PUBLIC WORKS TECHNICAL BULLETIN PWTB 200-1-149
30 DECEMBER 2014

DEMONSTRATION OF A MODULAR WETLAND TREATMENT SYSTEM FOR STORMWATER RUNOFF

Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, Washington, DC. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new DA policy.

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street, NW
Washington, DC 20314-1000

CECW-CE

Public Works Technical Bulletin 30 December 2014

No. PWTB 200-1-149

FACILITIES ENGINEERING
ENVIRONMENTAL

DEMONSTRATION OF A MODULAR WETLAND TREATMENT SYSTEM FOR STORMWATER RUNOFF

1. Purpose.

a. The purpose of this Public Works Technical Bulletin (PWTB) is to document the testing and evaluation of a commercially available Low Impact Development (LID) technology, "Modular Wetlands™" (MWS), to slow down and treat stormwater runoff, thus preventing contaminant migration to surface water. This report describes the performance of the technology over 1 year and evaluates the effectiveness of the technology to provide a treatment train for a high-use paved area with heavy pollutant loads. It also includes results of the treatment system for in situ treatment of Petroleum, Oils, and Lubricants (POL), heavy metals, and suspended solids from polluted stormwater runoff, along with maintenance requirements for the system.

b. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army Continental United States (CONUS) and Outside Continental United States (OCONUS) installations that are actively pursuing options for on-site stormwater management.

3. References

a. Army Regulation (AR) 200-1, “Environmental Protection and Enhancement,” 28 August 2007, http://www.apd.army.mil/pdffiles/r200_1.pdf

b. Department of the Army (DA), “Sustainable Design and Development Policy Update,” 16 December 2013, http://www.asaie.army.mil/Public/IE/doc/ASA%28IEE%29-SDD-policy-update-%2816-Dec-2013%29.pdf

c. Clean Water Act of 1972 (CWA) and Amendments of 1987: National Pollution Discharge Elimination System (NPDES) Phase II Stormwater Management Program.

d. Energy Independence and Security Act of 2007 (EISA), Section 438, Stormwater Runoff Requirements for Federal Development Projects, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf

e. Executive Order 13148, Greening the Government through Leadership in Environmental Management, 21 April 2000, http://www.epa.gov/epp/pubs/eo13148.pdf

f. Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management, 24 January 2007, http://www.wbdg.org/ccb/FED/FMEO/eo13423.pdf

4. Discussion

a. AR 200-1 contains policy for environmental protection and enhancement, pollution prevention, conservation of natural resources, sustainable practices, and compliance with environmental laws.

b. The Federal government is required to meet regulatory requirements including the CWA. Executive Order (EO) 13423 (2007) stipulates that all Federal land-holding agencies are to be environmental leaders, while EO 13514 (2009) requires that management of water quality and stormwater management issues on Federal lands are addressed. In part, the intent of EO 13514 and EO 13423 is to require compliance with Phases I and II of the NPDES of the CWA, i.e., to both reduce stormwater runoff and pollutants of concern and while increasing on-site infiltration.

c. The techniques of LID include innovative site design strategies and practices that work with the biological and physical systems of a site to achieve water and conservation goals. Small scale, close-to-the-source controls provide the means to meet the environmental standards for stormwater management under the auspices of NPDES, and Phase I and II of the CWA. This demonstration installed, operated, and evaluated a LID technology for stormwater and pollutant management, the MWS system, which has the potential to enable the Army to decrease stormwater runoff while treating and managing stormwater runoff from paved areas such as parking lots and staging pads in situ.

d. Appendix A provides background information on an off-the-shelf technology called a “Modular Wetland System,” or “MWS”, which is used for stormwater runoff treatment and retention.

e. Appendix B describes the MWS technology demonstration, the site location, system installation, results of monitoring, maintenance requirements, and lessons learned.

5. Points of Contact.

a. Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@us.army.mil. The POC at Engineering Research Development Center, Construction Engineering Research Laboratory (ERDC-CERL) is Ms. Heidi R. Howard, CEERD-CN-N.

b. Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
ATTN: U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
ATTN: CEERD-CN-N, Heidi R. Howard
PO Box 9005
Champaign, IL 61826-9005
Tel. (217) 373-5865
FAX: (217) 373-7266
e-mail: heidi.r.howard@usace.army.mil

FOR THE COMMANDER:

JAMES C. DALTON, P.E., SES
Chief, Engineering & Construction
U.S. Army Corps of Engineers

APPENDIX A

MODULAR WETLAND SYSTEMS

Constructed wetlands can be a low-tech, low-cost, effective method to reduce the amount of pollutants in wastewater and stormwater discharges. Constructed wetlands are designed to mimic nature by increasing retention time thru a series of biological, chemical, and physical methods that remove and reduce pollutants of concern. When used together, these methods constitute a “treatment train” that optimizes efficiency and space requirements. Over the years, extensive research has demonstrated the use of constructed wetlands as a polishing treatment system for wastewater and stormwater (Grego et.al 2003). An additional advantage of a constructed wetland is that it can potentially provide an efficient mechanism for on-site treatment of stormwater runoff within a limited space.

To test this application, in partnership with Assistant Chief of Staff for Installation Management, Installation Technology Transition Program (ACSIM-ITTP) and the Army Corps of Engineers for funding and guidance, ERDC-CERL chose to evaluate the “Modular Wetlands™” (MWS) precast concrete structure. The MWS system performs stormwater treatment using a screening process in combination with hydrodynamic separation, filtration, vegetative remediation, and microbial remediation. Applying this treatment train approach allows for the settling of suspended solids, biological remediation of POLs, uptake and utilization of high nutrient loads, and phytoremediation and phytoaccumulation of heavy metals and other pollutants.

The MWS is a compact multi-stage biofiltration system. It is a horizontal, linear system that flushes stormwater through a screen or inlet basket to separate large particles, debris, and trash from the water to be processed. The stormwater then gathers in a vault or settling chamber, where larger sized particulate matter is allowed to settle. The vault contains two “pre-filter cartridges” (filter boxes) that direct the flow laterally through microbial filters. After the stormwater goes through the first series of filters, it passes through the wetland chamber, which further treats the water using physical (expanded shale), chemical, and biological treatment. The biological treatment uses native species that can phytoremediate and phytoaccumulate both POLs and heavy metals. The stormwater then passes from the wetland chamber through either a high-flow bypass or a drain-down filter. The MWSs at Fort Hood, TX currently use the high-flow bypass to accommodate the intense rain flow events at that site.

