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De-icing Agents

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EXECUTIVE SUMMARY

- It is estimated that typically 12,000 tonnes per year of glycol is purchased for antifreeze or de-icing activities. Approximately 4750 tonnes are used for airfield and aircraft de-icing, 7,200 tonnes for antifreeze in engine cooling systems and 50 tonnes for miscellaneous uses. While the antifreeze consumption represents the largest proportion, its impact on the environment is significantly less as any discharge to the environment is over the whole year, is spread over the whole urban area of the UK and in many instances will be discharged to combined or foul sewers.

- Ethylene and diethylene glycol are toxic to humans but propylene glycol is relatively harmless. Recommended limits for glycols in drinking water are reported as 1 mgl^{-1} (USSR) and 0.14 mgl^{-1} (USA). Aquatic toxicity occurs at concentrations of approximately 100-1,000 mgl^{-1} for ethylene glycol and 1,000 mgl^{-1} for diethylene glycol and propylene glycol, although chronic effects such as loss of equilibrium in fish may occur at lower concentrations.

- Glycols are biodegradable and exert a heavy oxygen demand, with BODs of the order of 300,000 mgl^{-1} for diethylene glycol, 800,000 mgl^{-1} for ethylene glycol and 1,000,000 mgl^{-1} for propylene glycol. Physico-chemical treatment methods considered to date do not seem practical. Biological treatment, at suitable temperatures, appears to be the most practical treatment method. Treatability testing of contaminated runoff has given rise to problems of bulking and foam formation in activated sludge systems. Prolonged aerated storage appears to be an effective treatment system.

- Whilst reuse of glycol at centralised facilities for aircraft de-icing has been adopted at a few airports overseas, it does not eliminate pollution, due to de-icing of runways and taxiways. For several reasons it appears unlikely that centralised aircraft de-icing would be adopted in the UK.

* At all major commercial and military airfields stormwater will be contaminated as a result of the use of chemicals for de-icing activities in winter. At most of the large civil and military airfields using glycols, peak concentration in stormwater may exceed 1,000 mgl^{-1} on occasions. At civil airports glycol is used for aircraft de-icing and frequently for runway and taxiway de-icing. At military airfields any glycol use is associated with de-icing of runways and taxiways.

* Since at commercial airports de-icant chemicals are used as part of an industrial/commercial activity, contaminated stormwater is considered by several Regional Water Authorities (RWAs) to be an industrial discharge and consent conditions are starting to be applied. The consents are likely to vary depending on the location. Where airports are in a catchment upstream of a drinking water intake, or over an aquifer used for potable supply, the standards are likely to be fairly stringent; typically 20 mgl^{-1} glycol, or 15 mgl^{-1} BOD and 2 mgl^{-1} ammonia (generated as a result of the hydrolysis of urea).

* Apart from the potential for impairing the quality of water to be abstracted for water supply, there is little evidence from RWAs and Scottish River Purification Boards of regular major impacts due to the use of glycols at airports. There are more reports on the impact of ammonia (from urea). The lack of impact of glycol in most cases is likely to be due to:

  - low water temperatures, which mean that the oxygen demands exerted are much smaller than the 5 day 20°C BOD;

  - river flows in winter not generally being at their lowest;

  - the metabolic activities of flora and fauna being lower and therefore less sensitive to water quality;

  - upstream dissolved oxygen concentrations being significantly higher than in summer;

- much of the glycol load discharged not in fact being balanced at most airports, but being discharged in slugs following rain when receiving waters will also have higher flows.

* From the RWA point of view, they are bound by the requirements of COPA II and as such their records are open to inspection by the general public, pressure groups and other industrialists (or farmers) with direct discharges to rivers. They are also presently under pressure to improve river water quality. RWAs are also reluctant to attach a "percentage compliance" to an airport discharge as this means sampling programmes become extensive and costly and any legal action becomes extremely difficult and prolonged.

* It is open to discussion whether the criteria for water quality objectives in rivers which are not used for potable supply presently reflect the seasonal variation in glycol (ie BOD), which could perhaps be tolerated in winter in rivers when temperatures are low and flows are not at their minimum. However, the trend for European harmonisation of water quality standards together with a general tightening of standards would appear to preclude such an approach.

* Whilst RWAs sympathise with the problem of stormwater contamination at airports, since it is associated with safety connotations, they cannot be expected to treat airports as special cases otherwise they would have difficulty in justifying the consent conditions applied to their own sewage treatment works or, perhaps more importantly, to other direct discharges (eg industry or farms). This control in England and Wales in the future will be the responsibility of the National Rivers Authority.

* From the standpoint of the Airport Companies, they are faced with dealing with a problem which is largely outside their control. They do not know how severe and how prolonged the cold weather will be in many winters or the pattern of rainfall or snowfall.

Furthermore, the range of winter weather that can be experienced is very wide and it would be onerous to provide treatment and/or disposal facilities that would be used to their full extent only once in every 5 or 10 years. However, even if facilities to deal with such frequencies are provided, they will inevitably going to fail in a very severe winter (which could theoretically occur shortly after commissioning).

* Where facilities are designed on a 1 in 5 year or 1 in 10 year winter basis, they may involve airports in expenditures in the £1 - 10M range it fixed discharge standards of 20 mgl^{-1} glycol are imposed. Slight relaxation of standards to say 30 or 50 mgl^{-1} would not reduce expenditure; relaxation to several hundred mgl^{-1} on occasions would be necessary to have any major impact on cost implications for airports.

* The Airport Companies will need considerable time to study their problem and produce a solution which is reliable and cost-effective. The layout and drainage systems of most airports have not been constructed with a view to separation and treatment of contaminated stormwater. Furthermore, there are also new de-icant chemicals being developed, for example acetate compounds which have only about 30% of the BOD of equivalent glycol usage and which, if deemed acceptable, may have a significant bearing on any treatment proposals. Trials were scheduled in UK early this year but the prolonged mild weather caused their postponement.

* In the light of the foregoing summary, it is considered that a round-table discussion between the DoE and interested parties (or sub groups of the interested parties) would be beneficial to review the overall problem.

1 INTRODUCTION

In June 1987, Consultants in Environmental Sciences Ltd (CES) were commissioned by the DoE to undertake research studies into the use of timber preservative chemicals and deicing agents. The study of timber preservatives was 14 months duration while the programme for the glycol study comprised 12 months. Both studies were completed in July, 1988.

The objectives of the glycol study were:

a) to assess the scale of production and usage of glycols (including ethylene glycol, diethylene glycol and propylene glycol) for deicing applications and to investigate the potential impact upon water resources, water reuse and waste water treatment;

b) to identify the major sources of these substances;

c) to review and propose control strategies for the protection of water resources.

The study was directly primarily towards the use of glycols for de-icing at airports, since this forms the major point source.

2 PRODUCTION AND USAGE OF GLYCOLS

2.1 Major Suppliers and Uses of Glycol

One of the major markets for glycol-based de-icing agents is in aviation, for de-icing runways and aircraft at civil airports and military airfields. Other markets for glycol are for use in vehicle anti-freeze preparations and to a lesser extent for the de-icing of roads, bridges, freight trains, etc.

Major manufacturers and suppliers of glycol compounds were approached to obtain information on quantities of glycols produced and supplied to the UK market. These included:

Cargo Fleet Chemicals Ltd
Penetone (Kalon Group plc)
BASF UK Ltd
Shell Lubricants UK
BP Chemicals Ltd
Kilfrost Ltd
Hoescht Ltd
Dow Chemicals Ltd
Deutch-Texaco AG

Responses were received from the first five companies; sales figures were provided in confidence, thus only total production figures have been given here.

It is estimated that sales of glycol-based de-icing agents (mostly comprising 85-90% ethylene glycol) are of the order of 2,000 - 2,500 tonnes per year for runway de-icing at military airfields and 1,000 - 1500 tonnes per year for runway de-icing at civil airports. Sales of de-icing agents are highly dependent on weather conditions and on the pricing policies of companies competing for contracts. Consumption in a fairly "typical" winter, 1985/86, was

3,000 tonnes (MOD) and 1,500 tonnes (civil). Annual sales do not necessarily reflect usage rates since products are stored and are not always used in the year of purchase. A current shortage of glycols is likely to affect prices in winter 1988/89.

Information on sales of aircraft de-icers is unavailable since the major supplier, Kilfrost Ltd, felt it was not in their company's interest to release such information. Military use of aircraft de-icing agents is small because many aircraft are kept in hangars and have to be operational under all conditions; an estimate of MOD consumption made by one producer was 18,000 litres per year. Estimated usage for miscellaneous applications is approximately 50 tonnes per year.

2.2 Glycol usage at Commercial Airports

2.2.1 De-icing of Runways & Taxiways

In winter, snow and ice present potential hazards to the safe manoeuvring of aircraft, in particular during landing and take-off. In most areas suffering regular cold climatic conditions, chemical de-icing and anti-icing products are routinely employed to control ice on manoeuvring areas.

From the point of view of airport operation it is far better to prevent ice formation rather than to de-ice later, although de-icing after mechanical snow removal is also frequently needed. Effective anti-icing obviously requires a means of predicting weather conditions. Formerly this was achieved solely by observation, or meteorological prediction. More recently automated systems such as the 'Ice Alert' system have been installed at many airports, resulting in a reduction in the unnecessary use of chemicals. The chemicals commonly used are based on glycol formulations (mono- di- or triethylene glycol and propylene glycol being the main constituents) or urea in the form of granules (prills). More recently Clearway, an acetate compound marketed by BP, has been launched onto the market for de-icing runways and taxiways (Clearway I) and also motorway flyovers etc (Clearway II). It is claimed to have improved operational performance and has reduced pollution impact. It has not been used on a full scale in the UK but limited trials have been carried out apparantly sucessfully in Scandinavia. (The Road Research Laboratory have caried out comparison studies on operational characteristics such as skid resistance etc).

In general, the quantities of chemicals used depend on local conditions, such as weather patterns, size of hardstanding area treated, nature of surface, eg friction course asphalt or concrete. Reported glycol usage at BAA airports, both for runway and aircraft de-icing is shown in Table 2.1. Comparisons of runway area and passenger volumes for these and other major UK civil airports are given in Table 2.2. The information on glycol usage is limited because records are not routinely kept. However, the data suggest that typical usage is of the order of 150,000 litres per year for the larger airports. Heathrow is an exception since urea is largely used. Gay *et al* (1987) observed that at Gatwick 90,000 litres of glycol (effectively 100% solution) and 115 tonnes of urea were required to maintain safe operation over a 3-month period during a recent winter.

The glycol usage for runway/taxiway de-icing does depend on the nature of the surface. The necessity to prevent ice forming within porous friction course asphalt, since it is very difficult to de-ice and may also suffer damage, leads to greater pre-emptive use of glycol based on weather forecasts, compared to concrete surfaces where the application is generally later and also in reduced quantity. New grooved dense asphalt surfaces are gradually being adopted but their glycol requirement and wash-off characteristics have not yet been fully determined. Application of glycol to

Table 2.1 Reported use of Glycol-based De-icing Agents at BAA Airports

Airport	Application	Winter usage (1)*								Current
		1979/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	storage (1)
Aberdeen	runways	-	-	-	-	-	151,000	-	-	200,000
	aircraft	-	-	-	-	-	13,069	-	-	
Edinburgh	runways	-	-	-	-	48,828	45,317	73,365	93,870	109,104
	aircraft	-	-	-	-	17,450	25,017	23,830		
Gatwick	runways	23,184	29,549	101,875	26,766	50,642	151,922	185,659	95,161	95,000
	aircraft	-	-	-	-	-	-	-	-	
Glasgow	runways	-	-	-	-	-	-	148,500	137,350	90,920
	aircraft	-	-	-	-	-	-	72,812	85,903	
Heathrow	runways	-	11,637	50,915	38,413	-	177,657	7,500	123,878	100,012
	aircraft	-	-	-	233,755	295,835	224,263	428,974	146,617	
Prestwick	runways	-	-	-	-	-	-	-	-	18,184
	aircraft	-	-	-	-	-	-	-	-	
Stansted	runways	-	-	-	477	13,069	60,948	7,405	106,085	45,000
	aircraft	-	-	-	-	7,372	33,611	-	37,422	

* de-icer fluid for runway application is approximately 90% (w/w) glycol.

de-icer fluid for aircraft application is approximaately 50% (w/w) glycol.

