ESTCP
Cost and Performance Report

(CP-0007)

Enhanced Biological Attenuation of Aircraft Deicing Fluid Runoff Using Constructed Wetlands

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TABLE OF CONTENTS

Page

1.0 EXECUTIVE SUMMARY 1

2.0 TECHNOLOGY DESCRIPTION 3
- 2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION 3
- 2.2 PROCESS DESCRIPTION 3
- 2.3 PREVIOUS TESTING OF THE TECHNOLOGY 5
- 2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 5

3.0 DEMONSTRATION DESIGN 7
- 3.1 PERFORMANCE OBJECTIVES 7
- 3.2 SELECTION OF TEST SITES 7
- 3.3 TEST SITE/FACILITY HISTORY/CHARACTERISTICS 7
- 3.4 PHYSICAL SET-UP AND OPERATION 10
- 3.5 SAMPLING/MONITORING PROCEDURES 11
  - 3.5.1 Instrumentation 11
  - 3.5.2 Sampling Stations and Collection Frequency 12
- 3.6 PERFORMANCE CONFIRMATION METHODS 13
  - 3.6.1 BOD and COD Estimates 13
  - 3.6.2 Pollutant Mass Balances 14
- 3.7 ANALYTICAL PROCEDURES 14

4.0 PERFORMANCE ASSESSMENT 17
- 4.1 PERFORMANCE DATA 17
  - 4.1.1 Stormwater and Deicing Runoff 17
  - 4.1.2 BOD Concentration and Load Reductions 18
  - 4.1.3 Other Analytical Measurements 20
- 4.2 PERFORMANCE CRITERIA/CONFIRMATION 22
  - 4.2.1 Reduced Cost 22
  - 4.2.2 Slug Load Treatment 24
  - 4.2.3 BOD NPDES Permit Compliance 24
  - 4.2.4 Readiness 24
  - 4.2.5 Land Use 25
  - 4.2.6 Wetland Health 25
  - 4.2.7 Maintenance 25
  - 4.2.8 Effluent Toxicity 25
  - 4.2.9 NPS Removal 25
  - 4.2.10 Reliability 25

TABLE OF CONTENTS (continued)

Page

5.0 COST ASSESSMENT 27
- 5.1 COST REPORTING 27
- 5.2 COST ANALYSIS 27
- 5.3 COST COMPARISON 27

6.0 IMPLEMENTATION ISSUES 31
- 6.1 COST OBSERVATIONS 31
- 6.2 PERFORMANCE OBSERVATIONS 31
- 6.3 SCALE-UP 32
- 6.4 OTHER SIGNIFICANT OBSERVATIONS 32
- 6.5 LESSONS LEARNED 32
- 6.6 END-USER ISSUES 32
- 6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE 33

7.0 REFERENCES 35

APPENDIX A POINTS OF CONTACT A-1

FIGURES

Page

Figure 1. Subsurface Flow Constructed Treatment Wetland Typical Plan and Profile 4
Figure 2. Westover ARB and Surrounding Region.....8
Figure 3. SSF CTW Technology Demonstration Project Watershed, Westover ARB 8
Figure 4. Deicing Required for Aircraft Operation During Inclement Weather 9
Figure 5. ADF Release to Ground After Deicing.....9
Figure 6. Horizontal Subsurface Flow CTW Cross Section at the Westover Air Force Reserve Base, Chicopee, Massachusetts 10
Figure 7. SSF CTW Eleven Months After Planting (May 2003).....11
Figure 8. Aerial Photograph of the Horizontal Subsurface Flow Wetland at the Westover Air Force Reserve Base, Chicopee, Massachusetts.....12
Figure 9. Correlation Between the LAR TC Measurements and BOD Samples Collected in the SSF CTW Technology Demonstration Project 14
Figure 10. Estimated Bypass (Outfall 001) and Wetland Outflow 17
Figure 11. Time Series Plot of LAR TC and ADF Usage During the 2002-2003 Deicing Season.....18
Figure 12. Summary from Fourth Recorded Event (April 5-12, 2003) 21

TABLES

Page

Table 1. Constructed Treatment Wetlands Used for Enhanced Biodegradation of Glycol-Based Deicing Compounds 6
Table 2. Performance Objectives of the CTW Technology Demonstration Project.....7
Table 3. Baseline Water Quality Summary 9
Table 4. Period of Operation.....11
Table 5. Sampling Activities and Frequency.....13
Table 6. Surface Water Sampling Analysis Parameters and Methods.....15
Table 7. Summary of Results from the Westover ARB SSF CTW Technical Demonstration Project Performance, 2002-2003 Deicing Season.....19
Table 8. Summary of Other Analytical Results from the Westover ARB SSF CTW Technical Demonstration Project Performance, 2002-2003 Winter Deicing Season.....22
Table 9. Summary of Performance Confirmation from the Westover ARB SSF CTW Technical Demonstration Project.....23
Table 10. Costs Associated with the Collection, Storage, and Controlled Release of ADF Stormwater to a POTW 28
Table 11. Costs of Enhanced Biological Attenuation of ADF Runoff Using Constructed Wetlands (Demonstration).....29
Table 12. Costs of Enhanced Biological Attenuation of ADF Runoff Using A Full-Scale Constructed Wetland 30

ACRONYMS AND ABBREVIATIONS

ADF	aircraft deicing and anti-icing fluids
AFB	Air Force Base
ARB	Air Reserve Base
BASH	bird and animal strike hazard
BMP	best management practices
BOD	biochemical oxygen demand (five-day)
CFU	colony-forming unit
COD	chemical oxygen demand
CTW	constructed treatment wetland
CWA	Clean Water Act
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FOTW	Federally Owned Treatment Works
gpd	gallons per day
gpm	gallons per minute
HLR	hydraulic loading rate
HRT	hydraulic residence time
IWA	International Water Association
LAR	LAR Quick-TOC®
MeBT	methyl-1H-benzotriazole
NAS	Naval Air Station
NFESC	Naval Facilities Engineering Service Center
NPS	nonpoint source
NPDES	National Pollutant Discharge Elimination System
O/W	oil/water
O&G	oil and grease
O&M	operation and maintenance
OWin	oil/water separator inflow
POTW	publicly owned treatment works

SF	surface flow
SSF	subsurface flow
SWPPP	Storm Water Pollution Prevention Plan
TC	total carbon
TOC	total organic carbon
TSS	total suspended solids
UC	University of Colorado
VOC	volatile organic compound
Win	Wetland Inflow
Wout	Wetland Outflow

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Technical material contained in this report has been approved for public release.

1.0 EXECUTIVE SUMMARY

During winter months at Department of Defense (DoD) air bases, large amounts of aircraft deicing and anti-icing fluids (ADF) (primarily propylene glycol, ethylene glycol, and various additives) are used to ensure flight safety during certain adverse weather conditions. Standard practices at both military air bases and private airports are to direct deicing effluent to large stabilization ponds, the sanitary storm sewer, vegetated swales, or directly to the environment.

An issue with uncontrolled discharges of ADFs is the potential for high five-day biochemical oxygen demand (BOD) and low dissolved oxygen concentrations in receiving waters. Extreme conditions can cause eutrophication, algal blooms, acute fish die-off, and ecological risks. Discharge to the local publicly owned treatment works (POTW) or base federally owned treatment works (FOTW) is an alternative at some locations. However, the feasibility of this method needs to be determined on a site-specific basis for several reasons, including POTW design capacity, cost, logistics and regulations.

Constructed wetlands have a history of use for treating polluted waters dating back to the early 1950s. In many instances, constructed treatment wetlands can provide a cost-effective alternative to conventional treatment in a mechanical wastewater treatment facility. The use of constructed wetlands for treatment of ADFs is one possible method of resolving the problems described above. However, constructed wetlands have been applied to ADF treatment at only a few locations worldwide, and this application of wetland treatment technology is still innovative since it has rarely been applied on a large or full scale.

A 0.6-acre horizontal subsurface flow (SSF) constructed treatment wetland (CTW) system was installed at the Westover Air Reserve Base (ARB) in Massachusetts to demonstrate the efficacy of this innovative technology in treating the ADF from on-site deicing operations. An SSF CTW was selected for this demonstration because it is insulated from cold temperatures, efficient (higher surface area for microbial attachment), unlikely to have ecological risks, and free from bird air-strike hazard since there is no standing water.

The CTW demonstration project monitored the performance of the SSF CTW for a single winter season (2002–2003) of deicing at the Westover ARB. The CTW was less than 1 year old at the end of this demonstration. Deicing activity during the demonstration period was unusually great (about 5 times the average), and the SSF CTW was still able to meet the goals set for the project.

During the project the permit for the outfall had changed from an individual to a multisector permit. The objectives for effluent toxicity and non-point-source (NPS) removal were not assessed because higher than expected construction costs necessitated a reduction in project analytical costs. This change made the performance objective of compliance with the original individual national pollution discharge elimination system (NPDES) inapplicable. For the primary performance criteria of cost reduction, mission impacts (or readiness), and land use, the wetland system achieved the performance criteria. The system is estimated to cost $3,000 to operate and maintain annually, only $500 more than expected.

The wetland system demonstrated its ability to achieve significant BOD slug load reductions. BOD mass removal rates at greater than 220 kg/ha/d were higher than more than 97 percent of all of the annual average operational data values (N=191) in the North American Treatment Wetland Database (Version 2). [1] The apparent wetland background or minimum achievable BOD concentration during a deicing event was relatively high at approximately 133 mg/L. Peak inflow BOD concentrations ranged from 974 to 15,098 mg/L during 10 deicing events in 2002, and these were reduced by more than 50% in 5 of the 10 events. It is likely that BOD removal rates would have been higher in a fully matured and developed SSF CTW.

The performance of this system can reasonably be expected to increase for several years and achieve a higher level than was measured during this first year of operation. The wetland plant community should approach full coverage by the end of the 2003 growing season, and performance during the upcoming winter of 2003-2004 will reflect the effect of that increased coverage.

Due to the increased deicing activity during the demonstration period and the associated high loadings, the site area constraint was the major limitation for the project. The available area for the CTW was too small for the amount of flow and ADF application from the watershed in 2002-2003. Average annual usage at Westover is 10,000 gallons. Actual usage in 2002-2003 during the CTW Demonstration Project was higher than average with over 50,000 gallons. It is estimated that at least 2 to 2.5 acres of CTW would be required to fully treat the ADF discharging to Cooley Brook at Outfall 001 during normal and extreme deicing years.

The costs associated with discharging ADF wastes to a full-scale SSF CTW were compared to the estimated cost of discharge to a local POTW. POTW discharge was selected for cost comparison since it is considered the default treatment methodology for small- to medium-sized airports and military air facilities. These costs were evaluated for an average annual ADF usage of about 10,000 gallons. The life-cycle basis was a 20-year project life at a 6% discount rate.

