicity, the contaminants and additives in ADF pose a greater concern when released into the environment. Corrosion and rust inhibitors are highly reactive which translated into high biological toxicity.

Synonyms for EG include ethane-1-2-diol, ethylene glycol, ethylene dihydrate glycol, monothylene glycol, glycol alcohol, 1,2-ethanediol, and 1,2-dihydroxyethane (Miller 1979; Merck Index 1989). Common synonyms for DEG include 2,2-oxybisethanol, didlycol, and 2,2-oxydiethanol (Sax 1979; Merck Index 1989). The term propylene glycol (PG) refers to two isomers 1,2-PG and 1,3-PG. Common synonyms for 1,2-PG include 1,2-propanediol, methyl glycol, sirlene, trimethyl glycol, 1,2-dihydroxypropane, alpha-propylene glycol, monopropylene glycol, and methylene glycol (Miller 1979, Merck Index 1989). Common
synonyms for 1,3-PG include 1,2-propanediol, 1,2-dihydroxypropane, trimethylene glycol, beta-propylene glycol, and 2-deoxyglycerol.

The literature review did not provide production and use data for EG and DEG in isolation. The review did provide such data for the group of compounds known as ethylene glycols, which includes ethylene, diethylene, and triethylene glycols.

Ethylene glycols are primarily used in antifreeze mixtures, including aircraft deicing/anti-icing fluids, automobile coolants, and others applications. The second largest use of ethylene glycols is for the production of polyethylene terephthalate. Minor uses are in the processing of oil and gas and in the production of solvents, explosives, and glycol esters other than polyethylene terephthalate. In general, the production of ethylene glycols is increasing, directly related also to the industry expansion. The literature review did not provide production and use data for the individual isomers of 1,2-PG and 1,3-PG. Information was found for the group of compounds known as propylene glycols, which includes the two propylene glycol isomers, as well as dipropylene glycol and tripropylene glycol. The largest single use of propylene glycols is generally in the production of unsaturated polyester resins for fibreglass reinforced polyester products. They are also used as tobacco humectants, cosmetic softeners, and food additives, in animal feeds, and for miscellaneous uses (e.g. paint and anti-freeze products).

Glycols do not bioaccumulate in biota and are quite readily biodegraded in aquatic ecosystems. However, under some conditions, the biodegradation of glycols can be so rapid, and thus oxygen demanding, that it can deplete dissolved oxygen in receiving waters to levels that may threaten oxygen dependent aquatic biota. The rate of biodegradation, and thus oxygen depletion, is dependent upon the ambient temperature and the microbial populations of the receiving environment. Although microbial metabolic rate is generally decreased at winter ambient temperatures, glycol-laden stormwaters still have the potential to deplete dissolved oxygen levels in receiving waters. Oxygen
depletion may be hazardous to aquatic life in cases where stormwater runoff drains into ice-covered water bodies, since depleted oxygen levels could persist until the ice breaks up. Therefore, to ensure that biota are protected from both direct and indirect effects associated with the use of glycols, it is recommended that dissolved oxygen be monitored in affected receiving waters.

Although essentially more or less non-toxic to humans, ethylene and propylene glycol, both the operative elements in deicing and anti-icing mixtures, consume large quantities of oxygen as they break down in a soil or water matrix. The associated oxygen-consuming properties are identified as a potential cause of fish kill in rivers, lakes, or streams where glycols are highly concentrated. At airports, surface water run-off is usually controlled by drainage systems (storm-water sewerage) in combination with various treatment facilities, either on or off site. Such systems will either direct the run-off into separate receptacles at the airport or mix them with other waste-water streams in a combined sewer system leading to a treatment facility. Modern systems are usually constructed to keep waste water and storm water separate, to allow operational flexibility and to ensure compatibility with modern public infrastructure. A survey by ACI (ref. nr. 20) indicated that 86% of the 104 responding airports had separate storm and waste-water sewers. Contaminated surface run-off originating from airport activities, such as vehicle maintenance and washing, aircraft maintenance and washing, deicing, and fire-drill practices, are usually diverted into waste-water sewers for subsequent treatment. To meet storm-water run-off regulations, airlines, airports, and local authorities are seeking ways to collect, contain, and treat glycol run-off where it can create environmental problems. The approaches currently in use include vacuuming fluids with vacuum tanker recovery from ramp surfaces, collecting them in contained drainage systems, diverting them to the local public treatment works, confining deicing operations to specified areas, minimizing use of fluids, and collecting used glycols for use as automotive anti-freeze.
The Fate Of Aircraft Deicing Fluid After Application

In aircraft deicing operations, the mixture of deicing agent and melt water is caught in a system of channels surrounding the deicing areas. It is collected in large tanks and transported to a recycling plant where the mixture is purified and the deicing agent is collected for reuse. Runways are usually deiced with urea or glycols, which have high oxygen-consuming consequences. In the last few years, however, new acetate-based products for runway deicing have entered the market. These fluids consume less oxygen and are believed to have fewer harmful effects than urea and glycols. It is estimated that approximately 40% of airports of ACI-Europe have switched to acetate-based deicing fluids (ref. nr. 40). Airports in regions with significant snowfall must deal with the problem of snow disposal. Depending on the point of origin of the snow collected within the airport, it may contain contaminants such as hydrocarbons, aircraft deicing fluids, abrasives, salts, and even solid wastes.

Especially on runways, vast amounts of urea and glycols are used for deicing and anti-icing purposes (ref. nr. 39). The installation of drainage channels along the runways and taxiways is a very effective method in reducing contamination of the tarmac adjacent soil and water.

It is evident that a certain percentage of ADF applied to the aircraft does not reach the storm sewer collection system. Since ADF is applied in a spray form, some is lost to the atmosphere under windy conditions and some adheres to the aircraft surface. Additionally, some of the ADF which does reach the apron remains in the snow as it accumulates on the apron. Snow lying on the apron areas is removed to the snowdump. Depending on the location of aircraft deicing areas, ADF adhering to the deiced aircraft is transported via the taxiways from the aprons right out to the runways.

As already mentioned, deicing operations at most airports throughout the world are accomplished on the apron areas at airline gates by use of
mobile deicing trucks. The collection of spent deicing fluids from the many airline gates on an apron where deicing operations occur will be very difficult. This requires some type of reconfiguring and retrofitting of a subsurface piping system to collect this runoff and convey it to a storage area. This may include reducing the area from which runoff is collected, if deicing areas can be separated, to reduce the amount of contaminated runoff to be handled. It may also be desirable or even mandatory to reduce the points from which airport drainage is released to the environment by combining drainage systems.

The application of deicing fluids at numerous airline gates tends to spread the deicing operations over a large area. The normal stormwater collection systems are typically not geared to the collection and disposal of deicing fluids. The runoff is collected and conveyed to the surface drainage systems for direct discharge to the environment.

A similar storage system is in place at Detroit Metropolitan (Wayne County) Airport as stormwater runoff from ramp areas is directed to detention ponds. Other airports that are using facilities of this type include Salt Lake City International Airport, Seattle International Airport, Minneapolis/ St. Paul International Airport and Chicago-O'Hare International Airport. Usually, discharge from the detention ponds is released to the environment. Calgary International Airport directs storm runoff to a ponding area, but also uses vacuum sweepers and absorbent material to clean glycol-contaminated areas, disposing of these materials at a landfill. Ottawa International Airport discharges to a natural swamp area where, monitoring indicates, the glycol degrades satisfactorily into the local environment. Regulatory agencies may, in the future, direct that such discharges be only directed to wastewater treatment facilities. These types of system are feasible only if it is possible to collect and store runoff from areas where deicing occurs. As noted earlier, deicing operations are often scattered widely. Because of this, many airports discharge contaminated stormwater runoff directly into the environment.
The factors weighing in favour of these types of system include:

- Airlines and fixed base operators favour this approach since it will not interfere with the current type of operations or with existing deicing equipment; existing stormwater facilities are similar to the above and possibly can be modified to accomplish the desired goals; this procedure will generally be the least costly approach to all concerned parties.

Most airport operators will look strongly toward this approach to maximize the use of existing facilities and to incur the lowest cost in meeting the requirements of increased environmental protection regulations.

**Sources And Pathways For Entering The Environment**

For the majority of glycol uses, no data were found on releases to the environment or the resulting levels in receiving streams. Information was available, however, on the environmental pathways of glycols used in aircraft deicing/anti-icing fluids, which are generally applied to aircraft under snowstorm or freezing rain conditions. Aircraft deicing/anti-icing fluids on airport terminal aprons may be mixed with rain and melt water from runways, parking lots, and other storm water collection points, or they may seep through existing joints in the apron. The pathways aircraft deicing/anti-icing transport within airport boundaries may include on-site puddling and soil infiltration, overland flow to local watercourses, intake into stormwater drains, collection in on-site retention ponds, and discharge to wastewater treatment facilities. Most of the glycols used at airports are released into the environment via stormwater, though they may also enter groundwater. Water quality monitoring data collected at several international airports indicate that high EG concentrations occur in airport stormwater, ranging from below detection limits (<1.0×10 mg.L⁻¹) to as high as 19.800 mg.L⁻¹. DEG has been detected at concentrations as high as 5.575 mg.L⁻¹. The highest detected level of PG was 1.480 mg.L⁻¹. The data are highly variable, however, and depend on many
factors, such as seasonal use patterns, treatment technologies, and weather conditions. Additional sources of entry into the environment may include EG production, manufacturing processing using EG, use and disposal of EG products such as antifreeze, and transportation accidents. Based on the vapour pressures of EG, DEG, and 1,2-PG (0.05, <0.01, and 0.20 mm Hg at 20°C, respectively/Verschueren 1985), volatilization of these compounds from surface waters or soils is not likely to occur to any significant extent. The vapour pressure of 1,3-PG was not located in the literature, but based on its structural similarity; volatilization is also not expected to be significant. Photooxidation appears to be the primary degradation process for glycols that remain airborne.

Upon release into surface waters, a number of processes influence the ultimate fate of glycols in the environment. While no data have been collected on the losses of glycols from surface waters due to volatilization, their vapour pressures are such that only insignificant quantities are likely to be released into the air. Likewise, hydrolysis is not an important fate process for EG or DEG in water as they do not have any hydrolyzable groups. Hydrolysis may be an important fate process for DEG in water, however, as it has a hydrolyzable group. In the presence of bacteria, aerobic biodegradation is the most important environmental fate process affecting glycols in surface waters. The available data from aerobic biodegradation studies suggest that EG, DEG, and PG are relatively nonpersistent in surface waters, with aerobic biodegradation half-lives of <2-18, 3.5->20, and 2.5-9 d(d=days), respectively (Verschueren 1985). The rate of aerobic, bacterial decomposition of glycols depends on temperature. Evans and David (1974) reported that 100% of the EG in water samples from four different river systems was degraded in 3d at 20°C. Over a 14-d period at 4°C, however, <20% of the EG was degraded in water from two of the four examined rivers, and virtually no breakdown of EG occurred in the water from the two other rivers. These authors also reported that aerobic degradation of DEG was not observed in most water types at 8°C.
Estimates of aerobic biodegradation rates of glycols are also dependent on the source of the inculum used in tests. Available data from Evans and David (Evans and David, 1974) found marked differences in the degradation rates of EG in the water from different rivers. These differences may have been attributed to the different glycol-metabolizing capabilities of the bacteria present. Prior exposure of microbes to glycols is another recognized factor influencing the results of biodegradation tests.

Biodegradation of glycols may also occur in anoxic waters. A number of anaerobic bacteria capable of utilizing glycols as an energy source have been isolated from natural waters (Schink and Stieb 1983). The available data suggest that anaerobic metabolism of glycols is slower than aerobic biodegradation (Transport Canada 1985). Therefore, glycols released into, or transported to, anoxic aquatic environments or systems with low levels of dissolved oxygen may persist for longer periods of time.

Aerobic metabolism of glycols may release a number of relatively toxic transformation products into surface waters. Under laboratory conditions, anaerobic bacteria sequentially metabolized EG and DEG to acetaldehyde, ethanol, acetate, and, in the presence of methanogenic bacteria, methane (Dwyer and Tiedje 1983). Ethanol may be subsequently fermented to produce acetate and methane.

Biodegradation is the only significant fate process of glycols acting in groundwater systems. Degradation of glycols appears to occur more slowly in groundwater than in aerobic surface waters or in aerated laboratory studies. Several factors may affect the rate of glycol degradation in aquifers. Jerger and Flathman (1990) suggested that micronutrients may be a limiting factor in the degradation of glycols in some subsurface soils.

Anoxia may also influence glycol degradation in the groundwater. The high oxygen demand associated with aerobic degradation could result in a rapid depletion of the dissolved oxygen present in groundwater,
producing anoxia and reducing conditions. Under these conditions, anaerobic biodegradation would represent the predominant fate process. No data were available to evaluate the fate of EG, DEG, or PG in freshwater or marine sediments, However, from information obtained from field and laboratory studies suggest that these glycols do not absorb into aqueous sediments to any significant extent.

Ethylene glycol (EG), diethylene glycol (DEG), and propylene glycol (PG) (consisting of two isomers, 1,2-PG and 1,3-PG) are the primary constituents of aircraft deicing/anti-icing fluids (ADAF's). Because of concerns about the possible environmental effects ADAF use may have on aquatic ecosystems near airports, water quality guidelines have been developed for the protection of aquatic life for these three glycols. EG, DEG, and PG could contribute to oxygen depletion in aquatic ecosystems. Therefore, to ensure that aquatic life is protected, the recommended guidelines for glycols must be considered in conjunction with the guidelines for dissolved oxygen. However, national ambient water quality guidelines, criteria, or standards for the protection of aquatic life are not available for EG, DEG, or PG in the United States as well as in Germany. State guidelines of 68 and 190 mg.L⁻¹ have been developed for EG and PG, respectively, in Michigan (USA) for the protection of aquatic life (G. Hurlbert, 1992, Michigan Department of Natural Resources.

The most common pavement deicing materials used at airports for many years are ethylene glycol and airside urea. The use of glycols by the aviation industry for deicing operations has been consistently accepted without question. The impacts of runoff of this chemical on the environment have not been a concern of the industry. After all, glycol is an FAA (e.g. USA, valid also for Europe) approved deicing agent - it must be environmentally safe! However, airports have been abruptly brought to reality by actions (ref. nr. 9) of the U.S. Environmental Protection Agency (EPA) and in Europe by actions of national environmental protection authorities (e.g. Sweden and Germany).
The concerns are due to the high organic strength of ethylene and propylene glycol and the potential severe impact on the environment or on wastewater treatment facilities. Denver International Airport (ref. nr. 30) was forced to construct a $4.4 million facility for disposal of deicing runoff in response to action by EPA, citing the airport for discharge of ethylene glycol-contaminated runoff into a stream that runs through the airport property. In other instances, state regulatory agencies have banned the discharge of ethylene glycol, forcing the airports to treat the runoff or use as an alternative deicing agent. As a result, the need for environmentally safer deicing agents has continued to grow in recent years. Ethylene glycol is not identified as a hazardous waste, it is biodegradable (up to certain levels of concentration). It is possible, if concentrations are high enough, to recover the chemical for reuse.

Ethylene glycol also has a very low toxicity to aquatic organisms. The threat to the environment presented by ethylene glycol is the biological oxygen demand (BOD) loading to the receiving stream. In its pure state, it can be in a range of 400,000 mg/l. In diluted runoff, it can be in a range of 100,000 mg/l. The BOD of raw sewage is typically in the range of 200 - 300 mg/l. The impact of such loadings on streams is that glycol is broken down by bacteria and organisms that have the potential to deplete the surface water of oxygen. This can, in turn, result in fish kills and adverse effects on any aquatic life that requires dissolved oxygen in the water for respiration. It can lead to anaerobic conditions in the stream and to bacteria blooms. It is also notable that although ethylene glycol is indicated to have a low toxicity, it can be deadly to humans and animals. A single oral dose of approximately 100 ml of pure ethylene glycol would be lethal to a 165-pound man.

Impact Of Urea

Urea is used at many airports (ref. nr. 39) to keep runway surfaces free of ice. Urea works by lowering the freezing point of water to approximately -11.5° C. Urea is used in one of two ways: as a runway anti-icer or as a runway deicer. Used as an anti-icer urea is applied to
the runway before ice forms. Used as a deicer urea is applied to the runway surface after ice has formed. When used as a deicer, up to six times as much urea can be required to deice runways as to anti-ice them. High material cost and a reliance on prevailing temperature, wind and solar radiation make deicing less economical and less efficient than anti-icing.

A typical deicing event would consist of approximately 7 metric tonnes applied to a single runway (3200m x 20m discharge path). The loading therefore is approximately 1094 kg/ha runway or 2.2 kg/m of runway length. Approximately 12 events may be realized during a typical winter season. Generally, urea is not applied to taxiways or apron areas. However, during severe icing events, urea may be applied to all areas. Up to 16t of urea may be used on the aprons for a single event.

Urea is composed of 46.7% nitrogen by weight, is a commercial synthetic acid amide of carbonic acid and is generally used as an agricultural fertilizer. As a fertilizer, urea supplies plants with needed amounts of nitrogen necessary for growth. Problems arise, however, when urea is applied during winter months to runway surfaces to prevent ice formation. Urea degrades, given proper conditions, to ammonia, nitrite and nitrate. Urea applications load both urea and its degradation products of ammonia, nitrite and nitrate into the environment. Concerns regarding the toxicity of these products exist. Urea has a 24 hour LC100 of 30,000 mg/L for creek chub in fresh water (LC100 = Lethal Concentration in which all subjects died). At 16,000 mg/L for Creek Chub in fresh water all subjects survived within 24 hours. Urea is toxic to aquatic life and microorganisms at concentrations above 10,000 mg/l and to domestic animals at doses above 500 mg/kg. Ammonia has a toxicity rating, for human and aquatic life, of 2 on a scale of 0 to 4 where 2 is classified as slightly toxic.

Determining quantitatively the fate of urea into the various pathways established by the nitrogen cycle is very difficult, as constant monitoring of the various pathways of urea degradation has not been done. Airports have only recently started to set up permanent water monitoring
stations. Specific rates of nitrogen uptake by plants and the amounts of urea-nitrogen held in the soil systems surrounding the airport are difficult to precisely quantify. Arlanda Airport (ref. nr. 27) in Stockholm, Sweden, sampled runoff from October 1987 to May 1988 and determined the total nitrogen load at a number of stormwater monitoring stations. At one station 36 tonnes of Total Nitrogen was detected from an input of 77 tonnes of urea or 35 tonnes of nitrogen. At another station 45 tonnes of Total Nitrogen was detected from an input of 96 tonnes of urea or 43 tonnes of nitrogen. Almost 100% of the applied urea was measured in the airport runoff. A further example is even more dramatic. The application of four tonnes of urea (containing 1,680 kg nitrogen) to a runway showed that 1,070 kg or 64% of the total urea nitrogen applied was discharged in stormwater. The above example can be classified as a worst case analysis of possible urea loading into a surface water system due to heavy rainfall which occurred immediately after the urea application.

Concerns over lake eutrophication, oxygen demand, aquatic toxicity, drinking water contamination and soil contamination arise. Many factors will influence the dispersal of urea and its degradation products. The widespread use of urea came into effect shortly before environmental concerns became an important public issue. In Canada, the eutrophication of water bodies such as Lake Erie and many of the lakes in British Columbia are examples which received considerable publicity. Stagnation and algal growth in these and other lakes was due to the use of nitrogen fertilizers and the subsequent transport of these nutrients to lakes by runoff and/or groundwater. General lake quality degradation and oxygen depletion were the results. In Britain urea has been responsible for the dangerously high ammonia levels in receiving water bodies resulting in a number of fish kill incidents.

Urea can also contribute oxygen demanding material to airport stormwater. After application onto the airside pavement, urea will flow through the environment as dictated by the nitrogen cycle. Nitrogen, in its many forms, is very soluble in water and therefore moves easily
through the environment, including air, soil, surface water and ground water systems. Most of the meltwater containing nitrogen is collected immediately in the swales adjacent to runways which subsequently enters the surface drainage system. It has been estimated that approximately 50% of the urea applied to a runway is picked up during snow removal operations and spread on bordering grassed areas. Of the amount collected in the snowpack, some may infiltrate the ground surface and thus not enter the surface drainage system. The quantity lost to the ground is unknown, however, this amount is minimal since the ground is likely to be frozen.

A number of methods for lowering urea’s impact on the environment have been proposed and considered. The methods include: The blowing of snow over a larger area to increase the uptake of nitrogen by plants; the selective harvesting of airside grass to maximize the amount of nitrogen removed from the area; the construction of retention walls to slow down the escape of runoff and increase infiltration into the soil (Munich Airport); the ponding of urea laden storm and meltwater for summer watering of grass; the use of a vacuum sweeper to collect wastewater for treatment; and the actual treatment of urea stormwater by various methods. The intention of distributing urea laden snow and wastewater over a larger area of grassed infield is to allow plants to absorb more urea nitrogen. During the deicing season and in the early spring months following deicing, however, the plant communities are still in a dormant state and thus unable to absorb great quantities of nitrogen. Before plants can absorb the nitrogen, the stormwater runs off into the surface water system and is thus unavailable for plant uptake. The selective harvesting of airside plants and grasses will be insufficient as the majority of applied urea nitrogen will have already escaped into the surface and ground water systems. The ponding of stormwater and the construction of retention walls, will be ineffective because of the great quantity of stormwater involved in airport drainage. Major airports which use urea in amounts large enough to cause an environmental concern cover so much land and have so much paved airfield, that the collection of an entire winters worth of storm-water would be logistically
impossible. A bird strike hazard would also be created by the retained water. Retention walls would do little more than cause flooding problems as the often frozen soils would be unable to accept the vast quantities of storm and melt water. The treatment of urea wastewater by various biochemical processes would be impractical due to the large amount of stormwater. When examining the impacts of tarmac deicing fluids on the environment, it has to be noted that often a mixing of tarmac deicing fluids with aircraft deicing fluids occurs. The surface drainage systems (stormwater drainage systems) have to cope with both of these fluids and within different areas of the airport also with different concentrations of both of these fluids. It is estimated that 50% or more of the deicing fluid sprayed on an aircraft runs off into the surface drainage system. A residual amount remains on the surface of the aircraft to prevent icing during ground roll and takeoff.

Impact Of Tarmac Deicing Activities

In order to define the impacts of tarmac deicing activities on the natural environment of an airport, and obtain a better understanding of the dimension of such impacts, the following account is based on Munich Airport's experience. Munich Airport, as any other airport, is part of an ecological system like every other human activity. Whatever is being done at the airport has an impact on the environment. This is illustrated not least by the water that flows to and from the airport.

Groundwater contamination is a concern at such airport sites, where the groundwater recharge area for the community's drinking water wells is located beneath or in vicinity of the airport. During the winter season, manoeuvring areas and aprons have to be cleared and protected against snow and ice, to ensure safe aircraft operations. Besides the mechanical cleaning of these areas with special equipment (28 snow ploughs, 18 airblast sweepers, 5 rotary snow ploughs and 6 turbine snow loaders at Munich Airport) and the spreading of sand, chemical deicing agents are used. To diminish the potential ecological dangers for the natural water
system around the airport, the Designation Order from the Government of Bavaria stated the following: The procedures for deicing the manoeuvring areas and aprons are not to harm or disturb the groundwater table or natural water streams, nor the wastewater treatment plant of the nearby village of Eitting. Before chemicals of any kind are used, their environmental impact has to be demonstrated to the Bavarian Authority for Waterquality. Only if these chemicals have been found not to harm or disturb the environment under the proposed operational conditions at the airport, they may be used.

In order to fulfill these governmental requirements, the following measures were implemented:
- Optimization of snow removal operations
- Selective choice of deicing chemicals
- Minimisation of deicing fluid usage
- Construction of special snow dump areas with drainage systems
- Installation of a general drainage system with buffer tanks and measuring devices
- Construction of a purification system called ASG for the manoeuvring areas
- Recycling Plant for the recycling of aircraft deicing fluids.

In the area of the taxiways the meltwater contaminated with deicing agents is purified by natural bacteria. Along the inclining taxiways a 20-meter-wide sealing mat was laid in the ground (ref. nr. 28) at the depth of one meter. Gravel was placed on top of this completely waterproof layer. The soil bacteria which occur naturally here are able to break down the main component of modern deicing agents-the glycol-into harmless water and carbon dioxide. The meltwater that runs off the taxiway now cannot enter the groundwater but flows horizontally through the gravel. Built-in sand dams ensure that the water remains in the gravel layer until the soil bacteria have done their work. The water then seeps into the ground at the end of this imperious layer is then harmless. This Ground Purification System is the afore mentioned ASG system. In the normal operation of an airport, there is the potential for a
number of activities to result in contaminants gaining access to the surface water drainage system. The principal activities which have that potential include:

- Deicing of aircraft, runways and taxiways
- Aircraft washing
- Cleaning of parking stand
- Vehicle and ground equipment washing
- Occasional spillages
- Weed control activities

Of all these activities, deicing of aircraft, runways and taxiways as well as aprons represents by far the largest pollution potential in relation to soluble contamination. Runway and taxiway deicing has traditionally used both urea and glycol. At Munich Airport, however, the use of urea was phased out in 1990 because of the polluting effects urea has upon receiving waters when it hydrolyses to form ammonia (which is toxic to fish and impairs water quality). More recently a new compound based on acetates has become available for these deicing operations. This compound is more readily biodegradable than glycol and is therefore environmentally preferable. Munich Airport, in the interest of minimising environmental impacts, has moved to the use of this acetate compound.

Consumption Of Tarmac Deicing Fluids

At Munich Airport Winter 1993/1994, deicing fluids were used for the deicing of runways, taxiways, aprons and for special deicing activities (e.g. deicing of passenger steps, apron roads etc.)

During 50 days in total, deicing operations occurred and the amount of deicing fluids sprayed was as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>For the runways (2 x 4000m x 60m)</td>
<td>420 m³</td>
</tr>
<tr>
<td>For the aprons</td>
<td>847 m³</td>
</tr>
<tr>
<td>For the taxiways</td>
<td>253 m³</td>
</tr>
<tr>
<td><strong>Total consumption</strong></td>
<td><strong>1100 m³</strong></td>
</tr>
</tbody>
</table>
A number of stormwater monitoring studies have been undertaken at major airports in Europe. Two studies - Gatwick and Arlanda - are of special interest and are summarized here. Of interest are the urea usage levels and the effects on the environment.

**Gatwick Airport:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979/80</td>
<td>25.3 t</td>
</tr>
<tr>
<td>1980/81</td>
<td>21.1 t</td>
</tr>
<tr>
<td>1981/82</td>
<td>99.8 t</td>
</tr>
<tr>
<td>1982/83</td>
<td>62.4 t</td>
</tr>
<tr>
<td>1983/84</td>
<td>61.4 t</td>
</tr>
<tr>
<td>1984/85</td>
<td>212.5 t</td>
</tr>
<tr>
<td>1985/86</td>
<td>32.4 t</td>
</tr>
<tr>
<td>1986/87</td>
<td>121.6 t</td>
</tr>
<tr>
<td>1987/88</td>
<td>23.5 t</td>
</tr>
</tbody>
</table>

Average consumption: 73.3 t/yr

**Arlanda Airport:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986/87</td>
<td>120 t</td>
</tr>
<tr>
<td>1987/88</td>
<td>240 t</td>
</tr>
<tr>
<td>1988/89</td>
<td>260 t</td>
</tr>
</tbody>
</table>

Average consumption: 207 t/yr

The conclusions to be drawn from Chapter 3 are that the direct or indirect discharge of deicing agents and fluids, either uncontrolled or semi-controlled, into aquatic environment leads to subsequent detrimental effects on human health or animal and plant life. The responsibility for careful management of airport (deicing) operations rests with the airport operator or other responsible legal body. Glycols presently in use are by no means environmentally friendly and often have to meet conflicting requirements. Special attention should be paid to the environmental behaviour of the additives in the deicing fluids. To meet stormwater run-off regulations, airlines, airports, and local authorities may have to seek individual ways to collect, contain,
and treat glycol run-off where it can create environmental problems. The sources and pathways for entering the environment are widespread and sometimes difficult to trace. The impact of urea the environment is significantly higher when applied onto runway surfaces than any other deicing agent or fluid and thus lowering of the urea impact has a high priority. The proposed operational methods should be applied during snow removal operations. The amount of tarmac deicing fluids at chosen airports which impact the environment in some way or the other underline the imperative requirement to generally reduce consumption.
Chapter 4
Potentials For Reducing Degree Of Environmental Impact

The Need To Avoid Contamination With Non-recyclable Materials

This chapter addresses the need to avoid contamination and defines potentials for reducing the degree of environmental impact. In detail the following is addressed: The implementation of chemical usage minimization strategies and the potentials for the reduction of application rates and the reduction of operational rates; additional potential techniques for the minimization of chemical usage are listed such as the 'Two-Step Aircraft Deicing Procedure' and the 'Hot Water Deicing Procedure'; potentials for the reduction of application rates of tarmac deicing fluids such as alternative operational measures and deicing equipment utilization are addressed; the possibility of a dual washing and deicing role for aircraft deicing infrastructure is examined in detail, incorporating the issues site location, equipment utilization and environmental impact; the layout and location of a environmentally friendly snow dump facility and its integration into an existing effluent treatment concept is addressed as well as the availability of alternative deicing agents and the feasibility of installing thermal deicing methods; the location of provisional aircraft deicing areas and its potentials for reducing environmental impact as well as the implementation of flexible deicing procedures for aircraft. Finally, the increased fluid consumption of automated fixed deicing installations is discussed.

