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Pollutants in Airport Runoff Waters

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Runoff waters from airport areas constitute a serious environmental problem. It is essential to monitor levels of pollutants emitted into the environment and measure their toxicity on a continuous basis. The authors' aim was to critically review data on pollution from aviation fuel combustion, aviation fuel spillage, the washing and cleaning of aircraft and airport service equipment, and the use of de-/anti-icing agents published in scientific journals. The authors also summarize information on the analytical methodologies available for the determination of pollutants emitted during airport operations and provide data on the toxicity of runoff containing compounds used in de-/anti-icing operations.

KEY WORDS: airports, management of wastes, pollutants, runoff waters, toxicity

1. INTRODUCTION

Air transport is the safest, quickest, and most convenient means of travelling long distances.[1] In addition, it facilitates economic and cultural exchanges and is a significant source of employment and growth in many regions.[2] Despite the positive aspects resulting from the intensive development of aviation, airports are large-scale polluters of the environment. The everyday activities at airports, such as aircraft and ground vehicle washing, cleaning, aircraft maintenance and repair work (including painting and metalwork), fuelling operations, engine test cell operations, de-/anti-icing operations, and ground vehicle maintenance are all sources of wastes (Figure 1).[3]

Airport operations can contribute to the pollution of air, water, and soil; they can also adversely affect climate, the plant kingdom, and buildings (see Table 1).[4] However, their most destructive effects are on people and

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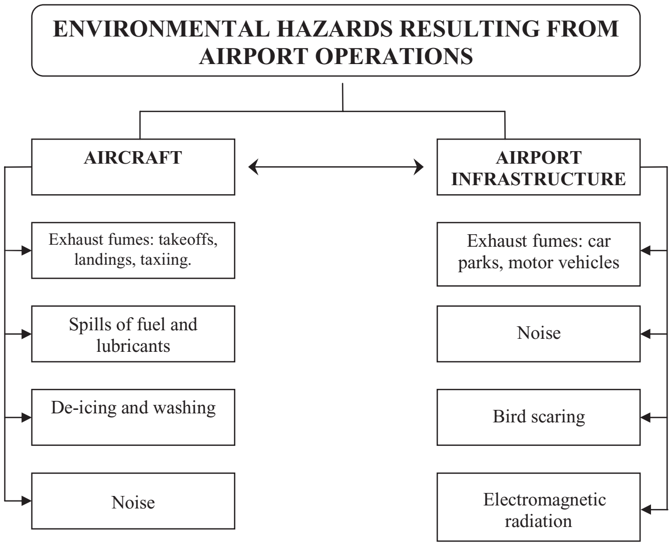

FIGURE 1. The environmental hazards resulting from airport operations.

animals.[5] The most effective way of reducing such pollution is, of course, to prevent it from occurring in the first place. So it is crucial to monitor levels of contaminants emitted into the environment and measure their levels of toxicity on a continuous basis.

One of the more important problems in this respect is the runoff waters that form when precipitation or atmospheric deposits flush the airport surface during its operation (runways, taxiways, washing and de-/anti-icing pads, aprons, transshipment points, fuel stores, repair shops, garages). The contaminants arising out of airport operation penetrate into all compartments of the environment.[4] In most cases airports do not possess their own effluent treatment plants, so all effluents carrying petroleum compounds, surfactants, the de-icing agents used in winter, and other organic and inorganic pollutants run off together with rain water or snow melt into drainage ditches, where they enter the soil, surface waters (rivers, lakes, ponds), and ultimately ground waters.

2. THE MAIN SOURCES OF EMISSION AND ANALYTES PRODUCED DURING AIRPORT OPERATIONS

2.1 Washing and Cleaning of Aircraft and Airport Service Vehicles

Another important source of pollution at airports is the use of solvents for cleaning. Solvents are used extensively in the aerospace industry for cleaning processes that touch virtually all aspects of the manufacture, maintenance, operation, and repair of space, commercial, and military air vehicles. They

TABLE 1. The principal contaminants produced during airport operations and their sources

Source	Xenobiotic	Reference(s)
Combustion of aviation fuels	CO_2, CO, CxHy	[1,6,7]
	Volatile organic compounds (VOCs)	[8]
	Nitrogen oxides, NOx (NOx = NO_2+ NO+ HONO+HNO_3)	[1]
	Water vapor	[1]
	Particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), including airborne metals	[1,3,9]
	Sulfates	[1]
	Polycyclic aromatic hydrocarbons (PAHs)	[10,11]
	Sulfur dioxide, SOx	[5,6]
	Aldehydes	[5]
	Aliphatic hydrocarbons	[5]
Spillage of aviation fuels and greases	Benzene, ethylbenzene, toluene	[5]
	n-heptane, n-pentane, n-hexane, 1-pentene, o-xylene	
	Phenol	
	Benzo(a)anthracene, benzo(a)pyrene, naphthalene, phenanthrene	
Cleaning of aircraft and of airport service vehicles	Anionic, cationic, nonionic detergents	[12]
	Glycols	
	Methyl esters of fatty acids	[12]
De-/anti-icing agents	Propylene glycol (PG), ethylene glycol (EG)	[13–16]
	pH buffers (potassium hydroxide)	[16]
	Water	
	Dyes	
	1,4-Dioxane	
	Surfactants	[16]
	Triazole	[14–16]
	Sodium nitrite	[16]
	Sodium benzoate	
	Borax	
	Diethylene glycol	
	Isopropyl alcohol (Isopropanol)	
	Alkylphenol ethoxylates (APEO)	[17]
	Urea (NH_2CONH_2)	[14,16]
	Ammonia (and conversion products—nitrites, nitrates)	[16]
	CO	[16]
	Potassium acetate, calcium magnesium acetate (CMA), sodium acetate	[16]
	Formate (sodium, potassium)	[16]
	Potassium chloride, magnesium chloride, sodium chloride	[14]

remove greases, oils, soot, and dust. Washing and polishing the body of an aircraft improves its performance by reducing friction. A clean aircraft consumes up to 3% less fuel and causes far less environmental contamination.[18,19] But these solvents are very harmful organic pollutants. The U.S. aerospace industry generates between 220,000 and 300,000 tons per year of hazardous air pollutants (HAPs) and 145,000–200,000 tons per year of volatile organic compounds. Solvent cleaning operations account for 62% of these emissions. The three solvents that generate more than 90% of the total emissions from solvent cleaning operations are methyl ethyl ketone (MEK), 1,1,1-trichloroethane, and Freon 113. All three solvents are on the HAP list; they are used for general purpose cleaning processes.[12]

The federal aerospace regulations in the United States were developed by a team of representatives from government and civilian aerospace organizations, environmental organizations, and the U.S. Environmental Protection Agency (EPA). The aerospace National Emissions Standard for Hazardous Air Pollutants regulates cleaning solvent categories: hand-wipe cleaning (the removal of residue or contaminants from surfaces by rubbing these with rags, usually wetted with solvents), solvent flushing (involves pumping solvent from a reservoir through a pipe or hose or through equipment or assemblies to remove contaminants), and spraying (involves applying the solvent to a surface through a nozzle so that the solvent is under pressure).

Aerospace cleaning solvents can be grouped into four general categories: aqueous, organic, semiaqueous and halogenated solvents. The EPA has approved categories of certified solvents: aqueous-neutral detergent, aqueous-nonionic detergent, aqueous-alkaline/hydroxide, aqueous-alkaline with detergent, semiaqueous, semiaqueous/terpene, semiaqueous/glycol ether, semiaqueous/abrasive, semiaqueous/hydroxide, aliphatic/terpene, aliphatic/glycol ether, glycol ether blends, and solvent solutions ≤ 5 mm Hg at 20°C.[12] Examples of commercial preparations used for washing aircraft include the MrMuscle[20] and Aero 9738 aircraft shampoos.[21]

Although solvent hand-wipe cleaning represents the largest pollutant source in the aerospace industry, difficulties are encountered in the formulation of regulations that would reduce pollutant emissions without compromising the operation being performed. The extreme variety of applications, required levels of cleanliness, and the location of the cleaning process (i.e., closed hangar vs. flight line) have complicated the process for identifying alternative solvent cleaning processes. The alternative solvents and processes used must be fully compatible with aircraft materials and not contribute to their degradation. A newly patented alternative cleaning agent is Spray Nine Q4 Corp (U.S. Patent No. 7,666,264 B2). This consists of at least one fatty acid methyl ester, and one or more surfactants in sufficient quantity to form an optically clear, stable, and effective emulsion.[12]

2.2 Application of De-/Anti-Icing Agents

During periods of low temperatures, it is standard practice at airports to use de-icing agents and substances preventing the re-formation of ice on aircraft. De-icing involves removing ice, snow, and hoarfrost from the aircraft surface, whereas the aim of anti-icing is to prevent ice from re-forming on the aeroplane.[16]

In the de-icing/anti-icing process, aircraft are usually sprayed with aircraft de-icing and antifreeze fluids (ADAFs) that contain chemical de-icing agents; however, nonchemical methods are also used. Numerous such operations may be in progress at airports: de-icing runways, de-icing and anti-icing aircraft, de-icing taxiways, aircraft maintenance, and salt de-icer application.[21]

Typically, the de-icing season lasts from October to April. In cooler climates this period may be longer, and in warmer ones it is usually shorter.[16] In winter, ice and snow on aircraft and runways impair the aerodynamic properties of planes and can compromise flight safety. The icing of aircraft increases their weight, makes it more difficult to achieve takeoff speed, and can cause mechanical equipment to become blocked.[23] Accumulating ice increases head resistance, adversely affects engine operation, and substantially reduces the stability and maneuverability of the aircraft. All larger aircraft are equipped with a battery of ice protection systems: heated leading edges and windowpanes, de-icing boots that can be inflated to break off ice, and a system for moistening propeller blades with alcohol. In most cases these arrangements are reasonably effective, but under certain conditions they may be insufficient, and in any case they use up a lot of energy.[24] That is why chemical de-icing and anti-icing agents are used at airports.

