The Design & Operation of a Very Large Vertical Sub-Surface Flow Engineered Wetland to Treat Spent Deicing Fluids and Glycol-Contaminated Stormwater at Buffalo Niagara International Airport

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Abstract An advanced type of constructed wetland (CW) called an engineered wetland (EW) has been developed which allows more efficient removals of contaminants from wastewaters and stormwaters at rates in many cases an order of magnitude higher than those achievable with ordinary CWs. In one type of advanced aerobic EW, the wastewater being treated flows sub-surface (SSF) beneath an aggregate substrate which is aerated mechanically from below. This ecotechnology allows very much higher removals (>95%) of those wastewater contaminants amenable to aerobic treatment (e.g., BOD, ammonia). A large 1.9 ha EW system treating glycol-contaminated water is now operating at Buffalo Niagara International Airport (BNIA) in upper New York State, USA. This system, which is successfully treating glycol-contaminated stormwater runoff and spent glycol from cold weather aircraft deicing activities, involves four very large aerated EW cells and is capable of treating up to 4,600 m³/d of glycol-contaminated water containing up to 4,500 kg/d of BOD, (the BOD-equivalent of a city of 50,000 people), even in the coldest weather.

Key Words: Aircraft deicing fluids, constructed wetlands, engineered wetlands, glycol,

GLYCOL DEICING AT AIRPORTS
In addition to other contaminants found in stormwater and snowmelt at airports (e.g., fuel & lubricant residuals, oil & greases, chemicals from cleaning operations, sewage leaks, washing product chemicals, fertilizers, decaying vegetation), airport stormwater runoff contains large amounts of the aircraft deicing fluids (ADFs) during and after periods when deicing and anti-icing operations are carried out. Deicers are used to melt and remove accumulated snow, ice and frost on aircraft surfaces just before departures. They have little adhesion and a large proportion of them are quickly shed at their point of application, usually a deicing pad. The remaining ADFs drop off during taxing and take off. Anti-icers are gel-like substances applied to aircraft after snow removal. Anti-icers tend to stick to aircraft surfaces, thereby inhibiting subsequent ice formation while the aircraft is stationary and later during taxing and take off. More of these types too are shed on taxiways and runways once an aircraft begins to move at higher speeds. The ADFs may be ethylene glycol (EG) propylene glycol (PG) or diethylene glycol (DEG) based. The volumes of ADFs used depend on weather conditions and the type of aircraft involved. In the approximately 50% solutions commonly used for aircraft deicing and anti-icing, EG and PG have BODs of approximately 200,000 mg/L and 320,000 mg/L, respectively (Higgins & MacLean, 1999). Although such levels are diluted by snow- and ice-melt, BOD concentrations in excess of 20,000 mg/L are common in stormwater runoff streams at many airports, over 100 times the BOD concentration of raw municipal sewage (EPA, 2000). Such high
concentrations, combined with the inherently variable nature of winter storms and the low temperatures of glycol-contaminated SW runoff, challenge the use of conventional stormwater/wastewater treatment technology and a large slug of glycol-contaminated water can quickly deplete the dissolved oxygen in receiving waters, killing fish and other organisms that need aerobic conditions. In addition, the additives used in commercial ADF formulations (e.g., surfactants, corrosion inhibitors, polymers) also contribute to toxicity (Higgins & MacLean, 1999, Higgins et al., 2007a, 2007b).

Glycol-contaminated water at airports usually involves two streams: 1) Spent ADF, relatively concentrated (up to several percent glycol) solution which is collected from beneath aircraft at deicing pads, snowmelt pads, and/or central deicing facilities for treatment, recycle or disposal at a local wastewater treatment plant (WWTP), and 2) Glycol-contaminated stormwater runoff, where ADFs are blown by jet or prop wash onto areas adjacent to deicing areas, drip off onto aprons and runways during aircraft movement, or are collected with removed snow and ice, ending up in stormwater sewers and ditches. The latter stream, glycol-contaminated stormwater, represents a significant part of the ADFs used (up to 90% at some airports but typically 40 - 60%) and is rarely treated. Concentrations of glycol and its daughter products in glycol-contaminated stormwater at airports can range from several tens of mg/L to many thousands of mg BOD/L.