There is a considerable need to avoid the contamination of runways, taxiways and aprons with non-recyclable or contaminative materials (ref. nr. 4) like, for example Urea, glycols and acetate materials used in deicing/ant-icing operations. Water is a limited resource that must be used efficiently and protected against contamination, both inside buildings and in the surrounding areas. Management of all forms of water circulation (potable water, waste water, run-off) at airports should aim to minimize the contamination of waters that are eventually discharged to the environment and will affect surface and ground waters. Generally, this can be achieved by striving for enhanced environmental awareness and improvements at all levels of airport operational
procedures; minimizing potable water requirements and replacing potable water with reclaimed water wherever possible; controlling and monitoring functions regularly, and improving and maintaining infrastructure (piping systems, recycling and treatment facilities, etc.). Surface water run-off is usually controlled by drainage systems (storm-water sewerage) in combination with various treatment facilities, either on or off site. To meet storm-water run-off regulations, airlines, airports, and local authorities are seeking ways to collect, contain, and treat glycol run-off where it can create environmental problems. The major problem is still how to treat non-recyclable or contaminative materials. Urea is such a non-recyclable material that may require, depending upon the intensity of usage, special treatment facilities. Runways in particular are usually deiced with urea, which has a high oxygen consuming consequence. The concentration of nitrogen in the stormwater run-off will therefore vary with the run-off flow rate, but will not be affected by meteorological conditions as in the case with the ADF’s. In the last few years, however, new acetate-based products for runway deicing have entered the deicing market. These fluids consume less oxygen and are believed to have fewer harmful effects than urea. It is estimated that approximately 40% of airports of ACI-Europe (ref. nr. 20) have switched to acetate-based deicing fluids. ACI-North America has stated that improper treatment, storage, handling, or disposal of contaminated substances can result in significant harm to the environment, resulting in liability for airport operators. They have encouraged airport users and tenants to adopt practices for handling, storage, and disposal of regulated substances that will not adversely affect the environment or airport operations. Such practices must necessarily involve incorporating environmental considerations into the development of acquisition policies, operations, chemical pollution prevention plans, and handling and disposal plans. Airports should, in order to avoid contamination with non-recyclable or contaminative materials, investigate and consider the use of alternative materials that may be more environmentally acceptable. The development of storage plans should become mandatory, in order to perform the release of materials into the surrounding environment in accordance with existing regulations. The monitoring of the application or of regulated materials to comply with environmental and safety standards has to be improved.

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The recycling and reuse of products to minimize the amount of regulated waste requiring eventual high disposal costs has to have highest priority so as to reduce both risks to the local environment and disposal costs. Effective environmental protection requires a situation where, throughout their entire life cycle from development to distribution to disposal products meet the demands posed by such protection and environmental policy must create the framework conditions for this new kind of product responsibility. The aim must be to change the structural composition of products offered in such a way that environmentally friendly products gain a greater and greater market share (ref. nr. 34). The aviation industry is unique among manufacturing industries in the range of its associated products, and in the broad array, complexity, and nature of its processes. Hazardous and other wastes are both harmful to the environment and costly to dispose of in a legal way. Sensitive materials enter the environment through direct release during usage or seep uncontrolled into the ground. Because such chemicals are integral to the very nature of aviation products and services, minimizing their use or finding alternatives is often complex, costly and time-consuming. Eventually, fluid manufacturers will be able to produce even more environmentally friendly deicing products or continue to increase the efforts to produce recyclable deicing products.

Chemical Usage Minimization Strategies

The deicing/anti-icing of aircraft is subject to high operational safety standards. The highest priority in aircraft operation is always and will always be aircraft operational safety. Additionally, more effort has to be put into operational strategies aimed at reducing chemical usage to an absolute necessary minimum. The operators of an individual aircraft deicing system at an airport have to develop a strategy, which not only ensures safe aircraft operation at any time, but also incorporates such a chemical usage minimization strategy into their deicing concept. That strategy will only be effective and successful if a compatibility between operational safety standards and chemical usage minimization policy can be achieved. As the first rule in aviation is still safety first, the achievement of such a compatibility is the precondition for a successful
system performance. To reduce fluid consumption from the current levels is the main aim to reduce subsequent environmental impact, since less fluid consumption means also overall less waste production at the end.

This is an important consideration from a number of perspectives. Firstly, the cost of deicing fluid makes up a significant proportion of the overall cost of deicing. At the present time, the amount of fluid used is totally dependent on the operator of the hose. This means that there is a wide variation in the amount of fluid used per aircraft (ref. nr. 29). There is a need for a system to ensure the consistent and effective application of fluid. By meeting these two factors, the level of fluid should be reduced. The need to reduce fluid levels is also driven by environmental concerns.

Reduction Of Application Rates

Reducing the application rate during an aircraft deicing operation means reducing the fluid consumption to a minimum within the limits of operational safety (ref. nr. 29). This can be achieved by:

- Having a well trained staff of deicing operators, experienced with all types of deicing operations in adverse weather conditions.
- Getting the nozzle of the deicing unit as close to the surface of the aircraft as possible in order to avoid temperature loss and wind effects (compare with Figure 4-1).
- Using a fluid mix system optimizing the ratio between holdover time and the use of expensive fluid.

These three steps together can be a generator for a significant reduction of fluid application.
The training of deicing operators is at least as important as the design of the deicing unit. An experienced and well trained operator will be able to deice safer, faster and more efficiently on a relatively simple deicer, than an inexperienced operator will be able to do on a relatively efficient deicer. Deicing can never be made fully automatic, since snow and ice formations are never uniform. The human factor will therefore have to be optimized. The establishing of a deicing training course is a crucial point when considering safety, efficiency and economy. The reduction of spray distance between aircraft surface and spray nozzle to a short as possible distance minimizes heatloss, minimizes wind effect and results also in an optimal dynamic force of the spray beam. The fluid system of a deicing unit, that is the tanks, filters, heaters, pumps, hoses, tubing, nozzles, etc., should have minimum or no effect on the quality of the used fluids. The capability of the operational unit to deliver a differentiated fluid flow depending on which type of deicing is being performed or required, reduces fluid application rates when a two-step deicing process is being applied. A
modern design of the nozzle and fluid system enables a full working pressure at the nozzle at all times independent of the actual flow. This ensures more dynamic deicing and prevents a loss of fluid. If deicing units are in operation, where pressure is built up far from the nozzle, several litres of fluid will be lost at each activation of the nozzle, increasing the total fluid consumption for one aircraft deicing by between 20-50 litres. This may not seem to be so large, but when evaluating annual figures for one deicing season, in aggregate it can mean an increase of up to 200,000 ltrs. This phenomenon is quite simple to explain and can be illustrated with a long garden hose, where the water tap can be opened either on the wall, or at the end of the long hose. In the first situation, a fluid flow and pressure has to be built up through the hose, and in the other situation, the flow and pressure is already available at the end of the hose. If calculating with approximately 10 activations of the nozzle during one deicing operation, the fluid loss cannot be neglected.

Reduction Of Operational Rates

The reduction of operational rates is defined as a reduction of any kind of secondary deicing operations after an aircraft has been fully or partially deiced on the ramp/at the gate. If an aircraft has to be deiced, the possibility of a secondary deicing prior to takeoff increases relatively with the increased distance between the initial deicing and takeoff point. Airports with deicing operations performed on the ramp/at the gates tend, because of long taxi distances, to operate secondary deicing areas near the runway ends. This kind of operational procedure means actually a doubling of deicing actions and thus a increase of fluid usage and a potential increase of the environmental impact.

In the United States, the Department of Aviation at Chicago O'Hare, has taken a very pro-active role in developing remote pad secondary deicing practices to maintain operational integrity. This occurs at several other US-airports. American Airlines and United Airlines have performed secondary deicing operatins for the past three snow seasons with various degrees of operational success (ref. nr. 43). These remote hold pads,
which facilitate remote deicing, were developed to assist the airlines, the airports and the FAA in minimizing the frequency of aircraft requesting a return to the gate for additional deicing. The main goal of this development was to maintain an acceptable level of aircraft throughput during adverse winter weather conditions and to reduce delays.

However, with this kind of policy, a reduction of environmental impact cannot be achieved. The more frequently an aircraft is deiced, the more fluid is required to achieve acceptable results and the higher are the chances, that the aircraft has to be deiced with different deicing fluids which cannot be recycled, if mixed. Airports operating such deicing procedures tend not to favour the recycling of their fluids, because the fluids have mixed. Because the technical requirement for separation is not economically feasible, the fluids are disposed into sewage treatment plants or by other methods previously discussed.

Only a full deicing of aircraft near the runway end, which limits secondary deicing to an absolute minimum, is a reliable method of reducing the operational deicing rates for an aircraft and thus minimizing chemical usage.

Additional Potential Techniques For Chemical Usage Minimization

Another potential method for minimizing glycol usage in aircraft deicing operations is to implement different deicing techniques. These techniques are highly dependent upon weather conditions and individual aircraft operator deicing requirements. They are by no means to be seen as a general effective chemical usage minimization strategy, applicable for every airport or every aircraft operator. These techniques have been tested in depth at some airports in Europe (ref. nr. 41) and have found to be not acceptable for several safety reasons. Here the absolute required compatibility between aircraft safety and reduction of environmental impact was not achieved and the techniques were found to be not practicable in daily routine operations. Still, they should be named and their individual potentials discussed in order to achieve a better understanding of the
problems of achieving operational and environmental compatibility.

I. Two Step Deicing (ADF Type I and II Fluids)
The "Two Step Deicing" technique is presently the only applicable deicing technique which is capable of minimizing chemical usage and environmental impact to a certain extent. The technique involves the application of different glycol mixtures and fluids and aims to reduce the consumption of non-recyclable Type II deicing fluids. For the full deicing process only ADF Type I is applied to the aircraft surface. This generally involves, depending upon prevailing weather conditions, the consumption of 400-800 litres of ADF Type I (mobile deicer's). After this deicing step a considerable lower amount (150-250 litres) of ADF Type II Fluid is applied to the clean aircraft surfaces. ADF Type I Fluid is recyclable, ADF Type II Fluid is presently not recyclable (as aircraft ADF). Depending upon the deicing concept operated at an airport, this technique may contribute considerably to the reduction of ADF Type II usage and thus increase the potential of fluid recycling for new aircraft ADF.

II. The deicing of aircraft with very low glycol concentrations, called "Hot Water Deicing" can only be implemented during non-precipitation conditions and on dedicated centralized deicing areas. Although this technique looked to be a promising technique capable of significantly reducing the environmental impact to airport wastewater treatment facilities, it turned out not to be operationally acceptable. The hot fluid temperature does effectively melt all the snow and ice formations on the aircraft surfaces, but the low glycol concentrations contribute significantly to the refreezing of the meltwater in the slats, flaps and mechanically sensitive areas of the aircraft. This refreezing endangers a safe aircraft operation and is therefore to be ranked as a critical questionable technique due to the fact that the detection of such refreezings is only possible by applying time consuming checks. The only improvement would be the additional treatment of these areas with considerable amounts of ADF Type II Fluid. Thus, the environmental impact minimization potential is highly questionable.
III. The deicing of aircraft with "hot air techniques" has also been examined and tested in depth and has been found to be operationally not viable. Additionally, the technique is also highly questionable and seems not to offer effective potential for an aircraft deicing chemical minimization technique. In order to remove considerable amounts of frozen accumulations (ice, snow) from aircraft surfaces, huge amounts of hot air at high pressures have to be applied. This technique requires a turbine jet engine mounted on a special vehicle, capable of not only being positioned at every angle and height to effectively treat all critical aircraft surfaces (wings, stabilizers, high mounted tail units, etc.), but also being environmentally acceptable concerning subsequent air pollution. Airports, by their very nature as active air-to-ground transportation links, serve as concentrators for both aircraft and surface vehicle emissions. For example, much of the air pollution in the vicinity of airports is due to aircraft engine emissions, emissions from airport motor vehicles, emissions from access traffic and fugitive emissions from other airport sources, such as maintenance and fuelling operations. Air pollutants resulting from airport operations are emitted from the named sources, two of the main sources being aircraft main engines and auxiliary power units. Hot air deicing would involve a considerable amount of special vehicles fitted with such hot air deicing unit's, powered by small to medium jet engines. Thus, the consequence would be the increased generation of the most harmful air pollutants, carbon monoxide (CO), oxides of nitrogen (Nox), volatile organic compounds (VOC), and unburnt hydrocarbons (HC). Additionally, during precipitation anti-icing with ADF Type II Fluid would have to be performed. This potential will certainly by no means at all contribute to a "chemical minimization" technique. The fluid consumption of ADF may be reduced then in favour of a significant and uncontrolable increase in harmful air pollution.
Reduction Of Application Rates Of Tarmac Deicing Fluids

The impact of tarmac deicing fluids can be substantially reduced by implementing alternative operational measures when performing snow removal. The following measures are seen to be most effective and reduce the environmental impact by reducing fluid usage:

- Implementation of aggressive snow removal procedures
- Use of steel brushes on snow sweepers
- Use of powerful snow blowers
- Reduction of operating speed, increase of clearing effect
- Spreading of small grain sand
- Operating snow removal equipment with the wind prevents snow blowing into cleared areas
- Optimization of equipment operation
- Installation of tarmac surface condition sensors
- Implementation of a airport snow comittee and snow plan
- Adaption of procedures published in ICAO Aerodrome Service Manual, Part 2, Chapter 7 (ref. nr. 44).

As the use of deicing fluids is unavoidable during adverse weather conditions and ensures safe aircraft operation, the residue of these fluids should technically be treated to such an extent, that the environmental impact is reduced. Chemical deicing and anti-icing agents should effectively melt snow and dissipate clear hoar frost, ice and residues of ice formed from traffic compacted snow, frozen snow ruts and patches formed by pavement radiation and cooling. These chemical agents should have no detrimental effects on aircraft materials, airport pavements and installations, nor should they be toxic, unacceptable in airport or public drainage systems, constitute a severe fire risk, or in themselves lower the coefficient of friction significantly. Especially on runways vast amounts of urea and glycols are used for deicing and anti-icing purposes. The installation of drainage channels along the runways and taxiways is a very effective method in reducing contamination of the tarmac adjacent soil and water. The snow cleared away is thrown onto green areas alongside the
runways and is thus contributing heavily to a soil contamination. So that these chemical constitutes cannot reach and pollute the ground water, the installation of a purification system for deicing is seen to be a good measure. Such a system has been installed at the New Munich Airport. The melted snow contaminated with glycol, as it seeps away, is biologically degraded by the activity of the bacteria in the ground. The seepage path just has to be lengthened, as the bacteria requires a certain ground structure and time for this conversion. Sheets of foil, 20 meters wide and fitted with sand and gravel barriers to check and slow down the flow of water, have been laid at a depth of one meter on either side of the two runways. This impermeable membrane only allows the water to flow into the groundwater at the end of a 20 meter long seepage path, by which time it has been purified (ref. nr. 28).

Evaluating The Possibility Of A Dual Washing And Deicing Role For Aircraft Deicing Infrastructure

The possibility of utilizing existing deicing infrastructure for aircraft washing and vice versa may seem to be a interesting aspect and worth examining further. However, due to the following reasons such a dual role is operationally and technically not feasible.

1. Site Location

Due to the differing operational requirements of an aircraft washing facility and an aircraft deicing facility, the site locations will generally always differ. An optimized aircraft deicing facility (from an operational and environmental point of view) will be located near the runway ends, an optimized aircraft washing facility will be located within the aircraft maintenance areas. Aircraft deicing areas are integrated into existing taxiway infrastructure and thus are also direct access routes for aircraft heading for the runway for departure. They have to be obstacle-free (excluding an deicing event) and accessible for optimized traffic flow control. Although the washing of an aircraft is not a time critical action,
it requires pre-planning activities, is very time consuming and weather dependant, and subsequently will block succeeding aircraft for a considerable length of time. Additionally, such a mixed-mode operation will degrade the deicing capacity for a departure runway for a certain period of time. Due to weather influence, aircraft washing is generally performed in shelters or hangar areas were aircraft can remain for further treatment (i.e. repainting, polishing, etc.)

II. Equipment Utilization

Due to the differing equipment utilization requirements further problems would evolve. Mobile deicing vehicles are designed specifically for aircraft deicing operations and cannot be converted into mobile aircraft washing vehicles without significant and time consuming technical modifications (revolving brooms and brushes, etc.). Presently Lufthansa is testing a mobile aircraft washing vehicle at Frankfurt Airport, which differs considerably in technical construction from an aircraft deicing vehicle. Fixed deicing facilities like the gantry construction at Munich Airport would also require substantial technical modifications, as already mentioned for the mobile units. The cleaning of an aircraft fuselage requires again special revolving brooms and brushes attached to existing steel frameworks, that are capable of "scraping" the dirt off the aircraft. Only water and detergents, as an alternative fluid usage to ADF, will ever succeed to perform the job effectively.

III. Environmental Impact

Both ADF and aircraft washing detergents are environmentally harmful and thus require treatment. Aircraft washing detergents require treatment in a sewage plant as further reuse would only be possible with special dedicated filtration and cleaning infrastructure. This solution may only be acceptable for airports with extensive maintenance activities, as the construction and operation of such facilities is cost intensive. ADF and aircraft washing detergents may be used theoretically on a dual
aircraft washing/aircraft deicing site, if the drainage system allows separation of the differing fluid streams in the drainage systems (flow diversion valves) to separate storage facilities for further treatment. Although a dual solution is very improbable, it still may be operationally and technically acceptable for small airports with a low hourly departure rate, minor to medium aircraft maintenance activities and stringent environmental regulations.

Snow Dump Facilities

If snow banks exceed a certain height, they have to be removed physically. This is mostly done by transporting the contaminated snow masses to dedicated snow dump areas. Here the snow masses begin to melt and the water drains often uncontrolled into the ground. The construction of environment friendly snow dump areas significantly reduces a contamination threat. A system of drainage channels impedes the meltwater to enter soil uncontrolled. The meltwater is directed via these drainage channels to underground detention ponds or large basins, where a given time factor enables the bacteria to react. Snow dump areas should be located, as in the Munich case, at the runway ends and additionally near the ramps.

Alternative Deicing Agents

Reducing enviromental impact by applying alternative deicing/anti-icing agents is most promising for the future. New aircraft deicing fluids now consist of non-toxic readily and completely biodegradable glycols. Carbon dioxide and water are practically the only decomposition products. When appropriate, diluted mixtures of deicing fluids and water from melted ice and snow can therefore be safely be discharged into municipal sewage treatment plants. New high-tech products have, compared with urea, a significant lower environmental impact and can fulfill strict ecological requirements. The basis of these products are potassium acetate or sodium acetate. Presently research has been undertaken to evaluate the
use of a new tarmac deicing fluid that consists mainly of formic acid and this could reduce the environmental impact by 80%, compared to fluids presently in use.

Thermal Methods

Thermal control for the disposal of snow has this far not been an outstanding success because of mechanical problems and high operating costs (ref. nr. 28 and 29). However, the future for some thermal methods looks hopeful and an increased application of these methods to airport operations can be expected as the equipment emerges from the development/prototype stages and costs decline. Yet data collected and research carried out so far has not been very promising. At Munich Airport, research has been undertaken to evaluate the economic and operational feasibility of such a thermal system for heating the runways (ref. nr. 28).

Assumptions were made that the chemical deicing of one runway (4000m length, 60m width) would annually require 90 t of urea (50% of total airport volume) and 350 t of deicing fluid (24% of total airport volume). A total urea reduction at the airport would already account for a 50% reduction of the assumed environmental impact. The heating of one runway system is seen to be technically, but not economically, feasible. It would have greatly exceeded the costs for the environmental protective measures already in place (180 million DM). The operational costs for such a thermal system were calculated to be around 6 million DM annually, compared to the costs for a conventional snow removal concept of around 3 million DM annually.

Location Of Aircraft Deicing Operations

Conventional aircraft deicing is always performed on the ramp or sometimes on maintenance ramps. These areas are mostly connected with adequate stormwater collection systems or even with wastewater drainage
systems, since fuel and oil spills are a hazard and action has been taken in the past to reduce possible environmental impact.

As traffic increases at airports, sometimes additional parking space is required on the ramps to accommodate larger aircraft. Older airports, like the Munich Riem Airport, tended to rearrange aircraft parking facilities. Often parking areas originally utilized for general aviation aircraft are transformed to standard parking stands for larger aircraft. These tarmac areas are often not connected to any drainage systems, since there had been no requirement for deicing general aviation aircraft. Full deicing of aircraft on these parking stands actually means that a high amount of the fluid residue will enter the soil and cause contamination.

A reduction of the environmental impact can be achieved by

- collecting the fluid residue after every deicing operation with suction vehicles
- towing the aircraft after passenger boarding to a nearby parking stand that is connected to a drainage system for deicing. The suction vehicles would not then be required.

Implementing Flexible Deicing Procedures For Aircraft

In this context it is important to state that in order to evaluate and measure a possible environmental impact, the collection and recycling of deicing fluid has to be considered. As already mentioned earlier, there are presently two general methods used to deice an aircraft. A one step deicing process and a two step deicing process. The former consists of applying heated fluid on the airplane surface to remove accumulations and prevent their subsequent build up. The primary advantage of this method is that it is quick and uncomplicated, both procedurally and in terms of equipment requirements. However, in conditions where large deposits of ice and snow must be cleared off the aeroplane surfaces, the total quantity of fluid will be greater than for a two step process. The two step process consists of a separate deicing and anti-icing step. In the deicing step, a heated fluid is applied on the aeroplane surface to remove the accumulated deposits. The heated fluid can have a very low glycol concentration. For
the anti-icing step, a more concentrated fluid, usually cold, is then applied to the now uncontaminated surfaces. Type I Fluids or Type II Fluids can be used for the first step, or Type I can be used for the first step and Type II for the second step. This choice would depend upon weather conditions, required holdover times, availability of fluids and equipment.

If an airport does not consider fluid recycling and the sprayed fluid is allowed to enter a stormwater drainage system for further disposal into a waste water treatment plant, the two step procedure may be cost intensive (municipal sewage disposal costs), but will not harm directly the environment (soil, surface and ground water). On the other side it is a question of economic feasibility in the long term to allow this procedure to continue, because the costs for disposal of millions of litres of glycol contaminated wastewater will increase considerably. Additionally, because of increasing disposal costs, some airports tend to favour means of disposal which are environmentally harmful but cheap. Glycol contaminated wastewater is often taken away from the airport by a third party contractor for further treatment. These third party contractors want to keep their costs as low as possible and tend to find means of disposal which might be legal but are unsatisfactory. In the long term, only the recycling process is a really environmental protective measure. It is the two step deicing process in conjunction with Type I and Type II Fluid usage within a deicing area that creates the problem. If Type I and Type II deicing fluids are used for deicing within a deicing area, they will, after flowing off the aircraft surface, mix in a drainage system and thus impede the recycling of the collected fluid. In order to reduce the negative impact of mixing Type I and Type II Fluids during deicing operations, the location of the deicing areas is of great importance and has a major influence on recycling possibilities and the degree of environmental impact. The location of the deicing areas at an airport influences the usage of the fluid (Type I or Type II) and the deicing procedure (one step or two step) because of the required holdover time which depends on the taxi distance from the deicing area to the final takeoff point (time factor).
Gate/Ramp Deicing:
Because of long taxi distances most airports favour Type II deicing fluids. A collection of the fluid is possible (if stormwater system is dimensioned with excess capacity), a recycling of the fluid cannot be performed.

Remote Pad Deicing:
Depending on taxi distances and possibility of integrating these pads into existing taxiway systems which is often very limited due to congested areas, airports favour Type I and Type II deicing fluids and a two step procedure. Again the collection of the fluids is possible, but recycling cannot be performed because of the mixing of Type I and Type II Fluids.

Runway End Deicing:
Due to a very short taxi distance to the takeoff point nearly all airports, including Munich, favour Type I deicing fluid. The very high usage factor of the Type I fluid enables not only a recollection of the fluid, but also recycling to be performed.

The degree of environmental impact depends on two main factors:
The number of aircraft operations during a certain period of time (winter season); the average fluid usage per aircraft and the annual/monthly aircraft movement rate, and the type of aircraft operated (fleet mix, jet transport aircraft, propeller transport aircraft and general aviation aircraft). Depending on the individual geographic location of a chosen airport, the winter season, or the period of time aircraft require deicing at this specific airport, there are major differences in climatic conditions. However, the period used for calculation should be from the first seasonal aircraft deicing operation to the last seasonal aircraft deicing operation.

The fluid usage per aircraft may differ significantly, which dictates the use of average fluid consumptions per each aircraft category. In general, the fluid consumption increases with the growing distance between aircraft deicing area and aircraft takeoff point, resulting often in a significant increase of fluid usage compared to the figures used for Munich Airport.
The aircraft movement rate during the deicing season in comparison with the annual aircraft movement rate enables some calculations to be made concerning the dimensioning of a combined stormwater/deicing fluid collection system. Depending on the seasonal flight plan schedule, some airports may encounter additional environmental problems. A major influencing factor is the type of operations at a given airport during the winter months or period of deicing.

For example, an airport like Salzburg in Austria or Aspen in Colorado has a traffic peak during the winter season because of the surrounding tourist and holiday skiing facilities. These airports encounter a reduction in aircraft movements during the summer time and additional peaks during the "white season". On the contrary, other airports in Europe and in the United States undergo a reverse development.

For demonstration purposes, Munich Airport has been chosen here, but actually this is to be seen as a general approach, usable for any other airport as well.

Annual total number of aircraft movements (1993) = 192,180
Total number of aircraft during the deicing season (1993) = 45,397
Total number of aircraft deiced during the deicing season (November - January) = 4,054
Percentage of aircraft deiced during the deicing season (deicing factor) = 8.93%

The Munich winter season is to be seen as a very mild one, but the tendency is generally that during this decade the winters have become more mild. For airports impacted by very adverse weather conditions, an average calculatory figure between 15-20% for aircraft deiced (in comparison with total seasonal aircraft operations as the afore listed data indicates) should be used in order to obtain data for equipment utilization and for planning purposes.

The deicing factor should be obtained from available historical data recorded during at least 10 winter seasons and should include the ICAO
Temperature Record for the airport. The climatological data for Munich Airport, in terms of temperature, can be illustrated in Table 4-2.

Table 4-2:
Mean Daily Maximum And Minimum Of Temperatures At Munich Airport

<table>
<thead>
<tr>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(1)</td>
<td>1 6</td>
<td>3.6</td>
<td>8.1</td>
<td>12.6</td>
<td>17.4</td>
<td>20.5</td>
<td>22.8</td>
<td>22.3</td>
<td>19.1</td>
<td>13.6</td>
<td>6.9</td>
</tr>
<tr>
<td>B(2)</td>
<td>-0.4</td>
<td>-0.8</td>
<td>2.6</td>
<td>6.8</td>
<td>10.2</td>
<td>12.1</td>
<td>11.8</td>
<td>8.9</td>
<td>4.4</td>
<td>-0.1</td>
<td>-3.7</td>
</tr>
<tr>
<td>A(1) = Maximum temperature in °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B(2) = Minimum temperature in °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In general, it can be said that for those airports which do not collect or recycle aircraft deicing fluid, an increase of 1% of the deicing factor would mean an equivalent additional fluid consumption of approximate 280,000 ltr deicing fluid which is disposed either into a municipal sewage treatment plant or in the worst case into the natural environment. Other airports, like Munich, encounter severe restrictions from the wastewater/sewage treatment plants during the winter season, because these plants can only accept certain limits of fluid within this period of time.

Another influencing factor is the fleet mix operating at an airport. For propeller aircraft different deicing procedures apply than for jet aircraft. Also, the deicing procedures for general aviation aircraft differ again from scheduled jet and propeller operations. This not only includes the usage of different deicing fluids but also separately located deicing areas.

A further influencing factor may be specific national labour legislation which can affect operational procedures and thus the deicing operation itself. An interesting example here is again the Munich deicing operation. Because of national safety regulations and corresponding labour legislation, propeller aircraft may not be deiced with running engines (turning propeller blades), when being deiced by mobile vehicles. The danger of propeller blade collision is seen to be too high. This means that
propeller aircraft have to be deiced with engines shut down on the ramp with a different deicing fluid (Type II Fluid). The fleet mix (the percentage of propeller aircraft operations versus total aircraft operation) may influence and even significantly increase an environmental impact. In Munich, the percentage of prop aircraft operation accounts for over 14% of the total daily aircraft volume. Consequently 14% of the total daily departures cannot be deiced with a recyclable Type I deicing fluid. These aircraft account for approximately 39 takeoffs, in which deicing fluid Type II has to be used because of the holdover time. These 39 aircraft takeoffs account for approximately 7,800 litres of non-recyclable Type II deicing fluid daily.