APPENDIX B

STUDY METHODOLOGY, RESULTS, CONCLUSIONS, RECOMMENDATIONS

Approach

ERDC-CERL conducted an initial elevation survey of several motor pools and the Recycling Center at Fort Hood, TX in November 2010(Figure B-1). The Fort Hood Recycling Center was selected as the demonstration site at a coordination meeting at Fort Hood in March 2011. The Recycling Center was chosen due to the unique relationship between recycling centers and stormwater runoff quality. Pollutants common to recycling centers include sugars, detergents, petroleum, oils, lubricants, and metals associated with aluminum cans, metal containers, construction debris, and emissions from forklifts and other vehicles. This site had exceeded permit benchmark parameters established in the Fort Hood Municipal Separate Storm Sewer System (MS4) permit for several constituents, including: Chemical Oxygen Demand (COD), TSS (Total Suspended Solids), Aluminum, and Copper (Fort Hood 2011). It was anticipated that the level of contaminants and debris from the recycling sorting and staging process would represent a “worst-case” scenario that would test the limits of the MWS for both maintenance and treatment.

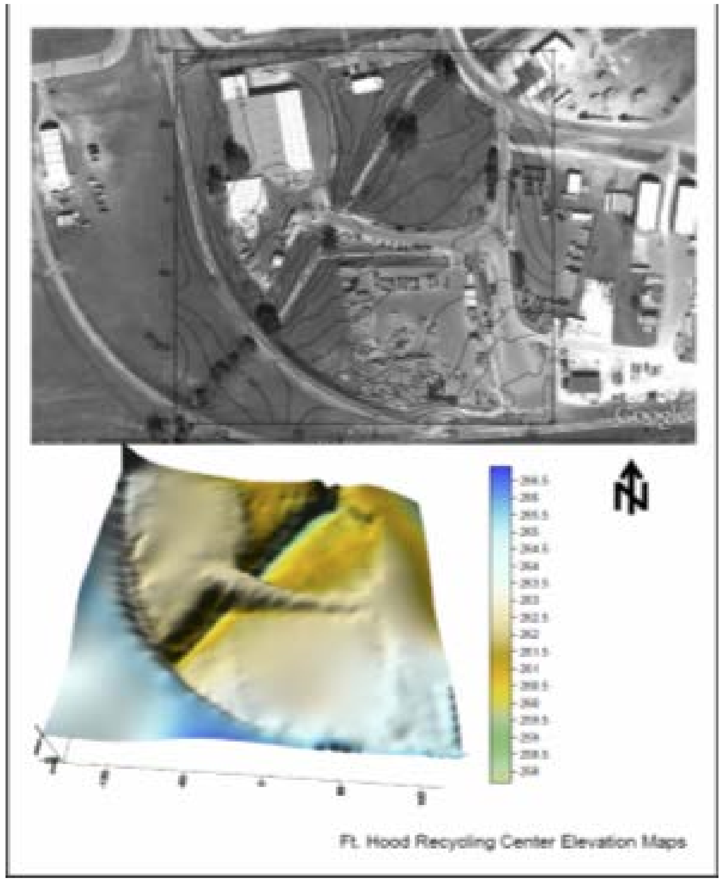


Figure B-1. Elevation survey results of the Recycling Center, November 2010.

The Recycling Center (Figure B-2) is comprised of several large metal buildings and a large amount of paved area that is used to sort, separate and store materials. The area is 100% impervious, with stormwater runoff and drainage of the site flowing into two primary areas, either towards the south east or the north east. Additionally, the site is located less than 25 meters from an open stormwater conveyance system. As part of Phase I of the NPDES, all industrial facilities are required to treat stormwater discharge, making the Recycling Center an optimal site to demonstrate this technology.

Figure B-2. Fort Hood Recycling Center plastic and aluminum sorting cells.

Stormwater Design Requirements

The site survey, elevations, roof runoff loads, and MS4 permit requirements were used to develop designs for the capture and treatment of stormwater from the Recycle Center (Figures B-3 and B-4). Treatment flow rates were set for 0.27 CFS, with a peak treatment volume of 4000 cu ft and an assumed 48-hour drainage down time. An open, flat grate MWS system was chosen due to the high level of debris, to help decrease maintenance and if clogging occurred, and also to allow for the overflow to be uninterrupted due to the high intensity short duration storm events common to Fort Hood.

The study site required three, 22-ft MWSs to handle the overland flow of the paved and roofed area calculated on historic rainfall data to determine the 90th percentile rainfall intensity. Based on the site's historical rainfall and rainfall intensity, it was determined that the MWS-L-4-21, which treats up to 0.27 CFS or 120 GPM, would be sufficient. Each of the MWSs was 22 X 5 X 4.7 ft in size, and had a treatment flow rate of 0.27 CFS and a storage capacity of 23.5 CF (Figure B-4). BioMediaGREEN filters were selected to treat the POL and COD, while an expanded shale growing media was used within the plant vault to allow for rapid uptake and evaporation.