CONSTRUCTED WETLANDS
Modern constructed wetlands (CW) technology developed in the late 1970s and early 1980s (Reed et al., 1995). Many early CWs failed to achieve their designers' goals as layouts were primitive and proper engineering design principles were rarely followed (Kadlec & Knight, 1996). CW design evolved through several stages to rectify such limitations through the kinds of wetland basin (cell) types used (e.g., from ponds and artificial bogs to free water surface [FWS, an open water, marsh type kind of CWs] and sub-surface flow, SSF cells); in morphology (e.g., from small facilities with one or few, long irregularly shaped cells to the current multiple train, multiple rectilinear cell, low aspect ratio systems); in the volumes of water that they could handle (e.g., from relatively low flow rates to thousands of cubic metres per day); in sizing methods used (i.e., from early empirical relationships based on hydraulic and/or contaminant loadings to the modern Rational Method based on reaction kinetics [Kadlec & Wallace, 2008]); and in engineering design (from ad hoc designs to the use of formal civil and chemical design engineering techniques) (Higgins et al., 1999). The technology of CWs for municipal and industrial wastewater treatment is now mature and there are tens of thousands of them in operation around the world (Vymazal, 2001).

With sub-surface flow CWs, pollutant removal occurs at/in microbial biofilms on a porous matrix (substrate) in which vegetation root systems grow. Although wetland vegetation is apparent in SSF wetlands, their surfaces are usually dry. Generally, SSF wetlands consist of many cells filled with beds of rock, gravel, or other kinds of aggregate substrates. Sub-surface flow CWs may be operated either with the wastewater being treated flowing horizontally through the substrate matrix (HSSF CWs), or with the water percolating down vertically through the substrate (VSSF CWs). SSF wetlands are usually much smaller in area than FWS wetlands for the same levels of contaminant removal, and can tolerate higher loadings. SSF wetlands are used where the wastewater being treated is noxious or odorous; where a higher degree of freeze protection is desired; where ample, economic supplies of suitable substrate material are readily available and/or where the attraction of wildlife (especially waterfowl) to open water areas may be undesirable (e.g., at airports).
Ordinary constructed wetlands provide reasonable removals of suspended solids, heavy metals, pathogens and some kinds of BOD from wastewaters being treated in them. However, although they are widely used in cold climates, winter operability often presents problems, and they normally only remove part of the nutrients in wastewaters being treated in them. In addition, they do not handle high and/or variable flows of wastewaters and on average remove only about half of the pollutants in their influents.

ENGINEERED WETLANDS

Engineered wetlands are advanced kinds of CWs in which process and/or operating conditions are more actively manipulated and/or controlled than in ordinary constructed wetlands. While any kind of wetland cell can be operated in the engineered wetland mode, SSF cells are mainly used (Higgins, 1997). There are various kinds of SSF EWs: ones in which mechanical aeration is provided below the gravel substrate (Aerated EWs) (Higgins et al., 2007a), ones in which anaerobic bioreactors (ABRs) provide for the removal of dissolved metals and chlorinated organics from wastewaters (ABR EWs) (Mattes et al., 2010), and ones where wetland cells are alternately dosed with wastewater, then left to drain before further dosing (Fill & Drain EWs), versions where Aerated EW cells are combined with aerated lagoons for the upgrading of municipal wastewater treatment lagoon systems (Higgins et al., 2010b) and ones where Aerated EWs are combined with advanced phosphorus removal technology (Wootton et al., 2010).

The Aerated EW is an advanced type of wetland in which a coarse bubble aeration matrix is placed under the gravel substrate of a sub-surface flow wetland basin, and air is supplied to it by a blower. This ecotechnology allows the removal rates of biologically-oxidizable contaminants (e.g., ammonia, BOD) to increase to almost stoichiometric levels. Aerated SSF EWs generally have much smaller surface areas (often less than one-tenth the size of an equivalent CW), have much higher treatment rate efficiencies (often 5 – 30X), use much less energy than alternative mechanical WWTPs (often as low as one-tenth as much), and can handle very much higher wastewater flow rates than can ordinary CWs (up to thousands of m³/d).