Another good example is the increasing requirement of aircraft with underwing mounted engines (e.g. B767, A300, B737) for underwing deicing prior takeoff, which mostly has to be performed on the ramp with Type II Fluids as a protective measure. Aircraft with rear mounted engines (ref. nr. 12) have to be protected against the build up of clear-ice prior to takeoff already on the ramp (also danger of ingestion of ice and snow). Airports having a high percentage of these aircraft types (e.g. DC9, MD80, FK100) in their fleet mix, encounter a considerable increase of Type II Fluid consumption and all the problems associated with the collection and disposal of these fluids (ref. nr. 27, 28 and 29).

Airports serving a high percentage of general aviation traffic suffer from the problem of having to deal with a totally different traffic component. The location of general aviation facilities is often very remote in comparison with the main terminal facilities. Also, it is not uncommon that the parking areas for these aircraft are not underlaid with concrete or asphalt, meaning that the danger of an environmental impact concerning fuel and oil spills is already very high, discounting aircraft deicing operations. On the other hand, general aviation traffic tends to operate on an irregular basis and adverse weather conditions tend to reduce the number of operations considerably.

However, the IFR-portion of this traffic does operate during winter conditions and require deicing. There is a great need for deicing of aircraft
to be cheap and effective and the use of equipment to be reduced to an absolute minimum. International deicing practice demonstrates that a variety of different fluids are used under differing operational procedures. The only way to actually control the usage and disposal of these deicing fluids is to construct and operate a dedicated general aviation deicing area. Then at least these fluids can be collected and disposed of in a regular way.

The amount of fluid consumption ranges widely, and is often not recorded at all at the airports. But in order to assess fluid usage amount, the following example of a general aviation carrier (corporate jet operation) is given. (The aircraft were always deiced on the deicing area for GA aircraft at Munich Airport data: winter season 1993). The deicing period extended from 30.01.1994 to 12.04.1994. The total fluid consumption was 820 litres of Type II deicing fluid. The used glycol has to be disposed into the sewage treatment plant. By analysing the fleet mix of a specific airport, reliable information may be obtained concerning a possible environmental impact and determining the requirements and costs for appropriate measures.

**Increased Fluid Consumption Of Automated Fixed Deicing Installations**

In order to evaluate factors which influence equipment performance and thus the degree of environmental impact of the systems presently in use, some data are reproduced here which compare fluid usage of the various systems and their compatibility with the two types of deicing fluids. Concerning the aspect of fluid usage, a clear distinction has to be made between manually controlled and operated deicing systems like mobile vehicles and computer controlled fixed spray booms.

The data used here reflects the Munich experience during the 1996/97 winter season and compares mobile vehicles with the gantry system (ref. nr. 29). Additionally, the comparison is only of relevance to environmental impact if fluid recycling does not take place. In the case of fluid collection
In conjunction with fluid recycling, it would mean whatever fluid amounts are generated by the deicing systems, this would be of minor environmental impact, because of the recycling process. An environmental impact only occurs in the sense that the fluid is collected but then disposed directly into the channels of an off-airport sewage treatment plant.

The general opinion is that computer controlled systems (e.g. gantry) require less fluid for the deicing of aircraft. This statement has been proven to be wrong because of the following reasons demonstrated in the direct comparison (compare with Tables 4-3, 4-4, 4-5).

**Table 4-3:** Fluid Consumption (ltr.)\(^{(1)}\) At Deicing Pad For Mobile Deicing Vehicles

<table>
<thead>
<tr>
<th>AIRCRAFT CATEGORY</th>
<th>NUMBER OF OPERATIONS</th>
<th>FLUID CONSUMPTION</th>
<th>ADF TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>593</td>
<td>325.044(^{(1)})</td>
<td>ADF 1</td>
</tr>
<tr>
<td>3</td>
<td>107</td>
<td>96 870</td>
<td>ADF 1</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>21 655</td>
<td>ADF 1</td>
</tr>
</tbody>
</table>

**Table 4-4:** Fluid Consumption (ltr.)\(^{(2)}\) At Deicing Pad For Gantry Deicing Operation

<table>
<thead>
<tr>
<th>AIRCRAFT CATEGORY</th>
<th>NUMBER OF OPERATIONS</th>
<th>FLUID CONSUMPTION</th>
<th>ADF TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>111</td>
<td>68 481(^{(2)})</td>
<td>ADF 1</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>58 220</td>
<td>ADF 1</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>17 910</td>
<td>ADF 1</td>
</tr>
</tbody>
</table>

Category 2 aircraft = B737, A320, DC9/MD80, F100
Category 3 aircraft = A300, A310, B757
Category 4 aircraft = DC10, L101, B747
Table 4-5:
Comparision Fluid Consumption Of Mobile/Fixed Deicing Facility

<table>
<thead>
<tr>
<th>AIRCRAFT CATEGORY</th>
<th>COMPARISION FLUID CONSUMPTION (ltr.)/DEICING EVENTS</th>
<th>FIXED DEICING FACILITY</th>
<th>MOBILE DEICING UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>617 (3)</td>
<td>+ 13%</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>987</td>
<td>+ 9%</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1,990</td>
<td>+ 18%</td>
</tr>
</tbody>
</table>

(3) Average fluid consumption/aircraft deicing events

The general opinion that the fluid consumption of an automated fixed deicing installation should be significantly lower than that of manual mobile deicing units has to be corrected. The major reason for this is because the majority of the automated fixed deicing installations are not equipped with a sophisticated ice detection system that is capable of detecting ice formations on aircraft wings and subsequently steering the deicing process. The present systems in use can only steer according to a few general deicing programmes, which are incapable of punctual spraying and treatment of these critical areas.

So the computer controlled and automated system always operate from a "worst case issue" (full spray pattern operation) rather than from an individual situation issue (reduced spray pattern operation according to individual wing status). This results in increased fluid consumption in nearly all deicing operations using an automated system. The manual system will certainly only treat those areas which are actually contaminated with snow or ice. Other aircraft wing areas not suffering from that degree of contamination will be treated with less intensity (less fluid consumption) or even be neglected, certainly always within required safety standards.

Most computer controlled automated systems are not so sophisticated and are incapable of a high degree measuring and calculating/decision making processes to cope with all differing factors (weather, aircraft status, etc.) of deicing situations. This is the reason that a manually operated system
will always be able to deice with less fluid consumption rates. The critical human detection system (the eye) and the human computer system (the brain) is still an unbeatable competitor in this business. Comparable technical and computerized systems presently would certainly exceed the required size of efficient equipment handling and operation under realistic aircraft deicing conditions. Certainly the development of such a sophisticated computer system capable of such a decision making process/evaluation process of varying fluid spray patterns and intensities can change the present situation. But the development of such a system may be more a cost issue than a technical one.

The conclusions to be drawn from this chapter are that due to the negative environmental impact of non-recyclable deicing materials the need to avoid contamination is evident. This can be achieved to some extent by applying chemical usage minimization strategies, reducing fluid application rates and operational deicing rates. The subsequent adaption of the procedures published in the ICAO Aerodrome Service Manual, Part II, Chapter 7 (ref. nr. 44), should become a mandatory duty for every airport operation. Additionally, the adaption of these strategies and techniques should be incorporated into every airport snow and ice plan. The controlled treatment of contaminated snow at specially designed snow dump facilities which are fitted with a dedicated drainage system for effluent treatment should be encouraged to reduce environmental impact of heavily contaminated snow masses. By investigating the potentials of applying alternative deicing agents, less environmental harmful deicing fluids can be used in tarmac deicing activities. The increased fluid consumption of automated fixed deicing installations, which is attributed to the operational 'worst case issue', may pose a problem for airports not operating a dedicated fluid collection and recycling system. A increase of the environmental impact rate would only occur however, if the fluid is collected but then disposed controlled or semi-controlled either directly into an off-airport sewage treatment plant or natural watercourses.
Chapter 5
Potentials For The Recovery Of Aircraft Deicing Fluids

This chapter examines in greater depth the treatment of deicing fluid runoff. It focusses on the following topics: The influences of industry and legal requirements on recovery potentials are examined as well as the existing technology of ethylene and propylene glycol recovery/recycling. The performance data of existing fluid recovery systems is analysed. The potential of distilled glycol reuse for industrial purposes is examined in detail. The potential for an off-airport location for a glycol distillation plant is adressed and several operational examples at chosen airports are pointed out. Conveyance and storage facilities as well as issues of peak discharge control of glycol contaminated stormwater are examined. The requirement for initial treatment of fluid runoff due to the highly contaminated first-flush issue is adressed and possible solutions are suggested.

Deicing Fluid Runoff Treatment

The SAE has developed standards for deicing and anti-icing fluids for aircraft. Both Type I and Type II ADF have performance requirements identified in AMS 1424 and AMS 1428. Because of the interest in the recovery of ADF, SAE issued a policy statement that recycled fluids be certified to original specifications (SAE, 1993). Consequently, recycled fluids must meet the same requirements as virgin glycol (ref. nr. 15 and 41). Certification that the ADF meets the appropriate standards (AMS 1424 or AMS 1428) is provided by the chemical industry. All recovered ADF used in the U.S. must be certified before reuse in the airline industry. Certification of recovered ADF fluid at on-site recovery systems is impractical due to performance testing requirements. Unless the SAE standards are changed to an ADF composition basis, it is unlikely the recovered ADF fluid will be recycled directly to aircraft at the airport. In
regard to runway deicers, the FAA requires certifications to AMS 1426. When deicing/anti-icing is performed outside the USA by a second party (e.g., another carrier, fixed base operator or some other service provider), there must exist an FAA approved contractor training program that meets all the mentioned criteria. The second party also has to comply with ISO 11076 titled Aerospace - Aircraft Deicing/ Anti-icing Methods with Fluids.

In Europe, AEA initiated a task force for aircraft de-/anti-icing. This task force was formed by the specialists of the IATA airlines of Air France, Finnair, British Airways, KLM, Scandinavian SAS, Sabena, Swissair and Lufthansa with one of its key objectives being the specification of de-/anti-icing fluids (ref. nr. 44).

Common aircraft deicing chemicals currently approved are ethylene glycol and propylene glycol. The environmental impact of deicers in airport stormwater runoff has become a problem, since environmental protection authorities in several countries established more stringent application regulations for stormwater discharges from airports. Because of this, airport managements and operations have directed ADF recovery from research-oriented efforts to practical applications of available technologies.

The amount of deicer required to adequately deice a plane is highly dependent on applicator device, aircraft size and weather conditions. Airport operators reported (AAAE Conference on Aircraft Deicing 1993) that the annual volume of ADF employed by the U.S. airlines has increased threefold since the accident at La Guardia Airport in 1992 in which icing was a factor (ref. nr. 10). Presently, annually nearly 35 million gallons of ADF is used in the United States. The AAAE recommended that the collection and recovery of these chemicals have to be considered.

It is relatively easy to process and recover the glycol present in the Type I Fluids. Type II Fluids presently cannot be recycled as they contain numerous complex polymers that are used to create some of the special characteristics of Type II. These complex polymers pose unique handling
problems for filtering and processing systems. Of the Type 1 deicing solution applied to aircraft, more than half will fall to the apron. The diluted product that is applied to aircraft typically contains about 58% glycols. Unless it is captured for recycling, recovery or treatment, this glycol laden solution flows away to be further diluted and possibly mixed with runway runoff, parking lot runoff, and other local sources of storm water. These data coupled with the figure of 35 million gallons of annual usage, suggest that if stormwater runoff from aircraft deicing operations is not adequately treated or contained, substantial amounts of deicing chemicals may be released to the ground and ultimately contaminate ground and surface water.

The technology of ethylene or propylene glycol recovery by primary filtration, ion exchange or nanofiltration, and distillation has been proven in other industries where glycol recovery is utilized, such as the petroleum industry. Chemical waste service companies have provided offsite treatment of ethylene glycol for the automotive and gas processing industries. A glycol recovery system is comprised of three process units (compare with Figure 5-1):

Primary Filtration:
- To remove suspended solids entrained in the ADF from contact with aircraft and asphalt. Suspended solids must be removed to avoid plugging of downstream processes and spray machinery.

Ion Exchange:
- To remove dissolved solids such as chlorides and sulphates. and/or

Nanofiltration:
- To remove polymeric ADF additives such as corrosion inhibitors, surfactants, and wetting agents.
Distillation:
- To remove water which has contaminated the ADF due to ice melt and stormwater dilution.

**Figure 5-1:**
Components Of A Glycol Recovery System

The key process step in the overall ADF recycling system is distillation. Distillation is defined as the separation of more volatile materials (in this case water) from less volatile materials (glycol) by a process of vaporization and condensation. Distillation has been used for many years for purification in chemical manufacturing and in processes involving internal solvent recycling. Distillation is capable of recovering volatile chemicals with little degradation, which is an advantage in this application where the recovered product can be sold or recycled.

Product purity of any desired level can theoretically be obtained by distillation, provided the process economics are not prohibitive. In the separation of water from the glycol mixture of ADF, two stages of distillation are employed to remove enough water to produce a minimum 50% glycol content in the recovered ADF. The recovered glycol is a stable material and can theoretically be stored for an entire winter season.
The details of the distillation process that each vendor employs are proprietary. Design variables include temperature, distillation column design (number of stages, type of packing, size) and reflux ratio (ratio of their cycle flowrate to the overhead product flowrate). Batch distillation systems are employed due to the variation in the composition of the influent and the irregular supply of the feed. Reverse osmosis may also be employed to concentrate very dilute glycol (<15%) prior to the distillation step.

Prior to designing an ADF recovery system, information on several parameters must be collected. Data in the following areas is required to design an ADF recovery system:

Deicing Fluid Data
- Type
- Total consumption per season
- Total consumption per peak-day
- Average consumption per aircraft

Airport Operations Data
- Length of deicing season
- Number of deicing days per season
- Future traffic extension plans

Effluent Fluid Data
- Volume generated
- Glycol concentration
- Contaminants

Reuser Specifications
- Glycol concentration
- Acceptable impurities
In Europe, recovered ADF can be reused at the same airport location as the recovery operations. Therefore, the glycol content in recovered Type I ADF is targeted to the 58% glycol content for direct use on aircraft after the addition of any necessary additives. In the U.S. and Canada, the recovered glycol must be returned (ref. nr. 9) to the chemical industry for performance-based testing and reformulation into ADF. The end-use specification in North America, therefore, is for higher glycol content in order to have a reusable end-product (ref. nr. 35).

In order for the spent ADF to be recovered or regenerated, it first must be collected at the airport. The implementation of ADF collection must respond to the unique requirements of each airport. The feasibility of recovery glycol is dependent on the ability of the collection system to contain a relatively concentrated waste stream without significant contamination by other stormwater components. It may not be cost effective to distill and recycle waste glycol solutions at low concentrations (<15%). However, environmental protection regulations of individual airports may require the collection and recovery of lower concentrations of waste glycol solutions. Remote or centralized deicing with the containment and collection of used glycol is one method for collecting concentrated used glycol. However, centralized deicing systems may be impractical for all but the largest airport operations due to the cost and physical size. For established airports, a switch to centralized deicing systems would present a number of operational and logistical problems. In lieu of a centralized facility, used glycol can be collected via vacuum trucks and fluid collections containers to siphon glycol from runway and aprons. The employment of vacuum trucks has shown good results. Roller sponge devices were employed at the Toronto Airport with mixed results. At Denver's Stapleton Airport a centralized collection facility consisting of a sloped pad, underground storage tank (UST), storm water diversion and piping and pumps was employed by Continental Airlines to collect ADF (ref. nr. 30). The system reportedly captured the used glycol solution at 25-40% glycol concentration. A centralized system is currently under construction at the St. Louis Lambert Airport. A pad has been designed that can hold 3 narrow body aircraft at one time. The fluid is collected from
the pad and held in a storage tank for processing. A skid mounted processing unit will reportedly treat the ADF when the system is started up.

Available Performance Data Of Systems In Use

Performance Data was available from three firms, Deicing Systems, Canadian Chemical Recovery (CCR), and Glycol Specialists (compare also with Table 5-2).

The Data supplied by Deicing Systems was from their fullscale operation in Munich, Germany and by Glycol Specialists for their recovery system at Denver Stapleton Airport. Performance data was provided by CCR from the pilot recovery system at Toronto Airport. The ADF streams before recovery had an average glycol content between 10-28%. The recovery systems produced an effluent stream with an average glycol content of between 55 - 98.5%. The glycol content of the recovered solution was dictated by the needs of the reuser and does not reflect performance limitations.

Table 5-2:
Performance Data Of Fluid Recovery Of Deicing Systems

<table>
<thead>
<tr>
<th>PROCESS OPERATOR</th>
<th>LOCATION</th>
<th>AVERAGE INFLUENT GLYCOL CONTENT(%)</th>
<th>AVERAGE EFFLUENT GLYCOL CONTENT(%)</th>
<th>MINIMUM GLYCOL SPECIFICATION BY USER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deicing System Inc.</td>
<td>Munich</td>
<td>18 6</td>
<td>55.1</td>
<td>50</td>
</tr>
<tr>
<td>Canadian Chemical Recovery</td>
<td>Toronto</td>
<td>10 - 20</td>
<td>87</td>
<td>80</td>
</tr>
<tr>
<td>Glycol Specialists Inc</td>
<td>Denver</td>
<td>28</td>
<td>98.5</td>
<td>90 - 95</td>
</tr>
</tbody>
</table>
Potential For Reuse Of Distilled Glycol For Industrial Purposes

The number of airports with on-site glycol recycling plants is increasing. Munich Airport and Aeroports de Paris are the pioneers in this area, since Munich is successfully operating one since the opening of the airport in May 1992 and Paris Airport has been operating such a plant for over 20 years. Fornebu International Airport, in Oslo, Norway, was given a 7 month deadline in 1990 to stop discharge (ref. nr. 26 and 27) of deicing fluids into the fjords. They successfully converted a nearby sewage treatment plant into a distillation plant, in order to recover glycol from the runoff generated on a centralized aircraft deicing pad built as part of the project. Lulea, Sweden, also operates a small plant. The New Denver International Airport has built an on-site recycling plant, similar to that at Munich International Airport. The two plants are similar, except that at Munich the glycol is distilled to achieve a concentration of 55% and additive packs from the deicing fluid manufacturer are remixed into the effluent so that the recycled deicing fluids can be reused to deice aircraft. In Denver, the distillation process takes the effluent back to pure glycol, because the plant product is sold for industrial reuse in glycol markets off-site. Oslo is planning to build a new airport by 1998 and they will build a new recycling plant as part of the new airport project (ref. nr. 27).

The alternatives for the treatment of glycols are actually very limited. It can either be hauled off and disposed of as a hazardous waste, or it can be distilled and reused as a product to sell. Fortunately, some cities in the United States have already recycling plants that are available to process the airport deicing run-off. By taking advantage of existing plants, who will pay for the diluted product, the airports or the airlines can recover the cost of trucking the material, rather than have that add to the cost of their total deicing operation. Another alternative is the use of distilled glycol for industrial low grade feedstock in the plastics industry (ref. nr. 30 and 35). This industrial reuse option depends mainly upon the location of such a distillation plant. Actually there are only two alternatives possible for a site selection, the on-airport location and the off-airport location. In the following only the off-airport location for a glycol distillation plant will be
discussed, since any on-airport recycling plant will have a specialized operation allowing only for the recycling of aircraft deicing fluid, having to comply with high quality standards for product reuse.

**Potential For An Off-Airport Location For Glycol Distillation Plant**

The key issues for the evaluation of such potentials are twofold, one having to consider the economical issues, the other having to consider the logistical issues of fluid transportation to a distillation plant (ref. nr. 34 and 35).

Industrial recycled products, especially fluids of the type Propylene Glycol and Diethylene Glycol are always subject to fierce competition, concerning the fluid pricing and marketing aspect, with "new fluid" production from the industry. Of considerable importance for the usage of recycled glycols is always the product price, product quality and regular product availability. Here the recycled product will always have to compete economically with the new product, as long as there are no legal settings which would favour a recycling policy by implementing higher environmental taxes on new products.

Allowing large volumes of glycol to flow into natural waters or sending large volumes to sewage treatment plants is no longer possible. Neither is it practical or necessary for airports to be required to collect and treat every drop of glycol. The economics of various alternatives are changing rapidly. In Denver, USA, the cost to process deicing fluid runoff into a saleable product is $2.00 per gallon. In Milwaukee, USA, the local sewage plant has increased their fees to treat the deicing fluid runoff to $1.00 per gallon. Costs to truck it for disposal range from $0.75–2.00 per gallon (USA).

Pittsburgh Airport, USA, will continue to recycle glycol in the near future. In the US there is a case that a recycling company is planning to recycle the deicing fluids from 8 American airports (ref. nr. 30). However, this company will decide when it is feasible and appropriate to recycle the
spent fluids rather than treating the runoff. This shows the weak points of such a centralized recycling concept. At Denver Airport, USA, it is very costly to recycle the contaminated runoff. In fact, on a per gallon basis, it is slightly more expensive to recycle the spent fluids, even for non-aircraft use with low specification standards, than it is to purchase virgin fluid. The reason is that a portion of the cost per gallon to recycle is attributable to the capital cost to construct the system at Denver Airport. An issue every newly constructed industrial recycling facility would have to deal with (ref. nr. 30).

Every airport has different physical opportunities and capital requirements. Every type of airline operation has different physical opportunities and capital requirements. Every type of airline operation has different deicing operational requirements and the airports must accommodate them all. These variables have to be sorted out and a sound, cost-effective decision should be made which provides safe, efficient, and environmentally sensitive facilities. The availability of any nearby glycol reprocessing plant, if not already installed at the airport, should be determined, along with the present and projected fees they will pay for the deicing runoff, with specified concentrations. It has to be remembered that the use of glycols for deicing aircraft is a very small proportion of the total glycol product usage in a country. Therefore, the recycled glycol has value. The purposes for glycol use vary by region but the largest uses are for fabrics, insecticides, plastics, and anti-freeze.

In general, there exists quite a large market for Propylene Glycol also in Germany and the other European States. The major problems associated with such a procedure are however quite severe and results of studies are not very promising at all. The major problems with such a potential course of proceeding are as follows:

- High investment costs for the construction of such an industrial plant. Industrial plants have to be operated continuously during the year, in order to operate efficiently, as manpower and operating costs in Europe are very high. The deicing of aircraft is a seasonal business which is
dependent upon weather criteria and thus fluid batch availability is always irregular and subject to continuous change.

- High energy costs required for the distillation process of large quantities of dilution (heating energy for water evaporation). There is no difference in the amount of energy required in comparison to end-product being either an aircraft or runway deicing fluid or road deicing fluid, as the amount of energy required to evaporate the water portion is generally the same. The high energy costs result in high production costs for the recycled fluid in comparison with new fluid.

- High costs for securing fluid quality to meet specified standards (although only for reuse as aircraft deicing fluid). Dilutions delivered are subject to differing degrees of contamination with solids (sand, metals, etc.) and hazardous chemicals. This results in additional expensive installation of filters and chemical cleaning systems.

- High trucking costs for off-site industrial distillation plants. The major problem is that when trucking fluids with low glycol concentrations, the operational trucking costs are too high in comparison with the result of the amount of recycled product (high trucking costs due to high amount of water –vs.– small amounts of recycled glycol). Increased distances between fluid collection and delivery result in additional costs for more trucks and manpower for operation (only seasonal and continuously differing in volumes).

- Effective recycling is under the mentioned conditions only possible, if the excess energy heat required for the distillation process may be reused for a central heating system, the trucking costs may be minimized for an off-site distillation plant within ultimate vicinity (alternative piping of the fluids may be viable then) to the airport and high costs for fluid disposal to a sewage treatment plant justify the recycling costs for the product in comparison with new fluid.

There is no solution that will work for every airport. It will always be a very airport specific solution. Small airports are likely to elect for a higher operating cost approach such as trucking, rather than high capital cost alternatives such as dedicated deicing ramps. Old, large hub airports are going to have to make best use of existing ramp drainage systems, but
install for flexibility (valves and pipes) for diversion of specified flows. New airport facilities are going to have the largest capital costs, because the permit requirements will be more stringent than for old facilities, which may be grandfathered into still higher allowable discharge rates for limited time periods. It is very likely that capital-intensive solutions, with reasonable returns on investment potential, such as reprocessing plants, will be performed with private investment, reflecting the changing economic conditions in a country.

Conveyance and Storage Facilities

Stormwater conveyance (ref. nr. 32 and 33) comprises two main methods; subsurface and surface means. Subsurface conveyance is predominantly done with pipe networks. For subsurface conveyance designs in undeveloped areas the predominant factor affecting the pipe network is the storm event which is to be safely conveyed via this mechanism. Pipe networks on the airport property are to be designed to convey a minimum of the 10 year storm within built-up areas or areas with high use. In existing areas where the subsurface conveyance network has been determined to be overtaxed (i.e. capacity exceeded, surcharge conditions present) the following measures can be considered to alleviate this situation:

- Diversion of some or all contributing flow into a relief sewer or other surface conveyance means prior to entering the sewer network
- Installation of a second sewer to expand the conveyance capacity
- Upgrading of existing sewer by increasing diameter
- Alleviate surcharge with temporary on-line or off-line storage (these techniques are discussed in next subsection) or infiltration beds.

Surface conveyance features typically comprise the following:

- Grassed swales
- Ditches
- Road surfaces
- Contoured channels
- Natural watercourses
- Structural means - bridges/culverts

Storage features to be provided within the airport property are primarily for the purpose of peak discharge control or sediment control. Peak discharge control is accomplished by temporarily detaining a portion of the run-off volume for a particular design storm and then releasing it at a lower flow rate. Sediment control is described in the section on first flush treatment.

The storage control facilities which can be considered are as follows:
- Wet ponds
- Dry ponds
- Extended dry ponds
- Storage chambers
- Super pipes
- Swales
- Infiltration basins
- Infiltration trenches
- Filter strip
- Porous pavement

Peak discharge control is normally accomplished through the use of a pond, storage chamber, or super pipe. These facilities provide the flexibility of allowing for various degrees of peak flow control depending on the design return period of a storm event. The infiltrative measures have a more limited capacity to control peak discharges or control sediment loading. They can reduce lower return period (2 years) peak flows when utilized with small drainage areas (up to 5 hectares). The infiltrative measures can be used where the existing soil conditions have the necessary permeability capacities. Surface ponding adjacent to the runway or taxiways is to be avoided. The facilities attract birds and thereby present a potential aviation hazard.
Requirement For Initial Treatment Of Fluid Runoff

It is essential to capture the highly contaminated first-flush (ref. nr. 32 and 33). It is the beginning of a precipitation event together with a deicing event, which washes away the surface residue which includes spills and sediment. A simple method of capturing the first flush is with an extended detention facility. Extended detention facilities rely primarily on settling of suspended solids to remove pollutants. Depending on how much and how long run-off is detained, it is possible to achieve moderate to high removal rates for particular pollutants that are relatively easy to settle. Removal rates for most soluble pollutants are quite low for normal dry detention facilities.

Extending the detention time of dry or wet facilities is an effective, low cost means of removing particulate pollutants and controlling increases in downstream bank erosion. If stormwater is detained for 24 hours or more, as much as 90% removal of particulate pollutants is possible. However, extended detention only slightly reduces levels of soluble phosphorus and nitrogen found in run-off.

Two types of extended detention facilities can be utilized to control the first flush. These facilities operate in different manners which are dictated by the type of outlet control. The two types of control available are an automated outlet or a continuous discharge outlet. The automated outlet consists of a straightforward design which sets up the control of the outlet with sensors that are activated by either precipitation or a particular water level in the facility. The release of the water that has been detained can be done by a timer which will activate the control to open and thereby discharge the treated stormwater.

The second type of outlet is not automated but relies on an opening which allows for a continuous discharge. The average time that a unit of water remains within the facility will equal the design time period which in this case is 24 hours. The second type of facility does not have any automated controls which can break down. This type of facility is more difficult to
design due to the fact that there is a constant variation in depth, settling velocity, and outlet discharge. The wet detention facility design can also incorporate the two types of controls that were outlined previously. The advantage of utilizing a wet detention facility is in the ease of operation in the early spring and the late fall due to the fact that both the inlet and outlet for the facility can have their respective intakes submerged and not have ice interface with the operation of the facility. The use of a wet detention facility design however will be determined by the effective storage required for the first flush as well as the need for any additional storm water management for that particular catchment. The wet detention facility design is more suited to larger facilities in which there is sufficient opportunity to provide enough water to maintain the static quality of the facility during non operational periods. The wet detention facility would in all likelihood require additional treatment in the form of aeration as well as possibly biological settling.

