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COST AND PERFORMANCE REPORT LOW IMPACT TECHNOLOGIES TO REDUCE POLLUTION FROM STORM WATER RUNOFF SI-200405

by
Gary Anguiano
Mark Foreman

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14. ABSTRACT
This project was to validate the performance of a dual media filtration system that removes metals, organic compounds, and sediment found in storm water runoff from DoD industrial sites. Full-scale demonstrations were conducted at the Navy Regional Recycling Center (NRRC) in San Diego, California and the Anniston Army Depot (ANAD) in Anniston, Alabama. The specific performance goal at NRRC was to meet the NPDES storm water permit by passing acute toxicity requirements, and by reducing copper and zinc to less than 63.6 μg/l and 117 μg/l respectively. All of the acute toxicity test requirements were met 100% of the time for the last 5 storm events, after slight modification to the media bed. The average removal efficiencies for the last five storm events of the test period met the permit requirements for aluminum, copper, and lead, and was within 3 percent of the 117 μg/l limit for zinc. The dual media filtration system met the performance goal at ANAD. No sheen, visible oil, floating solids, or visible foam was reported in the dual media storm water filters effluent during throughout the demonstration period.

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LIST OF ACRONYMS

ACOE	Army Corps of Engineers
Al	Aluminum
ANAD	Anniston Army Depot
ASTM	American Society for Testing and Materials
BMP	Best Management Practice
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CFS	Cubic Feet per Second
CNRSW	Commander Navy Region Southwest
COTS	Commercial Off-the-Shelf
CRWQCB	California Regional water Quality Control Board
Cu	Copper
DoD	Department of Defense
DMFS	Dual Media Filtration System
DRMO	Defense Reutilization and Marketing Office
EBCT	Empty Bed Contact Time
ECAM	Environmental Cost Analysis Methodology
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
Fe	Iron
FS-50	Ferrous Coated Activated Alumina
GPM	Gallons Per Minute
IR	Industrial Remediation
K	Thousand
µg/l	Micrograms per liter
mg/l	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
NASSCO	National Steel and Shipbuilding Company
NAVSTA	Naval Station
ND	Not Detectable
NAVFAC ESC	Naval Facilities Engineering Service Center
NOAA	National Oceanic and Atmospheric Administration
NOV	Notice of Violation
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
NRRC	Navy Regional Recycling Center
NS	No Sample
O&M	Operation and Maintenance
Pb	Lead
pH	Potential of Hydrogen – Measure of acidity/alkalinity
PVC	Polyvinyl Chloride
SMI	Storm Water Management, Inc.
STLC	Soluble Threshold Limit Concentration
SU	Standard Unit

LIST OF ACRONYMS (continued)

TMDL	Total Maximum Daily Loads
TRPH	Total Recoverable Petroleum Hydrocarbon
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WET	Waste Extraction Test
Zn	Zinc

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1.0 EXECUTIVE SUMMARY

1.1 Background

The Naval Facilities Engineering Service Center (NAVFAC ESC) was funded by the Environmental Security Technology Certification Program (ESTCP) to validate the performance of an innovative dual media storm water filtration-adsorption system that removes metals, organic compounds, and sediment found in storm water runoff from DoD industrial sites. Full-scale demonstrations of the technology were conducted at two sites, the first at the Navy Regional Recycling Center (NRRC) located on Naval Station San Diego in San Diego, California and the second at the Defense Reutilization and Marketing Office (DRMO) located on Anniston Army Depot (ANAD) in Anniston, Alabama.

DoD is under increasing pressure from regulators and local communities to reduce the amount of toxic pollutants being discharged with storm water into harbors, bays, lakes, and streams. Successful completion of this project will provide the DoD with a method of removing toxic contaminants from storm water runoff, thereby avoiding Notices of Violation from regulating agencies and improving public perception of DoD environmental stewardship.

Storm water runoff from DoD industrial sites is not easily treated by current commercial off-the-shelf (COTS) technology. Most COTS technologies for storm water treatment are designed for municipal applications such as trash, nutrient, and sediment removal. Also, many storm water treatment technologies require large areas of land for detention basins and similar structures. This type of space requirement is often at a premium at DoD sites, and is especially unavailable at many industrial locations.

The dual media storm water filtration system is inherently simple. It is based on a standard sand filter design used for treating storm water runoff. The original filter medium (sand) is replaced with inexpensive adsorbent materials. The system operates without manual intervention, has no pumps, controls, or other sophisticated mechanical or electrical components. Annual maintenance consists of removing and replacing top layer of pea gravel and geo-fabric, which strains sediment from storm water runoff as it enters the media bed.

1.2 Objectives of the Demonstration

The objective of this project was to validate the dual media storm water filtration system's capability to remove metals, organic compounds, and other toxic pollutants in storm water runoff.

The specific objective of the NRRC demonstration was to validate a technology that passes a 96-hour bioassay (toxicity) test as required by the California Regional Water Quality Control Board (CRWQCB), San Diego Region by removing copper and zinc from the runoff water. Our demonstration performance goal was to reduce copper to less than 63.6 μg/l and zinc to less than 117 μg/l.

The specific objective of the ANAD demonstration was to comply with their storm water permit requiring that “The discharge shall have no sheen, and there shall be no discharge of visible oil, floating solids, or visible foam in other than trace amounts.” In addition, a secondary objective was to further validate the filters capability to remove zinc and copper similarly to NRRC even though it is not specifically required in ANAD’s storm water permit.

1.3 Regulatory Drivers

Storm water discharges and municipal separate storm sewer systems (MS4s) are regulated by the U.S. Environmental Protection Agency (EPA). These storm water discharges are required to be covered under National Pollution Discharge Elimination System (NPDES) storm water discharge permits. Regulations can be found in 40 Code of Federal Regulations Parts 122, 123, and 124. Many States, including Alabama and California, have been delegated by EPA to implement the NPDES permitting program and to regulate federal facilities. The CRWQCB San Diego Region is one of nine regions in California that issues NPDES permits. The NRRC located at Naval Station San Diego falls under CRWQCB San Diego Region’s purview.

1.4 Demonstration Results

For the 11 storm events that occurred during the demonstration period (March 06 to April 07), the dual media storm water filter system passed the 90% survival requirement 64% of the time, and passed the 70% survival requirement 82% of the time. All of the acute toxicity test requirements were met 100% of the time for the last 5 storm events, after modifications were made to the configuration of the top fabric layer of the media bed.

The average removal efficiencies (efficiency ratio) for the last 5 storm events of the demonstration period met the permit requirements for aluminum, copper, and lead, and was within 4% of the 117 μg/L limit for zinc.

Tables 1 and 2 provide a summary of sampling results for ANAD. The effluent sampling results from the ANAD demonstration showed excellent pollutant removal efficiency. No sheen, visible oil, floating solids, or visible foam was observed in the effluent throughout the demonstration period. NAVFAC ESC also believes that the performance of the system at ANAD is similar to the NRRC results shown in Table 1, although not specifically required by the state of Alabama.

Table 1. NRRC Demonstration Results

Primary Performance Criteria	Performance Objectives Targeted	Results	Actual Performance (future) Objective Met?
Reliably pass the CRWQCB toxicity test for storm water runoff	Pass the 96 hour, continuous flow, acute toxicity test using undiluted storm water runoff with a 90% survival rate 50% of the time, and not less than 70% survival rate 90% of the time	94% survival 64% of the time, and 70% survival 82% of the time. 100% survival 90% of the time, and 100% survival 70% of the time after modification were made to the media bed.	**Achieved**
Reduce copper in storm water runoff	Reduce the concentration of copper in the storm water treatment system effluent to less than 63.4 μg/l	The EMC for Cu after modifications were made to the media bed was 40 μg/l,	**Achieved**
Reduce zinc in storm water runoff	Reduce the concentration of zinc in the storm water treatment system effluent to less than 117 μg/l	The EMC for Zn after modifications were made to the media bed was 122 μg/l,	**Not Achieved but within 4%**

Table 2. ANAD Demonstration Results

Primary Performance Criteria	Performance Objective Targeted	Results	Actual Performance Objective Met
Hazardous contaminant	The permit states that "The discharge shall have no sheen, and there shall be no discharge of visible oil, floating solids, or visible foam in other than trace amounts."	No sheen, visible oil, floating solids, or foam was reported during sampling.	**Achieved**

1.5 Stakeholder/End-User Issues

The limitation of the proposed technology is the susceptibility to plugging of the top layer of the media bed by a thin layer of fine suspended solids in the runoff water (this is a problem inherent to any technology used in treating storm water). Therefore, the end user must plan on removing the top filter medium (filter fabric and pea gravel) and replace with clean materials on an annual basis. The maintenance interval will vary by industrial site, and depends on the volume of water processed and the amount of suspended solids removed by the filter bed. Frequent plugging will increase maintenance costs, and could result in bypassing of the system.

2.0 TECHNOLOGY DESCRIPTION

2.1 Technology Development and Application

The technology utilized in these demonstrations was the combination of simple, low cost storm water treatment technology (sand filters) reconfigured with engineered materials (adsorbents) specifically selected to remove targeted industrial pollutants that makes the demonstrated technology innovative. Sand filters mimic natural sediment traps to trap particles of contaminating materials. Sand filters have been used in the past to treat storm water runoff from shopping center parking lots, residential areas, and other non-industrial applications. The main application has been to remove suspended solids. In these demonstrations, the design has been modified to allow the use of special adsorbent materials to increase the efficiency of removal of metals and organic compounds. A sketch of one media filter design called the Washington D.C. sand filter, is presented in Figure 1, with absorbent materials implemented. (See EPA web site: http://www.epa.gov/owmitnet/mtb/sandfltr.pdf).

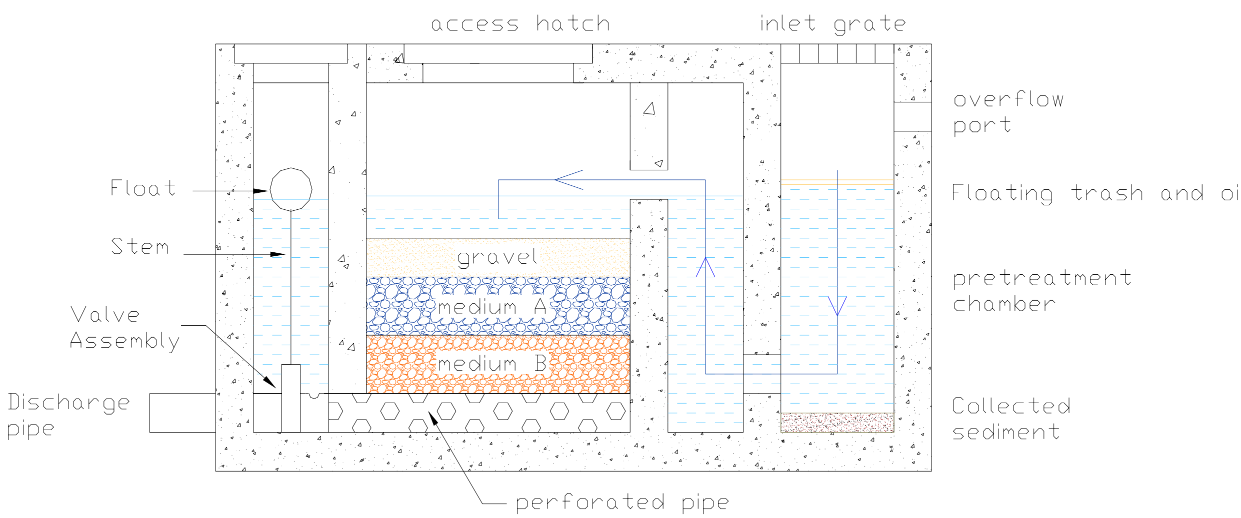

Figure 1. Elevation View of Dual Media Filter.

Various adsorbent media have been used in the past for a wide variety of water and wastewater treatment applications. Through a project funded by the Navy Environmental Sustainability Development to Integration (formerly Pollution Prevention Ashore Program), NAVFAC ESC has conducted bench scale tests on 24 different adsorbent media to determine the combination that is the most effective at removing heavy metals (Richard Kirts, Mark Foreman, Gary Anguiano, Nov 2004). As a result, NAVFAC ESC found that a bed of bone char over a bed of activated alumina, with a total Empty Bed Contact Time (EBCT) through both bed layers of 10 minutes, provides the best removal effectiveness for removing the specific pollutants (metals, hydrocarbons, particulates) of interest.

The technology works by way of filtration and adsorption. Laboratory tests of runoff water from NRRC have shown that a large portion of metals are in the form of filterable suspended solids. Much of these solids and particles are removed on the surface of the filter bed as well as within the interstitial pores within the filter bed. To meet discharge requirements, media adsorption in place of the sand is required. Adsorption can be attributed to a combination of several interactions between the surface of the media and contaminant: Van Der Waals attraction, ion-exchange, and chemisorption.

