Portable System for Field-feeding Greywater Remediation and Recycling
SI-0310

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AFSC	Advanced Food Sanitation Center
AVG	Average
BOD	Biological Oxygen Demand
CASCOM	Combined Arms Support Command
CBOD	Carbonaceous Biological Oxygen Demand
CK	Containerized Kitchen
COD	Chemical Oxygen Demand
CFD	Combat Feeding Directorate
CFR	Code of Federal Regulations
COTS	Commercial Off The Shelf
CU	Color Units
CWA	Clean Water Act
DTIC	Defense Technical Information Center
DO	Dissolved Oxygen
ECAM	Environmental Cost Analysis Methodology
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EET	Equipment & Energy Technology Team
FM	Field Manual
FSC	Food Sanitation Center
lbs	Pounds
gal	Gallons
gpd	Gallons Per Day
gph	Gallons Per Hour
hp	Horse Power
KP	Kitchen Police
KW	Kilowatt
gph	Gallons per Hour
L	Liter
LCCE	Life Cycle Cost Estimate
MANPRINT	MANpower and PeRsonnel INTegration
MTR	Membrane Technology Research
METT-T	Mission, Enemy, Terrain, Troops & Time Available
mg	Milligrams
MRE	Meals, Ready-To-Eat
MWCO	Molecular Weight Cut Off
NO_2/NO_3	Nitrite/Nitrate Nitrogen
NSC	Natick Soldier Center
NTU	Nephelometric Turbidity Unit
O&G	Oil and Grease
O&M	Operation and Maintenance

OFIG	Operational Forces Integration Group
ORD	Operational Requirements Document
P3I	Pre-Planned Product Improvement
pH	Hydrogen Ion Concentration
PM	Program Manager
PMCS	Preventative Maintenance Checks and Services
RDECOM	Research, Development, and Engineering Command
SOP	Standard Operating Procedure
SU	Standard Units
TB	Technical Bulletin
TDS	Total Dissolved Solids
TPhos	Total Phosphorous
TSS	Total Suspended Solids
USACHPPM	U.S. Army Center for Health Promotion and Preventative Medicine
UGR	Unitized Group Ration
VAC	Volts, AC (Alternating Current)
VCD	Vapor Compression Distillation / Vapor Compression Distiller

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ABSTRACT

The Army requires a portable greywater treatment system to remediate and recycle dirty sink water from its field feeding and sanitation operations. A greywater recycling system is expected to reduce field kitchen demand for fresh water by 55% and wastewater hauling expenses by 80%.

Under an Environmental Security Technology Certification Program (ESTCP) funded project, three systems were demonstrated at Ft. Lee, VA, in August 2004 as part of the "Log Warrior Training Exercise." The field test lasted two weeks and each of the three systems was operated out-of doors treating water created during actual field feeding operations. Water samples were taken before and after treatment. Systems were evaluated for water quality, percent reduction of contaminants, permeate flow rate, weight, and size.

There are no firm Environmental Protection Agency (EPA) regulations regarding the quality of recycled greywater for use in ware washing, so for the purposes of this study, the water was considered to be recyclable if it met the EPA Secondary Treated Water Quality (part of the Clean Water Act) outlined in the Code of Federal Regulations, 40 CFR 133.102[1]. This is defined by the following: biological oxygen demand (BOD) of 30 mg/L or less; total suspended solids (TSS) of 30 mg/L or less; pH between 6 and 9. In addition recyclable water should have a turbidity of 5 NTU or less. The rational for specifying Secondary Treated water is twofold; if the treated greywater is accidentally discharged to surface water such as a lake or stream, the water would be considered clean enough to do so. Secondly, most states with greywater reuse regulations[2] base their water quality standards on the Secondary Treatment standard.

In addition, each system's process rate was required to be fast enough to process the entire bulk of greywater before the next meal. The following tables summarize the results and indicate if the treatment systems passed or failed to meet any of the requirements.

Table A-1: System Performance Summary

System	Technology	Weight (lbs)	Permeate Flux Rate (gph)
Infinitex Splitter XD	Spiral-Wound Ultrafiltration	150 PASS	18 PASS
Bristol International	Tubular Ultrafiltration	150 PASS	16 PASS
Ovation Products	Vapor Compression Distillation	300 FAIL	23 PASS

Table A-2: System Performance Summary (cont.)

System	Permeate Quality					Volume Reduction
	BOD (mg/L)	TSS (mg/L)	O&G (mg/L)	Turbidity (NTU)	pH	
Infinitex Splitter XD	291.2 FAIL	3.8 PASS	6.9	4.7 PASS	6.1 PASS	91 %
Bristol International	447.3 FAIL	28.4 PASS	62.2	12.8 FAIL	5.8 FAIL	77 %
Ovation Products	17.3 PASS	1.4 PASS	5.6	2.1 PASS	7.0 PASS	88 %

The Ovation Products' vapor compression distillation (VCD) system produced the best quality permeate at an average flow rate of 23 gph. As shown in Table A-1 and Table A-2, the permeate had an average BOD of 17.3 mg/L, TSS of 1.3 mg/L, oil and grease (O&G) of 5.6 mg/L and turbidity of 2.1 NTU. It reduced the volume of greywater by 88%, the BOD by 99%, the TSS by 99%, the O&G by 96%, and the turbidity by 99%. It was, however, the heaviest system, weighing over 300 lbs and was not considered "field worthy" in its current configuration.

The permeate from the Infinitex Splitter XD spiral-wound ultrafiltration system had a BOD higher than the requirement but performed well in every other category. It reduced the volume of greywater by 91% and operated at an average flow rate of 18 GPH. It reduced the biological oxygen demand (BOD) by 78%, total suspended solids (TSS) by 98%, oil and grease (O&G) by 90%, and turbidity by 91%. The permeate had an average BOD of 291.2 mg/L, TSS of 3.8 mg/L, O&G of 6.9 mg/L, and turbidity of 4.7 NTU.

The results also showed that Bristol International's tubular ultrafilter system did not produce an acceptable permeate having a BOD of 447.3 mg/L, TSS of 28.4 mg/L, pH of 5.8, and turbidity of 12.9 NTU. As a result of its poor performance, the cost analysis for this system was not performed.

The VCD system displayed exceptional water quality but had a physical configuration that was too heavy and complicated while the both of the ultrafilter physical configurations were rugged and lightweight but displayed a sub-par water quality. A 1-year follow-on study was recommended to test Ovation Products' next generation prototype. Also work is proposed to the Surgeon General of the Army to develop new guidelines for greywater recycling.

The cost savings realized by any of these systems will be significant, as they will drastically reduce the cost of potable water and greywater disposal. Based upon average water and disposal costs, the estimated saving for the ultrafiltration system is $32.5 million per year for 25 years. The VCD system will save slightly more because of lower capital costs. It is estimated to save $33 million per year for 25 years.

1. INTRODUCTION

1.1. BACKGROUND

Army field-feeding generates hundreds of gallons of greywater each day, mostly the by-product of washing cookware after the meal. Current dishwashing operations use a three-sink Food Sanitation Center (FSC) that requires approximately 250 gallons of fresh water per day, and generates an equivalent amount of greywater. The current disposal approach is to store the greywater in large sump tanks or bladders and then backhaul it for proper disposal. This becomes a logistical and environmental burden because local storage fills quickly, and contracted waste removal services are expensive and can be hard to coordinate with erratic greywater generation. This can result in disposal of untreated greywater to the ground. While there is currently no specific EPA or Army regulation that prevents this, the practice poses health problems and harms the environment by adding high concentrations of BOD, promoting bacteria blooms..

A water treatment and/or recycling system is needed to reduce water consumption and greywater disposal while reducing the potential environmental impact. A requirement for such a device is stated as a pre-planned product improvement (P3I) in the Operational Requirements Document (ORD) for the FSC [3] currently being procured by the Army. Three greywater reduction systems are being considered, two different configurations of ultrafiltration (spiral-wound and tubular) and vapor compression distillation (VCD).

Each system has its advantages. The spiral-wound ultrafiltration device has a very simple construction; its only moving part is a pump. Sized to process 250 gallons per day, its membranes can remove more than 90% of O&G and 90% of the TSS. The effluent is then safe to dump directly on the ground; however, without regulatory approval, it is unclear whether the effluent is fit for reuse or not.

The tubular ultrafilter produces an effluent with similar properties as the spiral-wound unit. It is slightly larger in size, but requires no pre-filtration of the feed whatsoever. The third system being investigated uses VCD, a low powered, two-stage distillation process. Utilizing innovative engineering techniques and lightweight materials, the manufacturer has been able to shrink the size and weight of the VCD process considerably. And because it's distilled, the system outputs almost pure water which may allow for recycling of the water back into the wash and rinse sinks. While the existing design is small, it is much heavier and more fragile than either of the ultrafiltration systems and may pose more maintenance issues.

1.2. OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration was to measure the performance of three portable greywater systems as used with Army FSCs and determine the feasibility of each of the technologies used. Performance is measured by reducing the levels of contaminants in the feed water to comply with EPA standards for Secondary Treated Water, as outlined in the Clean Water Act (CWA), 40 CFR 133.102[1], and below in Table 1-1.

Table 1-1: Secondary Treated Water (CWA, 40 CFR 133.102)

BOD-5 day	(1) The 30-day average shall not exceed 30 mg/l. (2) The 7-day average shall not exceed 45 mg/l. (3) The 30-day average percent removal shall not be less than 85 percent.
TSS	(1) The 30-day average shall not exceed 30 mg/l. (2) The 7-day average shall not exceed 45 mg/l. (3) The 30-day average percent removal shall not be less than 85 percent.
pH	The effluent values for pH shall be maintained within the limits of 6.0 to 9.0 unless the publicly owned treatment works demonstrates that: (1) Inorganic chemicals are not added to the waste stream as part of the treatment process; and (2) contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0.