Annualized cost estimates were $26,940 for the existing 0.6 acre CTW, $71,394 for a full-scale CTW at this site (2 acres), and $105,182 for transfer of the glycol-containing stormwater to a POTW for treatment and disposal. The CTW technology is estimated to be about 32% less costly on an annualized basis ($7.14 vs $10.52 per gallon of ADF) than the most likely alternative technology, which is discharge to the local POTW. Further, the treatment wetland would be much less costly compared to other available alternatives such as a fixed-film bioreactor. A bioreactor would have higher capital and operating costs.

Cost savings will be less if a facility has been discharging to the POTW and now chooses to install a full-scale CTW because capital costs have already been expended for the POTW discharge and not for the CTW. The savings in annual costs with a CTW is $76,000 per year. The payback period for this scenario is 10.5 years. Capital costs for the demonstration and full-scale CTWs are estimated to be $286,000 and $795,800, respectively.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

Constructed wetlands have a history of use for treating polluted waters dating back to the early 1950s. The use of constructed wetlands for treatment of ADF is one potential method of resolving the problem of direct discharge of ADF wastes. However, constructed wetlands have been applied to ADF treatment at just a few locations worldwide and only one in the United States (see Section 2.3). Our application of the wetland treatment technology is innovative partly because it has rarely been applied on a large or full scale.

The key pollutant of concern for this project is ADF. At high concentrations ADFs have very high biochemical oxygen demand potential. High ADF loadings can pollute receiving waters by exerting this potential oxygen demand through promotion of rapid growth of heterotrophic microbial populations. In turn, this high oxygen demand depletes available dissolved oxygen in the receiving water and impacts or alters natural populations of flora and fauna, including primary producers such as algae, and heterotrophic consumers such as macroinvertebrate populations and fish.

Most ADFs include manufacturer additives that may have additional environmental effects. Of particular interest are triazoles (man-made aromatic compounds) which, at high concentrations, are known to be carcinogenic and acutely toxic to indigenous aquatic fauna.

Wetland treatment removes and/or degrades contaminants in water by physical, chemical, or biological means. Wetland treatment with respect to ADF-containing stormwaters is discussed further in Section 2.2.

2.2 PROCESS DESCRIPTION

There are two major categories of constructed wetland treatment: surface flow (SF) and subsurface flow (SSF). [2] In SF wetland treatment, water flows over the ground surface in a relatively shallow sheetflow similar to a natural wetland marsh. Plants in these systems are able to withstand continuously saturated soil conditions and the resulting anaerobic soil conditions. SF treatment wetlands have variable water column oxygen levels depending on several factors. Atmospheric diffusion, wind action, algae, and macrophytes introduce oxygen to the system. Dissolved oxygen levels are highest at the air/water interface and decrease with depth.

In an SSF treatment wetland, the water is designed to flow horizontally or vertically subsurface through a porous medium such as coarse sand or gravel. The system at the Westover ARB is a horizontal subsurface flow bed. Because the treatment zone is entirely underground and saturated, conditions in SSF wetland beds become anaerobic. Some oxygen is transferred from the atmosphere via plant leaves and stems to the roots. However, only a slight amount diffuses out of the rhizosphere, and this dissolved oxygen is rapidly scavenged by aerobic and facultative microbes nearby. Therefore, useful oxidation reactions such as aerobic degradation of carbonaceous material and nitrification of ammonia nitrogen are limited by oxygen availability in SSF constructed wetlands.

A 0.6-acre horizontal SSF CTW system was installed at the Westover ARB in Massachusetts to demonstrate the efficacy of this innovative technology in treating the ADF from on-site deicing operations. A SSF CTW was selected because it has several advantages over SF systems in this application. A SSF system is better insulated from cold temperatures, more efficient (higher surface area for microbial attachment), less likely to have significant ecological risks, and not an added bird wildlife aircraft strike hazard (BASH) since there is no standing water. [2,3]

Figure 1 illustrates the major features of a typical SSF CTW. An important design feature for improved performance and minimization of short-circuiting is to apply ADF contaminated waters evenly across the bed width. For this project we used a perforated pipe in coarse (>6-inch) rock. The size of perforations should be greater than 1 inch to prevent clogging. Purging of the inlet distribution pipe may be required if significant biomass builds up around the perforations.

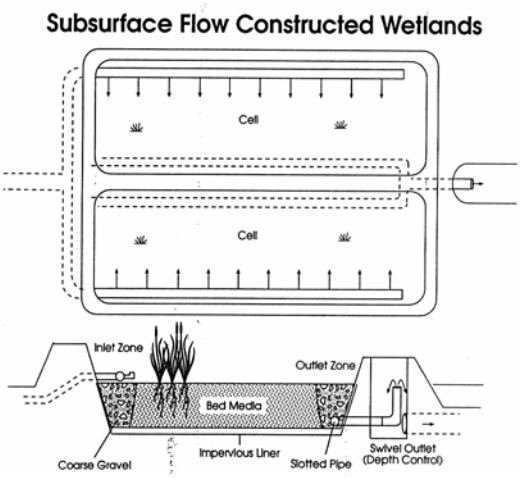

Figure 1. Subsurface Flow Constructed Treatment Wetland Typical Plan and Profile. [2]

With respect to treatment of ADF-containing stormwaters, CTWs consistently perform the following beneficial treatment processes:

- Degradation of dissolved organic matter through microbial growth and respiration.
- Transformation and metabolism of toxic organic compounds.
- Degradation and mass reductions of other stormwater contaminants including oils and grease, suspended solids, and nutrients.

Further, laboratory data show bio-utilization of glycols by hundreds of microbial cultures, by the number of full-scale, constructed wetlands successfully operating in cold climates [4,5,6,7], and by recently published data from Heathrow Airport's pilot-scale CWTs. [8]

Key regulatory drivers for the CTW Technology Demonstration Project were enhanced compliance with the requirements of the Clean Water Act (CWA) and a good faith effort to comply with DoD ADF guidelines. ADF discharges are considered stormwater and are regulated under the CWA NPDES. The NPDES program requires a permit for all discharges into regulated waters.

At the beginning of the project, Outfall 001 had an individual NPDES permit with required monitoring of pollutants and flow from storm events. During the demonstration, all outfalls at Westover were modified to a multisector permit that does not require sampling but does require a storm water pollution prevention plan (SWPPP). The treatment wetland system is considered a best management practice (BMP) under the base's SWPPP. However, if an airport uses more than 100,000 gallons of glycol-based deicing/anti-icing chemicals, monitoring is required.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

With more than 10,000 full-scale constructed wetlands in operation worldwide (International Water Association [IWA], 2002), there are ample data to provide a practical application of the technology for pollution control. However, the CTW technology has not been widely applied to the management and treatment of ADFs. The application of the SSF CWT technology for enhanced biodegradation of glycol-based deicing compounds has been sufficiently developed for demonstration at the field-scale. Pilot field testing of biological and CWT systems strongly suggest the technology can effectively treat deicing runoff. [8,9,10]

Data for glycol removal in constructed treatment wetlands have been reported from three pilot or full-scale system CTWs (Table 1). One of the full-scale systems is at the Airborne Express Airport in Wilmington, Ohio [11]; another full-scale system is at the Pearson Airport in Ontario, Canada [12]; and a series of pilot systems have been built at the Heathrow Airport in Great Britain. [8]

Pilot field testing of biological and constructed wetland systems strongly suggest that the technology can effectively treat deicing runoff. [8,9,10] The latest published data from a pilot-scale SSF reed bed CTW study at London's Heathrow airport show an average removal efficiency of 78% and stable and shock-load resistant populations of glycol-respiring microbes (10^{-5} – 10^{-7} colony-forming units [CFU]/g substrate dry weight). The reed bed's removal efficiency has steadily improved as the treatment bed has matured. Initial performance from Heathrow's pilot-scale system indicated that the technology was ready for field-scale testing.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Conventional practices and alternatives for ADF wastewater management include the following:

- Collection and recycle/reuse.
- Collection and treatment at a publicly owned treatment works (POTW).
- Detention with partial treatment.
- Collect and treat on site.
- No treatment with release to the environment.

All of these options are costly in terms of economic and/or environmental impacts.

The SSF CTW system at Westover ARB requires no collection system, functions continuously, and is passive. Minimal human intervention is required for operation. All storm events are intercepted and conveyed to the CTW site via the existing storm sewer. Normal flows from the airfield are passively diverted to the oil/water (O/W) separator, from which they then enter the CTW.

The major limitation for this project was the site area constraint. The available area for the CTW was too small for the amount of flow and ADF application from the watershed. It is estimated that at least 2 to 2.5 acres of CTW would be required to fully treat the ADF entering the O/W separator.

Table 1. Constructed Treatment Wetlands Used for Enhanced Biodegradation of Glycol-Based Deicing Compounds.

Parameter	Lester B. Pearson International Airport, Toronto, Ontario	Heathrow International Airport, London, England		Airborne Express Airline, Wilmington, Ohio
		Pilot	Full-Scale	
Wetland type	Vertical/horizontal subsurface flow	Surface flow, subsurface flow, floating reedbed	Floating Reedbed, Subsurface Flow	Reciprocation subsurface flow
Wetland area	1 acre	Substrate beds 5m x 30m; floating system 3m x 5m	2.7 acre Floating; 4.1 acres Subsurface Flow;	2 systems each approx. 3 acres
Substrate	Clean sand over graded gravel layers (total depth of 3 feet)	Gravel SSF	Gravel SSF	Gravel SSF
Vegetation	*Phragmites australis*	*Typha latifolia, Typha angustifilia, Phragmites australis, Schoenoplectus lacustris, Iris pseudacorus*	*Phragmites australis*	---
Drainage area	944 acres (70-80% impervious)	759 acres (80% impervious)	725 acres (80% impervious)	2,200 acre airpark (200 acres concrete ramps)
Design flow	1-year return event (1-inch rainfall)	---	1.8 mgd (aerated storage basin upstream)	0.36 mgd avg; 1.44 mgd peak
Residence time	24 - 48 hours	---	24 hours	---
BOD inlet	1,000 - 5,000 mg/L	3.9 kg/d average	240 mg/L peak	100 - 20,000 mg/L
BOD outlet	100 mg/L during deicing months, 15 mg/L otherwise	Removals: 30.9% (SF); 32.9% (SSF); 34% (floating)	40 mg/L	---
Construction cost	$2 million	---	$5 million	---
Reference	Flindall and Basran, 2001	Chong et al, 1998	Revitt et al, 2000	Arendt, unpublished

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The objective of the CTW Technology Demonstration Project was to demonstrate that SSF-constructed treatment wetland technology could cost-effectively remove harmful chemicals from deicing wastestreams for immediate and long-term compliance with water quality regulations. By constructing and monitoring a field-scale SSF treatment wetland system, this project illustrates the efficacy of the CTW technology for enhanced biological treatment of deicing effluent and runoff at DoD air bases.