For removing hoarfrost and ice from an aircraft a mixture of chemical reagents and hot water is used, which is sprayed at high pressure onto the fuselage. De-icing mixtures consist mostly of glycol and urea, but they may also contain various additives.

Two types of de-icing are performed: wet-weather and dry-weather de-icing, depending on a number of climatic and operational factors. Wet-weather de-icing is performed during storm events that include precipitation such as snow, sleet, or freezing rain. Dry-weather de-icing is performed when changes in the ambient temperature cause frost or ice to form on aircraft but no precipitation is present.[16]

The quantities of spray range from as low as 40 l/plane to as high as 15,000 l/plane for large aircraft during bad weather.[25] Aircraft anti-icing fluids are applied in much smaller volumes than their deicing counterparts. A commercial jet requires approximately 133 l of fluid for anti-icing after deicing. Generally, dry-weather deicing requires 76–190 l of deicing fluid, depending on the size of the aircraft.[16] The amount of de-icing fluid required to de-ice a commercial aircraft depends on its size, the weather conditions, and airport operations.[25]

After use, the fluid typically mixes with storm water runoff and may enter lakes, rivers, and streams.[25]

2.3 Types of Aircraft De-/Anti-Icing Fluids

Aircraft de-/anti-icing fluid formulations consist of ethylene glycol, propylene glycol, or diethylene glycol as the freezing-point depressant; water; and numerous proprietary additives.[26] On one hand, de-icing agents must be environmentally friendly (biodegradable), and on the other they must be effective and not corrode the materials used in aircraft construction. For this reason, they also contain corrosion inhibitors, surfactants, antifoaming agents, and dyes.[23]

Aircraft de-icers are categorized into four classes: Type I, Type II, Type III, and Type IV. Not all types are currently used.[16] Table 2 lists information characterizing the four types.

2.4 Pavement De-/Anti-Icing

Pavement de-/anti-icing removes or prevents the accumulation of frost, snow, or ice on runways, taxiways, aprons, gates, and ramps. Because ice, sleet, and snow may be difficult to remove by mechanical methods alone, most airports use a combination of mechanical methods and chemical de-icing agents. Common pavement de-/anti-icing agents include urea, ethylene glycol, propylene glycol, an ethylene glycol-based fluid known as UCAR (50% ethylene glycol, 25% urea, and 25% water by weight), sodium formate, potassium acetate, calcium magnesium acetate, and sodium acetate. Sand may be sprinkled onto the pavement to increase friction but may mechanically damage the aircraft surface. Salts such as sodium chloride or potassium chloride cannot be used to de-ice taxiways or runways because of their corrosive properties; they are used only on airport car parks and roads.

Pavement de-icing typically occurs during the same season as aircraft de-icing, but may be of shorter duration than the aircraft de-icing season.[16]

The U.S. Environmental Protection Agency has estimated that 40 million liters of ADAF are discharged annually to receiving waters in the United States.[26] Though crucial for flight safety, ADAFs are the principal source of airport pollutants entering water, soil, and air: along with rainwater and snowmelt, they flow off the pavement, ultimately getting into surface waters, then ground waters, and the soil.[5] The principal environmental impacts associated with ADAF discharge to the environment include reduced dissolved oxygen in receiving waters and potential toxicity.[27] Glycols, which constitute the majority of ADAF formulations, have both a high biochemical oxygen demand (BOD) and a high chemical oxygen demand (COD).[16,23,26,28]

The migration of these organic compounds to waters is also reflected in the ammonium nitrogen and total nitrogen factors. Nitrogen compounds are formed as a result of the biodegradation of urea and are responsible for

TABLE 2. Characteristics of the four types of de-icing fluids used at airports[16,25,27]

Type of de-icing fluid	Type I	Type II	Type III	Type IV
Application	Removes ice and snow from aircraft surfaces, ensures short-term protection from refreezing	Prevent aircraft surfaces from refreezing and the accumulation of ice and snow on them		
Composition	8% water, 90% glycol, and less than 2% additives (dilution essential)	33% water, 65% glycol, and 2% additives (no additional dilution necessary)	No data	The same as Type II
Freezing temperature	From –27 °C to –60 °C			
Hold time	6–15 min	45 min	No data	70 min
Cost	Cheaper than types II, III, and IV	More expensive than Type I		
Additional information	•the most commonly used de-icing agent used on aircraft •are diluted with water and heated before application	•are thicker and more viscous than type I fluids and contain a higher percentage of additives compared with type I fluids •are applied at full strength and ambient temperatures		•provide more effective protection against refreezing than Type I agents, but are less effective in depressing the freezing point of water •are thicker and more viscous than type I fluids and contain a higher percentage of additives compared with type I fluids •are applied at full strength and ambient temperatures

the accelerated eutrophication of waters.[23] The concentrations of these compounds in airport effluents vary widely, depending on climatic, hydrologic, and ADAF management conditions.[16] Table 3 sets out literature data on the action of de-icing agents on the environment.

3. PROBLEMS AND CHALLENGES POSED BY SAMPLES OF AIRPORT RUNOFF

The analysis of contaminants arising from airport operations comes up against ever newer challenges, especially the need to determine a wide range of analytes in samples with a very complex (and often variable) matrix composition. The development of suitable analytical techniques is driven by ecotoxicological concerns and the desire to describe the state of the environment more accurately.[29]

The basic problems faced by the analysis of airport runoff concern: the spatially different amounts of runoff (local conditions), the composition of the matrix, the presence of solid particles, and changes in composition during the various phases of the process.[30]

The objectives of runoff analyses are to ascertain the source, properties, and quantities of the pollutants it contains. Once these characteristics are known, measures for the proper management of airport effluents can be drawn up (reduction in amount, recycling, modification of processes).[3]

4. DETERMINATION OF POLLUTANTS PRESENT IN SAMPLES OF AIRPORT RUNOFF WATERS

Pollutants emitted from airports can be analyzed by examining samples of runoff (i.e., the rainwater or snowmelt flushing contaminants off the pavement surface). These waters find their way to the soil, surface, and then ground waters, which may be sources of drinking water. Airport runoff waters usually contain large quantities of toxic chemicals and need to be monitored constantly. The analysis of selected contaminants provides a basis for assessing the effects of airport operations on the environment.

4.1 Sample Collection and Pretreatment

The collection and preparation of samples for analysis is a key stage in every analytical procedure for determining a particular group of constituents.[31] Because any errors committed at this stage will affect the remainder of the procedure, it is very important to ensure that samples are representative.[32] However, such samples may be difficult to collect sample because waters

TABLE 3. Environmental impacts of de-icing agents

Compound	Characteristics	Effect on the environment	Reference(s)
		Aircraft de-icing fluid components	
PG	• synthetic clear liquid substances that absorb water • biodegradable (but more slowly than EG) • commonly used in small amounts as a food additive and in cosmetics and certain medicines to absorb moisture	• adverse effect on soil and ground waters • less toxic than EG • high BOD • toxicity √ 48-hr LC_{50} = 43,500 mg/l (*Daphnia magna*)	[13,14]
EG	• synthetic clear liquid substances that absorb water • biodegradable	• hazardous air pollutant—significant risks to humans and the environment • highly toxic to aquatic mammals and humans • oestrogenic action • 96-hr LC_{50} = 27,540 mg/l (*Lepomis macrochirus*) • 48-hr LC_{50} = 46,300–54,700 mg/l (*Daphnia magna*) • LC_{50} 96 hr >18,500 mg/l (Rainbow trout)	[14–16]
pH buffers (potassium hydroxide)	highly corrosive	• Toxicity: √ Risk of death following consumption √ LD_{50} = 1,230 mg/kg (rats)	[16]
Water		Neutral	[16]
Dyes	used to color ADAFs	No data available	[16]
1,4-Dioxane	moistening agent, dispersant, used in very low concentrations	• carcinogenic, teratogenic • toxicity • LD_{50} = 5,700 mg/kg (mice) • LD_{50} = 5,200 mg/kg (rats)	[16]
Surfactants	Reduce surface tension of liquids, improve adherence of liquids to the aircraft surface	May be very toxic toward aquatic organisms	[53]

(Continued on next page)