Wet detention facilities have a moderate to high capability of removing most pollutants, depending on how large the volume of the permanent pool is in relation to the run-off produced. Wet detention facilities utilize both settling and biological uptake, and are capable of removing both particulate and soluble pollutants. Combined treatment of contaminated runoff from ADF operation areas at a municipal sewage treatment plant is technically feasible since ADFs are composed of organics or food for microorganisms in the treatment plant process. Studies have been conducted on the treatment of deicing fluid runoff at several plants. The tests showed that these sewage plants could effectively accept and treat ADF runoff, provided the BOD (Biological Oxygen Demand) loading of the wastewater does not exceed 10-15% of the plant BOD loading and provided that the plant has adequate hydraulic and organic capacity to accept the ADF runoff.

Intercepting reservoirs could be utilized to minimize the hydraulic and organic shock loadings on the plant. The use of these storage facilities would allow the wastewater to be drained into the sanitary sewer at a controlled rate. Any wastewater discharged in excess of the storage
capacity could be accepted by the responsible municipal authorities under a surcharge agreement, if the plant has the capacity for the over-strength waste. The disadvantage of this option is the uncertainty of the long-term acceptance of the wastewater by the municipality. The high BOD demand of runoff water contaminated by ADF may be treated at an on-site treatment facility, provided that an appropriate treatment method is implemented. The aerated lagoon process utilizes mechanical aeration to meet the biological oxygen demand of the wastewater for rapid degradation and odour control. A gravity settling basin is normally incorporated into the process to separate the microorganisms from the discharge effluent and to remove settleable inorganic solids. After treatment the effluent may be discharged directly to a receiving stream or disposed of by land application. The aerated lagoon process requires extensive land to provide adequate treatment for direct discharge. Additionally, this practice has had only limited success because of problems with low temperatures and insufficient biomass. Exceptions being reed beds, and/or mixture with sewage.

Alternative Treatment Potentials

Concerning a possible reed bed solution, a series of comprehensive tests and studies made between 1985 and 1987 at Zürich Airport and a number of projects for purification of the sewage were designed which, however, could not be realized due to political issues. Thus a task force, consisting of representatives from Zürich Airport, the governmental Authority for Water Protection and Hydraulic Engineering, and Swissair, opted for a biological and comparatively cheap solution— a root bed sewage plant. A root bed sewage plant refers to a method in eco-technology by which a physically, chemically, and biologically active solid phase (here: a reed bed) is used to reduce and absorb pollutants from sewage effluent. The method makes use of the ability of micro organisms in a solid phase (around 2,000 different types of bacteria) to break down the substances. The proper composition of the soil is decisive for the successful functioning of the plant. Common reeds are planted in this soil so that
oxygen required for decomposing is introduced to it through the dense system of roots. The transport of oxygen is regulated passively by the soil according to requirement, so that it can even obtain oxygen in winter when the reeds are dead through their hollow stalks. Together with the hydraulic direction of flow this allows for aerobe and anaerobe structures which lead to decontamination in the soil partitions that are completely saturated by sewage effluent. The plant can run under winter and summer conditions without any caring for.

A pilot plant of 0.5 ha at Zürich Airport is to verify the results of successful preliminary tests that were of semi-technical size. A three year programme is presently running with final results to be expected at the end of 1997. They should indicate cleansing capacity of the plant and allow the dimensioning.

Another alternative, being very similar to a Reed Bed Concept, is a Aquaplant Concept. This system is similar to the existing reed bed sewage plant. One major difference is the fact that this plant is being aeriated through hoses in the soil. In addition the waste water runs through a cascade of ponds in series. In each pond, the water disperses vertically through the soil with decontamination taking place by a variety of existing micro organisms. This system is used at Dresden Airport. Its advantages are low maintenance costs and no drying up in summer time. The demand of space has yet to be determined.

The practibility of this treatment alternative is questionable for runoff water contaminated by ADF due to the intermittent flow to the treatment facility. ADF operations are conducted only during winter months. ADF may also be stored in the snow removed from the apron areas with high volumes of contaminated runoff generated during spring thaw. In order to provide a continuous flow of wastewater, a containment basin would be required. This may create potential odour problems as well as requiring large land areas for a collection reservoir and increase costs. The recovery and reuse alternative would minimize the environmental impact of ADF substantially and potentially reduce costs through the use of recycled ADF. The spent
ADF must be collected in its most concentrated form to allow for efficient recycling.

The following conclusions can be drawn from the contents of Chapter 5:
The recycled product must meet the same requirements as virgin glycol.
The certification of recycled fluids that meet the appropriate standards is provided by the chemical industry. The FAA and AEA have both initiated task force groups of specialists to continuously address these issues and key objectives to improve operational, training and specification aspects of de-/anti-icing fluids application worldwide. The recovery of Type I aircraft deicing fluid is assured and accepted within the air transport industry. Type II aircraft deicing fluids presently cannot be recycled and pose considerable harmful environmental threats if released uncontrolled to surface water or stormwater systems. The available performance data of the systems in use for recovery/recycling demonstrate that there are still significant performance limitations. The alternative potentials for the treatment of glycols are very limited. Especially the potential for an off-airport location for a glycol distillation plant is highly questionable. As the deicing of aircraft is a seasonal business the high investment costs for the construction and operation of such an industrial plant may not be justified. Additionally, the high trucking costs add significantly to the general cost issue. An alternative may be the installation of improved conveyance and storage facilities to effectively control peak discharge rates and to improve the capture of highly contaminated first-flush fluid runoff. Finally, alternative treatment potentials may lead to airport individual and effective means of reducing environmental impact. The Zürich Airport solution may not be applicable at other airports but it clearly demonstrates the wide spectrum of feasible technical and environmental alternatives.
Chapter 6
Case Study Of The Munich Aircraft Deicing And Fluid Recycling System

This chapter focusses on the Munich aircraft deicing/fluid recycling system. The following issues are examined and addressed in detail: The legal framework of the Bavarian State Government and the effects of the 'Designation Order' which resulted in the implementation of the environmental protective measures. The concept development and subsequent mandatory location and configuration of the aircraft deicing areas. The operational requirements for the layout of deicing areas for mobile units and the fixed deicing facility as well as the compatibility of deicing equipment are highlighted. In detail, the deicing operations are focussed. Of major importance is the operational experience concerning airport capacity during deicing conditions. The deicing system is evaluated, taking account of the issues, location of deicing areas, layout and size of deicing areas and facility/equipment performance. The communication aspect and air carrier acceptance is addressed. A evaluation of the recycling system is performed. In detail the issue 'optimized drainage system layout' on the aircraft deicing areas is focussed and alternative drainage system layouts are suggested. The problems associated with manpower planning and staff utilization are addressed. Finally, a possible approach to the economic evaluation of the recycling process and associated cost of fluid recycling is suggested. Closing Chapter 6 are experiences of Munich Airport with the relative deicing/anti-icing performance and operational efficiency of the systems.

In German Law, building a new airport requires thorough investigation by the authorities. The members of the public concerned, who have recourse to and can rely on the most citizen-friendly airport law in the world, are also involved in this democratic process. Decades can elapse from the point when the political decision to build a new airport is taken until it finally starts to
operate. But this does not mean that public discussion on an airport is thus brought to an end. Since permission to build and operate an airport is issued by the authorities it can - like any other administrative act - be tested in the courts. Many democratic bodies, authorities and commissions, citizens action groups and private persons have a say in the procedure to obtain planning approval. After an examination of possible locations for a new airport site (greenfield site), recommendations are made by a special official working group. After this has been accomplished in the Munich II Airport Case, the Bavarian State Government brought in the Regional Planning Procedure for the selected site location at Erding-North/Freising. This procedural course of action examined and weighed up all the viewpoints, and as a result the latter location was finally agreed upon. Following this is then a two-tiered approval procedure: the approval in accordance with aviation law is then granted after the required investigation time. Now the decisive designation order procedure is opened, in which citizens and local authorities affected by the project are to be involved. Thousands of objections from private persons and many requests from the local authorities are received and have to be incorporated into design features. Also expert opinions are drawn up, which comment and define the dangers of noise pollution, environmental impact and urbanization. Only after a decision has been taken to approve the Designation Order and incorporate it into the legal framework may the construction of a German airport begin, and finally begin operations. The Designation Order contains many regulations and also restrictions which have been laid down and affect airport operations and is an absolute binding legal framework for the operator. One of the many regulations in this framework, concerning especially environmental protection, had a significant effect upon the current deicing procedures for aircraft. The Designation Order clearly stated that special procedures are to be established, which will prevent contamination of the local groundwater table, any surface water and the municipal purification plant of the nearby communities with deicing fluids containing glycols. Additionally the Designation Order stated that prior to the use of any kind of deicing fluid, an official investigation has to be performed and the result of this investigation has to be that these deicing fluids are seen to be
environmentally harmless when released uncontrolled into the natural environment. As no such fluids presently exist on the market, alternative measures had to be implemented. Technical measures and systems have to be adapted and installed in order to ensure that both tarmac and aircraft deicing fluids may not penetrate soil, surface water and finally the groundwater table. The technical measures installed for tarmac deicing activities have already been described in a previous chapter. The large amount of aircraft deicing fluid required during the winter season was seen to be a technical and economic problem if being collected at the airport in underground retention basins for pretreatment and controlled disposal. This solution would have included the construction of a dedicated airport wastewater treatment facility with a minimum investment cost of 200 million Deutsch Marks, neglecting the annual operating costs for such a facility. The planning priority was then to devise a new deicing concept which will ensure environmental protection by collecting (ref. nr. 28) the glycol contaminated runoff via technical means and feeding the runoff into a recycling process for further reuse. As a result of this planning priority, the deicing fluid had to be recyclable (Type I Fluid) and thus the fluid characteristics (i.e. holdover time) dictated the location of the new deicing areas, mandated to be located as close as possible to the runway threshold.

Concept Development-Location And Configuration Of Deicing Areas

The mandatory requirement was to locate the deicing areas as close as possible to the runway thresholds, and since both runways are used for take-off this resulted in planning activities in total for the 4 runway ends of the runways 08R/26L and 08L/26R (compare with Figure 6-1).
In order to ensure sufficient deicing capacity, two deicing areas of different size were planned for each of the 4 runway ends, giving a total of 8 deicing areas (in order to ensure full deicing capability for a 08-operation as well as a 26-operation). Originally the deicing areas were planned to be incorporated into the existing taxiway systems. This idea was abandoned because of the potential danger of creating a "bottleneck deicing operation" in which any following aircraft would be unable to bypass.

Operational Requirements

In total, eleven operational requirements were deemed necessary:

(1) Location of deicing areas should be outside the runway sensitive area for low visibility operations (all weather operations CAT II/III), with a minimum distance of 150m from runway centreline to edge of deicing pad to ensure deicing operations under all weather conditions and to protect ATC-
operations (compare with Figures 6-2, 6-3, 6-4).

Figure 6-2:
Layout Of Aircraft Deicing Area For Mobile Deicing Units

(2) There should be sufficient illumination of deicing areas with floodlighting for operation during reduced visibility conditions in darkness, during snowfalls and fog.

(3) The deicing pads should be provided with permanent nighttime lighting structures or alternatively have portable lighting systems available so that ground crews have the necessary illumination for deicing/anti-icing operations and pre-takeoff inspections during night or low visibility conditions.

(4) Dimensioning of deicing pads should be calculated according to the requirements of the dimension of maximum aircraft size to be deiced (i.e. B747-400) and required maneuvering area for mobile deicing vehicles.

(5) The aircraft parking area should be defined as the area used for parking aircraft to receive deicing/anti-icing treatment. The width of the parking area should equal the upper wingspan length of the most demanding airplane design group using the deicing pad. The length of the parking area
should equal the fuselage length of the most demanding aircraft using the deicing pad.

Figure 6-3:
Layout Of Aircraft Deicing Area For Mobile Deicing Units

(6) The maneuvering area for mobile deicing vehicles should provide the vehicle lanes necessary for two or more mobile deicing vehicles to satisfactorily perform simultaneous and complete left and right side uniform fluid distribution techniques.

(7) To further maximize departure flows for all departing aircraft, the location of deicing pads should ensure a physical space so that a bypass taxiing capability in given. This feature permits the deicing pad to receive aircraft requiring treatment while allowing other aircraft to continue unimpeded for departure.

(8) The deicing pads should be accessible via vehicle service roads to reduce the likelihood of runway incursions by deicing vehicles and ground service vehicles. Reducing potential runway/taxiway incursions by deicing vehicles and ground service equipment is a safety objective. The service road has to accommodate deicing vehicle widths and turning radii requirements.
The deicing pads should have marked taxiway centrelines (for low visibility operations illuminated centreline guidance) for safe taxiing.

Each deicing area should be fitted with a passive fluid collecting system (drainage channels) which is a precondition for the proposed fluid recycling concept.

**Figure 6-4:**
*Layout Of Deicing Area For Fixed Deicing Facility*

The deicing should be performed with aircraft engines operating in idle power to ensure immediate takeoff after the deicing/anti-icing has been performed such as to compensate a shorter fluid holdover time (engine restart procedure) and to impede an increase in engine cycle time issues.

**Evaluation Of Compatible Deicing Equipment**

An evaluation of the deicing equipment currently available on the market was performed in order to determine the most operationally and economically suitable equipment for the new deicing concept.

The fixed deicing facility was seen to be a promising alternative to the mobile deicing vehicles, for the following advantages: Low manpower requirement.
(single-man operation), high aircraft throughput rate, extremely short aircraft deicing cycles, uninterrupted operation possible because of continuous fluid availability, automated system - thus reducing the human error factor, excellent human working environment.

In order to ensure that deicing capacity would not degrade runway capacity, four gantries were seen to be necessary, meaning only half of the previously proposed deicing areas would have been required. During discussions with the technical branch of Lufthansa, the potential future partner for this new concept, the following six disadvantages of a gantry concept were identified:

1. High capital investment costs:
   -30,340,000 DM  Construction cost of 4 gantries
   -15,000,000 DM  Infrastructure cost of deicing pad

2. System reliability and operational stability:
   -not been proven at any airport comparable to the size of Munich II.

3. In case of equipment failure:
   -no operational redundancy available
   -bottleneck operation at runway end inevitable due to closure of complete deicing pad.

4. Alternative of new mobile deicing vehicles:
   -with one-man operation, manpower requirements are reduced considerably.

5. Requirement of additional mobile deicing vehicles:
   -for redundancy during gantry operation failure and to perform pre-deicing of aircraft (i.e. underwing deicing, flap and landing gear deicing).

6. Operational constraints under certain meteorological conditions:
   -(i.e. heavy snow, freezing rain, etc.) because of lack of technical system compatibility with Type II deicing fluids.

With the development of new mobile deicing vehicles (one-man operation, enclosed operators cabin), an alternative deicing concept using only mobile
vehicles was also considered to be both operationally and economically feasible. The advantages of such an approach were seen to number six. These advantages were identified to be:

1. High operational reliability is demonstrated at many other airports.
2. High technical standard of vehicle and fluid spray system.
3. Improved human working environment due to enclosed cabin (deicing aircraft with running engines can be performed, jet blast and aircraft emissions are no longer a problem).
4. High operational flexibility, as being a mobile unit.
5. Lower investment costs compared to gantry solution, and
6. Technical system compatibility with Type I and Type II deicing fluids

After evaluating the alternatives and advantages/disadvantages of these two concepts, the following operational concept was agreed upon:
- Construction of 8 aircraft deicing areas, of which 7 would be serviced by mobile deicing vehicles.
- Construction of one fixed facility on the remaining deicing area of runway 26L, predominantly for the deicing of wide-bodied aircraft (B747, L101, MD11, A340 etc.).
- Availability of equipment for pre-deicing activities on the ramps (two conventional mobile deicing units).
- Construction of one recycling plant.
- Construction of 4 substations near the 4 runway ends to be operated as mobile unit fluid refill stations.

Deicing Operations At Munich Airport

The deicing operation at Munich Airport has become very complex. This is due to the following reasons:
- Different deicing procedures and location of deicing areas for jet aircraft and propeller aircraft.
- Operation of different deicing equipment (mobile units/fixed deicing facility).
- Consumption of differing deicing fluids (Type I and II Fluids).
- Special deicing requirements for rear engined aircraft types (i.e. MD80/DC9, FK100).
- Deicing requests of carriers, that have to be performed on the ramps with engines shut off (i.e. underwing deicing, deicing of landing gear and flaps).
- Differing national regulations concerning final pre-takeoff contamination checks and aircraft specific operational safety requirements (FAA-Regulation, legal responsibilities etc.).
- Increased communication and coordination activities between aircraft, ATC, deicing operator and airport operator.

In order to provide the users of this new system with a better understanding of the Munich Deicing Concept, the author of this thesis established a regulatory framework, the "Munich Airport Deicing Plan", which is published newly at the beginning of every winter season (ref. nr. 22). This deicing plan describes the relevant deicing procedures agreed upon between the airport operator, the deicing company and Air Traffic Control. This deicing plan is a formal document that is nearly identical to the present FAA requirement, which states that in the United States every airport has to produce such a document (ref. nr. 5, 6 and 7). In Europe, the AEA has welcomed this deicing plan and has officially accepted it as being a useful information source.

Deicing Concept Performance

Departing aircraft are assigned, according to their standard flight plan departure route, either northbound to runway 08L/26R or southbound to runway 08R/26L, by ATC to the deicing area (compare with Figure 6-5). Standard procedure is that four deicing areas (two pads for the northern runway, two pads for the southern runway) are always in operation for the runway direction (RWY) in use.
As large aircraft require a higher deicing capacity than narrowbodied aircraft, these aircraft (including B757 and A310) are assigned to the following deicing areas (DA):

**Table 6-6:**
**Deicing Area Allocation To Runway System**

<table>
<thead>
<tr>
<th>Runway - Designation</th>
<th>Deicing Area - Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWY 26 L</td>
<td>DA 1 (gantry)</td>
</tr>
<tr>
<td>RWY 08 R</td>
<td>DA 2</td>
</tr>
<tr>
<td>RWY 26 R</td>
<td>DA 1</td>
</tr>
<tr>
<td>RWY 08 L</td>
<td>DA 1</td>
</tr>
</tbody>
</table>

The deicing of these large aircraft is always performed with 3 mobile units, if not by the gantry. This vehicle capacity enables deicing to be performed within narrow time frames and additionally reduces the driving distance and pattern of each vehicle to an absolute required minimum within close proximity to the aircraft.
During the winter season 1995/96 (01.10.1995 - 30.04.1996) the split of deicing operations was as follows (compare with Table 6-7):

**Table 6-7:**

**Split Of Deicing Operations On Runway System And Ramps**

<table>
<thead>
<tr>
<th>Runway 26 L</th>
<th>DA 1 (gantry)</th>
<th>337 operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DA 2</td>
<td>491 operations</td>
</tr>
<tr>
<td>Runway 08 R</td>
<td>DA 1 + DA 2</td>
<td>285 operations</td>
</tr>
<tr>
<td>Runway 26 R</td>
<td>DA 1 + DA 2</td>
<td>976 operations</td>
</tr>
<tr>
<td>Runway 08 L</td>
<td>DA 1 + DA 2</td>
<td>405 operations</td>
</tr>
<tr>
<td>Ramp</td>
<td>Ramp 1 + 2</td>
<td>554 operations</td>
</tr>
</tbody>
</table>

According to these data, only 11% of all aircraft requiring deicing were actually deiced in the gantry. The reason for this low percentage is that the gantry can only be used for RWY 26-departure operations and the inflexible operation of ATC (no switch-over of RWY 26R-departures to RWY 26L). The high percentage of ramp deicing operations (18%) accounts for the deicing of propeller aircraft and MD80/DC9 aircraft.

The total fluid consumption of ADF Type I and ADF Type II Fluid was:

- ADF Type I (mix 55/45) = 1,609,026 ltr.
  - For deicing areas DA 1, DA 2
- ADF Type II (100%) = 67,719 ltr.
  - For ramp deicing activities

In theory, this would mean that 1.6 million ltr. could be used as a basic input for calculation when evaluating the recycling fluid return as a mixing of fluids has not occurred within the collection and drainage systems of the deicing areas DA 1 and DA 2. The fluid consumption for the ramp deicing activities of 67,719 ltr. Of Type II Fluid would alternatively be the basic figure for calculation when evaluating the additional biological impact of a sewage treatment facility, as this fluid drains into the stormwater collecting system.
(winter operation includes glycol collection in detention basins for controlled disposal). As Type II Fluid is not recyclable, this does actually not dramatically affect the recycling rate. The problem is that Type I Fluid is also used for ramp deicing, and the amount is quite considerable - as Table 7-6 shows.

Table 6-8:
Ramp Deicing Operations And Associated ADF Fluid Consumption

<table>
<thead>
<tr>
<th>Aircraft Category</th>
<th>Number of ops.</th>
<th>Type I consump. (litr)</th>
<th>Type II consump. (litr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A (* e. A734)</td>
<td>1</td>
<td>36</td>
<td>55</td>
</tr>
<tr>
<td>1B (* e. A759)</td>
<td>335</td>
<td>71,741</td>
<td>35,047</td>
</tr>
<tr>
<td>2 (* e. A747)</td>
<td>206</td>
<td>64,791</td>
<td>30,482</td>
</tr>
<tr>
<td>3 (* e. A311)</td>
<td>11</td>
<td>3,648</td>
<td>2,135</td>
</tr>
<tr>
<td>4 (* e. B742)</td>
<td>1</td>
<td>1,070</td>
<td></td>
</tr>
</tbody>
</table>

The ramp deicing activities include:

- Deicing of landing gear after aircraft has landed (slush, snow)
- Underwing deicing.
- Deicing of flaps and slats during long turnaround times.
- Deicing of rear engined aircraft (wing, clear-ice phenomenon).
- Deicing of air intake engine Nr. 2 of L1101, MD11 aircraft to prevent ingestion of snow and ice.
- Additional specific air carrier deicing activities.

The original aim - that all aircraft were to be deiced on the runway near deicing areas without any pre-deicing actions being performed prior to start-up - became unacceptable because of several operational aircraft safety issues:
• Heavily contaminated aircraft parts could not be examined by the pilot performing his visual inspection prior engine start.
• Refreezing of snow and slush on landing gear, flaps and slats endangered the taxi-operation and functional control checks
• Threat posed by ingestion of ice and snow into rear engined aircraft.
• Deicing of propeller aircraft with running engines as a potential safety risk (collision risk between the aircraft propeller and the mobile deicing vehicle).

Airport Capacity During Deicing Conditions

Previously, when deicing of departing aircraft was performed on the ramps at the parking stand, the capacity of an airport was normally not limited by deicing operations. After the servicing of the aircraft was accomplished and prior to engine start-up and push-out, deicing vehicles arrived at the aircraft and performed the deicing. Provided that the departures were "ready to go" when they reached the holding point, and the number of aircraft was equal to, or greater than the runway capacity, then deicing operations did not really affect capacity. With aircraft deicing operations being carried out near the take-off holding points, a compatibility between runway capacity and deicing capacity had to be achieved. The capacity of the runway system, when deicing is being carried out, will depend upon how the runways are used. As mentioned earlier, both runways are used for departures.

Deicing capacity

The deicing capacity is a theoretical calculation (ref. nr. 18) and may differ from actual operation. Taxi speeds into and out of the deicing pads differ, as they are dependant on weather conditions, braking action and visibility. The deicing service times are averages and include total required deicing times (including taxi-time to final stop position, aircraft and vehicle preparation for
operation, actual deicing time and taxi-out time). The service times have been calculated for the fixed and mobile units as follows: For the fixed deicing facility (gantry), deicing averages 5 minutes per aircraft (theoretical maximum: 20 a/c per hr), regardless of class of aircraft size. For the mobile units on the deicing pads, Class A aircraft (B747, DC10, A300, B767) deicing averages 15 minutes, and for Class B aircraft (A320, B757, B737, MD80), 10 minutes. The average deicing service times per hour depend upon the traffic mix at the specific runway, the time frame (i.e. the morning/afternoon peak) and the current weather condition.

Deicing Capacity 26-Departure

The capacity of the runway system depends upon how the runways are used. For 26L alone there is sufficient capacity for the aircraft using that runway because of the fixed deicing facility on deicing area DA1. However, the larger number of departures using 26R face some delays, if ATC does not reallocate departures. This can be achieved by sending 35 to 40% of departures to 26R, and the remainder to 26L (ref. nr. 18).

Deicing Capacity 08-Departure

As 08-departures cannot take advantage of the gantry system, the deicing capacity is reduced and even if ATC reallocates departures, still longer delays will to be accepted. Efficient operation of the mobile units is of crucial importance, as additional delays caused by time consuming refilling of the units with fluid add to the problem (ref. nr. 18).

Effect Of Weather on Runway Capacity During Deicing Operations

The detailed statistical summaries of wind and cloud ceiling/visibility for Munich Airport show that the 26 direction could be used for 86% of the year,
on an average basis, and assuming that up to 5 knots tailwind would be operationally acceptable. However, an average does not reflect the severe changes that have to be investigated in order to obtain realistic data for winter operations. During the deicing season (October 1995 - April 1996) the variations in runway direction operation are significant and account for the requirement of equal deicing capacity in the 26- and 08-direction.

Table 6-9:
Distribution Of Runway Directional Aircraft Departures

<table>
<thead>
<tr>
<th></th>
<th>Total Dep.</th>
<th>Dep. RWY 08</th>
<th>Dep. 08 (%)</th>
<th>Dep. RWY 26</th>
<th>Dep. 26 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>7.799</td>
<td>2.943</td>
<td>38%</td>
<td>4.856</td>
<td>62%</td>
</tr>
<tr>
<td>November</td>
<td>7.059</td>
<td>898</td>
<td>12%</td>
<td>6.161</td>
<td>88%</td>
</tr>
<tr>
<td>December</td>
<td>6.339</td>
<td>4.182</td>
<td>65%</td>
<td>2.157</td>
<td>35%</td>
</tr>
<tr>
<td>January</td>
<td>6.706</td>
<td>1.274</td>
<td>19%</td>
<td>5.432</td>
<td>81%</td>
</tr>
<tr>
<td>February</td>
<td>6.350</td>
<td>2.713</td>
<td>43%</td>
<td>3.637</td>
<td>57%</td>
</tr>
<tr>
<td>March</td>
<td>7.376</td>
<td>2.678</td>
<td>37%</td>
<td>4.698</td>
<td>63%</td>
</tr>
<tr>
<td>April</td>
<td>7.228</td>
<td>3.819</td>
<td>53%</td>
<td>3.409</td>
<td>47%</td>
</tr>
</tbody>
</table>

The data in Table 6-9 shows that a full deicing capacity is not only required for departures in 26-direction, but also for departures in 08-direction. Additionally, because of the effect of weather during the months of aircraft deicing, a high operational and locational flexibility of the system (that is of the mobile unit system) is required to satisfy the deicing demand. Full utilization of a fixed deicing facility is not achievable under such conditions and mobile equipment redundancy is inevitable.

Operations In Instrument Meteorological Conditions (IMC)

The definition of IMC as applied to airport capacity is based on visibility of 2nm and/or ceiling of 700ft. The weather data shows that the average annual IMC would be just over 17%. Most of this is CAT I, the values for CAT II and
CAT III during afternoon periods (17:30-19:30 local time) are 0.78% and 0.79% respectively.

Runway Operations In Snow

During snow removal activities (that is, with runway closures) only one runway is in operation. Presently a "switch-over operation" is performed, but experience during the 1995/96 winter showed that during heavy snow only one runway will be cleared and kept open for operation. Deicing equipment will then be shifted from the closed runway to the operating runway in order to increase hourly deicing capacity. A realistic figure for the runway capacity during heavy snowfall conditions has been agreed to be: 25-30 departures/hr (ref. nr. 18).

Table 6-10:
Traffic Mix Of Aircraft Departures Typical Week Winter 1995/96

<table>
<thead>
<tr>
<th>Aircraft Category</th>
<th>Number Of Departures</th>
<th>Percent Of Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A-Aircraft / wide-body</td>
<td>123</td>
<td>6.9%</td>
</tr>
<tr>
<td>Category B-Aircraft / narrow-body</td>
<td>1,281</td>
<td>71.8%</td>
</tr>
<tr>
<td>Category C-Aircraft / 70-seater</td>
<td>380</td>
<td>21.3%</td>
</tr>
<tr>
<td>Total Departures/week</td>
<td>1,784</td>
<td></td>
</tr>
</tbody>
</table>

Category A-Aircraft | A300 < A < B747
Category B-Aircraft | BAE 146 < B > B757
Category C-Aircraft | C < ATR 72
Standard Runway Capacity

Figures published for the runway system include both the north and south runways (compare Table 6-11).