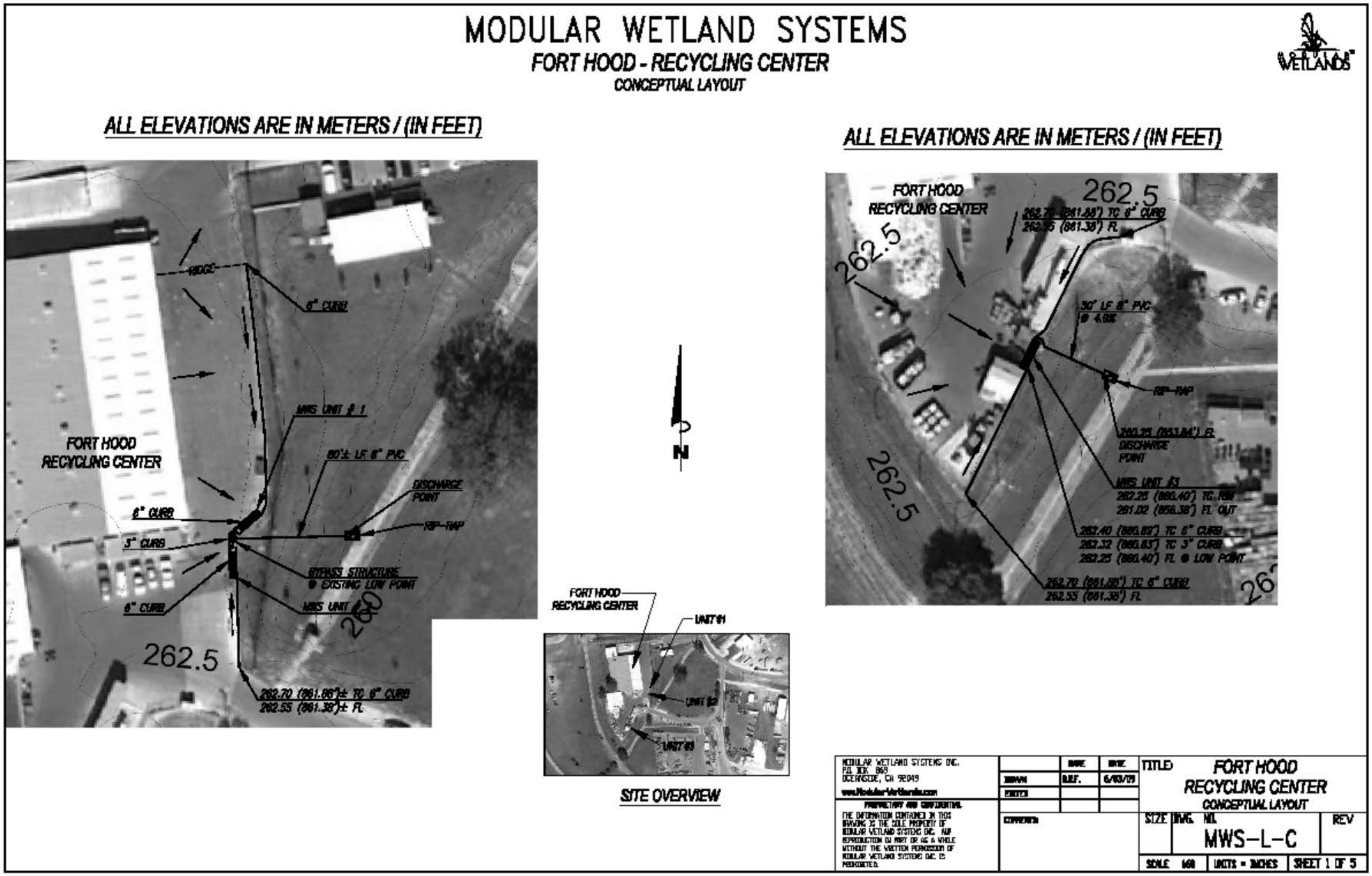


Figure B-3. Modular Wetlands System ™ Site Design for Recycle Center.

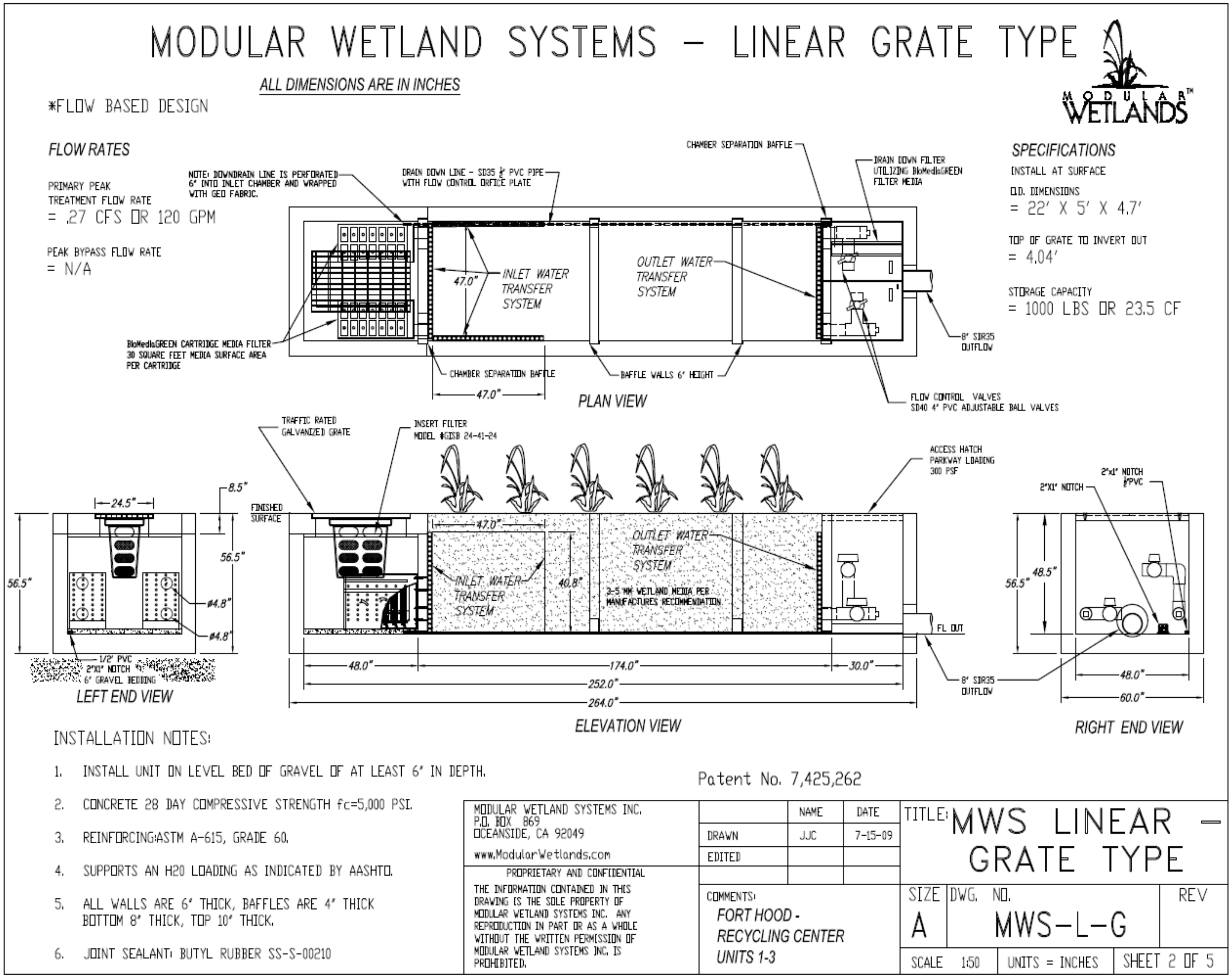


Figure B-4. Modular Wetlands System ™ Unit Design.

Installation

The three MWSs were delivered to the installation site on a flatbed trailer (Figure B-5) and installed during the second and third week of July 2011. MWS come as precast watertight concrete structures with pre-assembled internal filtration and drainage structures. Installation of the MWS required a significant amount of coordination, but proceeded without significant problems. (Installation of the MWS-Linear system must conform to American Society for Testing and Materials (ASTM) Specification C891, *Standard Practice for Installation of Underground Precast Utility Structures*.)

Six hundred fifty feet of 6-in. curbs were installed along the east perimeter of the paved area to direct stormwater flow from Recycling Center into the three MWSs. Curbing allowed for the runoff from the paved lot to be diverted to each of the MWSs for treatment.