Table 2.2: Data from UK Airline Traffic Statistics 1986/87 for the 30 Largest Civil Airports in the UK

Airport	Runway Surface	No of runways	Main runway area (ha)	MPPA+ 1986	ATMS++ 000's
Aberdeen	Asphalt	2	8.4	1.01	32.1
Belfast	Asphalt	2	12.5	1.86	37.1
Birmingham	Asphalt	2	10.4	2.09	44.9
Blackpool	Asphalt	3	8.5	0.14	10.8
Bournemouth	Asphalt	2	8.5	0.12	
Bristol	Asphalt	2	9.3	0.41	11.5
Cardiff	Asphalt	2*	10.8	0.49	
E Midlands	Concrete		10.5	1.12	30.1
Edinburgh	Asphalt	3	11.8	1.65	36.6
Glasgow	Asphalt	2	12.2	3.10	56.5
Guernsey	Asphalt		6.6	0.67	39.7
Humberside	Asphalt	2	7.0	0.11	16.2
Inverness	Asphalt	2*	8.7	0.17	6.5
IoM	Ash/Con	3*	8.1	0.37	17.0
Jersey	Asphalt		7.8	1.54	57.1
Kirkwall *	Asphalt	3	6.6	0.09	9.7
Leeds/Bradford	Concrete	2*	10.4	0.51	17.0
Liverpool	Ashphalt		10.5	0.25	19.6
Gatwick	Asphalt	2**	14.5	16.31	154.7
Heathrow	Asphalt	3	34.0	31.32	289.3
Stansted	Asphalt		15.7	0.54	16
Luton	Asphalt		9.9	1.96	27.6
Manchester	Ash/Con		14.0	7.67	85.5
Newcastle	Asphalt		10.7	1.25	21.5
Norwich	Ash/Con	2	8.5	0.15	11.7
Prestwick	Ash/Con		13.7	0.24	2.8
Southampton	Asphalt		6.4	0.27	14.1
Southend	Asphalt	2	5.9	0.12	11.5
Sumburgh	Asphalt	2	6.6	0.15	12.5
Tees-side	Asphalt		10.5	0.20	11.2

* = No glycol used
* = Second runway less wide
** = Emergency runway

\+ Million passengers per annum
++ Air traffic movements

Civil:- 172
Military, but available for civil use:- 31
Heliports:- 31

runway surfaces during a single operation is variable but is typically in the range of 1 litre of glycol solution (100%) per 60-90 m^2. The quantities of glycol used for runway/taxiway de-icing are discussed further in Section 2.2.3.

2.2.2 De-icing of Aircraft

The use of advanced aerodynamics in the design of modern aircraft, in particular the main wing, means that they are extremely sensitive to the effects of ice.

The major safety risk created by ice is that the profile of the wing can effectively be altered by an ice coating, creating non-laminar flow over the upper surface. This increases the pressure over the wing and reduces lift. In addition the icing of pitot tubes, vents and control surfaces can seriously affect the aircraft's performance. Clearly, public safety demands rigorous attention to the problem of ice.

In the UK and most of Europe, a glycol solution with additives, which give non-Newtonian flow characteristics, is used either to prevent icing, or remove accumulations before take-off. De-icing, the most common operation, is normally carried out by mobile dispensers which spray a solution (approx. 25% propylene glycol in the UK) at about 90°C, onto the ice sensitive surfaces of the aircraft. Ice removal is achieved by the use of high temperatures, while the film of glycol remaining gives a period of up to 8 hours protection against further icing, depending upon weather conditions. Anti-icing differs in that a cold 50% glycol solution is used.

There are variations on the above procedure, such as the use of diethylene- and other glycol solutions and even the use of hot water prior to glycol treatment. One major variation on some overseas sites is the use of centralised de-icing facilities to enable glycol wastes to be collected. This will be discussed later in Section 5.2.

Aircraft sizes differ widely, but on average 200 kg of glycol are used to de-ice the main types of aircraft at a large international airport (eg Gatwick) whereas 55 kg is more typical of the range of aircraft sizes encountered at a smaller largely domestic airport (eg East Midlands). The viscosity characteristics of de-icers are designed so that all of the fluid 'rolls off' before take-offspeed, to provide clean flying surfaces. Thus, apart from evaporative loss, virtually all of the glycol remains on the airfield.

As with airfield de/anti-icing, there is no average figure for usage, but as an example, recordings from Gatwick gave an instance of 320,000 litres of product (equivalent to 160,000 litres of pure glycol) being used by the airlines over the 3-month winter period studied by Gay *et al* (1987). Data in Table 2.1 indicate that glycol use for aircraft de-icing is significant compared to that for runway de-icing. Therefore, aircraft de-icing can be the major influence on the overall glycol load, particularly at large airports.

2.2.3 Predictions of Quantities of Glycols used and the Degrees of Contamination of Stormwater

In order to predict pollutant loads in stormwater run-off during winter, a computer model has been developed by Balfours, with operations advice from British Airports Services Ltd, (BASL), to simulate de-icing activities in the light of meteorological data.

The computer model carries out the following basic steps during each simulated day:

- consults temperature and precipitation data and compares against selected control values;

- predicts whether de-icing takes place and then calculates glycol load from aircraft de-icing;

- similarly predicts glycol (or urea) load from runway and taxiway de-icing;

- calculates de-icant load in run-off if rainfall has occurred;

- calculates de-icant load carried over to next day if no rain or only light rain;

- if rain has occurred, adds volume of run-off and pollution load to any balancing storage facility specified; and

- calculates outflow from balancing storage and glycol load to treatment after consulting any governing constraints imposed on these parameters.

For each of the above steps the computer uses various input data and logic procedures to predict loads etc. The main parameters are given below with brief descriptions of assumptions made.

Glycol loads from aircraft de-icing are dependent on the following: number of aircraft departures per day; the number of these which are night-time or daytime flights; the proportion of daytime flights which are short turnarounds; the amount of glycol applied per aircraft; and day minimum and night minimum temperatures. By varying each of the parameters, the model can be refined so that for any year for which records are available, the total mass of glycol used as predicted by the model approximates to the actual use. The amount used is related to the particular methods of operation of the airport under consideration.

The glycol (or urea or acetate) loads from runway de-icing are dependent on the amount of chemical applied and day and night minimum temperatures. Again the model can be locally calibrated for periods when records of chemical usage are available. Furthermore, experiments by Balfours and BASL have determined the wash-off characteristics of glycol from concrete and friction course asphalt. As might be expected, it takes approximately three times as much rain to wash out glycol from a porous asphalt surface compared to a concrete surface.

Should rainfall not occur on the day of application it is assumed that the load is carried forward to the next day with a loss factor (which can be varied) to allow for unspecified glycol losses from the system eg. by jet-blast, evaporation etc. If rainfall occurs, the proportion of the glycol load that would be washed off and carried into any balancing pond facility depends on the actual amount of rainfall.

The model can also be varied so that following a cold spell and subsequent rainfall of a specified amount, if the minimum temperature is consistently greater than 0°C the run-off can be diverted from any balancing pond on the assumption that it will contain no de-icant load. Differing pump-out rates from any balancing pond to disposal/treatment can also be accommodated in the model such that the load for treatment can be varied.

The model has been used at Stansted and East Midlands, and following initial calibration has been used to process the most recent 10 winters of meteorological data (November - April).

The results for East Midlands (see Table 2.3), where the model was calibrated against results for a recent winter, showed that the predictions of annual glycol use for a level of airport activity related to approximately 1.5 million passengers per annum (MPPA), were highly variable over the meteorological period 1976-86. The airport also uses urea for de-icing the apron and certain taxiways (as do most airports at present) and the predicted quantities are also shown in Table 2.3.

Table 2.3 Forecasts of Glycol Use at East Midlands Airport

WINTER CONDITIONS	AIRCRAFT			RUNWAYS			TOTAL GLYCOL USAGE kg
	No of days days Deicing Occurred	Number of Planes in Year	Total Amount Glycol kg	Nos of Days Deicing Occurred	Total Amount Glycol kg	Total Amount Urea kg	
1976/77	35	198	10 880	28	46 200	12 000	57 080
1977/78	38	248	13 660	23	39 600	10 800	53 260
1978/79	65	521	28 660	39	75 900	20 800	104 560
1979/80	25	154	8 470	17	28 050	7 200	36 520
1980/81	27	136	7 480	13	21 450	5 200	28 930
1981/82	41	455	25 050	30	62 700	16 000	87 750
1982/83	28	169	9 290	13	23 100	6 400	32 390
1983/84	32	197	10 820	16	26 400	6 800	37 220
1984/85	43	362	19 880	31	54 450	14 400	74 330
1985/86	53	486	26 770	25	46 200	14 400	72 970
Average	39	293	16 100	24	42 400	11 400	58 500

From Table 2.3 it can be seen that the average annual consumption of glycol for this airport of 1.5 MPPA size is estimated at 58,500 kg. However, in the 1 in 10 year mild winter the consumption may be half of this, while in the 1 in 10 year severe winter the consumption is approximately double the average. Similar projections for the future 8 MPPA Stansted development, based on calibration data from Gatwick, give an estimated average annual glycol consumption for the 10 year period of 287,000 kg with similar ranges. It is interesting to note that it is not necessarily the coldest weather that causes the greatest glycol use. Alternating cold/damp periods create a larger demand than prolonged cold/dry periods.

2.3 Glycol Usage at Military Airfields

Discussions have been held with the DoE Property Services Agency, DCES Croydon, concerning the use of glycol at military airfields. The PSA and MOD recognised the potential polluting characteristics of glycols approximately 20 years ago and, as a result, had discussions with River Authorities, undertook field monitoring exercises, and subsequently obtained River Authorities' approval for use of glycol. They have continued the dialogue with Regional Water Authorities (RWAs) since 1974.

It should be recognised that military airfields tend to be of a size comparable with the smaller commercial civil airports. PSA information suggests that aircraft de-icing using glycols is minimal. Consequently the total amounts of glycol used at military airfields will generally be less than those used at civil airports of comparable size. Generally the glycol usage rate for military airfield surfaces is 1 litre of glycol per 85 m^2 for a single application, however if frost has become established in the asphalt only 15 m^2 may be treated by 1 litre of glycol.

Glycol-based de-icing agents used by MOD have to conform to the

TA10228A formulation specified in 1981. This comprises mono-ethylene glycol/di-ethylene glycol (50/50) with 10% water and 2% sodium benzoate and 0.5% sodium nitrate as corrosion inhibitors.

Available information on usage at military airfields has been reported by PSA as follows:

	1984/85	1985/86	1986/87
Liquid chemicals (l) (predominantly glycol-based)	1,170,000	1,877,000	1,583,000
Urea (t)	1,840	2,100	-

This refers mainly to use by RAF bases. Glycol use at Army, RNAS and MOD (PE) bases is generally low. USAF bases are not bound by MOD central buying and make independent arrangements for de-icing. It is understood that Alconbury is the major USAF base using glycols.

Of the 60 military airfields currently listed by the PSA for de-icer usage, 29 are authorised to use urea and/or glycols, 17 are authorised to use urea only and 14 are authorised to use only glycol (Table 2.4). Glycols may therefore be applied at a maximum of 43 airfields.

It is interesting to note that on the basis of these data, the average annual glycol use in 1985/86 was 43,650 litres/airfield, which is comparable with the figure of 44,000 litres (ie 46,200 kg - see Table 2.1) for runway de-icing at East Midlands in 1985/86.

Table 2.4 Number of Military Airfields Listed by PSA as using De-icing Chemicals (1987/88).

	Glycol	Glycol/urea	Urea
RAF	14	24	8
USAF	-	1	8
RNAS	-	4	-
ARMY	-	-	1
TOTAL	14	29	17

2.4 Comparison of Production and Consumption Figures

An actual value for the overall use of glycols cannot be given because of the limited records on usage which are available. However, a total has been derived based on a typical annual runway application of 100,000 litres for larger airports (eg Gatwick) and 45,000 litres for smaller airports (eg East Midlands). Applying the former to Aberdeen, Belfast, Birmingham, Edinburgh, Gatwick, Glasgow, Heathrow and Manchester, and the latter to the remaining airports listed in Table 2.2 (excluding Kirkwall), gives a total for runway de-icers of 1.75×10^6 litres per year. Taking a glycol content of 90% (w/w) and a specific gravity of 1.05 gcm^{-3} as being representative of those preparations which may be used, this is equivalent to approximately 1,650 tonnes per year of glycol.

For military airfields, a total usage of 1.9×10^6 litres was reported by the PSA for the year 1985/86; a fairly 'typical' winter (see Section 2.3). This is equivalent to approximately 1,800 tonnes per year of glycol.

The total estimated usage of runway de-icers is thus:

Civil	1,650
Military	1,800
Total	3,450 ty^{-1}

Reported market figures provided by manufacturers indicate sales as follows:

Civil	1,000 - 1,500
Military	2,000 - 2,500
Total	3,000 - 4,000 ty^{-1}

There would appear to be reasonable agreement between the production and consumption totals, although the distribution between the military and civil markets differs somewhat. The additional sales may be accounted for by use at minor airfields.

A similar calculation has been made for aircraft de-icing use. Typical figures for a large airport (Gatwick) would be 460 tonnes per year (as glycol, not fluid) for aircraft de-icing, and recorded figures at a small airport (East Midlands) are 26.7 tonnes per year. Dividing this usage by the number of million passengers per annum (MPPA) gives a factor of 0.018 for large airports and 0.011 for smaller airports. This factor can be applied to other airports according to their individual MPPA. Summing these for the airports in Table 2.2 gives a usage of 120 tonnes per year for smaller airports and 1,170 tonnes per year for large airports, with a total of 1,290 tonnes per year.

The use of glycols both for runway and aircraft de-icing at civil airports and for runway de-icing at military airfields is thus estimated as 4,750 tonnes per year.