Table 2 summarizes the performance objectives of the CTW Technology Demonstration Project as published in the Final Demonstration Plan. [14] For demonstration purposes, each objective consists of a performance criterion and a corresponding performance expectation or metric.

Table 2. Performance Objectives of the CTW Technology Demonstration Project.

No.	Performance Objective	Expected Performance and Metrics
1	Reduced cost	Annual cost <$2,500 or annualized cost <$1/lb BOD/yr
2	Slug load treatment	> 80% reduction when BOD > 500 mg/L
3	NPDES permit compliance	BOD < 30 mg/L (monthly mean)
4	Readiness	Improved deicing logistics and flight scheduling
5	Land use	No BASH impacts; no odors

3.2 SELECTION OF TEST SITES

A number of DoD air bases were considered for the proposed SSF CTW Technology Demonstration Project. The air bases ranked highest as candidates were:

- Whidbey Island Naval Air Station (NAS), Washington
- Fairchild Air Force Base (AFB), Washington
- Westover ARB, Massachusetts

Considerable work had already been conducted at Westover ARB concerning the effects of deicing on receiving waters, including natural wetlands. Westover also had an existing stormwater collection and pretreatment oil/water separator for its main deicing area. The previous work, existing infrastructure, and the strong interest shown by environmental personnel at the base were the primary factors in selecting Westover ARB as the top candidate for the SSF Constructed Treatment Wetland ADF Attenuation Technology Demonstration Project (CTW Technology Demonstration Project).

3.3 TEST SITE/FACILITY HISTORY/CHARACTERISTICS

Westover ARB is composed of approximately 2,511 acres of land within the communities of Chicopee and Ludlow in the northern portion of Hampden County, Massachusetts (Figure 2 and Figure 3). The Base is situated approximately 2 miles east of the Connecticut River, and is traversed and/or bounded by Cooley and Stony Brooks. Site soils are sandy with some gravel.

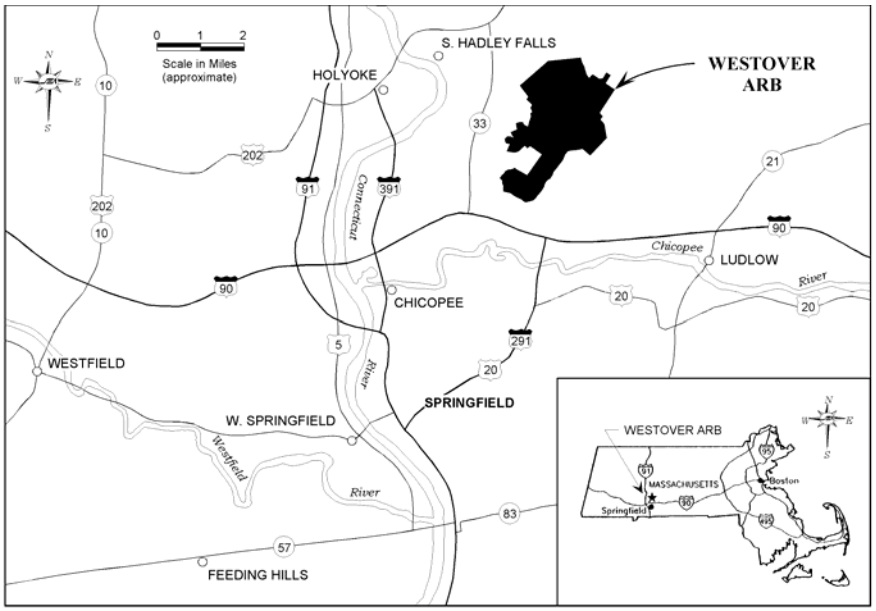

Figure 2. Westover ARB and Surrounding Region.

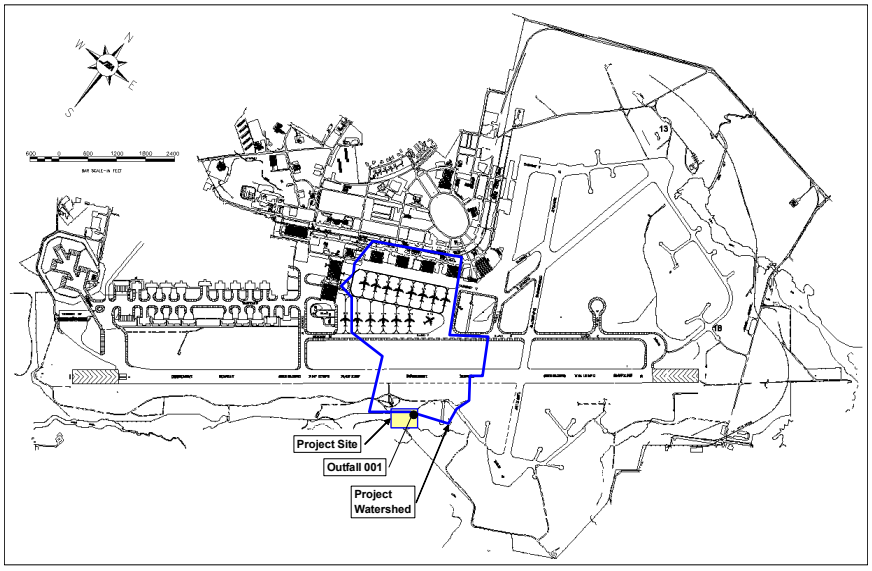

Figure 3. SSF CTW Technology Demonstration Project Watershed, Westover ARB.

Groundwater at the site varies from approximately 2 feet to more than 10 feet below the original (pre-construction) ground surface, depending on location and season. The climate at Westover ARB is continental temperate with cold winters and warm summers. The Hampden County area averages 138 days each year with average temperatures less than 33º F. [15] The mean annual precipitation for a 20-year period-of-record (1969-89) was 42 inches. Average annual snowfall is 49.7 inches, with an average of 12 days per year with greater than 1.5 inches of snow recorded.

Westover ARB performs deicing/anti-icing operations on its aircraft and runways, respectively, during snow storms and freezing rain events (Figure 4). The application of deicing chemicals generates contaminated runoff that can enter the storm sewer system and severely impair surface water quality in adjacent surface waters (Figure 5).

Figure 4. Deicing Required for Aircraft Operation During Inclement Weather.

Figure 5. ADF Release to Ground After Deicing.

At Westover ARB, deicing can be conducted numerous times throughout the winter, depending on weather conditions. Westover ARB currently uses propylene glycol for aircraft deicing at a 20-30/80-70% glycol/water ratio. Propylene glycol use during the past six winter seasons was 2,655 gallons (FY 1998), 8,175 gallons (FY 1999), 3,715 gallons (FY 2000), 6,775 gallons (FY 2001), 14,730 gallons (FY 2002), and 76,150 gallons (FY 2003) for an average of 18,700 gallons. An average of approximately 12,880 gallons (FY 1999–FY 2003) was used within the Outfall 001 watershed area (Figure 3).

Baseline data are critical for the comparison to operational data collected during the SSF CTW Technology Demonstration Project. Baseline sampling was conducted at the site from February 1994 through March 2001. Table 3 summarizes the surface water quality data collected in the O/W separator and Cooley Brook during this period. BOD reductions as a result of the demonstration project were assessed against the background of preproject pollutant releases from Outfall 001.

Table 3. Baseline Water Quality Summary.

Parameter	Statistics	O/W Inflow	Outfall 001	Cooley Brook
Ammonia (mg/L)	Average		0.36	
	Maximum		0.44	
	Minimum		0.27	
BOD (mg/L)	Average		179	
	Maximum		1,800	
	Minimum		1.00	
Chemical Oxygen Demand (COD) (mg/L)	Average		1,255	7.5
	Maximum		21,500	7.5
	Minimum		2.50	7.5
Propyleneglycol (mg/L)	Average	250	1,892	
	Maximum	250	11,000	
	Minimum	250	25.00	
TOC (mg/L)	Average		1,306	
	Maximum		7,517	
	Minimum		0.50	

Note: Baseline sampling collected February 1994-March 2001

3.4 PHYSICAL SET-UP AND OPERATION

The SSF CTW Technology Demonstration Project is located in the Southeast section of the Westover ARB. Wastewater from aircraft deicing performed on the primary jet parking ramp is collected and conveyed by the storm sewer system through Outfall 001 (Figure 3).

Outfall 001 drains a 172-acre watershed with 106 acres (62%) of the area being impervious. Under low flows (about 400,000 gallons per day [gpd]), water in the storm sewer is diverted to an existing 35,000 gallon oil/water separator. Storm flows greater than 3,000,000 gpd bypass the O/W separator and discharge directly into Cooley Brook, which discharges into the Connecticut River 2 miles away.

The Westover SSF CTW system was designed for an event mean flow of 100,000 gpd (69 gallons per minute [gpm]) with peak loadings approaching 400,000 gpd (278 gpm). The inlet to the CTW was placed at a lower elevation than the overflow from the O/W separator so that the CTW captures the first stormwater 'slug,' which typically has the highest BOD concentrations. All baseflow in Outfall 001 passes through the O/W separator and through the CTW system. Bypass in the O/W separator occurs during larger storm events when water levels in the O/W separator are able to exit via the bypass V-notch weir to Cooley Brook.

Because of highly permeable sandy soils at the site, a 30-mil PVC liner was placed between the wetland and surrounding soils. Approximately 2 feet of 1½-inch gravel media was placed on the liner for the CTW system base and a 3-inch layer of ¾-inch gravel was placed on the surface for a planting medium. Perforated inlet and outlet pipes were buried in course rock (>0.5-ft) diameter along the upper and lower boundary of the CTW to encourage flow distribution and minimize short circuiting through the wetland. The system is completely passive and operates under gravity flow, a design feature established because of a 4-foot elevation change across the site as the elevation changes from 206.0 to 202.0 ft above mean sea level. Figure 6 illustrates a cross-section of the CTW.