Each MWS structure required a 26 ft X 9 ft X 5 ft, 2 in., pre-excavated, leveled trench (Figure B-6) with a base compacted to 95% of maximum density (Figure B-7). Establishing level trench construction is critical to the MWS function to ensure that the joints of the precast structure remain water tight. As such, a 6-in. gravel bed for the vault was established for the MWS to sit on. Once the trenches were complete, the systems were hoisted into place by crane (Figure B-8).

Figure B-5. MWS delivery.

Figure B-6. Trench excavation.

Figure B-7. Trench compaction.

Figure B-8. MWS in place.

Backfill material must be clear of debris and should be added in lifts of no more than 6-in. at a time to ensure proper compaction where soil contacts the structure (Richardson 2013). An asphalt backfill was placed around the face of the MWSs and guard posts were installed to protect the double system from potential vehicle damage (Figure B-9). For erosion control, scour pads were installed at the effluent outlets and riprap at overflow areas (Figure B-10), and disturbed areas were hydroseeded and mulched.

Plants and Irrigation Methodology

Native grasses were chosen for the MWS. Little Blue Stem (*Schizachyrium scoparium*) and Big Muhly Grass (*Muhlenbergia lindheimeri*) were selected for their drought tolerance and capability for remediation and phytoaccumulation. Supplemental irrigation requirements for the MWS were considered to enable the system to withstand the record drought currently being experienced in Texas.

Figure B-9. Guard posts installed to protect against vehicle damage.

Figure B-10. Scour pads and riprap at overflow areas

Personnel from ERDC-CERL and Fort Hood discussed potential methods of water capture that would reduce the use of potable water for irrigation, and decided to use stormwater runoff from the roof of a small storage. In September 2011, ERDC-CERL installed a gravity fed rainwater collection system that feeds a drip irrigation system for the single MWS (Figure B-11) and a hose bib and drip irrigation system for the double MWS (Figure B-12). Nevertheless, 70% of the vegetation was replaced in March of 2012 due to the extreme temperatures and drought conditions of 2011.

Figure B-11. Drip irrigation setup for single MWS.

Figure B-12. Drip irrigation setup for double MWS.

Modular Wetland System Costs

Table B-1 itemizes the costs of the modular wetland system.

Table B-1. Modular wetland system costs.

Item	Unit	Qty	Cost	Total
Modular wetlands	Each	3	$22,000	$66,000
Native plants	Each	54	$15	$810
Delivery of vaults and media	Each	1	$4,190	$4,190
Installation	Each	1	$54,400	$54,400
SWPPP Plan	Each	1	$2,500	$2,500
SWPPP Implementation	Each	1	$2,500	$2,500
Total Cost				**$130,400**

Monitoring Methodology

Teledyne Isco samplers were installed to automatically sample and collect composite samples of the initial influent, and post-treatment effluent from the MWS systems. Three influent and two effluent automatic samplers were installed the first week of August 2011 (Figure B-13). Four ISCO Avalanche refrigerated samplers were installed, one each on the influent and effluent of the single MWS, and one each on the south influent and the effluent of the double MWS system. A single, non-refrigerated ISCO 6700 was installed on the north influent of the double MWS system.

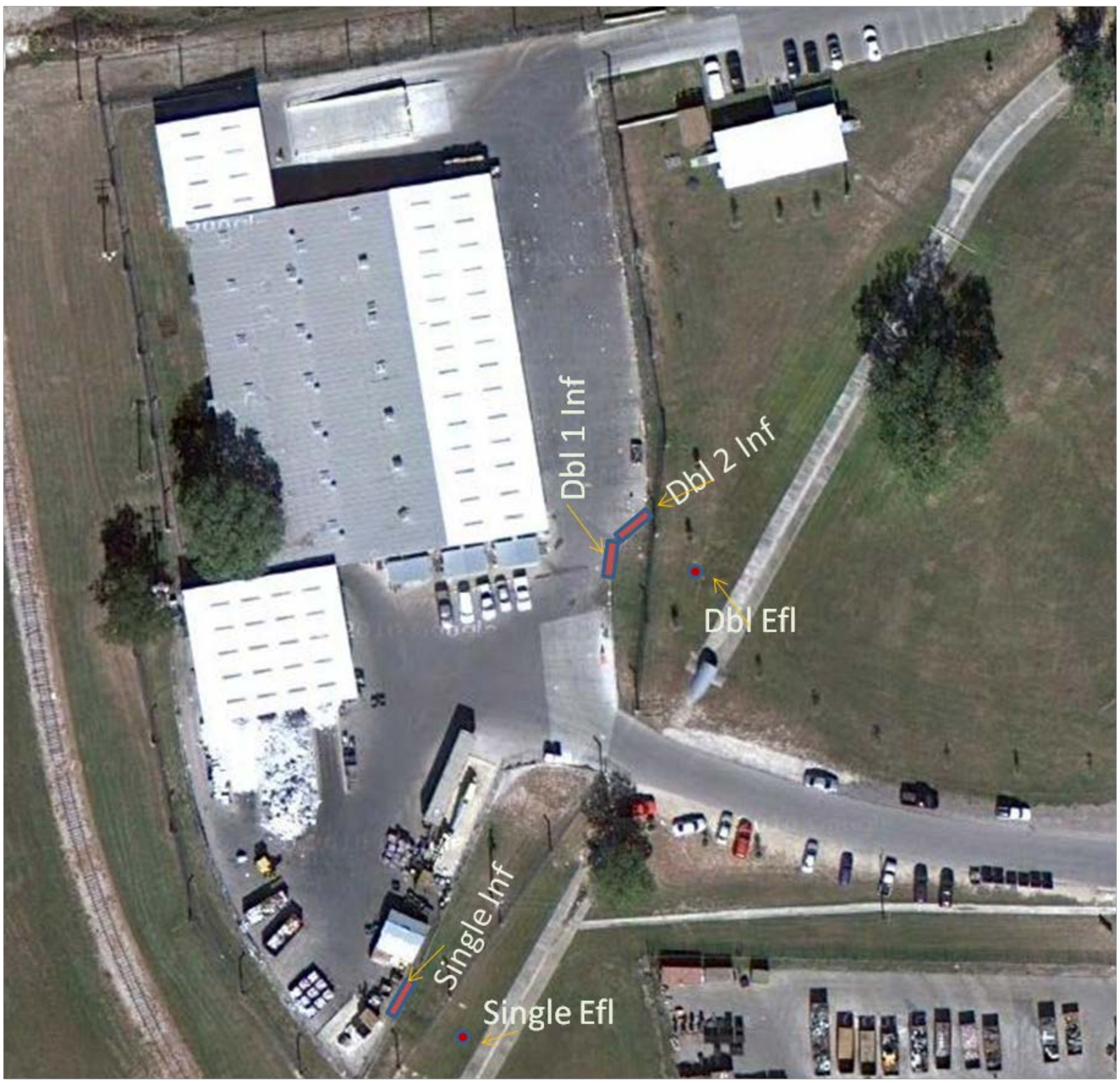


Figure B-13. Locations for influent and effluent ISCO samplers.

