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Technical Note

The Use of a Very Large Constructed Sub-Surface Flow Wetland to Treat Glycol-Contaminated Stormwater from Aircraft De-Icing Operations

JAMES HIGGINS[1]* AND MICHAEL MACLEAN[2]

[1]*Jacques Whitford Environment Limited, Toronto, Canada*
[2]*Edmonton Regional Airports Authority, Edmonton, Canada*

All of the pollutants found in stormwater runoff at airports, including surface and aircraft de-icing/anti-icing glycols, can be treated and removed to low levels in well-designed sub-surface flow (SSF) constructed wetland systems. There are two common forms of constructed wetlands used for pollution control: those where water flows over the surface among wetland plants (free water surface or marsh type wetlands); and SSF types where the wastewater flows below the normally dry surface of a gravel substrate in which the wetland plants grow. SSF wetlands have no open water to attract waterfowl and are particularly suitable for use at airports.

Of the glycol used at Edmonton International Airport (EIA), 80 to 90% eventually entered surface runoff. Edmonton International Airport's operator, the Edmonton Regional Airports Authority (Edmonton Airports) evaluated a number of glycol management options, including constructed wetlands. As a result, a very large SSF wetland system was installed to handle glycol-contaminated stormwater. This paper reviews results of a feasibility study carried out to define design parameters and scale up kinetics for this wetland system, the detailed design that resulted, the SSF wetland's construction, and the start-up of the Edmonton facilities in August of 2000. It also compares the Edmonton wetland system with a similar facility at Heathrow Airport in the United Kingdom.

Key words: **constructed wetlands, glycol de-icing, sub-surface flow (SSF) wetlands**

Introduction

In addition to the usual stormwater pollutants in colder weather, runoff and snowmelt at airports contain glycols and other de-icing and anti-icing chemicals used to remove/prevent ice build up on aircraft and ground surfaces (Higgins and Maclean 1998). The major glycols used as antifreezes are ethylene glycol (EG), 1,2-propylene glycol (PG), and diethylene glycol (DEG). The volumes used depend on weather conditions and the type of aircraft involved. Amounts may range from a few hundred

* Corresponding author; jhiggins@jacqueswhitford.com

litres for a small corporate aircraft to several cubic metres for large commercial aircraft (Pellon 1995). Regardless of how de-icing/anti-icing is carried out, and despite efforts in some cases to recover glycol at the pads, much of it is lost. Some drifts or is windblown away as aerosol. Some runs off through cracks or channels on and beside the pads. Some glycol flows into drains, sewers and ditches. Some infiltrates into groundwater. Blasts from jets and propellers blow a lot of glycol off the de-icing pads onto adjacent areas. A small amount evaporates. Some adheres to the aircraft skin (especially anti-icers, which are designed to do so) and later runs or blows off elsewhere as aircraft taxi and take off. At least 80% can be expected to run off on airport property (O'Connor and Douglas 1993).

The handling of airport glycols varies from airport to airport. At some, surface sealed and drained de-icing pads are used to ensure the collection and removal of a large proportion of the glycols used for aircraft de-icing (up to 60% is possible). At other airports little or none is recovered, and excess glycols and surface de-icing chemicals are simply allowed to flow or blow into nearby ditches and grassed areas. In colder weather, they may accumulate in contaminated snow drifts beside the de-icing pads, some of which may be scraped up for deposit elsewhere on the airport. Wherever it accumulates, the contaminated snow eventually melts, releasing the glycol and other contaminants into runoff, usually over a short period.

There are very few options for the off-site disposal of glycol-contaminated water at airports. The limited amounts that can be collected at de-icing pads, even sophisticated centralized ones, can be sent to a local wastewater treatment plant (if one is available locally). However, the bulk enters the huge volumes of stormwater runoff that are inevitable due to the large areas occupied by airports and as such, off-site treatment is usually not an option.