Table 6-11:
Standard Runway Capacity For Planning Purposes

<table>
<thead>
<tr>
<th>Maximum Slot-Capacity</th>
<th>10-Minute Period</th>
<th>60-Minute Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrivals</td>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>Departures</td>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>Movements/Mix</td>
<td>15</td>
<td>80</td>
</tr>
</tbody>
</table>

Considerable peaking is encountered as the graph (compare with Figure 6-12) for a typical week’s operation demonstrates. During the morning peak up to 29 departures/hr and during the afternoon peak up to 36 departures/hr have to be considered for deicing action. The maximum deicing capacity for the 26-direction under heavy snowfall conditions is 30 deicings/hr. For the 08-direction, the maximum deicing capacity drops to around 24 deicings/hr. Currently during these morning and afternoon peaks under heavy snowfall conditions delays have to accepted, as the deicing capacity cannot cope with the runway capacity (ref. nr. 18)

Figure 6-12: Graph Of Daily Peak Operation Aircraft Movements
Deicing System Evaluation

The following evaluation is limited to the deicing concept only. The recycling concept will be evaluated separately, although there is a strong correlation between centralized aircraft deicing operation and fluid recycling. However, a centralized deicing concept can be operated independently from a recycling concept and because of this fact two separate evaluations are being made. It is sensible to perform only an operational evaluation of the deicing concept and undertake an economic and environmental evaluation when examining the fluid recycling concept, as only the fluid recycling concept (or recollection concept without recycling) necessitates the implementation of a centralized deicing concept (due to the possibility of fluid collection).

The centralized deicing of aircraft on dedicated remote deicing areas near the runway ends has been operating since the airport opened in May 1992. There is now sufficient experience, information and data collected (ref. nr. 29) to permit a reliable evaluation. In order to address all the aspects of system operation, the following six issues were identified to be of major importance and influence or to contribute most to the operational performance:
1. Location of deicing areas.
2. Layout and size of deicing areas.
3. Fixed deicing facility (gantry) performance.
5. Communication.
6. Air carrier acceptance.

Location Of Deicing Areas

The location of the deicing areas are judged to be nearly the optimal possible solution, if applying the "as short as possible distance criteria", though this does not apply for the layout of the deicing areas. The deicing
areas are located less than 300 meters distance from the runway centreline at the runway ends (ref. nr. 29).

Under low visibility operations (CAT II/CAT III) no operational interference has been encountered, which means that deicing operations, especially of the mobile units, do not degrade low visibility runway operations nor runway safety (danger of runway vehicle incursion). The deicing fluid used on the deicing areas has been restricted to Type I Fluid with a reduced holdover time. Due to the short taxi distance after deicing to the take-off point Type 2 fluid application for protective measures was not required. Even under heavy snowfall conditions the aircraft, deiced with Type I Fluid, could take-off within the fluid holdover time. After three winter seasons, the standards of safety are clearly demonstrated to be very high and reliable. With the exception of RWY 08L, all deicing areas are served by dual taxiways, which enables ATC to plan, organize and allocate the aircraft to the deicing areas immediately after the aircraft enter their area of authority. Bypassing of deicing areas can be performed and operational flexibility of ATC is high. Aircraft with slot problems can be treated differently and thus the integration of departing aircraft into the arrival stream can be performed very flexibly.

Layout And Size Of Deicing Areas

The layout and size of a deicing area for a fixed deicing facility is always dictated by the size and design of the facility, in this case a gantry system capable of deicing aircraft up to the size of a B747/400. As the gantry system travels over the aircraft, the aircraft wingspan and length is of maximum importance. The size of the gantry deicing area is considered to be sufficient, but is limited to the size of a B747/400. The introduction of aircraft with unconventional features, such as folding wings would require major changes to the sprayboom system, but this is seen not to be a problem for the future. This also includes the present development of increased wing-tip size. The introduction of NLA (New Large Aircraft) into service would exclude the use of the gantry system for these type of
aircraft. These type of aircraft would have to be deiced with mobile vehicles (compare with Figure 6-13).

Figure 6-13:
Comparision of External Dimensions NLA/B747-400

Clearly, the introduction of NLA's into service will present a general operational challenge for every airport and thus the deicing operation of a NLA will one of the more minor problems with which the airport will be confronted with.

The layout and size of a deicing area for mobile units certainly is also limited to a maximum design criteria aircraft, in the Munich case this is also the B747/400. However, more flexibility is given by this option, because additional concrete can be laid and mobile units can operate much more flexibly and can be adjusted to the new aircraft dimensions and contours. Of major importance is the layout of a deicing area. At Munich Airport, the deicing area can cope with only one aircraft at a time, regardless of aircraft size. Aircraft requiring a relative longer deicing time and different procedure (i.e. prop deicing/MD80 deicing) will consequently block the deicing area for succeeding aircraft. The deicing areas were designed for deicing of aircraft with engines running. Additionally, the uncoordinated 'after deicing checks' of some air carriers are time consuming. The aircraft deicing industry is under constant change, because of the implementation of new regulatory frameworks and/or national/international legislation. A high degree of operational system
flexibility is required. The deicing areas at Munich offer a very low operational flexibility potential (ref. nr. 29) for the following reasons:

- Different aircraft types require varying numbers of technical air carrier staff for checking the deicing process prior to take-off. Stacking areas are not sufficiently dimensioned to cope with additional vehicle operation and positioning.
- If engine shut down is required for after deicing checks, the occupancy time of the pad increases and reduces the hourly throughput rate considerably.
- 'One deicing pad/one aircraft' philosophy stops following aircraft from taxiing onto the deicing pad and being prepared for the deicing operation.

By increasing the size of a deicing area in order to allow more than one aircraft to enter and be deiced, a higher operational flexibility for the mobile deicing units can be achieved (ref. nr. 11). The mobile units could move over to the next aircraft (parallel stacking, uncongested aircraft taxiing onto the pad area due to increased space availability) for deicing. Also longer lasting check procedures or engine shut down/restart would not cause delay, as deiced aircraft could freely taxi off the deicing pad.

Fixed Deicing Facility (Gantry) Performance

The operation of the gantry is presently limited to the following aircraft types: B747, B767, B757, B737, Airbus (all types), MD11, DC10, MD80/DC9 and L101. The Russian type aircraft TU 134, TU 154 cannot be deiced in the gantry, as the configuration of rear engines/tail unit is deemed unsafe from a system programming point of view. The spray boom system cannot be technically operated within this area. This is a general problem which this facility has with all rear engined aircraft, where the distance between engine inlet, wing tip and tail unit is very small. Underwing deicing cannot be performed by the gantry for technical reasons, although a manual operation with hose is feasible, but is ruled out due to safety reasons. The computerized deicing programme causes
problems, if an initial deicing was not satisfactory. If minor snow deposits are still on the aircraft surfaces, a second full deicing has to be undertaken. This is both time and fluid consuming and demonstrates low operational flexibility. However, the technical performance of the system is good and the reliability rate is very high. This is an especially important consideration for airports planning to operate only a fixed deicing facility and when discussing equipment redundancy issues (mobile backup units). Operational system performance in terms of aircraft actually deiced and gantry utilization is seen to be unsatisfactory because of the previously mentioned operational criteria (ref. nr. 29).

Mobile Deicing Equipment Performance

Seven of the eight deicing areas are served with mobile deicing units. This accounts for 75% and more of all deicing operations to be performed. Additionally, ramp deicing is also performed with mobile units to cater for the diversified deicing requirements of the airline customers. The utilization of mobile deicing vehicles accounts for a high degree of operational flexibility. Mobile deicing units are able to adjust their technical spray systems (elevated spray boom, free movable operators cabin) to different aircraft contours. All types of aircraft can be deiced and depending on the amount of vehicles used for a single deicing, the results of the deicing operation in terms of time requirement and fluid consumption are very satisfactory. The operator of a mobile system is very close to the treatment area and can reliably judge the results without any additional sophisticated technical equipment (e.g. an ice scanner).

Technical system improvements have optimized the telescopic spray boom, the fluid pumping system, stability and manoeuvrability and the one-man operation. As the deicing units are built on a standard truck this ensures high speed transportation when needed (long distances to filling stations, transport for service or maintenance, relocation to another pad).
Communication

Deicing aircraft with running engines requires increased communication between the deicing operator and flight crew. The exchange of information and data is so demanding that the only safe, orderly and efficient method to transport this information is via a dedicated VHF-radio channel. The more deicing areas are required at an airport, the more VHF channels may be required. The minimum requirement identified in this study is one VHF frequency for one runway system. A major problem for the flight crew is that although they have the final decision for undertaking a take-off, they are not able to judge reliably the contamination on the aerodynamic surfaces of their aircraft. The only possible solution is a visual control from inside the aircraft, as other technical means of ice detection on wings do not yet exist. For all Airline Pilots Associations, this issue has been identified to cause the most problems in a decision making process where the safety aspect has highest priority. The introduction of VHF communication for deicing has been welcomed by all pilots and ensures safe application of procedures. Due to the use of these VHF-deicing frequencies at Munich Airport, the deicing operation is very efficient in terms of transfer of information and clearances. No delays are experienced which can be caused by time consuming verification of phraseology and information. Also misinterpretations can be effectively excluded. The flight crew can now actually request an individual deicing of their aircraft and additionally be immediately informed of the status of contamination of the aircraft prior to and after the deicing. The clear information flow concerning the application of the previously mentioned guidelines and published holdover times of fluids under differing weather conditions ensures a generally high safety standard.

Air Carrier Acceptance

The successful implementation and operation of any new concept within the air transport industry, like a totally new deicing concept, greatly depends upon the acceptance and willingness to cooperate of all involved with such a new concept (ref. nr. 28, 29 and 30). A new deicing concept
can influence the regulations and procedures of the air carriers operating at that airport to such an extent, that major organizational and operational problems arise causing confusion, disruption and even total loss of compatibility in this area. At Munich Airport three major problems were identified which caused difficulties and which were responsible for grudging acceptance:

- Increase of the time requirement for technical maintenance staff engaged with activities prior actual aircraft departure.
- Additional responsibility for technical maintenance staff during the aircraft deicing process.
- Increased range of operating distances of technical maintenance staff due to remote location of deicing and longer travel distances.

It is standard procedure at nearly every airport that walkout assistance is given to the aircraft during pushout or that visual assistance is provided during engine start procedure with final "free of object" check and clearance. In general the time calculated for such assistance is less than 20 minutes, depending on the size of the aircraft, number of engines and travel distance of the tow tractor. After the aircraft has been cleared to be free of all objects and this has been signalled to the pilot, taxi clearance is requested and the aircraft will proceed towards the runway. Aircraft deicing was usually performed on the ramp in the past and the pilot had no further requests for his ground assistant. The new deicing concept requires the technical maintenance staff now to accompany the departing aircraft out to the deicing area (if deicing is actually required), perform the checks and report to the cockpit crew. The formal release of the aircraft and the end of duty is no longer the ramp, but the remote deicing area. The increased duty timespan is considerable and has been calculated to be an average of 40 minutes (from aircraft departure of break away position until return of staff back to the ramp). This can be a major staff utilization problem and may even lead to an additional staff requirement just for this specific duty. Smaller air carriers operating with minimum staff will have to operate a cooperative technical pool with other carriers in order not to increase
manpower costs. In general however, this does mean additional costs of some kind to the air carriers operating at Munich Airport.

Additional responsibility for technical maintenance staff will also change the working environment. At airports where the deicing of aircraft is performed by an independant agency, air carriers still have to ensure that their specific national regulations concerning safe aircraft operation in icing conditions are applied and controlled (ref. nr. 6). The FAA has issued the mandatory rule that an aircraft has to be checked to be free of all contamination after the deicing has been performed (ref. nr. 5). This responsibility presently cannot be delegated even to a qualified deicing operator and means that airline staff have to give the pilot the final release sign (ref. nr. 6). Additional operational safety requirements like the checking of wing areas of MD80/DC9 aircraft (for the danger of clear ice) with physical means (such as the hand on wing check/special check rod) has increased the workload and responsibility of the ground technician on the deicing areas.

Remote deicing areas cause increased travel distances for the technical airline staff. In the Munich case, travel distances of five to six kilometers are quite common. During winter conditions and slippery tarmac, additional problems arise for vehicle driving. To reach the departing aircraft on the deicing area in time, there is also considerable pressure on the driver and there is the danger of increased accident rates, if the access roads to the deicing areas are not cleared sufficiently by the airport operator in time. Staff operating within these sensitive areas, especially under low visibility conditions, require intensive training and need to have firm knowledge of locations. It is the responsibility of the airport operator to offer training programmes in order to maintain a high safety standard in vehicle operation within these aircraft movement areas. These staff training programmes include good training in radio communication procedures/equipment, and inspection of operating areas (i.e the deicing pads, access roads, low visibility lighting systems and danger zones). This completes the amount of the operational deicing system evaluation At Munich Airport. The next section presents the evaluation of the recycling system.
Recycling System Evaluation

Evaluating the operation of the recycling system means in this context an economic and environmental evaluation, since it is evident that it is now technically feasible to construct such a system. Also the achievable recycling rate is not so much a function of technical methods presently available (as shown in previous chapters), but seems to be more a fluid collection problem (ref. nr. 9 and 29) which has to be optimized and which may significantly contribute to an economic success or even failure. This section examines the following aspects in detail: The collection and recycling potentials of the deicing fluid runoff. The adaption of an alternative drainage system layout for aircraft deicing areas and ramp aircraft deicing areas. Staff utilization and manpower requirements are addressed as well as cost of fluid recycling. Closing this section are statements addressing relative tarmac deicing/anti-icing performance as well as relative aircraft deicing/anti-icing performance. The aspect of operational efficiency and performance monitoring is also addressed.

Environmental Evaluation

As previous chapters have shown, collecting and further recycling of the deicing fluid runoff certainly reduces environmental impact. Deicing fluid entering uncontrolled airport stormwater drainage systems and even sewage systems leading to a wastewater treatment plant creates very harmful impacts, the effects of which have been described earlier. The construction of dedicated deicing areas with special drainage systems should lead to the conclusion that there will be no or little adverse environmental impact/contamination. However, this is only partly true because of the following reasons: The fluid runoff from the aircraft on the deicing area accounts for about 60% of total fluid sprayed. Some 18% of the sprayed fluid is blown away by wind, and approximately 16-20% remains on the aircraft and thus is transported away from the deicing area onto the taxiway and finally onto the runway. The amount of deicing fluid
transported by the aircraft onto the runway is dependent on the taxi
distance between deicing pad and aircraft take-off point on the runway and
from the type of deicing fluid used. These two factors will influence
average fluid fate percentages as noted above. Depending on the
individual airport protective measures, this runoff can contaminate soil and
surface water adjacent the runway system.

The fluid runoff on the deicing area, if the drainage system is effective, will
drain into the collection channels and not harm the environment at all. An
ineffective drainage system will therefore contribute significantly to a
contamination of the environment, as a relatively large percentage of the
fluid runoff bypasses the drainage system and will enter the soil in an
uncontrolled way. A further problem is that the jet blast of aircraft
departing the deicing area will divert the fluid flow away from a drainage
system, even if the fluid normally should flow in another direction due to
the built-in gradient.

The deicing fluid transported by the aircraft onto the runway and deposited
on the runway prior to reaching rotation speed cannot be neglected.
Airports which do not have a system comparable to the Munich ASG
System - where channels along the sides of the runway and a system of
sand barriers, an impermeable membrane and gravel prevent quick soil
penetration - will suffer soil contamination. As Munich Airport has
constructed such a protective measure for the runway system in order to
reduce the environmental impact of tarmac deicing and snow removal
activities, there is no significant contamination of soil or water.
An effective ring of drainage channels surrounding a deicing area prevents
the fluid runoff from leaving this area by natural flow pattern or being
pressed away by jet blast. The deicing areas at Munich Airport are fitted
with a drainage system that is not optimal and encourages fluid runoff
losses (compare with Figures 6-14, 6-15, 6-16).
Approximately 15-20% of the fluid runoff is lost and thus contaminates the natural environment. A differently arranged drainage system on the deicing areas would prevent a fluid runoff loss (compare with Figures 6-15 and 6-16). The environmental impact is quite significant, taking account of total annual fluid consumption for the deicing of the aircraft on these deicing areas.
Implementing the Munich figures for annual deicing fluid consumption on the deicing areas DA 1 and DA 2, the amount of 153,600 ltr of ADF could theoretically enter the soil in an uncontrolled way. The weather factor has great influence here, as the fluid then has a higher dilution rate or the flow characteristics change. Also snow removal activities further may reduce the environmental impact, as the contaminated snow on the areas adjacent to the deicing areas is then collected and transported to the dedicated and protected snow dump areas at the runway ends. Figure 6-17 illustrates the layout of an alternative drainage system for ramp deicing of regional aircraft up to the size of a FK50 and ATR 72. As stated in Table 6-8, the Fluid Consumption of ADF on the ramp is quite considerable and adequate measures should be adapted (compare with Figure 6-17). Due to the policy of flexible positioning of aircraft on the ramp, such an aircraft parking area may also be used for other aircraft positionings.
Staff Utilization

Aircraft deicing operations require extensive manpower input. When discussing manpower requirements it is important to examine the following aspects:

- Geographical location of the airport and duration of deicing season.
- Statistical average of deicing days per winter season.
- Organizational structure of the deicing service supplier.
- Staff utilization during the summer season.

Presently, most deicing services are supplied either by airline operators or handling companies (ref. nr. 29). Because of historical reasons, airlines always had prime interest in having operable aircraft under all weather conditions and because they wish to protect and influence their own operations. Smaller airlines tend to share equipment and staff in pools in order to keep costs as low as possible. Generally the largest airline gives a major technical and manpower input and the other airlines participate by paying an annual member fee according to the frequency of their operations. By nature of their business and operation, handling agents also supply deicing services especially at airports, where the deicing season is
short and the deicing frequencies are low. Calculating manpower requirements is problematic, as weather conditions are unpredictable and may change quickly. This demands operational flexibility and short response times. Additionally, unproductive standby times are costly and have to be kept to an absolute minimum. For these reasons, the general procedure throughout the deicing business is to recruit staff from the airline technical division (aircraft maintenance) or from the handling agent operations division (ground handling staff). In general, the larger the available manpower source, the higher the flexibility rate and the shorter is the response time. When deicing is foreseeable or required, trained staff may be drawn out from their original duties and the "aircraft deicing machinery" starts to operate. This policy ensures that unproductive standby times and the employment of additional seasonal manpower are kept as low as possible. Service suppliers which specialize in aircraft deicing are rare and are limited to areas of the far northern hemisphere (i.e. Scandinavia) where the winter season is long (up to 9 months). In these areas the staff can be utilized during the summer season for general maintenance activities.

Alternative manpower utilization activities during the summer season may include grass cutting, maintenance of airport snow removal equipment and/or the cultivation of public park areas at the airport. Because of the unique geographic location of every airport, general solutions are not applicable but often a combination of alternatives may prove to be the best solution. In terms of evaluating an operational and economic feasibility of a centralized aircraft deicing operation and recycling of deicing fluids, less attention should be paid in focussing on manpower issues, as the associated costs of concept change (from decentralized to centralized operation) do not increase to such an extent than system capital costs and additional costs for secondary systems or expansion requirements of all kinds (i.e. construction of additional taxiways and apron parking stands, "intelligent" drainage and collection systems etc.). If applicable, any manpower requirement calculation should only include actual manpower costs involving active aircraft deicing operations and only to a limited extent the associated costs for standby or off-duty. This is because currently there is no service supplier that is dedicated solely to
offering aircraft deicing to customers. Aircraft deicing is mostly still to be seen a seasonally offered service and a by-product in the diversified business of aircraft handling and servicing. Generally, the average deicing season lasts 6 months and incorporates between 140-180 days of actual deicing operations. Usually, as in the Munich Airport case, a deicing coordination centre is established to organize the operation of equipment/staff and to communicate with the airlines during deicing situations.

Taking account of the above mentioned criteria, the following manpower requirement for deicing operations at Munich Airport can be determined:

**Table 6-18:**

**Equipment/Facility Requirements For Deicing Operations**

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of mobile deicing units (one-man operation)</td>
<td>12</td>
</tr>
<tr>
<td>Number of mobile deicing units (two-man operation)</td>
<td>2</td>
</tr>
<tr>
<td>Number of fixed deicing facilities (gantry)</td>
<td>1</td>
</tr>
<tr>
<td>Number of mobile units required for full deicing operations Runway 08-departure direction (2+3 for RWY 08R + 2+3 for RWY 08L)</td>
<td>10</td>
</tr>
<tr>
<td>Number of mobile units required for full deicing operations Runway 26-departure direction 2+3 for RWY 26R + 3 + gantry for RWY 26L</td>
<td>8</td>
</tr>
</tbody>
</table>

Staff operation is performed in three shifts. The morning shift consists of 16 workers (5x2 + 4 + 2), with 10 workers for remote deicing operations, 4 workers for ramp deicing operations (two-man operation) and 2 workers for up-front coordination. The late shift consists of 16 workers (5x2 + 4 + 2), equivalent to the morning shift. The night shift consists of three workers, as Munich Airport has a night curfew for all aircraft operations with the exception of the night postal services (4 departures per night).

**Utilization Of External Manpower**

In order to reduce expensive and unproductive manpower during non-deicing times, deicing suppliers often "borrow" manpower from other similar organizations on an hourly or daily basis. At Munich Airport this is
the case with Lufthansa Maintenance. Due to the high staff numbers at Lufthansa Maintenance it is possible to plan manpower very flexibly. During the winter season more manpower can be set free for the deicing operation, as aircraft maintenance activities (in commission) can be planned into the summer season. The result is that "borrowed manpower" is distributed in the following way that of the staff for the morning shift (total 16) are 9 from Lufthansa, for the late shift (total 16) are 9 from Lufthansa and for the night shift (total 3) are 3 from Lufthansa.

Total Manpower Requirement For Operation

70 staff are required for the winter season, with a duration 6 months, excluding the gantry operators (6 operators). The winter flight plan schedule comprises over 35,000 take-offs and the average deicing rate over a period of 8 years has been calculated to be 13.5% (4,748 deicings), but actual data have demonstrated a lower deicing rate (between 9-12%).

This manpower model enables the deicing supplier to negotiate a pay-back contract, if manpower is not required due to fewer deicing days than originally calculated (ref. nr. 29). On the other hand, manpower supplied by a cooperating partner may generally be more expensive than the utilization of own staff resources. This is the case if the staff of the cooperating partner are generally higher qualified (i.e. certificated aircraft mechanic) than required for the job performance in deicing operations.

Economic Evaluation Of Recycling Process

The recycling plant constructed at Munich Airport is presently the world's largest (ref. nr. 29 and 34). The plant functions fully automatically and only requires a maximum staff of two technicians with experience in the chemical industry. The recycling of fluid is performed in batch processes, in order to save energy costs. This means that a certain amount of fluid must be stored for processing, before the recycling operation can be started.
The recycling plant was built by a Swedish company, Deicing Inc., with support from subcontractors and logistical input from the FMG Technical Division. Due to the stringent requirements of fluid specification (that recycled fluid specification should be equal to new fluid specification) imposed on the airport operator by the national flag carrier (and certainly also by other air carriers), the recycling plant is operated by the chemical company Hoechst (ref. nr. 34) - who is responsible for the whole process of controlling fluid specification to be equal to the current AEA standards. It is thus of major importance that the fluid specification of the recycled product accords with set standards, as otherwise there will be suspicion and lack of acceptance of the concept among the air carriers.

Cost Of Fluid Recycling

The calculation of the cost of fluid recycling includes all the operational costs for the recycling plant which in turn includes all costs associated with the cleaning process of the fluid and the following distillation process. Excluded, however, is the cost for staff overheads and the transportation of the fluid (both fluid residue and fresh fluid) between the four deicing substations and the recycling plant. As the construction of a piping system was technically not feasible due to the late decision to implement the new deicing concept during the final phase of airport construction, fluid transport has to be performed via surface road system. This would involve additional investment costs for the purchase of adequate transport vehicles or delegating this task to a subcontractor. In all cases the current fluid transport concept is seen to be extremely ineffective and expensive and is not recommended.

Of major importance for the economic evaluation is the comparison between the market price of new deicant product (ref. nr. 34 and 35) and the material from a recycled source. It should be stated that this decision depends also heavily upon the different type of deicing fluid used by the airport, since there exist major price differences between EG (ethylene glycol) and PG (propylene glycol). If the product price of virgin fluid is relative low on the market, as it is in the case of PG, then the recycling
aspect will not succeed in the economic calculation. In Germany the market price for Type I Fluid for PG is about 1,500 DM/m³ and for MP is about 2,250 DM/m³. The price of the recycled product is about 415 DM/m³, however, the price for oil consumption for heating the steam boiler has to be added, which accounts for a further 400 DM/m³. The present recycling rate has been calculated to be about 35% (ref. nr. 29).

Of importance is also the cost for transportation of the effluent and "fresh recycled fluid" from/to recycling plant and refill stations at the four runway ends. This has been calculated to be 10,000 DM/100 m³. The present fluid amount required for operation during an average deicing season has been calculated to be 2,450 m³ of Type I (premix 55%). Disposal costs account for about 68,00 DM/m³ of captured fluid runoff. The investment costs for the ion exchange components have been calculated to be about 35,000 DM/1000 m³. The glycol portion of the captured effluent has been calculated to be about 15%.

Table 6-19 on the following page describes a generic cost calculation modell of the associated costs for recycling or disposal of the Type I fluids EG and PG and the possible economic gains of fluid recycling. An average annual financing rate of 17% for investment cost coverage is applied for the economic gain of the EG and PG calculation.
<table>
<thead>
<tr>
<th></th>
<th>With Fluid Recycling</th>
<th>Without Fluid Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EG</td>
<td>PG</td>
</tr>
<tr>
<td>Virgin Product</td>
<td>1,459,792</td>
<td>2,189,688</td>
</tr>
<tr>
<td>Recycled Product</td>
<td>355,863</td>
<td>391,449</td>
</tr>
<tr>
<td>Destillation/oil cost</td>
<td>71,042</td>
<td>71,042</td>
</tr>
<tr>
<td>Energy reuse</td>
<td>23,419</td>
<td>23,419</td>
</tr>
<tr>
<td>Effluent Transport</td>
<td>85,750</td>
<td>85,750</td>
</tr>
<tr>
<td>Effluent Disposal</td>
<td>30,013</td>
<td>30,013</td>
</tr>
<tr>
<td>Ion Exchange</td>
<td>30,013</td>
<td>30,013</td>
</tr>
<tr>
<td>Total</td>
<td>1,979,040(1)</td>
<td>2,744,522(2)</td>
</tr>
<tr>
<td>(2) - (1) for EG Cost Saving for recycling vs. non-recycling</td>
<td>480,597</td>
<td>838,032</td>
</tr>
<tr>
<td>Finance rate/yr For tech. facility</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>Investment Cost Coverage/yr</td>
<td>2,827,041</td>
<td>4,929,587</td>
</tr>
</tbody>
</table>

An analysis of the cost comparison exercise shown in Table 6-19 would lead to the following conclusions:

I. The economics affecting the decision to recycle are based principally on the composition and volume of the runoff to be treated, and the market value of the recovered glycol if the decision is made to recycle the runoff.

II. Recycling requires the use of a single glycol, because at present EG and PG are difficult to separate by a single distillation.

III. The glycol concentration in the runoff must be maintained above 25% by weight for recycling to be economical, as the generally used concentration of glycol in deicer solutions is >50%.
IV. An average financing of construction facilities (based on Munich Airport estimates) of 17% of total investment cost coverage/yr would enable to cover the required construction costs for a compatible recycling facility for EG and PG as demonstrated.

Even then, taking account of all further additional investment costs for secondary construction facilities and technical infrastructure (e.g. mobile and fixed facilities and equipment), recycling is incrementally more expensive (ref. nr. 29, 34 and 35) than biotreatment or controlled release to sewage treatment facility in almost all cases. That said, the lower the glycol portion of the effluent runoff at an airport, the higher the sale value of the recycled glycol. In conclusion then, it is possible to state that:

I. That recycling is realistically only an option (especially in Europe) when environmental pressures dictate that the stormwater (during deicing season) must be treated or recycled to comply with stormwater permits or stringent water quality guidelines (as in the Munich case).

II. Recycled fluid is less expensive than any virgin product available on the market; in addition, it allows for the option of selling-off the product for industrial reuse - which is an additional economic gain.

III. Recycled fluid is less expensive than any virgin product on the market and reusable as dedicated aircraft deicing fluid in compliance with existing chemical and operational worldwide applicable standards.

Performance Monitoring

It is one thing to plan or construct facilities for deicing, and to operate them, but quite another thing to monitor how the operations are taking place. Increasingly these days it is necessary for airports to include the monitoring of deicing performance as part of an overall performance monitoring system. Performance monitoring here is to be seen in the context of an airport’s relative deicing/anti-icing performance, its operational efficiency and environmental compliance. In order to examine
relative deicing/anti-icing performance, it is important to incorporate not only aircraft deicing/anti-icing performance but also tarmac deicing/anti-icing performance. A clear distinction has been made between these two system operations (ref. nr. 29 and 30).

Relative Aircraft Deicing / Anti-icing Performance

During the winter season 1996/97, a total of 4,292 aircraft deicings were performed. This accounts for over 30% less deicings in comparison with the 1995/96 winter season. The main reason for this reduction was a relative increase in temperature in comparison to previous winter seasons.