2.2 Process Description

Figure 1 shows the basic flow pattern of this technology. The storm water first passes through a pretreatment chamber where coarse sediment and solids are removed via sedimentation or screening. The storm water then flows through an under-weir and then over an over-weir, flowing to the top of the filter bed and through the filter media. Any floatable contaminants such as oil and grease would be trapped within the pretreatment chamber. The treated water is collected at the bottom of the bed with an array of perforated pipes, and then conveyed to the discharge channel. Water may flow through the media bed faster than desired. Therefore, a modulating valve at the discharge of the system may be required to control the velocity of water through the bed. An overflow port was designed into the system in case storm water runoff rate exceeds the design capacity of the system or if the filter media becomes plugged with sediment. A float-controlled valve on the discharge pipe keeps the water level over the media beds constant, regardless of input flow rate. If the water level is constant, water is flowing out of the unit as fast as it flows into the unit. The velocity through the bed is equal to the flow rate divided by bed cross sectional area of travel.

The factors that affect the performance of this technology include: the filter media used, hydraulic conductivity of the filter media, and the adsorption capacity of the media.

A combination of bone char and activated alumina has been selected as the media for use in these demonstrations. These materials were selected based on bench scale testing, and the combinations of these two media were found to be more effective than any single medium or other combinations of media in removing heavy metals such as copper and zinc. Figures 2 and 3 show the setup for NRRC and ANAD, respectively. The activated alumina used is Alcan Chemical Corporation’s FS-50 product. FS-50 is an activated alumina coated with ferrous oxide, ferrous hydroxide, and ferrous sulfide. FS-50 has the appearance of rust colored sand. Bone char is a black, granular solid obtained by calcining cattle bones. Through the calcining process, crushed bone is cooked in an oxygen deficient atmosphere, leaving carbon and tri-calcium phosphate as the residue. Bone char is used to adsorb heavy metals, fluorides, and iron. Although it has a low total surface area, with respect to adsorption of certain compounds, bone char outperformed the activated carbon products.

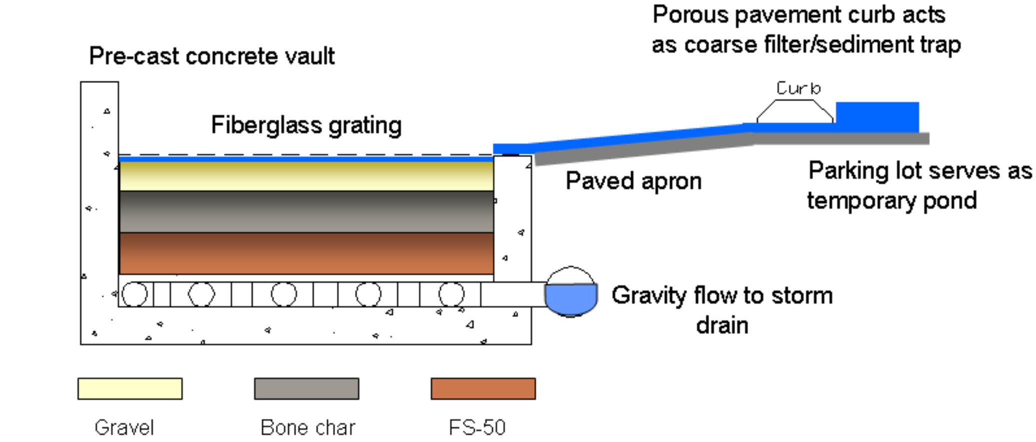

Figure 2. Concept as Designed and Built at NRRC.

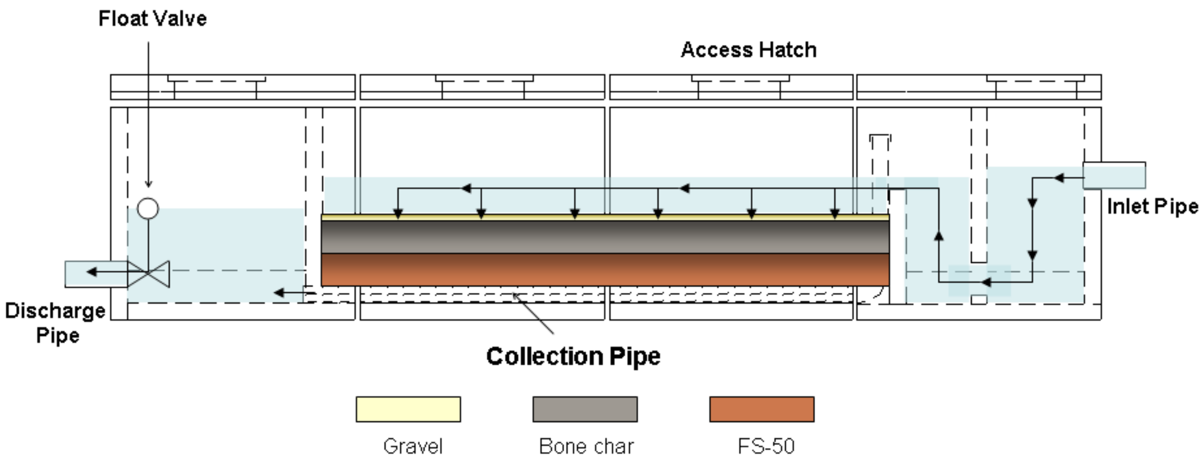

Figure 3. Concept as Designed and Built at ANAD.

Hydraulic conductivity (also called porosity) is a measure of the resistance of a column of material to the passage of water. The higher the value of the hydraulic conductivity, the easier water passes through the media. Knowledge of hydraulic conductivity is needed to determine the required availability of hydraulic head for a known depth of media bed. Coarser material tends to have higher hydraulic conductivity over finer material; however, higher conductivity through a set bed depth would have a lower EBCT and the coarser material may have less total surface area available for adsorption for a given media bed volume. As sediment is filtered in the first few inches of the media, the hydraulic resistance of the bed will increase. At some point, the top layer of media will have to be removed and replaced with new media. Coarser material would also enable more sediment to be filtered through the bed depth as opposed to just of the top of the filter bed. The hydraulic conductivity of FS-50 (28 x 48 mesh) and bone char (8 x 30 mesh) is approximately 19 ft/hr and 342 ft/hr respectively.

Adsorption capacity is the amount of the target metal species that can be adsorbed onto the media. Adsorption capacity is expressed in milligrams of metal per gram of media. The life of the bed of media in a treatment system can be estimated based on the adsorption capacity of the media, expected metals concentration, flow rate through the system, and average rainfall duration. Analysis has shown that the adsorption media for both NRRC and ANAD should last for well over 10 years before the adsorption capacity is exceeded. Table 3 below shows the adsorption capacity for FS-50 and bone char for copper, lead, and zinc.

Table 3. Results of Adsorption Capacity Test

	Iron Coated Activated Alumina	Bone Char
	mg metal/g media	mg metal/g media
Copper	3.96	6.29
Lead	0.74	2.22
Zinc	3.58	6.18

The velocity of the water through the filter bed (in ft. per minute) equals Q/A, where Q is the flow rate in units of cubic feet per minute and A is the cross sectional area of the bed in square feet. The contact time between the water and the filter-adsorption materials is equal to the bed depth divided by the water velocity through the bed. The filter-adsorption system is designed so that the EBCT will always be 5 minutes per media under the design flow conditions. If the flow rate is less than the design value, the total EBCT will be greater than 10 minutes.

At both NRRC and ANAD, a perforated pipe array is surrounded by a bed of washed river stone to the level of the top of the perforated pipes. Next, a layer of filter fabric is laid over the stone, followed by a layer of activated alumina (FS-50), another layer of filter fabric, a layer of bone char, another layer of filter fabric, and topped with a layer of pea gravel.

Installation of this system required a site survey, locating and marking underground utilities, identifying storm drain features, collecting and analyzing soil samples for purposes of excavation, and verifying the depth of the water table. Major system components consist of pre-cast concrete filter units, accessories such as inlet grating and access hatches, and filtration/adsorption media. Installation required excavation, placement and sealing of the pre-cast sections, connection of the discharge to the local storm drain system, back-filling of soil, and removal of excess soil and construction debris.

The system needed to be sized to meet NPDES permit requirements and minimize cost while maximizing storm water runoff treated. The factors that influenced the design treatment flow rate were drainage area, rainfall characteristics, and drainage area characteristics that would affect runoff quality and quantity.

Operation of this storm water treatment technology requires very little manpower. Storm water flows through this system by way of gravity and the only moving part is a float valve. The only labor that would be required for this system is the periodic cleaning of the top of the media, inspection of the system, sampling of the effluent, and the eventual replacement of media.

Sampling would be conducted as required by a NPDES permit and to verify system effectiveness.

2.3 Previous Testing of the Technology

Prior to this demonstration, a combination of bone char and surface modified activated alumina was evaluated as the filter media. These materials were selected based on bench scale testing. See Figure 4 for view of bench scale test apparatus. The media are minerals or have mineral-like physical properties. Samples of the media were immersed in water for over one year and showed no signs of swelling, decomposition, dissolving, or other change in physical properties that would affect the performance of the system.

Figure 4. Bench Scale Test Apparatus.

2.4 Advantages and Limitations of the Technology

The advantages of the technology are increased contaminant removal performance and lower implementation cost (compared to commercial off-the-shelf {COTS} technology). To establish a baseline for comparison of performance and cost, a storm water treatment technology manufactured by a commercial manufacturer was leased and tested. Testing was done both in the laboratory and under field conditions.

The limitation of the COTS technology is its potential susceptibility to plugging of the media bed by fine suspended solids in the runoff water. Frequent plugging would require frequent removal and replacement of the top layer of media bed. This would increase maintenance costs. Pretreatment devices such as centrifugal separators can remove a large portion of the suspended solids, but extensive pretreatment increases the size and cost of the total treatment system.

The COTS storm water filter system was tested at NAVFAC ESC, at the manufacture's laboratory (using water samples shipped to the manufacturer by the Navy), and in the field. The field test unit collected performance data from three storms. The flow rate for the unit is 15 gallons per minute. The filter medium is a pelletized mixture of leaf compost and peat moss. Filter life depends on contaminant concentration. Typically filters are replaced annually, whether or not the filter is completely expended.

3.0 DEMONSTRATION DESIGN

3.1 Performance Objectives

Table 4. Performance Objectives for NRRC San Diego

Type of Performance Objective	Primary Performance Criteria	Performance Objectives (Metric) Targeted	Actual Performance (future) Objective Met?
Quantitative	Reliably pass the CRWQCB toxicity test for storm water runoff	Pass the 96 hour, continuous flow, acute toxicity test using undiluted storm water runoff with a 90% survival rate 50% of the time, and not less than 70% survival rate 90% of the time	**Achieved**[1]
	Reduce copper in storm water runoff	Reduce the concentration of copper in the storm water treatment system effluent to less than 63.4 μg/l	**Achieved**
	Reduce zinc in storm water runoff	Reduce the concentration of zinc in the storm water treatment system effluent to less than 117 μg/l	**Not Achieved**[3]
	Reduce lead in storm water runoff	Reduce the concentration of lead in the storm water treatment system effluent to less than 82 μg/l	**Met**[3]
	Reduce aluminum in storm water runoff	Reduce the concentration of aluminum in the storm water treatment system effluent to less than 750 μg/l	**Achieved**
	Reduce TSS in storm water runoff	Reduce the concentration of total suspended solids in the storm water treatment system effluent to less than 100 mg/l	**Met**
Qualitative	Lower capital costs	Less than $50,000 per acre of drainage	**Met**
	Lower annual O&M costs	Less than $15 per 1,000 gallons of water treated.	**Met**
	Versatility	The process should be applicable to other industrial sites where runoff water exceeds discharge standards	**Met**
	Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	**Met**

1 – Performance criteria has been achieved, though inconsistent
2 – Performance criteria has been successfully and consistently met
3 – Performance criteria has not been successfully met or achieved

The NRRC quantitative performance objectives shown in Table 4 were established to measure the performance of the technology, and to comply with the storm water discharge permit.

The qualitative performance objectives were established to compare capital and maintenance costs associated with the operation of the dual media filtration system and a demonstrated COTS technology.

Table 5. Performance Objectives for ANAD Alabama

Type of Performance Objective	Primary Performance Criteria	Performance Objectives (Metric) Targeted	Actual Performance (future) Objective Met?
Quantitative	Effluent complies with current NPDES permit.	The permit states that "The discharge shall have no sheen, and there shall be no discharge of visible oil, floating solids, or visible foam in other than trace amounts.	**Met**
Qualitative	Lower capital costs	Less than $50,000 acre of drainage	**Not Achieved**
	Lower annual O&M costs	Less than $15 per 1,000 gallons of water treated.	**Met**
	Versatility	The process should be applicable to other industrial sites where runoff water exceeds discharge standards	**Met**
	Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	**Met**

The quantitative performance objectives for ANAD shown in Table 5 were established to measure the performance of the technology, and to comply with the ANAD pollution prevention goals. The qualitative performance objectives were established to compare capital and maintenance costs associated with the operations of the dual media filtration system and a demonstrated COTS technology..

3.2 Selecting Test Sites/Facilities

3.2.1 Navy Regional Recycling Center, San Diego, California

The test site selected for the Navy demonstration was the Naval Regional Recycling Center located on Naval Station San Diego. Figure 5 shows an aerial view of the NRRC site. Figure 6 shows a map of the demonstration site relative to Naval Station San Diego, the city of San Diego and the San Diego Bay. NRRC was selected as the site for the demonstration because they have a problem with metals in their storm water runoff and have served as the host site for field tests of COTS storm water treatment technology. In addition, NRRC had a comparative abundance of space available to accommodate a demonstration and its attendant infrastructure.