The influent samplers were programmed to collect a composite sample over a 30-minute time period once the level actuator was triggered. Level actuators were secured within the vault chamber and attached to the filter box on the south east side of the box. For the inlets, each sampler hose and actuator were set at approximately 24 in. above the chamber floor.

The effluent samplers were programmed to start collecting 15 minutes after the level actuators were trigged, providing a “flush” of any potential residual outflow. The level actuator and sampler hose for the effluent were set into the outlet tile with a handmade “box weir,” allowing for “pooling” of the sample. Both influent and effluent samplers were programmed to collect 1 liter every 15 minutes for a total composite sample of at least 5 liters. This allowed for a more uniform and representative sample over time versus a “first flush,” which would not have represented normal conditions.

All samples were kept at 4 °C for up to 72 hours before laboratory analysis.

Results

Army installations are becoming increasingly conscientious of the potential for installation activities to contribute to increasing levels of pollutants in U.S. Waters. The Fort Hood MS4 permit has set limits for pollutants of concern, and the installation monitors its sites annually and/or semi-annually for such typical pollutants as heavy metals, TSS, Total Petroleum Hydrocarbon (TPH), Biological Oxygen Demand (BOD), COD, etc. Monitoring water quality samples was an integral part of this technology demonstration to help the installation reduce pollutants of concern.

A series of ISCO samplers were installed to collect samples where stormwater “influent” entered the settling chamber, and after the processed “effluent” discharged from the high-flow bypass. Parameters for sampling were established by water levels within the settling chamber. Analysis of these samples followed standard methods of storage, preservation, and analysis. Standard methods of analysis were used to allow for meaningful comparison of the MWS treatment with the manufacture claims.

A total of 14 rain fall events occurred during the monitoring time period from August 2011 to June 2012. The first rain event occurred on 29 September 2011, and the last on 22 June 2012. Due to the lack of rainfall for 8 months before September 2011, an excessive accumulation of sediments and associated contaminants were “stored” within the asphalt pavement of the Recycling Center. The high levels of sediment were “washed-out” or “flushed” from the pavement within the first three rainfall events (Figure B-14).

During the fourth and fifth rainfall events, a gravel pad was built for a new building directly across from the double MWS, which resulted in excessively high levels of fine clay sediments and heavy metals. Additionally, between the “flush” and construction activities, the biofilters pre-maturely clogged. The clogging of the MWS system led to a winter shut down in early December 2011 to prevent potential ISCO equipment failure and to replace the biofilters.

In March 2012, after the settling chambers were cleaned, biofilters replaced, and the native vegetation lost due to the prolonged drought restored, the MWSs and ISCO samplers were brought back on-line.

To ensure valid laboratory results, duplicate quality control/quality assurance (QC/QA) testing was performed. ERDC-CERL sent split samples from several rainfall events to an alternative NELAP-qualified laboratory for analysis. Results were equivalent and within range of the contracted laboratory. Additionally, due to low TPH results, a series of spiked water samples were sent to the contracted laboratory and another NELAP-qualified laboratory for analysis using SW8015 to confirm the low TPH values.

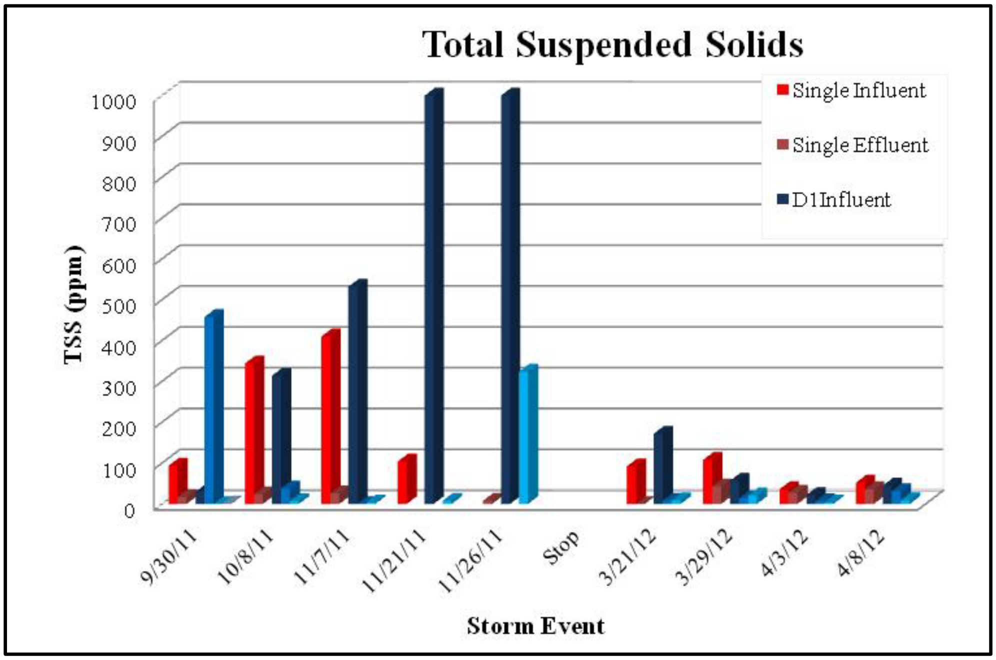


Figure B-14. Levels of suspended solids during storm events.

Overall analysis results were equivalent to or better than manufacture claims, indicating that the use of a MWS is an effective method for treatment of stormwater runoff. The following sections discuss results by pollutant of concern in detail.

Total Suspended Solids (TSS)

In general, TSS is related to activities that produce quantities of detached soil particles and dust, e.g., transportation of heavy equipment, construction, centralized vehicle wash systems, and motor pool activities, all of which are common on Army installations.

At this site, TSS levels were above allowable limits for the MS4 permit, under which the Recycling Center operates. Due to the high level of heavy vehicle traffic, debris and dust generated from paper shredding, cardboard compression, and “dirt” attached to materials dropped off to the Recycling Center, it is difficult to keep TSS within limits. General results showed an average efficiency removal rate of 71.6% for the single MWS and 88.7% for the double MWS. Removal rates ranged from 20% to above 99% (Figure B-15). Effluent results were below allowable limits for the MS4 permit for the site, and significant differences between the influent and effluent samples were observed (Figure B-16).