TABLE 3. Environmental impacts of de-icing agents *(Continued)*

Compound	Characteristics	Effect on the environment	Reference(s)
Corrosion inhibitors			
Triazole • Benzotriazoles 1H-benzotrizaole[a] √ Tolyltriazole[b] √ 4-methyl-1H benzotriazole[c] • 5-methyl-1H-benzotriazole[d] • 1H-benzo-1,2,3-triazole (BTri) Sodium nitrite Sodium benzoate Borax	• are generally used to reduce the flammability hazard posed by the corrosion of metal components • high reactivity potential • highly reactive with glycols • 1H-benzo-1,2,3-triazole and its methylated analogues (tolyltriazole, TTri) are corrosion inhibitors • high polarity	• high biological toxicity • 5-methyl-1H-benzotriazole is significantly more toxic than glycols: √ 96-hr $LC_{50} = 31$ mg/l (*Lepomis macrochirus*) √ 48-hr $LC_{50} = 71$ mg/l (*Daphnia magna*)	[14–17]
Other freezing-point depressants			
Diethylene glycol	• a clear, colourless liquid with the consistency of syrup • reaches higher eutectic temperatures	• toxicity comparable with that of EG, death can follow swallowing; but not as toxic to humans and mammals • Fathead minnow $LC_{50} = 75{,}200$ mg/l (96 h) • Oral administration of 1.34 ml diethylene glycol per kilogram body weight damages kidneys and the central nervous system, causes inflammation of the liver and spleen, coma, and death • Exposure leads to vomiting, nausea, headache, unconsciousness	[16]
Isopropyl alcohol (Isopropanol)	Colorless inflammable liquid with a slight smell resembling that of ethanol and acetone	• Affects the airways, absorbed by the skin • Teratogenic, negative effects on the reproductive system (extreme cases)	[16]

Alkylphenol ethoxylates (APEO)	APEO are low-cost nonionic surfactants that reduce surface tension and are characterized by a relatively low foaming potential	• potentially toxic to aquatic organisms • have been shown to degrade into several • by-products, including nonylphenol (NP), NP1EO, NP2EO, octylphenol (OP), OP1EO, and OP2EO, which are more toxic than their parent compounds • considered to be endocrine disruptors	[17,54]
	Pavement de-icers		
Urea (NH_2CONH_2)	• applied in granular form	• nontoxic • one of its degradation products is ammonia, which is highly toxic to aquatic organisms • a source of nitrogen for algae, which may then consume large amounts of oxygen needed by other aquatic animals • in humans may cause sneezing, irritation, sore throat, cough • LD_{50}(intravenous) = 4,600 mg/kg (mice)	[14,16]
Ammonia	• product of urea hydrolysis • may be converted to ionic forms: NH_4^+, NO or N_2	• highly toxic to aquatic organisms, even at low concentrations • LC_{50} = 1–10 mg/l	[16]
CO_2	hydrolysis product of urea	• highly toxic to aquatic organisms, even at low concentrations	[16]
EG	see above		
Potassium acetate	• may damage the insulation materials used in electrical systems • inflammable in combination with corrosion inhibitors • corrosive • BOD_5 = 140,000–300,000 mg/kg • COD = 315,000 mg/kg	• toxicity relatively low • may cause irritation of the eyes • LD_{50} = 3,250 mg/kg (rats)	[16,17]
Calcium magnesium acetate (CMA)	Solid, granular texture	• Relatively non-toxic to the environment LD_{50} (oral) >5,000 mg/l	[16]
Sodium acetate	• BOD = 580,000 mg/kg • COD = 780,000 mg/kg	• may cause irritation on contact • can be inhaled • LD_{50} = 3,530 mg/kg (rats; oral)	[16]

(Continued on next page)

TABLE 3. Environmental impacts of de-icing agents *(Continued)*

Compound	Characteristics	Effect on the environment	Reference(s)
Sodium formate	• Highly biodegradable • BOD = 230,000 mg/kg (highly dependent on temperature) • COD = 242,000 mg/kg	• LD_{50} (oral) = 11,200 mg/kg (mice) • LD_{50} (intraperitoneal) = 807 mg/kg (mice) Significant exposure to sodium formate de-icer may adversely affect people suffering from chronic complains of the respiratory system, skin and/or eyes	[16]
Potassium formate	• Low BOD during biodegradation (BOD_5 = 40 mg/l) • does not contain toxic corrosion inhibitors	No data available	[16]
Alternative pavement de-icers			
Chlorides Potassium chloride Magnesium chloride Sodium chloride	No data available	• corrosive, can cause ground and surface water contamination • harmful to vegetation and streams • can damage cars and other manufactured products • that come in contact with them • large doses may adversely affect human health (irritation of the alimentary canal, weakness)	[14]
Synthetic fire-fighting surfactants			
Perfluorooctanoate (PFOA)	No data available	• significant increase in prostate cancer mortality • PFOA perturbs sex hormone homeostasis	[55]
Perfluorooctane (PFOS)	No data available	• an analogue chemical of PFOA; very similar action	

[a] Other names of 1H-benzotrizaole: BT, 1H-BT, BTri, BTAH, BTA, BZT, Bz. [b] Tolyltriazole: TT, TTri, MBT, MeBTA, MBz. [c] 4-methyl-1H-benzotriazole: 4-MeBT, 4-TTri. [d] 5-methyl-1H-benzotriazole: 5-MeBT, 5-TTr.

running off airport pavements are rarely homogeneous: their composition may change radically within the space of a few minutes.

In order to determine the properties of contaminants, initial sample collection should be frequent (e.g., a few samples should be collected each time pollutants are generated). Thereafter sampling should take place at regular intervals (e.g., every month, every year), to check whether the properties of the runoff waters have changed or not. Flow-proportional samples are recommended where applicable.[3]

All samples collected should be preserved in the proper manner according to the latest Standard Methods for the Examination of Water and Wastewater and thoroughly completed by the sampler.[3]

4.2 Collection and Preparation of Runoff Water Samples for Analysis

The usual means of collecting samples of runoff water is to install an appropriate drainage system. Then samples of runoff water can be scooped from a specially prepared erosion ditch and then taken to the laboratory.[32]

Another solution is to place the sampling container (a glass bottle) in an earthen embankment.[33,34] The bottle is placed in a plastic container with a metal cover to prevent damage and also to prevent rainwater from getting into the bottle. The bottle's neck should protrude 2 cm above the soil surface to prevent insects from falling into it.[33]

Runoff can also be sampled using fully automated equipment.[35] Apart from the actual sample collection, a number of parameters—the intensity of runoff, its temperature, conductivity, and pH—can all be measured using the system described in Grynkiewicz et al.[32] The main part of this setup is a 10-l glass vessel connected by means of polyethylene tubing to measurement instruments operating on-line. The whole system is placed inside an erosion pipe lying 0.5 m deep in the soil. Runoff samples are pumped out of the glass bottle to other, smaller vessels (made from glass for samples to be analyzed for organic compounds and from polyethylene for samples analyzed for inorganic compounds) and are then analyzed for target compounds. Automated sampling systems such as this one are complex and expensive, which is why they are rarely used in practice.[32] The simplest and cheapest way of sampling runoff waters is hand sampling using hermetic polyethylene syringes fitted with rubber hoses. These samples are taken from drainage ditches, drainage installations, or places where water naturally collects and poured into sealable glass or plastic containers. Before use, every container and syringe is washed, and before sample collection flushed with the water to be sampled.[16]

Environmental samples are a very heterogeneous research material because of the different sampling sites, types of matrix, and the possible spectrum of analytes. The preparation of environmental samples for

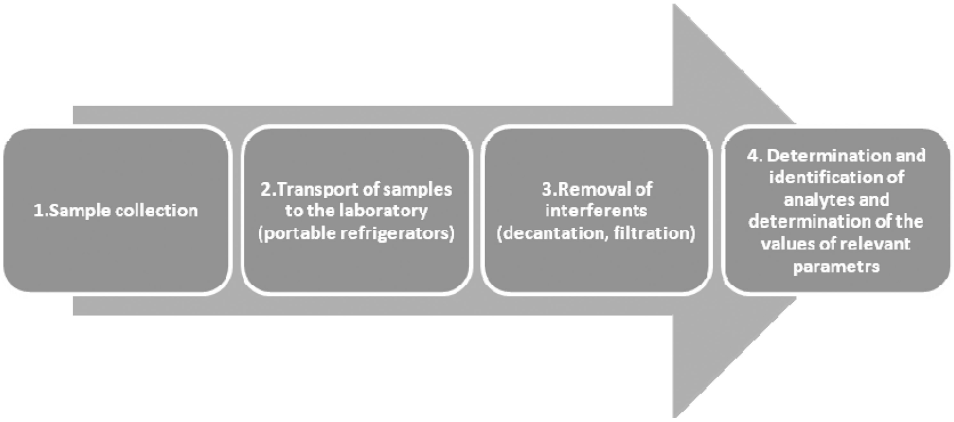

FIGURE 2. The steps involved in preparing samples of airport runoff water for analysis.

analysis is thus a complicated process. The operations carried out at this stage may cause loss of analytes and may also be a source of additional contamination.[36]

Samples should be stored at a low temperature (around 4°C). At the same time, they should be taken to the laboratory and analyzed as soon as possible after sampling. If this is not possible, appropriate measures should be taken to ensure sample stability during transport and storage.[16] If samples are highly contaminated with solid particles/bodies (sand, leaves, insects), they must be filtered or the liquid decanted before further analysis can be embarked upon.[37] Figure 2 shows a scheme for preparing samples for the determination of target analytes and the relevant parameters.