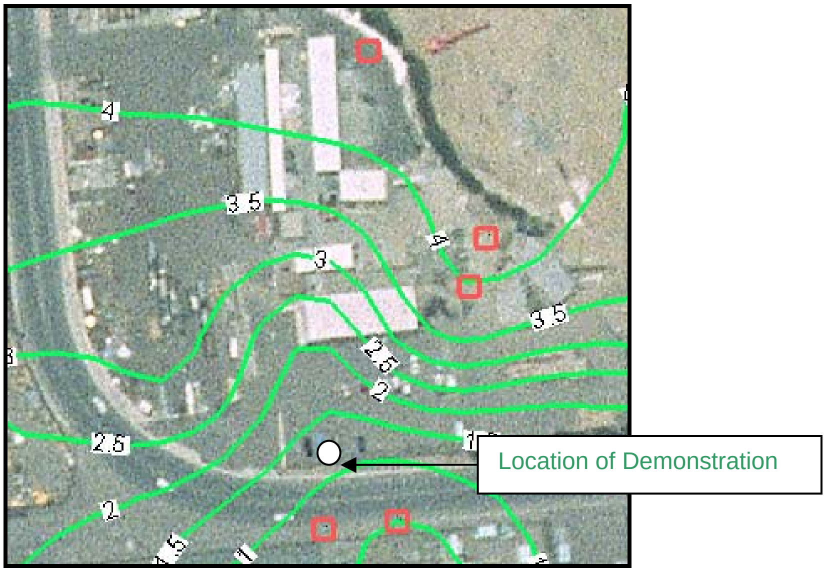

Figure 5. Demonstration Location at NRRC.

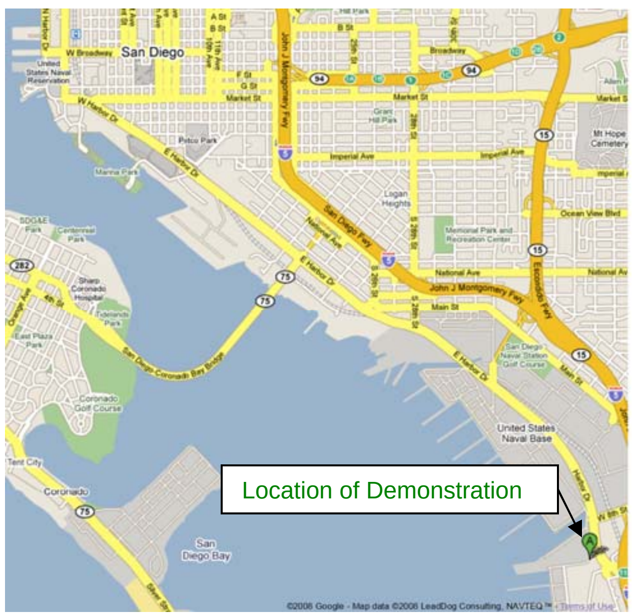

Figure 6. Location Map.

In 2002, the CRWQCB San Diego Region issued an order (Order R9-2002-0169, dated 13 November 2002) setting limits for toxicity in industrial storm water discharges from certain Navy activities, including the NRRC.

Effective four years after the adoption of the Order (November 2006), storm water discharges from NAVSTA industrial activities must pass “a 96-hour bioassay (toxicity) test using standard test species, protocols, and undiluted storm water runoff, and not produce less than a 90% survival, 50% of the time, and not less than a 70% survival, 90% of the time." Demonstration of a technology that will permit compliance with the CRWQCB Order was a significant factor in selection of NRRC as the test site.

3.2.2 Anniston Army Depot, Alabama

The test site selected for the Army demonstration was the DRMO at ANAD. ANAD is located in northeastern Alabama. Figure 7 shows the location of ANAD in northeastern Alabama. The site characteristics and contaminants of concern at ANAD differed from those being addressed at the NRRC. Although the discharge requirements at ANAD are not as restrictive as those at the NRRC, the impacts from spills at the ANAD DRMO could potentially impact facility operations. The ANAD site was also representative of the issues present at most of the Army sites at which the runoff treatment technology would be of great value. The performance information gathered at the ANAD DRMO demonstration site will be applicable to other Army sites and useful in supporting the transfer of the technology to the Army. The DRMO site was selected since it had a comparative abundance of space available to accommodate a demonstration and its attendant infrastructure. In addition, ANAD staff has been very receptive to the idea of a storm water treatment demonstration at their facility.

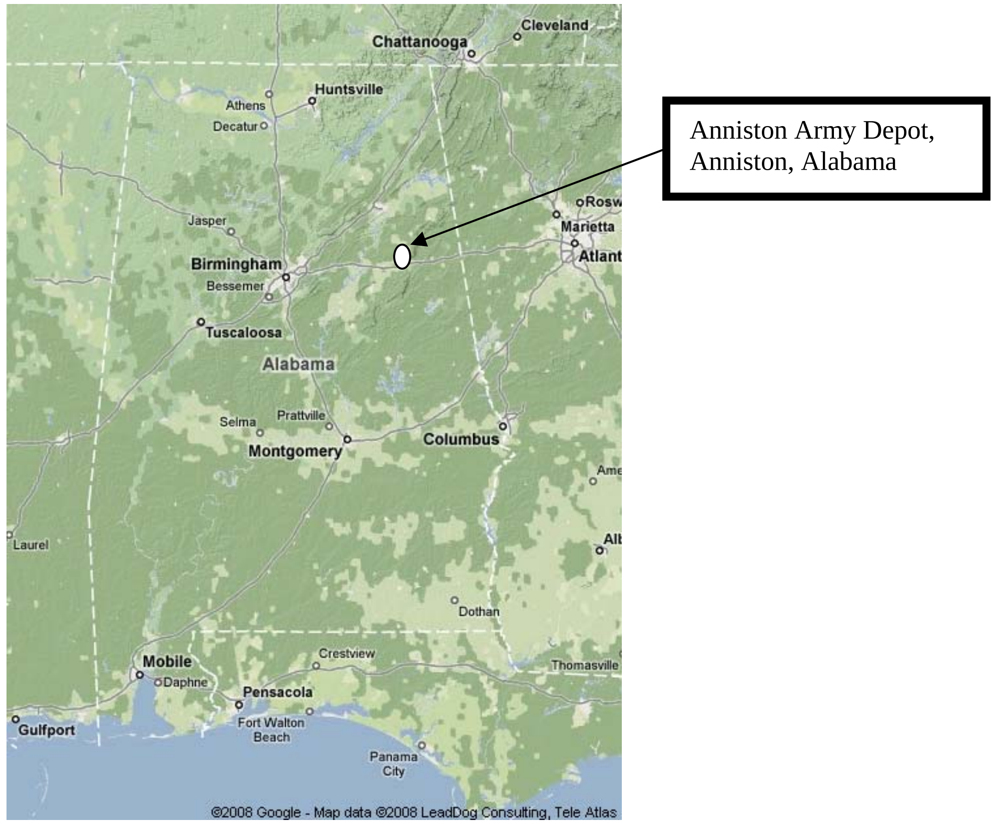

Figure 7. ANAD Site Location Map.

3.3 Test Facility History/Characteristics

3.3.1 Navy Regional Recycling Center, San Diego, California

NRRC is located within the Naval Station San Diego, by San Diego Bay. NRRC accepts used and scrap materials such as metals, paper, cardboard, and plastic for recycling and resale. NRRC is one of several Navy Regional Recycling Centers.

All runoff from NRRC would eventually make its way to San Diego Bay, portions of which are listed by the State of California as impaired for benthic impacts, sediment toxicity, and excess copper, zinc, and mercury in the sediment. In 2002, the California Regional Water Quality Control Board (CRWQCB) San Diego Region issued an order (Order R9-2002-0169, dated 13 November 2002) setting limits for toxicity in industrial storm water discharges from certain Navy activities, including NRRC. High risk areas at the Naval Station San Diego, including NRRC, were facing a requirement to terminate the first ¼-inch of storm water runoff, and to pass "a 96-hour bioassay (toxicity) test using standard test species, protocols, and undiluted storm water runoff. The toxicity of the storm water runoff was required to not produce less than a 90% survival, 50% of the time, and not less than a 70% survival, 90% of the time." Staff members of the Commander Navy Region Southwest (CNRSW) are the liaison with the California Regional Water Quality Control Board San Diego Region, and have worked with CRWQCB to amend the order to accept a treatment technology that produces effluent that passes the toxicity testing. Demonstration of a technology that would permit compliance with the CRWQCB Order was a significant factor in selection of NRRC as the test site.

The drainage area for NRRC is 3.55 acres. At San Diego, storms of less than 0.5 inches (in 24 hours) provide over 90 percent of all rain. Fewer than 5% of storms deliver more than an inch of rain. The treatment system at NRRC is designed to handle 0.59" of rain (6 month rain event) over a three hour period, which generates a maximum expected flow rate of 265 gallons per minute.

3.3.2 Anniston Army Depot, Alabama

ANAD's primary mission is refurbishment of artillery, wheeled vehicles, and tracked vehicles. ANAD is also the site of a chemical weapons storage facility. ANAD's DRMO accepts used and excess materials from military activities throughout Alabama and the southeast. The materials are processed to prevent reuse as military hardware (demilitarized), then sorted and packaged for sale. Due to the nature of the materials processed at DRMO, hydrocarbons would be of greater concern in the storm water runoff than at NRRC.

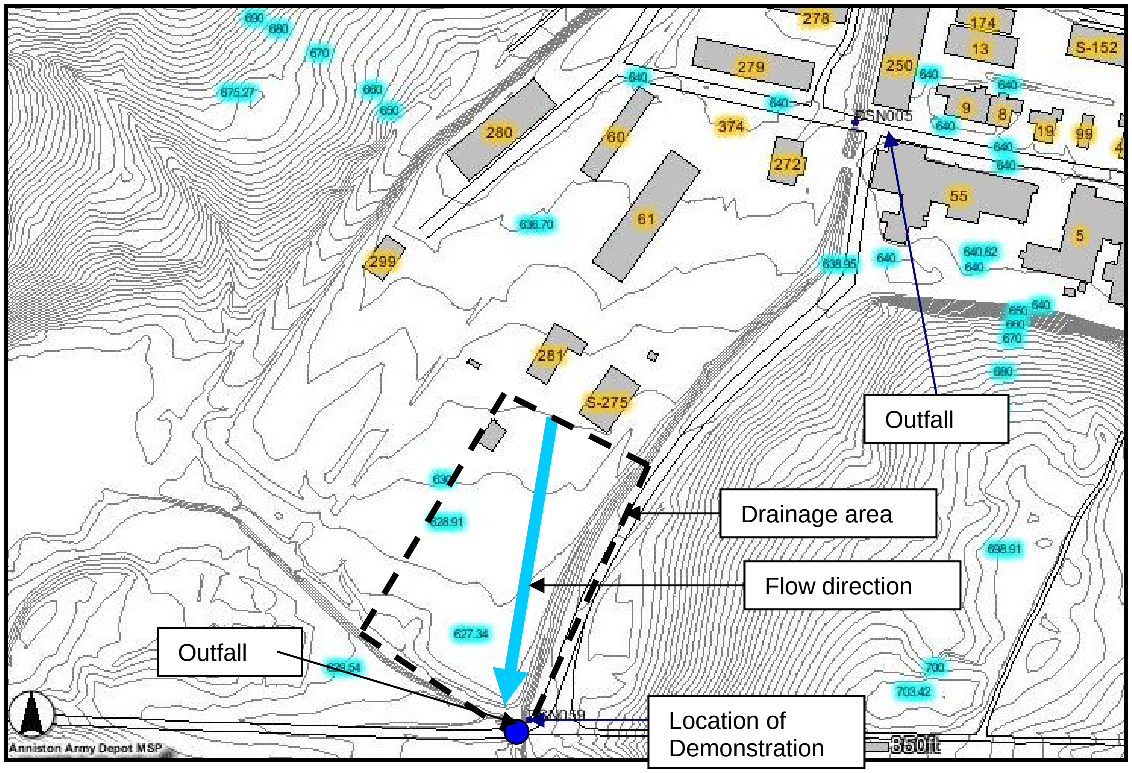

Figure 8. DRMO Drainage Area.

The drainage area of the DRMO site is approximately 400 ft by 200 ft, or 1.9 acres (see Figure 8). Storm water runoff flows across the work areas to the low point in the southwest corner of the paved area. This location was chosen as the site for storm water treatment demonstrations. The slope of the drainage area is roughly 1.5 percent.

National Oceanic and Atmospheric Administration (NOAA) weather data indicates that Anniston averages about 50 inches of rain each year. Anniston is on the border between a Type II and Type III rainfall distribution. Type III rainfall is shorter duration, more intense rainfall produced by storms generated over the ocean. A storm condition of four inches of rain over a period of 6 hours was selected as the design condition. The storm water treatment system for ANAD was designed to treat 1 CFS, (about 500 GPM). The total flow per design storm is 19,500 cubic feet or 146,000 gallons.