The parameters being tested and their definitions are listed below:

Table 1-2: Testing Parameters

Test	Definition
BOD-5 day	A measure of the amount of oxygen used by aerobic bacteria in a 5-day period to decompose the organic matter in water. An indirect measure of the amount of nutrients in water.
Carbonaceous BOD - 5 day (CBOD)	CBOD is the result of the breakdown of organic molecules such cellulose and sugars into carbon dioxide and water.
Chemical Oxygen Demand (COD)	Measures the amount of the organic matter in wastewater that can be oxidized (burned up) by a very strong chemical oxidant.
Total Suspended Solids (TSS)	Concentration of total suspended solids in water
Total Dissolved Solids (TDS)	Concentration of total dissolved solids in water
Oil & Grease (O&G)	Concentration oils and greases water
pH (SU)	A measure of hydrogen or hydroxide ions available in water and given on a 0-10 scale. Numbers under 7 are acidic and above 7 are basic.
Phosphorous, Total (Tphos)	Concentration of phosphorous in water
Nitrogen, Nitrate/Nitrite (NO_2/NO_3)	Soluble forms of nitrogen that act as nutrients for bacteria, algae, and plants. Too much can cause pollution.
Turbidity (NTU)	The relative clarity of water that can be affected by suspended and dissolved solids.
Color (CU)	The color of the effluent water that can be affected by suspended and dissolved matter.

1.3. REGULATORY DRIVERS

While the primary driver of this technology is cost savings through the streamlining of logistics, environmental regulations heavily shape the performance requirements. In many units, the standard operating procedure is to dispose the greywater in a leach pit, a practice that causes environmental damage, attracts pests, and can pose a health risk. In many sites, this practice has been replaced with collecting and backhauling the greywater; an expensive practice that requires contractor support.

1.4. STAKEHOLDER / END USER ISSUES

The primary stakeholder is the combat developer, the US Army Combined Arms Support Command (CASCOM). This demonstration addressed their concerns for a low-powered, light, durable system that is easily operated by inexperienced soldiers performing kitchen police (KP) duties.

This demonstration did not address cold weather operation, a requirement for both this system and the system that it supports, the FSC. This requirement will be addressed when choosing between systems.

As with much Army field kitchen equipment, systems are designed so that most parts are field replaceable and only a few maintenance actions require a depot. In the case of Infinitex's Splitter XD ultrafilter, the only moving part is the pump. All the other parts such as the ultrafilters, the hoses, the housings and the fittings can be replaced in the field.

The Ovation Products VCD system is more complex and unique and would require many maintenance actions to be performed in a depot. The extent of time spent on maintenance and in a depot will have to be determined before the decision to procure the item.

2. TECHNOLOGY DESCRIPTION

2.1. TECHNOLOGY DEVELOPMENT AND APPLICATION

2.1.1. Infinitex's Splitter XD Ultrafilter

The Infinitex Splitter XD is a small, Commercial Off-the-Shelf (COTS) ultrafiltration system that utilizes a semi-permeable spiral-wound membrane in a cross flow configuration to filter water. Ultrafiltration membranes typically have molecular weight cut off (MWCO) values between 5000 and 120,000 Daltons. The membrane selected with this unit has a MWCO of approximately 8000 Daltons, meaning approximately 90% of all material that passes through the membrane is 8000 Daltons or smaller, corresponding roughly to a pore size of 0.005 µm. As Figure 1 shows, the membrane will reject bacteria, viruses, and some proteins, but not sugars or aqueous salts [4].

The filters are made by rolling a sheet of membrane with a spacer to create a spiraling tube. This rolled filter fits into standard 20-inch filter housing. Pressurized water is forced in one end of the roll. Because the water flow is parallel to the membrane, also called crossflow, most of the water is passed through unfiltered and returned to the feed tank so that it has another chance to be filtered. The sheering action of the water on the membrane helps to reduce fouling. Figure 2 shows how normal filtration allows more build-up of solids on the membrane surface than crossflow filtration [5]. The filtered water (permeate) is collected in a tube that runs through the center of the roll, and discharged through a small permeate tube.

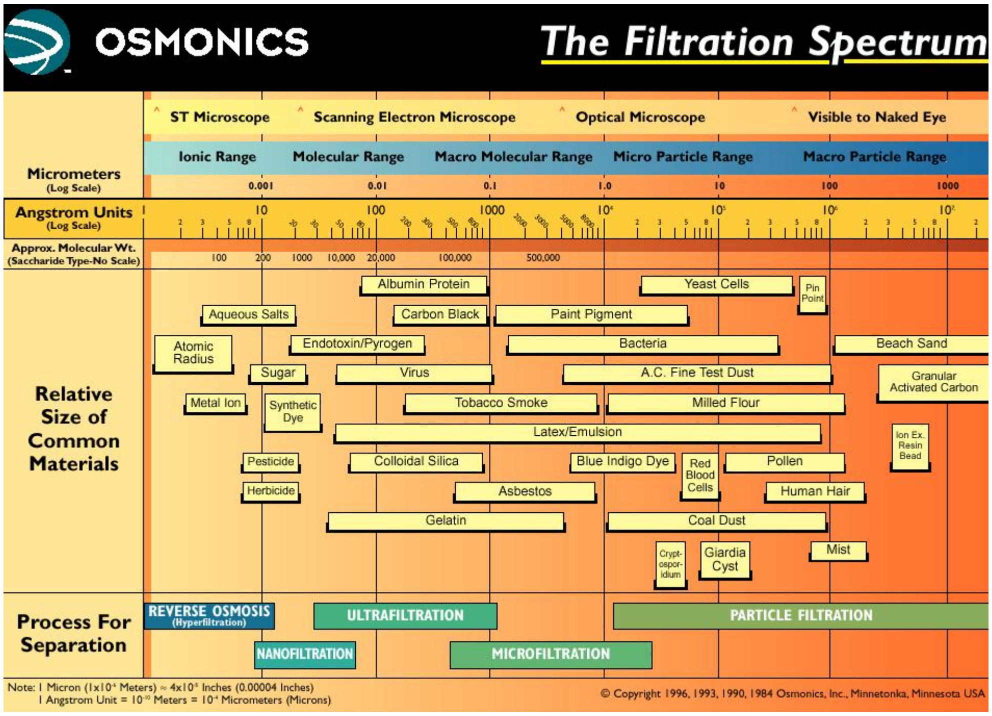

Figure 1: The Filtration Spectrum

The Infinitex Splitter XD, shown in Figure 3, uses two 20-inch membranes in parallel to filter approximately 250-300 gal of waste water per day (gpd). It is equipped with a 1.5 horsepower (hp) centrifugal pump (1120 watts) that operates on 120 VAC power. The inlet and recycle ports are equipped with quick disconnect fittings and valves on the supplied hoses. The effluent outlet is also equipped with a ball valve. The front panel features a pressure gauge and a power switch. An on-board logic board performs several safety functions as well as timed cleaning cycles. Backwashing is not needed; membrane cleaning is performed by pulsing water at high pressures through the membrane. Typically, a specialized membrane cleaner solution is used; however, Infinitex is confident that the detergent used in the washing process will act as a membrane cleaner. The overall dimensions of the Splitter XD are 17” x 22” x 39” and it weighs 150 pounds (lbs).

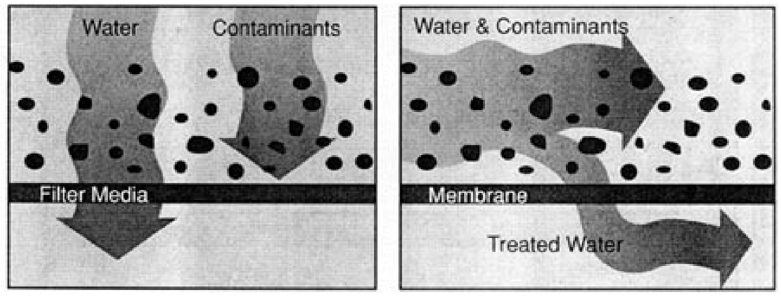

Figure 2: Normal Filtration (left) vs. Crossflow Filtration (right)

2.1.2. Bristol International’s Tubular Ultrafilter

Bristol International’s tubular ultrafiltration system (Figure 4) works on the same principle as the spiral-wound ultrafiltration system but in a different configuration. The ultrafiltration membrane is shaped into a five-foot long tube with a diameter of just under one inch. The tube is mounted inside a 1" nominal chlorinated poly (vinyl chloride) (PVC) tube with a spacer on the outside. As water passes over the membrane, some water and other small molecules are allowed to pass through, while the bulk of the feed passes by. The concentrated feed is returned to the feed tank. The feed is recirculated and concentrated until it is approximately 10% of its original volume. The Bristol International system was initially outfitted with 120,000 Dalton MWCO membranes but was upgraded (solids exclusion) to 75,000 Dalton MWCO membranes for use in this technology demonstration.

2.1.3. Ovation Products’ Vapor Compression Micro-Distiller

The Ovation Product’s micro-distillation system is shown in Figure 5. It uses mechanical VCD to achieve high efficiencies. It is able to process nearly 20 GPH of wastewater using only 750 W of power, but weighs approximately 300 lb,. The following excerpt for the Ovation Products’ website explains the system and the technology:

“Mechanical vapor compression-distillation is a well-known, highly refined industrial process. The technique has been applied to many processes for concentration of fluids in such diverse applications including desalination, dewatering of food products (whey, vegetable and juice concentrate), and chemical and petroleum refining. Figure 6 shows the flow arrangement of a basic vapor compression-distillation process for a dilute water stream. In operation, steam drawn from the evaporator is compressed, so that it can be condensed at a higher temperature. Droplets

Figure 3: Infinitex's Splitter XD Ultrafilter

Figure 4: Bristol International's Tubular Ultrafilter w/ Tank

Figure 5: Ovation's Mechanical Vapor Compression Distiller

of the liquid are separated before entering the compressor. The condensation of the compressed steam occurs in a heat exchanger that transfers the latent heat of vaporization to the incoming water, evaporating additional liquid. The same heat exchanger serves as both an evaporator on one side and condenser on the other. The temperature difference (and associated pressures) between the two streams can be quite small, resulting in very little power input to the compressor. Additional heat is recovered in secondary counter-flow heat exchangers in which the cold incoming water is heated to nearly the same temperature as the outgoing hot streams.