2.5 Glycol Use as Antifreeze in Vehicle Cooling Systems

A calculation of the quantity of glycols associated with antifreeze, based on a total car population of 20,000,000 and a truck population of 2,000,000 (Soc. Motor Manuf. Traders); cooling systems of 5 litres and 10 litres respectively (RAC Tech. Dept.); maximum use of 50% glycol in cooling systems (Esso Tech. Dept.), average say 33%; and an assumed turnover period of 5 years for sealed cooling systems, gives a total glycol usage of approximately 7,200 tonnes per year. Manufacturers' estimates for the antifreeze market were of the order of 8,000 tonnes per year, suggesting that the calculated figure is a reasonable estimate. It would be assumed that the majority of discharge of used vehicle anti-freeze would go to combined or foul sewers.

In order to compare the impact of this glycol use with airfield de-icing activities, a simplistic calculation has been carried out. If the total annual antifreeze load were discharged over 250 days (ie during vehicle servicing) and were reasonably evenly spread over the urban areas of the country, the daily discharge would be approximately 5 kg from a 400 ha area. When compared to the daily load of up to 15,000 kg that can be applied at an airport of similar area, it can be seen that the comparative impact is small. Furthermore, much of the antifreeze glycol would be discharged to combined or foul sewers.

2.6 Other Uses

Other uses identified by glycol producers included keeping large bridges ice-free, eg the Erskine Bridge; de-icing freight containers during storage in depots; and keeping emergency areas such as hospital forecourts ice-free. Specific uses mentioned by RWAs included as coolant in railway engines (BR depot at Plymouth: South West Water); de-icing bridges (Kessock Bridge on A9: Highland River Purification Board); de-icing surfaces at industrial plant (Shell fractionation plant: Forth River Purification Board; Stockley Park Industrial area: Thames Water); aircraft engine coolant (North East River Purification Board); as coolants in industrial cooling systems and large deep-freeze installations (Northumbrian Water). The market for miscellaneous uses was estimated by one producer as 50 tonnes or less per year.

Glycols and the new BP acetate de-icer have been considered for use as road de-icants where the use of traditional rock salt has resulted in corrosion problems and the use of urea causes unacceptable ammonia levels in surface waters. Salt has been implicated in the structural deterioration of elevated sections of the M6 and M5 motorways. The Department of Transport three years ago converted to the use of urea on a 20km section. Runoff and snowmelt drains off this section into the River Tame and its tributaries, and subsequent to the use of urea, resulted in very high concentrations of ammonia in the river. The relative warmth of the River Tame, due to a baseflow of sewage and industrial effluents, permitted hydrolysis of urea to ammonia. Small ammonia peaks were observed as far downstream as Nottingham on the River Trent. Ammonia levels were observed to exceed the EIFAC safe limit for fish on several occasions in the Tame and Trent. A management programme entailing limiting applications to times of low air temperature and high humidity has been agreed between the Department of Transport and Severn Trent Water. The use of the acetate product Clearway II is now under consideration for this particular case, and has been tested by MOD. Tests on fish toxicity and biodegradability suggest that it is environmentally benign in these respects.

2.7 International Data

Figures for typical de-icer usage for aircraft applications at European, Scandinavian, Canadian and US international airports are given in Tables 2.5 - 2.7. The information was collated in a survey by Transport Canada, carried out in 1984.

It is of interest to note that the glycol usage (reported as 50% solution) per MPPA reported for Charles de Gaulle (0.007); Hamburg (0.01); Indianapolis (0.01) and Portland (0.011) are comparable with the factors derived for small (0.011) airports in the UK.

2.7.1 European and Scandinavian Airports

Many European and Scandinavian airports are concerned with the potential pollution problems arising from use of de-icing fluids. Most either have mitigatory measures in operation usually via discharge to a local sewage treatment works, or as in the case of Schipol Airport in the Netherlands, discharge directly to sea.

Table 2.5 Glycol Usage at European and Scandinavian Airports (Transport Canada, 1985)

		Annual Traffic Volume		Approximate	Operating Authority
Country	Airport	Aircraft	Passengers	Glycol Usage* (ly^{-1})	
Finland	Helsinki-Vantaa	84,500	3,800,000	200,000**	Helsinki Airport Authority
Norway	Oslo	67,900	4,522,000	N/A	Civil Aviation Administration
France	Charles de Gaulle	133,600	13,411,000	193,000	Aeroport de Paris
Netherlands	Amsterdam/Schiphol	187,600	9,680,000	N/A	Schiphol Airport Ltd.
Switzerland	Zurich	165,700	8,256,000	N/A	Zurich Airport Authority
West Germany	Dusseldorf	84,200	7,138,000	60-80,000	Flughafen Dusseldorf GmbH
	Frankfurt	206,800	17,016,000	N/A	Flughafen Frankfurt (Main)
	Hamburg	62,000	4,120,000	80,000	Flughafen Hamburg GmbH
	Hanover	38,200	1,729,000	10,000***	Hanover Airport Authority
	Stuttgart	48,800	2,505,000	N/A	Flughafen Stuttgart GmbH

* Generally AEA Type II Fluid unless otherwise indicated

** Finnair fluid, 80% propylene glycol by weight

*** German airlines usage only

Table 2.6 Typical Glycol Usage for Aircraft De-icing at Major Canadian Airports (Transport Canada, 1985)

Province	International Airport	Annual Traffic Volume: Aircraft	Annual Traffic Volume: Passengers	Approximate Glycol Usage * ($l y^{-1}$)	Operating Authority
Alberta	Calgary	187,731	3,767,200	310,000	Transport Canada
	Edmonton	75,867	1,952,900	N/A	Transport Canada
Manitoba	Winnipeg	130,263	2,004,800	N/A	Transport Canada
Nova Scotia	Halifax	61,466	1,388,000	N/A	Transport Canada
Ontario	Ottawa	161,892	1,877,100	407,500	Transport Canada
	Toronto	238,305	13,577,200	1,380,000	Transport Canada
Quebec	Dorval	149,661	5,143,100	808,000	Transport Canada
	Mirabel	46,079	1,278,200	450,000	Transport Canada

* As de-icing agent, not glycol

Meets AEA Type I fluid specifications.

Table 2.7 Glycol Usage at Major US Airports (Transport Canada, 1985)

STATE	AIRPORT	ANNUAL TRAFFIC VOLUME		APPROXIMATE GLYCOL USAGE* (ly^{-1})	OPERATING AUTHORITY
		AIRCRAFT	PASSENGERS		
Illinois	Chicago-O'Hare	688,00	41,244,000	N/A	City of Chicago Dept. of Aviation
Indiana	Indianapolis	176,000	3,500,000	69,000	Indianapolis Airport Authority
Maryland	Baltimore-Washington	239,000	5,259,000	30,300	Maryland State Aviation Administration
Michigan	Detroit Metropolitan	282,000	9,157,000	N/A	Wayne County Road Commission
Nebraska	Eppley Airfield	190,000	2,200,000	N/A	Omaha Airport Authority
New York	Greater Buffalo	161,000	3,750,000	N/A	Niagara Frontier Transport Authority
Oregon	Portland	208,000	4,600,000	102,200	Port Authority of Portland
Washington	Sea-Tac	210,00	9,100,000	N/A	Port Authority of Seattle
Washington	Spokane	109,000	720,000	47,300	Spokane Airports
Washington D.C.	Washington-Dulles	145,000	2,374,000	218,400	Federal Aviation Administration

* As specified by MIL-A8246 Specification (AEA Type I fluids)

At Charles de Gaulle, Roissy Airport in Paris, discharge of glycols has been reduced by the installation of a centralised de-icing facility for aircraft. The de-icing fluid, applied either in 30% or 50% solution, is collected, settled, filtered and its concentration readjusted to 30% or 50% by the addition of pure glycol. A centralised de-icing facility for aircraft was also evaluated at Kallax airport near Lulea in Sweden. The automatic, computer-controlled facility was installed in 1984 at a cost of $US 1.6M. Glycol is collected via porous asphalt in the spray platform, collected in 25m^3 tanks, distilled, filtered and the concentration readjusted with pure glycol before reuse.

At Helsinki-Vantaa in Finland, pilot plant testing showed that 50 -80% BOD removal could be achieved in stormwater runoff contaminated with glycols, using a two-stage high rate trickling filter or a rotating biological contactor. Airport runoff was discharged to a brook up until 1976 but, on the order of the Water Court of West Finland, has since 1987 been discharged to the municipal sewage treatment system for the Helsinki area. From November to May, stormwater runoff and meltwater from the aprons is collected in a 1,900m^3 equalising basin and subsequently pumped to sewer. Effluent quality is monitored biweekly and wastewater charges determined according to glycol concentration. No special modifications were required at the municipal sewage treatment works to cope with the glycol waste. During the rest of the year, runoff is to a local watercourse.

Problems have arisen at Arlanda airport, Stockholm, with pollution of receiving waters by de-icing agents. Vehicles carrying apron-cleaning suction equipment are used to remove meltwater and glycols from stand areas for subsequent discharge to the municipal sewerage system for treatment and disposal. Recovery of 85% of applied de-icer is reported by the equipment manufacturers. The vehicles can only operate at 2.5-10 kmh^{-1} and are only really effective at the lower end of this range, thus for large stands they are slow. The vehicles cost of the order of £150,000 each. One is understood to be on order for Oslo airport.

At Copenhagen airport, which is adjacent to the sea, there is sufficient dilution of glycols and degradation products in the receiving water to prevent any deterioration of water quality.

In West Germany, stormwater from aprons and runways at Dusseldorf airport discharge through outlets which can be closed automatically in the event of chemical discharge or fuel spillage. The effluents can be treated in sludge tanks or diverted to sewer. At Hanover airport, stormwater effluents are led via oil weirs into retention basins. After sufficient buffering has been achieved, the effluent is discharged to receiving waters. Most other German airports drain to local sewage treatment plants. At the new Munich 2 airport, land treatment of glycol waste has been proposed and it is understood that trials are currently underway. Several military airports in Germany are not allowed to use de-icing chemicals and are restricted to the use of sand.

At Vienna airport, where glycols are now used exclusively for de-icing, there is a sewage treatment plant operating within the airport area.

2.7.2 US and Canadian airports

At Spokane airport in Washington, de-icing fluid is removed from the apron during normal snow-removal procedure and blown into infield areas lying between the aprons and taxiways. Stormwater drains to soakaway areas. There are no surface watercourses nearby, thus pollution problems are minimal.

Monitoring of airport discharges from Appley Airfield near Omaha, Nebraska, showed that BOD_5 levels were acceptable except under conditions when de-icing fluids were in use. It was recommended in

1976 that hot water de-icing was substituted for the use of glycols, and that discharge of contaminated effluent should be to foul sewer.

Retention ponds are used at Detroit Airport to reduce glycol loading and subsequent sulphide odour problems in receiving watercourses. The ponds are not completely effective since high BODs are still observed in the effluent discharged. A large 90 acre retention pond, Lake O'Hare, was constructed at Chicago - O'Hare airport in the 1970's, permitting selective discharge to either surface waters or foul sewer depending on flow and pollution loads. Discharges are monitored daily for water quality and toxicity. It is estimated that 36% of all stormwater runoff is directed into Lake O'Hare. Of this, 85% arises from the application of aircraft and runway de-icing fluids.

A stormwater retention pond constructed at Calgary airport in 1977 for collection of apron and taxiway drainage, led to problems of hydrogen sulphide odour, both in the pond itself and in the receiving creek. Accumulation of ethylene glycol was identified as the major contributor to the odour problem. Surface aerators were installed in the pond in 1984, at a cost of approximately $Can 84,000, and are reported to achieve "acceptable" BOD_5 levels for discharge. Similar odour problems arising from the use of glycol - based de-icing agents have been reported at Dorval airport, where significant quantities of glycol drain into the receiving Bouchard Creek.

Investigations into the fate of glycols at Ottawa airport indicated little off-site migration of glycols retained in runway snow cleared and dumped during the winter. However it was suspected that seepage was occuring through sandy soils under the snow dumping area, through perforated sewers, or through cracks in the apron itself. Analysis of the groundwater beneath the airport indicated that significant concentrations of glycol compounds and by-products were present in the upper soil layers and perched water table below the infield and apron areas of the airport.

An assessment of de-icing of aircraft at individuals stands at Mirabel airport in Quebec, carried out by Transport Canada, indicated the pollution potential and mitigatory measures necessary to overcome this. It was estimated that if de-icing fluid was discharged directly to receiving waters, dilutions of 25,000:1 to 30,000:1 would be needed to reduce the BOD concentration from 400,000mgl^{-1} to the required 15mgl^{-1}. Runoff of as little as 45-90 l of de-icing fluid could give an effluent BOD of 15 mgl^{-1}. Control strategies recommended for on-stand de-icing included use of hot water de-icing to reduce glycol usage; rigorous stand-cleaning after each de-icing operation; storage of runoff for recovery or treatment of glycols; and controlled discharge of snowmelt where glycol is collected and dumped with cleared snow.

3 PHYSICOCHEMICAL AND TOXICOLOGICAL PROPERTIES OF GLYCOLS AND GLYCOL-BASED DE-ICING AGENTS

3.1 Physicochemical Properties

Glycols are dihydric alcohols derived from aliphatic hydrocarbons by the substitution of hydroxyl groups for two of the hydrogen atoms in the molecule. The general formula for glycols is $C_nH_{2n}(OH)_2$. They are colourless, hygroscopic liquids of relatively high viscosity and low volatility. The physicochemical properties of those commonly used in de-icing preparations are shown in Table 3.1.