4.3 Techniques for Determining the Physicochemical Parameters and Analyte Contents in Airport Runoff Samples

In the runoff water samples collected from airport areas the following physicochemical parameters were determined: pH and conductivity[16]; summary parameters (BOD_5,[17] COD,[38] total organic carbon,[39] total suspended solids,[39] total Kjeldahl nitrogen[40]); and different chemicals such as phosphorus (all forms),[41] petroleum hydrocarbons,[42] semivolatile organic compounds[43] (fats, oils, and grease[44]), de-icing agents (glycols,[16,45] nonylphenol ethoxylates,[46] benzotriazoles,[17] alkylphenol ethoxylates[17]), and metals.[17,47,48]

The following techniques were used to determine the previously mentioned parameters: gas chromatography,[16] liquid chromatography,[49] gel permeation chromatography,[43] electrochemical technique,[16] spectrophotometry,[42] gravimetric techniques,[44] and potentiometric techniques.[40]

5. LITERATURE INFORMATION ON XENOBIOTICS DETERMINED IN SAMPLES OF AIRPORT RUNOFF WATERS

The world literature boasts a large number of articles dealing with the study of contaminants discharged at airports. The majority of them focus on the pollutants generated by the washing and cleaning of aircraft and airport pavements. Most (around 70%) of these studies were carried out in the United States over the last 15 years or so, their objective being to record the changes taking place in the environment when contaminants emitted by airport operations get into it. The following constituents/parameters of airport runoff waters were determined: ethylene glycol, propylene glycol, BOD (5-day), COD, total organic carbon, total nitrogen, total suspended solids, total Kjeldahl nitrogen, metals (magnesium, copper, lead, calcium, sodium, potassium, iron, manganese), and hydrocarbons.

Table 4 reviews the results of analyses of runoff waters from airports in different parts of the world.

6. THE TOXICITY OF AIRPORT RUNOFF WATER SAMPLES

In tandem with the chemical analysis of airport runoff waters, their toxicity is also evaluated. Tests using biological material are crucial, as they constitute the basis for assessing the overall degree of contamination of particular compartments of the environment.[29]

6.1 Assessment of Toxic Effects

Determining the toxicity of runoff samples may provide solutions to a number of basic problems, for example, hazard assessment (the probability of a factor acting destructively on living organisms), evaluating the scale of toxicity (determining the dose eliciting a toxic effect), and estimating the long-term effects of exposure of organisms to toxic substances (mutagenic and/or carcinogenic effects, compounds with embryotoxic and/or teratogenic properties).[29]

The quantitative measure of an analyte’s toxicity is given by the values of indices determined on a dose-response basis (Table 5). This relationship is expressed by (a) effective concentration (EC) 25 or EC50 or (b) effective dose (ED) 25 or ED50. They define the concentration of a toxin in the environment or the maximum dose of it that elicits a given biological effect in 25% or 50% of the organisms tested. Inhibition concentration (IC) 50 or IC25 defines the concentration of an environmental toxin that impairs (inhibits) by 50% or 25% a given process (e.g., growth).

The lethal concentration (LC) 50 parameter presents the dose causing the death of 50% of individuals in a population after a given time. Often,

TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
COD	Airport, Gdańsk, Poland	runways, internal roads, aprons, car park, passenger terminal	31–807	—	Storm water runoff and liquid drainage	401	—	1999	[23]
			32–202					2000	
			45–287					2001	
			44–177					2002	
			38–145					2003	
		commuter terminal	89	—			35,689	1999	
			227				91,027	2000	
			83				33,283	2001	
			42				16,842	2002	
			60				24,060	2003	
	Heathrow International Airport London, England		8.0–150.0	47.0	Liquid drainage	NA[b]	—	September 1994 September 1995	[57]
	Newark International Airport, New York, USA		49–338	189	Storm water	NA	—	Winter 1997–1998	[16]
	Salt Lake City International Airport, USA		104–3,880	835	Liquid drainage	NA	—	Winter 1997–1998	[16]
	Baltimore–Washington International Airport, USA	main terminal area[c]	11,000–270,000	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	700–2,700	—					
	Dallas/Fort Worth International Airport, Texas, USA	upstream reference	14–80	26	Rainfall	NA	—	November 2002–April 2004	[26]
		airport drainage	10–37,900	—	Liquid drainage				
		receiving stream	<9–1,600	71	Rainfall				
	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	47–84	—	Drainage liquid	NA	—	January 29, 2001–March 16, 2003	[46,54]
		primary outfall	5,600–10,200	—	Drainage liquid				
		receiving stream	330–480	460	Drainage liquid				
	Nashville International Airport, USA		<20–130	—	Effluent from treatment basin	NA	—	Winter 1997–1998	[16]

BOD$_5$	Airport, Gdańsk, Poland	runways, internal roads, aprons, car park, passenger terminal	4.1–130.0	—	Storm water runoff and liquid drainage	401	—	1999	[23]
			5.6–30.9					2000	
			7.7–18.9					2001	
			7.0–10.3					2002	
			4.1–26.6					2003	
		commuter terminal	—	15.5			6215.5	1999	
				47.9			19207.9	2000	
				8.1			3248.1	2001	
				7.5			3007.5	2002	
				6.9			2766.9	2003	
	Westchester County Airport, New York, USA	taxiway, drainage system	2–8.4	2.53	Storm water from taxiways and ditch drainage	NA	—	Winter 1997–1998	[16]
		buildings, hangars	2–37	4.9	Storm water from buildings and hangars				
		ponds	2–7.2	2.8	Storm water from pounds				
	Salt Lake City International Airport, USA		11–1,050	332	Liquid drainage	NA	—	Winter 1997–1998	[16]
	Baltimore–Washington International Airport, USA	main terminal area	23–2,510	1,010	Storm water runoff	NA	—	Winter 1997–1998	[16]
		commuter terminal	197–769	412	Liquid drainage				
	Dallas/Fort Worth International Airport, Texas, USA	upstream reference	2–3.1	2.5	Rainfall	NA	—	November 2002–April 2004	[26]
		airport drainage	93–9,500	—	Liquid drainage				
		receiving stream	<2 to >100	>20	Rainfall				
	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	—	16.6	Drainage liquid	NA	—	January 29, 2001–March 16, 2003	[54]
		primary outfall	738	—	Drainage liquid				
		receiving stream	—	201	Drainage liquid				
	Kansas City International Airport, USA		—	5,100	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	39,000	Liquid drainage	12.6^d	491,400	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		>7.3	—	Storm water	NA	—	Winter 1997–1998	[16]
	Louisville International Airport, USA		3–1250	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
	Nashville International Airport, USA		3–98	—	Effluent from treatment basin	NA	—	Winter 1997–1998	[16]

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location	Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
BOD	Baltimore—Washington International Airport, USA: main terminal area[c] commuter terminal[c]	3–64 138–1,900	— —	Liquid drainage	NA	—	1993	[58]
	Heathrow International Airport London, England	0–18.4	5.54	Liquid drainage	NA	—	September 1994–September 1995	[61]
Dissolved oxygen (DO)	Muddy Bridge Branch (receives runoff directly from Baltimore—Washington International Airport), USA	— —	4.5 6.4	Liquid drainage	450 270	2,025 1,728	March 1991 April 1991	[64]
	Louisville International Airport, USA	0.270–13.0	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
	Nashville International Airport, USA	6.4–11.9	—	Effluent from treatment basin	NA	—	Winter 1997–1998	[16]
TOC	International Airport, Warsaw, Poland	—	446.5	Storm water sewage	NA	—	2002	[58]
	Newark International Airport, New York, USA: runway terminal	7–1120 9–23	83.5 16	Storm water	NA	—	Winter 1997–1998	[16]
	Kansas City International Airport, USA	—	3,000	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA	—	3,500	Liquid drainage	12.6[d]	44,100	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA	—	12	Storm water	NA	—	Winter 1997–1998	[16]
Total nitrogen- (TN)	International Airport, Warsaw, Poland	—	142.1	Storm water sewage	NA	—	2002	[62]
TKN	Airport, Gdańsk, Poland: runways, internal roads, aprons, car park, passenger terminal	3.1–158.50 3.4–69.00 3.27–11.00 2.50–3.21 2.80–17.90	—	Storm water runoff and liquid drainage	401	—	1999 2000 2001 2002 2003	[23]

		commuter terminal	—	7.10 4.60 2.40 2.21 2.91			2847.1 1844.6 962.4 886.21 1166.91	1999 2000 2001 2002 2003	
	Baltimore–Washington International Airport, USA	main terminal area	2–27	12.8	Storm water runoff	NA	—	Winter 1997–1998,	[16,58]
		commuter terminal	ND-26	—	Liquid drainage			1993	
			2–3	2.25	Liquid drainage			Winter 1997–1998	
TSS [mg/l]	Newark International Airport, New York, USA	runway	<2–64	<12.5	Storm water from runway	NA	—	Winter 1997–1998	[16]
		terminal	3–38	11.3	Storm water from terminal				
	Baltimore–Washington International Airport, USA	main terminal area[c]	11–31	—	Liquid drainage	NA	—	1993	[61]
		commuter terminal[c]	14–31	—					
	Louisville International Airport, USA		2–3,530	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
	Nashville International Airport, USA		18–55	—	Effluent from treatment basin	NA	—		[16]
Ammonia-NH_3 [mg/l]	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-23	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	ND-5	—					
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		—	0.003	Liquid drainage	450	1.35	March 1991	[64]
			—	0.043		270	11.61	April 1991	
	Kansas City International Airport, USA		—	3.9	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	23	Liquid drainage	12.6[d]	289.8	Winter 1997–1998	
	Louisville International Airport, USA		<0.03–171	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	46	Storm water	NA	—	Winter 1997–1998	[16]
Total phosphorus-P [mg/l]	Baltimore–Washington International Airport, USA	main terminal area[b]	0.2–60	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[b]	ND-6	—					