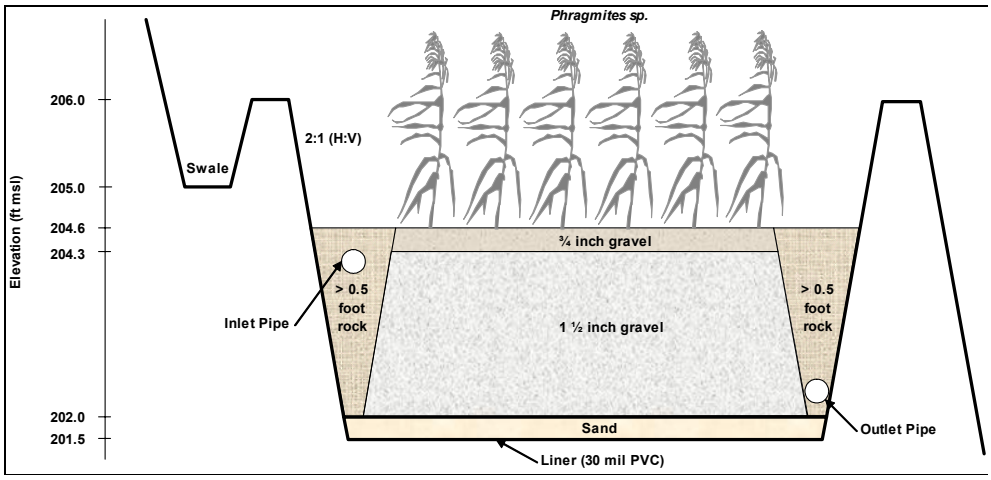

Figure 6. Horizontal Subsurface Flow CTW Cross Section at the Westover Air Force Reserve Base, Chicopee, Massachusetts.

Construction of the 0.6-acre field-scale SSF CTW system began in August 2001 and was completed in January 2002. Wetland planting of *Phragmities sp.* rhizomes was conducted in June 2002. Approximately 3 inches of ¾-inch diameter gravel was placed on the surface for a planting medium of about 2,000 bare root rhizomes planted on 3-foot centers. The source of wetland plants was from Southern Tier Consulting in West Clarksville, New York. Figure 7 shows the relatively sparse plant cover on the CTW system at the end of the first year of operation. The plant community was observed to fill in and provide complete cover by the end of the second growing season.

Figure 7. SSF CTW Eleven Months After Planting (May 2003).

The period of operation for the CTW Technology Demonstration Project is indicated in Table 4.

Table 4. Period of Operation.

Item	Start Date	End Date	Duration (Days)
Baseline monitoring	10/1/00	3/15/01	165
Construction	8/1/01	1/1/02	153
Establishment	6/15/02	9/30/02	107
Experiment	10/1/02	5/6/03	217

3.5 SAMPLING/MONITORING PROCEDURES

3.5.1 Instrumentation

A Hydrolab H20 Multiprobe was installed in October 2000 to measure baseline pH, temperature, oxidation-reduction potential (Eh), conductivity, salinity and turbidity in the O/W separator. Two pressure transducers were also installed to monitor water depths in the O/W separator and

wetland outlet pipe, prior to discharge to Cooley Brook. Data from the Hydrolab and pressure transducers were reported to a Handar data logger and retrieved periodically by Westover ARB personnel.

A LAR Quick-TOC® continuous water and process online analyzing system was installed on site in December 2002 to measure total carbon (TC) concentrations in the O/W separator and at the wetland outflow to Cooley Brook.

Two additional pressure transducers (Infinities USA, Inc.) were installed in December 2002 at the O/W separator and at the wetland outflow box. Water levels in the O/W separator were used to estimate the amount of wetland bypass flow through Outfall 001. Water levels in the wetland outlet box were used to estimate flows being discharged to Cooley Brook and to monitor water levels in the wetland.

3.5.2 Sampling Stations and Collection Frequency

There were four surface water quality sampling stations (illustrated in Figure 8) for the SSF CTW Technology Demonstration Project:

- Oil/water separator inflow (OWin)
- Oil/water separator outlow (Outfall 001)
- Wetland inflow (Win)
- Wetland outflow (Wout)

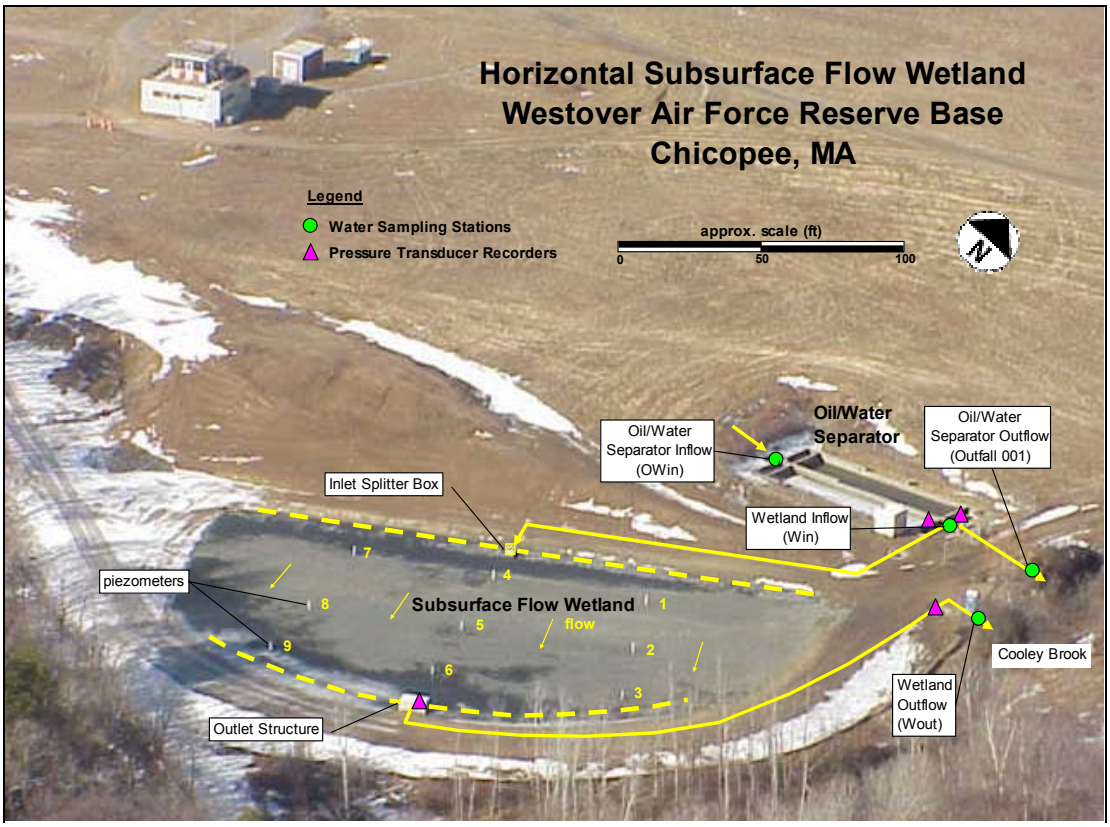

Figure 8. Aerial Photograph of the Horizontal Subsurface Flow Wetland at the Westover Air Force Reserve Base, Chicopee, Massachusetts.

Semicontinuous water quality monitoring of pH, Eh, dissolved oxygen, temperature, conductivity, and turbidity were conduced in the O/W separator and wetland outflow. In addition to the water quality monitoring, water levels were continuously measured at these two stations using pressure transducer data loggers (see Table 5). Water levels were used to estimate flow with weir equations. Flow measurements were used in the calculation of pollutant loads entering and exiting the constructed wetland and bypassing via Outfall 001. Westover ARB weather station records were used to estimate daily precipitation at the project site.

Table 5. Sampling Activities and Frequency.

Station	Flow	Field Parameters[1]	Surface Water Parameters
Oil/Water Separator Inlet	---	---	O
Oil/Water Separator Outlet	SC	SC	M
Wetland Inlet	SC	SC	M, SC
Wetland Outlet	SC	SC	M, SC

SC = semi-continuous; flow measurement using stage vs. discharge relationship
O = monthly or other frequency
M = monthly
[1] Including temperature, pH, Eh, turbidity, and conductivity

Surface water grab samples were collected at least monthly during the baseline period at Outfall 001. These samples were analyzed primarily for BOD, COD and total organic carbon (TOC). Total phosphorus, total kjeldahl nitrogen, nitrate+nitrite nitrogen, oil and grease (O&G), propylene glycol, ADF additive constituents of concern and ADF breakdown products were also sampled less frequently.

Water samples during the experiment were collected from the two surface water monitoring stations (Win and Wout illustrated in Figure 8). Both grab samples and continuous surface water sampling were conducted during the 2002-2003 deicing season. These samples were analyzed primarily for BOD, COD, and methyl-1H-benzotriazole (MeBT), which is an additive component contained in ADF. TOC concentrations in the O/W separator and wetland outflow were measured continuously using a LAR Quick-TOC® continuous water and process online analyzing system.

3.6 PERFORMANCE CONFIRMATION METHODS

The following section describes the procedures used in analyzing the performance of the SSF CTW Technology Demonstration Project for flow attenuation and removal of BOD in the waste stream.

3.6.1 BOD and COD Estimates

A LAR Quick-TOC® (LAR) continuous water and process online analyzing system was installed during the demonstration project to report continuous TC concentration in the O/W Win and Wout. To reduce sampling and analytical costs, the LAR TC measurements were used to estimate BOD concentrations entering and exiting the wetland, therefore estimating the wetlands BOD removal efficiency. The correlation between the LAR TC measurements and BOD samples collected in the SSF CTW Technology Demonstration Project resulted in an R2 of 0.75

and a BOD/TC ratio of 0.65 (Figure 9). Correlations between BOD and COD were established using baseline and operational period monitoring data (Period of Record: February 1, 1994 to April 7, 2003) and resulted in a median BOD/COD ratio of 0.40.

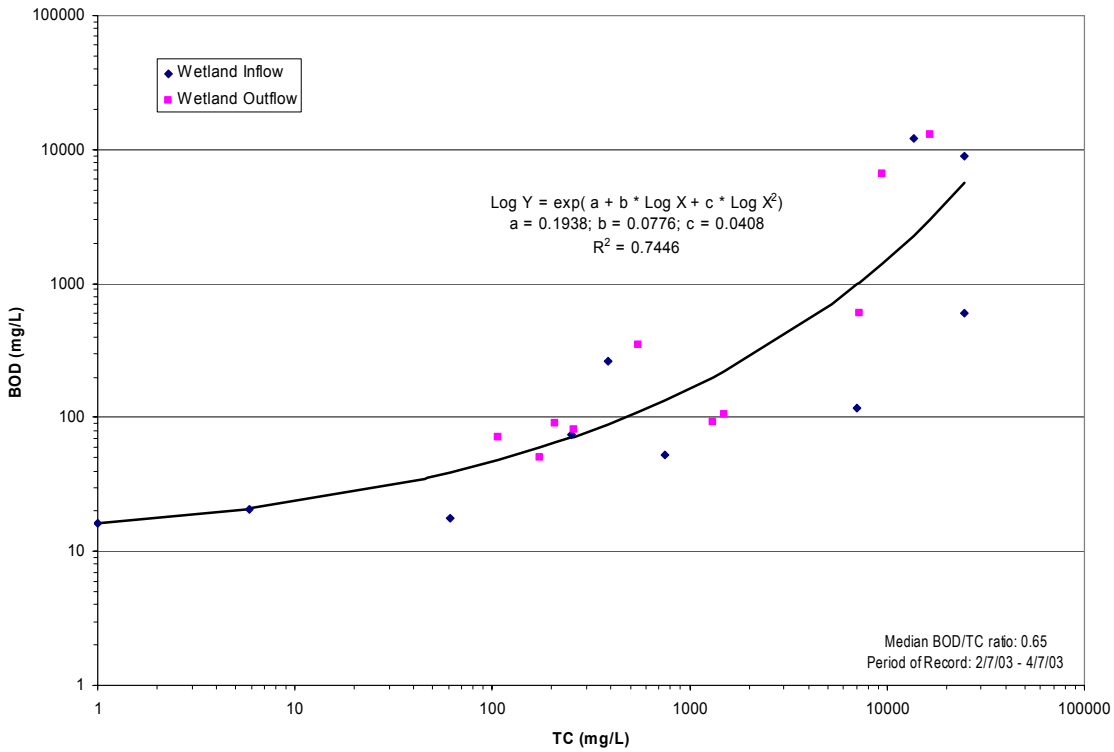

Figure 9. Correlation Between the LAR TC Measurements and BOD Samples Collected in the SSF CTW Technology Demonstration Project.