3.4 Physical Set-up and Operation

In preparation for installing the storm water treatment systems, NAVFAC ESC conducted the following:

- Surveyed the site to determine precise elevations and distances
- Determined and marked the location of any underground utilities
- Verified the locations of the nearest existing storm water vault and drainpipe
- Collected and analyzed soil samples for purposes of excavation
- Verified the depth of the water table.

A detailed design and installation plan was prepared. Following review of the installation plan by the host installation's construction agent, a contract for procurement and installation of the filter was awarded. The system components consisted of pre-cast concrete filter units, suspended solids pretreatment, accessories such as inlet grating and access hatches, and filtration/adsorption media. Installation required excavation, placement and sealing of the pre-cast sections, connection of the discharge to the storm drain system, back-filling of soil, and removal of excess soil and construction debris.

Figure 9 displays the porous curb pretreatment system in front of the technology that was used to remove sediment and debris. Following the first rain event, the porous curb plugged very readily and a filter fence was included to insure adequate flow to the system.

Figure 9. Porous Curb and Filter Fence used for Debris and Sediment Removal.

NAVFAC ESC installed the monitoring equipment consisting of automatic water sampling systems, flow meters and flow totalizers. At NRRC a data logging system and a recording rain gauge were also installed. The main safety issues during construction were work in open trenches and work in an enclosed environments, such as the concrete filter housings. The unspent filter media (alumina, bone char, river stones, and geofabric) are non-hazardous.

Testing began on January 2006, after completion of construction and acceptance of the installation by Navy contracting personnel. Because almost all of the rain in San Diego falls between the months of November and April, operation was intermittent and occurred mostly during the winter months. Due to sampler malfunctions, reliable sampling data did not occur until the end of March 2006. Testing began at ANAD in October 2006, and concluded in June 2007. The actual dates of the demonstration were dictated by rain events. As discussed in detail later, the rain events after installation spanned the time form 3/28/2006 until 4/20/2007. A total of 11 rain events were captured at NRRC, San Diego, and 6 rain events, from 10/17/2006 until 4/4/2007, were captured at ANAD, Anniston.

Previous treatment processes for these locations were non-existent. ANAD had installed an oily water separator in order to manage any accidental oil spill runoff from the base, but NRRC had no treatment technology at all for their location. However, as will be discussed later, NRRC is required to comply with Order R9-2002-0169, which requires termination of the first ¼-inch of storm water runoff. This would require NRRC to capture the first ¼-inch of rain water during any rain event and dispose of it as hazardous waste water. Similarly, ANAD must comply with state law which requires:

(a) State waters shall be free from substances attributable to sewage, industrial wastes or other wastes that will settle to form bottom deposits which are unsightly, putrescent or interfere directly or indirectly with any classified water use.
(b) State waters shall be free from floating debris, oil, scum, and other floating materials attributable to sewage, industrial wastes or other wastes in amounts sufficient to be unsightly or interfere directly or indirectly with any classified water use.
(c) State waters shall be free from substances attributable to sewage, industrial wastes or other wastes in concentrations or combinations which are toxic or harmful to human, animal or aquatic life to the extent commensurate with the designated usage for such waters.

The dual media treatment operates as follows. Storm water first passes through a pretreatment chamber where coarse sediment and solids are removed via sedimentation or screening. The storm water then flows through an under-weir and then over an over-weir, flowing to the top of the filter bed and through the filter media. Any floatable contaminants such as oil and grease would be trapped within the pretreatment chamber. This chamber should be cleaned on an annual basis. The treated water passing through the media is collected at the bottom of the bed with an array of perforated pipes, and then conveyed to the discharge channel. In future installations, installers should verify that the flap modification is added to insure storm water is not short circuiting the media along the edge walls.

The effluent should be collected and analyzed periodically to evaluate performance and need for replacement. It is projected that the media should last longer than 10 years. For planning purposes, spent media will likely be required to be disposed as a hazardous waste for industrial areas like NRRC.

3.5 Sampling/Monitoring Procedures

3.5.1 Regional Recycling Center, San Diego, California

The filter trench at NRRC was equipped with two American Sigma refrigerated auto samplers. One of the American Sigma auto sampler collected samples of the process influent, and the other American Sigma auto sampler collected samples of the process effluent. Each auto sampler was equipped with a 24 x 1 liter sample container carousel. Each sample container was filled after a certain time interval had passed. The first four sample containers for each Sigma sampler were combined together as a "first-flush" sample. The rest of the sample bottles (the number of samples varied with the duration of the storm) were analyzed independently. A third auto sampler was used to collect samples for toxicity testing of the process effluent.

A flow rate meter (with flow totalizer) was connected to the outlet of the treatment system. This flow meter was connected to an automatic data logging system. This allowed determination of the flow profiles for each storm as well and the minimum, mean, and peak flow rates. The totalizer permitted computation of the runoff processed.

A weather station was located on site and recorded the precipitation during the demonstration period. The weather station was connected to the data logger.

3.5.2 Anniston Army Depot, Alabama

The filter adsorption system had been equipped with two Global Water dual mode storm water samplers. One sampler collected samples of the process influent; the other sampler collected samples of the process effluent. Each sampler was capable of collecting both a "grab" sample and a "composite" sample. In a grab sample, the sample pump ran continuously until the sample bottle was full. The grab sample was more representative of a "first flush" sample. The first portion of runoff from a storm (first flush) tends to contain higher concentrations of pollutants than samples taken later. As such, it is more representative of the maximum pollutant loading. A composite sample is a sample collected intermittently during operation. For example, to gather a composite sample the sampler might collect 100 milliliters of runoff water every 6 minutes until the sample bottle is full. A composite sample is a time average of samples of runoff water and is representative of time-averaged pollutant concentrations.

One composite sample and one grab sample of influent, and one composite sample and one grab sample of effluent (a total of 4 samples) were collected for each storm event that was sampled. One rain event was collected per month. A minimum inter-event period of 72 hours from the previously measurable storm event was used.

3.6 Analytical Procedures

USEPA or Standard Analytical Methods (SM) have been used to evaluate the effectiveness of the dual storm water runoff treatment system. Table 6 below shows the test methods utilized for each parameter.

Table 6. Analysis and Test Methods

	NRRC	Method	ANAD	Method
Hardness			✓	SM2340
Toxicity	✓	*		
pH	✓	EPA150.1	✓	EPA150.1
Total Suspended Solids	✓	EPA2540D	✓	EPA160.2
Total Dissolved Solids	✓	EPA2540C	✓	EPA160.1
Specific Conductivity	✓	SM2510B	✓	SM2510B
Total Organic Carbon (TOC)	✓	SM5310B		
Chemical Oxygen Demand (COD)	✓	EPA410.4	✓	EPA410.4
Biochemical Oxygen Demand (BOD)	✓	SM5210B	✓	EPA405.1
Surfactants – Methyl Blue Active Substance (MBAS)	✓	SM5540C	✓	EPA377.1
Nitrogen (Total)			✓	SM4500N
Ammonia	✓	EPA350.2		
Total Kjeldahl Nitrogen (TKN)	✓	EPA351.3		
Nitrite	✓	EPA300.0		
Nitrate	✓	EPA300.0		
Phosphorus (Total)	✓	EPA365.2	✓	EPA365.4
Total Recoverable Petroleum Hydrocarbon (TRPH)	✓	EPA418.1		
Oil and Grease	✓	EPA1664	✓	EPA1664
Benzene, Toluene, Ethylbenzene, Xylene (BTEX)			✓	EPA602
Naphtha			✓	EPA602
Total Petroleum Hydrocarbon – Diesel Range			✓	EPA SW846 8015B
Metals				
Aluminum	✓	EPA200.8		
Antimony			✓	EPA200.7
Arsenic	✓	EPA200.8	✓	EPA200.7
Barium			✓	EPA200.7
Beryllium			✓	EPA200.7
Cadmium	✓	EPA200.8	✓	EPA200.7
Chromium	✓	EPA200.8	✓	EPA200.7
Cobalt			✓	EPA200.7
Copper	✓	EPA200.8	✓	EPA200.7
Iron	✓	EPA200.8		
Lead	✓	EPA200.8	✓	EPA200.7
Mercury			✓	EPA245.1
Molybdenum			✓	EPA200.7
Nickel	✓	EPA200.8	✓	EPA200.7
Selenium	✓	EPA200.8	✓	EPA200.7
Silver	✓	EPA200.8	✓	EPA200.7
Thallium			✓	EPA200.7
Titanium	✓	EPA200.8		
Vanadium			✓	EPA200.7
Zinc	✓	EPA200.8	✓	EPA200.7

*EPA/821/R-02/012, 2002
SM-Standard Methods

4.0 PERFORMANCE ASSESSMENT

4.1 Performance Data

Successful results were obtained at both demonstration sites. For the demonstration project at NRRC, the primary goal of the demonstration is to show that the storm water runoff treatment system complies with the CRWQCB Order R9-2002-0169 Section B, Paragraph 4 which states: "… industrial activities must pass a 96-hour bioassay (toxicity) test using standard test species, protocols, and undiluted storm water runoff, and not produce less than a 90% survival, 50% of the time, and not less than a 70% survival, 90% of the time."

Several 5-liter polypropylene containers of process effluent were collected from each storm event, transported to an environmental testing laboratory, and underwent toxicity testing in accordance to the CRWQCB. The brine shrimp *Mysidopsis bahia* was used in San Diego. The test protocol is EPA 1991 (Acute). Standard Statistical analysis software (such as TOXCALC, Version 5.0) was used by the laboratory for data analysis and presentation of survivability results.

4.1.1 Navy Regional Recycling Center, San Diego, California

The primary goal is passage of the bioassay test. Reducing the copper and zinc concentrations in the runoff water would assure a high probability of passage of the toxicity test. Data from NRRC initially showed unfavorable results, including a higher than desired mortality rate and decreasing zinc and copper removal. These issues were corrected by modification of the unit with favorable results as seen in Table 7. The modification consisted of gluing geofabric flaps to the inside perimeter walls of the vaults, above the existing geofabric to decrease edge effects and redirect the influent to flow through the center of the media bed. See Figure 10 for view of modification.

Table 7. Acute Toxicity Results

	Acute Toxicity Test Requirements	
NRRC Requirement	90% Survival 50% of the time	70% survival 90% of the time
All NRRC Results	90% Survival 64% of the time	70% survival 82% of the time
NRRC Results After Design Modification (Last 5 Storm Events)	90% Survival 100% of the time	70% survival 100% of the time

Table 7 shows that the system passed the 90% survival requirement 64% of the time. However, the 70% survival requirement was met only 82% of the time. This statistical result is likely due to acute toxicity test results (45% survivability) from the 16 October 2006 storm event, where the subcontracted bioassay laboratory in San Diego, Nautilus Environmental, noted a significant drop in dissolved oxygen levels during the first 24 hours of testing. The test report indicates that the test chambers were aerated after this observation, but it is not clear whether low dissolved oxygen levels or a toxic substance in the sample caused mortality.

Figure 10. Geofabric Reconfiguration.

Upon further inspection of the test results by NAVFAC ESC, the survival rate for the remaining species was 70% after the test chambers were aerated. Nautilus Environmental considered repeating the test, but there was not enough of the sample left to conduct the analysis. Had the 70% survival rate *after aeration* of the test chambers been accepted, the 70% survival requirement for the eleven rain events would have been met 91% of the time.

Table 7 also shows that the last five storm events of the demonstration period met both the 90% and 70% acute toxicity test requirements 100% of the time. For the previous storms, it was hypothesized that storm water was bypassing the media bed along the perimeter walls of the vaults (edge effects), resulting in partial treatment of the influent, and non-optimal media bed performance. As mentioned earlier, this was resolved by adding the flap to redirect the flow through the center of the media.

The hazardous contaminant requirements stated that storm water effluent concentrations of copper in effluent were to be less than 64 μg/l, the concentration of zinc in the effluent to less than 117 μg/l, and the concentration of lead in the effluent to less than 83 μg/l. Lastly, the hazardous contaminant requirements stated to reduce concentration of aluminum in effluent to less than 750 μg/l, and reduce the concentration of TSS in the effluent to less than 100 mg/l. The first flush concentration measurements for copper and zinc at NRRC are shown in Table 8. Table 9 shows the first flush results for all (measured) hazardous contaminants at NRRC.

The results of composite effluent sampling, including first flush measurements, are shown in Figures 11 and 12. As can be seen in the graphs, effluent copper concentrations fall under the permit limits in later tests, except for some first flush values. Zinc concentrations were still greater than the zinc permit limit.

The elevated iron influent concentration had a minimal affect on adsorption of the target metals, which include copper, zinc, lead and aluminum, (Anguiano, Foreman, Sept 2008)

A secondary goal intended to reduce annual maintenance costs was minimizing the amount of debris and trash blinding the top layer of the media beds. During the first rain events, it was observed that the porous curb pretreatment readily blinded and was not flowing at the intended flow rate. Most of the storm water flowed underneath the porous curb at less than the design flow rate. Although sediment and debris were captured upstream of the porous curb, the impeded flow was a drawback that required correction.

NAVFAC ESC resolved the issue by adding filter fence sections within several 3-foot wide gaps between the porous curbs as shown in Figure 9. The filter fence removed sediment and trash while maintaining adequate flow to the system, thereby decreasing the maintenance frequency of the system.