Because of the large volumes of stormwater involved, on-site handling usually has to be considered. There are various methods and all involve assembling the runoff into drains, ditches and sewers at the airport and directing it into one or more detention ponds, basins or flow-balancing tanks of some sort to even out their periodic natures. Wherever glycol-contaminated water is collected, it must eventually be dealt with. At some airports, it is still discharged untreated to receiving waters. The reality is that more on-site treatment of the runoff will be required before disposal, especially as traffic levels (and hence de-icing requirements) are increasing at many airports. There are a very limited number of feasible, on-site treatment options for glycol-contaminated stormwater runoff at airports (Higgins and Maclean 1999) and the following table (adapted from Worrall et al. [2001]) summarizes some of them as well as their perceived acceptabilities.

The nature of the glycol-contaminated runoff from airports—usually cold, intermittent, containing varying amounts of contaminants, often causing hydraulic and chemical shocks to treatment processes (Higgins 2000a,b)—suggests that natural wastewater treatment systems such as

Table 1. The relative merits of different glycol treatment options

Approach	Key factors in acceptance or rejection
Impoundment and natural attenuation	Odours, overflows to receiving waters, non-acceptance by regulators
Anaerobic digestion	Energy costs, inability to deal with "shocks"
Reverse osmosis	Capital and maintenance costs, pre-treatment equipment
Carbon filtration	Maintenance and management implications
Modified cellulose filtration	Energy costs related to disposal
UV catalytic oxidation	Energy costs, inability to deal with "shocks"
Bacterial bioremediation	Experience and maintenance issues
Constructed wetlands	Land requirements, attraction of waterfowl

constructed wetlands are the only practical options for treating the large volumes of glycol-contaminated stormwater runoff and snowmelt at airports (Higgins and MacLean 1999).

There are two common forms of constructed wetlands used for pollution control: those where water flows over the surface among wetland plants (free water surface or marsh type wetlands); and sub-surface flow (SSF) wetlands where the wastewater flows below the normally dry surface of a gravel substrate in which the wetland plants grow. The problem of airport wetlands attracting waterfowl can be solved by using SSF wetlands (Higgins 2000a) which have no open water surfaces, and by designing any required surge or balancing ponds to either be unattractive to waterfowl and/or to be covered by floating rafts of vegetation (Higgins and MacLean 1998; Worrall et al. 2001).

Of the aircraft de-icing glycol used at EIA in the province of Alberta in Western Canada, 10 to 20% is recovered using vacuum trucks. Most of the remainder enters surface runoff. Since most aircraft de-icing occurs during winter, spilt glycol can accumulate in contaminated snow and be released almost all at once when thaws occur. The airport's tight clay soil exacerbates the problem.

Surface runoff from EIA property used to be directed to temporary impoundment areas, from which it later was discharged to the receiving waters, a nearby cold water stream. Glycol in impounded runoff was allowed to attenuate naturally until its levels were low enough to allow release. However, too often the volumes of glycol-contaminated water impounded became so large that discharge had to occur despite contaminant levels being still too high. This coupled with odours led Edmonton Airports to initiate a number of studies to evaluate glycol management options. One was a feasibility study on constructed wetland alternatives for treating the runoff, a study that included a treatability test at pilot-scale constructed wetland facilities using feedwater simulating EIA runoff under worst possible conditions.

Feasibility Study

In designing the EIA wetland system, a feasibility study was carried out for which the following were investigated (Higgins and MacLean 1998, 1999): 1) the chemistry, properties, handling and degradation of both glycols used for aircraft de-icing and anti-icing, and of chemicals that were used for surface de-icing of EIA's aprons, taxiways and runways; 2) conditions for runoff containing the highest possible amount of glycol contamination that might be encountered; 3) wetland alternatives for treating contaminated runoff at the airport, including various kinds of aerated and un-aerated SSF wetlands; 4) the impact on wetland size of any ammonia and nitrate contamination in the runoff; and 5) the effects on wetland design (size and cost) of building new, centralized glycol de-icing and glycol recovery facilities at EIA which would reduce the amounts of glycol in the contaminated runoff requiring treatment.