3.6.2 Pollutant Mass Balances

Pollutant mass balances were determined by multiplying flows and concentrations. Inflow loads were based on hourly inflow estimates and estimated BOD concentrations as described above. Outflow loads were calculated from outflow flow and concentration estimates. Flow-weighted mean concentrations were prepared by totalizing loads over a given time period and dividing by the total cumulative flow for that period. Pollutant removal rates were calculated as the difference between the inflow and outflow loads.

Pollutant load reduction was determined for three specific deicing/storm flow events that occurred during the experimental period (February 8-24, 2003; March 1-3, 2003; and April 5-13, 2003). Complete data records were available for each of these events (see Final Report). [16] Concentration reductions were also calculated for an additional event (December 9-12, 2002).

3.7 ANALYTICAL PROCEDURES

The analytical methods used were standard Environmental Protection Agency (EPA) Methods (or equivalent) for all but the ADF additives. [17,18] Table 6 provides a more detailed breakdown of the baseline and experiment sampling efforts, including analytical methods. The

University of Colorado (UC)-Boulder performed analytical procedures for the additives of concern. Since no standard method exists for many of the additives, UC-Boulder used a gas chromatograph technique developed at the university (see Final Report). [16] The analytical laboratory at Western Washington University is also capable of accurate analysis of ADF additives.

Table 6. Surface Water Sampling Analysis Parameters and Methods.

Parameter	Analytical Method	Analytical Lab	Monitoring	
			Baseline	Experiment
BOD	405.1 [1], 5210B [2]	CT / SA	X	X
COD	410.1 et al. [1], 5220B+C or D [2]	CT / SA/UC	X	X
Propylene glycol	8015M [6]	CT / SA/UC/WU	X	X
ADF additives	[3]	CT / SA/UC/WU	X	X
TOC	415.1/415.2 [1], 5310B [2]	CT / SA	X	
Total suspended solids (TSS)	160.2 [1], 2540C [2]	CT	X	
Nitrate/nitrite	353 Series [1], 4500 Series [2]	CT	X	
Kjeldahl nitrogen	351 Series [1], 4500 Series [2]	CT	X	
Total phosphorus	365 Series [1], 4500 Series [2]	CT	X	
Oil & grease	413 Series [1], 5520 Series [2]	CT	X	
Volatile organic compounds (VOCs)	624 [5], 6210 [2]	CT	X	
Semivolatile organic compounds (SVOCs) Polynuclear aromatic hydrocarbons (PAHs)	625 [5], 6410 [2]	CT	X	
Metals (15)	200.7 [1]	CT	X	

[1] Method reference from "Methods for Chemical Analysis of Water and Wastes," USEPA, EPA 600/4-79-020, Revised March 1983.
[2] Method reference from "Standard Methods for the Examination of Water and Wastewater," AWWA-WPCF-APHA, 17th Edition, 1989.
[3] Method does not exist. WU and UC protocols to be used.
[4] CT = Con-Test; SA = Spectrum Analytical; UC = University of Colorado; WU = Western Washington University

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

4.1.1 Stormwater and Deicing Runoff

The CTW system was designed for an event mean flow of 100,000 gpd (69 gpm) with peak loadings approaching 400,000 gpd (278 gpm). The actual estimated mean flow to the CTW during storm events was approximately 170,000 gpd (118 gpm) with a peak flow of 506,160 gpd (352 gpm). These flows are considerably higher than the planned design flows. The average flow to the CTW (baseflow and storm events) during the December 17, 2002 through May 6, 2003 period was 70,315 gpd (49 gpm). Bypassed flow over the O/W separator V-notch weir for the same period averaged 64,570 gpd (45 gpm) with an instantaneous peak flow estimated at approximately 6,000,000 gpd (4,100 gpm).

A time series of estimated CTW outflows and bypass flows from the O/W separator are shown in Figure 10. Total flow from the O/W separator during the experimental period from December 2002 through May 2003 was 20.43 million gallons. Of this total flow, about 51% was routed through the CTW, and 49% was bypassed directly to Cooley Brook without additional treatment.

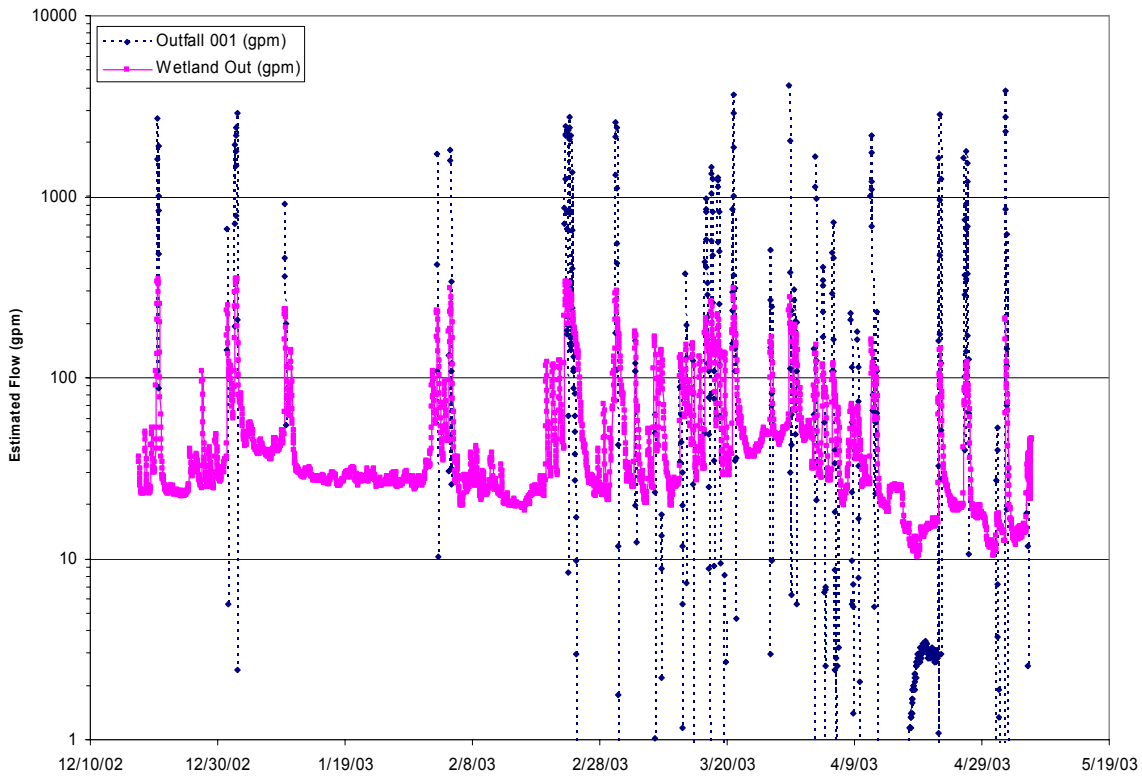


Figure 10. Estimated Bypass (Outfall 001) and Wetland Outflow.

4.1.2 BOD Concentration and Load Reductions

Period-of-record data for TC from the LAR and ADF usage records are plotted in Figure 11. There were 38 recorded deicing events in this watershed during the experimental period, most of which resulted in immediate TC concentration responses downstream at Outfall 001. A total of 51,355 gallons of ADF was applied in this basin during this period of record.

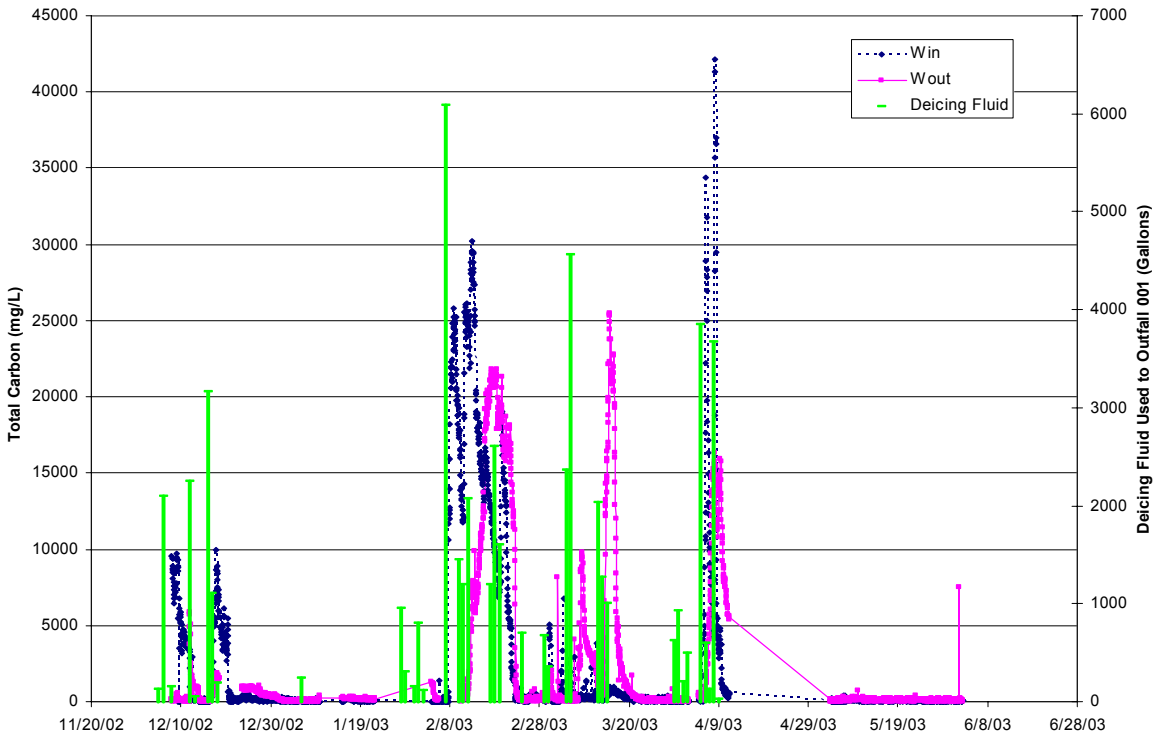


Figure 11. Time Series Plot of LAR TC and ADF Usage During the 2002-2003 Deicing Season.