Nearly all [pre-existing] vapor compression-distillation applications involve very large-scale systems for which the designs are not easily transferred to “appliance type” water treatment systems. In particular, problems of handling and disposing of a dilute wastewater effluent containing suspended solids as well as dissolved gasses and solids are quite considerable on small- scale systems. Ovation's technology deals with these problems in four distinct stages: particulate filtration, degassing, distillation, and final heat recovery. In operation, the incoming water first passes through a 20-micron pre-filtration stage. After being filtered, the incoming water flows through a highly effective (95%) counter-flow heat exchanger, raising its temperature to above 205° F. Dissolved gases and low temperature boiling point volatiles are vented from the water before entering the evaporator. Also, to limit the build-up of concentrated contaminates in the evaporator, a fraction of the liquid, about 15% of the incoming flow, is continuously discharged to the drain. The evaporating water, at a temperature of 212°F, is compressed to a pressure of 25-40 inches water column (0.9-1.4 psig), an equivalent saturation temperature of 214.5- 217°F. At this elevated pressure, the steam condenses as clean condensate. The hot condensate is then cooled down in the counter-flow heat exchanger by the incoming cold water, to nearly 205° F. Based on these operating parameters, the specific distillation energy requirement over the expected operating pressure range is quite low, estimated to be 25-35 Wh/gal.” *Source: Ovation Products Corporation, Nashua, NH*

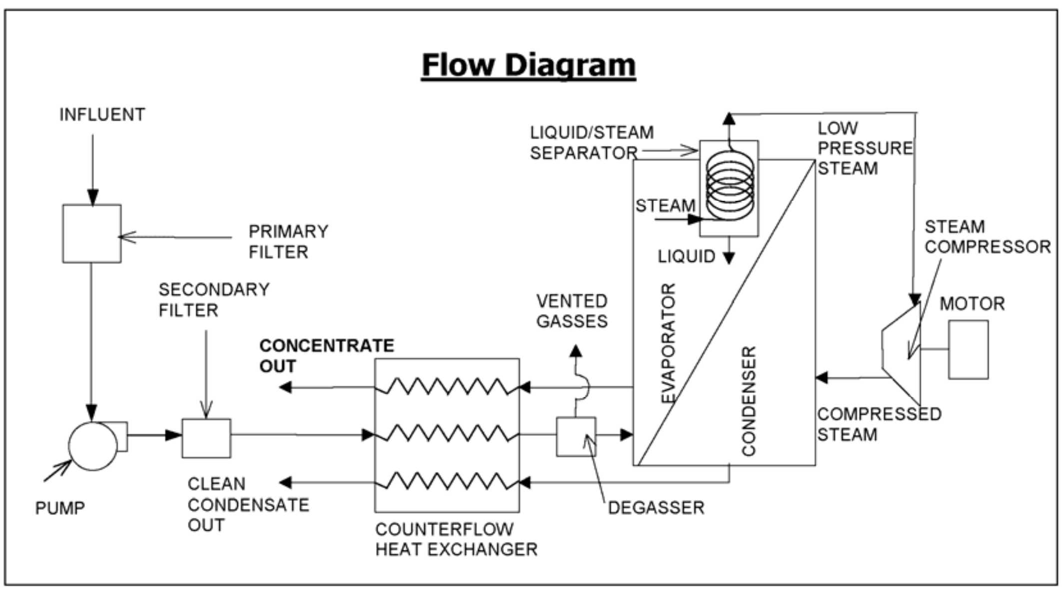

Figure 6: Mechanical Vapor Compression-Distillation Flow Diagram

Source: Ovation Products Corporation, Nashua, NH

2.2. PREVIOUS TESTING OF THE TECHNOLOGY

Engineers at the Natick Soldier Center (NSC) have tested COTS ultrafiltration systems extensively for this application. Although no studies have been published, ultrafiltration has been compared to many filtration methods, including: oil separation, filter bag media, woven filter cartridges, spin filtration, passive ceramic filtration, and single stage distillation.

Ovation Products is the only company to provide micro VCD as a COTS item. Another New Hampshire company, DEKA is working on similar technology but is not at a point in their development to offer a system for demonstration. The Ovation Products' micro-distillation unit is the first of its kind and the only such unit to be tested at the NSC for this application.

Tests were focused on measuring permeate flow rate, permeate quality, and percent reduction of contaminants. The Infinitex Splitter XD ultrafilter was tested with multiple membranes, including ultrafiltration membranes, and nanofiltration membranes.

Each system was tested with simulated greywater or "challenge water" made from canned chili con carne, baked beans, vegetable oil, and powdered soap in the proportions shown in Table 2-1. The food mixture was designed to resemble greywater encountered at previous field tests.

Table 2-1: Simulated Greywater Recipe

Ingredient	Per gal	80 gal	110 gal	165 gal
Food Mixture	0.015 L	1.25 L	1.67	2.5 L
Vegetable Oil	5.24 mL	430 mL	577 mL	865 mL
Soap	0.0136 lbs	1.125 lbs	1.5 lbs	2.25 lbs

Table 2-2 gives an overview of data collected during in-house tests.

Table 2-2: Average Results from Previous Testing

System	Permeate Flow Rate (GPH)	BOD (mg/L)	TSS (mg/L)	pH (mg/L)	Oil and Grease (mg/L)	Turbidity (NTU)	Comments
Bristol Ultrafilter w/ 200,000 MWCO tubes	41	200	8.8	10	10.5	5.8	BOD too high. Decided to trade extra flow rate for permeate quality
Bristol Ultrafilter w/ 75,000 MWCO tubes	8.9	190	0	10	5.3	0.2	

Ovation Beta 2 (VCD)	4.8	10.5	0	7.0	0	2.6	Flow rate too slow but good water quality results
Infinitex Splitter XD Ultrafilter	8.7	210	12	9.7	4.5	1.8	BOD high, but good turbidity. Poor prefiltration contributed to sub-optimal results
Infinitex Nanofilter	5.3	7.0	0.0	n/a	0	9.6	Flow rate too low
Ceramic Filtration	3.6	200	38	6.9	38	50	Low flow rate – fragile design
Mesh spin-filtration	65	610	230	6.4	16	68	Inadequate filtration

Using these results, the Infinitex Splitter XD spiral-wound ultrafilter, the Bristol International tubular ultrafilter and the Ovation Products VCD were chosen to be field tested.

2.3. FACTORS AFFECTING COST AND PERFORMANCE

There are several factors affecting cost and performance in ultrafiltration:

1) Membranes flux capacity vs. water quality
    a. Membranes with higher MWCO values and yield an effluent of marginal quality have a high flux capacity. Quality refers to the levels of BOD, CBOD, pH, TSS, TDS, turbidity and O&G concentration in the effluent, according to Table 2-3. However, only a few of these membranes are required to achieve the effluent flow requirement of 250 gallons/day.
    b. Membranes with lower MWCO values and yield a higher quality effluent have a low flux capacity. Therefore, a greater number of these membranes are required to achieve the flow requirement.
    c. As an example: Using a membrane with a MWCO of only 200 Daltons yields BOD levels below 10 mg/L, zero suspended solids and turbidity around 1 NTU. However, the permeate flow rate was less than 7.8 GPH. By comparison, an 8000 Dalton MWCO filter with the same surface area had an average permeate flow rate of 12 GPH, BOD levels around 200 mg/L, and turbidity levels close to 1.5 NTU. Membranes with 200,000 Dalton MWCO tested to have a flux of 42 GPH, but result in a permeate with BOD levels averaging greater than 200 mg/L and turbidity greater than 5 NTU.

2) Redesign of the system for:
   a. Ruggedness
      i. Drop Test requirement
      ii. Vibration Requirement
   b. Human factors
      i. Manpower and Personnel Integration (MANPRINT)
      ii. Safety
   c. Weight reduction

The factors affecting vapor compression distillation system include:

1) Redesign of the system for:
   a. Foaming control
   b. Ruggedness
      i. Drop Test requirement
      ii. Vibration Requirement
   c. Weight Reduction

The reliability of both systems were qualified under this effort. This will lead to the possibility of further redesign to enhance the reliability of the systems.

2.4. ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Each system has its advantages. Infinitex's Splitter XD, a spiral-wound ultrafiltration device has a very simple construction; its only moving part is a pump. Sized to process 250 gallons per day, its membranes can remove more than 90% of O&G and 90% of the TSS. The effluent is then safe to dump directly on the ground; however, without EPA regulatory approval, it is unclear whether the effluent is fit for recycling or not.

When it is outfitted with comparable membranes, Bristol International's tubular ultrafilter would produce an effluent water quality similar to that produced by the spiral-wound unit; however, due to the low membrane surface area in each tube, a large number of tubes are necessary for an acceptable permeate flow rate, and consequently require a larger pump. To compensate, the Bristol International tubular ultrafilter was outfitted with membranes that have a higher MWCO than the spiral-wound membranes. Doing so allows more water to permeate membrane at a higher rate but of course, adversely affects the permeate quality. The advantage of the tubular system is that the system requires no pre-filtration of the feed due to its large diameter tubes. Large food particles simply pass through the 1" tubes. The lack of a pre-filter means less waste, fewer pumps and water storage tanks.

The advantage to Ovation Products' VCD is that it outputs almost pure water. This will allow for recycling of the water back into the wash and rinse sinks. While the existing design is small, the drawback is its weight. At 300 lbs, it's currently twice as heavy as either of the membrane systems and too heavy for field use.

Table 2-3 below outlines these advantages and limitations.

Table 2-3: System Advantages and Limitations

System	Advantages	Limitations
Infinitex Splitter XD Spiral-Wound Ultrafilter	• Simple construction • Few moving parts • Rugged design • Adequate size and weight	• Effluent may not be fit for recycling • Requires pre-filtration • Membrane will foul over time • Freezing damages membranes • Drying damages membranes
Bristol International Tubular Ultrafilter	• Simple construction • Few moving parts • Flexible configurations • Doesn't require pre-filtration	• Lack of surface area means more tubes or higher MWCO to achieve proper flow • Requires pre-filtration • Membrane will foul over time • Freezing damages membranes • Drying damages membranes
Ovation Products VCD	• High quality effluent	• Too heavy • Not a rugged design • Complex construction • Depot maintenance

3. DEMONSTRATION DESIGN

3.1. PERFORMANCE OBJECTIVES

The objective of this demonstration was to measure the performance of three portable greywater systems when used with Army FSCs, and determine the feasibility of each of the technologies used. Performance was measured by reducing the levels of undesirable materials in the feed water to comply with EPA standards for Secondary Treated Water, as provided in the Clean Water Act (CWA), 40 CFR 133.102[1] and in Table 1-1.