Table 8. NRRC First Flush Rainfall Cu and Zn Data

Date	Total Rainfall (inches)	First Flush Intensity (in/hr)	Survival 100% Concentration (%)	First Flush Influent/Effluent Cu (µg/l)	Cu % Removal	First Flush Influent/Effluent Zn (µg/l)	Zn % Removal
3/28/06	0.35	0.17	95	1170 339	71	1480 343	77
4/14/06	0.16	0.07	85	550 201	63	981 711	28
4/23/06	0.11	0.08	60 [3]	351 228	35	1270 913	28
5/22/06	0.60	0.4	90	987 397	60	2620 1140	57
10/16/06[1]	0.40	0.06	45 [4]	1070 401	63	4810 1330	72
1/29/07	0.85	0.11	85	488 85	83	1960 277	86
2/18/07[2]	0.9	0.06	100	307 63	79	1170 180	85
2/22/07	0.2	0.19	100	143 29	80	572 102	82
2/27/07	0.24	0.07	97	356 34	91	1870 167	91
3/22/07	0.06	0.25	100	335 81	76	928 222	76
4/20/07	0.53	0.18	100	342 88	74	1260 251	80

1. Top layer cleaned, and fabric configuration modified prior to this rain event
2. Top layer cleaned, and replaced existing top layer of fabric with more porous mesh prior to this rain event
3. Mortality attributed to insufficient contact time
4. Mortality attributed to low dissolved oxygen levels

Table 9. NRRC First Flush Data for Cu, Zn, Pb, Al, TSS and Fe

Pollutant	**NRRC First Flush Results (1)**										
	3/28/06 Influent Effluent	**4/14/06** Influent Effluent	**4/23/06** Influent Effluent	**5/22/06** Influent Effluent	**10/16/06** Influent Effluent	**1/29/07** Influent Effluent	**2/18/07** Influent Effluent	**2/22/07** Influent Effluent	**2/27/07** Influent Effluent	**3/18/07** Influent Effluent	**4/20/07** Influent Effluent
Cu (µg/L)	1170 339 (71)	550 201 (63)	351 228 (35)	987 397 (60)	1070 401 (63)	488 85 (83)	307 63 (79)	143 29 (80)	356 34 (91)	335 81 (76)	342 88 (74)
Zn (µg/L)	1480 343 (77)	981 711 (28)	1270 913 (28)	2620 1140 (57)	4810 1330 (72)	1960 277 (86)	1170 180 (85)	572 102 (82)	1870 167 (91)	928 222 (76)	1260 251 (80)
Pb (µg/L)	149 25 (83)	60 16 (73)	43 22 (49)	204 81 (60)	106 37 (65)	73 8 (89)	101 16 (84)	36 3 (92)	93 7 (93)	66 9 (86)	52 12 (77)
Al (µg/L)	5620 750 (87)	2080 1210 (42)	1950 742 (62)	5140 1680 (67)	3260 803 (75)	2280 207 (91)	2200 390 (82)	1020 105 (90)	1820 327 (82)	3180 265 (92)	1210 217 (82)
TSS (mg/L)	54 22 (59)	46 37 (20)	84 35 (58)	253 88 (65)	182 66 (64)	140 ND (100)	300 22 (93)	107 ND (100)	197 ND (100)	152 ND (100)	104 ND (100)
Fe (µg/L)	3262 290 (91)	3469 1524 (56)	2401 1486 (38)	2851 1204 (58)	2893 789 (73)	1375 406 (70)	1229 219 (82)	826 106 (87)	1242 285 (77)	5350 524 (90)	1084 208 (81)

1. Numbers in parenthesis are percent removed

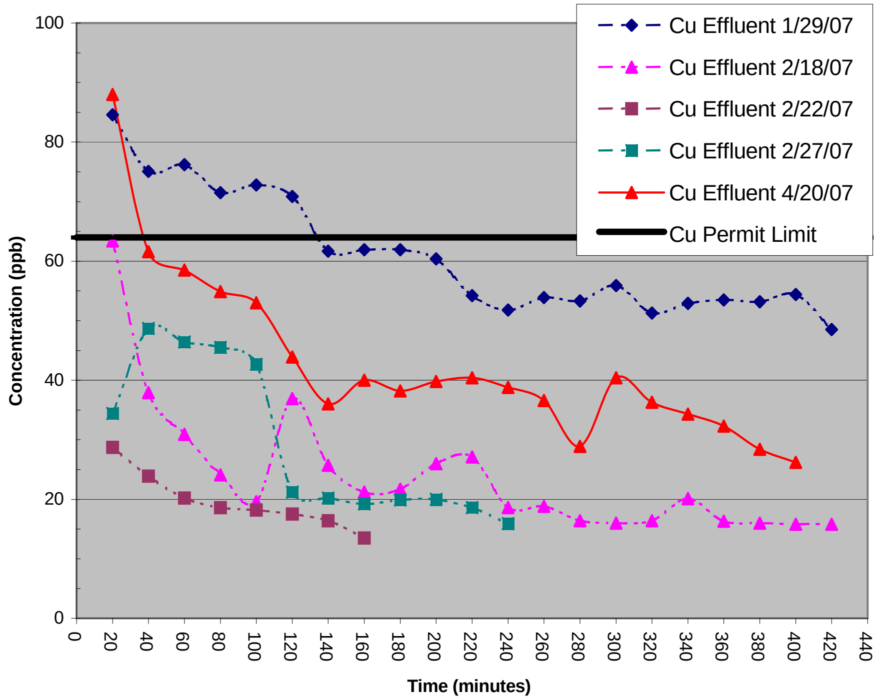

Figure 11. Copper Concentration Over Time

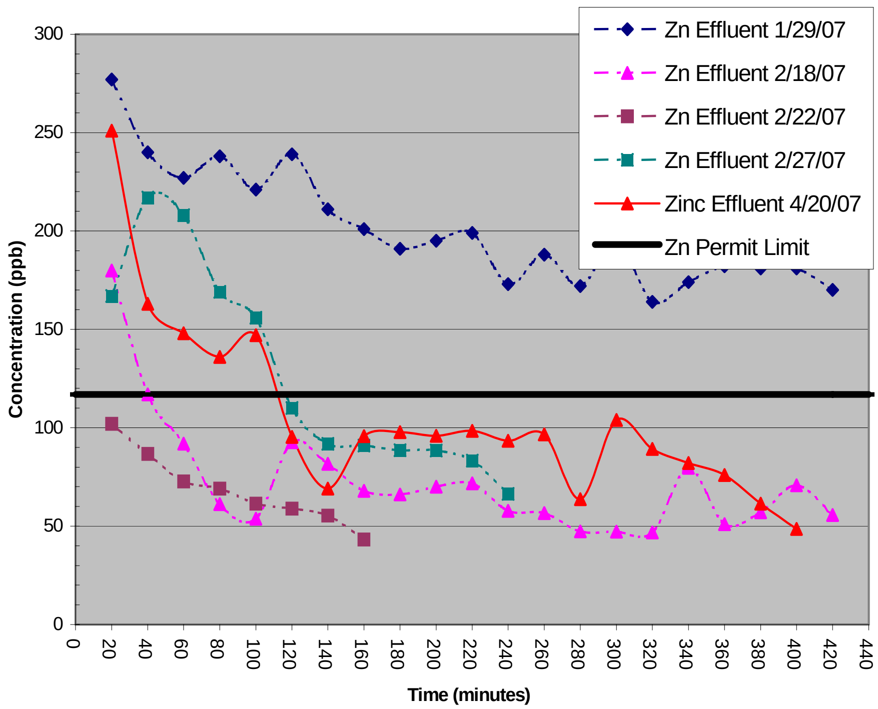

Figure 12. Zinc Concentration Over Time.

4.1.2 Anniston Army Depot, Alabama

The site characteristics and contaminants of concern at ANAD differ, and are not as restrictive as those addressed at NRRC. The basic instrumentation at ANAD was designed to capture real time flow rate data, total flow, and grab and composite samples of the storm water influent and effluent. Data was collected for six storm events during the period October 2006 to April 2007. Limited flow rate data is available from the demonstration period due to a malfunction of the Greyline Instruments area-velocity flow meter with data logger.

Performance data was analyzed to determine if there is a relationship between media performance (as expressed as metal concentration in the effluent) and initial metals concentration. This is in effort to determine whether the performance of the media changed with inlet contaminant concentration. It was deemed desirable to know whether it improved, worsened, or stayed approximately constant upon changing inlet conditions.

Table 10 displays first flush results for copper, lead, zinc, total suspended solids, purgeable aromatics, and extractable petroleum hydrocarbons (diesel) for all ANAD storm events sampled during the demonstration period.

Table 11 displays composite results taken at 15-minute intervals for copper, lead, zinc, total suspended solids, purgeable aromatics, and extractable petroleum hydrocarbons (diesel) for all ANAD storm events sampled during the demonstration period.

As can be seen from the tables, the results show a great deal of consistency in metals removal. While metal such as lead is clearly reduced, others of concern, such as copper and zinc, show reduced and occasionally increased concentrations, depending on the sampling method. Similarly, the extractable petroleum hydrocarbons show both an increase and decrease, depending on the sampling method used.

Effluent grab and composite sampling results may be questionable due to the clear well sampling location being submerged by the receiving body of water during periods of heavy rainfall. The outlet of the dual media storm water filtration unit was installed at a depth greater than originally intended as a result of the inlet basin (which feeds both the storm water unit and oil water separator) being installed differently than the initial design. Field engineers determined that the system hydraulics would only be slightly compromised, but did not consider the potential effects on the sampling protocol.

Sampling personnel were not able to collect sufficient quantities of storm water to run the entire analyses for oils and grease. This was caused by limited storm water available from the low intensity storms events. As a result, oil and grease removal efficiency could not be determined at ANAD. However, no sheen was reported in the influent or effluent by sampling personnel during the demonstration period. Rainbow oil sheen on water is generally accepted to have an oil concentration greater than 15 mg/l. Consequently, no correlation between influent oils and grease concentration and impact on heavy metal removal in the effluent could be made at the Anniston demonstration.

Effluent grab and composite sampling results may be questionable due to the clear well sampling location being submerged by the receiving body of water during periods of heavy rainfall. The outlet of the dual media storm water filtration unit was installed at a depth greater than originally intended as a result of the inlet basin (which feeds both the storm water unit and oil water separator) being installed differently than the initial design. Field engineers determined that the system hydraulics would only be slightly compromised, but did not consider the potential effects on the sampling protocol. The reason for the effluent sample values being greater than the influent sample value is unknown.

Table 10. First Flush Results for ANAD

Pollutant	Rain Event Date and Influent/Effluent Concentrations					
	10/17/06 Influent/Effluent	**11/15/06** Influent/Effluent	**1/18/07** Influent/Effluent	**2/13/07** Influent/Effluent	**3/16/07** Influent/Effluent	**4/4/07** Influent/Effluent
Copper (mg/L)	0.0384 / ND (97)	0.0693 / ND (99)	0.0408 / ND (98)	0.0625 / ND (98)	0.0371 / 0.0243 (35)	0.0324 / ND (97)
Lead (mg/L)	0.0121 / ND	0.0514 / ND	0.0236 / ND	0.0631 / 0.0061 (90)	0.0427 / ND	0.00610 / ND
Zinc (mg/L)	0.0973 / ND (90)	0.185 / ND (95)	0.113 / ND (91)	0.318 / ND (97)	0.254 / ND (96)	0.0931 / ND (89)
Benzene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Ethylbenzene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Naphthalene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Toluene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Xylenes, total (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Diesel (µg/L)	1990 / 2150	1600 / 254 (84)	528 / 178 (66)	4420 / 597 (86)	NS	2260 / 505 (78)
TSS (mg/L)	64 / 5 (92)	NS	NS	360 / <5 (99)	NS	NS
Oil & Grease (mg/L)	NS	NS	NS	13 / 4 (69)	NS	NS

1. Numbers in parenthesis are percent removed
2. NS – No Sample
3. Yellow - effluent > influent (The increased diesel level in the effluent from storm event 10/17/2006 cannot be adequately explained. It may have been the result of a sampling or lab error.)
4. ND – Not detectable

Table 11. Composite Flush Results for ANAD

Pollutant	**Rain Event Date and Influent/Effluent Concentrations**					
	10/17/06 Influent/Effluent	**11/15/06** Influent/Effluent	**1/18/07** Influent/Effluent	**2/13/07** Influent/Effluent	**3/16/07** Influent/Effluent	**4/4/07** Influent/Effluent
Copper (mg/L)	0.0363 / 0.0486	0.0623 / ND (98)	0.0222 / ND (95)	0.0389 / ND (97)	0.0374 / ND (97)	0.0382 / ND (97)
Lead (mg/L)	0.0096 / 0.0055 (43)	0.0445 / ND	0.00951 / ND	0.0331 / 0.0051 (85)	0.0286 / ND	0.00570 / ND
Zinc (mg/L)	0.0912 / 0.134	0.179 / ND (94)	0.0724 / ND (86)	0.176 / ND (94)	0.176 / ND (94)	0.0813 / ND (88)
Benzene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Ethylbenzene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Naphthalene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Toluene (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Xylenes, total (µg/L)	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND	ND / ND
Diesel (µg/L)	3740 / 3030 (19)	1210 / 175 (86)	284 / ND	2590 / 371 (86)	NS	NS
TSS (mg/L)	NS	NS	NS	160 / <5 (97)	NS	NS
Oil & Grease (mg/L)	NS	NS	NS	7 / 6 (14)	NS	NS

1. Numbers in parenthesis are percent removed
2. NS – No Sample
3. Yellow – effluent > influent
4. ND – Not detectable

4.2 Performance Criteria

4.2.1 Navy Regional Recycling Center, San Diego, California

The primary goal was passage of the bioassay test. Passage of the bioassay test was a requirement of CRWQCB Order R9-2002-0169. Reducing the copper and zinc concentrations in the runoff water to the levels stated in Tables 12 and 13 assured a high probability of passage of the toxicity test.