Four specific events were analyzed for either estimated BOD concentration or load reductions. Summaries are provided below of the detailed analysis for each of these storm events. Table 7 provides a summary of these results. Hydraulic loadings into the system varied greatly and steady state flow conditions were not achieved during any of the four events.

Average estimated inflow and outflow BOD concentrations for the CTW during these four events ranged from 165 to 2,644 mg/L and 100 to 1,667 mg/L for an average concentration reduction of 11% to 78%, respectively. Average estimated bypass BOD concentrations ranged from 58 to 790 mg/L for these events. Since the inlet to the CTW is placed at a lower elevation than the O/W separator overflow, it captures the first stormwater 'slug,' which typically has the higher BOD concentrations. As a result, bypass flows had lower average BOD concentrations than the CTW inflows.

Table 7. Summary of Results from the Westover ARB SSF CTW Technical Demonstration Project Performance, 2002–2003 Deicing Season.

Parameter	Dec 2002	Feb 2003	Mar 2003	Apr 2003
BOD Average				
CTW inflow (mg/L)	455	2,655	165	1,228
CTW outflow (mg/L)	100	1,667	112	1,090
CTW removed (mg/L)	355	977	52	137
CTW removed (%)	78.0	36.9	31.7	11.2
Bypass (mg/L)	---	58	81	790
BOD Flow-Weighted Mean				
CTW inflow (mg/L)	---	1,434	129	1,183
CTW outflow (mg/L)	---	1,247	133	937
CTW removed (mg/L)	---	186	-4	246
CTW removed (%)	---	13.0	-3.0	20.8
Bypass (mg/L)	---	58	75	319
Combined Outfall 001 (mg/L)		524	94	581
BOD Mass Removals				
CTW inflow (kg/d)	---	414	109	334
CTW outflow (kg/d)	---	360	113	265
CTW removed (kg/d)	---	54	-3	69
CTW removed (%)	---	13.0	-3.0	20.8
Bypass (kg/d)	---	26	130	122
Combined Outfall 001 (kg/d)	---	386	243	386
CTW inflow (kg/ha/d)	---	1,705	450	1,374
CTW outflow (kg/ha/d)	---	1,484	464	1,088
CTW removed (kg/ha/d)	---	221	-13	286
Removed (%)	---	13.0	-3.0	20.8
Wetland/Bypass Flows				
Average wetland flow (gpm)	---	53	151	51
Total wetland flow (Mgal)	---	1.29	0.33	0.59
Average bypass flow (gpm)	---	82	310	70
Total bypass flow (Mgal)	---	2.01	0.67	0.80
Total flow (Mgal)	---	3.31	0.99	1.40
Treated flow (Mgal)	---	39.1	32.8	42.5
Average temperature (F)	27.1	19.5	26.7	36.4
Average precipitation (in/d)	0.19	0.22	0.25	0.15
Average HLF (in/d)	---	4.7	13.3	4.5
Average residence time (d)	3.0	3.9	0.5	1.6

Notes:

Wetland area (ha) = 0.243
Wetland flows are based on wetland outflow measurements.
Dec 2002 = 12/8/02 - 12/14/02 (7 days)
Feb 2003 = 2/7/03 – 2/23/03 (17 days)
Mar 2003 = 3/1/03 – 3/3/03 (1.5 days)
Apr 2003 = 4/5/03 – 4/12/03 (8 days)

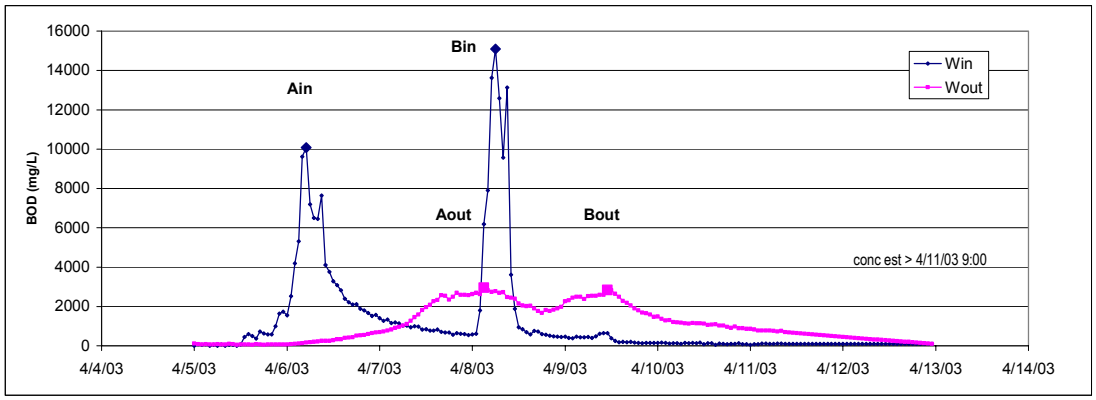
The first recorded event (December 8-14, 2002) occurred before flow measurement instrumentation was fully in place and therefore includes only concentration estimates. Event flow-weighted mean BOD concentrations for the remaining three events ranged from 129 to 1,434 mg/L at the CTW inflow and from 133 to 1,247 at the CTW outflow, for an estimated mass reduction range of -3 to 21%. The third event (March 1-3, 2003) resulted in no BOD mass reduction due to the relatively low inlet BOD levels; however, average concentrations of BOD entering Cooley Brook were lowered (32%) by the CTW.

Figure 12 summarizes the data from the fourth recorded event (April 5-12, 2003). This event includes BOD concentration, flow, and BOD mass estimates for at least five closely spaced flow events. Average estimated inflow and outflow BOD concentrations for the CTW during this entire event were 1,228 and 1,090 mg/L, for an average concentration reduction of 11%. Peak inflow and outflow concentrations were reduced from 10,082 and 15,098 mg/L at the inflow to 2,818 and 2,949 mg/L at the outflow, or by 71% to 81% (Event A and B in Figure 12). The apparent hydraulic residence time (HRT) in the bed estimated from these concentration peaks was from 1.3 to 1.9 days. Event mean flow through the CTW was 51 gpm for an average hydraulic loading rate (HLR) of 4.5 in/d. Recorded precipitation during this period averaged 0.15 in/d.

Event flow-weighted mean concentrations for BOD were 1,183 and 937 mg/L at the CTW inflow and outflow for an estimated mass reduction of 21%. The estimated inflow and outflow masses of BOD were 2,655 and 2,103 kg, for a net mass removal estimate of 552 kg or 286 kg/ha/d. The estimated mass of BOD going directly from the O/W separator overflow to Cooley Brook was 969 kg at a flow-weighted mean concentration of 319 mg/L. These data indicate that the SSF CTW lowered the average BOD concentration (11%) and load (21%) entering Cooley Brook compared to the original system with no CTW in place. The CTW operated as designed with no recorded surface flow and no apparent freezing throughout this period of severe weather.

4.1.3 Other Analytical Measurements

Table 8 summarizes the analytical measurements from surface water grab samples and the Hydrolab multiparameter sonde installed in the O/W separator Win and Wout during this study. Peak concentrations of MeBT were reduced with travel through the CTW but there was no measurable change in the average concentration. Dissolved oxygen percent saturation and redox potential decreased with passage through the CTW while pH increased. There was a slight reduction in turbidity with passage of the stormwater through the CTW and a slight increase in water temperature. Insufficient data existed to assess any added performance from the O/W separator because outflow from the separator was not collected. It is expected very little BOD reduction occurs in the brief time stormwater resides in the separator.



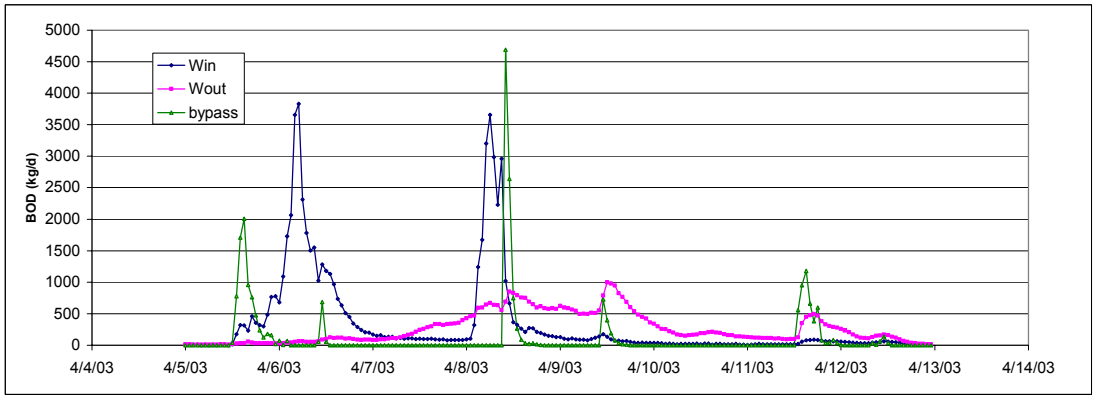
Event	Time In	Time Out	# Days	BOD (mg/L) In	BOD (mg/L) Out	BOD (mg/L) Diff	BOD (mg/L) %
A	4/6/2003 5:00	4/8/2003 3:00	1.9	10,082	2,949	7,133	70.7
B	4/8/2003 6:00	4/9/2003 12:00	1.3	15,098	2,818	12,280	81.3

Start:	4/5/2003 0:00
End:	4/12/2003 23:00
# days:	7.96
# hrs:	191

Average		
HLR (in/d)	Precip (in/d)	Temp (F)
4.5	0.15	36.4

Parameter	Average mg/L	FWM mg/L	Mass kg	Mass kg/d	Average gpm	Total gallons
BOD_in	1,228	1,183	2,655	334	51	593,089
BOD_out	1,090	937	2,103	264	51	593,089
BOD_bypass	790	319	969	122	70	803,020

Mass Removed	
286	kg/ha/d
552	kg
20.8	%



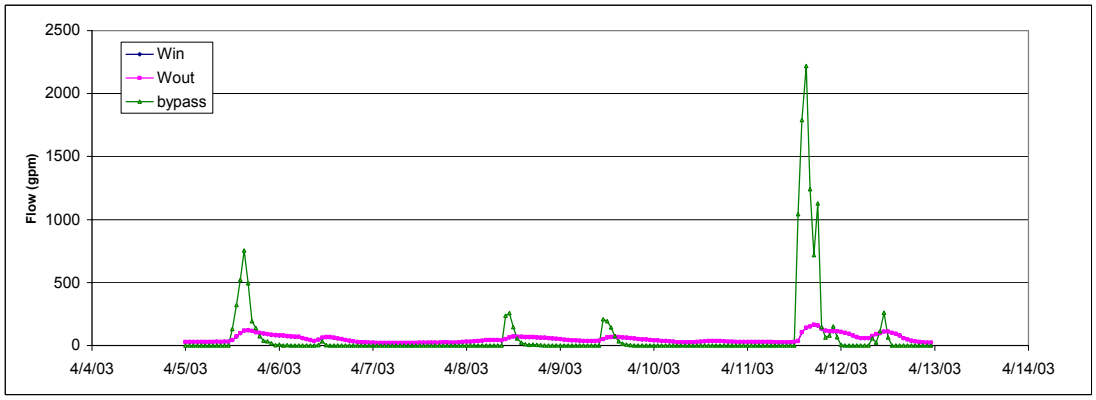


Figure 12. Summary from Fourth Recorded Event (April 5–12, 2003).