The characteristics of primary importance for use as a de-icing agent are freezing point depression and viscosity. The relationship between concentration of ethylene glycol, depression of freezing point of an aqueous solution and its relative viscosity is shown in Table 3.2. Ethylene glycol is the most efficient freezing point depressant, requiring a lower concentration than di- or tri-ethylene glycol to achieve the same effect.

Types of glycol-based de-icing agents are distinguished on the basis of their physicochemical properties. Specifications for those used for aircraft application in Europe, known as AEA Type I and Type II fluids, are given in "The Association of European Airlines Recommendations for De-icing/Anti-icing of Aircraft on Ground". The specifications cover material requirements and physical properties including freezing point, rheological properties (viscosity and plasticity) and anti-icing performance.

AEA Type I fluids contain a minimum concentration of 80% glycol and are considered to be of relatively low viscosity. Their low viscosity means that they do not remain on an aircraft after application and thus have no adverse effect on its aerodynamics or performance. At a 50/50 dilution with water, Type I fluids have a

Table 3.1 Physicochemical Properties of Glycols

Name, Synonym	Formula	Molecular weight	Boiling point (°C)	Melting point (°C)	Density*	Refractive index+	Solubility
Ethylene glycol 1, 2-Ethanediol	$HOCH_2CH_2OH$	62.07	198.93	-11.5	1.1088^{20}	1.4318	Water alcohol ether acetone
Diethylene glycol	$HOCH_2CH_2OCH_2CH_2OH$	106.12	245	-10.5	1.1197^{15}	1.4472	Water alcohol ether
Triethylene glycol	$HO(CH_2CH_2O)_2CH_2CH_2OH$	150.17	278.3	-5	1.1274^{15}	1.4531	Water alcohol benzene
Propylene glycol 1,2 Propanediol	$CH_3CH(OH)CH_2OH$	76.10	189.96	-	1.0361^{20}	1.4324	Water alcohol ether benzene

* specific gravity ie density of liquid at 15°C or 20°C (see superscript) in relation to water at 4°C

+ refractive index is reported for the D line of the sodium spectrum at 20°C

Table 3.2 Relationship between concentration of ethylene glycol, depression of freezing point and viscosity

Anhydrous solute weight % g solute/100g solution	depression of freezing point (°C)	relative viscosity* (n/n_o)
0.5	0.15	1.008
1	0.30	1.078
2	0.61	1.046
3	0.92	1.072
4	1.24	1.097
5	1.58	1.223
6	1.91	1.151
7	2.26	1.180
8	2.62	1.210
9	2.99	1.241
10	3.37	1.274
12	4.16	1.345
14	5.01	1.421
16	5.91	1.497
18	6.89	1.575
20	7.93	1.658
24	10.28	1.839
28	13.03	2.043
32	16.23	2.275
36	19.28	2.532
40	23.84	2.826
44	28.32	3.160
48	33.30	3.537
52	38.81	3.973
56	44.83	4.466
60	51.23	5.016

* ratio of the absolute viscosity of solution at 20°C to the absolute viscosity of water at 20°C.

minimum freezing point of -20°C. They are designed to provide protection against refreezing under conditions of no precipitation.

AEA Type II fluids contain a minimum of 50% glycols. At a 50/50 dilution with water, Type II fluids have minimum freezing point of -10°C. A thickening agent is incorporated to enhance adhesion to the aircraft surface, forming a thick coating to protect from freezing precipitation. The high viscosity of fluid may, however, cause excess retention on the wing and affect take off performance. They are thus recommended for use mainly on aircraft with takeoff rotation speeds greater than 85 knots, at which speed Type II fluid is thought to be sheared off the wing. The pseudo-plastic characteristic of Type II fluids necessitates specialised storage and handling facilities (Mayer, 1986).

For de-icing runways, preparations are usually 80-95% glycols with added corrosion inhibitors such as sodium nitrate and sodium benzoate. Physiochemical properties of both aircraft and runway de-icers are shown in Table 3.3.

3.2 Toxicity

3.2.1 Human Health Effects

Toxicity data for glycols for humans and experimental animals are presented in Table 3.4. The comparative toxicity of glycols is ethylene glycol, diethylene glycol > triethylene glycol > propylene glycol.

Ethylene and diethylene glycol are considered toxic to humans whereas propylene glycol is not. The lethal dose for humans of ethylene glycol is 1.4 ml kg^{-1} (Boughey, 1984) or approximately 100 g for an adult, and of diethylene glycol is estimated at 1 ml kg^{-1} (Doull *et al*, 1980). Glycols are nephrotoxins, causing damage to the functional unit of the kidney, the nephron.

Table 3.3 Physicochemical Properties of De-icing Preparations

	Aircraft de-icers		Runway de-icers				
Physical properties	Kilfrost ABC	Aeroshell 07	Konsin	Ice Control Agent	BP Runway De-icer	Frigantin	Frigantin E108
Appearance	Clear, amber, no visible impurities. Water miscible	-	Clear, mobile, free from particulates	Mobile water miscible	Colourless water miscible	Clear yellow, water miscible	Clear, colourless water miscible
Specific gravity (gcm^{-3} @ 20 °C)	1.04	1.094^{15}	1.114-1.124	1.09	1.05-1.15	1.085-1.098	1.107
Viscosity (mm^2S^{-1} @ 0 °C)	-	12.4	55	120	-	55 - 70	48
pH	9.5 - 10	6.9	-	6 - 9	6 - 8	8 - 10	8.5
Pour point (°C)	-	-	< -30	< -30	-	-50	< -50
Flash point (°C)	None	54.4	>100	-	None	None	None
Major Components (v/v)	Propylene glycol	85% ethylene glycol 5% alcohol 10% water	30-40% mono-ethylene glycol 60-70% diethylene glycol	-	90% ethylene glycol 10% water	propylene glycol urea 20% water	diethylene glycol 20% water

Table 3.4 Toxicity data for glycols

Organism	Exposure		Toxicity ($mgkg^{-1}$) Ethylene glycol	Diethylene glycol	Triethylene glycol	Propylene glycol	Data Source
Human	oral	LDL_0	786	1,000	5,000	-	NIOSH
			1,400	1,000	-	7,000	Transport Canada
			1,500	1,100	-	-	BASF
Dog	oral	LD_{50}	-	-	-	22,000	NIOSH
	intraperitoneal	LD_{50}	-	-	-	26,000	NIOSH
Rat	oral	LD_{50}	4,700	13,500	17,000	20,000	NIOSH
			6-10,000	15-21,000	-	21-30,000	BASF
			13,000	15,650	-	32,000	Plugen (1952)
			8,540	14,800			Sax (1984)
	intraperitoneal	LD_{50}	-	-	-	6,600	NIOSH
	intravenous	LD_{50}	3,260	-	-	-	NIOSH
Mouse	oral	LD_{50}	7,500	23,700	-	24,000	NIOSH
	intraperitoneal	LD_{50}	8,050	13,300	-	-	Plugen (1952)
			-	-		9,718	NIOSH

LDL_0: Lowest published lethal dose
LD_{50}: Lethal dose, 50% kill

The major toxic route of exposure is by ingestion, thus contamination of water supplies is of particular concern.

On ingestion, ethylene glycol is slowly oxidised by alcohol dehydrogenase to oxalic acid. This causes severe tubular damage to the kidneys, often accompanied by the formation of oxalate crystals in the tubules. Depression of the central nervous system and necrosis of the liver may also occur. Symptoms are initially similar to those of ethanol intoxication, but worsen to nausea and vomitting, abdominal pain, cyanosis, tremors and convulsions, narcosis and coma, frequently ending in death. The cause is either central nervous system depression, usually the result of one massive dose, or renal failure from smaller repeated doses. It has been estimated that there are approximately 50 fatalities annually in the USA where ingestion occurs by mistake or through abuse as an alcohol substitute.

Diethylene glycol causes similar effects to those of ethylene glycol and renal and cerebral damage resulting from intoxication may be permanent. However, it is regarded as less of an industrial hazard. The lethal dose for humans (1000 $mgkg^{-1}$) was estimated from one incident of 105 fatalities in the USA in the 1930's, caused by ingestion of sulphanilamide in an aqueous mixture containing 72% diethylene glycol.

Propylene glycol has a very low order of toxicity and is utilised in food products, cosmetics and pharmaceuticals with little apparent harm. The recommended daily adult intake (ADI) is 20 $mgkg^{-1}$ (FAO/WHO, 1964). On ingestion, propylene glycol is absorbed by the gastro-intestinal tract and converted by the liver to lactate and single carbon compounds. Its rapid breakdown in the body reduces the potential occurrence of lactic acidosis. A large proportion is excreted without conversion or as a gluco-uronide conjugate.

As glycols have low volatility they generally present little hazard from inhalation. However, accidental inhalation of ethylene glycol vapour will cause headache and throat irritation and use of heated solutions in enclosed areas may result in nausea and vomitting (Mayer 1986). The threshold limit values (TLV) for ethylene glycol given by the Health and Safety Executive (1987) are as follows:

Long-term exposure (8h TWA value)	vapour :	60 mgm^{-3}
	particulate:	10 mgm^{-3}

Short-term exposure (10 min TWA value) vapour: 125 mgm^{-3}

Exposure of humans and animals to saturated and supersaturated atmospheres of propylene glycol for long periods indicated no significant effects of inhalation.

Although poorly absorbed by the skin, glycols may cause irritation on contact, and protective clothing is usually recommended by manufacturers. Eye contact may also cause transient irritation. Occasional allergic contact reactions have been reported for propylene glycol (Fisher, 1978).

3.2.2 Aquatic Toxicity

Data on the aquatic toxicity of glycols are infrequent, probably due to the fact that it is not regarded as a particularly common threat to aquatic ecosystems. Data which are available (Table 3.5) have been largely generated by manufacturers' investigations.

A threshold range of aquatic toxicity for ethylene glycols has been given by the US Federal Government as 1,000-10,000 mgl^{-1}, while a generalised LC_{50} for freshwater species of 10-10,000 mgl^{-1} has been indicated by MAFF. It is thought that the toxicity to marine species would be of a similar order. Sax (1984) reported aquatic toxicity ratings derived from 96h LC_{50} values for different

Table 3.5 Toxicity of glycols to fish

Species	Exposure	Compound	Concentration (mgl^{-1})	Data Source
unspecified	48h LC_{50}	ethylene glycol	>5,000	Anglian Water
		diethylene glycol	>5,000	
		propylene glycol	>5,000	
unspecified	96h LC_{50}	ethylene glycol	100-1,000	Transport Canada
		diethylene glycol	10,000	
		propylene glycol	1,000	
unspecified	TLM_{96}	ethylene glycol	>1,000	BP
Mosquito fish	96h LC_{50}	diethylene glycol	32,000	WRC
Rainbow trout	48h no deaths	Kilfrost ABC	100	Kilfrost
			300	
			500	
Rainbow trout	96h LC_{50}	Frigantin E108	>1,000	BASF
Goldorf	48h LC_{50}	Frigantin	>500	
Rainbow trout	96h LC_{50}	UCAR de-icer	6,600	Jank (1973)
		Dow de-icer	9,200	
Harlequin fish	24h LC_{50}	50% Konsin	1,400	MAFF
Brown trout	96h LC_{50}	Konsin	1,000	ICI

species of 100-1000 mgl^{-1} for ethylene glycol and 1000 mgl^{-1} for diethylene and propylene glycol. The glycols are of relatively low toxicity to fish; no attributable fish kills have been reported (PSA, 1986).

Reported LC_{50} values indicate concentrations at which acute effects are exerted by glycols. Studies by Jank (1973) on the toxicity of two de-icing agents showed that significant chronic effects such as loss of equilibrium in fish could occur at concentrations approximately half of those which were lethal.

Significant reductions in toxicity were observed following aeration of wastewater contaminated with glycol-based de-icing agents. Unaerated de-icer with a glycol content of 19,000 mgl^{-1} gave a median survival time for trout (ET_{50}) of 200 minutes, whereas the same wastewater continuously aerated at 10 ml l^{-1} min^{-1} gave an ET_{50} of 3,000 minutes. The toxicity reduction did not appear to be related to glycol, however, since no degradation was observed; it was suggested that aeration stripped out the corrosion inhibitors which caused part of the toxic effect. On this basis, extended aeration was recommended as a treatment method since stripping or degradation of inhibitor compounds after time would give an effluent of lower aquatic toxicity.

3.3 Biodegradability

Experimental studies indicate that the order of biodegradability of glycols is;

propylene glycol > ethylene glycol > diethylene glycol, triethylene glycol.

Studies carried out at Zurich airport indicated that degradation rates for mixed de-icer fluid runoff under anaerobic and aerobic conditions were as given in Table 3.6.

Table 3.6: Degradation Rates of Glycols in Storage (Boller, 1988)

	degradation rate (g C $m^{-3}d^{-1}$)		
	propylene glycol	ethylene glycol	diethylene glycol
Anaerobic storage	9.7	8.1	0.56
Aerobic storage (no phosphorus addition)	6.9	4.6	1.45
Aerobic strorage (with phosphorus addition)	30.0	22.6	3.8

Reported BOD_5 values for glycols fall within the following range:

	gO_2g^{-1} @ 20°C (Douglas, 1986)
Propylene glycol	1.06-1.35
Ethylene glycol	0.37-0.78
Diethylene glycol	0-0.52

A comparison of experimental values of BOD compared to the theoretical BOD for individual glycols indicates that not all of the biodegradable content is generally oxidised by seed micro-organisms within the 5 day period of the standard BOD test. Testing carried out by Shell (Table 3.7) using sewage micro-organisms at 20°C indicated that propylene glycol had good degradability characteristics, as the experimental BOD was >50% of the theoretical BOD, ethylene glycol was moderately degradable (BOD 30-50% of the theoretical value) while di- and triethylene glycols were resistant to degradation (BOD <10% of the theoretical value).