Table 12. ESTCP Performance Criteria for NRRC

Performance Criteria	Description	Primary or Secondary
Bioassay (toxicity) test	Static or continuous flow bioassay test using undiluted storm water runoff associated with industrial activity shall not produce less than 90% survival 50% of the time and not less than 70% survival 90% of the time using standard test species and protocols	Primary
Hazardous contaminant	Reduce concentration of copper in effluent to less than 64 μg/l, reduce the concentration of zinc in the effluent to less than 117 μg/l, and reduce the concentration of lead in the effluent to less than 83 μg/l.	Primary
Hazardous contaminant	Reduce concentration of aluminum in effluent to less than 750 μg/l, and reduce the concentration of TSS in the effluent to less than 100 mg/l.	Primary
Capital investment	Reduce capital investment to less than $50,000 per acre of drainage	Secondary
O&M costs	Reduce annual O&M costs to less than $15 per 1000 gallons treated.	Secondary
Scale-up Constraints	This is planned as a full-scale demonstration.	Secondary

Table 12. ESTCP Performance Criteria for NRRC (continued)

Performance Criteria	Description	Primary or Secondary
Factors Affecting Technology Performance	Operating conditions consist of the frequency, intensity, and duration of rainfall and the type and concentration of contaminants in the subsequent runoff. We have no control over these conditions and must accept what occurs.	Secondary
Process waste	Process waste consists of sludge and sediment at the upstream side of the porous concrete and, eventually, spent adsorption media. Wastes will be handled by contract.	Secondary
Ease of use	The process does not require any operators to be routinely present. Data acquisition is automatic.	Secondary
Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	Secondary
Versatility	The process should be applicable to other industrial sites where metal concentration in runoff water exceeds discharge standards	Secondary

4.2.2 Anniston Army Depot, Alabama

Table 13. ESTCP Performance Criteria for ANAD

Performance Criteria	Description	Primary or Secondary
Hazardous contaminant	Effluent complies with current NPDES permit. The permit states that "The discharge shall have no sheen, and there shall be no discharge of visible oil, floating solids, or visible foam in other than trace amounts.	Primary
Capital investment	Reduce capital investment to less than $50,000 per acre of drainage	Secondary
O&M costs	Reduce annual O&M costs to less than $15 per 1000 gallons treated.	Secondary
Scale-up Constraints	This is planned as a full-scale demonstration.	Secondary
Factors Affecting Technology Performance	Operating conditions consist of the frequency, intensity, and duration of rainfall and the type and concentration of contaminants in the subsequent runoff. We have no control over these conditions.	Secondary
Process waste	Process waste consists of sludge and sediment in the pretreatment chambers and, eventually, spent adsorption media. Wastes will be removed by contract.	Secondary
Ease of use	The process does not require any operators to be routinely present. Data acquisition is automatic.	Secondary
Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	Secondary
Versatility	The process should be applicable to other industrial sites where runoff water exceeds discharge standards	Secondary

4.3 Data Assessment

The purpose of this demonstration was to obtain information on the effectiveness of a new storm water filter system that is not currently available in the literature. Therefore, the overall success of this project was measured in terms of the quality of data acquired and its acceptance by the scientific community. The results of the performance criteria and the demonstrated results for NRRC and ANAD are shown in Tables 14 and 15, respectively.

Table 14. Expected Performance and Performance Confirmation Methods for NRRC

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual Performance
Primary Performance Criteria			
Bioassay test	Static or continuous flow bioassay test using undiluted storm water shall not produce less than 90% survival 50% of the time, and not less than 70% survival 90% of the time.	EPA/821/R-02/012, 2002 Acute Testing Manual	94% survival 64% of the time, and 70% survival 82% of the time. 100% survival 90% of the time and 100% survival 70% of the time after modification were made to the media bed.
Hazardous contaminant	Reduce concentration of copper in effluent to less than 64 μg/l, reduce the concentration of zinc in the effluent to less than 117 μg/l, and reduce the concentration of lead in the effluent to less than 83 μg/l.	EPA Standard Methods 200.8	The seasonal EMC for Cu, Zn, and Pb were 95 μg/l, 297 μg/l, and 11 μg/l respectively. The EMC for Cu, Zn, and Pb after modifications were made to the media bed were 40 μg/l, 122 μg/l, and 5 μg/l respectively.
Hazardous contaminant	Reduce concentration of aluminum in effluent to less than 750 μg/l, and reduce the concentration of TSS in the effluent to less than 100 mg/l.	EPA Standard Methods 200.8	The seasonal EMC for Al was 377 μg/L. TSS values were all below 100 mg/L.
Secondary Performance Criteria			
Capital investment	Investment less than $50K per acre	Complete and accurate record keeping	Capital investment is $27K per acre.
O&M cost	O&M less than $15/1000 gallons	Complete and accurate record keeping	O&M cost based on estimated annual flow is $1.73/1000 gallons. The O&M cost from the demonstration is $15.77/1000 gallons.
Scale-up Constraints	None	Experiences from demonstration operation	No scale-up constraints.

Table 14. Expected Performance and Performance Confirmation Methods for NRRC (continued)

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual Performance
Process waste	Process waste consists of sludge and sediment at the upstream side of the porous concrete and, the top layer of the media bed. Eventually, spent adsorption media. Wastes will be handled by contract.	Experiences from demonstration operation	Annual maintenance is required to remove sediment from the top layer of the media bed to minimize system plugging. Semi-annual sweeping of the upstream side of the porous concrete is required to minimize the amount of sediment reaching the media bed.
Ease of use	The process does not require any operators to be routinely present. Data acquisition is automatic.	Experiences from demonstration operation	The system did not require operators to be present.
Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	Experiences from demonstration operation	The system required no repair.
Versatility	The process should be applicable to other industrial sites where metal concentration in runoff water exceeds discharge standards	Experiences from demonstration operation	The process is applicable to other industrial sites with runoff containing similar influent concentrations.

Table 15. Expected Performance and Performance Confirmation Methods for ANAD

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual Performance
Primary Performance Criteria			
Hazardous contaminant	Effluent complies with current NPDES permit. The permit states that "The discharge shall have no sheen, and there shall be no discharge of visible oil, floating solids, or visible foam in other than trace amounts."	EPA standard analytical methods, and observations made during sampling	No sheen, visible oil, floating solids, or foam was reported during sampling.
Secondary Performance Criteria			
Capital investment	Reduce capital investment to less than $50,000 per acre of drainage	Complete and accurate record keeping	Capital investment is $67K per acre.
O&M cost	Reduce annual O&M costs to less than $15 per 1000 gallons treated.	Complete and accurate record keeping	O&M cost based on estimated annual flow is $1.45/1000 gallons.
Scale-up Constraints	This is planned as a full-scale demonstration.	Experiences from demonstration operation	No scale-up constraints.
Factors Affecting Technology Performance	Operating conditions consist of the frequency, intensity, and duration of rainfall and the type and concentration of contaminants in the subsequent runoff. We have no control over these conditions.	Experiences from demonstration operation	The system was able to filter all rain events occurring during the demonstrations period. The concentrations of targeted contaminants appear to be reduced.
Process waste	Process waste consists of sludge and sediment in the pretreatment chambers and, eventually, spent adsorption media. Wastes will be removed by contract.	Experiences from demonstration operation	Maintenance was not required during the demonstration period. Annual maintenance will likely be required to remove sediment from the pretreatment chambers.
Ease of use	The process does not require any operators to be routinely present. Data acquisition is automatic.	Experiences from demonstration operation	The system does not require operators to be present.
Reliability	The process is inherently simple, has no moving parts, and requires no electrical or mechanical power. It is inherently reliable.	Experiences from demonstration operation	The system required no repair.
Versatility	The process should be applicable to other industrial sites where runoff water exceeds discharge standards	Experiences from demonstration operation	The process is applicable to other industrial sites with runoff containing similar influent concentrations.

4.4 Technology Comparison

A similar storm water treatment system manufactured by a commercial manufacturer was demonstrated at the Steel and Shipbuilding Company (NASSCO), San Diego, California. The demonstration system at NASSCO found that a combination of fine- and coarse-grained leaf compost media with a 7.5 GPM/unit reduced average total copper from 0.312 to 0.163 mg/L, for an average copper removal of 45.6 percent, and reduced average total zinc from 1.688 to 0.849 mg/L, for an average zinc removal of 49.0 percent. Though the NASSCO system significantly reduced the toxicity of the storm water runoff, it fell short of meeting the toxicity limits of their permit, which is the same as NRRC. The NASSCO system cost $530,000 to construct, and an estimated $41,000 per year to maintain. This is equivalent to a capital cost of about $57,000 per acre and a maintenance cost of $17 per 1000 gallons of runoff treated.

5.0 COST ASSESSMENT

5.1 Cost Reporting

Cost reporting and comparison of the dual media storm water filtration system provides an assessment of the technology cost, and its applicability to DoD installations as pollution prevention and an environmental investment. Implementing any storm water treatment system at military installations involves new capital and operating costs. And like many industrial installations, neither NRRC nor ANAD had storm water treatment systems in place. NRRC was facing the prospect of having to capture and dispose of the first ¼-inch of potentially hazardous storm water runoff from the site, and ANAD was concerned about pollution of nearby water bodies with contaminants and metals from their runoff.

The baseline for cost comparison used in the Environmental Cost Analysis Methodology (ECAM) is the hypothetical installation and implementation of a tank and pump system. This system would require capacity for the first ¼-inch of rainfall on the 3.5 acre NRRC site (approximately 25,000 gallons). An additional comparison is against an installed COTS cartridge filter at a shipyard five miles from the NRRC site, facing the same regulatory pressures and having the same typical rainfall patterns as the NRRC.

As background to understanding what is being compared, flow diagrams are provided for each management scenario including existing condition. Figure 13 shows the process flow diagram for the storm water management practice before the demonstration units were installed at NRRC and ANAD.

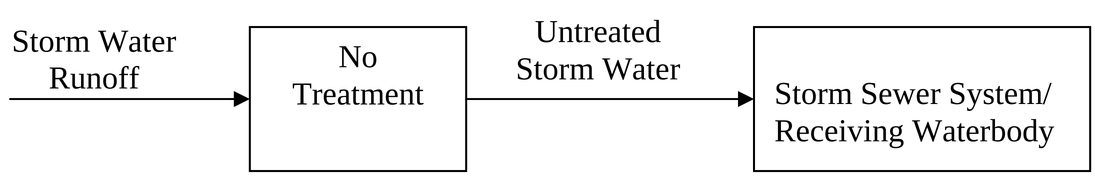

Figure 13. Existing Storm Water Management at NRRC and ANAD.

Figure 14 shows the process flow diagram for what NRRC would have been required prior to the installation of the dual media storm water filtration system.

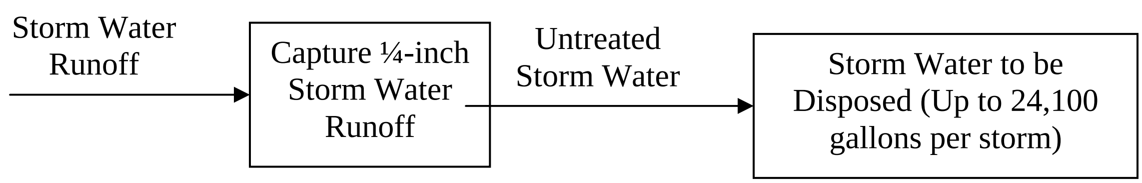

Figure 14. Potential Storm Water Management Requirement at NRRC.

Figure 15 shows the process flow diagram for the storm water management at NRRC after installation of the dual media storm water filtration system.

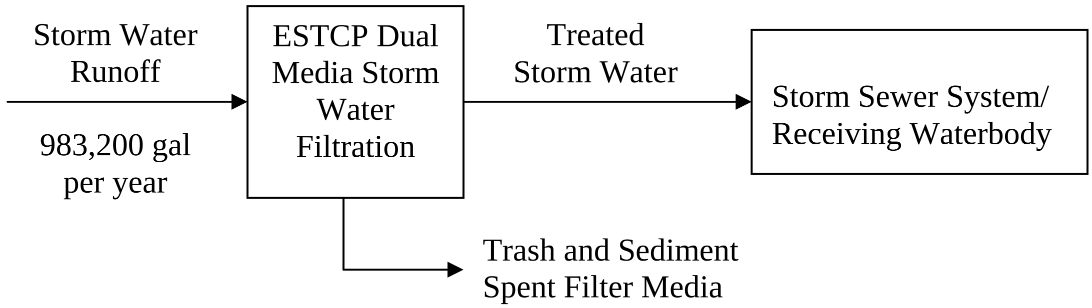

Figure 15. Process Flow Diagram at NRRC with Dual Media Storm Water Filtration System.