Table 3-1 below shows the performance objectives and whether or not each of the systems met each objective. These results differed only slightly from laboratory testing. The only surprise was the failure of Bristol International's tubular ultrafiltration system to retain all of the TSS.

Table 3-1: Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)
Quantitative	Permeate / Effluent Quality	<30 mg/L BOD / CBOD
		<30 mg/L TSS
		pH 6-9
	Reduction in Waste Volume	8–10 fold
	Clear water that can be recycled	=≤ 5 NTU
	Permeate Flow Rate	At least 60 gal of water processed by the next meal
Qualitative	Ease of Use	Set-up breakdown by 1 or 2 cooks. Operate w/o monitoring
	Reliability	No breakdowns inherent to the design

3.2. SELECTING TEST SITES/FACILITIES

An Army testing facility was selected for the initial demonstration facility because the water treatment system is being designed for use with an Army kitchen and FSC. The initial test site was selected based on convenience, facility support, and intensity of training. Close coordination and cooperation of the hosting facility was heavily weighted, as was the ease of access to the site itself so the numerous and voluminous water samples could be easily transported into and out of the facility. One site that met all of these criteria was Ft. Lee, near Richmond VA.

3.3. TEST SITE/FACILITY CHARACTERISTICS/HISTORY

Ft. Lee's "Log Warrior" training exercise was chosen for the occasion of this field demonstration. It is a natural choice for a first test of food equipment as Ft. Lee, VA is the home of the Quartermaster School, the combat developer for mobile food service equipment. It also provides a maximum likelihood of success because of its existing infrastructure. The test site includes two large concrete hard stands for the kitchen and the sanitation center, a built-in greywater sump tank with contracted backhaul support, access to a 120V electrical power grid, and port-a-potties.

Because of these amenities, Ft. Lee's facilities are not a mirror image of an actual field site, but they provide an excellent first testing ground for items being considered for field use. The cooks are trained to perform functions according to doctrine. This provides a solid baseline from which to work. The Log Warrior training site, while wooded, is not considered very large. A well-maintained dirt road allows for easy access to the kitchen site. A layout of the testing site is shown in Figure 7.

3.4. PRESENT OPERATIONS

Characterizing the Army’s current food service operations is a very complicated process that is continuously studied and evaluated. Practices change depending heavily on the Mission, Enemy, Troops, Terrain, and Time (METT-T) including the food service equipment, the number of soldiers being fed, the meals being prepared, and the wastewater disposal methods available. The prescribed methods for greywater disposal, which include digging a leach pit, are described in Field Manual (FM) 10-239.

This greywater treatment solution was compared to both leach-pit disposal and the storage and backhauling of greywater. In Ft. Lee, the greywater from sinks is dumped into a large sump tank buried in the ground. A contractor is hired to pump it out when it is full. Data were collected as to the cost of the contractor, the frequency of visits, and total volume of water pumped each time. Cost and volume data were sought and collected from Ft. Lee officials for the entire year.

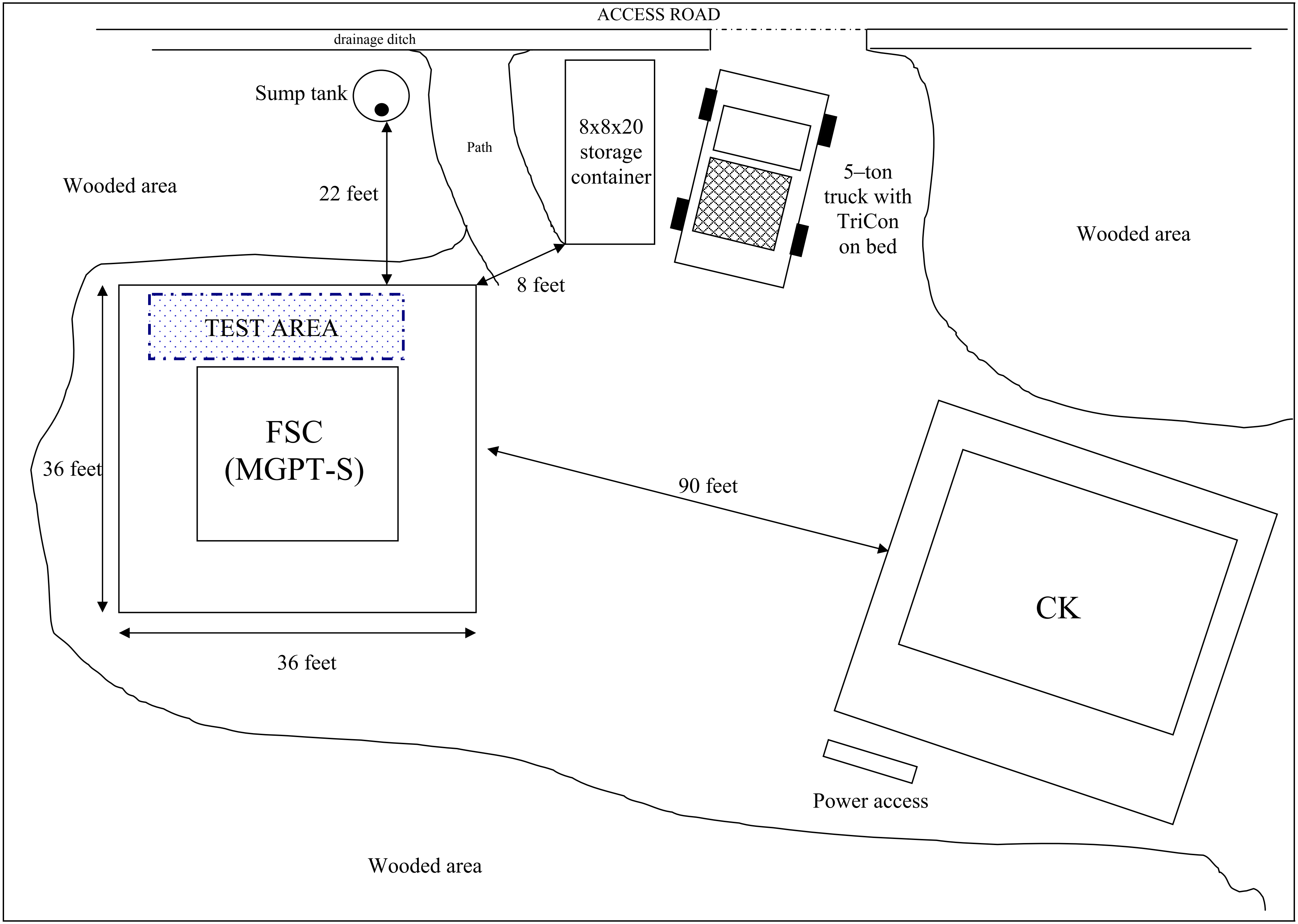

Figure 7: Test Area Layout

3.5. PRE-DEMONSTRATION TESTING AND ANALYSIS

3.5.1. Challenge Water Development

Pre-demonstration testing (in-house at NSC) consisted of pre-qualifying greywater systems for the field demonstration. They were tested with a standardized greywater solution or "challenge water" which mimics actual field greywater (see Table 2-1). The levels of suspended solids, and BOD found in the "challenge water" parallel levels typical to field greywater.

To achieve the correct proportions, water quality data was compiled from 8 meals prepared in a field test of the AFSC in Fort Lee, Va. in 1999, and 2 meals prepared at a full-scale in-house demo of the Containerized Kitchen (CK) with an AFSC in 2002. Typical ranges for each measurable greywater characteristic (BOD, TSS, TDS, pH, Turbidity) were established and are shown in Table 3-2. These ranges also closely resemble the ranges shown in other greywater remediation applications such as the one being conducted by the Naval Surface Warfare Center, Carderock Division (NSWCCD)[10].

Table 3-2: Measured Range of Levels from Prior Field Feeding Observations

	Range	Maximum	Mean
BOD-5 (mg/L)	700-1000	1000	850
TSS (mg/L)	200-400	400	300
TDS (mg/L)	1500-3500	3500	2500
O&G (mg/L)	200-300	300	250
Turbidity (NTU)	90-150	150	120

Using these requirements as a guideline, a recipe for challenge water using food was developed. Chili Con Carne with beans and Pork and Beans were used as a base for the food because it contains a balanced mixture of protein, fats and carbohydrates and is easy to work with. Pork and beans contains 68% carbohydrates, 13% fat and 19% protein while Chili Con Carne contains 23%, 39% and 38%, respectively. The recipe is shown in Figure 8.

Materials:

- Canned B&M Baked Beans
- Canned Hormel Chili con carne
- Water
- Standard Issue *NON Silicated* Powdered Detergent Soap NSN 7930-00-281-4731
- Vegetable Oil
- Industrial sized blender

Procedure:

1. In a large, industrial-sized blender add 1, #10 can (3.01 kg) of baked beans and 3, 15-oz (425 g) cans of chili con carne.
2. Mix well with a spoon.
3. Add 4 cups of water (2 small cans)
4. Bend on medium speed for approx. 4 seconds.
5. Briefly stir to free up the mixture.
6. Repeat step #3.
7. Refer to **Error! Reference source not found.** to determine the amount of food mixture, oil and soap to add to the water.

Ingredient	Per 60 gallons
Food Mixture	500 mL
Vegetable Oil	150 mL
Soap	20 oz

Figure 8: Challenge Water Recipe

In-house testing of the three systems with the challenge water revealed potential for meeting the requirements of the field test. Both ultrafiltration systems exhibited flow rates that were adequate when the inlet water was hot (120°F – 140°F) but sluggish when the inlet was cold (<120°F). The distillate flow rate of the micro-distillation unit, at only 5 GPH, was not adequate. This system's output is not related to the temperature of the inlet water. Ovation Products Inc. provided a newly designed system that processes 20 GPH for the field test. This unit was tested briefly at the Natick Soldier Center (NSC) to verify the manufacturer's claims before the field demonstration.

3.5.2. Membrane Selection for the Bristol Tubular Ultrafilter

The Bristol was shipped with 5, 200,000 MWCO filter tubes which provided more than adequate process flow rates, but poor removal performance. Therefore, the system was outfitted with 75,000 Dalton MWCO filters to enhance the removal performance. To keep the process flow rates in an acceptable range, the system was outfitted with two extra tubes. During room-temperature tests with an inlet temperature of 75ºF, the permeate flux rate averaged 11 GPH. As shown in Figure 9, the flux rate increased significantly with temperature. At a moderate temperature of 110ºF, the flux rate jumped to 18 GPH. Testing showed that in these membranes, the flux rate varied linearly with temperature. Using this as a model, a field inlet temperature of 140ºF can be extrapolated to a flux rate of approximately 24 GPH.