Acclimation of organisms has been shown to be important in the degradation of glycols. A comparison of the BOD_5 values given in Table 3.7 for non-specific seed and acclimated micro-organisms shows an increased BOD was obtained within the 5 day period when using the acclimated seed. Northumbrian Water determined the biodegradability of 10 mgl^{-1} glycol solutions at 20°C using a sewage seed acclimated to Kilfrost ABC (mainly propylene glycol).

The results showed a 95% reduction in concentrations of propylene glycol and Kilfrost ABC within 4 days. However, the ethylene glycol concentration was reduced by only 46% in 4 days but by over 90% after 10 days (Table 3.8).

Similarly, Union Carbide reported a 5 day BOD value for ethylene glycol of 0.465 gg^{-1} (36%) but a 20 day BOD value of 1.29 gg^{-1}

Table 3.7. Biodegradability testing of glycols carried out by Shell, Netherlands and ICI, Brixham (Kilfrost, pers. comm.)

	Seed	BOD_5 g oxygen per g compound	BOD_5 % of theoretical BOD	COD g oxygen per g compound	COD % of theoretical COD	COD: BOD ratio
Ethylene glycol	-	0.37-0.47	36	1.24	96	2.6-3.3
	acclimated	0.72-0.81	63			
	acclimated	0.78		1.78		2.3
Ethylene glycol (FN grade)	-	0.09-0.15	12			
	acclimated	0.45-0.67	52			
Diethylene glycol	-	0.11-0.12	8	1.49	99	12-13.5
	acclimated	0.05		1.90		38
Diethylene glycol (special grade)	-	0.05	3			
	acclimated	0.07-0.10	6			
Triethylene glycol	-	0.03	2			
	acclimated	0.02-0.03	2			
	acclimated	0.32		2.02		6.3
Propylene glycol	-	1.06-1.08	64	1.63	97	1.5
	acclimated	1.35		1.94		1.4
Dipropylene glycol	-	0.08-0.09	5			

Table 3.8 Biodegradability testing of glycols carried out by Northumbrian Water (Kilfrost, pers. comm.)

	% reduction in glycol concentration		% reduction in BOD
	after 4d	after 10d	after 10d
Ethylene glycol	46.6	90.3	>95
Diethylene glycol	0	28.7	-
Propylene glycol	>94.5	>94.5	>95
	92	>95	-
Kilfrost ABC	>94	>94	>95
	92	96	-
Kilfrost KF 313	19.6	55	-

(100%). These data suggest that degradation may be prolonged while organisms become acclimated. Lag phases of approximately 2 and 5 days have been observed at temperatures of 17°C and 4°C respectively before dissolved oxygen uptake indicated that biodegradation had started (Douglas, 1986).

ICI undertook BOD and respirometer testing and activated sludge studies on glycol degradation. Propylene and ethylene glycol were reported to exert a rapidly large BOD; di- and triethylene glycols exerted an equally large demand but over a longer period. It was thought that highly stable ether linkages in di- and triethylene glycol, which are known to be resistant to biological breakdown, were responsible for the different degradation rates. Alcohol groups, as in propylene glycol, have greater susceptibility to biodegradation.

Biodegradability begins to decrease at a certain threshold level as toxic effects are exerted. ICI found that a 10 mgl^{-1} concentration of triethylene glycol reduced the BOD by over 500% in comparison to a 3 mgl^{-1} solution. This toxic effect however, appeared to be attenuated in the activated sludge units, as the toxic threshold was raised. This may have been due to the higher density of micro-organisms present.

Temperature has a significant effect on biodegradability. Degradation of a 10 mgl^{-1} mixture of Kilfrost and Konsin at 17°C gave a BOD of 77%, whereas at 4°C biodegradation did not occur (Douglas, 1986). The Laboratory of the Government Chemist reported complete degradation of ethylene glycol in 3 days at 20°C but at normal river temperatures (< 8°C) ethylene glycol degraded partially or completely within 7 days, depending on river characteristics. Di- and triethylene glycol were removed partially or completely at 20°C within 7 days, but river degradation was thought to be minimal. Ethylene glycol was not degraded at winter temperatures as readily as had been hoped, and di- and triethylene glycols had degraded more slowly than ethylene glycol.

Treatability studies commissioned by BAA have shown that biological treatment, both aerobic and anaerobic, can remove glycols effectively from wastewaters over a wide range of concentrations. A pilot scale investigation of anaerobic treatment used an attached growth system based on sponges as the support material. At a glycol loading of 12 kgd^{-1} for a bed of 2.5 m^3 theoretical volume, a throughput of 0.5 m^3d^{-1} and at a temperature of 32°C, a COD reduction of approximately 75% was obtained. Gas production was 4.5 m^3d^{-1}, with a methane content of 70-75%. The process performed well even under intense shock loading conditions, however, a pH of 7 could only be maintained by continuous dosing with sodium hydroxide. Although the trial showed that the use of anaerobic systems was feasible, a number of problems were identified. These included high operating costs (largely due to high energy costs that would be necessary to raise the temperature of the incoming flow, particularly if it were weak and generated little methane), difficulties in operating on an intermittent basis, and dependence on high glycol concentrations for efficient treatment.

Pilot aerobic trials using a full scale aeration unit at Rye Meads STW in 1986/87 involved adding a mixture of glycols to settled sewage at concentrations in the range 75-200 mgl^{-1}. Glycols could not be detected in the plant effluent (detection limit 5 mgl^{-1}) and nitrification was unaffected. However, problems occurred with the formation of a stable foam on the surface of the aeration tanks, particularly when the concentration was toward the upper end of the range. A further factor affecting aerobic treatability is the low temperature of contaminated stormwater in winter, which is not conducive to efficient aerobic treatment in isolation. Repeat trials in 1988 again produced good effluent quality. Although in one trial at a glycol dosage of 25 mgl^{-1} a foam appeared, on a subsequent trial no significant foam was detected at approximately 50 mgl^{-1} glycol.

Trials were also commissioned by East Midlands International Airport plc at Loughborough STW, during the winter of 1987/8, using a diffused aeration pilot plant. Mixtures of settled sewage and glycol, glycol and acetate, and acetate were tested. Unfortunately the winter was very mild, however the pilot plant results suggested that all the compounds were fairly readily degradable and no stable foam was produced at dosages up to 65 mgl^{-1} glycol; 40 mgl^{-1} glycol + 65 mgl^{-1} acetate; or 123 mgl^{-1} acetate.

Loadings of glycol wastewater to a pilot scale activated sludge plant in Quebec were restricted because of the stimulation of filamentous organisms and sludge bulking. Treatment of de-icer wastewater and municipal sewage at <10°C to give an effluent with a BOD of <20 mgl^{-1} and SS of <25 mgl^{-1} necessitated a loading of 0.15 kg BOD kg^{-1} MLSS d^{-1} (Jank, 1973). At 20°C, the loading could be doubled. Observation of glycol degradation suggested that there was sequential removal of different glycols. However, in contrast to other studies, ethylene glycol was apparently degraded in preference to propylene glycol, giving breakdown products of methanol, ethanol, acetone and two unidentified compounds.

Nutrient requirements for glycol degration were found to be temperature dependent. At 10°C, a C:N:P ratio of 100:5:1 was required, while at 5°C a ratio of 100:7:1 and at 2°C a ratio of 100:9:1 was required. This indicated that, in the absence of urea, nitrogen addition may be necessary for low temperature treatment of glycol wastewaters.

A study on the treatability of de-icing fluids from Zurich airport (Boller, 1988) concluded that the large fluctuations in load, composition and concentration of the effluent necessitated long-term (weeks) buffering and storage facilities. Treatment of large quantities of comparatively strong, fresh or anaerobically stored de-icer effluent combined with municipal sewage in a STW was found to be impractical because of bulking problems (these occurred even when the de-icer wastewater comprised only 10% of flow).

Degradation rates of de-icing compounds, particularly isopropanol and diethylene glycol, were found to be low during anaerobic storage, thus further treatment was required before discharge to receiving water or transfer to a municipal STW. It was recommended that fixed biofilm processes or activated sludge systems with flotation should be used. Trials with RBCs resulted in production of large amounts of surplus sludge with poor settling and dewatering characteristics. Investigation of aerobic storage showed that full degradation of all de-icer substances could be achieved after 1.5 - 2 months. Phosphorus dosing was necessary to enhance biological growth. The water quality after storage was suitable for transfer to a municipal STW for nitrification of urea-containing effluents. An additional benefit noted was an increase in temperature of approximately 3-4°C during the initial phase of high biomass activity, which stimulated biodegradation.

In consideration of practical and economic aspects, it was concluded that of the treatment systems studied, prolonged aerobic storage with discharge to a muncipal STW for final polishing and nitrification was the preferred option.

4 POLLUTION IMPACT OF GLYCOLS

Since 1974 the Regional Water Authorities have been vested with the responsibility for monitoring and protecting river quality in England and Wales. All main rivers have been assigned quality objectives with a view to maintaining existing standards and identifying stretches of river where quality is in need of upgrading. The pollution of rivers with chemical substances can have a number of adverse effects:

- some pollutants can exert an oxygen demand, reducing dissolved oxygen concentrations and causing stress to fish and other riverine fauna and flora.

- some pollutants are toxic to fauna and flora, and some can be toxic to man if the water is abstracted for drinking.

- some pollutants (eg oil) affect the capacity of the river for self-purification.

- when water is abstracted for potable supply some pollutants cause treatment problems or lead to a failure to achieve the standards set by the EC Directives for surface water intended for abstraction (75/440/EEC) and drinking water (80/778/EEC).

Glycol, acetate and ammonia (from the hydrolysis of urea) have implications in respect of the above, although the impact of deicing glycols and acetates primarily relates to the first factor. The proprietary de-icing compounds can contain small amounts of other compounds, such as corrosion inhibitors, and these should also be reviewed for their potential impact in specific cases.

4.1 Environmental Concentrations

There are many recorded cases of glycol concentrations (measured asglycol, COD or BOD) in excess of 1000 mgl^{-1} (as glycol) in stormwater from airports both in the UK and overseas. These concentrations tend to be peaks of comparatively short duration, ie hours rather than days. Nevertheless the daily mass load can be high particularly compared with other discharges over the winter period, eg effluents from small local sewage treatment works and industries.

The computer programme referred to in Section 2.2.3 can be used to generate typical concentrations based on glycol usage and meteorological data, however the actual amounts discharging to surface waters, or groundwaters, will depend on several factors:

- the topography of the airfield;
- the design of the airfield and apron drainage system;
- the nature of the soil and subsurfaces in the grassed area;
- the amount lost by evaporation or wind-blown spray;
- any decomposition in balancing ponds (aerobic and anaerobic).

At the two airfields where the computer model has been applied, the runways lie along appreciable ridges and the taxiways and aprons are located on land of considerable gradient. At both sites the drainage systems are, or will be, efficient and the soils are essentially impermeable. Consequently at both locations it would be expected that 40-75% of the glycol applied to aircraft and runways may appear in the surface water drains. At airports on flat sites having sandy soils and using earthen ditches or field drains for part of the drainage network, the amount of glycol from runway de-icing may be substantially less, however the run-off from apron areas should be similar.

Mayer (1986) has reported that American studies have shown that approximately half of the glycols applied to aircraft enter the airport sewer system or flow directly to receiving water (44% spills on apron, 35% carried away by the wind, the remaining 16% not specified).

Work was undertaken by PSA in the early 1970's to define the washoff amounts of de-icants from runway deicing operations at certain airfields. The experiments encountered several difficulties, but the measured quantities of de-icants (urea and a mixture of Konsin/Imsol) washed off never exceeded about 40% of the amount applied and were frequently substantially less. Nevertheless glycol concentrations in the stormwater discharges in excess of 1000 mgl^{-1} were measured at several locations.

Similar investigations carried out at Zurich airport showed that 30-45% of the load which was applied reached the sewer system. De-icer was lost to adjacent embankments and surrounding areas by the spray effect during takeoff and landing, and by snow removal from runways (Boller, 1988). Concentrations of glycols in runoff collected and stored over several weeks were up to 1,200 mgl^{-1} ethylene glycol; 1,500 mgl^{-1} propylene glycol; 500 mgl^{-1} diethylene glycol; and 500 mgl^{-1} urea.

4.2 Pollution Incidents

Reviewing the figures quoted earlier for Gatwick in Sections 2.2.1 and 2.2.2, if during the 3 month period (assume 100 days for total run off) 40% of the runway application (90,000 x 0.4) ie 36,000 litres, and 66% of the aircraft application (160,000 x 0.66) ie 106,000 litres, found their way to the stormdrains then the average daily BOD load over that period would be:

$$\frac{(106,000 + 36,000) \times 0.85}{100} = 1207 \text{ kg}$$

When compared to the approximate 3.6g of BOD per population equivalent permissible in a 30/20 treated sewage effluent, this gives a treated sewage population equivalent of 335,000 or a raw sewage population equivalent to 20,100. Even if the amounts reaching the stormwater drains were half of those assumed, the figures would still be appreciable.