Figure 16 shows the process flow diagram for the storm water management at ANAD after installation of NAVFAC ESC's dual media storm water filtration system.

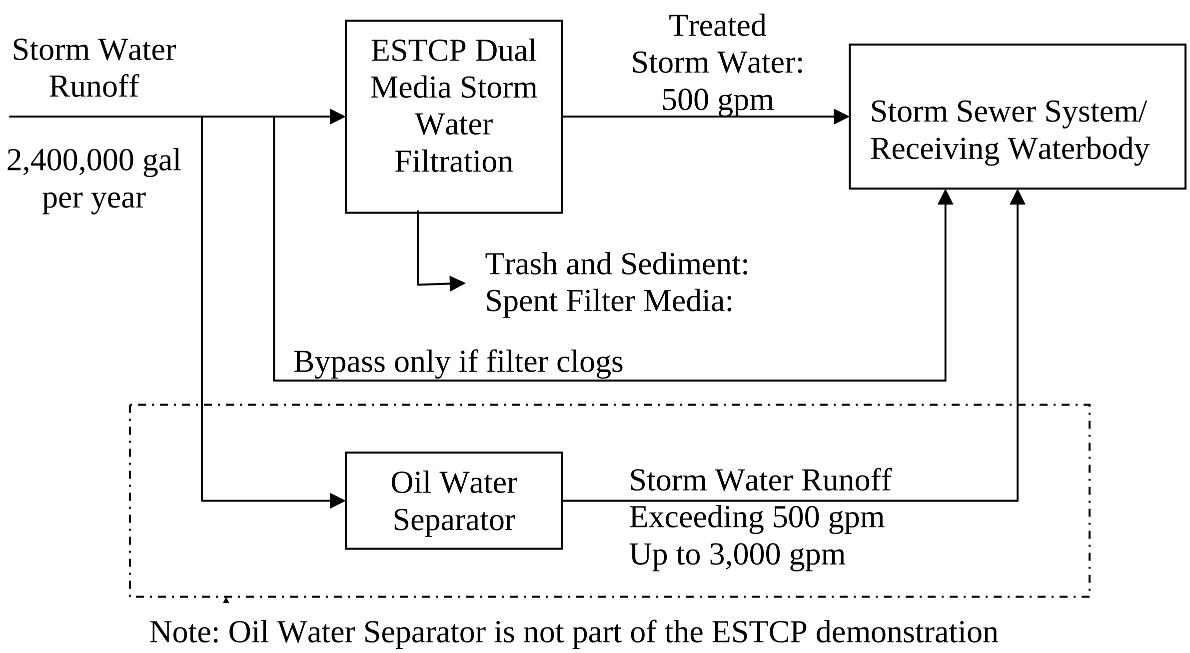

Figure 16. Process Flow Diagram at ANAD with Dual Media Storm Water Filtration System.

Total equipment and material cost for the 3.55 acre NRRC site excluding instrumentation is $52,300. The direct capital costs used in the ECAM analysis of the dual media storm water filtration system include the purchase of pre-cast concrete containment, filter media (FS-50, bone char, coarse gravel, and pea gravel), slotted PVC drain pipes, float valves, and associated minor equipment and material such as pipes, couplings, and grout. The costs of sampling and flow monitoring equipment (flow meter, metering manhole, automatic samplers, and data logger) are not included, since these costs would not be a normal expense for installing a storm water treatment system.

The design investment cost at NRRC is $15,500 and includes the site survey, engineering, and hydraulic analysis.

The installation cost is estimated at $43,000. This cost covers excavation, grading, leveling, compacting, concrete containment placement, media placement, manifold installation, and sewer system connections. This estimating installation costs is considered moderately higher than normal because the implementation site was on an Industrial Remediation (IR) site and the system was installed directly above a high voltage concrete vault due to lack of available space and location/elevation of discharge point. These two conditions are not considered normal site conditions. Actual costs were not de-rated in the ECAM model.

The total annual maintenance cost is approximately $1,700. The major task associated with annual maintenance of the dual media filtration system is the periodical replacement of the top layer of pea gravel (approximately 1.35 tons). Estimations show that the pea gravel requires annual replacement at a cost of $45 per ton. The spent gravel will require hauling (as a non-regulated hazardous waste) and disposal as a solid waste. Hauling is estimated at $1000 per year and disposal at a fee of $41 per ton, which includes the facility disposal fee and taxes. Labor is estimated at $500.

No startup costs or operator training costs were incurred for this system. Once the system was installed, it was ready to operate without human intervention.

Indirect costs may include permit re-application and negotiation, permit fees, monitoring, storm water pollution prevention plan updating, and reporting requirements. However, the additional indirect costs should be minor or none in most cases since these costs would be incurred with or without the storm water filtration technology.

Based on media cost at installation, a one time, conservative media replacement cost of $18,000 for 5.7 tons of media at year 10 is added to the annual operating section. Based on a recent study evaluating the adsorption capacity of the FS-50 media, historic rainfall data, and storm water heavy metal loading profiles, the filter media is predicted to actually last at least 30 years before needing replacement. However for purposes of this analysis it was de-rated to a 10 year service life. The replacement cost includes an estimate of $5,700 for labor and equipment and disposal fees of $600 per ton for a hazardous waste.

The baseline capital cost on the capture and disposal of the first ¼ inch of storm water runoff by a tank and pump system is $90,000 (materials and installation). The annual operating cost is $37,500. The estimates are based on the RS Means construction cost reference manual for an above ground storage tank system with associated pipes and pumps, an estimated average of 150,000 gallons of storm water captured per year (estimating 6 storm events) for disposal, and $0.03 per pound disposal cost for the captured storm water.

The COTS cartridge system at the nearby shipyard cost a total of $530,000 for a 9.2 acre site, including the costs for validating the technology. Since validation costs were not included in the analysis, the costs for validating the cartridge system were deducted. The total cost was further reduced proportionally to reflect equivalent watershed areas (9.2 acres to 3.5 acres). The comparable capital cost (materials and installation) used for the cartridge system is approximately $203,000 and the annual operating cost is $14,200.

Table 16 shows the direct and indirect costs that were incurred for NRRC San Diego.

Table 16. Annualized Cost Data for NRRC San Diego (Based on 10 year service life)

Direct Costs				Indirect Costs		Other Costs	
Start-up		Operation					
Activity	$K[1]	Activity	$K	Activity	$K	Activity	$K
Design	1.5			Reporting requirements	See Below	None	None
Media purchase (initial)	1.9	Media replacement	2.7	Monitoring, inc. chemical analysis	See Below		
Equipment purchase	3.4			Test waste streams	0.2		
Installation	4.3			Permit fees	See Below		
		Annual Maintenance (Top layer)	1.7	Document maintenance	See Below		
				Permit / Document Update	4.0		
Total	11.1		4.4		4.2		0
Grand Total	19.7						

[1] Cost are in thousands of U.S. dollars ($K)

Table 17 shows the direct and indirect costs that were incurred for ANAD Alabama.

Table 17. Annualized Cost Data for ANAD Alabama (Based on 10 year service life)

Direct Costs				Indirect Costs		Other Costs	
Start-up		Operation					
Activity	$K[1]	Activity	$K	Activity	$K	Activity	$K
Design	1.5			Reporting requirements	See Below	None	None
Media purchase (Initial)	4.8	Media replacement	$6.1	Monitoring, inc. chemical analysis	See Below		
Equipment purchase	4.5			Test waste streams	0.2		
Installation	4.1			Permit fees	See Below		
		Annual Maintenance (Top layer)	1.2	Document maintenance	See Below		
				Permit / Document Update	See Below		
Total	14.9		7.3		0.2		0
Grand Total	22.4						

[1] Cost are in thousands of U.S. dollars ($K)

No fees are associated with modifying the CRWQCB permit for storm water discharges. Annual fees apply for California NPDES permits, but these fees would have applied with or without the storm water treatment system.

The system at ANAD was installed in the summer of 2006. Media replacement cost is estimated and annualized based on the actual media cost incurred during system installation. It is estimated that the top layer of pea gravel will need to be replaced every five years at a cost of $27 per ton, with 3 tons needed, and a solid waste disposal fee of $34 per ton. An estimate of $6,000 is used for labor and equipment for replacing the pea gravel. We also assumed that the filter media will need to be replaced every 10 years, though it is very likely that the media has the capacity to last longer, possibly up to 30 years. The system uses 13,000 pounds of bone char and 20,000 pounds of FS-50. An estimate of $13,000 is used for labor and equipment for replacing the filter media. The cost of labor is higher for pea gravel and media replacement at ANAD than NRRC due to site specific differences. The system at ANAD is buried underground and will likely require earthwork to remove the lids over the media bed.

5.2 Cost Analysis

The economic analysis performed on the NRRC dual media storm water filtration system was completed using the ESTCP approved ECAM cost estimating tool. The majority of the cost analysis is focused on the data from the NRRC site. The NRRC dual media filtration system provides a cost benefit over the baseline and the COTS technology. The ECAM analysis indicates the Net Present Value (NPV) of the dual media storm water filtration system at NRRC is $235,762 at 10 years with a discounted payback of 0.65 years. Based on actual adsorption tests, the media should actually last up to 30 years without requiring change out, which provides a higher NPV than reported and a much higher NPV than the baseline.

Cost of procurement and installation of the dual media storm water filtration system at ANAD is approximately the same magnitude as the NRRC despite the doubled design flow rate. Since ANAD does not have specific requirements for rainwater capture nor does the recently installed oil water separator target the same pollutants as the dual media storm water filtration system, a complete ANAD analysis was not done and the oil-water separator was not included in the ECAM comparison analysis.

5.3 Cost Comparison

The ECAM analysis indicates that the dual media storm water filtration system has greater cost savings when compared to both the COTS cartridge filters implemented at the nearby shipyard and the theoretical installation of a pump and tank system. While the initial costs for the dual media storm water filtration system are approximately $20,000 more than the baseline, the annual costs are 10 times lower per year making up for the initial investment in less than one year. The initial and annual costs are lower for the dual media storm water filtration system than the COTS alternative. In addition, the NPV of the dual media storm water filtration unit at NRRC is $235,762 and the Cartridge system is $174,604, based on a 10 year life cycle, a difference of $61,158 over 10 years.

From a standpoint of implementation at other industrial activities, there is other tangible cost benefits not calculated here that can be realized with the dual media storm water filtration system.

- Longer service life in submerged conditions (where the media bed is unable to completely drain and dry between storm events) as compared to compost adsorption media cartridge filters. (systems installed near tidal water near the sea or in areas of fluctuating water tables may be exposed to intermittent submerged conditions)
- Reduced depth of excavation (as shallow as three feet) when compared to depth requirement needs for COTS cartridge technology.
- Reduced logistics for maintenance, i.e., no air purging system and ambient air pumps required to enter confined space vault as required for cartridge filter vault.
- Reduced human exposure to the media and any heavy metal contaminants since the media can be removed with mechanical suction equipment and/or backhoes.
- Easier containment and clarification of any accidental spills to the storm systems.

- Fewer NOVs and better protection of the environment because of better pollutant removal efficiency.

5.3.1 Cost Basis

The basis for the cost of the dual media storm water filtration system was throughput of water to be treated (i.e., ¼-inch of water captured from NRRC), cost of the equipment installed, cost of the materials purchased, and the anticipated maintenance costs of each system. This was compared to the COTS technology used near NRRC and the hypothetical installation and implementation of a tank and pump system. Given these two scenarios, the economic evaluation was constructed and compared.

5.3.2 Cost Drivers

The cost of the implementing a dual media storm water filtration system is highly variable and are briefly discussed because they will impact overall cost for activities interested in implementing the technology. Site conditions such as the size of the runoff area, rainfall characteristics (intensity and duration) and pollutant loading will have a dramatic effect on cost on the dual media storm water filtration system or any storm water BMP implementation. Other factors that could affect the cost of the system include runoff coefficient, water table, topography, receiving water/sewer elevation, and runoff contaminant characteristics. An area with a larger drainage basin size would require a larger system. Areas that tend to have more intense rainfall will also require a larger system. The topography of the drainage basin as well as the receiving water/sewer elevation would influence whether a pump is needed or not. The runoff contaminant characteristics would influence the frequency required for cleaning the top layer of pea gravel as well as the frequency of changing out the media. Other factors include location of the site with regards to proximity to landfill disposal sites and shipping distance for from media distribution points. Local wages and construction cost will impact final cost.

6.0 IMPLEMENTATION ISSUES

6.1 Cost Observations

There were several factors affecting the cost of treating storm water runoff with a multi-media filter: design cost, construction cost, and maintenance cost. For this project we used standard filter housing to contain the media that will treat storm water runoff. The filter housing was made in pre-cast concrete sections in a factory and was trucked to the job site. Oldcastle Precast, Inc., was one supplier of sectional pre-cast concrete vaults for storm water runoff.

The cost of the pre-cast filter media container for NRRC, including shipping, was approximately \$33,000. The filter system required approximately \$19,300 worth of media. Installation labor cost at NRRC San Diego was approximately the same as the materials, or about \$43,000.