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
			Malals [μg/l]						
Fe	Fornebu International Airport, Oslo, Norway (sampling done 2 years after airport closure)	aircraft de-icing point	0.2–6.5	—	Liquid drainage	100,000 m^3/ year [f]	—	2000	[14]
Cd	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-3	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	ND-1	—					
Cr	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-1	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	ND	—					
Cu	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-45	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	3–9	—					
	Kansas City International Airport, USA			14	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	44	Liquid drainage	12.6[d]	554.4	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	9.2	Storm water	NA	—	Winter 1997–1998	[16]
Pb	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-16	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	1–11	—					
	Kansas City International Airport, USA		—	15	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	50	Liquid drainage	12.6[d]	630	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	4.3	Storm water	NA	—	Winter 1997–1998	[16]

Ni	Baltimore–Washington International Airport, USA	main terminal area[c] commuter terminal[c]	ND-5 5	— —	Liquid drainage	NA	—	1993	[58]
Zn	Baltimore–Washington International Airport, USA	main terminal area[c] commuter terminal[c]	240–1,430 35–60	— —	Liquid drainage	NA	—	1993	[58]
	Kansas City International Airport, USA		—	140	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	340	Liquid drainage	12.6[d]	4,284	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	45	Storm water	NA	—	Winter 1997–1998	[16]
Potassium-K	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	—	6.25	Drainage liquid	17	106.25	2000–2007	[67]
		primary outfall	—	59.1	Drainage liquid	62	2,664		
		receiving stream	—	15.5	Drainage liquid	309	4,789		
	Kansas City International Airport, USA		—	13,000	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	ND (900)	Liquid drainage	12.6[d]	—	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	64,000	Storm water	NA	—	Winter 1997–1998	[16]
Aluminum-Al	Kansas City International Airport, USA		—	860	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	1,100	Liquid drainage	12.6[d]	13,860	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	270	Storm water	NA	—	Winter 1997–1998	[16]
Magnesium-Mg	Kansas City International Airport, USA		—	2,500	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	2,000	Liquid drainage	12.6[d,e]	25,200	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	3,000	Storm water	NA	—	Winter 1997–1998	[16]
Manganese-Mn	Kansas City International Airport, USA		—	170	Storm water	NA	—	Winter 1997–1998	[16]

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield^{a} (mg/l)	Sampling year	Reference(s)
	Bradley International Airport, USA		—	140	Liquid drainage	12.6^{d}	1,764	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	360	Storm water	NA	—	Winter 1997–1998	[16]
Sodium-Na	Kansas City International Airport, USA		—	1,100	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	10,000	Liquid drainage	12.6^{d}	126,000	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	7,900	Storm water	NA	—	Winter 1997–1998	[16]
Calcium-Ca	Kansas City International Airport, USA		—	3,400	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	33,000	Liquid drainage	12.6^{d}	415,800	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	14,000	Storm water	NA	—	Winter 1997–1998	[16]
			Specific organics						
Crude oil extract	International Airport, Warsaw, Poland		—	26.4	Storm water	NA	—	2002	[62]
Petroleum ether extract	Airport, Gdańsk, Poland	runways, internal roads, aprons, car park, passenger terminal	14.4–553.7	—	Storm water runoff and liquid drainage	401	—	1999	[23]
			11.2–40.6					2000	
			7.6–26.1					2001	
			11.5–13.4					2002	
			5.6–10.4					2003	
		commuter terminal	—	19.1			7,659	1999	
				208.5			83,609	2000	
				7.7			3,088	2001	
				8.1			3,248	2002	
				6.1			2,446	2003	

Oil and grease	Westchester County Airport, New York, USA	taxiway, drainage system	5	5	Storm water from taxiways and ditch drainage	NA	—	Winter 1997–1998	[16]
		buildings, hangars	5	5	Storm water from buildings and hangars				
		ponds	5	5	Storm water from pounds				
Oil	Baltimore–Washington International Airport, USA	main terminal area[c]	ND-29	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal[c]	ND-14	—					
Glycols	Airport, Gdańsk, Poland	runways, internal roads, aprons, car park, passenger terminal	16.2–356.6	—	Storm water runoff and liquid drainage	401	—	1999	[23]
			11.2–161.8					2000	
			9.2–25.5					2001	
			13.3–20.6					2002	
			9.6–10.2					2003	
		commuter terminal	—	50.4			20,210	1999	
				17.2			6,897	2000	
				11.1			4,451	2001	
				3.4			1,363	2002	
				3.1			1,243	2003	
Propylene glycol	Fornebu International Airport, Oslo, Norway (sampling done 2 years after airport closure)	aircraft de-icing point	—	<1	Liquid drainage	100,000 m^3/year [f]	—	2000	[14]
		drainage ditch	—	<2					
	Westchester County Airport, New York, USA	taxiway, drainage system	0.05–1.3	0.213	Storm water from taxiways and ditch drainage	NA	—	1997–1998	[16]
		buildings, hangars	0.05–0.82	0.13	Storm water				
		ponds	0.05–220	32.8	Storm water				
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		—	<50	Liquid drainage	270 l/s	—	April 1991	[64]
	Dallas/Fort Worth International Airport, Texas, USA	upstream reference	<18	—	Rainfall	NA	—	November 2002–April 2004	[26]

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
		airport drainage	<18–3,800	—	Liquid drainage				
		receiving stream	<18–39	<18	Rainfall				
	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<18	—	Liquid drainage	NA	—	January 29, 2001–March 16, 2003	[46,54]
		primary outfall	1,900–4,400	—	Liquid drainage				
		receiving stream	130–150	150	Liquid drainage				
	Kansas City International Airport, USA		—	16,000	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	160,000	Liquid drainage	12.6[d]	$2{,}016 \times 10^6$	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	ND (5.0)	Storm water	NA	—	Winter 1997–1998	[16]
Ethylene glycol	Baltimore–Washington International Airport, USA	main terminal area	<10	<10	Storm water runoff	NA	—	Winter 1997–1998	[16]
		commuter terminal	<10	<10	Liquid drainage				
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		—	2.100	Liquid drainage	450	945	March 1991	[64]
			—	<25[c]	Liquid drainage	270	—	April 1991	
	Dallas/Fort Worth International Airport, Texas, USA	upstream reference	<18	—	Rainfall	NA	—	November 2002–April 2004	[26]
		airport drainage	<18–20,000	—	Liquid drainage				
		receiving stream	<18–230	37,6	Rainfall				
	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<18	—	Drainage liquid	NA	—	January 29, 2001–March 16, 2030	[46,54]
		primary outfall	32–280	—	Drainage liquid				
		receiving stream	—	<18	Drainage liquid				
	Kansas City International Airport, USA		—	3,200	Storm water	NA	—	Winter 1997–1998	[16]

	Bradley International Airport, USA		—	3,000	Liquid drainage	12.6^{d}	37,800	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	ND (10)	Storm water	NA	—	Winter 1997–1998	[16]
Diethylene glycol	Kansas City International Airport, USA		—	>20 000	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	15,000	Liquid drainage	12.6^{d}	5000000	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	ND (5.0)	Storm water	NA	—	Winter 1997–1998	[16]
Dissolved organic carbon (DOC)	Fornebu International Airport, Oslo, Norway (sampling done 2 years after airport closure)	aircraft de-icing point	21–79	—	Liquid drainage	100,000 m^3/year^{f}	—	2000	[14]
Hydrocarbons	Newark International Airport, New York, USA	runway	<0.4–8.8	<1.98	Storm water from runway	NA	—	Winter 1997–1998	[16]
		terminal	1–3.9	2.45	Storm water from terminal				
	Baltimore–Washington International Airport, USA	main terminal area^{c}	ND	—	Liquid drainage	NA	—	1993	[16]
		commuter terminal^{c}	1	1				Winter 1997–1998	[16]
Acetate	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<5.0	—	Drainage liquid	17	—	2005–2007	[67]
		primary outfall	—	120	Drainage liquid	62	7,440		
		receiving stream	—	8.75	Drainage liquid	309	2,703		
Formate	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<2.5	—	Drainage liquid	17	—	2005–2007	[67]
		primary outfall	—	11	Drainage liquid	62	682		
		receiving stream	—	<2.5	Drainage liquid	309	—		
Phenol^{e}	Kansas City International Airport, USA		—	93	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	340	Liquid drainage	12.6^{d}	4,284	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	ND (10)	Storm water	NA	—	Winter 1997–1998	[16]