Table 8. Summary of Other Analytical Results from the Westover ARB SSF CTW Technical Demonstration Project Performance, 2002–2003 Winter Deicing Season.

Parameter	Units	Statistics	Wetland Inflow	Wetland Outflow
BOD	mg/L	Average	2,226	2,094
		Max	12,100	12,900
		Min	16.2	50.8
COD	mg/L	Average	1,883	1,335
		Max	37,900	23,100
		Min	3	100
MeBT	mg/L	Average	0.68	0.72
		Max	20.93	4.77
		Min	0.02	0.02
DO	%	Average	52.2	47.7
		Max	103.9	69.8
		Min	8.8	8.8
pH	SU	Average	7.58	9.54
		Max	8.95	13.92
		Min	5.61	6.54
Redox	mV	Average	391	172
		Max	596	518
		Min	235	-272
Temp	C	Average	17.3	18.9
		Max	26.8	32.7
		Min	10.8	12.1
Turbidity	ntu	Average	5.22	4.61
		Max	10.7	7.06
		Min	0.88	1.16

Period of Record:
Grab samples (BOD, COD, MeBT): 2/20/02–4/7/03
Hydrolab Parameters: 6/6/02–7/2/02

4.2 PERFORMANCE CRITERIA/CONFIRMATION

Table 9 provides a summary of the performance confirmation provided by the operational monitoring data. Detailed performance objectives and assessment methods are presented in the Project Demonstration Plan. [14]

4.2.1 Reduced Cost

The CTW Technical Demonstration Project met the primary BOD removal cost reduction criterion of less than $2,500 per year operation and maintenance (O&M) cost. The cost associated with operation and maintenance of the LAR Quick-TOC® analyzing system was not included in this estimate since it was used only for the demonstration and would not be required in a full-scale system. There was no additional monitoring due to the CTW Technical Demonstration Project other than the normal quarterly permit water quality samples.

Table 9. Summary of Performance Confirmation from the Westover ARB SSF CTW Technical Demonstration Project.

Performance Criterion	Expected Performance	Performance Confirmation Methods	Actual Performance	Criterion Met
Primary Criteria (quantitative performance objectives)				
Reduced cost	Annualized cost < $1/lb BOD /yr or cost per year < $2500	Estimated demo costs without research costs	Nondemonstration costs are < $2500, per year.	Y
Slug load treatment	> 80 % BOD reduction	Monitoring during principal deicing events	All events: -47 to 81%; average = 44%	N
NPDES permit compliance	BOD < 30 mg/L, monthly mean	Monthly mean concentrations during experimental period	Monthly mean range: 56 – 1,879 mg/L	N
Primary Criteria (qualitative performance objectives)				
Readiness	Improved deicing logistics and flight scheduling	General observations	No data re: flight scheduling; minimal operation and maintenance requirements	Y
Land use	No BASH impacts; no odor problems	General observations	One pair killdeer nesting on site; no odor problems noted	Y
Secondary Criteria (quantitative performance objectives)				
Wetland health	Vegetation cover within +/- 20% of expected values; normal growth	Survival estimate in May 2003	Estimated 90% survival	Y
Maintenance	No more burdensome than baseline technology	Estimate by Jack Moriarty/Westover ARB	1.5 hrs per week	Y
Effluent Toxicity	Acceptable risk [1]	Monitoring during experimental period	No operational monitoring data	---
NPS Removal	Removal rates within one standard deviation of available stormwater wetland technology	Estimate removal rates of nonpoint source (NPS) pollutants during experimental period	No NPS pollutants reported during experimental period	---
Secondary Criteria (qualitative performance objectives)				
Reliability	Consistent performance, no upset conditions	General observations	No upset conditions	Y

[1] Acceptable risk is defined in both the generic and specific case. Generically, concentrations of chemicals of concern in the effluent should be below established aquatic toxicity screening benchmarks or more exact, site specific or local surface water criteria.

4.2.2 Slug Load Treatment

The CTW Technical Demonstration Project generally resulted in BOD mass removal rates at greater than 220 kg/ha/d, which is higher than more than 97% of all of the annual average operational data values (N=191) in the North American Treatment Wetland Database v. 2. [1] The apparent wetland background or minimum achievable BOD concentration during a deicing event was relatively high at approximately 133 mg/L. This result was not entirely unexpected since Kadlec and Knight (1996) [2] estimate a background BOD concentration of about 110 mg/L at an inlet BOD concentration of approximately 2,000 mg/L.

Lower outflow BOD concentrations could likely be achieved with greater storage. Storage would allow steady state operation and significantly improve CTW removal rates. In addition, pretreatment before the CTW or an increase in the area of the CTW would increase performance. It is estimated that at least 2 to 2.5 acres of CTW would be required to fully treat the existing ADF discharging to Cooley Brook at Outfall 001.

Peak concentration reductions were generally very high and were greater than 50% in 5 of the 10 individual winter storm events that were measured. BOD mass removal efficiencies were much lower (-3 to 21%) due to very high incoming loads. It is likely that BOD removal rates would have been higher in a fully matured and developed SSF CTW. The performance of this system can reasonably be expected to increase for the next several years and level out at a higher mass removal rate than was observed during this first year of operation. The wetland plant community was observed to reach full coverage by the end of the 2003 growing season, and performance during the upcoming winter of 2003-2004 may reflect the beneficial effects of that increased coverage.

4.2.3 BOD NPDES Permit Compliance

The BOD NPDES permit compliance primary performance criterion of less than 30 mg/L (monthly mean) discharge from the CTW Technical Demonstration Project was not met during the experiment period. This was an inappropriate criterion set for the CTW as it was for an individual permit on an outfall, and now Outfall 001 is under the multisector permit. Therefore, the expected performance metric is irrelevant as Outfall 001 is in compliance with the NPDES permit requirements.

4.2.4 Readiness

Impacts to the Westover ARB mission were considered a primary performance criterion for the CTW Technical Demonstration Project. Mission and operational aspects evaluated include improved deicing logistics, ease of operation, and flight scheduling. This performance criterion was met since the CTW reduced the need for costly ADF collection alternatives, such as vacuum trucks or screen/filter mat placement over storm drains. The Westover ARB received an increased flight schedule during the CTW Technical Demonstration Project because of the war effort in Iraq, resulting in an increased number of deicing events during this period.

4.2.5 Land Use

The last primary performance objective was land use compatibility. The goal of this objective was not to create or increase any BASH at Westover ARB and not to produce objectionable odors. One of the advantages in the selection of SSF CTW technology is the lack of surface water, which makes it the least attractive to wildlife. Only one pair of killdeer was observed nesting on site during the experiment period. Killdeer are not considered a significant BASH threat at Westover ARB and their density did not increase as a result of this project. There were no reports of objectionable odors during this demonstration.

4.2.6 Wetland Health

Survivability or wetland health was a secondary performance objective. Wetland planting was conduced in June 2002 and the percent survival estimated approximately 1 year later. The percent survival was estimated in May 2003 at 90%.

4.2.7 Maintenance

Another secondary performance objective for this demonstration was the maintenance requirements and impact of base operations as a result of the CTW. Base operations were not adversely impacted by this project. This project resulted in minimal operator training and maintenance (approximately 1.5 hours per week during the deicing season).

4.2.8 Effluent Toxicity

Due to budget constraints, ecological effluent toxicity sampling was not conducted at the CTW Technical Demonstration Project site.

4.2.9 NPS Removal

The removal of NPS pollutants was a secondary performance objective for this demonstration. Due to budget constraints no NPS pollutants were monitored during the experiment period.

4.2.10 Reliability

Reliability of the CTW was a secondary performance objective for this demonstration. Reliability includes CTW sensitivity to interruptions or cold. The CTW operated as designed with no recorded surface flow and no apparent freezing throughout the experiment period.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

The costs associated with discharging ADF wastes to a CTW versus a local POTW are presented in Table 10, Table 11, and Table 12.

5.2 COST ANALYSIS

POTW discharge was selected for cost comparison since it is considered the 'default' treatment methodology for small- to medium-sized airports and military air facilities. These costs were evaluated for an average annual ADF usage of approximately 10,000 gallons. The life-cycle basis was a 20-year project life at a 6% discount rate. Actual usage in 2002-2003 during the CTW Technical Demonstration Project was higher than average with more than 50,000 gallons.

Annualized cost estimates were $26,940 (± $8,082) for the existing 0.6 acre CTW, $71,394 (± $21,418) for a full-scale CTW at this site (2 acres), and $105,182 (± $31,555) for transfer of the glycol-containing stormwater to a POTW for treatment and disposal. A full-scale CTW at this site, in comparison to a POTW, would result in an annual cost savings of approximately $33,788 (± $10,136).

Capital costs for the demonstration CTW and full-scale CTW have been estimated at $286,000 and $795,800, respectively. The most significant costs for both systems are equipment purchase and installation. The full-scale system has an added $70,000 cost for pretreatment and storage. Pretreatment already existed at Westover so there is no cost associated with pretreatment and storage for the demonstration wetland.

5.3 COST COMPARISON

Assuming a facility has no existing treatment, the CTW technology is estimated to be about 32% less costly on an annual basis than the most likely alternative technology, which is discharge to the local POTW. Further, the treatment wetland would be much less costly compared to other available alternatives such as a fixed-film bioreactor. A bioreactor would have higher capital and operating costs.

Cost savings will be less if a facility has been discharging to the POTW and now chooses to install a full-scale CTW because capital costs have already been expended for the POTW discharge and not for the CTW. The savings in annual costs with a CTW is $76,000 per year. The payback period for this scenario is 10.5 years.

Table 10. Costs Associated with the Collection, Storage, and Controlled Release of ADF Stormwater to a POTW.