The distribution of the deicings in western and eastern operation patterns shows that for the 1996/97 deicing season a 2% increase in eastern deicing in comparison to western deicing operations. The gantry deicing operations accounted for 177 aircraft deicings in 1996/97 - 4% of total deicing operations. In the 1995/96 winter season, gantry deicings accounted for 5% of the total deicing operation. The reduction of the gantry deicings is a result of an increase in Type II deicing operations on several days, where due to very adverse weather conditions, a high percentage of deicings had to be treated in a two step procedure. This is then a major problem for the gantry operation, as the system is not capable of a Type II deicing operation. The gantry anti-icing performance is known to be very unsatisfactory, because under these weather conditions it means a total closure of the gantry and its associated deicing pad. A painful reduction in deicing capacity is then the direct result. The relative deicing performance overall is seen to be good. No significant delays were registered that could have been responsible for late aircraft departures. Aircraft are only actually directed onto the deicing pads if ATC and the deicing agents are able to ensure an immediate departure within the defined holdover times of the deicing fluids. Delays presently only occur during snow removal operations on the runways, as the mandatory runway closures will increase the aircraft line-up on the ground as well as the amount of aircraft in the ATC holding patterns. The anti-icing performance of the mobile deicing units are to be seen only as average, as these units are only capable of transporting a
limited amount of Type II Fluid in their tank system. This may cause considerable problems when having to operate under Type II Fluid weather conditions (typically freezing rain and ice) and will certainly result in the closure of deicing areas resulting in significant departure delays. These specialized vehicles cannot be refitted in a short time with different tank, pumping and spray systems for Type II deicing fluid application. The anti-icing performance is generally to be seen as a weak component of the whole aircraft deicing concept. Due to the general weather conditions encountered at Munich Airport during the winter seasons, however, these conditions occur only on a very limited number of days. It is the airport operators decision then to perform an economic trade-off, when setting up the performance requirements of such a deicing concept. Presently, airports may encounter major problems when trying to achieve a relatively high deicing and also anti-icing performance, since this will require considerable technical installations for the separation of the differing deicing fluids (only for recycling). Such systems and concepts can only offer a relatively high deicing/anti-icing performance if they have a built-in-flexibility being capable to be adjusted to changing weather conditions within a very limited time span.

Concerning the issue of Holdover Times of Type I and II deicing fluids, based on the results of operational experience and mathematical recordings, it is possible to state that at Munich Airport:

1. The effective holdover times of Type I deicing fluids were sufficient for 96% of all aircraft deicing operations performed during the deicing season. This was a result of the close vicinity of all the remote deicing pads to the runway take-off points and due to the weather conditions experienced at the airport. The fluid pre-mix concentration (glycol/water fluid mixture) had been established under the precondition that nearly all weather situations can be safely covered. Due to the technical pre-mix capability of the refilling station at the recycling plant, within two hours the fluid concentration could be changed to cope with a significant weather downgrade. However, the major problem is then a logistical one, as the fluid in the tanks of the deicing units (mobile and fixed installation) requires total replacement. This certainly result in a
downgrading of the aircraft deicing capacity during refill operations.

2. The effective holdover times of Type II deicing fluids were sufficient for the remaining deicing operations performed during the deicing season. Type II Fluid was only sprayed during weather conditions of freezing rain, freezing fog and wet snow on cold soaked aircraft wings. During these weather conditions the two step deicing procedure (deicing with Type I Fluid/anti-icing with Type II Fluid) was successfully performed. The volumes used for the anti-icing step generally did not exceed the Type II tank volumes of the deicing trucks, although this might cause a problem if such afore mentioned special weather conditions would continue for a longer period of time.

Relative Tarmac Deicing / Anti-icing Performance

The main issue concerning relative tarmac deicing/anti-icing performance is the effectiveness of a fluid consumption programme aimed at minimum fluid consumption for any type of tarmac deicing activity. Of essential assistance is certainly the previously mentioned airport temperature and tarmac status reporting system installed at Munich Airport. This system enables an improved decision process that leads to the treatment of tarmac areas prior to any weather situation which can significantly reduce operational safety standards. The fluids in use today enable a quite reliable calculation of their holdover time, comparable to aircraft deicing/anti-icing fluid performance characteristics. In defining more accurately holdover times of tarmac deicing fluids, more reliable status reports of fluid treated tarmac areas are required. A precondition of such status reports is certainly the total monitoring of all vehicle activities which are involved in preventive and actual deicing/anti-icing operations on the tarmac. With the implementation of such a computerized monitoring system, fluid spray operations could be launched at that moment, when the former treatment activity begins to expire within the designated tarmac areas. Up to now these activities are still relevant to human judgement and experience, thus secondary treatment activities are started longer in advance prior to the calculated expiry of the holdover time of the fluids.
This subsequently results in often unnecessary additional deicing/anti-icing actions within the aircraft movement areas.

An airport’s relative tarmac deicing/anti-icing performance can be influenced significantly in at least two ways:

I. Through the implementation of aggressive snow removal procedures and alternative operational methods to reduce the existing environmental impact of deicing/anti-icing fluids.

II. Through the implementation of a sophisticated fluid consumption monitoring system. Such a system could operate with the assistance of a satellite navigation system (such as GPS) thus enabling the location, tracking and monitoring of all vehicles in snow removal and deicing/anti-icing operations. Additionally, fluid consumptions, holdover times as well as secondary deicing/anti-icing tarmac treatment activities could be coordinated and planned more effectively. The main aim of such a concept is to reduce fluid consumption prior to any fluid being released on the tarmac in the first place.

Operational Efficiency

Operational efficiency at Munich Airport has been about the 90% level under frost and light snow conditions. Under heavy snow conditions, including freezing rain and fog conditions, operational efficiency has been at about the 75% level. 100% operational efficiency has been defined as the basis of four criteria:

- Maximum 5 minute delay factor for every deiced aircraft
- No second deicing sequence required due to ATC delay after accomplished deicing
- All deicing pads in operation with fully operable and available/assigned equipment
- Ramp deicing, including secondary deicing operations, performed immediately upon request prior to engine start-up
The following 10 factors have also been identified as contributing to a considerable system downgrade in operational efficiency at Munich:

1. Transportation of fresh fluid from the recycling station to the 4 remote fluid refill stations is performed with tank trucks through surface road access. Due to prevailing road conditions (snow, ice, slush), transport takes too long and especially during peak deicing operations the remote fluid refill stations suffer considerable fluid shortage, resulting in closures of deicing pads for time consuming vehicle refill operations. The installation of a piping system could be considered, but as decisions for the implementation of the Munich deicing concept were performed too late, construction plans for an underground and above-surface dedicated piping system had to be halted.

2. Communication logistics are still not sufficient to cope with ATC requirements concerning especially active aircraft movement control and aircraft deicing pad allocation procedures. Improvements need to be made to cope with aircraft slot delays and departure priority regulations (i.e. ramp deiced aircraft assigned to preferential line-up/bypassing for take-off).

3. Pilot guidance procedure for positioning aircraft on deicing pad for intermediate stop during deicing operation needs to be redesigned from the current "manual and verbal" guidance procedure to an "automated automatic visual" guidance system for optimal positioning. The current guidance procedure is too time consuming and is mainly responsible for the mandatory required but time-intensive aircraft positioning procedure.

4. The current procedure for mandatory after-deicing inspection needs to be changed from a manual and visual inspection (with a technician inspecting with ladder or lifting device the wing areas of all aircraft types) to an automated and computerized detection system (infra-red-camera), capable of safe and high speed operation. Additionally, this would require that the existing inspection procedures would have to be standardized and be accepted by all operating carriers.
5. The aircraft deicing equipment operated on remote deicing pads and areas has to become more compatible in order to be utilized also for secondary deicing operations (i.e. underwing and landing gear deicing). There is an increasing requirement for these type of special deicings prior to take-off. Aircraft sometimes have to turn back to the ramp for additional treatment, which is a very unsatisfactory operational aspect.

6. Airport snow removal actions and aircraft deicing operations require an improvement in coordination activities between ATC, airport operator and aircraft deicing agent. The implementation of a 'Snow Coordinator Board' may be a promising step in improving present operations and coordination activities. As an airport operates as a system, only full and effective coordination of all available resources, facilities and operations will result in a smooth and undelayed airport operation under adverse weather conditions.

7. The configuration of the remote deicing pad layout does not allow aircraft to shut down engines for special deicing operations and inspection procedures, as this will result subsequently in a blocking of the deicing pad. The Munich configuration has been proven to be inappropriate, as there is no built-in flexibility to effectively stack aircraft with differing deicing and inspection procedures within the pad area (compare with Figure 6-20).

Figure 6-20: Inappropriate Layout And Configuration Of Deicing Pads
The planning philosophy of "one pad fit for one aircraft" has been a significant error and demonstrates very clearly that the FAA design criteria for deicing pads and areas (ref. nr. 11) should be definitely considered and applied (compare with Figure 6-21)

**Figure 6-21:**
**FAA Design Criteria For Deicing Areas**

8. Equipment malfunctioning of fixed and mobile deicing facilities is too high, especially considering the operation of the fixed installation. Technical improvements have to be performed with the computerized system operation in general as well as optimization of spray patterns and an increased diversity of deicing programmes available to cope with various weather situations. It seems that the human error factor is still a major contributor to system failure (in both mobile and fixed facilities), suggesting that currently operating technical systems may have become too complicated to be operated safely with reduced labour. This certainly questions the belief that single-man deicing vehicle operations are not only efficient from the manpower aspect but also from the operational safety aspect.
9. As the pricing structure for the deicing/anti-icing of an aircraft is dependent upon the individual fluid consumption rate, the air carriers and their cockpit crews being aware of this fact, a certain percentage of cockpit crews tend to claim that clear ice is present on wings in order to officially bypass the gantry and thus receive mobile deicing. Clear ice cannot be treated in the gantry due to existing safety regulations and incompatible deicing fluid (only Type II Fluid allowed). This causes major delays for departing aircraft, as the bottleneck effect of only one available deicing pad for Runway 26L-Departures is increased dramatically within a very short period of time.

10. When operating departures in the 26-direction, runway allocation during peaks could be made by ATC to try and equalize the growing deicing delays for all departing aircraft. This could be achieved by sending about 25% of the departures to runway 26R, and the remainder to 26L. This planning issue has never been implemented by ATC with the result that there is insufficient deicing capacity available to cope with the morning and evening peaks. When operating the runway departures in the 08 direction, ATC could again try to equalize departure delays between the two runways. Here the same problem exists, but ATC has again not reconfigured their departure operation with the runway system. During the morning and evening peaks there is still no compatible capacity for deicing available, thus sometimes causing considerable delays. A solution could be to deice remaining aircraft on the ramp, but due to the reduced holdover time of Type I Fluid this cannot be accepted for safety reasons. The deicing capacity on the ramps is presently so limited that major deicing delays on the ramps would increase the general delay situation.

The main conclusions to be drawn naturally have to focus on the overall airports environmental compliance performance. The main intent of the Munich concept was to achieve environmental compliance with existing or newly established environmental protective regulations. Environmental compliance at Munich Airport is seen to be very good, mainly due to the fact that only very limited amounts of glycol or tarmac deicing fluid can enter soil, surface- or ground water uncontrolled. The environmental protection authorities confirm that the deicing operations conform with the
existing regulatory framework. This, however, does not mean that Munich is perfect. A further improvement could be the possibility of recycling Type II Deicing Fluid, as means have now been found to extract the thickener of the Type II Fluid prior to the start of the recycling process. This could be achieved with the help of an additional filtration unit. With this significant improvement, Type I and Type II deicing fluids could be allowed to mix within the drainage and collection systems and subsequently reduce the automatic diversion of Type II Fluids to the sewage treatment plant during deicing operations requiring dedicated Type II Fluid usage only (i.e., freezing rain, etc.). Also new regulatory standards now allow a limited mixing of EG and PG fluids for recycling and dedicated further reuse as aircraft deicing fluids. This is a significant improvement that could increase environmental compliance and environmental preventive protection.

Some problems, however, still exist and should be pointed out in order encourage other airports to focus especially on these issues. For example snow blower activities on the runways sometimes result in the blowing and dropdown of glycol contaminated snow outside the installed impermeable membrane system. An improvement here could be achieved through the optimization of snow blow patterns of the existing equipment. This will need more intensive observation, as the different snow compounds and influencing weather factors have to be analysed. Also during periods of heavy snowfall and snow removal activities, drainage channels can become blocked with heavy and compacted snow from snow removal operations within the areas of the remote deicing pads. This results in an uncontrolled seepage of glycol contaminated effluent into the soil and ground water. However, this is more an operational snow removal problem and has been focussed upon more intensively during the last winter season. More intensified monitoring of this issue will be performed by a specially appointed observer within the snow removal organization. Immediate clearing of these drainage channels will result in a considerable reduction of this threat. During longer periods of rain, wet snow and temperatures above 0°C, an overflow of the special stormwater collecting basins is often inevitable. The construction of a larger stormwater basin (50 m²) has been proposed and is currently under construction. Due to the low groundwater
table at the Munich Airport site, this critical situation occurs very quickly and presently cannot be effectively dealt with. However, due to the high dilution of the glycol under these weather conditions, the contamination rate of the uncontrolled seepage is relative low, but should not be neglected in the long term.

It is clear that fluid recycling process is efficient and causes no direct, primary environmental contamination. The additional and environmental harmful additives for the production of new fresh fluid are extracted from the filtration and mixing processes to be treated in a dedicated off-site facility for hazardous materials. However, the exhaust fumes of the tank truck operation (transportation of effluent and fresh fluid) should not be generally neglected, as their operation during deicing peaks is substantial.

Environmental awareness and acceptance is high among those all involved in the deicing operation and thus environmental compliance has highest priority and is so successful. This is of major importance, as it is a fact that daily operational deicing business sometimes tend to adapt "workable" solutions rather than "workable, environmental and regulatory acceptable" solutions. This is not the case for the Munich Deicing Concept, but this also being a direct result of the very stringent environmental protective measures which have been implemented by the responsible governmental authorities.

Finally, and due to the construction of the additional stormwater collection basin where minor diluted glycol effluent can be stored for a controlled release into the municipal sewage treatment plant, the present limitation of 3-5 m³ of effluent per day should not cause further significant capacity problems for the sewage treatment plant. Depending on the capacity limitations of such sewage treatment plant, it is of major importance that the airport should consider the dimensioning of such retention basins well in advance. A controlled release of such fluid amounts on a daily basis over a longer period is a promising solution for those airports which encounter heavy glycol contamination of their stormwater system only a few times during a deicing season. Certainly the dilution has to have a
relative low glycol contamination and the capacity of the sewage treatment plant has equal fluid handling compatibility.
Chapter 7

Objectives and Performance Levels Of An Ideal Recycling System

This chapter discusses the objectives and performance levels of an ideal recycling system. In particular it focusses on the requirement to define clear objectives and to establish key principles for an environment management plan such as sustainable development, community responsibility and accountability, and coordination with service partners. The need for the airport operator to define the conditions and operational requirements for the particular airport scenario is addressed. The definition of all available facilities for effluent handling is highlighted. The development of an alternatives analysis of both capital, operating and maintenance costs for an airport ideal recycling system examined. Finally, the decision factors for establishing a generic calculation model for a technical/economic evaluation of recycling vs. biotreatment are focussed.

The Requirement To Define Clear Objectives

Allowing large volumes of glycol to flow into natural waters or sending large volumes to sewage treatment plants is no longer possible, as environmental protective measures increase the pressure on more and more airports (ref. nr. 20). Neither is it practical or necessary for airports to be required to collect and treat every drop of glycol. The economics of various alternatives are changing rapidly and will continue to change also in the near future. Every airport has different physical opportunities and capital requirements. Every type of airline operation still has differing deicing operational requirements and the airports must accommodate them all (ref. nr. 24). Taking the Munich Airport case as an example, the airport operator has to cope with operational requirements of presently 107 airlines. This certainly does not result in 107 different deicing procedures for aircraft, but it certainly demonstrates the case for considerable negotiation requirements to achieve a compromise for a system acceptable to all aircraft operators. So the real question is how to define and sort out
these variables and develop a sound, cost-effective decision which provides safe, efficient, and environmentally sensitive facilities?

Most important is that the airport operator should set the objectives of an "ideal airport individual" recycling concept within an airport's overall deicing and environmental strategy, as this will make a lot of difference to the viability of such a concept. When establishing an airport's overall deicing and environmental strategy, which incorporates the objectives for an ideal recycling system, it is important to evaluate the existing airport environmental strategy for compatibility, and if required, adoption of new principles and strategies.

Establishing The Key Principles For An Environment Management Plan

The following key principles should be established for an environment plan that incorporates the strategies required to implement an ideal recycling system at an airport.

1. Sustainable Development

Achieving sustainability means that the airport operator has to understand how the world is changing. The airport operator must then ensure that its development and operation is in step with its changing commercial, social, political and environmental situation. The airport operator has to clearly identify the environmental issues related to its operation which also concerns the airport neighbours. Adopting a policy of environmental consciousness and to sustain its development by making the most of the social and economic benefits whilst keeping the environmental consequences to an acceptable minimum is absolutely crucial.
II. Community Responsibility

Economic benefit from an airport is spread across a region or state, but it is mainly the residents of the local communities in airport vicinity who bear the environmental consequences of an operating airport. The development of an airport environmental plan is mandatory and should be accessible publically for information on environmental effects upon the local communities.

III. Accountability

Everyone using or working on an airport should understand and accept their individual part in delivering environmental responsibility. This includes airline operators, handling agents and even governmental organizations like Air Traffic Control. An increase in extensive awareness and training by assigning appropriate accountability for environmental performance throughout the aviation business should be encouraged.

IV. Coordination With Service Partners

The airport operator should develop and reach agreed environmental standards with its customers (the airlines), the suppliers (delivering deicing fluids) and tenants (ground handlers and system operators) in order to achieve a broad system acceptability and thus also ensure a high system usability factor (ref. nr. 22).

An effective Environment Management Plan should contain the following objectives:

- Annual review examinations in order to identify environmental effects, relevant legislation and regulations and best current control techniques;
- Ensuring that sufficient resources to achieve the set environmental goals are available and are utilized;

- Continuous examination of relevant existing environment laws together with details of future legislation development; and

- Continuous efforts in seeking more influence to enforce international environmental standards;

**Establishing Operational Requirements**

The airport operator has to define the conditions and operational requirements for the particular airport scenario. These need to include in detail data containing information about:

- Airport weather conditions
  (quantity and time of day of snow/ice conditions)

- Operational requirements
  (total aircraft activity during storm periods and time of day of departure peaks)

- Definition of geographic areas of fluid application
  (areas of application and types and quantities of glycol for air carrier, cargo, commuter, and general aviation separately, so the collection and treatment can be tailored)

- Airline surveys
  (Airlines have to be surveyed to evaluate how they expect their deicing operations to change, both in total usage and types of product, such as use of Type II Fluids).

All these data are required to calculate quantities of glycol and a range for the dilution and peak rates that any proposed treatment system will have to handle. The airport operator has to identify a realistic "fluid capture" goal for the total glycol to be used on an annual basis. The data should contain information on fluid concentration if the concentration is sufficiently small, biological treatment in the runway/ramp shoulder grades may be acceptable and comply with existing environmental regulations). Samples taken at several airports in Europe and the United States at the edge of the
pavement as well as from displaced and submerged measuring points parallel to the runway edge showed no trace of glycol.

Definition Of Available Facilities For Effluent Handling

The airport operator has to define all the available facilities to handle all or portions of this effluent. The data collection should focus upon:

- Present and future allowable contamination limits:
  Present and future allowable limits for the sewage treatment plant should be defined in some detail. Hourly, monthly, annual and other peak and total limitations should be registered, so the controlling numbers can be determined. Charges for this treatment and their projected increases should be evaluated. Allowable discharge limitations both at the plant and at the airport should also be determined.

- Availability of glycol reprocessing plants:
  The availability of any nearby glycol reprocessing plants should be determined, along with the present and projected fees they will pay or even charge for deicing runoff (as in the Munich case), with specified concentrations. It should be remembered that the use of glycol for deicing aircraft may be a relative small portion of the total glycol usage in a country. Therefore, depending on the national policy and industry requirement, the recycled glycol may have value. The purposes for glycol usage vary be state and by region, but the largest uses are for fabrics, insecticides, plastics, and antifreeze products in the automotive industry.

- Evaluation of alternative control measures:
  Alternative measures of control should be defined such as: existing drainage conveyance and storage facilities; available tracts of land near runway thresholds, to minimize holdover times after aircraft deicing/anti-icing has been performed.
The Development Of An Alternatives Analysis

These and other data and information should be utilized to produce a comprehensive alternatives analysis of both capital, operating and maintenance costs for an airport ideal recycling system. Once the airport operator has a clear understanding of the most likely combination of treatments, discussions should be held with the airline users and the approving agencies as well as the governmental institutions to define a clear position and airport policy and to get a 'system buy-in' prior to the involved parties locking into firm positions. The airport course of action policy should clearly be straight forward, but mostly, operate as a reasonable, concerned, well-informed mediator. Projects of such a size tend to produce a variety of less important objectives, which are often overlooked as having only minor influences on the result of the total system performance. Often way down the line prior to the final system completion, they do turn out not to be minor problems and often may influence total system performance very negatively. Several small mistakes and overlooked aspects can contribute significantly to a system downgrade and thus even question cost calculation.

• Some of the most commonly overlooked areas are the sealing of all ramp penetrations such as utility manholes where glycol can seep in fairly large quantities and the jet blast areas of influence, requiring careful location of collection drains.

• People issues should be a part of the final comprehensive plan such as: training for application of fluids for airline personnel to prevent excessive overspray; flushing procedures for combination (clear stormwater and glycol) removal systems for airport maintenance personnel; and communication standards for air traffic, airline operational staff and airport operational staff to be used during deicing conditions to anticipate changing conditions and keep operations running safely and smoothly (ref. nr. 22). Integrating the regulatory agencies early into the process of decision finding is important.
• The more analysis is available and communicated between the involved parties, the better the airport operator has the chance to negotiate a reasonable solution.

There is no general solution that will work for every airport. Each approach must be evaluated and judged differently to incorporate all individual airport data and airport criteria. Small airports (Case I) are likely to elect for higher operating costs when operating their ideal recycling system. They will carefully evaluate operating costs for effluent trucking (ref. nr. 35) to an available recycling plant (including effluent collection methods on the ramp), rather than choose large capital cost alternatives such as dedicated deicing ramps and dedicated effluent treatment facilities at the airport. Old, large hub airports (Case II) are going to have to make best use of existing ramp drainage systems, but install more flexibility (valves and pipes) for controlled diversion of specified flows.

New facilities are going to have the largest capital costs, because the permit requirements will be more stringent (i.e. Munich Airport case) than for old facilities, which may still be grandfathered into higher allowable discharge rates (applicable at the German airports). It is very likely that capital-intensive solutions, with reasonable return on investment potential, such as reprocessing plants, will be performed with private investment, reflecting the changing economic conditions in a country. But this also depends upon the political pressure imposed on the industry to increase the general material recycling policy (ref. nr. 30).

Case I - The Small Airport

Small airports are likely to elect for higher operating costs when having to operate their an ideal recycling system. They will have to evaluate carefully all relevant operating costs for effluent collection and treatment/transportation rather than choose large capital cost alternatives such as dedicated deicing ramps for aircraft, "intelligent" fluid drainage systems or dedicated effluent treatment facilities at the airport. Further
preconditions have been identified to be applicable and valid for the analysis as follows:

1. Decentralized aircraft deicing activities on the ramp in vicinity of the terminal on the aircraft parking stand. Decentralized aircraft deicing is still performed at the majority of European airports and the adoption of a new deicing concept would require significant procedural changes and integration of new equipment and facilities into existing infrastructures. Construction activities of new deicing areas would impose additional costs to small airports, that would have to be incorporated into a realistic calculation resulting either in unacceptably high single aircraft deicing costs or general system investment costs.

2. Aircraft deicing/anti-icing is performed with mobile deicing units and with the aircraft engines shut down.

3. Aircraft deicing fluid and ground deicing fluids are allowed to drain into sanitary sewers and are pre-treated in the airport stormwater system before being allowed to be further processed to a municipal wastewater treatment plant. The stormwater and drainage collection systems are relative old and would have to be modernized in order to fulfill the new regulations.

4. More stringent environmental regulations have been established by the governmental authorities or negative environmental impacts have been eventually identified, questioning or even prohibiting further current operational procedures for aircraft deicing/anti-icing and ground/tarmac deicing activities as well as effluent treatment and disposal (discharge rates, contamination of surface water, etc.)

Definition Of Operating Costs

The definition of operating costs is of crucial importance, as these will dictate the system choice for effluent treatment either on-airport or off-airport. The operating costs and their evaluation can be defined as follows:

- Operating costs for suction vehicles
- Operating costs for effluent transportation of glycol to an off-airport recycling plant
Operating costs for effluent treatment in a municipal sewage plant.

Due to the unavailability of data for operating costs for effluent transportation of glycol to an off-airport recycling plant, no analysis of these costs could be produced. Presently there is no such case in Germany. Additionally, there presently does not exist a central located recycling plant, capable of servicing more than one airport. The only existing recycling plant is located at Munich International Airport. No further airport utilizes this recycling plant. Nevertheless, some findings do exist, which can be incorporated into such an effluent transportation analysis:

1. Transportation costs consist of vehicle costs and manpower utilization costs. These costs are generally very high in western countries. As mostly water will be transported on the road, the concentration of the effluent has to be extremely high in order to have an economic return on such an operation. Small airports with relatively low traffic volumes, high effluent capture rates and high effluent concentration rates and short transportation distances to a possible existing recycling plant may opt for such a solution. By taking advantage of an existing recycling plant (i.e. in the United States), who will pay for the diluted product, the airport operator may be able to recover the cost of trucking the material, rather than have that add to the cost of the total deicing operation/single deicing event cost.

2. Operating costs for suction vehicles need to be evaluated carefully, as this equipment is expensive in both capital cost (parallel suction operations required resulting in more than one vehicle) and operating cost (manpower requirement, operation and maintenance issues) terms. Suction vehicles are very capable of collecting effluent with high glycol concentrations at aircraft parking stands where deicing is being performed. It is a flexible type of operation that requires only effective coordination of the tarmac cleaning activities. When utilizing suction vehicles, a cost-benefit analysis will demonstrate, if the transportation costs are economically acceptable that it will be feasible to recycle glycol, provided the runoff comes from smaller ramp areas, where the
dilution would be less. This would also prevent a small airport from having to rebuild or totally rearrange its existing ramp drainage system in order to install a higher flexibility in the system for the diversion and differing treatment of specified flows. It is a very expensive course of action to rebuild or change existing drainage systems.

3. The operating costs for the effluent treatment in a municipal sewage plant have to be examined in depth. Discharge rates for glycol concentrations and increased fees to treat deicing fluid runoff have to be taken into account when planning long term solutions. There may be future limitations for sending large, uncontrolled volumes of glycol effluent to sewage treatment plants. If there is a good chance of capturing a high amount of concentrated glycol effluent from the ramp areas, it should be considered to rather truck the effluent to a possible recycling plant, have it distilled and have a usable product to sell to the industry, than to divert the effluent to a municipal sewage treatment plant where the airport is highly dependant on external discharge rates and increasing discharge fees. An alternatives or cost-benefit analysis would favour the trucking of smaller amounts of high effluent concentrations of glycol to a recycling plant within an acceptable distance from the airport.

Case II – The Old, Large Hub Airport

Most of these airports have to make best use of their existing ramp drainage/stormwater systems and try to create greater flexibility for the controlled diversion of specified flows. Four further preconditions have been identified to be applicable and valid for the analysis:

1. due to the high amount of effluent from aircraft deicing/anti-icing and ground deicing operations, these airports will have to evaluate the possibilities for recycling glycol at the airport site in detail. Uncontrolled release of effluent into the environment will cause severe conflicts with existing environmental regulations. Controlled release of effluent to sewage treatment plants will be a long term cost intensive course of
action being also dependant on changing permit charges and continuously rising disposal fees. The precondition for efficient recycling of aircraft deicing fluids is to centralize all the aircraft deicing operations at an airport, meaning to deice all aircraft on dedicated deicing areas thus enabling the fluid runoff to be collected with a special 'intelligent' system of drainage channels surrounding these deicing areas.

2. the existing ramp drainage/stormwater system will have to be upgraded in order to obtain greater flexibility to allow the controlled diversion of differing concentrations of effluent flows. This will enable an airport to control the specified flows of glycol effluent and direct them to dedicated collection systems for further treatment.

3. the construction of an airport on-site glycol recycling plant will have to be considered, if not an existing nearby sewage treatment plant may be partially converted into a glycol recycling plant (as in Sweden).

4. these airports already mostly suffer ramp congestion and will have even more problems in constructing such special deicing areas within the existing infrastructure. As these dedicated aircraft deicing areas require extensive concrete infills, it is often difficult to integrate them into existing apron areas or taxiway systems.