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
n-tetradecane[e]	Kansas City International Airport, USA		—	ND (10)	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	140	Liquid drainage	12.6[d]	1,764	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	ND (10)	Storm water	NA	—	Winter 1997–1998	[16]
Benzene[e]	Louisville International Airport, USA		<5–97	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
Ethylbenzene[e]	Louisville International Airport, USA		5–127	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
Naphthalene[e]	Louisville International Airport, USA		5–361	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
Toluene[e]	Louisville International Airport, USA		<5	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
Xylene[e]	Louisville International Airport, USA		<5	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
Benzotriazole[e]	Glatt River near Zurich International Airport, Switzerland		0.16–5.44	—	Surface water	7000m^3/l[f]	—	Winter 2003/2004	[59]
	Fornebu International Airport, Oslo, Norway (sampling done 2 years after airport closure)	aircraft de-icing point	1.2–1100	—	Liquid drainage	100,000 m^3/year[g]	—	2000	[14]
		drainage ditch	1.5–3.5	—					
4-MeBT[e]	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<0.08	—	Liquid drainage	NA	—	29.01. 2001–16.03.2003	[46,54]
		primary outfall	<0.08–0.6	—	Liquid drainage				
		receiving stream	—	<0.08	Liquid drainage				
5-MeBT[d]	Sites near General Mitchell International Airport, Milwaukee, USA	upstream site	<0.08	—	Liquid drainage	17	—	2005–2007	[67]
		primary outfall	<0.08–0.8	—	Liquid drainage	NA	—	29.01.2001	[46]
		receiving stream	—	<0.08	Liquid drainage			29.01. 2001–16.03.2003	[46,54]

	Kansas City International Airport, USA		—	17,000	Storm water	NA	—	Winter 1997–1998	[16]
	Bradley International Airport, USA		—	90,000	Liquid drainage	12.6[d]	$1{,}134 \times 10^6$	Winter 1997–1998	[16]
	Greater Rockford International Airport, USA		—	120	Storm water	NA	—	Winter 1997–1998	[16]
Totyltriazole[e]	Glatt River near Zurich International Airport, Switzerland		0.04–0.91	—	Surface water	7000m^3/l[f]	—	Winter 2003/2004	[63]
Nonylphenol ethoxylates-NpnEO[e]	Sites near General Mitchell International Airport, Milwaukee, USA	primary outfall receiving stream	— —	776 16.9	Liquid drainage	NA	—	January 29, 2001–March 16, 2003	[46,54]
			Inorganics						
Nitrate/Nitrite	Salt Lake City International Airport, USA		0.9–9	4.73	Liquid drainage	NA	—	Winter 1997–1998	[16]
SO_4^{2-}	Fornebu International Airport, Oslo, Norway (sampling done 2 years after airport closure)		87–1600	—	Liquid drainage	100,000 m^3/year [g]	—	2000	[14]
Conductivity [μS/cm]	Heathrow International Airport London, England		347–890	628	Liquid drainage	NA	—	September 1994–September 1995	[61]
	Baltimore–Washington International Airport, USA	main terminal area commuter terminal	120–540 120–2000	—	Liquid drainage	NA	—	1993	[58]
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		— —	210.5 328.0	Liquid drainage	450 270	2,025 1,728	March 1991 April 1991	[64]
pH	Heathrow International Airport London, England		6.4–8.1	7.2	Liquid drainage	NA	—	September 1994–September 1995	[61]
	Westchester County Airport, New York, USA	taxiway, drainage system	6–8	—	Storm water from taxiways and ditch drainage	NA	—	Winter 1997–1998	[16]
		buildings, hangars	6.3–8.8		Storm water from buildings and hangars				

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TABLE 4. Literature information on the analytes of samples of runoff water from airports in different parts of the world *(Continued)*

Parameter/ Analyte	Sampling location		Range of concentration (mg/l; unless otherwise noted)	Mean value (mg/l)	Type of flow	Water flow (l/s)	Mass yield[a] (mg/l)	Sampling year	Reference(s)
		ponds	6.9–8.6		Storm water from pounds				
	Newark International Airport, New York, USA	runway	5.1–7.5	—	Storm water	NA	—	Winter 1997–1998	[16]
		terminal	6.1–7						
	Salt Lake City International Airport, USA		6.6–9.5	—	Liquid drainage	NA	—	Winter 1997–1998	[16]
	Baltimore–Washington International Airport, USA	main terminal area	6.7–7.5		—			Winter 1997–1998	[16]
		commuter terminal	6.7–7.1						
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		—	7.0	Liquid drainage	450	945	March 1991	[64]
				7.4	Liquid drainage	270	—	April 1991	
	Louisville International Airport, USA		7–9.1	—	Storm water runoff	NA	—	Winter 1997–1998	[16]
	Nashville International Airport, USA		7.2–8.6	—	Effluent from treatment basin	NA	—	Winter 1997–1998	[16]
Alkalinity	Baltimore–Washington International Airport, USA	main terminal area	6.7–7.5	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal	30–158						
	Muddy Bridge Branch (receives runoff directly from Baltimore–Washington International Airport), USA		69.0	—	Liquid drainage	450	945	March 1991	[64]
			84.2			270	—	April 1991	
Hardness	Baltimore–Washington International Airport, USA	main terminal area	28–800	—	Liquid drainage	NA	—	1993	[58]
		commuter terminal	46–168						

[a] Mass yield = flow*concentration. [b] NA = Data not available. [c] Data sample type: peak, composite, and grab. [d] Maximum flow rate. [e] Concentration in sample [μg/l]. [f] Only data about flow of surface water. [g] Approximate total amount of storm water for one year.

TABLE 5. Literature data on acute and chronic toxicity information on aircraft de-icing and anti-icing fluids as pure compounds

Organism	Test type/ Parameter	Literature review of mean values of toxicity indices	Reference
		Ethylene glycol	
Pimephales promelas	Acute toxicity tests:		
	• 48-hr LC_{50}	81,950 mg/l	[59]
		9.82 ml glycol/l	[60]
	• $LC_{50}{}^{a}$	24,700 mg/l (Type I^{b})	[26]
		371 mg/l (Type IV^{c})	
	Acute toxicity tests:		
	• 96-hr LC_{50}	72,860 mg/l	[57]
		9.82 ml glycol/l	[64]
		49,000–57,000^{d} mg/l	[61]
	• 7-day LC_{50}	9.82 ml glycol/l	[64]
	• NOAEC	39,140 mg/l	[57]
	Chronic toxicity test:		
	• NOEC	32,000	[57]
	√ Mortality		
	√ Reprod. or growth	15,380 mg/l	
	• IC_{25}	22,520 mg/l	
	• IC_{25}	4,400 mg/l (Type I)	[26]
		179 mg/l (Type IV)	
Ceriodaphnia dubia	Acute toxicity tests:		[57]
	• 48-h LC_{50}	34,440 mg/l	
	• LC_{50}	15,700 mg/l (Type I)	[26]
		449 mg/l (Type IV)	
	• NOAEC	24,000 mg/l	[57]
	• 48-hr EC_{50}	12.85 ml glycol/l	[64]
	• 96-hr EC_{50}	8.95 ml glycol/l	
	• 7-day LC_{50}	3.02 ml glycol/l	
	Chronic toxicity test:		[57]
	• NOEC :		
	√ Mortality	24,000	
	√ Reprod. or growth	8,590 mg/l	
	• IC_{25}	12,310 mg/l	
	• IC_{25}	5,500 mg/l (Type I)	[26]
		113 mg/l (Type IV)	
Daphnia magna	Acute toxicity tests:		
	• <48-hr neonate; 48-hr EC_{50} (s, m)^{e}	50,450 mg/l	[62]
	• <24-hr-neonate; 48-hr LC_{50} (s, n)^{e} 3 different samples	46,300–51,100 mg/l	[58]
	• Age not reported; 48-hr LC_{50} (s, n)	>10,000 mg/l	[58]
	Acute toxicity tests:		[64]
Daphnia pulex	• 48-hr LC_{50}	8.44 ml glycol/l	
	• 96-hr LC_{50}	4.25 ml glycol/l	
Vibrio fischeri	• EC_{50}	11,800 mg/l (Type I)	[26]
		7,700 mg/l (Type IV)	
Selenastrum capricornutum	Chronic toxicity tests		[29]
	• IC_{25}	4,600 mg/l (Type I)	
		1,430 mg/l (Type IV)	

(Continued on next page)

TABLE 5. Literature data on acute and chronic toxicity information on aircraft de-icing and anti-icing fluids as pure compounds *(Continued)*