A major component of the feasibility study was a treatability test using simulated "worst case conditions" stormwater (1250 mg EG/L, 10 mg NH_3/L, 10 mg NO_3/L, 10 mg oil and grease/L, 50 mg NaCl/L, 2 mg phenol/L). The test was carried out using two 1.2-m^2 area pilot SSF wetland cells in series containing gravel (0.6 m thick) and vegetated with acclimatized cattails. Residence time in the cells ranged from 2 to 4 days. Better than 99% EG removals were obtained, with and without cell aeration.

The feasibility study and its treatability test showed that an un-aerated SSF wetland would be the best choice; that there was room at the airport for one of the size needed; that such a facility could be expected to do the job even under worst case conditions; that ammonia and nitrates at the above levels would be adequately removed by any wetland that dealt with the glycol; and that it was far more economic to treat the glycol-contaminated runoff in a wetland than to try to reduce its volumes with centralized de-icing pads (logistical nightmares for airlines and much runoff would require later treatment anyway). From the results of the treatability test, the kinetic rate constants and other parameters needed to design and build a full-scale SSF wetland system were defined.

As a result of the feasibility study, Edmonton Airports installed a very large SSF wetland system to handle glycol-contaminated stormwater. This system is capable of handling up to 230,000 m^3 of runoff annually.

Edmonton SSF Wetland Design

The SSF Wetland at EIA was designed using standard, first-order plug flow design methods (Kadlec and Knight 1996; Reed et al. 1995) and data from the treatability test. The SSF wetland is part of a larger Stormwater Management System for the 500+ ha airport property. It is a twelve cell gravel bed system with a surface area of just over 2.7 ha and is located in a field on a flight path a few kilometres west of airport facilities. An extensive network of existing and new stormwater sewers and ditches around the airport delivers glycol-contaminated runoff via a flow splitter to an existing surge pond in front of a local, public skeet club (the Gun Club). This surge pond (the Gun Club Surge Pond) accumulates low-flow water, highly contaminated water from snowmelt, and "first flush" runoff during and after periods of de-icing in spring and fall. These waters are then slowly delivered from it over an extended period via a pipeline and feed pump to the SSF Wetland where pollutants in it are removed/degraded.

Relatively uncontaminated runoff is directed to a large (440,000 m^3), normally dry Stormwater Detention Pond, bypassing the wetland (although there is provision to send water from this pond to the wetland). Cleaned-up effluent from the wetland enters the receiving waters via a weir. The wetland does not operate in winter and any contaminated runoff collected then is stored in the Gun Club Surge Pond for later treatment.

The twelve cells (each 47.5 m by 47.5 m) of the SSF Wetland are arranged in six trains of two cells each, sloping away from a central berm in three rows. The cells are square basins, with the soil scooped out for their construction being formed into berms (earthen dykes) surrounding them. Berm slopes are 2:1 inside the cells and 3:1 outside, with three metre-wide, grassed tops between the rows of cells. The SSF Wetland and its ancillaries have a "footprint" of 4.5 ha. Contaminated water is pumped to the trains via aluminum irrigation piping along the wetland's central berm into aluminum inlet distributor pipes lying on the surfaces of the first (primary) cells of each of the six trains at their upstream ends. The inlet distributors direct water onto the surfaces of the cells where it percolates down into the gravel substrate (0.7 m thick) in each and flows underground along their lengths into perforated PVC outlet distributor pipes buried in the cells' gravel at their deepest, furthest downstream ends.

An even distribution of water into each of the six primary cells is achieved by adjusting thirty adjustable nozzles (3/4" ball valves) along the length of the inlet distributor to ensure a balanced flow of water into each cell where pollution control is achieved largely through microbially mediated processes in biofilms which exist in the interstices of the gravel particles. Water detention time in each cell can range from two days when large amounts of water are being treated in warmer weather, to almost five days when lower volumes are being treated in colder weather.