A technical/economic evaluation of recycling vs. biotreatment of glycol deicer runoff has to be made in order to be able to analyse specific and realistic airport situations. The design for such an evaluation needs to define the following influencing factors: Type of glycol, evaluation of glycol concentrations of the runoff, number of seasonal (aircraft) deicing operations, storage needs for glycol, equipment requirements for the recycling design studies, equipment requirements for the biotreatment design studies, market prices of virgin glycol, evaluation of estimated costs for operating a recycling system, evaluation of estimated costs for operating a biotreatment system, evaluation of permit limits for stormwater or water quality guidelines. The following Figure 7-1 shows that these decision factors may help structure such an evaluation model.
The conclusions to be drawn from this chapter are that of significant importance for the final decision process are the evaluation of the overall operating costs for both recycling and an on-site biotreatment operation vs. Glycol concentration in the airport runoff. Two factors actually dictate the decision process and are mainly responsible for the choice: Concentration of the glycol runoff and the market price of the recycled glycol vs. market prices of virgin glycol.

Performance criteria have to be established taking account of the recommended levels of operation and applicable national and international regulatory framework. A regulatory framework that can generally be applied for any case study has not been identified. Every feasibility study has to be viewed differently, according to the specific national and local regulations concerning especially the aspect of environmental protection (fluid collection and controlled disposal, fluid collection and recycling). However, for every case an individual regulatory framework is essential in order to define the specific performance criteria. The regulatory framework has to be divided into two main parts, one concerning the operational part of aircraft deicing, the other concerning the environmental part of fluid collection, disposal or recycling under applicable legislation. A relatively
high percentage of standardization has already been achieved for the operational aircraft deicing procedures by international bodies and organizations (FAA, AEA, IATA, ICAO, etc.).

However, there is still no standardization in environmental protection measures concerning the treatment and controlled environmental "friendly" disposal of deicing fluids containing glycols (ref. nr. 20, 31 and 32). Environmental protection legislation differs from country to country. Depending upon the interactions and influences between a wide variety of objectives, performance levels, environmental regulations and airport policies, the economic recycling of deicing fluids may not be viable.
Chapter 8
Conclusions - Part I

Appropriate Design Criteria For The Development Of An Environmentally Sensitive Airport Aircraft Deicing/Anti-icing Strategy

This chapter focusses on appropriate design criteria for the development of an environmentally sensitive strategy. In detail five main topics are addressed: The major importance of the issues of an appropriate strategy and the definition of design criteria of an ideal recycling system. The evaluation of operational requirements is performed, covering in detail different physical characteristics, climatic conditions and capital cost requirements. The importance of the location and design of dedicated aircraft deicing facilities is addressed. The organization of aircraft deicing operations and the requirement for system flexibility are highlighted. Closing this chapter is an evaluation of the environmental requirements and an evaluation of the economic requirements concerning the two main alternatives - to recycle or biotreat.

Any effective deicing/anti-icing strategy will inevitably have to address one of the main environmental issues, and some possible solutions, related to world civil aviation - namely the contamination of surface water, soil and groundwater.

The aims of such a strategy and its implementation should be defined as: To limit contamination of waters by accidental or routine emissions of deicing fluids, waste oils, cleaning fluids, paints, solvents, spillage, aircraft and equipment fuels, batteries, and chemicals and other dangerous goods; and to control surface water run-off and treat contaminated waters; To replace hazardous materials with safer alternatives.

Despite the successes achieved over the years, governments and industries are beginning to recognize that conventional approaches to
solving environmental problems are severely limited. We have entered an age in which industrial growth must be considered in the light of global sustainable development. That is, development must progress in a manner that does not exceed the future capacity of the environment to sustain itself and its human populations. New approaches are required, based on a new generation of integrated policy and technological solutions. New strategies must be developed so that the aviation industry can not only survive, but also continue to grow, in an age of increasingly restrictive environmental concerns. To achieve the objective of sustainable development of air transport, its environmental burden must be limited as much as possible, even if sometimes immediate proof of harm is not yet available. To limit the present effects of aviation on the environment and to counter the effects of the expected high rate of growth in the future, it will be necessary to encourage the development of practical solutions to environmental problems. While noise and air pollution have historically received the greatest attention, it has been shown that many other environmental effects are also of major concern. The challenges facing the aviation industry are not just related to solving specific environmental problems, but involve the development of managerial tools, including methods to indicate where efforts should be focussed first to achieve the best results and policies to address new concerns as they arise.

Issues Of An Appropriate Strategy

It is of major importance that an airport’s appropriate aircraft deicing/anti-icing strategy is embodied in an airport’s overall environmental strategy, since it is a must and also a legal requirement for all airports and airport users to undertake continuous efforts to improve their environmental performance. This can only be achieved if the opportunity to improve current practices and eliminate further environmental damage is grasped and coordinated professionally without any delay. Airports that have already made an effort to assist local communities to understand airport issues and constraints have demonstrated the value of establishing good working relations with those who could easily have a negative impact on their operations. This lesson must be extended to all sectors of the
aviation industry: airports, airlines, aircraft manufacturers, and service industries.

The following principles of environmental management need to be incorporated into an airport's aircraft deicing/anti-icing strategy:

- Corporate priority – To recognize environmental management as among the highest corporate priorities and as a key determinant to sustainable development; and to establish policies, programmes and practices for conducting operations in an environmentally sound manner;
- Integrated management – To integrate these policies, programmes, and practices fully into each operational action as an essential element of management in all its functions;
- Prior assessment – To assess environmental impacts before starting a new operational activity and before decommissioning a facility or leaving a site;
- Products and services – To develop and provide products or services that have no undue environmental impact and are safe in their intended use, efficient in their consumption of energy and natural resources, and can be recycled, reused or disposed of safely;
- Facilities and operations – To develop, design and operate facilities and conduct activities taking into consideration the efficient use of energy and materials, the sustainable use of renewable resources, the minimization of adverse environmental impact and waste generation, and the safe and responsible disposal of residual waste; and
- Research – To conduct or support continuous research on the environmental impacts of raw materials, products, processes, emissions, and waste associated with the deicing/anti-icing of aircraft and on the means of minimizing such adverse impacts;
- Contractors and suppliers – To promote the adoption of these principles by contractors acting on behalf of the enterprise, encouraging and, where appropriate, requiring improvements in their practices to make them consistent with those of the enterprise; and to encourage the wider adoption of these principles by suppliers;
- Compliance and reporting – To measure environmental performance; to conduct regular environmental audits and assessments of compliance
Design Criteria Definition

A precondition of an ideal recycling system (or alternatively a controlled fluid disposal concept) for an airport is first of all to achieve a compatible aircraft deicing/anti-icing concept (ADC). A recycling system (or controlled fluid disposal concept) cannot function efficiently if the aircraft deicing/anti-icing concept fails to be compatible. For clarification, it has to be stated that the overall aim in setting a clear criteria definition is to encourage the development of an environmentally sensitive airport’s ADC which can be achieved either by an glycol effluent recycling policy or a controlled (sewage treatment plant) fluid disposal policy. When defining the appropriate design criteria and planning approach for such an ideal airport ADC, always being airport unique, it has to be noted that present ADC’s are mostly incapable of performing the required preconditions. Present ADC’s (including also tarmac deicing) generally do not take account of environmental considerations, with some notable exceptions, and subsequently require changes. Considering these issues, the following approach is recommended in order to evaluate operational, environmental and economic requirements of a preferable system.

Evaluation Of Operational Requirements

As every airport has different physical characteristics, climatic conditions and capital cost requirements concerning funding and operation, there is nothing like a standardized and generic ADC applicable at a specific airport. Nearly every type of airline operation has different operational deicing requirements and airport operators must accommodate them all in some way or other. In order to produce a cost effective management decision which provides safe, efficient and environmentally sensitive facilities, all these variables have to be identified and analysed in order to
achieve the best concept for an individual airport. This is a mandatory precondition for the production of a comprehensive alternatives analysis of the operational, environmental and economic requirements and associated costs of a preferred system. The projected increases in sewage disposal fees and environmental fines should be included. Also considered should be primary and secondary costs and benefits, to the extent possible. Operational efficiencies are hard to identify but should be considered in the final decision. Airlines are usually reluctant to share this specific information with airport operators, but it is recommended that airport operators should continuously inform the airlines operating at their airports of the project status. Evaluating operational requirements in this context means setting certain operational standards for an ADC which are sufficient to achieve a high compatibility with an efficient fluid recycling system. An efficient fluid recycling system dictates the following requirements, which are essential for successful overall performance:

- Centralized deicing pads located near the ends of departure runways improve safety and operational efficiency. This type of deicing operation minimizes aircraft taxi time and therefore minimizes the risk of exceeding holdover times (ref. nr. 11 and 13). It also enables aircraft to leave gates and ramp as early as possible, allowing arriving aircraft a faster gate/terminal access. Centralized pads ease the problem of ramp congestion caused by additional deicing equipment and personnel operating at the already busy ramp areas. Especially during adverse snow and ice conditions the congestion of service vehicles at the gates is immense. The dedicated centralized and remote deicing areas also reduce the number of personnel exposed to deicing fluids, fluid overspray and slippery ramp conditions;

- The usage of an deicing/anti-icing fluid that is compatible with the technical and chemical requirements of a recycling process, official international standards for fluid specification and further reuse as an aircraft deicing fluid. Alternatively an intelligent drainage/stormwater system for the diversion of specified and differing effluent flows could be installed; at present only Type I deicing fluids fulfill these requirements for recycling. The main negative aspect is the reduced
holdover time of the Type I Fluids which dictate the location of any aircraft deicing operation to be within close vicinity of the runway thresholds for take-off;

- Fluid recycling can only be performed effectively if a high collection rate of the runoff can be achieved. The areas where aircraft are deiced should therefore be limited in their dimensions to the absolute operationally required minimum. Therefore aircraft deicing operations have to be centralized and performed on dedicated deicing pads which have been designed to meet individual fleet mix requirements (ref. nr. 11 and 30). These deicing pads need to be fitted with a dedicated drainage system, that allows the fluid runoff to be directed to a recycling plant. During the 'off-winter period' a divert to the 'normal' stormwater runoff should be installed. The policy should be that for full-scale deicing, aircraft should routinely contact these pads. As the fluid runoff comes from relatively small ramp areas, the dilution would be at a minimum. As the exclusive dependence on such centralized pads may constrain the departure capacity of the airport, especially during departure peaks, controlled partial deicing of aircraft on the ramp at the gate/parking stand may be necessary;

- In order to ensure that all aircraft requiring deicing are deiced in the designated areas, it should be mandatory that the deicing concept is operated in such a way, that maximum flexibility in terms of facility layout and design is given for the implementation of deicing procedures of all aircraft types. Exemptions and low deicing volumes will lead to considerable fluid losses for a recycling process and reduce the possible gains in fluid collection and reuse.

Location Of Dedicated Aircraft Deicing Facilities

The location of aircraft deicing facilities should be as close as possible to the take-off positions, without degrading runway operational safety and without reducing aircraft manoeuvering flexibility within those sensitive areas (ref. nr. 11). From an operational point of view, the deicing facilities
(for mobile units or small robotic systems) should be located between 200 to 500 m distance from the runway centreline at those runway thresholds, which are assigned for the longest TORA/TODA (aircraft take-off run available, aircraft take-off distance available) normally the runway ends. The minimum distance chosen for a location of a fixed deicing facility from the runway centreline should be at least 400 m. If possible, the aircraft deicing facilities should be located within the competency area of the airport operator and not within the competency area of local ATC. A location of deicing areas/facilities within the responsibility area of local ATC, as demonstrated in the Munich Airport case, requires extensive regulations concerning the movement and operation of vehicles and personnel within such a safety sensitive area (ref. nr. 22). Especially under low visibility conditions, the danger of runway incursions by vehicles requires precautionary measures which are not only very complex but also expensive and not 100% safe. The centralized deicing areas/facilities can be constructed, depending on the individual layout of an airport, at numerous sites with increasing operational constraints towards the runways. Airport terminal/apron areas which are already close to main departure runways have the chance to upgrade their environmental runoff structures for gate/aircraft parking stand deicing operations. The precondition for such a location is that excessive gate delays do not exist, taxi times are within the limitations of fluid holdover times and weather conditions do not impede the operational safety status of the aircraft between the time frame of accomplished deicing and final take-off.

Design Of An Aircraft Deicing Facility

The design of such a facility (ref. nr. 11) should obviously incorporate the design criteria of the chosen deicing equipment. The design criteria for a fixed deicing facility, in this context either a deicing gantry (i.e. Munich Airport) or fixed spray booms, will result in different layouts of deicing pads for fixed and mobile facilities. When planning to operate mobile deicing facilities (i.e. deicing trucks or semi-robotic systems), the following design should be chosen:
The deicing area is designed to accommodate all operating types of departing aircraft for simultaneous deicing operations. Aircraft can enter and depart the deicing area unimpeded from other aircraft which require either a more complicated deicing procedure (i.e. prop aircraft) or require a total engine shut-down for visual and manual after-deicing checks (i.e. MD80/DC9). The deicing times may be standardized for certain aircraft groups, but as deicing procedures differ among airlines operating even same aircraft types of one nationality, delays due to different procedures and check requirements will have to be accepted. The suggested design standards allow a compensation of this particular issue and ensures a flexible and undelayed deicing operation, as aircraft to be deiced will enter a free lane for flexible positioning. Queueing or subsequent blocking of following aircraft on the taxiways will then seldom occur and may only build up under very adverse weather conditions. The deicing units can operate unobstructed within the designated deicing areas, as well as other technical assistance vehicles (i.e. electrical power supply units, air starters, tow tractors, etc.) Depending on the existing aircraft fleet mix, the layout of the deicing area should be either a common pad or composite pad layout.

- Deicing areas in a remote location close to a departure runway require permanent floodlighting systems, as the lighting systems of the deicing vehicles is not sufficient for safe operation in darkness.

- Access roads should be designed to accommodate heavy deicing vehicles and tow tractors, for those aircraft which require towing from the terminal area to the deicing pads.

- Finally, the deicing area should be totally surrounded by a fluid runoff collection system (dedicated drainage system), that will ensure a high effluent collection rate for recycling.
Organization Of Aircraft Deicing Operations

The operation of aircraft deicing should be organized in a way that reduces additional deicing of aircraft to an absolute minimum (ref. nr. 13 and 24). This includes any pre-engine start-up/pre-taxi deicing actions of flaps, slats, underwing and undercarriage as well as clear ice removal on the ramp. Additionally it should be ensured, through negotiation with ATC, the implementation of regulations stating, that deiced aircraft have a take-off priority within a time frame of a few minutes or otherwise have the beginning of the deicing operation delayed until a take-off clearance can be issued. Double deicings, due to lack of coordination with ATC, and departure delay due to inbound traffic, are not acceptable for economic reasons, as these situations are not only increasing the delay factor, reduce the safety margin, but also tend to lead to a drastic increase in the costs of deicing/aircraft. The equipment chosen for the deicing operation should be flexible to such an extent that the deicing of aircraft underwing areas is possible, subsequently reducing these deicing operations on the ramps. Regretably the present tendency is that the new high-tech deicers are not capable of performing these special kind of deicings, due to technical and operational limitations.

The Requirement For System Flexibility

As aircraft deicing operations vary in locations and procedures, a key issue is the requirement for system flexibility concerning the flow pattern of the drainage collection and, if chosen as a solution, a controlled fluid disposal system. The surface water collection and treatment systems at airports vary in their complexity and structure (ref. nr. 20 and 32), depending primarily on the age of the airport and therefore the technology available during drainage design, and the availability of sufficient area for surface water balancing and pollution abatement technology, including balancing ponds and diversion lagoons. In recent years the primary collection systems/stormwater systems for aprons, where aircraft are generally deiced, and the taxiways and runways have been designed to have separate drainage systems. The initial separation of drainage in this way
has allowed the provision of alternative treatment arrangements for the
different types of runoff associated with each area. A further development
of this approach is the design of specific deicing areas incorporating
deicing pads with dedicated fluid drainage. During deicing periods the
runoff from these areas is diverted to a recycling facility where techniques
are employed to separate the spent deicant from the surface water runoff.
The treated and cleaned runoff is then returned to the main surface
stormwater runoff collector system and the reclaimed deicant is either
reused, or more commonly, reallocated for industrial use. This will involve
the construction of supplemental "dirty" drainage systems additionally to
the dedicated glycol runoff fluid collection system intended for a recycling
process. The fluid discharge stream needs to have at least two, if not three
potential outlets which are - the recycling plant, the wastewater treatment
facility, and a receiving water course (if sensitive measuring equipment is
installed at the outlet)

This approach will help ensure maximum flexibility in fluid disposal and
recycling concepts. Certainly the receiving water course discharge
potential should be discouraged as a long term solution, as it contains
uncalculable risks and may conflict with the airport's environmental
protection policy.

Evaluation Of Environmental Requirements

The growing pressure on airports to maintain and improve their
environmental performance, and the recognition of deicants as a potential
source of aquatic pollution, has actually already resulted in a concentrated
effort by airport authorities around the world to identify the problems and
provide possible solutions. On environmental grounds it is, therefore,
desirable to minimize application rates. Especially in the western
hemisphere, environmental regulatory authorities are growing impatient
that airports continue to discharge deicing fluids in an often uncontrolled
way, causing severe damage to the biological health of receiving streams
and damage to wastewater plants from irregular flows of deicing fluids. In
many areas of the United States and Europe, environmental regulatory
authorities are beginning to impose fines and legal pressure on airport operators for uncontrolled glycol discharges. New constructed airports like the Munich Airport have experienced stringent and very painful new environmental protective measures imposed upon by the local and federal authorities. But these airports already now fulfill the most stringent environmental regulations ever imposed upon an airport operator. Many other airport operators will also undergo this development in the next years, as governmental authorities have the tendency to react slowly but reliably towards the changing climate of public environmental awareness. The development of new chemicals which will possess the same deicing capability as the existing formulations, with significantly reduced environmental impact potential, may help to improve the escalating discussions. But as airport operators have to face environmental pollution problems now, this issue is only of minor interest. The move towards deicant recycling, either for dedicated reuse as aircraft deicing fluid or for further industrial reuse and the growing utilization of intelligent drainage/stormwater systems and appropriately engineered pollution mitigation technology (i.e. biological treatment of glycol through water weed filtration – like the Zürich Airport Project - should enable airports to provide the necessary deicing capability and capacity while at the same time ensuring maximum environmental protection.

The following overall objectives should be regarded as mandatory to establish a comprehensive programme of operational management, water quality monitoring and reporting in order to minimize environmental effects and ensure compliance with glycol regulations:

- **Operational Management Objective** to ensure the establishment and implementation of Site Gycol Operational Management Plans (GOMP’s) for each airport where glycol is applied.
- **Water Quality Monitoring Objective** to develop and implement a surface water sampling and analysis programme at airports where glycol is applied in order to monitor compliance.
- **Reporting Objective** to ensure the preparation and submission of regular reports that detail product consumption, sampling information and climatic conditions for airports where glycol is applied.
Evaluation Of Economic Requirements
Recycle Or Biotreat

For most airports facing the runoff disposal issue, the decision must be made between recycling and biotreatment. In either case, means must be provided to collect and segregate the runoff and move it to the treatment facilities. For an airport the financial consequences are enormous. Investment at new airports like the New Denver International Airport (ref. nr. 30) or Munich International Airport (which amounted to over 30 million DM) can be huge, without considering the additional costs for deicing areas and additional technical and construction infrastructure. On the other hand without recycling, the deicing of aircraft would not be possible because the existing sewage treatment plants would not be capable, without the construction of cost-intensive large buffer bassins, to handle the large amount of fluid and BOD during a short period. By investing in recycling plants, the investment in storage enlargements of sewage treatment plants and subsequent increases in disposal costs for effluents may be saved (ref. nr. 32). In Denver, for example, the fee for delivering reduced glycol amounts to the metropolitan sewage treatment installation was lowered by 20%. An examination for the New Oslo Airport (ref. nr. 27) showed that at the present it is not economical to invest in the construction of a recycling facility. These different results show that at the present there is really no unique solution and each airport has to cope with different restrictions, thus specific cost and benefit calculation models have to be examined. As discussed previously, the economics affecting the decision are based principally on the composition and volume of the runoff to be treated, and on the market value of the recovered glycol if the decision is made to recycle the runoff (ref. nr. 45). Some airports may be fortunate in being able to arrange to dispose of their runoff water, at a reasonable cost, to a local sewage treatment plant. Such an arrangement would, of course, still require installing a means to collect and segregate the runoff, which would then be transported (if possible by pipeline) for treatment. But this disposal method is not always an available or economical option; many municipal systems are already overloaded and unable to process additional volumes. It would appear therefore that recycling is potentially viable for only a few large airports because available data indicate that the usage of deicing
fluids must be at least two million liters per deicing season, as diluted for use, for economic feasibility. Recycling also requires equipment that can distill and purify the glycol in the runoff from other contaminants such as fuel, hydraulic fluid, runway deicers, and cleaners so the recycled product is marketable. Even with extensive treatment after recovery, it is unlikely that recycled glycol can meet the quality requirements of the high-value segment of the marketplace. Anything less relegates the recycled product to low end applications. And finally, the wastewater from the recycling process contains organics that require a biotreatment operation before it is released into the environment. The cost of treating this water is often overlooked in recycling economics. Both capital and operating costs are higher for dilute streams of deicer runoff because of the need for increased storage volume and boiler capacity, additional evaporator stages, and increased throughput. Biotreatment of runoff is the more economically viable and technically assured option for the vast majority of affected airports. Both installation and operation costs are lower than those required for recycling, and the process utilizes proven technology, widely used by various industries (i.e. food and beverage, tannery, petrochemical) in successfully complying with environmental protection legislation and local requirements. The biotreatment design is different from that used in a conventional chemical plant aerobic facility, however, because deicer runoff will be segregated, resulting in high chemical oxygen demand (COD) in the airport runoff.

The main conclusions of Chapter 8 are that an airport's appropriate aircraft deicing/anti-icing strategy has to be embodied in an airport's overall environmental strategy. This can only be achieved by improving the current operational practices and the coordination issues together with local communities. The principles of environmental management need to address corporate priority and to establish policies, programmes and practices for conducting operations in an environmentally sound manner with all involved in the deicing process. Of major importance for an airport is to achieve a compatible aircraft deicing/anti-icing concept (ADC), since a recycling system cannot function efficiently if the aircraft deicing/anti-icing concept fails to be compatible. Airport operators have to identify analyse all variables in order to achieve the best concept for an individual airport. This
is a precondition for the establishment of a alternatives analysis which should incorporate operational, environmental and economic requirements and associated costs of a preferred system. The requirement for system flexibility is high, as aircraft deicing operations vary significantly in location and procedures. A key issue is the requirement for system flexibility concerning the flow patterns of the drainage collection system and a controlled fluid disposal system. Depending on the market price of virgin glycol, and according to information from several airports in the United States and Europe as well as reflecting on the Munich Airport case, recycling can never be profitable on a standalone basis with the cost of the recycling system infrastructure fully allocated. It is realistically only an option when environmental pressures and regulations (i.e. on Munich Airport) dictate that the stormwater must either be treated or recycled to comply with stormwater permits or water quality guidelines. Even then, recycling will be incrementally more expensive than biotreatment in almost all cases. Recycling costs have been found to increase dramatically as the scale of the unit is downsized or in years where mild weather yields less glycol for recycling. On the other hand, some revenues can be achieved from the sale of recycled glycol or possibly from the salvage of heat. The following Table 8-1 shows the savings in variable costs achievable through fluid recycling (aircraft deicing/anti-icing fluid). Savings can be compared with financial investment costs for the construction of a recycling plant or subsequent enlargement of an existing (not airport dedicated) sewage treatment plant.

<table>
<thead>
<tr>
<th>Deicing Fluid Formulation</th>
<th>Fluid Recovery Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diethylene glycol</td>
<td>19.5%</td>
</tr>
<tr>
<td>Propylene glycol</td>
<td>23.4%</td>
</tr>
</tbody>
</table>

Table 8-1: Comparision Of Cost Saving Potentials Through Fluid Recycling

For the vast majority of airports, however, biotreatment will still be the more economically viable and technically assured option.
Chapter 9

Conclusions - Part II

Developing A Generic Strategy

This final chapter attempts to identify the factors necessary for developing a Generic Strategy applicable to all airports, as well as examining the associated negative impacts and issues of the treatment alternatives. Finally, some overall conclusions are presented.

The rapid growth of the aviation industry has undoubtedly brought many economic and social benefits to the world. The ability to travel safely, comfortably, and quickly over long distances has given human beings greater access to distant places and a growing awareness of cultural diversity. However, it must be recognized that aviation, like any other human activity, has adverse environmental consequences that are increasingly becoming the focus of public attention. Environmental restrictions and legislation have become increasingly important in all sectors of the economy, and aviation, because of its visibility and its continuing image as a significant mode of transportation, has already been singled out for greater scrutiny.

It is not just the industry's current size that makes it so environmentally crucial. Another important factor is its continued rapid growth in many areas of the world. This rapid growth, coupled with changing public attitudes towards the environment and new information emerging on environmental problems that may be associated with aviation, means that efforts will need to be intensified in the future. While the environmental challenges facing the aviation industry seem daunting, it must be acknowledged that many improvements have been made, especially in the last two decades. Although notable successes have been achieved in the areas of airport planning and aircraft noise and emissions, efforts must be intensified in the future to continue to deal with these and many other
issues of importance. The international aviation, travel, and tourism industries are well positioned to lead the way and play an active role in minimizing a possible global ecological crisis. How can international air transport contribute to sustainable development? It could begin with the collection and transfer of environmentally sound technologies to assist international aviation, and the improvement of personnel training with a view to better management of environmental problems. However, a much larger task could also be envisaged, in the sense of a global approach to future environmental problems. If the aviation industry is to continue to survive and expand, and to be healthy and profitable, it must recognize the growing seriousness of environmental concerns in today’s society. Industry members must find productive ways to demonstrate that they are collectively committed to balancing their own needs with those of the environment. They must recognize that coordinated methods and measures are more effective in protecting the environment and in keeping down costs, and cause fewer problems for all parties than locally instituted strategies and policies do. Effective coordination can only be accomplished if all sectors of the industry are willing to share knowledge and work cooperatively, taking a global perspective.

A myriad of environmental problems are created as a result of activities associated with air transport. While noise and emissions from aircraft have historically received the greatest attention, following publication of Annex 16 (ref. nr. 46) of the Chicago Convention in 1969, it has been shown that many other environmental effects are also of major concern and demand attention. Many environmental programmes and initiatives have been developed in isolation by various airports and airlines around the world. However, the aviation industry as a whole lacks a coordinated approach to solving common environmental problems. As a consequence, the effects of these environmental initiatives are very localized and do not achieve their full potential. The global nature of air transport requires a system for dealing with environmental issues on an international basis, rather than through individual efforts that result in inconsistent and sometimes incompatible changes in technologies, regulations and policies. Isolated efforts on the part of individual sectors of the aviation industry have the
potential to produce a system fraught with incompatible practices and standards. The main challenge to the aviation industry appears to be the coordination of efforts to find timely and cost-effective solutions to environmental problems. Coordinated efforts would result in harmonization of standards and practices, sharing of the burden of achieving environmental compliance, promotion of the exchange of information and technologies, and reduced duplication of initiatives. Till then, airports are left alone to find effective solutions concerning their locally created environmental problems and to develop strategies which will enable them to continue the operation of their systems in an environmental friendly manner. It is contended that the issue of what to do with deicing fluids is a particular example of this overall problem. The following section attempts to develop a generic strategy to cope with this problem.

The Requirement For A Glycol Operational Management Plan

The increasing concern regarding glycol discharges at airports has become a major issue. Glycol discharges to surface waters have not only environmental consequences but also regulatory effects. Airport operations involve the use of a variety of pollutants which, if not properly used, contained, or collected, can make their way into nearby watercourses. The chemicals used in aircraft deicing and anti-icing activities, runway, taxiway, and apron deicing operations as well as runway cleaning operations are of primary concern. Storm-water run-off should be protected from these potential sources of pollution by minimizing the use of threatening chemicals; ensuring good housekeeping in their application; containing, collecting and recycling residual discharges; and where necessary, treating contaminated effluents prior to their release into natural water courses. The most effective means of determining whether the run-off from the airport property is degrading surface water, on and off the airport, is by sampling and analysing the water being discharged. A monitoring programme provides the data with which management can determine whether allowable levels of pollutants are being exceeded, identify the source of the problem, and address the problem by, for example, altering the practices that caused it. With a monitoring
programme, airport management can ascertain whether the airport is in compliance with existing legislation or standards, and react accordingly. Should a pollution incident occur, management will then be given early warning to put an environmental emergency plan into effect. To effectively address this issue, a Glycol Operational Management Plan needs to be developed by all airports concerned with the deicing/anti-icing of aircraft and ground deicing operations (deicing of runways, taxiways and aprons) and where glycol is generally applied in any form (compare with Figures 9-1 and 9-2). Such a plan should be prepared by the glycol operators/applicators in conjunction with the airport management, confirmed by the airlines representative board and be approved annually by the Airport Operations Director prior to the start of the deicing season (ref. nr. 22). Ideally such a plan should be integrated into an overall Airport Snow and Ice Management Strategy Plan, thus to ensure that all operational activities have been effectively coordinated and therefore their implementation is optimized and complies with the applicable environmental regulations. A Glycol Operational Management Plan should contain three sections:

- **Part One - Operational Requirements**
  Operational details including the description of deicing locations (aircraft deicing and ground deicing), glycol types and quantities, application methods of fluids (aircraft and ground deicing) and storage and handling of fluids at the airport.