Organism	Test type/ Parameter	Literature review of mean values of toxicity indices	Reference
Propylene glycol			
Ceriodaphnia dubia	Acute toxicity tests:		[57]
	• 48-hr LC_{50}	18,340 mg/l	
	• 48-hr EC_{50}	0.44 ml glycol/l	
	• 96-hr EC_{50}	0.12 ml glycol/l	
	• 7-day EC_{50}	0.07 ml glycol/l	
	• NOAEC	13,020 mg/l	
	Chronic toxicity test:		[57]
	• NOEC		
	√ Mortality	29,000	
	√ Reprod. or growth	13,020 mg/l	
	• IC_{25}	13,470 mg/l	
Pimephales promelas	Acute toxicity tests:		
	• 48-hr LC_{50}	>62,000 mg/l	[57]
		0.07 ml glycol/l	[64]
	• 96-hr LC_{50}	55,770 mg/l	[57]
		0.03 ml glycol/l	[64]
	• 7-day LC_{50}	0.03 ml glycol/l	[64]
	• NOAEC	52,930 mg/l	[57]
	Chronic toxicity test:		[60]
	• NOEC :		
	√ Mortality	<11,530	
	√ Reprod. or growth	<11,530 mg/l	
	• IC_{25}	6,940 mg/l	
Daphnia magna	Acute toxicity tests:		[64]
	• 48-hr LC_{50}	0.24 ml glycol/l	
	• 96-hr LC_{50}	0.05 ml glycol/l	
Daphnia pulex	Acute toxicity tests:		[64]
	• 48-hr LC_{50}	0.27 ml glycol/l	
	• 96-hr LC_{50}	0.06 ml glycol/l	
1,3-Propylene glycol			
Daphnia magna	Acute toxicity tests		[58]
	• 24-hr neonate, 24-hr LC_{50} (s, n)	8,285 mg/l	
	• <24-hr neonate, 48-hr LC_{50} (s, n)	7,417 mg/l	
1,2-Propylene glycol			
Daphnia magna	Acute toxicity tests:	>10,000 mg/l	[58]
	• <24-hr neonate, 48-hr LC_{50} (s, n)		
	• <24-hr neonate, 24-hr LC_{50} (s, n)	>10,000 mg/l	
Diethylene glycol			
Pimephales promelas	Acute toxicity tests:		[58]
	Juvenile (35-day); 96-hr LC_{50} (s, n)	75,200 mg/l	
Daphnia magna	Acute toxicity tests:		[58]
	• <24-hr neonate, 24-hr LC_{50} (s, n)	>10,000 mg/l	

TABLE 5. Literature data on acute and chronic toxicity information on aircraft de-icing and anti-icing fluids as pure compounds *(Continued)*

Organism	Test type/ Parameter	Literature review of mean values of toxicity indices	Reference
	Potassium acetate de-icing fluid[f,g]		
Vibrio fischeri	Acute toxicity test		[63]
	• Microtox (EC_{50})	6,560 mg/l	
Pimephales promelas	Acute toxicity test		[67]
	• LC_{50}	298 mg/l	
	Chronic toxicity test		
	• IC_{25}	54.5 mg/l	
Ceriodaphnia dubia	Acute toxicity test		[67]
	• LC_{50}	421 mg/l	
	Chronic toxicity test		
	• IC_{25}	54.5 mg/l	
Selenastrum capricornutum[h]	Chronic toxicity test		[67]
	• IC_{25}	19.9 mg/l	
	Sodium formate de-icing fluids		
Vibrio fischeri	Acute toxicity test		[67]
	• Microtox (EC_{50})	1,780 mg/l	
Pimephales promelas	Acute toxicity test		[67]
	• LC_{50}	4,130 mg/l	
	Chronic toxicity test		
	• IC_{25}	1,200 mg/l	
Ceriodaphnia dubia	Acute toxicity test		[67]
	• LC_{50}	1,860 mg/l	
	Chronic toxicity test		
	• IC_{25}	584 mg/l	
Pseudokirchneriella subcapitata	Chronic toxicity test		[67]
	• IC_{25}	1,670 mg/l	

[a] Toxicity test results for four different species to ethylene glycol–based type I and type IV aircraft de-/anti-icing fluids. [b] Ethylene glycol content in type I fluid is 92%. [c] Ethylene glycol content in type IV fluid is 64%. [d] The test organisms were of different ages (fry, juvenile, subadult). [e] s = static; n = nominal concentrations; m = measured concentrations. [f] Multiply by 0.66 for toxicity endpoint expressed as potassium concentration. [g] Multiply by 3.32 for toxicity endpoint expressed as original K-Ac de-icing product. [h] Previously name as *Pseudokirchneriella subcapitata.*

the LC50 parameter is also used: this defines the lethal concentration of a substance in water, soil, or air, causing the death of 50% of individuals in a population. But the determination of the acute toxicity level is preceded by a step in which the effects a substance has on an organism are assessed—this then enables further toxicity tests to be specified more precisely.[29]

The dose-biological response relationship can also be used to predict the level of risk—a dose or exposure time for which the probability of toxic effects manifesting themselves is suitably low. Threshold (boundary/limiting) concentrations or doses are expressed using the following parameters: No Observed Effect Level/Concentration (NOEL or NOEC); Lowest Observed Effect Level/Concentration (LOEL or LOEC), NOAEL or NOAEC (No Observed

Adverse Effect Level/Concentration), Lowest Observed Adverse Effect Level (LOAEL).[29,50]

6.2 Methods of Testing Toxicity

The aquatic toxicity tests described here are the most commonly used ones; they are highly standardized.

6.2.1 ACUTE FRESHWATER TOXICITY TESTS

The following tests measure the lethality of water samples to freshwater organisms, indicating the toxicity of water samples. The *Daphnia pulex* or *Daphnia magna* (Daphnid) acute toxicity test evaluates the acute toxicity of a sample to a water flea belonging to the genus *Daphnia*. The test uses a static or static-renewal design and lasts 24, 48, or 96 hr. Observations at 24, 48, and 96 hr or 7 days permit the calculation of 24-, 48-, 96-hr and 7-day LC values.[51,64]

The procedure using the fathead minnow (*Pimephales promelas*) and the water flea (*Ceriodaphnia dubia*) is also used to measure acute toxicity.[50,52]

6.2.2 CHRONIC FRESHWATER TOXICITY TESTS

These tests measure both lethal and sublethal effects over the life cycle or partial life cycle of freshwater organisms, providing information useful in assessing the potential long-term effects of contamination.[57]

The *Ceriodaphnia dubia* survival and reproduction test estimates the chronic toxicity of a sample to *C. dubia*, a water flea. The test uses the static-renewal design and lasts for seven days, monitoring both the survival of test organisms and the number of offspring they produce.[57]

The fathead minnow (*Pimephales promelas*) larval survival and growth test uses the static-renewal design and lasts for seven days, tracking the survival of test organisms and their increase in weight.[57]

The fathead minnow (*Pimephales promelas*) embryolarval survival and teratogenicity test assesses the chronic toxicity of a sample to minnows, beginning as embryos and extending to the larval stage. The test uses the static-renewal design and lasts for seven days, noting both the survival of the fish and the induction of terata.[57]

The algal (*Selenastrum capricornutum*) growth test identifies the biostimulatory and chronic toxic effects of a sample to a one-celled freshwater alga. The test uses the static design and lasts 96 hr, most commonly monitoring cell density (cells per ml). Alternative measures include biomass.[57]

6.2.3 MICROBIAL TOXICITY TESTS

Microbial toxicity tests assess toxic effects on the microbial community and can serve as cost-effective and rapid screening indicators.[57]

The Microtox test measures the toxicity of water samples or elutriates to *Photobacterium phosphoreum*, a species of bioluminescent marine bacteria.[57] Two features of *Vibrio fischeri* bacteria—rapid division and the triggering of luciferase (combined with cell respiration)—make these organisms ideal for measuring chronic toxicity.[56] Some contaminants inhibit the bacteria's metabolism, decreasing the intensity of light emitted; others stimulate the bacteria and cause an increase in luminescence.[57] Samples containing one or more toxic chemicals retard the reproductive cycle, growth, respiratory activity, and triggers luciferase, which can be detected at low levels by comparing the level of light in the control cuvette with that in the sample cuvettes after 22 hr of incubation.[60]

6.3 Literature Information on the Toxicity of Runoff Water Samples From Airports

The airport runoff waters may contain chemicals such as ethylene glycol, propylene glycol, 1,3-propylene glycol, 1,2-propylene glycol, diethylene glycol, potassium acetate, and sodium formate. These compounds are characterized with high toxicity (Table 5). For example, propylene glycol concentration levels in the runoff samples are very high and may reach even 160,000 mg/l with flow rate intensity 12.6 l/s (Bradley International Airport, Windsor Locks, CT, USA).[16] Similarly high concentration levels were determined in case of ethylene glycol and diethylene glycol, and reach levels exceeding 20,000 mg/l (Dallas/Fort Worth International Airport, Dallas, TX, USA; Kansas City International Airport, Kansas City, MO, USA).[16]