The factors which prevent dramatic impacts on the receiving waters include:

- low water temperatures which mean that the oxygen demands exerted are much smaller than the 5 day 20°C BOD;

- river flows in winter are generally not at their lowest;

- metabolic activities of flora and fauna are lower and therefore less sensitive to water quality;

- upstream dissolved oxygen concentrations will be significantly higher than in summer;

- much of the load will not in fact be balanced at most airports but will be discharged in slugs following rain when the receiving waters will also have higher flows.

Data on the usage, quality of receiving watercourses and pollution incidents arising from de-icers, as reported by individual RWAs, are given in the following sections.

4.2.1 Anglian Water

Anglian Water have over 50% of all military airfields in their region, but there is only one case where glycols are known to cause water problems; RAF Wattesfield. The airfield is sited on a hill and drains away either side to two catchments. The receiving waters are small, unclassified streams which drain to:

- Upper River Gitting (class 2) which drains to Ipswich
- Upper River Brett (class 1B) which drains into the River Stour, which is abstracted for water supply.

Intermittent growths of sewage fungus have been observed in these rivers as a result of glycol usage, although fungus growth is not observed in every year when glycols are used. On one occasion, concentrations in the River Stour approached 1 mgl^{-1} glycol. This concentration is regarded as a trigger value for drinking water quality, based on data from Russian research. Anglian Water considered closure of the abstraction point but other factors mitigated against closure.

The use of urea has not been known to cause problems; none have been identified during monitoring. In many cases stormwater goes to soakaways and degradation occurs during percolation to groundwater, thus problems do not show up in surface waters. The PSA have however reported one incidence of limited fish mortality in early 1986, attributed to the use of urea at the military airbase at Alconbury in Cambridge.

There has been recent public concern over the discharge of glycol regenerator condensate produced during recovery of glycol-based anti-freeze from gas plant pipelines at Bacton gas terminal, Norfolk. Although discharges have been made to sea for 20 years, Anglian Water are currently considering applying discharge consents for such effluents.

4.2.2 Clyde River Purification Board

Known users of glycols for runway de-icing are Glasgow and Prestwick airports. Drainage at Glasgow is to mains sewer, under the control of the regional authorities. Runoff at Prestwick is to a number of small streams, but the airport is generally frost-free because of its westerly maritime aspect. There have been no known pollution events arising from the use of de-icing agents at either civil or military airfields in the region.

4.2.3 Forth River Purification Board

The major user of glycols is Edinburgh airport. There are no specific consents in force on surface water drainage, as the discharge conditions existed prior to 1974, when consents were first issued. Runoff from Edinburgh airport is to the River Almond (class 2-3) and Gogar Burn (class 2) comparatively near to the Forth estuary. High BODs have been observed in the discharges but have not caused noticeable effects in the receiving rivers.

Glycol is also used for de-icing surfaces at a fractionation plant at Mossmorran. Usage to date is reported as 25 l (as product) and is thus negligible. Urea is produced at a chemical plant also at Mossmorran, but no pollution events have been reported for either plant.

4.2.4 Highland River Purification Board

Glycol based de-icing agents are used at RAF Kinloss; Dalcross airport, Inverness; and on the Kessock Bridge (A9, North of Inverness). Pollution problems have been experienced at RAF Kinloss in the ditches draining the airbase. The ditches are classified as 4 (grossly polluted). BOD values of 60-360 mgl^{-1} were recorded in the ditches in the winter 1982/83. In 1983, when glycol-based de-icers only were used, the River Purification Board made representations to the PSA regarding the condition of the drainage ditches. It was recommended that urea be used for mild frost protection and glycols only when severe frost was forecast. Subsequently, the condition of the ditches improved, with peak BODs reducing to 5-150 mgl^{-1} in winter 1983/84, and 6-36 mgl^{-1} in 1984/85. Since the winter 1983/84, BODs in the affected ditches were reduced in all but the most severe weather conditions, but a consequent increase in ammonia concentration has been observed, as the result of using urea.

Glycols are only used at Dalcross airport, Aberdeen, for de-icing rather than preventative anti-icing. Usage is estimated at 22,700 litres per winter. The Dalcross airport ditch is unclassified; although slightly polluted its condition is less severe than those at Kinloss and thus the River Purification Board have not found it necessary to make representatives to the Airport Authority.

The Highland Regional Council also use glycol based formulations to de-ice the Kessock Bridge on the A9. Usage is estimated at 30,000 litres per winter depending on frost. The recent installation of frost detectors on the bridge has reduced the requirements for chemical de-icing. No detrimental effects have been observed as a result of this application.

4.2.5 North East River Purification Board

Two sites where de-icing agents are used are Aberdeen airport and Lossiemouth airbase. Runoff from Aberdeen airport (10 ha of runways and taxiways) drains to mains of the Dyce Burn and Far Burn, which both flow into the River Don. River Don is class 1 at Dyce, but both burns are too small for classification. There are no consented discharges for glycols.

No specific pollution incidents have been reported, but routine sampling has shown that the water quality index falls rapidly in both small streams commensurate with the first use of de-icers in winter. Fungus is also observed particularly in the Far Burn, to which the main terminal apron drains. Aircraft de-icing is currently carried out on this apron. Although a survey specifically to determine the impact of de-icers on the water quality of the River Don has not been carried out, it is considered that the dilution factor in the river would minimise any adverse effects.

Aberdeen Airport Ltd have recently invested in a Kupper multi de-icer, at a cost of £138,000, to permit greater control over spraying and hence de-icer usage. Anticipated accuracy for measuring the volumes used is 0.5 litres per 1000 litres sprayed.

Lossiemouth airbase is drained by several small watercourses, the most significant of which is Covesea Burn. This drains in a north-easterly direction to the sea. Water quality in the burn is poor because of the large quantities of septic tank effluent which drain into it; periodic contamination by aircraft spirit; iron from ferruginous groundwaters; glycols from aircraft engine coolant; and glycols and urea from the use of de-icing agents.

Estimated usage in the winter 1985/6 was 383,000 litres of glycol de-icers and 99 tonnnes of urea. Much of the runoff is dispersed via soakaways into the porous sandy soils at the air station, and it is considered that only a small proportion of the load applied reaches the surface water drainage system. A programme of winter sampling of Covesea Burn is to be initiated to assess the degreee of contamination arising from the use of de-icing chemicals.

4.2.6 Northumbrian Water

Major civil airports within the region include Newcastle and Teesside. It is understood that Newcastle airport currently uses urea, but is installing storage facilities for liquid chemicals.

Glycol based de-icers are used at helipads at RAF Boulmer, Millfield airfield, Albermarle Barracks and Otterbourne Range. No pollution problems have been experienced with either civil or military use.

Two potential pollution incidents have occured with glycol discharged from industrial cooling systems and refridgeration systems. In one, leakage was contained in bunding. In the other case, a fluorescent dye was released simultaneously with the glycol, which auspiciously permitted the pollution plume to be monitored visually. No fish mortality was observed in the receiving stream within 12 hours.

One manufacturer of de-icer preparations discharges into the Tees. There is no consent for glycols specifically, but only for effluent organic strength.

4.2.7 North West Water

Usage of glycols and other de-icers in the North West Water region is detailed in Table 4.1. There is a consent in force for surface water discharged from Manchester airport, but this does not refer specifically to glycols. No pollution incidents were reported.

4.2.8 Severn Trent Water

Glycols are used at Birmingham International Airport, but runoff passes through oil interceptors and settlement lagoons, thus peaks are dissipated by buffering in the system. The discharge enters the River Blythe via some minor tributaries and substantial environmental problems have not been experienced.

At East Midlands airport, dishcarge is to minor ditches and streams which are often dry between rainfall. Unacceptable algal and fungal growth has been observed in these watercourses, arising from the use of glycols and detergents from aircraft washing. Severn

Table 4.1 Usage of de-icing agents at airfields in the North West Water Authority Region

AIRPORT	DE-ICERS USED	STORAGE ARRANGEMENTS	AREA OF USE	AMOUNTS USED	FREQUENCY OF USE	SPILLAGES/ INCIDENTS	DRAINAGE ARRANGEMENTS	RECEIVING STREAM	CLASS
Manchester	(1) Urea	Soild store)	Runways	Weather	Weather	None known	95%	Cotterill	4
Ringway		150)	taxiways	dependent	dependent		contaminated	Clough	
							areas		
	(2) Glycol	Bulk storage)	and		Average		5%	Baguley	3
		)	apron		30 times		contaminated	Brook	3
		73,000l			per year		area		
	Glycol	-	Aircraft						
British		Bulk storage	Long runway	1000l	Weather		All	Red	3
Aerospace	Glycol		2.4 km	1000l	dependent	None known	surface	Brook	
Woodford				per	Average		water		
		22,500l	Small	appli-	30 times				
			apron	cation	per year				
Liverpool	Urea	Bulk	Runways)	2250l	Weather	None	All	River	C
Airport		Storage	taxiways)		dependent	known	surface	Mersey	(Tidal)
			apron)				water	estuary	
	Glycol	Tank	Aircraft)						
		storage							
		3500l							

AIRPORT	DE-ICERS USED	STORAGE ARRANGEMENTS	AREA OF USE	AMOUNTS USED	FREQUENCY OF USE	SPILLAGES/ INCIDENTS	DRAINAGE ARRANGEMENTS	RECEIVING STREAM	CLASS
British Aerospace PLC Warton	(1) Glycol	Bulk storage capacity 55,000l Normal stocks 20,000l	Taxi areas dispersal bays 140 l/y	Max use any one time 4500l	Estimated 30 times per year	None known	Runways and taxiways Roadways Wrea Brook	Trib. of Wrea Brook	
	(2) Urea	Bulk storage	Footpaths and taxiways	5/6 tonnes at any one time max 200 t/y					
	(3) Rock Salt Salt	Bulk storage	Domestic areas only	Not known					
British Aerospace PLC	(1) Glycol	Quantity stored	All areas	22,500 l/y	Estimated 30 times per year	None known	Most of the site	Mellor Brook	Both streams are unclassified at points of discharge Class 2 d/s of Aerodromes
	(2) IMSOL	9,000 l (1) 4,500 l (2) in 200 l drums	Runways and taxiways	250 l/y			SW portion of site	Hole Brook	

AIRPORT	DE-ICERS USED	STORAGE ARRANGEMENTS	AREA OF USE	AMOUNTS USED	FREQUENCY OF USE	SPILLAGES/ INCIDENTS	DRAINAGE ARRANGEMENTS	RECEIVING STREAM	CLASS
Blackpool Airport Ltd Blackpool Aerodome Squires	(1) Urea	Sealed 50 Kg bags, Average stored 3 tonnes	Apron taxiways main runway	5 t/y	Average 30 days year	None known	15" diameter surface water drain	Unnamed trib. of Liggard Brook	X
	(2) Glycol	Volume stored 680 l in 200 l drums	Main runway	2000 - 3000 l/y	When temp $-2^{\circ}C$ or lower and wet conditions				

Trent are currently making representations to the Airport Authority for improved on-site management and disposal facilities for runoff. There is currently only an overloaded flow-balancing lagoon.

Use of rock salt and subsequently urea on the elevated sections of the M5 and M6 motorways has been discussed in Section 2.5.

4.2.9 Solway River Purification Board

The Solway River Purification Board reported no uses of glycol-based de-icing agents for airfields. One military airfield is a potential user but does not use de-icers at present. There are no consented discharges of glycols and no pollution incidents have been recorded.

4.2.10 Southern Water

Glycols are used at Manston airfield in Kent and Dunsford aerodrome in West Sussex. Manston lies over chalk, through which adits from a nearby Southern Water abstraction source pass. There is, however, no evidence of groundwater pollution by glycols. There have been no recorded spillages or pollution events relating to glycol use. Proposed use of Manston airfield by a charter airline is to be monitored.

Eutrophication of local ditches bordering the aerodrome at Dunsfield has been observed, with prolific algal growths. The main receiving watercourse, the Loxwood Stream, has however remained unaffected.

4.2.11 South West Water

The Royal Naval stations at Culdrose and St Mawgan and RAF Chivenham have used glycol-based de-icers for 10 years without undue problems. Within the last two years, South West Water suggested that urea should be substituted, and this has been implemented.

Plymouth and Exeter airports use some glycol but are phasing it out in favour of urea. Discharge from the airports is reported to be to soakaways; no pollution problems have been reported.

4.2.12 Tay River Purification Board

The only specified site for glycol use is RAF Leuchars, which discharges runoff to the Eden estuary (class B). No consent is in force at present. In January 1985, a spillage of glycol de-icer due to a coupling breaking during transfer of the chemical resulted in discharge of approximately 18,000 litres to surface water drains. Inspection and sampling did not reveal any adverse environmental impact on the Eden estuary, due to the dilution of the spillage in the drainage system. The PSA subsequently provided bunding to prevent a repeat occurrence.

4.2.13 Thames Water

Thames Water covers Heathrow, Stansted, Luton and Stolport in the Eastern Division and Gatwick and a number of military bases in the Western Division (see Table 4.2).