Aerated EWs allow the treatment of wastewaters in more economic treatment systems, ones which require relatively little operator attention or maintenance, and which can easily and consistently meet stringent wastewater discharge criteria over extended periods (Higgins et al., 2010a, 2010b, Wootton et al., 2010). Aerated SSF engineered wetlands have been successfully used to treat all sorts of municipal, industrial, and agricultural wastewaters and, as has been demonstrated in dozens of facilities treating a wide variety of wastewaters, can operate summer and winter, even under the coldest air and water temperatures. Aerated EWs are patented under the trade name Forced Bed Aeration™ (Wallace, 1998, 2000). Almost 70 of smaller HSSF and VSSF Forced Bed Aeration™ EWs are now in operation in a number of northern U.S. locations, as well as several large ones such as the one described herein.

THE TREATMENT OF WATER AT AIRPORTS USING WETLANDS

Controlling and treating such glycol-contaminated stormwater runoff and other streams from airport facilities is a matter of increasing environmental concern and is now having a major effect on airport design and operations. The United States Environmental Protection Agency (EPA) is now implementing new regulatory guidelines [EPA, 2009] for the management of ADFs and glycol-
contaminated stormwater at airports. This activity varies from airport to airport. At some, sophisticated deicing pads and vacuum sweeper trucks are used to ensure the collection of a large proportion of the ADFs used (up to 65%). At others little or none is recovered, and excess glycols and associated surface deicing chemicals are simply allowed to flow or blow into nearby sewers, ditches and grassed areas. In colder weather, glycols may accumulate in contaminated snow drifts beside the deicing pads, some of which may be scraped up for deposit elsewhere on an airport. Wherever it accumulates, the contaminated snow eventually melts, releasing its contaminants into runoff, usually over a short period. There are only a few options for the off-site disposal of glycol-contaminated water at airports. In some cases, that which is vacuumed up at the deicing pads (the Spent ADFs) can be sent to municipal WWTPs (if such are available locally). However, even so, much will still enter the huge volumes of stormwater runoff inevitable due to the large areas occupied by airports, and for such, off-site treatment is usually not an option.

This then dictates that on-site glycol management be considered (Switenbaum et al., 1999). There are various methods and all involve assembling the runoff into drains, ditches and sewers and directing it into one or more detention ponds, basins or flow balancing tanks to even out their periodic natures, skim off any floating oil & grease and debris, and allow grit to settle out. However the glycol-contaminated water is collected, it must eventually be dealt with. At some airports, it is still discharged untreated to receiving waters, but the reality is that, more and more, on-site treatment of the runoff will be required before disposal. Although there are several options for treating Spent ADFs, there are a very limited number of feasible, on site treatment options for glycol-contaminated stormwater runoff at airports (Higgins & Maclean, 1999). Impoundment and natural attenuation is no longer an option. Many kinds of active wastewater treatment technologies (e.g., activated sludge WWTPs, anaerobic bioreactors, carbon filtration, membrane systems) might be considered for treating Spent ADFs from deicing pads but they are not suitable for the high volumes, often cold temperatures, and intermittent natures of airport stormwater runoff; and their maintenance requirements would be undesirably high anyway. FWS CWs could handle airport runoff streams but might attract waterfowl, creating birdstrike hazards.