Toxicity of particular chemicals being present in the runoff water samples constitutes total toxicity of such kind of environmental samples (Table 6). Sometimes, the toxicity of runoff water samples may be very high and may reach LC50 values of 85%. If the impact of de-icing chemicals toxicity effects on aquatic organisms is to be concerned, several toxicity tests should be applied to assure compliance. The test species and conditions are specified in EPA guidelines for acute and chronic whole effluent toxicity tests. Freshwater species mentioned in most requirements described in legal system of United States include the fathead minnow (*Pimephales promelas*) and the daphnid *Ceridaphnia dubia* as presented in Table 5.[17,54]

7. MANAGEMENT OF AIRPORT INDUSTRIAL WASTE

Because of the possible adverse environmental effects of airport runoff and pending regulation, various technologies and management approaches are being investigated or implemented.[25] Many large airports, and airports that face severe weather conditions frequently through the winter months, are

TABLE 6. Toxicity studies conducted airport water

Toxicity test/organism	Sampling location		Values measured	Sampling time	Reference
48-hr LC_{50}Fathead minnow	Baltimore–Washington International Airport	main terminal area	LC_{50}: NT[a]-70.0%	October 1990	[58]
Daphnid			LC_{50}: NT-85.3%		
Fathead minnow and Daphnid		commuter terminal	NT		
Microtox	Muddy Bridge Branch (receives runoff directly from Baltimore—Washington International Airport)		• EC-50 (5 min) = NR[b] [ml glycol/l] • EC-50 (15 min) = NR [ml glycol/l]	March 1991	[64]
Microtox	A major North American international airport		• 5 min IC_{50}[c] = 21–25% • 15 min IC_{50} = 23–27%	—	[64]

[a]NT = not toxic (no mortality in 100% storm water treatment). [b]NR = no response. [c]IC50 = the inhibition concentration causing a 50% decrease in light production at 5 and 15 min.

TABLE 7. Airport runoff management techniques

Research site	Time of experiment	Technique	Plants/organisms/ materials used in remediation techniques	Compounds, total parameters	Removal efficiencies (%; unless otherwise noted)		Reference(s)
			Remediation techniques				
Heathrow Airport, England	September 1994–September 1995	Reedbed systems: • Surface flow system (SF) • Sub-surface flow system (SSF)	Macrophytes: • Reedmace (*Typha* species) • Common reed (*Phragmites* species)		SSF system	SF system	[61]
				BOD, COD	31.0^{a}		
				BOD	23.0	18.0	
				Ortophosphate	63.5	40.4	
				Nitrate	52.6	37.4	
				Ammonia	46.5	27.5	
				Metals			
				Zinc	43.8	46.9	
				Lead	12.4	—	
	• August–September 1995 • January, June and October 1996	Constructed wetland (soil surface flow, grab subsurface flow	• *Typha latifolia* • *Typha angustifolia* • *Phragmites australis* • *Schoenoplectus lacustri* • *Iris pseudacorus*		SSF system	SF system	[66]
				EG	99.4^{b}	60.2^{c}	
					71.6^{c}	50.1^{d}	
					76.6^{d}	—	
				1,2-Propylene glycol	99.6^{b}	48.6^{c}	
					59.2^{c}	59.7^{d}	
					95.3^{d}	—	
				Diethylene glycol (DEG)	90.0^{b}	61.3^{c}	
					69.1^{c}	44.5	
					44.5^{d}	—	

(Continued on next page)

TABLE 7. Airport runoff management techniques *(Continued)*

Research site	Time of experiment	Technique	Plants/organisms/ materials used in remediation techniques	Compounds, total parameters	Removal efficiencies (%; unless otherwise noted)	Reference(s)
Moreppen (neighborhood of Oslo International Airport, Gardermoen), Norway	—	Microbial degradation in the vadose zone	Microbial population	• Sodium formate •PG • Potassium acetate • Toluene • Benzotriazole	NA[e]	[67]
Gardermoen Airport, Norway	Snowmelt 1994/1995	Degradation in the unsaturated zone	Extracting soil water from 30 or 40 suction cups placed at depths between 0.4 and 2.4 m. Degradation was analyzed by spatial moment calculations.	PG Potassium acetate	0,015 $\text{day}^{-1,f}$ (1994) 0,047 $\text{day}^{-1,f}$ (1995) NA	[68]
Dane County Regional Airport, Wisconsin, USA	April–July	Aerobic bioremediation	• Bacteria (*Pasteurella multocida*, *Acinetobacter anitratus*, *Pseudomonas stutzeri*) • Nutrient mixes • Enzyme mixes • Ultrasonic stimulation	• BOD • COD	The amount of sludge generated from this technique ranges 5% to 10% beginning volume.	[69]
Airport, Ohio, USA	—	Aerobic fixed-film biodegradation	Macronutrients, passively	EG	over 90%	[70]
Several north-eastern airports, USA	1966–1967	Anaerobic degradation	Anaerobic treatment	PG EG	3,5 $\text{day}^{-1,f}$ 5,2 $\text{day}^{-1,f}$	[71]

Miami International Airport, USA	—	Thermal Treatment	Dewatering procedures	• TSS • TOC • TDS (total dissolved solids) • Heavy metals	NA	[72]
General Mitchell International Airport, Wisconsin, USA	—	• Recycling • Anaerobic biotreatment • Aerobic biotreatment		• De-icers • BOD	Anaerobic biotreatment: degrade the waste sludge solids to produce biogas containing approximately 65% CH_4 and 35% CO_2	[25]
Airport, Texas, USA	—	Mineralization in root zone soil	• Legumes: *Medicago sativa, Lotus corniculatus* • Grasses: *Panicum virgatum, Poa pratensis L., Lolium perenne L., Sporobolus cryptandrus, Festuca arundinacea* • Mixtures: grass mix, grass mix + legumes	• PG	NA	[69]
Airport, USA	—	Microbial degradation	A microbial consortium (EG-c) especially: Gram-negative rod (EG-y)	• EG • PG	NA	[73]
	Waste de-icing fluid minimization					
General Mitchell International Airport, USA	—	Forced hot air de-icing and reduced fluid usage	Mixtures (more water and less glycol)	• ADAF	NA	[25]

(Continued on next page)

TABLE 7. Airport runoff management techniques *(Continued)*

Research site	Time of experiment	Technique	Plants/organisms/ materials used in remediation techniques	Compounds, total parameters	Removal efficiencies (%; unless otherwise noted)	Reference(s)
Milwaukee Airport, Wisconsin, USA	—	Recycling	The runoff is distilled to remove water and concentrate glycol.	• Glycol	NA	[25]
Buffalo International Airport, New York, USA	1997 and 1998	Infrared heating	Heating units	• ADAF	NA	[25]
Rhinelander/Oneida County Airport, Wisconsin, USA						
Airport, USA	—	Three-stage steps	Filtration	Suspended solids (greater than 10 microns)	NA	[74]
			Ion exchange or nanofiltration	chlorides, sulfates		
			Distillation	PG		
				EG	reduced from 10% to < 6% (within 7 days)	
				Antifreeze agents (ethylene glycol–based)	reduced from 5% to < 2%	

[a]For both raft systems. [b]Time of measurement: winter. [c]Time of measurement: summer. [d]Time of measurement: autumn. [e]Not available. [f]Degradation rate constant for PG and EG; percentage of data of removal efficient data was not avilable.

striving to reduce ADAF-laden wastewater runoff. Better weather forecasting and ice sensing instrumentation can reduce the amount of de-icing fluid needed to keep aircraft safe.[65] Technologies being developed include technologies remediation, forced hot air de-icing, appropriate use of less glycol, recycling and infrared de-icing (Table 7).[25]

8. SUMMARY

The need to describe more accurately the state of the environment and the processes taking place in it is a great challenge to analytical chemists where determining the concentrations of a wide range of analytes in samples with a complex matrix composition is concerned. Runoff waters from various surfaces are among the most interesting of such environmental samples.

A particular example of samples with a very complex composition are the waters due to rainfall and/or snowmelt running off the various surfaces to be found at airports. The greatest danger is caused by runoff from such surfaces as runways,[16,23] taxiways,[16] aircraft de-/anti-icing pads,[14] aprons,[5,15] transshipment points,[5] fuel stores and distribution points,[5,16] and repair shops and garages.[5,16]

Runoff waters generated by airport operations pose a serious hazard to the environment because they contribute to the contamination of the air, water, and soil. Airport operations also exert an adverse effect on the climate, plant kingdom, and above all, on human beings and animals. The principal pollutants discharged during airport operations are fuel, oil, grease, detergents, combustion gases, de-/anti-icing chemical wastes, toxic metals, alkalis, acids, and organic solvents; all these compounds are very often highly toxic.[3,16,54,60]

Analysis of the contaminants present in samples of airport runoff waters provides a clearer picture and understanding of the xenobiotic cycle in the environment. The worldwide increase in air traffic (more takeoffs and landings, more aircraft) means an increase in the amounts of pollutants getting into the environment. The runoff waters generated by these activities thus require special management procedures (e.g., technologies remediation, forced hot air de-icing, appropriate use of less glycol, recycling, infrared de-icing).[25]

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