Discharges from Heathrow, where both urea and glycols are used, is to the River Crane (class 2B) via lagoons which receive the majority of drainage from the terminals. A severe pollution incident occurred in 1979 when a major input of de-icers from the eastern reservoir at Heathrow caused a growth of sewage fungus on the bed of the River Crane for approximately half a mile downstream. The eastern reservoir consists of two 9 ha ponds, and in early 1979 only the first had aeration facilities. The DO depression in the second pond was severe and of considerable

Table 4.2 Impact on Watercourses Receiving Drainage from Military Airfields in Thames Water Area

Airfield	Receiving Watercourse	Classification	Pollution Problems
Northolt	Yeading Brook	2B	Brook also drains large urban area; difficult to attibute source of any pollution incidents
Odiham	underground	-	None known
Farnborough	Cove Brook	2B	None known
Upper Heyford (USAF)	Gallos Brook	2B	None known
Fairford (USAF)	Dudgrove Brook	1A	Some high ammonia related to use of urea
Kemble	underground	-	None known
Brize Norton	Highmoor Brook via Brize Norton Stream	1B	Some high ammonia related to use of urea
Abingdon	Wildmoor Brook	X	None known
Dunsfold	Wey and Arran Canal	X	None known

duration. Aerators were subsequently installed in the second pond. A further incident was reported in 1982, when the aerators (activated by DO probes) only tripped after a considerable plug of contaminated water had passed through the lagoons and into the River Crane. The aerators are now activated manually when required.

Runoff from Heathrow also enters Clockhouse Lane Pit (2B), from where it is pumped into Feltham Hill Brook. The brook is class 4 for 1.7 km below the airport and then 1B as far as the Thames. A fish kill occurred in 1982 in Clockhouse Lane Pit due to excessive algal blooms and deoxygenation. Another fish kill occurred in the southwestern reservoir attributed to high ammonia resulting from the use of urea.

Gatwick airport discharges stormwater to the River Mole (class 2B) and to the Gatwick stream, which is class 2 above the discharge point and class 3 below. Discharge is via lagoons, but drainage from the Crawley STW and the airport enter together, so it is difficult to identify the source of any pollution incidents. There has been a recent incident of fish mortality in the River Mole, attributed to high ammonia levels (> 100 mgl^{-1}).

At Luton airport, where annual de-icer usage for runways is of the order of 80 tonnes of urea and 20,000 litres of glycol (as product), drainage goes to soakaways into chalk or to the River Lea. The River Lea is class 2B from Luton to Luton Hoo Lakes; 1B for 3 km to Luton STW and 2B downstream. The 1B section below the STW and airport discharge point does not always comply, thus Thames Water are concerned to ensure that weirs which currently divert low flows of airport runoff to foul sewer are functioning correctly. There have been problems with the weir design (blockages) and contaminated water going to surface drains.

Stansted airport discharges to Great Hallingbury Brook (X) which joins the river Stort just downstream of the Bishop Stortford STW outfall. The eastern side of the airport drains to Pincey Brook (1B), part of which is designated as an EC cyprinid fishery. De-icer usage is similar to Luton, but is mostly glycols. Runway de-icing is not expected to increase significantly with the new terminal, because Stansted is kept ice-free at all times as a back-up for Heathrow. There will, however, be an increase in the number of planes being de-iced.

Stolport currently discharges to the Royal Albert Dock. When the new LDDC sewer is constructed discharge will be to the Thames tideway. Thames Water are concerned that present arrangements may cause problems with de-icer accumulation and degradation in spring/summer since the dock is effectively a lake. Intended usage is of the order of 20 litres per 1,000 m^2, with individual applications of approximately 1,200 litres.

4.2.14 Tweed River Purification Board

The Tweed River Purification Board has no known users of glycols within the region. The only reported effects of any de-icing activity are occasional elevated chloride levels in rivers, arising from the use of road salt.

4.2.15 Welsh Water

Welsh Water have four military airfields in the region using glycols. Application rates are in the range 0.2 - 0.4 litres per m^2, with individual applications ranging from 300-2,000 litres. No evidence of downgrading of water quality has been detected. Discharges are to non-classified watercourses or tidal waters.

4.2.16 Wessex Water

Bristol airport uses mainly urea, with some glycol. Runway drainage soaks away via french drains; adjacent springs have been monitored but have shown no effect from the airport discharge. Small quantities of glycol are also used at Boscombe Down airfield on Salisbury Plain. Like Bristol airport, all drainage soaks away to ground and no adverse effects have been observed. RNAS Yeovilton is mainly used for helicopters and Harriers so the use of de-icers has declined. Slight increases in BOD and ammonia concentrations in the River Yeo (class 1B) have been detected following de-icing, but substantial dilution of airfield discharge occurs, therefore the effect is not significant.

Environmental problems are experienced at RAF Lyneham, a major RAF transport base. Typical use at the base is 3,000 litres of glycol de-icer or 3,000 kg of urea per application. The number of applications depends on the weather, but may be daily in bad conditions. Drainage is mainly to the southern end of the airfield, where surface water runs off to the Strings watercourse, a small tributary of the Cowage Brook. This drains into the River Marden and subsequently the Bristol Avon. The volume of runoff is usually small, but with high concentrations of de-icer; as a Crown Property there is no consent condition.

Ammonia concentrations of 15-20 mgl^{-1} have been measured in the Cowage Brook as a result of the hydrolysis of urea. The glycols increase the BOD, but do not appear to be rapidly broken down in the Brook due to the low temperatures; DO is thus relatively unaffected. Growth of sewage fungus occurs in the Strings watercourse. The Cowage Brook is class 3 as a result of the effects of airfield discharge and farm effluents. Wessex Water have made representations to the PSA regarding airfield runoff, requesting provision of a lagoon to contain the concentrated runoff, from where the contents could be dispersed by spray irrigation or disposal to land away from the watercourses.

4.2.17 Yorkshire Water

Yorkshire Water do not permit the use of glycols for runway de-icing in the drinking water catchments of North Yorkshire and North Humberside. Urea is used but only in accordance with daily tonnage limits and subject to regular submissions of records on dates and tonnages spread.

Elsewhere, it is understood that both urea and glycols are employed. RAF Church Fenton (which is not in a drinking water catchment) caused a fish kill after urea spreading, giving ammonia concentrations in the receiving watercourse of 40 mgl^{-1}. After this incident glycols only were used. Yorkshire Water are apparently in discussion with both RAF Church Fenton and Leeds/Bradford airport with the objective of agreeing on diversion of first flush runoff to foul sewer, for treatment at a local STW.

4.2.18 York Waterworks Company

Use of urea for de-icing at a group of RAF airfields which discharge into the River Ouse has caused problems with abstraction for drinking water downstream. Hydrolysis of urea to ammonia gives elevated concentrations in the River Ouse (up to 1 mgl^{-1}), which through chloramine formation, prevents breakpoint chlorination being achieved at the water treatment works downstream. When ammonia levels in the Ouse reach 0.25 mgl^{-1}, York Waterworks company changes the drinking water disinfection system from chlorine to chlorine dioxide. This is expensive but is necessary to maintain water quality. The option of using glycols rather than urea at the airfields for runway de-icing (glycols are already used for aircraft de-icing) is not approved by York Waterworks Company, since there is concern over their toxicological properties. The limit adopted by the Company is 1 mgl^{-1} glycol, based on a Russian limit for river water abstracted for potable use.

4.3 Water Quality Standards and Legislation

The RWAs' approach to commercial airport stormwater discharges appears to have changed since the implementation of Control of Pollution Act 1974 (COPA II). Both Thames Water and Severn Trent Water have given notice of their intention to apply future consent conditons on stormwater discharges as follows:

Thames Water intended conditions for Stansted Airport (approx 1990) include:	Severn Trent Water intended conditions for East Midlands Airport (conditions apply to flows up to 1:1 year maximum flows) include:		
	Approx 1989	Approx 1991	
20 mgl^{-1} glycol	15	10	mgl^{-1} BOD
2 mgl^{-1} ammonia	30	30	mgl^{-1} SS

These consents, which have been proposed and are currently being discussed, will be absolute and will not reflect a 90 or 95 percentile approach. It is quite clear that present airport operational procedures mean that the limits will be exceeded many times during the winter. Any measures taken to reduce glycol use, substitute alternative chemicals, find alternative disposal arrangements and/or provide treatment of the contaminated stormwater will go a long way to achieving the standards, but there will inevitably be periods of severe weather when the standards may not be reasonably achieved.

Thames Water are presently reviewing the position of Gatwick, Heathrow and Luton Airports while Severn Trent Water are reviewing the position at Birmingham.

5. CATCHMENT MANAGEMENT AND TREATMENT/DISPOSAL OPTIONS

5.1 Localised Catchment Management

Airport developments create large expanses of impermeable surfaces often where natural catchments previously existed, consequently run-off from storms increases both in quantity and, more particularly, in rate. To prevent flooding downstream, it is frequently necessary to install balancing storage on the stormwater outfalls to reduce storm flows, certainly those up to 1 in 10 year frequency.

When designing the stormwater drainage system for a new airport or airport extension there are likely to be advantages in keeping the trunk drains from a) the apron stands, b) runways and taxiways, and c) "landside" urban areas separated up to the balancing storage facilities such that segregation and treatment of contaminated streams can be undertaken effectively. This also provides flexibility in the event that de-icants change in the future. Unfortunately at most existing airports drainage systems are not segregated and have developed spasmodically along with airport growth. This will lead to greater difficulty in managing specific areas of the catchment.

As discussed earlier, the levels of stormwater contamination in winter can be well in excess of maximum allowable concentrations for direct discharge to small rivers. Indeed concentrations of several thousand mgl^{-1} of glycol can be measured in stormwater on occasions; consequently, treatment will often be necessary at major commercial airports if stringent consent conditions are imposed. To permit economic design and practical operation of treatment and disposal systems, design loadings should be balanced where possible. The computer model described earlier in Section 2.2.3 can size the necessary balancing capacity, based on extensive historical meteorological data, to accommodate inputs of all rainfall from contaminated areas from November - April, or only the first specified quantity of any rainstorm when the temperature is low, or only those flows where the glycol level exceeds a specified figure, and outputs which can be constrained by flow and/or pollution load. The model selected depends on the degree of sophistication of the control system one is prepared to adopt.

In most instances the residence time in balancing ponds is insufficient to permit much treatment to be achieved during cold weather when the input flow has a temperature of 2°C or less. BAA and Balfours have been considering how extended storage together with covered storage and compressed air aeration (which adds heat) can be used to provide an element of pretreatment even in cold weather. This is a similar concept to the pilot scale work undertaken by Boller (1988) at Zurich. Preliminary indications are that the storage volume required would be very large unless there is further heat addition to accelerate pretreatment. The computer model has been modified to simulate pretreatment in storage for specified temperatures.

The design of balancing ponds to meet hydraulic requirements is normally based on summer storm conditions. As winter storms are of lesser intensity, not all of this capacity is required, consequently a portion of the summer capacity can be allocated to provide part of the storage necessary for contaminated flows in winter, thus optimising facilities. This can be achieved by providing the balancing capacity in inter-connected segments. Limited aeration facilities should be provided in any storage capacity for load balancing in order to avoid septicity prior to treatment and possibly for pretreatment as discussed above.

5.2 Reuse, Treatment and Disposal Options

In the course of reviewing the general possibilities of reuse, treatment and disposal of glycol contaminated stormwater, consideration has been given to whether the problem of glycol contamination of stormwater could be reduced by utilising centralised de-icing of aircraft. In centralised aircraft de-icing (eg at Paris, Charles de Gaulle) the aircraft pass through a gantry where they are sprayed and the excess glycol is collected and recycled. Nonetheless some glycol remains on the aircraft and drips off elsewhere and jet blast blows some out of the treatment area. At small airports the bulk of the glycol load arises from runways and taxiways, consequently, the scope for pollution load reduction by a new centralised de-icing unit is limited. At very large airports the operational constraints of a centralised de-icing unit can be unacceptable. The problem of who would own and operate such a unit and where insurance responsibilities would lie are added complications which have precluded the adoption of the system in the UK. At present in the UK, airlines are responsible for aircraft de-icing.

A further method of reducing the amount of glycol discharged to storm drains is to collect the bulk of the glycol which has dripped off aircraft at the stands. This can be achieved by using specially designed vacuum tankers which have reportedly recovered about 80% of the glycol solution lying on the stand. Unfortunately, the rate of movement of the machine is slow and, in order to keep turnaround times at a stand to a reasonable level, two machines working in parallel would be necessary to clear a stand suitable for a jumbo jet. This means that for a large airport up to ten of these vehicles would be required with drivers operating on a three shift basis. A Scandinavian company (Frimokar) has produced units working at Stockholm airport and estimates that the cost of a unit would be of the order of £150-200,000, although this cost may reduce if there were orders for a number of machines. A UK manufacturer has estimated that he could produce an acceptable machine for less than £100,000 but the progress rate and number of drivers would be similar.