Water exits the primary cells into control structures (round, flat-bottomed, concrete sewer structures topped by manholes) in the centres of their downstream berms where risers on swivelling elbows are used to control water level in the upstream primary cells. Water from the primary cell control structures flows down onto similar inlet distributors on the surfaces of the lower level, downstream (secondary) cells of each train.

Flow in the secondary cells is similar to that in the primary ones except that effluent from the secondary cells' control structures flows out into a peripheral ditch which almost surrounds the wetland on three sides and directs water via an outlet weir to the receiving waters.

The maximum contaminated water flow rate into the wetland depends on the temperature of the water and the concentration of glycol in it. Design flow rate is almost 1300 m^3/d at a maximum design glycol contamination level in the water of almost 1400 mg EG/L at an average annual water temperature of 13°C. In practice the SSF Wetland is capable of treating up to 1500 m^3/d of contaminated water when water temperatures are warmer and/or glycol contamination levels lower. It treats lower volumes when water temperatures are cooler. The system's operating license calls for maximum outlet effluent water contaminant concentrations of 25 mg/L for biochemical oxygen demand (BOD) and 100 mg/L for EG. The 12 wetland cells have each been vegetated with about 750 cattail clumps transplanted from local stormwater ditches.

Comparison of Edmonton and Heathrow SSF Wetland Systems

A second SSF wetland system for treating glycol-contaminated stormwater runoff started up early in 2002 at Heathrow Airport in London, United Kingdom (Worrall et al. 2001). This more complex system will handle glycol-contaminated runoff (EG, PG and DEG are all present) from two catchment areas totaling almost 600 ha. In one, a floating curtain in an aerated surge pond will separate "clean" runoff from "dirty" runoff, the latter of which will be pumped into an aerated surge pond. Floating rafts of reeds (*phytoremediation rafts*) in exit channels surrounding this surge pond will provide extra treatment capability and discourage their use by waterfowl. Water from the phytoremediation raft system will join water from the second catchment area in an aerated balancing pond in front of a large, multi-cell SSF wetland. The following table compares some aspects of the two SSF wetland systems.

Discussion

In past, airport authorities and airlines have tried to ignore the environmental problems resulting from the contamination of stormwater runoff at airports with de-icing chemicals, often with the excuse that there was no way to deal with it effectively. With the start-ups of the two large SSF wetland treatment systems described herein, it is likely that regulators will begin to insist that such problems now be addressed. Large volumes of glycol-contaminated runoff can be treated effectively and economically. In addition, these wetlands show that constructed wetlands can be designed in a manner so as to not provide habitat for or attract waterfowl, which can be a hazard at airports due the danger of bird strikes by aircraft.

In the past it has been "common knowledge" that SSF wetlands

Table 2. Comparison of the Edmonton and Heathrow SSF wetland systems

	Edmonton SSF wetland	Heathrow SSF Wetland
Wetland surface area, ha	2.7	2.1[a]
Number of cells	12	12 (48 sections)
Cell design	Square, with earthen berms	Rectangular, with concrete berms
Wetland vegetation	Cattails (9000 transplants)	Reeds (200,000 seedlings)[b]
Design inlet water condition	1353 mg EG/L	>2000 mg BOD/L
Target outlet water condition	25 mg BOD/L	40 mg BOD/L
System cost	$1.8 Can MM ($4.8 MM for entire stormwater system)	£1.2 MM (£20 MM for entire stormwater system)

[a] Not including the ~1-ha area of the phytoremediation rafts in channels between the surge ponds.

[b] Including those for phytoremediation rafts.

could not be used for treating stormwater, and that such systems were better limited to relatively low flow situations. The large SSF wetland system at EIA, and that at Heathrow, demonstrate that both of these assumptions are untrue. Sub-surface flow wetlands can be used effectively for stormwater treatment and they can be built to treat very large volumes of water. It is also worth noting that both of these SSF systems continue trends in modern constructed wetlands design towards multi-train configurations (versus earlier constructed wetland designs often involving single flow trains), and relatively low aspect ratio (length/width) cells (versus earlier designs which were built with long, narrow cells).

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