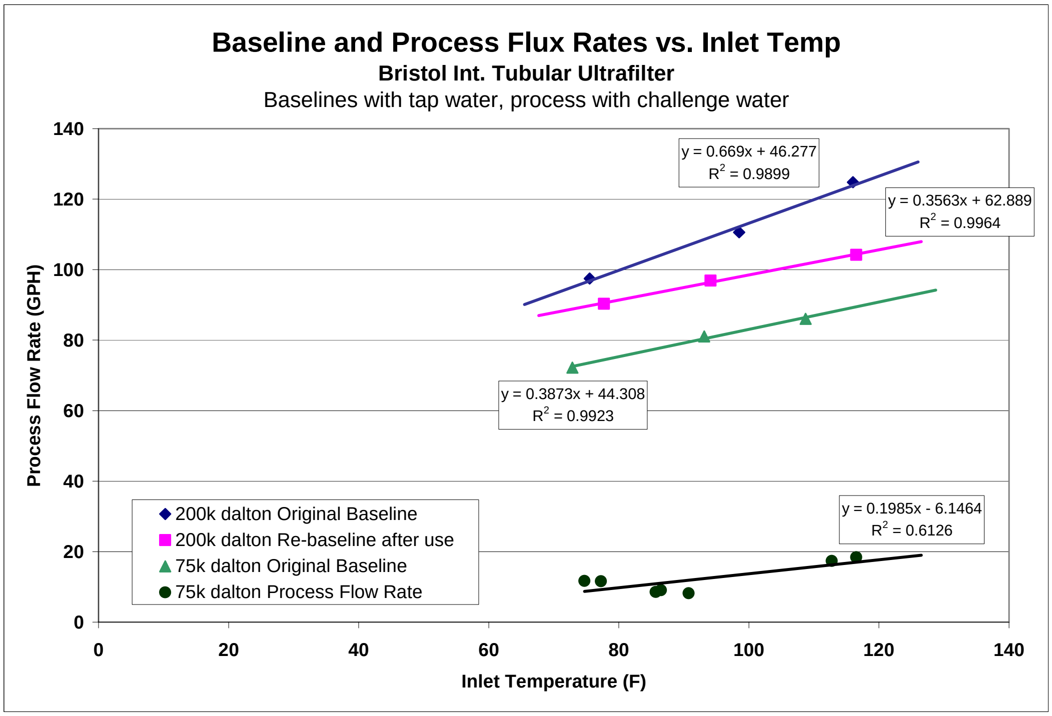

Figure 9: Flux Rate vs. Inlet Temperature of Bristol Tubular Membranes

3.5.3. Membrane Technology Research

The Infinitex Splitter XD system was tested with two types of filters, the ones supplied from the manufacturer and filters purchased from Membrane Technology Research (MTR) of Menlo Park CA. MTR collaborated directly with Infinitex to design and roll the membranes to specification; however, this did not preclude some form-factor discrepancies. The membranes were adjusted and eventually worked.

Both membranes performed similarly with respect to flux rate. The stock membranes had a flow rate of about 9 GPH at an inlet temperature of 77ºF and 10 GPH and a temperature of 92ºF. This extrapolates to about 13 GPH at the expected 140ºF temperature of the actual greywater in the field test.

Percent removal of TSS and BOD was about 85% in every water quality test, which falls within the guidelines of 40 CFR 133.102, although the absolute BOD concentrations did not always reach below the 30 mg/L mark. However, the inlet BOD, TDS and TSS were slightly overloaded in the in-house tests, and depending on field levels, could easily allow for the membranes to achieve the set goals.

3.5.4. Ovation Products VCD

The first beta prototype tested at NSC proved to be capable of producing distilled water with very low power consumption of only 1 KW, but produced distillate at only 3-5 GPH. Ovation Products was able to supply an updated prototype a few weeks before the field test that produced distillate at 20 GPH. This was verified at NSC with a few simple tests before the field test.

3.6. TESTING AND EVALUATION PLAN

3.6.1. Demonstration Set-Up and Start-Up

The greywater system was incorporated into the sink system as shown in Figure 10. The 3 sinks hold 20 gallons of water each and are dumped 4 times per day for a total of 240 gallons. After washing, rinsing and sanitizing the cookware, the water is dumped into the greywater system. This system, as explained in the next few sections, includes not just the greywater filtration device, but also the holding tanks, pumps and plumbing necessary to support the system's operation

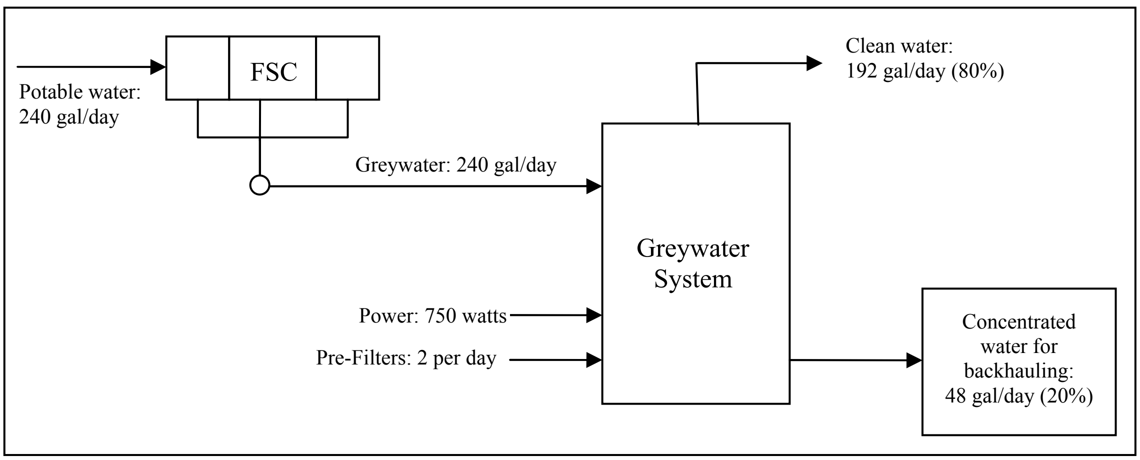

Figure 10: Overall Greywater System Setup

In order to reduce the weight, bulk, and complexity of the demonstration, all three of the systems tested shared many of the same sump pumps, hoses, and tanks. However, due to differences in operation, the set-ups are not quite the same. For instance, the Bristol International tubular ultrafilter does not require pre-filtration and the Ovation VCD comes equipped with its own pre-filtration system while the Infinitex's prefiltration system was designed in-house at NSC. The following sections explain the setup and startup procedures in detail.

3.6.1.1. Bristol International Ultrafiltration System

3.6.1.1.1 Setup

The setup is shown in Figure 9 with the schematic in Figure 12. The Bristol International system was set up in the following manner:

The FSC drain hose was connected to a 1/3 hp sump pump, which moved the greywater into a 120-gallon tank for sampling and processing. The inlet to the tubular ultrafiltration system was connected to the lower access port on the tank and the return hose was connected to the top access port. The permeate hose was placed in either 55-gallon holding tank for flow measurement purposes or into the 1/3 hp sump pump that moved the wastewater to the to the in-ground sump tank where the wastewater is normally collected. For safety and regulatory purposes, the clean permeate was not recycled as wash water. All electrical connections were made through a single 15-amp circuit via an outdoor power strip.

3.6.1.1.2 Startup

The following steps were taken to start the Bristol International system:

1. All electrical and water connections were made.
2. The main power switch was set to the 'On' position, the inlet valve was set to 1/2, and the outlet valve was set to full open.
3. The red 'pump start' switch was turned on and held.
4. The inlet valve was slowly turned full open, and the outlet valve was turned until the system pressure read 15 psi.
5. The red 'pump start' switch was released as soon as the system pressure read greater than 10 psi.

Figure 11: Bristol Setup

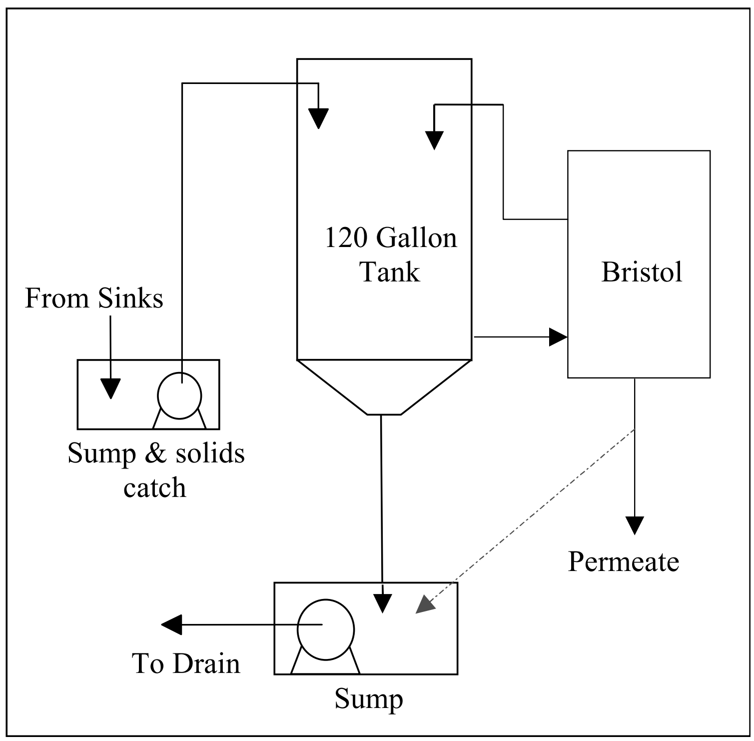

Figure 12: Bristol Setup Schematic

3.6.1.2. Ovation Products VCD

3.6.1.2.1 Setup

The Ovation Products VCD was set up according to the schematic in Figure 13 and the following manner:

An adjustable cart was used to raise the system to a level above the distillate sump tank, or about 2 feet off the ground because the distiller runs on low pressures and lifting it helped to maximize the distillate flow rate out of the unit. The distillate sump was constructed from a 5-gallon bucket, a level switch, a Teel aquarium pump, and a control box. This moved the water into a much taller 55-gallon drum.