The cost of the pre-cast filter media container for ANAD, including shipping, was approximately \$45,500. The filter system required approximately \$40,800 worth of media. Installation labor cost at ANAD was approximately \$41,250. The higher cost at ANAD for the pre-cast filter media container and the media was due to the larger design size at ANAD. The system at ANAD was designed for a maximum treatment rate of 500 GPM while the system at NRRC was designed for a maximum rate of 275 GPM. Therefore, is should be understood for future installations that larger treatment systems will have an increased cost than these demonstrated systems. This increased cost may not be linear with treatment area.

Annual maintenance of the filter will be required. While the system was designed as a passive system, this requirement is unavoidable. The maintenance interval will depend on the volume of water processed and the amount of suspended solids removed by the filter bed. The media filter used at ANAD has an integral dual-pretreatment chamber that should capture a large portion of the sediment load. As the top of the filter accumulates fine particles, the resistance to flow will increase. For this demonstration, the filter will be cleaned by removing the thin layer of material from the top layer of media. For the system in ANAD, the accumulated sludge and debris in the pretreatment chambers will have to be removed occasionally.

Another potential method of cleaning the filter is backwashing, which forces clean water upward through the filter, lifting the particles off the media and carrying them into a chamber where they can be later removed. This would require more capital expenditures for valves, pipes, and controls, may result in media loss, and create a large volume of contaminated water that must be disposed. Backwashing was not used in this demonstration.

It was also decided that manual cleaning of the filter system was more cost effective than implementing an automated system, which would increase the capital cost and increase the complexity of the system (power requirements, mechanical breakdowns).

6.2 Performance Observations

The primary goal is passage of the bioassay test. Passage of the bioassay test is a requirement of CRWQCB Order R9-2002-0169. Reducing the copper and zinc concentrations in the runoff water to the levels stated previously will assure a high probability of passage of the toxicity test.

Both the NRRC and ANAD systems met nearly all of the ESTCP performance criteria. Both systems were shown to be effective, reliable, and ran operator-free during the demonstration. The bioassay tests on the NRRC system were met once modifications were made to the filter media design, and while the concentrations of copper and zinc were initially high, the concentrations were lowered dramatically after the system modification. Additionally, the 122 μg/l zinc concentration falls within 4% of the 117 μg/l performance criteria.
The capital investment of the ANAD system was approximately $17K per acre higher than the desired $50K per acre criteria, but as this was a secondary performance criterion, and as the other performance criteria for the ANAD system were met, this was found to be acceptable.

In all, the major factor that affected the performance of the NRRC unit was that it was hypothesized that storm water was bypassing the media bed along the perimeter walls of the vaults (edge effects), resulting in partial treatment of the influent, and non-optimal media bed performance. Additional flaps of geofabric were glued to the perimeter walls of the vaults, above an existing sheet of geofabric, to decrease edge effects and redirect the influent to flow through the center of the media bed. The reconfiguration did redirect flow through the center of the media bed, but significantly decreased the porosity of the top fabric layer. Therefore, the top layer of geofabric was replaced with a more porous mesh to reduce the flow restriction through the top fabric layer, and prevent premature clogging of the media bed. The high removal efficiencies for copper and zinc are a direct result of minimizing undesirable edge effects, and redirecting flow through the center of the media bed. The 45% survivability rate observed during toxicity testing could very well be attributed to low dissolved oxygen levels in the acute toxicity test chambers, but as Nautilus Environmental states, it is not clear whether low dissolved oxygen levels or a toxic substance in the sample caused mortality.

6.3 Scale-up

As both units installed at NRRC and ANAD are full scale functioning units. The dual media storm water filter system is a combination of commercially available components that are customized to meet site-specific end user requirements. The system could eventually be made available in modular units that treat a specific volume of storm water. The technology is scalable in a 1:1 ratio. If the runoff volume at a site is double that at NRRC, the size of the treatment system will double; if the runoff volume is half, the size of the treatment is will be halved.

6.4 Other Significant Observations

Different designs of the dual media filter may need to be used for different situations. For example, there existed a site constraint at NRRC which precluded using a Washington DC type sand filter. Also, depending on the dimensions of the filter needed, activities need to also consider size of the pre-cast concrete section (i.e. can it be transported, does it need to be poured on site, etc.). This could be cause for significantly more time, cost, and regulatory issues.

Other significant occurrences that would influence the implementation of this technology are: proper elevation topography, which was a problem at ANAD (drain elevation vs. water table height), whether pumping/piping water is necessary, price changes in media, changes in emissions requirements, unplanned spillage of toxic materials (hydrocarbons, other) into dual media filter, and potential blockage of the filter media bed.

The disposal of used media is governed by local regulations. For the NRRC demonstration, the regulating body is the CRWQCB. Whether the used media is disposed of as a solid or hazardous waste requires collecting samples and sending to an EPA certified lab for analysis. One or more of the following test may be required; soluble threshold limit concentration (STLC), toxicity characteristic leaching procedure (TCLP), or the wet extraction test (WET). Since the pollutants in storm water vary from site to site, it is difficult to predict every outcome. For planning and budgeting purposes it is advisable to assume that the spent media is hazardous until determined otherwise.

6.5 Lessons Learned

Lessons learned from this demonstration are listed below:

- For planning purpose, used media should be assumed to be hazardous at the end of service life.
- The dual media filtration system performs significantly better with a geofabric flap around the perimeter walls to direct flow toward the center of the media bed.
- Automatic sampling equipment is prone to fault interruptions and mal-functioning. Any future sampling should include full protection of sampling equipment from stray electrical current to prevent fault interruptions. Furthermore, future sampling should include manual sampling during storm event to insure the maximum amount of available data.
- Test planning should account for possible drought conditions.
- The porous curbs developed as a coarse filter and sediment trap were easily plugged and are not recommended as a stand-alone pretreatment on future system installations.
- Verify tail water hydraulics in receiving waters and as-built construction elevations before final design and construction of concrete vault system.
- NAVFAC ESC should consider developing modular treatment system that can be nested together to treat storm water. Modular systems are more likely to be commercially accepted/produced than custom designs.

6.6 End-User Issues

Based on the results of these demonstrations, NAVFAC ESC recommends that DoD use the dual media filter system where storm water discharge requirements are stringent and protection of the receiving water body is vital. Coordination and approval with state regulators is imperative.

Potential end users in the San Diego area include the Naval Station San Diego, Naval Air Station North Island, Amphibious Base Coronado, Marine Corps Base Camp Pendleton, Naval Supply Center San Diego, Submarine Base Point Loma, and the Ship Intermediate Maintenance Center San Diego. Each of these activities has multiple storm water outfalls. (At the conclusion of this project, CNRSW began designing a second dual media treatment system at a nearby industrial yard.)

The primary stakeholder issues related to the technology are regulator acceptance, permitting requirements, and maintenance requirements. NPDES permits will be the regulatory drivers, as well as TMDLs.

Commander Navy Region Southwest (CNRSW) is an example of a major stakeholder in California. CNRSW holds the discharge permits for all Navy and Marine Corps activities in the San Diego area and is responsible for compliance. CNRSW will need to work closely with the CRWQCB to permit future use of the dual media filter system.

6.7 Approach to Regulatory Compliance and Acceptance

6.7.1 Navy Regional Recycling Center, San Diego, California

Storm water discharges are regulated under the CWA through the NPDES permitting program. The Office of the Commander Naval Region Southwest has worked with the CRWQCB, San Diego Region, to get a modification to the existing storm water NPDES permit to allow the installation of the storm water dual media filter system. The modification is entitled, "Addendum No. 1 to Order No. R9-2002-0169, NPDES Permit No. CA0109169."

The Federal law governing the proper management of hazardous and non-hazardous solid waste is the Resource Conservation and Recovery Act (RCRA). Federal regulations related to hazardous waste can be found in 40 CFR Part 261. California regulations can be found in the California Code of Regulations, Title 22 Chapters 11 and 12.

NRRC should follow California regulations for determining the proper management of hazardous waste given that California regulations are presently more stringent than federal regulations. Solid waste generated by the storm water dual media filter system, such as spent media and trapped sediment, should be tested using the Waste Extraction Test (WET) procedure each time the system is maintained to ensure that it cannot be characterized as a hazardous waste.

The demonstration period WET results for sediment and gravel that were sampled from the top layer of the dual media filter system during annual maintenance indicate that the solid waste can likely be disposed of as non-hazardous. However, spent media requiring replacement upon reaching the end of its lifespan will likely have to be disposed of as hazardous waste.

Another regulatory issue is the amount of metals that enter San Diego Bay if the storm water runoff is "terminated" as compared to if the storm water runoff is treated. CNRSW expects that the reduced amount of contaminants that enter San Diego Bay when the runoff is treated as compared to when only the first ¼-inch is "terminated" to a be significant factor in convincing regulators to approve this technology for widespread use.

The amount of water that CRWQCB Order R9-2002-0169 requires to be “terminated” will be 43,560 sq ft/acre x 0.25 inch/12 x 7.48 gal/cu ft = 6,788 gallons per acre per storm for each storm. Assume that all storms of greater than ¼-inch of rainfall (15 storms total) produce at least ¼-inch of runoff, i.e. all rainfall runs off. For the 3.55 acres of paved area at the NRRC, this amounts to 24,100 gallons of water that will have to be collected and either 1) stored for haul away to a disposal site or 2) slowly released into the sanitary sewer system (if permitted). A total of 24,100 gallons/storm x 15 storms/ year = 361,500 gallons/year must be “terminated”.

Historically, the average annual rainfall in San Diego is 10.2 inches. Thus, 43,560 sq ft/acre x 10.2/12 x 7.48 gal/cu ft x 3.55 acres = 983,200 gallons runs off the NRRC site. Thus, only 37% of the rainfall will be terminated under the CRWQCB ¼” rule. In years when the size or number of storms exceeds the historical average, the proportion of runoff terminated will be lower than 37%. By comparison, if a treatment system is installed, more than 90% of the water will always be treated.

6.7.2 Anniston Army Depot, Alabama

The Directorate of Risk Management at ANAD has determined that a new NPDES permit or a permit modification is not required to install the demonstration storm water treatment system. This is because the permit governing the discharge from the demonstration site requires only that the discharge be monitored, not meet specific discharge limits.

Alabama regulations related to hazardous waste generally follow the Federal regulations, and can be found in Alabama Department of Environmental Management Administrative Code Chapter 335-14-2.

6.7.3 Acceptance

NAVFAC ESC will work with transferring the technology to the Army via the US Army Corp of Engineers upon final ESTCP approval of this report. The approved Final Report and this Cost and Performance Report also will be sent to the Technology Acceptance and Reciprocity Protocol office for potential technology transfer. Specific points of contacts for each entity have been identified and are awaiting final approved report. NAVFAC ESC is currently working with Techlink to identify commercial partnership.

Future development of the technology will focus on developing a modular system to draw higher interest for commercialization in the private sector.

For additional information on this technology go to https://www.denix.osd.mil/portal/page/portal/denix/publications/source/Navy/Currents/2006/Winter/Win06_Technology_Tips.pdf

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8.0 POINTS OF CONTACT

Table 18. Points of Contact

Point Of Contact Name	Organization Name Address	Phone/Fax/Email	Role in Project
Gary Anguiano P.E.	NAVFAC ESC 1100 23RD Avenue Port Hueneme, CA. 93043	(805) 982-1302 (voice) (805) 982-4832 (fax) gary.anguiano@navy.mil	NAVFAC ESC Principal Investigator
Mark Foreman	NAVFAC ESC 1100 23RD Avenue Port Hueneme, CA. 93043	(805) 982-1334 (voice) (805) 982-4832 (fax) mark.foreman@navy.mil	NAVFAC ESC Mechanical Engineer
Gene Fabian	U.S. Army Aberdeen Test Center TEDT-AT-SL-E 400 Colleran Road APG, MD. 21005-5059	(410) 278-7421 (voice) (410) 278-1589(fax) gene.fabian@us.army.mil	Technology transfer specialist and QA officer
Neil Weinstein P. E.	Low Impact Development Center, Inc. 5010 Sunnyside Avenue, Suite 200, Beltsville, MD 20705	(301) 982-5559 (voice) nweinstein@lowimpactdevelopment.org	Consultant and deputy QA officer
Ronald Levy	Anniston Army Depot 6 Frankfort Ave (AMAST-AN-RKR) Anniston, AL 36264-4199	(256) 235-4804 (voice) Ron.Levy@us.army.mil	ANAD representative
Charlie Ketcham	Navy Region, Southwest Mainside Complex 4790 Cummings Road, San Diego, CA 92136-5610	(619) 556-5149 (voice) (619) 556-9018 (fax) Charles.Ketcham@navy.mil	NRRC representative
Rob Chichester	CNRSW Environmental Department (Code N45) San Diego, CA 92132-0058	(619) 532-2611 (voice) Rob.chichester@navy.mil	NRRC Regulatory Review
Tracy Williams	Anniston Army Depot 7 Frankfort Ave (AMAST-AN-RKR) Anniston, AL 36201-4199	(256) 235-7947 (voice) tracy.lynne.Williams@us.army.mil	ANAD Environmental Oversight
Marti Elder	TechLink Licensing & SBIR 2611 Westridge Dr. Bozeman, MT 59715	(406) 586-7621 (voice and fax) www.martielder.com	Technology Transfer