With SSF CWs, the risk of their attracting large waterfowl is removed, and there are several examples of such use. These include facilities at Pearson International Airport in Toronto, Canada (Flindall et al., 2001); at the DHL facilities at the Wilmington, Ohio, USA airport; Edmonton International Airport in Alberta, Canada (Higgins and Maclean, 2002); Heathrow International Airport near London, UK; and small pilot facilities (no longer operating) in Zurich Switzerland (Richter et al., 2004), Berlin, Germany (Abydoz, 2005), and Kalmar, Sweden (Thoren et al., 2003). However, until the one at Buffalo was built, only Wilmington, Edmonton and Heathrow represented practical, operating, full-scale facilities. The Edmonton and Heathrow wetland facilities for treating glycol-contaminated waters involve ordinary HSSF CWs, while that at Wilmington involves reciprocating flow HSSF EWs. All three are associated with surge ponds in front of the wetlands. The wetland at Edmonton treats stormwater contaminated with EG, that at Heathrow, EG, PG and DEG; and that in Wilmington, PG. The Edmonton HSSF CW operates only part of the year, being frozen in the coldest weather. The Heathrow HSSF CW can operate year round. The Wilmington HSSF CW attempts to operate most of the year but tends to impound water in the very coldest periods. The twelve CW cells at Edmonton are vegetated with transplanted cattails; the twelve CW cells at Heathrow are vegetated with reeds. The Wilmington CW is not vegetated. At Edmonton and Wilmington, influent contaminated runoff flow rates are keyed to water temperatures, with lower throughputs occurring.
when the water is colder. None of the wetlands is insulated. All three wetlands use gravel as their substrates: it is 0.7 m thick in Edmonton, 0.6 m thick at Heathrow, and 2.1 m thick in Wilmington (Higgins et al., 2007). None of these three SSF wetlands is mechanically aerated, although there is an aerated pond upstream at Heathrow treating some runoff. (This has resulted in some plugging of the downstream HSSF cells with biosolids sludge formed in the aerated pond. Any organic sludge formed in well-designed and properly operated SSF EWs does not accumulate but is removed by rhizodegradation. A project is now underway to convert the Heathrow HSSF CW into an aerated VSSF EW.)

THE AERATED VSSF WETLAND SYSTEM AT BNIA

New engineered wetland facilities have been constructed and commissioned at the Buffalo Niagara International Airport (BNIA) in upstate New York, USA. The airlines using BNIA currently use PG-based ADFs and during the deicing season, Spent ADFs from around the deicing pads and from a snowmelt pad used to be collected and piped for disposal at a local municipal WWTP. However, a large fraction of the glycol (50 – 60%) still was lost, most of it ending up in the airport’s stormwater system where it sometimes led to exceedances of a mandated 30 mg BOD/L stormwater discharge limit. It became increasingly difficult to deliver the Spent ADFs to the local WWTP, and the airport’s owner, the Niagara Frontier Transportation Authority (NFTA), wished to ensure that the concentration of BOD in the glycol-contaminated stormwater did not continue to occasionally exceed the discharge limit, so it was decided to install an SSF EW system at the airport to treat both collected Spent ADFs and glycol-contaminated stormwater. The project proceeded through several phases: feasibility analyses; treatability testing at an off-site, pilot-scale EW test unit; preliminary design; final design; tendering; and construction and commissioning.

During the treatability testing phase carried out at pilot-scale engineered wetlands test facilities at Campus D’Alfred of the University of Guelph in Canada, aerated SSF EWs were evaluated against non-aerated SSF CWs using imported stormwater from BNIA spiked with PG as the feedstock. Aeration was found to profoundly affect treatment performance. When aerated at 0.85 m³ air per hour (per m² of wetland bed), the carbonaceous BOD₅ removal rate constant averaged 5.4/d with an Arrhenius temperature coefficient (θ) of 1.03, based on treatability testing carried out at 22°C and 4°C and assuming hydraulic conditions in an aerated EW can be modelled by a 2 tanks-in-series (TIS) reactor in which first order kinetics are extant (Higgins et al., 2007b, Wallace et al., 2007). This information was used to design the full-scale facilities for BNIA.

The 1.9 ha engineered wetland selected and designed by Stantec Consulting (formerly Jacques Whitford) and NaturallyWallace (formerly Jacques Whitford NAWE) for BNIA involves four large (51 m by 91m each) aerated VSSF EW cells excavated from an open area near the airport’s main runway. The EW system can accommodate large fluctuations in flow and influent BOD concentrations and operates easily during the coldest weather. It is designed to ensure compliance with the airport’s stormwater discharge permit and not only removes the glycol, but also other organics, grit, suspended solids, dissolved metals, and ammonia present in stormwater from normal airport operations.