A second 5-gallon bucket served as a condensate and vent collection tank. As shown in Figure 14, the greywater from the sinks entered a sump and was pumped, using a 1/3 hp greywater sump pump, into a 120 gallon feed tank where the greywater was mixed, sampled and stored while being fed into the distiller.

A 1/12 hp "Little Giant" pump, located in the bottom of the feed tank, delivered greywater through a 3/8 inch hose to a set of cotton wound prefilters (shown in Figure 13 but not Figure 14) that were plumbed in parallel and mounted on a wooden stand. The filtered greywater was fed to the distiller through the "influent" input on the right side of the unit.

Designed for the European market, the Ovation micro-distiller and the influent pump ran on 220v power. A 110-220v step down transformer was implemented so that the system could be plugged into an 110v circuit. All other pumps were 110v and plugged into the same circuit via an outdoor power strip.

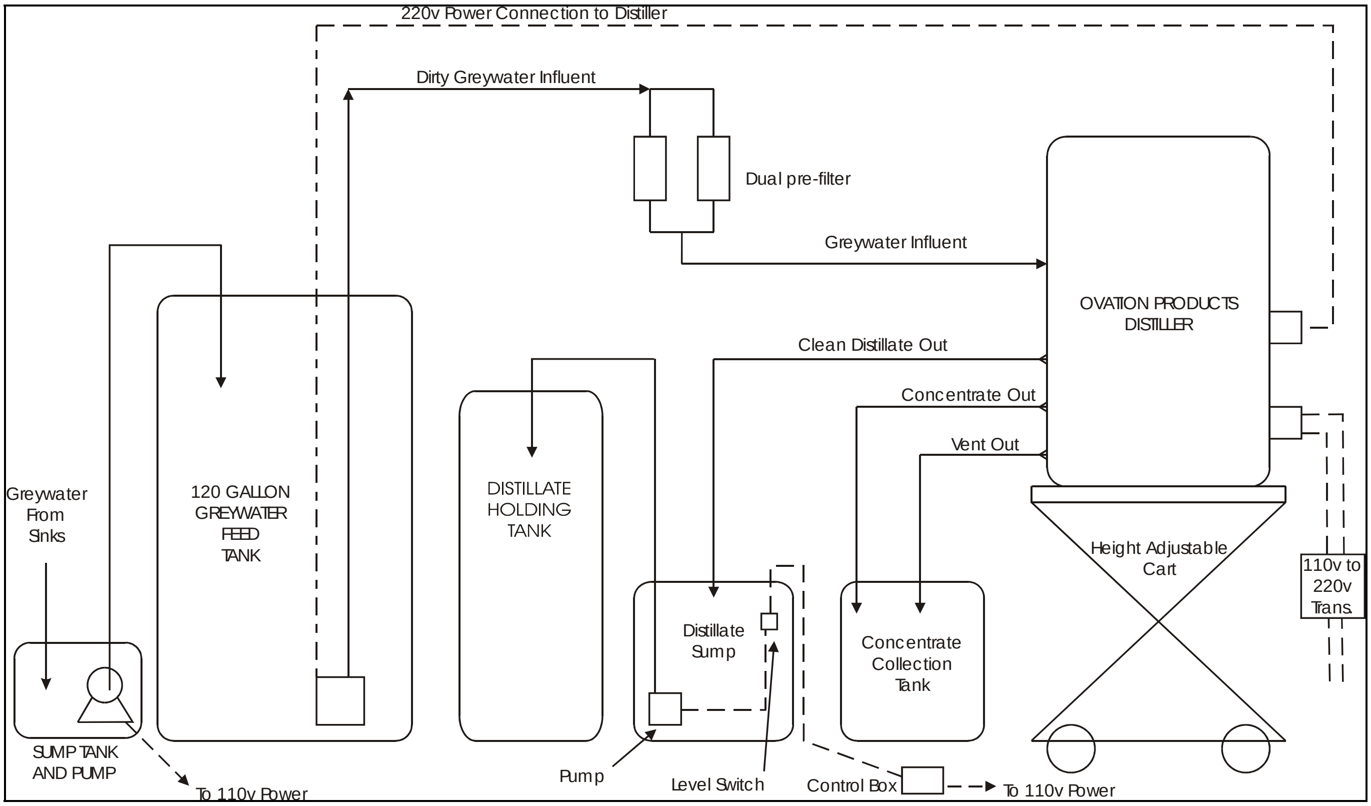

Figure 13: Ovation VCD Setup Schematic

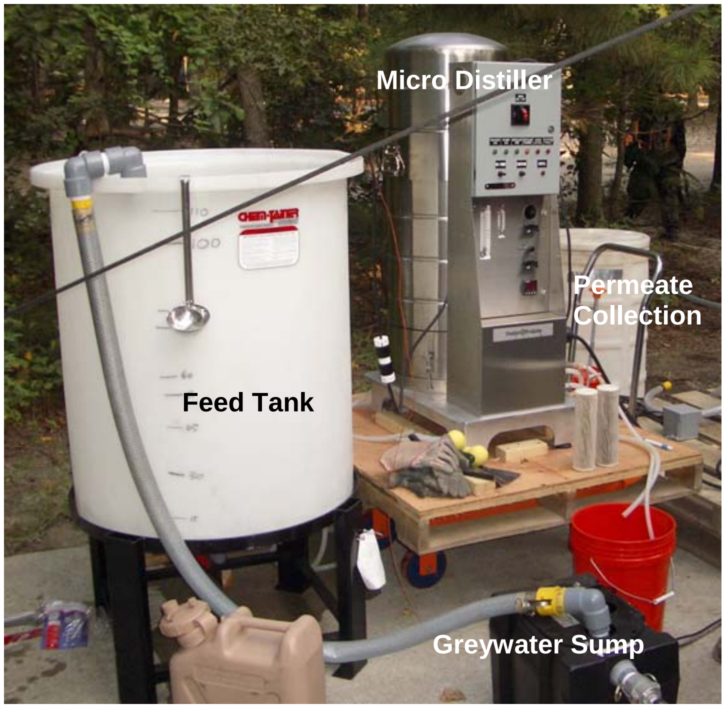

Figure 14: Ovation VCD Setup

3.6.1.2.2 Startup

The distiller must undergo a 45-60 minute long warm-up procedure if it is cold or has been in standby mode or off for more than 2 hours. The following procedure allowed the distiller to warm up using clean water rather than greywater:

1. To warm the system up, the system was fed 5-gallons of potable water from a bucket via a submergible Teel pump.
2. The distillate hose and the pump were placed into the 5-gallon feed bucket.
3. On the control panel, making sure the system was in 'Standby', the 'Power' knob was turned to the 'ON' position.
4. After the water connection was made, the system was turned from 'Standby' to 'Run' and the pump was plugged in (turned on).
5. The distiller was considered warm when it began producing distillate. At this point, the system was placed back in standby and the feed pump unplugged (turned off).
6. The water connections for normal operation were prepared as shown in Figure 13.
7. The distiller was then available to process greywater.
8. If the system is not used to process greywater within 2 hours of step 6, steps 1-5 must be repeated.

3.6.1.3. Infinitex Splitter XD

3.5.1.3.1 Setup

Figure 15 and Figure 16 show the setup of the Infinitex Splitter XD spiral-wound ultrafiltration system. A 1/3 hp sump pump (sump #1) was used to move the greywater from the sanitation center to a 120-gallon wastewater tank so that it can be held for sampling. This is where the raw water samples were taken from.

A second 1/3 hp sump pump (sump #2) was used to direct the feed water through a 50-micron bag filter for pre-filtration and into a second 120 gallon holding tank. A sample of the pre-filtered water is taken from this tank. And as Figure 15 shows, the tank is also used as a feed for the ultrafilter. The ultrafiltration system draws from, and recycles the concentrate back to, this second tank. The inlet to the ultrafiltration system was connected to the lower access port on the second tank as shown in Figure 16 while the return hose was connected to the top access port (not shown). The permeate hose was directed to a 55-gallon holding tank for sampling purposes (not shown).

A third sump pump was used to pump the waste to the in-ground sump tank were the greywater is normally placed. For safety and regulatory purposes, the clean permeate was not recycled as wash water during this demonstration.

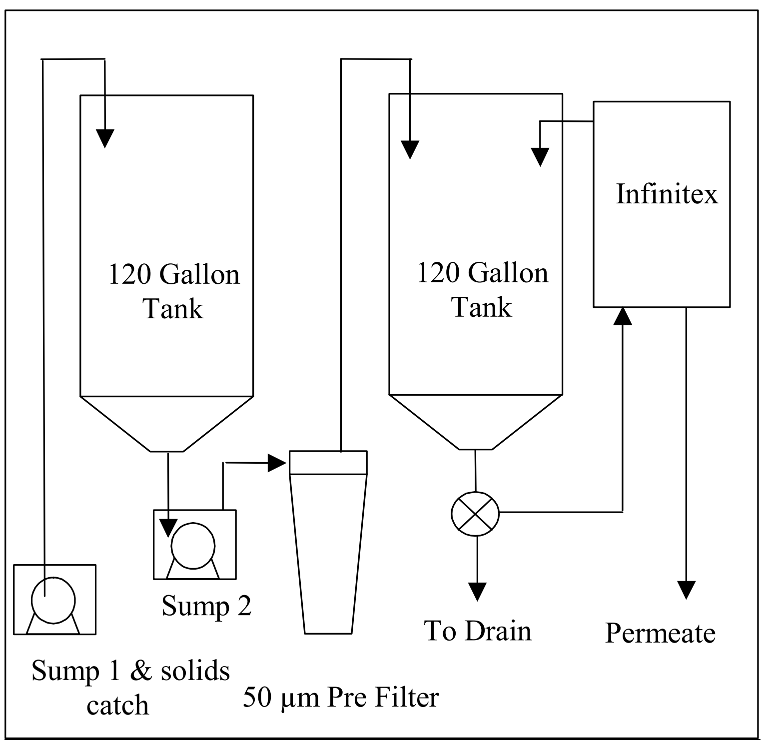

Figure 15: Infinitex Setup Schematic

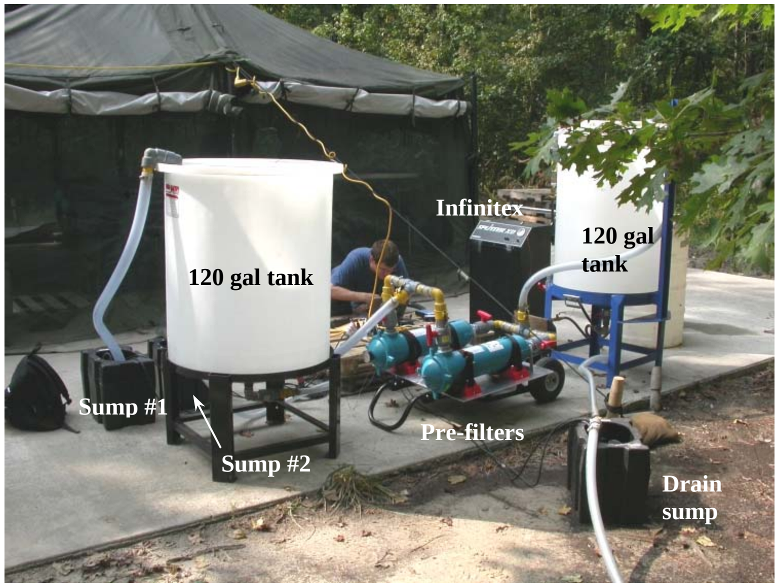

Figure 16: Infinitex Setup

3.6.1.3.2. Startup

The following steps were followed to start the Splitter system:

1. The Infinitex system was filled with water and primed for its first use.
2. After all the greywater was prefiltered and in the feed tank (#2), the Infinitex system was connected to the feed tank.
3. All of the valves on the input, output, and vent lines were opened.
4. The system was filled with greywater because the level of greywater in the tank was higher than the Infinitex unit.
5. The system was then purged of air by placing the vent line in the feed tank and turning the system on.
6. The 'ON' switch was held for several seconds at a time until the vent line was free of foam.
7. The vent line was then closed and the 'ON' button was held until the system achieved running pressure.

3.6.2. Period of Operation

The Demonstration Plan[6] stated that each system would operate for a full 4-day Log Warrior exercise, totaling two systems for two weeks, seven meals per week. This changed dramatically (with approval of the ESTCP Program Office) due to many factors. A third system (Ovation Products) was introduced, as were a second set of filters from MTR that were to be tested with Infinitex's Splitter XD ultrafiltration system. This brought the total number of systems to four.

The Log Warrior schedule then was reduced to 5 meals the first week and, due to one day of bad weather, 3 meals the second week, for a total of only 8 meals. The schedule is shown in Table 3-3. Each of the four systems operated for two consecutive meals with the exception of the Bristol International's tubular ultrafilter, which operated three consecutive meals, and the MTR filters, which saw only one meal.

Better communication with the Log Warrior organizers could have resulted in better planning, and a more thorough test, but each system did get a chance to be tested.

Table 3-3: Test Schedule

<table>
<tr><th></th><th></th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td rowspan="3">Week 1</td><td>0500-0900
Leftover from previous night</td><td rowspan="3">Arrive @ Ft Lee

Meet & Greet

Coordinate logistics to test site</td><td rowspan="2">Arrive @ test site

Move equipment

Setup equipment</td><td>Bristol.</td><td>Bristol.</td><td>Ovation</td></tr>
<tr><td>0900-1330
Breakfast</td><td>Heat & Serve Breakfast

Bristol</td><td>UGR-A Breakfast

Ovation</td><td>MRE
(no test)</td></tr>
<tr><td>1330-2100
Dinner</td><td>Heat & Serve Dinner

Bristol.</td><td>UGR-A Dinner

Bristol .</td><td>UGR-A Dinner

Ovation</td><td></td></tr>
<tr><td rowspan="3">Week2</td><td>0500-0900
Leftover from previous night</td><td rowspan="3"></td><td rowspan="3">Log Warrior Canceled due to weather

(Hurricane & Tornado)</td><td></td><td>Infinitex - MTR</td><td></td></tr>
<tr><td>0900-1330
Breakfast</td><td>Setup for evening meal</td><td>UGR-A Breakfast

Infinitex</td><td>Pack up

Move out</td></tr>
<tr><td>1330-2100
Dinner</td><td>UGR-A Dinner

Infinitex - MTR</td><td>Heat & Serve Dinner

Infinitex</td><td>Meet with Ft. Lee facilitators and depart</td></tr>
</table>

3.6.3. Amount /Treatment Rate of Material to be Treated

The amount of greywater to be treated varied greatly from meal to meal from a low of 45 gal to a high of 105 gal. The factors determining the amount of greywater generated included the initial volume of water in each sink and the frequency of water changes. The sinks were filled with 15 to 20 gal each. Sink water was typically changed when it became too dirty; however, because of the time involved with draining the sink, replacing the water and heating to the appropriate temperature, the KPs often chose not to replace the water in order to complete the job in a timely fashion.

3.6.4. Residuals Handling

Greywater was not recycled in this test. All streams were directed to the typical wastewater storage facility. For Ft. Lee, this consists of an in-ground sump tank of an indeterminate size.

3.6.5. Operating Parameters for the Technology

All of the equipment was operated solely by Natick Soldier Center personnel. The role of Army cooks, KPs, and all other personnel present was only to observe and comment on the implementation of the technology.

3.6.6. Experimental Design

To minimize field test logistics, test beds were designed to be modular and interface with multiple greywater remediation systems. A resulting benefit of this approach was uniform test conditions across each greywater system. One minor drawback was that we had to rinse the equipment between tests, so that the feed of one test did not become cross-contaminated with that of the previous test.

3.6.6.1. Process Approach

The test was set up as a semi-batch process with the feed being the greywater stream from the FSC and CK. Greywater is typically disposed of in 60-gallon batches by opening valves on the back of each 20-gallon sink. Each meal, breakfast and dinner (MRE rations are served for lunch), typically requires two batches of 60 gallons, at the rate of one batch per hour. Each test typically began after the first batch and subsequent batches were added to the feed as necessary. Changes in feed concentration were monitored. Adding a second batch of greywater to the first significantly changes the chemistry of the feed, so the feed was typically mixed at this point and sampled. Breakfast and dinner operations are separated by approximately five hours. There was almost no time to process the water after dinner, so a portion of the water was left overnight and processed first thing in the morning. As shown in the schedule in Table 3-3, there are typically 4 hours available for greywater processing before the breakfast sanitation operations begin.

3.6.6.2. Digital Data Sampling

A laptop computer and a 'Data Translation' DT9805 USB Data Acquisition Function Module were implemented to record the following parameters once every 5 seconds:

- Ambient temperature

- Bulk feed temperature
- Permeate temperature
- Permeate flow rate

The flow meter was powered by a 12-volt power supply. A portable frequency meter was used to read the digital flow meter. This was due to a hardware incompatibility between the flow meter and the DT9805.

3.6.6.3. Test Log and Manual Data Collection

Each of the three test engineers kept a log of all events during the two-week demonstration. Notes on the food prepared, the amount of dishes being cleaned, and means of maintaining and cleaning equipment were also taken. Also, in the test log were instantaneous flow rates taken by a handheld frequency meter and feed tank levels. These data were compiled, merged with the digital data, and analyzed.

There are no automated process instruments that determine or track the fouling of membranes or indicate when filters are at the end of their service life; however, pressure gauges are included on each system and give an indication as to the performance of the system, for example, low pressure typically indicates fouling while unusually high pressure typically indicates a ruptured membrane. The Ovation unit is the only system to contain automated process instrumentation. It has safety algorithms in place that monitor and control operating conditions. The ultrafiltration systems have minimal or no automated controls but do shut down automatically if pressure is above or below operating limits.

3.6.6.4. Water Sampling

Feed water was homogenized and sampled before filtering. Each time a new batch was added to the feed water, the filtration process was momentarily stopped while the feed was re-homogenized and sampled. Permeate samples were taken as necessary or when system conditions changed. Water was sampled at each stage of the filtering process. The raw water, the pre-filtered water, the permeate water, and the concentrate were all sampled.

The sample names were formatted in the following manner:

[system name]_[meal #]_[location code]{sample #}

The location codes were: R = raw feed, P = permeate (or distillate), F = pre-filtered and C = concentrate. Example: "Bristol 2 R2" would be the second composite raw feed sample from Bristol International's second meal. The complete list of the 43 samples taken and a brief description of each are shown in Table 3-4.

Table 3-4: Water Sample Names and Descriptions

SAMPLE NAME	DESCRIPTION
BRISTOL INTERNATIONAL	
Bristol 1 R1	Initial raw feed from dinner 8/24/04
Bristol 1 P1	Permeate from 1 R1
Bristol 1 R2	Raw feed left overnight, sampled morn. 8/25/04
Bristol 1 P2	Permeate from 1 R2
Bristol 1 C1	Final concentrate
Bristol 2 R1	Initial raw feed from breakfast 8/25/04
Bristol 2 P1	Permeate from 2 R1
Bristol 2 C1	Concentrate
Bristol 3 R1	Initial raw feed from dinner 8/25/04
Bristol 3 P1	Permeate from 3 R1
Bristol 3 R2	Raw feed left overnight, sampled morning 8/26/04
Bristol 3 P2	Permeate left out overnight
Bristol 3 P3	Permeate from 3 R2
Bristol 3 P4	Permeate after sponge ball cleaning
Bristol 3 C1	Final concentrate
OVATION PRODUCTS	
Ovation 1 R1	Raw feed from breakfast 8/26/04
Ovation 1 P1	Distillate from 1 R1
Ovation 1 C1	Concentrate
Ovation 2 R1	Raw feed from dinner 8/26/04
Ovation 2 C1	Concentrate
Ovation 2 P1	Distillate from 2 R1
Ovation 2 R2	Feed left overnight, sampled morning 8/27/04
Ovation 2 P2	Distillate left overnight, sampled morning 8/27/04
Ovation 2 R3	Feed after pre-filters (should be labeled 'F')
Ovation 2 P3	Distillate from 2 R2 and 2 R3
INFINITEX	
Inf 1 R1	First batch - dinner 8/31/04 - MTR brand filters
Inf 1 F1	Feed – pre-filtered to 50 µm
Inf 1 P1	Permeate
Inf 1 R2	Mix of 1st & 2nd batch
Inf 1 F2	Mix of 1st & 2nd batch
Inf 1 P2	Permeate from 1 F2 and 1 R2
Inf 1 F3	Left overnight sampled morning 9/1/04
Inf 1 P3	Permeate left overnight
Inf 1 P4	Permeate from 1 F3
Inf 1 C1	Final Concentrate
Inf 2 R1	Raw greywater from breakfast 9/1/04 Infinitex brand filters
Inf 2 F1	Pre-filtered greywater feed
Inf 2 P1	Permeate
Inf 2 C1	Final concentrate - Low volume, only 4 parameters tested
Inf 3 R1	Raw greywater from dinner 9/1/04 – Infinitex brand Filters
Inf 3 F1	Pre-filtered greywater feed
Inf 3 P1	Permeate
Inf 2 C1	Final concentrate

The water was tested for the following parameters. See section 0 for a list of analytical test methods.