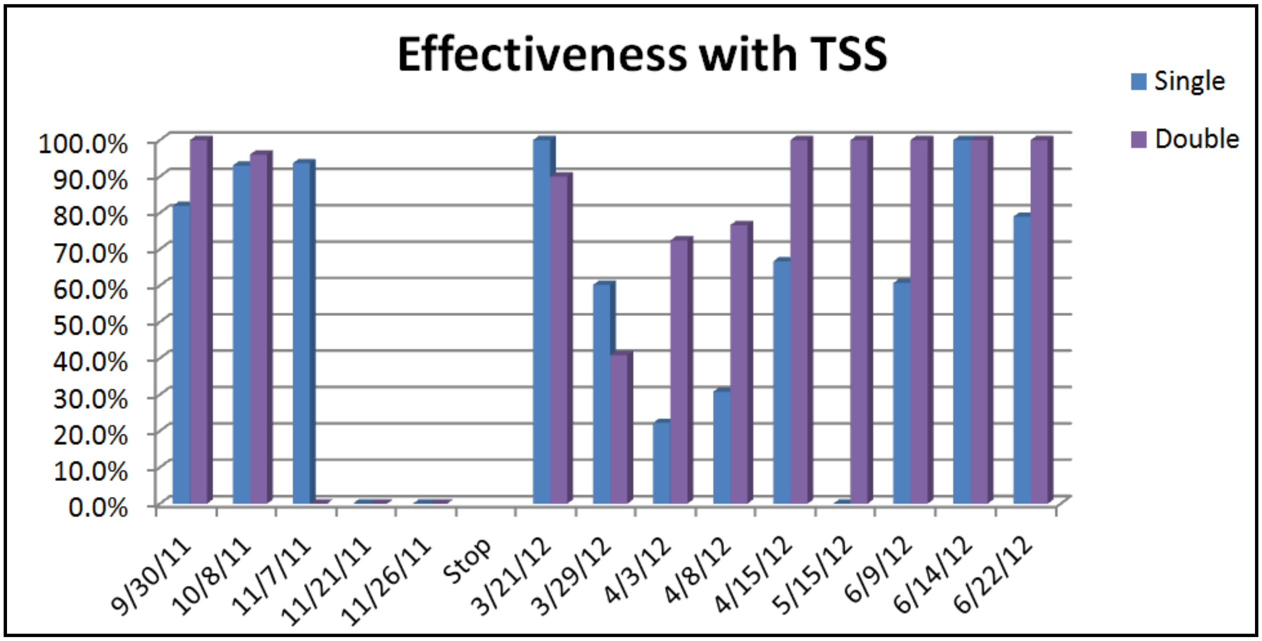


Figure B-15. Percent Effectiveness of MWS for removal of TSS for all sampling events.

a.

b.

c.

Figure B-16. Collected “dirty” pre-treatment influent (a, b) and “clear” post-treatment effluent (c) samples.

Chemical Oxygen Demand (COD)

COD is a method of analysis that measures the amount of organic matter (pollutants) in an aqueous solution (here, the water sample) that is susceptible to oxidation by a strong chemical oxidant. High levels of carbon sources create an organic-rich food source that depletes oxygen levels in natural water systems. In short, COD levels describe the “environmental heath” of water.

COD levels for the Recycling Center were above desired levels due in part to a combination of runoff resulting from soda, juice, milk, alcoholic beverages, remnant detergents, and other sugars and fats found in plastic and glass containers. These pollutants enter the stormwater runoff stream leading to high levels of organics, increasing COD and BOD levels.

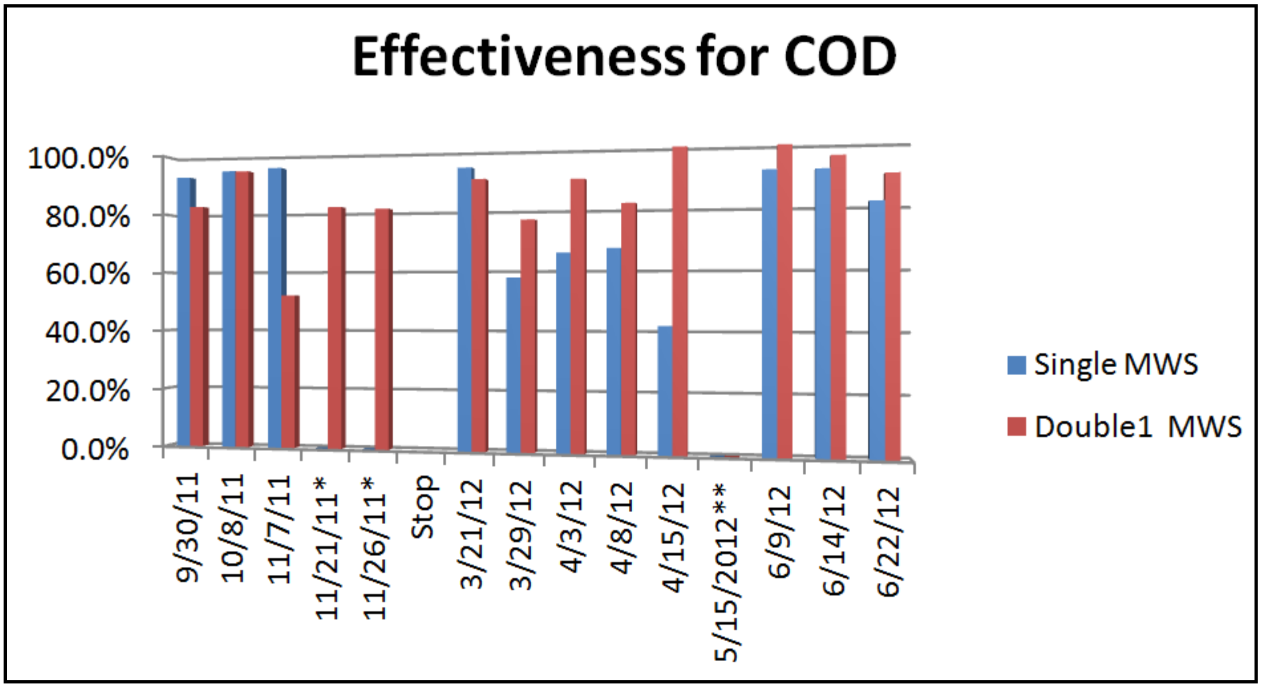
For this demonstration, BOD was not performed due to storage and preservation timeline requirements. COD was performed on the two effluents and the refrigerated south double MWS influent. COD results from the double MWS, which are assumed to reflect the general trend for the contributing stormwater runoff, showed a COD removal efficiency rate of 92.4%.