The below-grade aerated VSSF EW beds at BNIA contain screened and washed gravel (10 – 15 cm dia.) 1.5 m thick, and are designed to sustain between the gravel particles a resident, attached community of bacteria (biofilm) acclimated for the specific task of glycol removal. Influent is distributed uniformly over the cell surfaces via inlet distributor chambers buried near the substrate.
surface, and flows vertically down through the gravel to a system of underdrains. Air supplied from four nearby air blowers (250 HP each) located in a nearby Utility Building, and is pumped to the cells through a network of perforated aeration tubing. The substrate beds for the EW cells are insulated on top with a layer of peat mulch.

In addition to the four sub-surface flow wetland basins, the US$10 million EW System for BNIA consists of equalization and other tankage; aeration equipment; grit removal vessels; stormwater vaults; pumps and their control chambers; piping systems; instrumentation & controls; EW cell outlet control structures; an electrical supply system; the Utility Building housing the blowers, instruments and electrical equipment as well as chemical injection equipment (stormwater is deficient in needed microbial nutrients); and associated infrastructure. The nominal deicing season at BNIA is 190 days, and design was based on a total glycol usage of about 1150 m$^3$ of pure PG/yr. Flows rates for design were up to 820 m$^3$/d for Spent ADF plus 3800 m$^3$/d for glycol-contaminated stormwater. The following picture shows three of the four aerated VSSF EW cells under construction at various stages of completion during early 2009.

**Figure 1. EW Cells Under Construction at BNIA**

The following picture shows an operating EW cell. Only a field of grasses growing from a “dry” mulch surface is observable at ground level.
CONCLUSIONS
The EW System for BNIA was designed to meet the following criteria:

1) Siting near an operating runway.
2) Simplicity of operation with minimum attention.
3) The ability to treat cold and variable strength wastewaters (both Spent ADFs and glycol-contaminated stormwater) year round.
4) Integration into the airport’s existing stormwater management system.
5) The ability to handle large seasonal variations in influent flows and to operate steadily even under the harshest winter conditions.
6) To produce effluent to stormwater system meeting discharge criteria.
7) Not to be any sort of birdstrike or Airside hazard.
8) To produce little or no odours.
9) Not to produce organic sludge requiring additional management.
10) To have low operating and maintenance costs.

While commissioning is still underway and performance testing has not yet been fully carried out, it appears that the EW system will be able to meet all of these objectives. The savings obtained by BNIA by treating its spent ADFs and glycol-contaminated stormwater runoff (e.g., eliminating fees for sending spent ADFs to the local WWTP, eliminating sweeper trucks at the deicing pads) much more than compensate for the additional costs incurred in operating the EW System (e.g., electricity for blowers, nutrient chemicals). An early result in March of 2010 indicated the reduction of average mixed Spent ADF/SW runoff cBOD concentration from 2,400 mg/L in the influent to 33 mg/L in the effluent, with optimization to come. The NFTA is now considering expanding the size of the BNIA EW System and converting back to more economic and lower BOD ethylene glycol-based ADFs. Although it could easily do so now that the EW System is in place, BNIA is not considering switching back to urea-based Airside surface deicing chemicals (although urea is added to the nutrient-deficient stormwater anyway).
By any measure, for treating both spent ADFs and glycol-contaminated stormwater runoff, the EW system at BNIA represents Best Available Technology Economically Available. Recently, for this project’s design, Stantec (along with its client, the NFTA, its civil engineering sub-consultant, Urban Engineers of NY, and its process sub-consultant, Naturally Wallace) was awarded the Diamond Award in the Environmental Category by the NY branch of the American Council of Engineering Companies (ACEC) and a very prestigious Honor Award by the US National ACEC. Its design has also won the 2010 Project of the Year Award (Environmental Category) from the American Public Water Works Association (APWA) of Western NY, the APWA NY Environmental Project of the Year Award and has been nominated for several other awards.

REFERENCES


12th International Conference on Wetland Systems for Water Pollution Control, Venice, Italy, Oct. 4-9, 2010


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