- **Part Two - Environmental Issues**
  Environmental Contingency Procedures outlining the procedures to be implemented and any equipment/infrastructure to be established to clean-up discharged glycol when glycol guidelines have been exceeded. Additional information should be incorporated containing the methods of glycol capturing by fixed installations (dedicated drainage collection system or stormwater collection system with controlled outlets) or by mobile units (vacuum cleaning trucks). Any Exceedences are to be identified through a mandatory airport water quality monitoring plan.
• Part Three - Legal Requirements

The completion of a monthly glycol report may have to be submitted to the responsible governmental institution for interpretation and formal reporting to the local environmental control authority. The data should include information on weather conditions, glycol consumption, sampling times/locations and analytical results.

Figure 9-1:
Structure Of An Overall Deicing Management Plan

Figure 9-2:
Structure Of A Glycol Mitigation Plan
Safe and efficient aircraft operations are of primary importance in the
development of any aircraft deicing facility. The design of deicing facilities
should, to the extent practicable, meet the needs of air carriers as outlined
in the aircraft ground deicing/anti-icing programmes as well as all other
elements of the aviation community. A key element in this effort is
designing a facility that is efficient and offers the users operational
flexibility (ref. nr. 11). By coordinating an airport manager's Snow and Ice
Control Plan and user's ground deicing/anti-icing programmes with inputs
from the regulatory authorities (ref. nr. 13 and 14), an airport is in a better
position to handle icing conditions. Because the primary concern with
airborne transportation is safety, and the use of chemical deicers is a very
effective means to that end, the reasonable use of aircraft chemical
deicers must continue. Therefore airports must continue their deicing
practices without compromise while implementing changes designed to
minimize or eliminate the discharge of deicing chemicals to surface and
groundwaters. One option which may be feasible for airports to consider is
to capture deicer-laden runoff in aerated retention basins. This would
result in a greater degree of biodegradation on-site, reducing the BOD of
the waste. However, this treatment may require extensive storage capacity
and long retention times, and may carry with it the aesthetic problem of
odours. Such a solution may be completely impractical for the problem of
glycols in runway stormwater runoff, due to the excessive storage capacity
that would be necessary. If aircraft deicers could be collected at
sufficient on-site retention and biodegradation, the waste may be acceptable
for discharge to a municipal wastewater treatment facility under
prearranged terms that would prevent hydraulic or organic overload of the
system. Because the glycols are valuable organic chemicals derived from
petroleum, the potential for recycling the waste from aircraft deicing is
very attractive and necessary. However, the feasibility of this option is
dependent on the ability to collect a relatively concentrated waste stream
without significant contamination by other stormwater components. It may
not be cost effective to distil and recycle waste glycol solutions or
reconcentrate them by glycol addition, at concentrations lower than 15 percent.

To obtain a relatively clean and concentrated used glycol solution, a system of centralized deicing seems necessary. Central deicing facilities can provide a closed circuit, for which the aircraft deicing fluid is then completely recovered, at the same time eliminating the risk of glycol release to the environment. Such systems are uncommon, but are reportedly in use by UPS (United Parcel Service) in Louisville, Kentucky; Continental Airlines in Denver, Colorado and Munich Airport in Germany. The system used at Stapleton International Airport by Continental Airlines reportedly captures the used glycol solution at 25-40% glycol concentration. Centralized deicing systems may be impractical for all but the largest airport operations due to the cost and physical size. For the established airports, a switch to centralized deicing would present a number of operational and logistical problems that may prevent this from being the most cost-effective solution (ref. nr. 29 and 30).

A possibility which may evolve in the future is the development of alternative chemicals for deicing which may be more environmentally friendly (ref. nr. 34). A few such products are currently being developed and evaluated for effectiveness, cost, toxicity and environmental impacts. Since deicing/anti-icing fluids are chemical products with environmental consequences, deicing facilities require runoff mitigating structures. The recommended structures collect and retain runoff for proper disposal or even recycling. In terms of "best management" practices, this approach to "control the source" offers airport managers an effective and economical means to comply with storm water requirements.

The mitigation alternative should allow users of the deicing facility continued use of deicing fluids within the framework of Federal, state, and local storm water runoff regulations via discharge permits. It is strongly recommended that the proposed alternative be reviewed by the Federal, state, or local environmental authority having jurisdiction to verify its effectiveness to place the deicing facility in regulatory compliance. Prior to
final selection, all alternatives should be evaluated on a life cycle cost basis to avoid an accepted long term alternative with a short useful life. Additionally, it should reflect the best alternative afforded by the facility's site and integration with the airport master drainage plan.

Effluent fluid recovery with a vacuum tank truck may be another means of collecting dilutions and obtaining feedstock for a recycling plant. The objective of such an operation is to collect in a controlled way concentrated fluid and to reclaim the glycol in this fluid dilution for further use. Vacuum tank trucks are mainly operated outside trench drain systems of apron areas or where existing stormwater systems cannot cope with any kind of glycol dilutions. This generally reduces considerably the risk of glycol dilutions escaping to below the surface of aprons or escaping uncontrolled into glycol-uncompatible stormwater systems. Especially prior to a rainfall period and precipitation of any kind, such ways of fluid collection ensure that the captured diluted fluids have a relative high glycol concentration and airport stormwater systems are only contaminated with very low glycol dilutions. Although this type of fluid recovery seems to be an effective course of action, there are six sets of problems associated with such an operation:

- Aircraft aprons and aircraft parking stands suffering considerable peak congestion during daily operating hours inhibit the use of such vacuum tank trucks, as there is only very limited opportunity to deploy the sweepers before the next aircraft is parked on the stand. Airports with a high proportion of terminal pier stands have this problem, with one aircraft on push-out and the succeeding aircraft just landed already waiting to taxi onto the parking stand. There is then already considerable pressure to reposition the new aircraft servicing equipment, leaving little time and possibility to perform time consuming vacuum cleaning actions.
- The fluid storage capacity of a standard vacuum cleaning truck is limited and thus it has to be considered to operate more than one vehicle at the same time. Due to the fact that this kind of operation is generally implemented at airports where aircraft deicing operations are performed
in a decentralized way on apron areas, this will involve considerable vehicle investment costs (as well as operating and maintenance costs) and manpower utilization. Especially during the daily peak operations an extensive fleet of vacuum vehicles would be required to ensure continuous collection of fluid dilutions at all aircraft parking stands where deicing has been performed.

- Special fluid vacuum vehicles are only in use for very limited periods of time, even during the deicing season, thus in general questioning their economics and even effectiveness under differing weather conditions. Especially during weather conditions with considerable precipitation, the concentration of the diluted fluids may be reduced to such an extent that the vacuum vehicles actually only collect water with a very low glycol concentration. Depending on the intensity of aircraft deicing/anti-icing operations undertaken in conjunction with parallel snow removal and ground deicing operations, glycol dilutions may be transferred to areas not receiving any treatment at all, as being outside the official deicing areas. The operation becomes uneconomic and highly questionable.

- The operation of vacuum recovery on aircraft parking stands during precipitation under freezing conditions requires additional pavement deicing/anti-icing operations in order to prevent the quick build-up of further icing conditions on the parking stand. This is due to the fact that the vacuum sweeper collects not only aircraft deicing fluids but also all other sprayed ground deicing fluid.

- The use of vacuum sweepers on centralized deicing areas or pads also requires time intervals between two aircraft deicings for pad cleaning activities. Again, such deicing areas suffer even higher aircraft congestion during peak times. Without an existing and compatible fluid recovery system, the uncontrolled fluid loss (into adjacent soil) would be significant, as the vacuum vehicle could not operate continuously.

- Due to differing concentrations of the dilution and fluid specifications the collected fluid cannot be recycled and effectively reused as a specified aircraft deicing fluid. The dilution will then contain a continuously differing mixture of aircraft deicing/anti-icing fluids (ADF Type I and II) as well as ground deicing fluids or substances (e.g. dissolved urea dilutions, glycols, etc.). The cleaning of this type of dilution for further
reuse, even if only for any kind of ground deicing fluids or further industry reuse, is complicated and requires extensive and high sophisticated technical treatment facilities.

Recommendations For The Deicing/Anti-icing Of Aircraft

I. Deicing or anti-icing are important flight safety factors and should consequently be given high priority. Anti-icing of aircraft is carried out shortly after landing or shortly after deicing, with the intent to avoid or reduce deicing prior to the subsequent departure of the aircraft. Deicing of the aircraft takes place immediately before departure.

II. Deicing or anti-icing agents may cause severe environmental damage if disposed of into surrounding waters and they can cause pollution of soil and ground water if disposed of in an uncontrolled way.

III. To avoid pollution, the construction of separate facilities for deicing and anti-icing should be encouraged, so as to ensure that the glycol and other liquids are collected for recycling or destruction to the maximum extent possible.

IV. The adoption of anti-pollution measures already at the planning stage will minimize expensive remedial and purification action at a later stage.

Summary:

Disposal of chemicals used for deicing and anti-icing of aircraft may cause severe environmental damage. These chemicals should therefore be collected for recirculation or destruction.
Recommendations For Deicing And Anti-icing Of Runways, Taxiways, Aircraft Stands, Pavements And Other Similar Locations

I. Airports are normally responsible for deicing and anti-icing of runways, taxiways, aircraft stands, pavements and other similar airside locations to secure the safe operation of aircraft and ground traffic, when so required by weather conditions.

II. Various chemical materials are available for this purpose, for example, glycols, urea, and acetate products. Depending on local conditions, these products may cause pollution of soil, ground water and surrounding waters. Airports should therefore evaluate carefully their local conditions and select the product or combination of products that would cause the least pollution.

Summary:

Airports should pay particular attention to the extensive environmental damage that can be caused by products for deicing and anti-icing of their aircraft movement areas or other similar airside locations.

Integrating these recommendations into the ICAO Annex 16 would encourage more airports to reconsider their policy and thus would lead to a better acceptance of these recommendations. As long as only few airports are required to implement environmental protective measures, due to national and local administrative pressure, the acceptance within the industry will only be very limited, as the implementation of such measures demand high investment costs for the airports and also the users of the system, the air carriers. Due to the growing competition between airports, the tendency will be that no airport will be willing to go ahead on a voluntary basis with such an environmental protective measure, as this airport is bound to suffer some kind of operational and financial penalty.

Improving the environmental record of airports and their infrastructure is crucial, if any progress is to be made towards the enhancement of the worlds environment. If the aviation industry is to survive and expand, and
to be healthy and profitable, it must recognize the growing seriousness of environmental concern in today's society. Industry members must find productive ways to demonstrate that they are collectively committed to balancing their own needs with those of the environment. They must realize that coordinated methods and measures are more effective in protecting the environment and keeping down costs and cause fewer problems for all parties than locally instituted strategies and policies do. Effective coordination can only be accomplished if all sectors of the industry are willing to share knowledge and to work cooperatively, taking a global perspective. Specific efforts should be directed to reducing disturbance from aircraft operations, improving air and water quality, increasing energy efficiency, minimizing the use of environmentally sensitive materials, promoting recycling and the use of recycling materials where cost-effective, minimizing waste and the consumption of material resources, developing environmental standards and practices and promoting these throughout the aviation world, developing compliance standards for noise, water quality, waste management, energy use and regular monitoring performance.

As higher regulatory standards for aircraft safety, personnel safety, and environmental protection are being established, the costs of deicing aircraft are significantly increasing. Additionally, competitive market demands are forcing airlines and also airport operators to reduce their costs. These factors combine in generating a need for a review of current and alternative deicing processes, equipment, and last not least environmental protection methods.

Developing A Generic Strategy For All Airports

There is no perfect alternative—no one solution to the aircraft deicing problem fit for all sizes. When evaluating spent ADF disposal alternatives, site-specific conditions need to be addressed and taken into account when developing a generic concept. It is of importance to focus in short again, prior to further considerations, on some disposal options for deicing fluids
that can be and have been implemented by various airports. There presently exist only three viable disposal options which are acceptable considering environmental protection criteria. These are discussed below.

**Discharge To A Local Publicly Owned Treatment Works (Alternative I)**

Many municipalities operate Publicly Owned Treatment Works (POTWs) to treat the sewage generated by the community. The POTWs are designed to treat a certain amount of BOD per day, but are often over-designed to accommodate possible increased growth of a community. In such cases, the POTW may be able to treat the spent ADF generated by the local airport. If the POTW is willing and able to treat the spent ADF, airport and POTW personnel should establish the conditions under which the POTW will accept the spent ADF. The POTW may charge the airport on a per liter basis or on the amount of BOD treated. As the POTW has a maximum daily capacity, the amount of ADF or BOD treated in a day may have to be limited. In such cases the airport will have to consider building additional storage facilities for spent ADF to ensure operational flexibility and thus deal effectively with bottleneck discharge limits during certain periods of the year.

**Off-Site Treatment (Alternative II)**

Airports may appoint a contractor to dispose of its collected effluent. The contractor will haul the spent ADF to a sewage treatment plant for further disposal. The airport will probably be charged on a per liter basis. A major problem though are the costs associated with the transportation of the effluent by trucks and the operational logistics of such a concept (ref. nr. 35).
Recycling Of Spent ADF (Alternative III)

The glycol contained in the spent ADF may be of value to the chemical recyclers. However, the recycler must remove any other contaminants from the glycol solution to prepare it for sale. The spent ADF contains water, but it may also contain residual fuels, oil, grease, sand and grit. The recycler may select a membrane process to separate out the desired contaminants leaving the glycol and water. A distillation system could be used to separate the water from the glycol, thus making the product ready for sale. This type of procedure is mostly common for effluent recycling. Recycled fluid can then be sold for industrial purposes or brought back as dedicated aircraft deicing fluid. In the latter case special attention has to be focused upon a quality assurance programme and operational safety regulations (ref. nr. 29 and 34).

Effective And Efficient Treatment Of ADF Effluents

Airlines prefer to handle all aircraft operations at or near the departure gates. These operations include cleaning the interior and exterior of the aircraft, fuelling, servicing, loading passengers, bags, freight and meal services - and deicing. Servicing aircraft at the gate provides all services at one location and provides the optimum efficiencies of manpower and equipment utilization. Most potential spills of deicing fluids, toilet fluids, residual jet fuel, oil and grease can be contained into a single drainage system and collected and treated with one process if all servicing activities are accomplished at the gate. This arrangement may provide the best operation efficiencies for the airlines and the lowest cost treatment of discharged fluids at the airports for the airport authorities. Since all airports now have paving and drainage at the terminal areas, no new construction would be required at the terminals to facilitate collection of spilled fluids in these locations. No new taxiways or deicing pads would be required. Construction would only be required at remote airport locations for storage facilities. Construction costs would be considerably less than those required for new centralized or remote deicing pads. Treatment
systems would still be required for fluids collected at remote deicing pads.

Remote deicing pads and associated treatment systems would not be able to collect those fluids that are spilled during other servicing operations at the gates, therefore additional treatment may be required for those facilities. Building remote deicing pads may require more than one treatment system as well as the additional construction costs for taxiway and aircraft parking facilities. Aircraft operation and servicing costs would be more expensive with remote deicing facilities due to ground personnel being required to work in two different locations to prepare the aircraft for take-off.

The Biological Treatment Alternative

While deicing fluids containing glycol based chemicals have BOD concentrations, other potential fluid spills can also cause serious environmental contamination of rivers and streams. Many of the treatment alternatives, including distillation for glycol recycling, focus on just the ADF and will not be effective in treating all potential spills. Using a treatment system that can treat spills from all of these fluids would be important for contamination as well as cost control (ref. nr. 31).

Microorganisms used in dedicated biological treatment systems have proven to be able to treat the high levels of BOD found in deicing fluids. Treatment can either be by aerobic or anaerobic processes. The cost of these systems can be considerably lower than the activated sludge plants found at POTW's and have much lower operating costs. Historically, aerobic treatment systems have processed more contaminated wastewater than anaerobic facilities in an equivalent period of time, while anaerobic facilities generally generate less sludge and have lower energy costs. Sludge production in an anaerobic facility has been shown to be on the order of one-tenth that produced by an aerobic plant. Recently, new high-rate anaerobic processes, including the anaerobic Mobilized Film Technology (MFT) and the upflow anaerobic sludge blanket, have proved to be superior to conventional aerobic facilities in treating high strength
wastewaters such as ADF’s. They have proved that they can do the same job in less time at a fraction of the capital and operating cost. Anaerobic treatment systems can be installed at airports in locations that can intercept the existing runoff associated with precipitation and washing of ramp areas. Most of the contamination associated with these fluids can be efficiently removed by the anaerobic system leaving a contaminant free effluent liquid for discharge to the domestic sewage collection system for polishing by the local POTW or the natural drainage system at levels that are within the approved local and national discharge limits.

Operating costs and capital costs are lower for anaerobic treatment systems than for large activated sludge treatment plants. Sludge production, electricity demand and chemical requirements for anaerobic treatment of ADF are significantly less than those associated with an activated sludge treatment plant. All ADF can be accomplished either on airport property or trucked to a dedicated treatment site. Construction costs for central or remote deicing pads including new taxiways can be very expensive when compared to the cost for intercepting existing drainage lines and installation of an anaerobic treatment system. Yearly maintenance and operation costs for an anaerobic treatment system may be much less than paying for treatment at most POTW’s. Providing a system that would allow the airlines to perform all operations at the departure gate would present the airlines with the most efficient use of equipment and manpower. Additional equipment or personnel would not be needed to prepare the aircraft for take-off. Holdover times may, depending on the general airport layout, be better controlled by ATC than by deicing the aircraft at centralized or remote deicing pads. Considering capital, operation and maintenance costs for anaerobic treatment systems, these costs would be inexpensive and substantially lower when compared to the associated costs of remote deicing pads, transportation costs for trucking or surcharge on discharge to domestic sewage collection systems, and treatment costs charged by POTW’s. Anaerobic treatment systems can be used in strategic locations at airports to control and treat airport generated contamination prior to discharge to domestic sewage collection systems or to natural water courses. This would include deicing fluids, oil and grease,
toilet spills, residual jet fuel, and some types of cleaners used to clean the equipment and facilities at airports. Anaerobic treatment systems can treat petroleum based contaminants and chlorinated solvents without detrimental effect to the microorganisms and provide low capital and maintenance costs when compared to other alternatives considered for solving the airport contamination problems.

Associated Negative Impacts And Issues Of The Treatment Alternatives

The three alternatives that have been considered for the disposing of glycol contaminated stormwater have associated negative impacts for the airports and have to be addressed and taken into consideration when evaluating the treatment alternatives.

Alternative 1 - Discharge to POTW

- ADF’s are high strength wastewaters, thus they will impact negatively on POTW’s in many ways. POTW’s, especially aerobic facilities, are designed to treat low strength wastewater to a very high degree, not to treat high strength wastewater. The ADF effluent occupies treatment capacity reserved for residual growth and increases aeration requirements, thus increasing electricity costs.
- An increase of biosolids (sludge) generation is unavoidable, which occupies anaerobic digestion system capacity, increases chemical costs for biosolids conditioning, increases operation costs for sludge dewatering and for sludge disposal.
- An increase in the risk of violating discharge permits.
- An increase in the level of manpower, monitoring, and analytical input.

This results in POTW operators becoming more and more reluctant to accept high strength wastewater such as ADF’s, especially as the true potency of these fluids are becoming better known.
Alternative II - Off-site Treatment

Airports planning to transport ADF effluent to an off-airport site for disposal not only have to consider the issues of effluent transportation and operational logistics, but also the following negative impacts of such an operation:

- Dedicated off-site treatment systems are biological systems that have to be specifically designed to treat the ADF stormwater prior to discharge to local receiving waters or the local POTW domestic sewage collection system. These systems have to consist either of aerobic facilities (activated sludge, aerobic ponds, sequencing batch reactors, biological contactors and extensive wetlands) or conventional anaerobic facilities (mixed digesters, anaerobic ponds, anaerobic packed-column trickling filters).
- Aerobic systems, like most POTWs that use them, are not designed to treat high strength waters such as those associated with ADFs. This results again in high capital and operating costs.
- A significant disadvantage is the low decay rates which occur as the temperature of the liquid decreases. Since the greatest treatment capacity is required during the coldest times of the year, the rate of treatment is very slow requiring extensive and large systems and the need for containment.

Alternative III - Recycling

The recycling of spent ADF, consisting of either ethylene or propylene glycol, is an energy-intensive process. Airports considering a recycling concept must consider the following issues and negative impacts that are associated with such a concept:

- The use of ethylene or propylene glycol has to be standardized, as the
mixed streams of the two compounds have virtually no recycle value.

- There exists a significant market for recycled glycol, though not for the reuse on aircraft due to SAE batch certification requirements.
- Recycling is quite effective when ADF glycol concentrations are 30%-50%; however, they become economically unattractive as the concentration decreases. Since most ADF stormwater has glycol concentrations less than 10%, recycling, as an ADF treatment alternative, is not economically viable until airports develop methods to retrieve the glycol prior to dilution, i.e. construct facilities such as covered, centralized deicing pads. Even then, it is anticipated that significant volumes of ADF with concentrations less than 30% will continue to be generated.

Final Conclusions
Considerations In Establishing A Generic Strategy

When establishing a generic strategy aimed at being able to assist an airport’s decision making process in defining the most economic, operational and environmental compatible alternative for a fluid treatment system, it has to be noted that only the combination of general and airport specific considerations will lead to an individually successful airport fluid treatment concept for ADF’s. Of major influence is also the national regulatory framework concerning environmental protection legislation and national economic factor’s (i.e. construction costs, manpower costs, etc.). That said, the following general generic considerations have been identified to be of special importance and influence in a decision making process:

Weather Forecasting

The predictability or forecasting of icing conditions, the problem of “now casting weather situations” is still an area where significant improvements could be achieved. This is of fundamental importance to any efficient
functioning of airport operations in winter conditions and is also a precondition to achieve an environmentally sensitive concept of glycol consumption for aircraft and ground deicing/anti-icing operations. The major aim is to effectively minimize glycol consumption by implementing the "just-in-time" fluid spray concept, thus reducing glycol consumption to an absolute minimum (within acceptable safety limits) in relation to current calculable weather conditions. Such a concept has to be computer aided and controlled, in order to process and evaluate all available weather data in various airport locations.

Development Of Compatible Aircraft Deicing Facilities

The development of compatible aircraft deicing facilities (capable of effectively collecting glycol runoff) that meet or exceed airport/aircraft departure capacity (ref. nr. 18) in a cost effective manner is a further generic consideration to be addressed. Since aircraft deicing facilities are a very expensive investment, an important issue may be the effective use of such dedicated deicing areas during non deicing periods or events for alternative uses (i.e. additional aircraft parking areas, engine run-up positions, etc.). The design of an aircraft deicing facility (ref. nr. 11) has been addressed as well as the additional mandatory operational requirements concerning equipment, manpower resources and training, communication and programme control process and last not least airport facility issues (i.e. the airport snow clearance concept). General design criteria may have to be changed significantly in order to achieve full operational compatibility with existing facilities or airport layout restrictions.

Environmental Considerations/Treatment Of Glycol Effluent

Today, within an increasing number of airports worldwide, the need to contain spent glycol effluent's from reaching natural waterways (otherwise known as Glycol Mitigation) is rapidly coming to the forefront of airport
operation and directly affecting air carriers and thus deicing operators deicing operations. At some airports extraordinary efforts have been extended to not only contain deicing fluid runoff, but in some cases to treat spent fluids for the purpose of recycling the same for either reuse to deice future aircraft, or to be sold to secondary markets. Examples of these advanced operations include world leading airports such as Munich International, the new Denver Airport as well as Paris Charles de Gaulle. Specially designed remote off-gate deicing facilities are currently under development at Montreal Dorval and Toronto Lester B. Pearson International Airport. For most airports facing the runoff disposal issue, the decision must be made between recycling and biotreatment. In either case, means must be provided to collect and segregate the glycol runoff and move it to treatment facilities, the alternative being an on-airport or off-airport treatment facility. Economics affecting the decision will be based principally on the composition and volume of the runoff to be treated, and on the market value of the recovered glycol if the decision is made to recycle.

Development Of An Ice Scanning/Detection System

The development of an ice scanning/detection system, an automated scan system to confirm 'aircraft clean' prior to take-off, needs to be encouraged in order to ensure a total "clean" (free of any deposits) aircraft for take-off, a significant reduction of the human error factor, a significant reduction of fluid consumption if applied prior to the fluid application process. Icing on aircraft is an important issue for flight safety and recent accidents have brought this to the attention of regulating authorities and also to the public. This has led to a further evaluation of the actual effects ice accumulation can have on aircraft performance. The effect on stall speeds even on larger jet aircraft can be dramatic. Also, ground wing contamination issues are rising to the forefront with renewed emphasis placed on the requirement for a "clean" wing on take-off. Pilots, as well as ground deicing crews, have no reliable way to assess the amount of ice accumulation on the aircraft. The lack of accurate input available to the pilots plus increased demands to
maintain flight schedules has caused decisions regarding ground icing to be some of the more difficult faced by pilots in routine operation. The integration of flush mounted sensors is presently being examined and developed by several companies, the sensor system providing a pilot with accurate, reliable information on the state of the wing or fuselage surface. This includes detection, thickness, and characterization of ice and snow, the ability to distinguish ice from de-/anti-icing fluids, and to provide a measure of the state of the fluids. It can also be used in the determination of contaminants likely to be encountered in the environment such that these do not cause erroneous readings. For ice detection on the ground, the development and use of infrared cameras could help to reduce the "human error factor" of the aircraft deicing crews when evaluating the status of aircraft wings and fuselage.

However, there still exist considerable technical and operational problems with the implementation of such a system. Initial laboratory prototypes have been tested, but results were not sufficiently successful that the working prototype could be used in all weather aircraft deicing conditions; the working prototype being too heavy and large in size to be operated manually by hand from a platform or ladder. The system will only be successful, if a dual aircraft ground ice detection approach is being made. This includes an aircraft surface ice detection system as well as an airport facility freezing rain detection system. If aircraft surface ice detection becomes part of the overall ground icing prevention strategy, then the role of such an ice detector must be determined within national and international regulatory bodies, the systems must be tested in actual use and finally there is a need to define a timetable for the implementation of such systems. The sensor requirements in particular need to be internationally defined to meet generally agreed standards.

Consideration Of New Aircraft Deicing Technologies

New technologies in aircraft deicing may change present aircraft deicing operations considerably and may have the potential to reduce the
environmental impact substantially, that nearly all present environmental issues concerning conventional (fluid) deicing of aircraft may become obsolete. Such a technology is being presently tested and seems very promising. The application of infrared energy to aircraft surfaces, having a high, concentrated output and a wavelength matched to optimize the removal of ice and snow has successfully reached prototype status. Such a system could incorporate a high degree of flexibility in order to address many aircraft sizes. Tests have demonstrated that even severe icing on aircraft can be effectively removed within a very short period of time. Many operational questions are still unanswered, but it is a promising new technology that may effectively question existing glycol usage and glycol collection (disposal or recycling) in the near future. Airport operators should therefore incorporate such new technological potentials in their overall decision making process in order to ensure that they adopt an aircraft deicing policy which is as modern and open minded as possible.
Glossary

ATC  Aerodrome Control Office

ADF  Aircraft Deicing Fluid

APU  Auxiliary Power Unit

ADF Type I  Aircraft Deicing Fluid Type I
(unthickened)

ADF Type II  Aircraft Deicing Fluid Type II
(thickened)

AEA  Association Of European Airlines

BOD  Biological Oxygen Demand

CAB  Civil Aeronautics Board, United States

COD  Chemical Oxygen Demand

FAA  Federal Aviation Administration, United States

FMG  Munich Airport (Airport Operator)

EPA  Environmental Protection Authority, United States

GANTRY  Fixed deicing facility installation

IMC  The designation for Instrument
Meteorological Conditions for aircraft
operations in reduced visibility conditions
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<tr>
<td>ISO</td>
<td>International Organization For Standardization</td>
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<tr>
<td>MFT</td>
<td>Mobilized Film Technology -high rate anaerobic process</td>
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<tr>
<td>NTSB</td>
<td>National Transportation Safety Board, United States</td>
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<tr>
<td>NLA</td>
<td>New Large Aircraft (present planning status)</td>
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<tr>
<td>POTW</td>
<td>Publicly owned sewage treatment works</td>
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<td>SAE</td>
<td>Society Of Automotive Engineers</td>
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