The potential use of such a strategy may be precluded by the surface slope of the stands and the drainage facilities. If the slope is appreciable, a significant amount of the glycol may reach the drains before the suction machine arrives, as may be the case where there are many drainage inlet points in the stand area. Even if the suction vehicles achieve their objective, and say 66-80% of the glycol applied to aircraft is recovered, the de-icants applied to runways and taxiways will still reach the stormwater drains together with the remaining 20-35% from the stands and part of the glycol applied to the aircraft which continues to drip off between the stands and the takeoff point. The residual levels of contamination are such that treatment and/or disposal systems are still likely to be required for contaminated stormwater. In addition, the recovered glycol would not be suitable for reuse on aircraft and is unlikely to be wanted by manufacturers for reprocessing. There is a possibility that it may be suitable, with further glycol addition, for runway applications but this is not certain. At Stockholm, the recovered glycol is bled into into the foul sewerage system at a controlled rate. However, based on the pilot work undertaken on anaerobic digestion (Section 3), this would appear to be a plausible, cost-effective pretreatment system for such a high strength waste.

The conclusion of the option for suction cleaning of stands is that whilst from a conceptual point of view, it is a step in the right direction, there are a number of physical, operational and cost constraints which may prevent its adoption. However, it is worthy of review and consideration in individual circumstances.

Another approach to dealing with the overall problem is to determine whether it is possible to dispose of the stormwater from the airport under consideration into a large body of water, eg. a large river or estuary, where impact would be significantly less and where treatment prior to disposal may not be necessary (or perhaps be less demanding).

If none of the foregoing options are possible and treatment of comparatively large volumes of contaminated stormwater has to be undertaken, one possibility for dealing with the problem would be to consider reuse of glycol, probably after re-concentration, for de-icing of runways and taxiways. The specification for aircraft de-icing may, however, be too demanding to permit continued reuse in this manner. Recent discussions with a manufacturer of reverse osmosis equipment to determine whether the glycol solutions could be concentrated to at least 25%, at which they *may* be of interest for reuse. However, they confirmed earlier reports that glycol solutions can only be concentrated up to about 10-12% using the maximum normal working pressures for reverse osmosis equipment. At these pressures the recovery rate is poor and the life of membranes presently available would be limited. The process at its current stage of development is therefore considered unsuitable to achieve the required performance, furthermore, the capital and operating costs would be very large.

Glycol removal and concentration by adsorption on activated carbon has also been considered, but because glycol is highly soluble it is not readily adsorbed; at the high concentrations of glycol which can be reached on occasions, this option is not considered to be practical at this time.

Since glycol cannot readily be removed and recovered, a further treatment option which can be considered is to destroy it by chemical methods. Normal oxidising agents such as ozone and peroxide are not considered to be suitable as the destruction would not be complete. In the case of ozone, the capital cost of the generation plant is likely to be excessively expensive, while peroxide would require substantial quantities of an iron catalyst.

Irrigation of the contaminated water over airfield grasslands might be possible in some cases but trials would have to be carried out to determine the efficiency and the effects of factors such as impermeability and/or permeability above an aquifer. Irrigation onto frozen land during prolonged cold periods would present considerable problems. Reed-bed treatment would probably have similar drawbacks, and may attract birds, but may may be worthy of development trials for small airfields.

Should treatment prove necessary, it presently appears that biological treatment is the most suitable process, although it is considered that for further exploratory work on physico-chemical treatment would be worthwhile. Biological treatment can be sub-divided into two main types: anaerobic treatment, where organic wastes are reduced by the micro-organisms in the absence of oxygen; and aerobic treatment where micro-organisms oxidise the wastes in the presence of oxygen. Anaerobic treatment is best suited to wastes having biochemical oxygen demands in excess of 1500 mgl^{-1} and has the advantage that the amount of residual microbial sludge generated by the treatment process is much smaller (less than 10% of aerobic systems). The process is normally used as a pretreatment process and final polishing treatment by aerobic treatment is usually required. For anaerobic treatment to be most effective, the temperature of the waste is normally raised to 30-35°C which necessitates pre-heating of the waste and insulation of the reaction tank (digester). To offset this, a by-product of the anaerobic process is methane gas which can be collected and burned to assist with heating the waste stream.

A modification of the anaerobic process has been considered in Sweden but not implemented. This comprises using an underground permeable substratum as a low rate anaerobic reactor in a similar fashion to the method used for *in situ* denitrification. It is not clear how large volumes of water at 2°C could be treated in this way, nor how the solids generated when the waste was strong could be prevented from clogging the substratum (unless an artificial coarse gravel bed was constructed), nor how mixing and seeding could be achieved reasonably efficiently to prevent "stuck" digestion. Because of the problems associated with geometry on the large scale, it is unlikely that a small scale pilot plant could be used to develop design criteria.

Aerobic systems on the other hand usually operate at ambient temperatures. Consequently in winter, at surface water temperatures of 5°C or below, they are not at their most efficient due to reduced micro-organism activity; therefore the treatment of stormwater would only be really effective if it were undertaken in admixture with comparatively warm domestic sewage or were heated. It should perhaps be mentioned that the contents of stormwater balancing lagoons at Gatwick have had ice cover during the 1985/6 and 1986/7 winters.

Aerobic systems are energy-intensive because of the power required for aeration and are more sensitive to intermittent operation due to the characteristics of the micro-organisms. Indeed, the major problem that would arise with aerobic treatment of the stormwater in isolation would be the variation in loading. During a mild spell there may not be sufficient load to sustain the biomass at the required level for the peak load and sludge settleability may also be adversely affected. In this connection, the variability of UK winters is likely to be greater than in Scandinavia, Switzerland or Canada, where treatment systems have also been considered. Anaerobic systems would also be energy intensive in the case of the treatment of a cold, contaminated stormwater particularly as the heat input requirement would be large when liquid temperatures were low and waste streams weak.

Summarising the biological treatment possibilities, anaerobic pretreatment is not preferred in most instances as:

- the waste strength is unlikely to be sufficient to maintain adequate heat-balance;

- the process involves considerable mechanical/electrical equipment; and

- the system requires regular process supervision.

It may, however, have an application if the suction tanker concept discussed earlier were adopted. Aerobic treatment is only fully effective if the temperature of the stormwater can be raised by an external source, eg. admixture with domestic sewage or injection of waste heat, particularly if urea is used and an ammonia standard has to be met. Consequently aerobic treatment at a sizeable sewage treatment plant is the preferred option, provided that sufficient dilution is available to preclude glycol levels which generate stable foam in activated sludge units, and the treatment can be achieved within reasonable economic constraints. With reference to the presence of stable foam, as discussed earlier in Section 3, BAA have commissioned trials at Rye Meads STW to determine how these could be dealt with in the future. The results may have wider application for any treatment works suffering from "chocolate mousse" which is by no means restricted to treatment works receiving glycols.

A further aspect of general catchment management would be the controlled use of de-icant chemicals. In this respect, airport operations management should consider the chemicals not solely in terms of purchase or application price but should take full account of the environmental implications in terms of meeting standards (for discharge to rivers or treatment facilities) and capital and operating costs for treatment facilities. It is also important that they are aware of the implications of moving to any new de-icant chemical and arrange for a full appraisal on the environmental impact before making any final decision on the proposed change.

6 DISCUSSION

At all major commercial and military airfields stormwater will be contaminated as a result of the use of chemicals for de-icing activities in winter. At most of the large civil and military airfields using glycols, peak concentration in stormwater may exceed 1,000 mgl^{-1} on occasions. At civil airports glycol is used for aircraft de-icing and frequently for runway and taxiway de-icing. At military airfield any glycol use is associated with de-icing of runways and taxiways.

Since at commercial airports de-icant chemicals are used as part of an industrial/commercial activity, contaminated stormwater is considered by several Regional Water Authorities (RWAs) to be an industrial discharge and consent conditions are starting to be applied. The consents are likely to vary depending on the location. Where airports are in a catchment upstream of a drinking water intake, or over an aquifer used for potable supply, the standards are likely to be fairly stringent; typically 20 mgl^{-1} glycol, or 15 mgl^{-1} BOD and 2 mgl^{-1} ammonia (generated as a result of the hydrolysis of urea).

Apart from the potential for impairing the quality of water be abstracted for water supply, there is little evidence from RWAs and Scottish River Purification Boards of regular major impacts due to the use of glycols at airports. There are more reports about the impact of ammonia (from urea). The lack of impact of glycol in most cases is likely to be due to:

- low water temperatures, which mean that the oxygen demands exerted are much smaller that the 5 day 20°C BOD;

- river flows in winter not generally being at their lowest;

- the metabolic activities of flora and fauna being lower and therefore less sensitive to water quality;

- upstream dissolved oxygen concentrations being significantly higher than in summer;

- much of the glycol load discharged not in fact being balanced at most airports but being discharged in slugs following rain when receiving waters also have higher flows.

From the RWAs point of view, they are bound by the requirements of COPA II and as such their records are open to inspection by the general public, pressure groups and other industrialists (or farmers) with direct discharges to rivers. They are also presently under pressure to improve river water quality. RWAs are also reluctant to attach a "percentage compliance" to an airport discharge as this means sampling programmes become extensive and costly and any legal action becomes extremely difficult and delayed.

It is open to discussion whether the criteria for water quality objectives in rivers which are not used for potable supply presently reflect the seasonal variation in glycol (ie BOD), which could perhaps be tolerated in winter in rivers when temperatures are low and flows are not at their minimum. However the trend for European harmonisation of water quality standards together with a general tightening of standards would appear to preclude such an approach.

Whilst RWAs sympathise with the problem of stormwater contamination at airports, since it is associated with safety connotations, they cannot be expected to treat airports as special cases otherwise they would have difficulty in justifying the consent conditions applied to their own sewage treatment works or, perhaps more importantly, to other direct discharges (eg industry or farms). This control in England and Wales in the future will be the responsibility of the National Rivers Authority.

From the standpoint of the Airport Companies, they are faced with dealing with a problem which is largely outside their control. They do not know how severe and how prolonged the cold weather will be in many winters or the pattern of rainfall or snowfall. Furthermore, the range of winter weather that can be experienced is very wide and it would be onerous to provide treatment and/or disposal facilities that would be used to their full extent only once in every 5 or 10 years. However, even if facilities to deal with such frequencies are provided, they will inevitably fail in a very severe winter (which could theoretically occur shortly after commissioning).

If facilities are designed on a 1 in 5 year or 1 in 10 year winter basis, they may involve airports in expenditures in the £1 - 10M range if fixed discharge standards of 20 mgl^{-1} glycol are imposed. Slight relaxation of standards to say 30 or 50 mgl^{-1} would not reduce expenditure; relaxation to several hundred mgl^{-1} on occasions would be necessary to have any major impact on cost implications for airports.

Furthermore, from the airports' standpoints, they will need considerable time to study the problem and produce a solution which is reliable and cost-effective. The layout and drainage systems of most airports have not been constructed with a view to separation and treatment of contaminated stormwater. Furthermore, there are also new de-icant chemicals being developed, for example acetate compounds, which have only about 30% of the BOD of equivalent glycol usage and which if used may have a significant bearing on any treatment proposals. Trials were scheduled in UK early this year but the prolonged mild weather caused their postponement.

In the light of the foregoing discussion, it is considered that a round-table discussion between the DoE and interested parties (or sub groups of the interested parties) would be beneficial to review the overall problem.

7. REFERENCES

Boller M (1988) Alternative treatment of de-icer fluids from airports. In: *Pretreatment in Chemical Water and Wastewater Treatment*, Ed H H Hahn and R Klute, Springer-Verlag, Berlin, 201-215

Boughey J E (1984) The use of chemical de-icants on military airfields in the UK. In: IPHE Symp *Aspects of Airports*, Metropolitan District Centre, April 1984.

Douglas W G (1986) The control of airport de-icing compounds in the water cycle. MSc Thesis, Imperial College, 90pp.

Fisher A A (1978) Immunological and delayed allergic contact reactions to polyethylene glycol. *Contact Dermatol*, 4, 135-138.

FAO/WHO (1964) 17th Report of the Expert Committee on Food Additives - Tech Rep Ser WHO No 281, World Health Organisation, Geneva.

Doull J, Klassen C D and Amdur H O (Eds) (1980) Cassarett and Doull's *Toxicology - The Basic Science of Poisons* 2nd Ed, McMillan Pub Co, New York.

Health and Safety Executive (1987) Occupational Exposure Limits, Guidance Note EH 40/87.

Jank B E, Guo H M and Cairns V W (1973) Biological treatment of airport wastewater containing aircraft de-icing fluids. Wastewater Technology Centre, Report No. 4-WP-73-5, Canada Environmental Protection Service, Canada.

Gay J, Jeffcoate R, Dunn P and Hawkins J (1987) Stormwater contamination at airports and remedial options - with particular reference to Stansted. *J Inst Water Environ Management*, 1, (3), 253-262.

Mayer D (1986) State-of-the-art of ground aircraft de-icing technology. In: Proc *Aerospace Technology Conference*, Long Beach, California Oct 13-16. Soc Automotive Eng, Paper Ser 861656.

Sax N I (1984) *Dangerous Properties of Industrial Materials*. 6th Ed, Van Nostrand Rheinold Co, New York.

Transport Canada (1985) State-of-the-art report of aircraft de-icing\anti-icing. Document AK-75-09-129, Canada.

Property Services Agency (1986) Chemical de-icing of airfields - pollution aspects. Directorate of Civil Eng Services, PSA, Croydon.

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