Project Capital Cost	**$315,000**	**Project Annual Costs**	**$79,700**	**Net Present Worth (20 Yr)**	**$1,206,219**	**Annual Worth (20 Yr)**	**$105,182**
Direct Environmental Activity Process Costs			**$77,700**	**Indirect Environmental**	**$2,000**	**Other Costs**	**$0**
Start Up		**Operation and Maintenance**	**$77,700**				
Activity (capital cost)	**$315,000**	**Activity (annual cost)**	**$77,700**	**Activity (annual cost)**	**$2,000**	**Activity (annual cost)**	**$0**
Equipment purchase [1]	$225,000	Equipment labor[3]	$8,000	Compliance audits	$0	Process overhead	$0
Design	$30,000	Labor to manage hazwaste	$0	Document maintenance	$0	Productivity/cycle time	$0
Mobilization	$5,000	Utilities	$0	Environmental management plans	$0	Working injury/heath costs	$0
Site preparation	$5,000	Treatment of by-products	$0	Reporting requirements	$0		
Permitting	$5,000	POTW disposal fees[2]	$67,200	Analytical testing requirements	$2,000		
Installation	$30,000	Raw materials	$0	Labor medial exam requirements	$0		
Construction management	$10,000	Process chemicals/nutrients	$0	Waste transportation	$0		
Demobilization	$5,000	Consumables and supplies	$0	OSHA/EHS training	$0		
		Equipment maintenance	$2,500				
TOTAL	$315,000	TOTAL	$77,700	TOTAL	$2,000	TOTAL	$0

[1] 20,000 gal storage tank ($20,000), vacuum truck ($200,000), metering pump ($5,000)
[2] Discharge to POTW: ($0.80/lb BOD5) * (10,000 gal ADF/yr)* (8.4 lb/gal) = $67,200/yr
[3] Assumes 2 operators for 40 hours per year at $100/hr
Net present and annual worth use a 6% interest factor or discount rate

Table 11. Costs of Enhanced Biological Attenuation of ADF Runoff Using Constructed Wetlands (Demonstration).

Project Capital Cost	**$286,000**	**Project Annual Costs**	**$3,000**	**Net Present Worth (20 Yr)**	**$308,940**	**Annual Worth (20 Yr Life)**	**$26,940**
Direct Environmental Activity Process Costs				**Indirect Environmental**	**$2,000**	**Other Costs**	**$0**
Start Up	**$326,000**	**Operation and Maintenance**	**$6,900***				
Activity (capital cost)	**$286,000**	**Activity (annual cost)**	**$1,000**	**Activity (annual cost)**	**$2,000**	**Activity (annual cost)**	**$0**
Equipment purchase [1]	$116,000	Labor to operate equipment	$500	Compliance audits	$0	Process overhead	$0
Design	$44,000	Labor to manage hazwaste	$0	Document maintenance	$0	Productivity/cycle time	$0
Mobilization[2]	$27,000	Utilities	$900*	Environmental management plans	$0	Working injury/heath costs	$0
Site preparation	$10,000	Management/treatment of by-products	$0	Reporting requirements	$0		
Permitting	$5,000	Hazwaste disposal fees	$0	Analytical testing requirements	$2,000		
Installation	$50,000	Raw materials	$0	Labor medical exam requirements	$0		
Construction management	$29,000	Consumables/supplies/chemicals	$0	Waste transportation	$0		
Monitoring equipment	$40,000*	Monitoring equipment	$5,000*	OSHA/EHS training	$0		
Demobilization	$5,000	Equipment maintenance	$500				
		Operator training	$0				
TOTAL	$326,000	TOTAL	$6,900	TOTAL	$2,000	TOTAL	$0

Net present and annual worth use a 6% interest factor or discount rate
* Items are due to demonstration data collection requirements and would not be incurred in a real-world installation
[1] Includes wetland media, liner, piping, and associated structures
[2] Includes bid package, site visit, contractor selection, and equipment mobilization costs

Table 12. Costs of Enhanced Biological Attenuation of ADF Runoff Using a Full-Scale Constructed Wetland.

Project Capital Cost	**$795,800**	**Project Annual Costs**	**$4,000**	**Net Present Worth (20 Yr)**	**$818,740**	**Annual Worth (20 Yr Life)**	**$71,394**
Direct Environmental Activity Process Costs				**Indirect Environmental**	**$2,000**	**Other Costs**	**$0**
Start Up		**Operation and Maintenance**					
Activity (capital cost)	**$795,800**	**Activity (annual cost)**	**$2,000**	**Activity (annual cost)**	**$2,000**	**Activity (annual cost)**	**$0**
Equipment purchase [1,2]	$382,800	Labor to operate equipment	$1,000	Compliance audits	$0	Process overhead	$0
Pretreatment[3]	$70,000	Equipment maintenance	$1,000	OSHA/EHS training	$0	Working injury/heath costs	$0
Design	$50,000	Labor to manage hazwaste	$0	Document maintenance	$0	Productivity/cycle time	$0
Mobilization[4]	$30,000	Utilities	$0	Environmental management plans	$0		
Site preparation[2]	$33,000	Management/treatment of by-products	$0	Reporting requirements	$0		
Permitting	$10,000	Hazwaste disposal fees	$0	Analytical testing requirements	$2,000		
Installation[2]	$165,000	Raw materials	$0	Labor medical exam requirements	$0		
Construction management	$50,000	Consumables/supplies/chemicals	$0	Waste transportation	$0		
Demobilization	$5,000						
TOTAL	$795,800	TOTAL	$2,000	TOTAL	$2,000	TOTAL	$0

Net present and annual worth use a 6% interest factor or discount rate
[1] Includes wetland media, liner, piping, and associated structures
[2] Costs extrapolated from 0.6 acre system to 2 acre system (3.3 x higher)
[3] Estimate for approximately 70,000 gal pretreatment lagoon or oil/water separator
[4] Includes bid package, site visit, contractor selection, and equipment mobilization costs

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The most significant costs for use of SSF CTWs for the treatment of ADFs are the capital costs. Of these costs, purchase and delivery of the bed media, bed liner, and excavation are the most significant. Besides the purchase and operation of the demonstration monitoring equipment, operation and maintenance costs for the system are low.

Site specific factors affect construction cost. At Westover ARB, additional costs for excavation were incurred because the system was built on a slope. The slope required additional excavation to achieve the proper bed bottom level. Costs for the bed liner were significant. In the case of an SSF CTW built on less permeable material (e.g., clay), the necessity for a liner could be avoided resulting in a cost savings.

Additional costs were incurred because of the procurement method used. A cost-plus type contract was used to acquire construction services. A firm-fixed price contract would have been more cost effective. The higher cost-plus contract costs are reflected in the design, mobilization and construction management costs in Section 5 of this report.

6.2 PERFORMANCE OBSERVATIONS

The constructed wetland system achieved most of the performance objectives as established by the acceptance criteria from the demonstration plan. Five of the 10 performance objectives were met during 1 year of operation (Table 9). The objectives for effluent toxicity and NPS removal were not assessed because higher-than-expected construction costs necessitated a reduction in project analytical costs. The permit for the outfall had changed from an individual to a multisector permit making the NPDES permit compliance performance objective inapplicable.

For the primary performance criterion of cost reduction, mission impacts, and land use, the wetland system achieved the performance criterion. The system is estimated to cost $3,000 to operate and maintain annually, which is only $500 more than expected. Even though the NPDES permit objective no longer applies, the wetland system achieved BOD slug load reductions. Peak BOD concentration was reduced more than 80% in one deicing event. Flow-weighted mass reductions reached only 21% removal efficiency. Nevertheless, Westover ARB plans to continue use and maintenance of the CTW because of the significant benefits documented by this demonstration project.

It is considered likely that the CTW system did not achieve a higher BOD mass removal because it was undersized for the actual ADF loads experienced during this performance period, there was insufficient pretreatment storage volume to reduce peak flow rates, and the system was immature. It is also considered possible that system performance suffered due to microbial toxicity from ADF additives because of the higher-than-normal ADF loading during this deicing season.

For these reasons, it is recommended that additional funds be made available to continue monitoring the CTW system during the next 3 to 5 years to develop a more complete picture of performance within the range of year-to-year climatic variations and due to system maturation.

6.3 SCALE-UP

The most significant scale-up issue will be finding available land situated away from runways. A full-scale system at Westover would be 2.0 to 2.5 acres in size and would require a 70,000 gallon pretreatment lagoon or oil/water separator. Available land for full-scale implementations could be farther from deicing operations and require pumping and additional piping.

6.4 OTHER SIGNIFICANT OBSERVATIONS

In order to get a CTW system functional in its first deicing season, all construction contracts should be in place by the previous fall (e.g., November). Construction should commence as early as possible during winter so planting can occur during the early part of the growing season (e.g., April).

Pretreatment and/or storage is necessary to reduce peak flows and loads. This 0.6-acre system relied on a 35,000 gallon oil/water separator for pretreatment and had minimal flow equalization. Front end storage reduces peak flow and lessens the "shock" load of ADFs to the CTW.

Another observation was that there was microbial excessive growth and some clogging of the inlet pipe holes where nutrient rich water enters the CTW. This problem caused preferential flow at the ends of the inlet distribution pipe and probably reduced treatment efficiency. This problem was fixed after the demonstration period was over by enlarging the pipe orifices.

6.5 LESSONS LEARNED

A larger SSF constructed treatment wetland would improve BOD mass load reduction efficiency. For better performance during peak or shock loading events, significant storage volume should be considered, using either a storage tank or pond. Influent pipe clogging resulted because of insufficient hole sizes in the pipe. These holes should be 1 to 1.5 inches in diameter for both the influent distribution and effluent collection pipes.

6.6 END-USER ISSUES

Concerns for the end-user of a properly designed, fully functioning system should be minor. In the case of infrequent storm events during portions or the year in arid climates, a source of supply water may be necessary to ensure plant health. An existing or new surface or groundwater supply could be used to keep the system from drying up.

While several military air facilities have expressed interest, there are currently no plans for implementation of this CTW technology at other Air Force or DoD installations. A thorough review of needs and opportunities should be conducted at all DoD installations that conduct

aircraft deicing operations to determine if this technology can provide a feasible alternative to existing or planned control measures.

Future implementations of the technology is expected. This cost and performance report provides access to information that will enable using CTW technology for treating ADF wastes and will surely benefit prospective users of the technology. A brochure of the technology demonstration is being disseminated at conferences and directly to interested individuals.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The information, lessons learned, and insight into the implementation process gained from this project can be used to determine if this technology can be cost effectively applied to a particular installation. The technology should be considered a best management practice, or BMP. It should not be considered a treatment plant or treatment system since ADF runoff is associated with precipitation (stormwater) events and is not an industrial waste stream.

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APPENDIX A

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