The single MWS had a significantly higher COD load that the double MWS. The single MWS was located next to the separation center for plastics and aluminum cans (Figure B-3); stormwater runoff from this source is a primary source of sugars and fatty acids. General results from the single MWS showed an average efficiency removal rate of 78.1%.

For both MWSs, removal rates ranged from 20% to above 99% (Figure B-17).

Total Petroleum Hydrocarbon (TPH)

TPH was detected on all sampling events. Results fell right at or below the confidence interval for the detection limits. Levels of TPH greater than 5 ppm only occurred on three sampling events: two samples from the single MWS (occurring on 08 October 2011 and 15 April 2012), and one sample from the north influent of the double MWS (on 22 June 2012), which had TPH levels high enough to detect.



Note: * indicates that samples for these storm events were not analyzed due to lack of either an influent or effluent sample; ** indicates that for this sampling event levels of COD were below detection.

Figure B-17. Percent Effectiveness of MWS for treatment of COD.

Statistically, the levels detected in all but the three samples were below 5ppm making the removal efficiency extremely high, from 98 to 100%. Due to the low levels of TPH found, samples were re-measured and spiked control samples were sent off to another laboratory as well as the contracted laboratory to determine potential errors. Results for both laboratories were equivalent and within range of one another.

Aluminum

One might expect aluminum levels to be high in an area where aluminum cans are stored, crushed, and packaged for recycling. Additionally, soils tend to have high levels of aluminum naturally, and heavy equipment will have aluminum in parts, fuel, and lubricants. The naturally alkaline pH of Fort Hood soils and associated water allows for the aluminum to be soluble, resulting in higher than normal levels for the Recycling Center. However, Results for aluminum were unusual.

In general, aluminum levels were low, but several events showed higher levels in the effluent samples than then influent samples. These samples were re-run for QA/QC. Since aluminum was the only pollutant to have this unusual trend, it was assumed that potential contamination of the sample occurred from overland flow entering into the sampling weir. Additionally, the general removal effectiveness of aluminum improved over time, indicating that plant uptake was occurring. General results showed an average efficiency removal rate of 85.6% for the single MWS and 84.1% for the double MWS (Figure B-18).

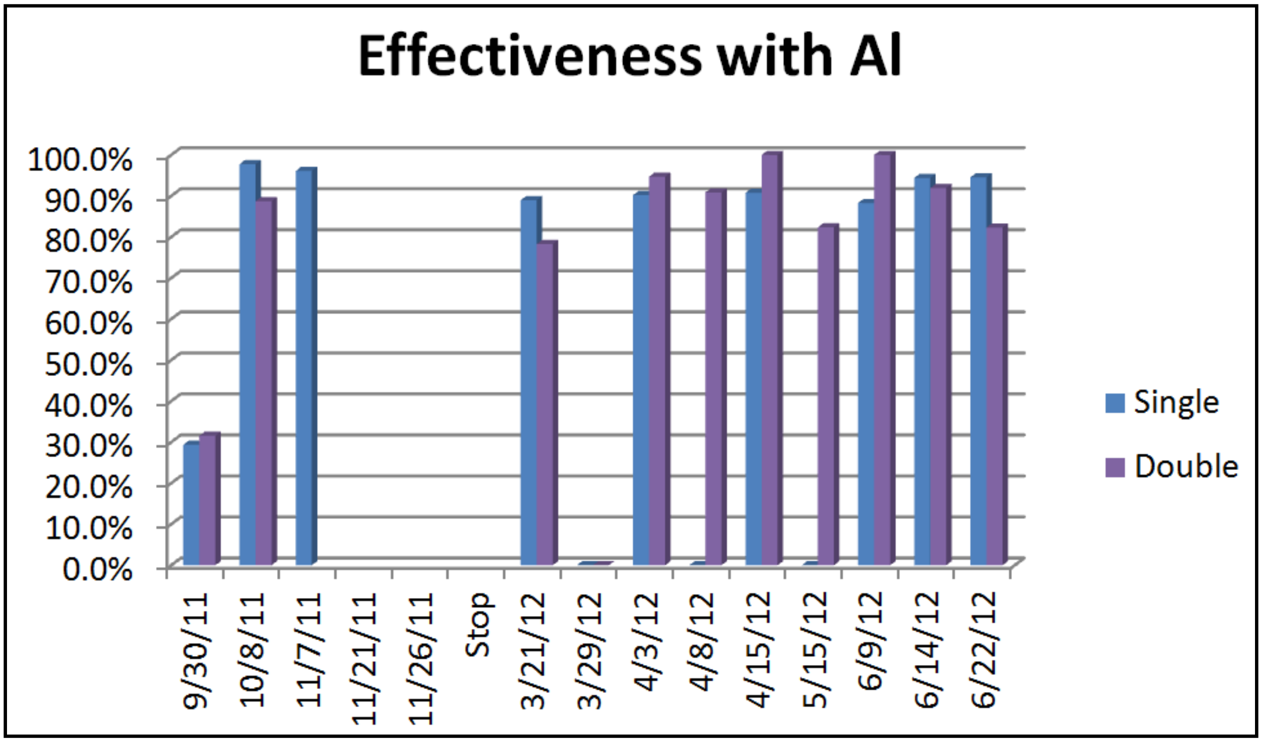


Figure B-18. Percent Effectiveness of MWS for removal of Aluminum for all sampling events.

Maintenance and Operation

The MWS is designed as a multi-stage, self-contained treatment train for stormwater treatment. Stages include screening, separation, cartridge media filtration, and biofiltration. The filter removes gross solids, including litter, and sediment greater than 200 microns. Each stage is designed to protect subsequent stages from clogging. Nevertheless, the study site, with its excessive paper and plastic debris, detergents, and other pollutants, required careful system maintenance. Even though the routine at the Fort Hood Recycle Center included nightly pickup of all recyclables (paper shreds, plastic bottles, etc.), maintaining clear grates was problematic (Figure B-19). Additionally, several oil spills occurred and absorbants were used, which complicated assessment of the technologies maintenance requirements.

Figure B-19. Accumulation of recyclables on MWS grate.

MWS maintenance must be routinely performed (Table B-2). Although the sediment capacity for the drop or grated inlet configuration was 4 cu ft, service was required to clear the trash, sediment, and POL loads well before the 4 cu ft capacity was reached. At the study site, the sediment chamber and catch basin filters were cleared of coarse sediment, trash, and other floatables monthly (Figure B-20a-d). A high pressure washer was used to clean the grates, basket, and catchment basin filter (Figure B-20e,f). The filter cleaning procedure is easily done by hand or with a small industrial vacuum device (Figure B-20g,h).

Table B-2. Routine MWS maintenance schedule.

Task / Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Clean Catch Basin Filter	X	X	X	X	X	X	X	X	X	X	X	X
Boom Filter Replacement			X								X	
Dewater and Vacuum Separation Chamber			X				X				X	
Replace Biomedia Filters			X				X				X	
Drain-down Filter Media Block	X						X					
Trim Wetland Vegetation			X									
Remove and replace wetland plants and media (10-year interval)												


a.


b.


c.


d.


e.


f.


g.


h.

Figure B-20. Cleaning grates, basket, and catchment basin filter with a high pressure washer.

The pre-treatment chamber and pre-filter cartridge were serviced on a 3-month rotation. The pre-treatment chamber's settling area, which collects trash, debris, and sediments, is located directly under the grated inlet. For most MWS model sizes, this chamber has a capacity of approximately 21 cu ft. The chamber targets TSS and particulate metals and nutrients. The settling area was vacuumed and washed down using a vacuum truck (Figure B-21). In general, there was only a small accumulation of sediments in the settling area (Figure B-22), indicating that the catch basin pre-filter cartridges were performing well.

The filter media life depends on local sediment loading conditions. At the study site, the BioMediaGREEN™ filters or pre-filter cartridges, which provide initial filtration of the horizontal flow, were replaced on the same 3-month service schedule. Filter media can easily be replaced with hand tools and spent filters disposed of into the landfill. For Fort Hood sites, due to high levels of metals and POLs, filters were disposed of as if hazardous materials. The BioMediaGREEN media is held within the media cartridge pre-filters that are housed in the pre-treatment chamber (Figure B-23), where it was also noted, during service, that a layer of oil and algae growth occurred (Figure B-24).

Figure B-21. Settling area being vacuumed.

Figure B-22. Typical accumulation in settling area.

Figure B-23. Pre-treatment chamber.

Figure B-24. Oil and algae growth in pre-treatment area.

The native vegetation was trimmed yearly, in March (Figure B-25). Annual inspection is required to evaluate plant health and trim excess vegetation. Native grasses known to be both phytoaccumulators and phytoremediators were transplanted in the wetland chamber to enhance pollutant removal. The life expectancy of the vegetation is approximately 10 years, after which grasses and filter media should be removed and replaced.

Figure B-25. Native vegetation planted on MWS system.

Costs for the maintenance of the MWS were estimated per unit. The costs and labor hours were tracked for general maintenance and cleanout events. The estimates reflect the conditions at the Recycling Center and are anticipated to be higher than what one would expect at a more traditional site such as a motor pool or parking lot. Estimates were based on a WG-8 labor rate. Note that neither the cost of the vacuum truck, nor the costs of water and gas resources are reflected in these estimates. General maintenance guidelines (Big Clean Environmental Services, Inc. 2013) can be found at: http://www.modularwetlands.com/wp-content/uploads/2014/07/Maintenance-Manual-Modular-Wetland-System-LINEAR.pdf

Table B-3. Yearly maintenance cost per unit.

Item	Unit	Qty	Cost*	Total
Monthly Basket Cleanout	Hour	12	$23.33	$279.96
Vault Cleanout	Hour	4	$46.66	$186.64
Hydrocarbon Booms	Each	1	$37.98	$37.98
BioMediaGREEN™ Filter Replacement	Each	4	$158.88	$635.52
Native Plant Cutback	Hour	1	$23.33	$23.33
Total Cost				**$1,163.43**
***Labor based on WG-8; Cost per MWS**				

Lessons learned

This demonstration and evaluation of off-the-shelf MWS technology showed that the MWS was successful at reducing pollutants of concern from a difficult-to-manage area. Treatment efficacy for this technology ranged from a low of 20% to a high of 99% reduction rates. The chosen location stress-tested this system beyond normal conditions and provided many lessons learned:

1. Hydrological assessment is necessary to determine stormwater runoff peak volumes for proper sizing of the MWS.
2. Site selection for MWS installation proved critical throughout the testing process.
3. Before installing the wetland system, determining potential issues with debris, trash, and other contaminants will be critical to obtain optimal results.
4. Dense vegetation coverage or placement of large stones may be required to hinder vermin such as raccoons and feral cats from using the wetland chamber as a litter box.
5. Maintenance frequency of the MWS is highly dependent on levels of POL and TSS. Subsequently, the maintenance costs can be high.
6. Finally, it is necessary to establish responsibility of MWS maintenance throughout all stages of construction and use, before, during, and after implementation.

Acknowledgements

Funding for this evaluation was provided by the Assistant Chief of Staff for Installation Management, Installation Technology Transition Program (ACSIM-ITTP) and the Army Corps of Engineers. On behalf of the DA and the U.S. Army Corps of Engineers, thanks are offered to a few integral persons, without whom this study would not have taken place: Ms. Jennifer Rawlings and Mr. Randy Doyle, Fort Hood Department of Public Works Environmental Divisions, and Mr. Rufus Walker and Mr. Hector Nunez, Fort Hood Recycling Centers.

APPENDIX C
REFERENCES

Big Clean Environmental Services, Inc. 2013. Maintenance guidelines for Modular Wetland System – linear. Oceanside, CA: Big Clean Environmental Services, Inc., http://www.modularwetlands.com/wp-content/uploads/2014/07/Maintenance-Manual-Modular-Wetland-System-LINEAR.pdf

Gerber, M. A. (1994). In situ remediation integrated program evaluation and assessment of containment technology. Washington, DC: U.S. Dept. of Energy, Office of Environmental Management, Office of Technology Development.

Fort Hood, TX. October 2011. *Fort Hood Integrated Natural Resource Management Plan*, http://www.hood.army.mil/dpw/Environmental/Files/2011%20INRMP.pdf.

Richardson, Alisa (2013). Modular Wetland System linear stormwater treatment system overview. [Providence, RI]: Rhode Island Department of Environmental Management.

APPENDIX D

ACRONYMS AND ABBREVIATIONS

Term	**Definition**
AR	Army Regulation
ASTM	American Society for Testing and Materials
CECW	Directorate of Civil Works, US Army Corps of Engineers
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CEMP	Directorate of Military Programs, US Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
COD	Chemical Oxygen Demand
CONUS	Continental United States
CWA	Clean Water Act
DA	Department of the Army
EISA	US Energy Independence and Security Act of 2007
EO	Executive Order
ERDC	Engineer Research and Development Center
HQUSACE	Headquarters, US Army Corps of Engineers
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
MWS	Modular Wetlands™
NPDES	National Pollutant Discharge Elimination System
NW	Northwest
OCONUS	Outside Continental United States
POC	Point of Contact
POL	Petroleum, Oil, and Lubricants
PWTB	Public Works Technical Bulletin
TSS	Total Suspended Solids