- Biological Oxygen Demand (BOD)
- Carbonaceous Biological Demand (CBOD)
- Chemical Oxygen Demand (COD)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- Oil and Grease (O&G)
- pH
- Total Phosphorous (TPhos)
- Nitrogen as NO_2/NO_3
- Turbidity
- Color

3.6.7. Demobilization

Test items are mobile and were shipped to and from test locations on pallets or in shipping containers. At the conclusion of the demonstration, items were washed, packed in a QuadCon shipping container, and shipped back to the Natick Soldier Center for inspection and follow-on testing.

3.7. SELECTION OF ANALYTICAL/TESTING METHODS

Each water sample was tested for the parameters listen in . Water quality analysis was performed according to the ASTM specifications also listed in below.

Table 3-5: Water Quality Testing Methods and Techniques

Test	Method / Technique
Biological Oxygen Demand - 5 Day	EPA 405.1 / SM 5210B
Carbonaceous BOD - 5 day	SM 5210B
Chemical Oxygen Demand	EPA 410.4 / SM 5220D
Solids, Total Suspended	EPA 160.2 / SM 2540D
Solids, Total Dissolved	EPA 160.1 / SM 2540C
Oil & Grease - Hexane Method	EPA 1664
PH	EPA 150.1
Phosphorous, Total	EPA 365.2 / SM 4500P-E
Nitrogen, Nitrate/Nitrite	EPA 353.2 / SM 4500NO3-F
Turbidity	EPA 180.1 / SM 2130B

3.8. SELECTION OF ANALYTICAL/TESTING LABORATORY

Water quality testing as described in Table 3-5 was conducted by Analytics Corporation, 8040 Villa Park Drive, Suite 250, Richmond, Virginia 23228. All purchases were made prior to the test via a sole source contract. Analytics was selected because of their location and past performance. Analytics provided greywater testing for a similar Army demonstration at Ft. Lee in May 1999.

4. PERFORMANCE ASSESSMENT

4.1. PERFORMANCE CRITERIA

The performance criteria used to evaluate system performance are tabulated below in Table 4-1. The system must be able to process all of the greywater produced by the kitchen and the sanitation center between cleaning cycles. It must produce clean water that can be recycled back into the wash and rinse sinks and it must be easy to use. It is preferred that the system be lightweight, 4-man portable, and rugged to withstand harsh environments and rough handling.

Table 4-1: Performance Criteria

Performance Criteria	Description	Primary or Secondary
Permeate/Effluent Quality	The system should produce effluent that can be safely dumped on the ground; however, the goal is for the water to be able to be recycled.	Primary
Reduction in Waste Volume	The system must process 250 gallons per day. The goal is to produce 90% useable permeate and 10% concentrated waste by volume.	Primary
Clear Water That Can be Recycled	The appearance of the waste water is drastically improved. The turbidity is measured to be low (=<5 NTU), making the clarity high.	Primary
Permeate Flow Rate	The permeate flow rate is fast enough to process at least 60 gallons of clean water to use in the sinks at the next meal.	Primary
Ease of Use	Set-up required by one or two cooks and operated without monitoring.	Primary
Reliability	The system must be failsafe. Any equipment failure should not result in a release of waste to the environment or any other hazardous condition that might harm an operator.	Primary
Maintenance	Ultrafiltration will frequently require cleanings with membrane-cleaning solution; frequency is to be determined. Filters will need to be changed by one person requiring minimal training. Regular maintenance for the VCD system would be to clean and/or replace the pre-filters. Infrequent pump breakdowns in all systems will require a more involved level of training.	Secondary

Performance Criteria	Description	Primary or Secondary
MANPRINT (Manpower and Personnel Integration)	Each system must conform to strict human factors. The weight should be light enough for 5 soldiers to carry as per MIL-STD-1472F [7]. The item should be rugged enough to be considered mobile, and hot surfaces will have to be clearly marked.	Secondary
Versatility	Dual use is an important feature for the Army, but will not be considered a performance criterion for this demonstration.	Tertiary
Scale-Up Constraints	There are no scale-up issues associated with these technologies	Tertiary

4.2. PERFORMANCE CONFIRMATION METHODS

4.2.1. Permeate Flow Rate

The flow rate monitoring process was designed to be redundant. An analog flow meter was attached to the permeate line of each system and fed a digital data acquisition system as described in section 3.6.6.2. In addition, the permeate was collected in a 55-gallon drum. A test log was kept that showed when flow to the collection tank began and ended. Lines were drawn directly on the collection tank, with marker, showing the level of the water at various times. After the demonstration, the 55-gallon drum was filled to each line and weighed. The volume was determined from the weight of the water and, when divided by the time, resulted in the flow rate.

The redundancy of the system became necessary during the demonstration when the backpressure of the flow meter impeded the flow of the Ovation system. The Ovation system operates at very low pressures and actually uses gravity to coax the distillate out of the system. The small backpressure inherent in the flow meter was too much for the system to overcome.

The permeate collection tank was also useful because the output of the flow meter turned out to be incompatible with the Data Translation DT9805 USB Data Acquisition Function Module. The flow meter's output was frequency. It was unknown that the Data Translation unit could only read frequency measurements that were encoded a certain way. To solve the problem, a handheld multimeter was used to record the frequency in Hertz at 5-minute intervals.

4.2.2. Waste Reduction

The reduction in waste was calculated by measuring the amount of raw greywater that was generated by the sanitation center and the amount that was left over after the processing was complete. This was then confirmed by comparing to the amount of permeate that was collected or the flow rate that was observed.

4.2.3. Permeate Water Quality

Consistent, contaminant-free data were a priority in the sample collection. All bottles were opened seconds before sampling, the permeate samples were filled directly from the permeate line without touching the sides of the bottle, and the bottles were filled completely to the top to reduce interaction with air. Dirty greywater was stirred vigorously before sampling and the suction device that was used for the transfer of samples was cleaned and sanitized in between runs.

Table 4-2: Performance Data Summary

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual Bristol	Actual Infinitex	Actual Ovation
PRIMARY PERFORMANCE OBJECTIVES Quantitative Criteria					
Permeate/Effluent Quality - BOD - TSS - O&G - pH	*≤ 30 mg/L* *≤ 30 mg/L* *≤ 30 mg/L* *6 ≤ pH ≤ 9*	*Secondary Treatment See Table 1-2.*	Averages 447.3 mg/L 28.4 mg/L 62.2 mg/L 5.8 SU	Averages 291.2 mg/L 3.8 mg/L 6.9 mg/L 6.1 SU	Averages 17.3 mg/L 1.4 mg/L 5.6 mg/L 7.0 SU
Reduction in Waste Volume - Filters - Sludge	*Disposed as municipal waste* *- 10% of feed* *- Backhauled for further treatment*	*Measured beginning and ending levels – weighed water*	23% of feed*	9% of feed	18% of feed*
Clear Water That Can be Recycled - Turbidity	*≤ 5 NTU*	*See Table 1-2.*	12.8 NTU	4.7 NTU	2.1 mg/L
Permeate Flow Rate	Fast enough to process before the next batch is needed	Digital flow meter and manual time and water level log	16 GPH yes	18 GPH yes	23 GPH yes
PRIMARY PERFORMANCE OBJECTIVES Qualitative Criteria					
Ease of Use	*Item can be set-up by one or two cooks and operated without monitoring.*	*Observation*	Very Easy to set up and use	Moderately easy to set up, easy to use	Involved set-up. Easy to use
Reliability	*No breakdowns inherent to design*	*Record keeping*	One minor breakdown – required 5 min repair	No breakdowns	No breakdowns
SECONDARY PERFORMANCE OBJECTIVES Quantitative Criteria					
MANPRINT	*4 man portable*	*Weight of system < 157 lbs according to Army MANPRINT specs*	< 150 lbs	~ 150 lbs	~ 300 lbs

SECONDARY PERFORMANCE OBJECTIVES **Qualitative Criteria**					
Performance Criteria	**Expected Performance**	**Performance Confirmation Method**	**Actual Bristol**	**Actual Infinitex**	**Actual Ovation**
MANPRINT	*Controls are located in appropriate places, hot surfaces are marked, handles are in proper places etc.*	*Observation*	Controls are awkward. Tubes are hard to move and manage in current configuration	Controls are on opposite side of fittings. Access door is awkward	Too heavy. Needs to be elevated 3 feet for proper use.
Maintenance - Spiral-Wound Ultrafilter	- Use Membrane cleaner every 24 hours of run time - Clean process tanks - Replace filters once a year	Record Keeping		- Replaced pre-filters before each run. - Jellylike substance formed on top of the filters – was cleaned off with water after 2 uses - Cleaned process tanks	
Maintenance - Tubular Ultrafilter	- Clean process tanks - Replace filters once a year	Record Keeping	Sponge balls were used once –action was not needed - Cleaned process tanks		
Maintenance - VCD	- Clean or replace pre-filters before every run - Clean with anti-fouling cleanser every 50 hours of runtime - Clean process tanks	Record Keeping			Replaced pre-filters before each run - Cleaned process tanks

*Limited by system configuration, not by technology

The effectiveness of each system was determined by measuring the contaminant levels for each run at each point in the greywater process. The levels in the permeate were compared to EPA

Secondary Water Treatment values. This value represented the system's overall effectiveness. Each system's relative effectiveness was measured by the percentage that it reduced the level of each contaminant.

4.3. DATA ANALYSIS, INTERPRETATION, AND EVALUATION

4.3.1. Permeate Flow Rate

The permeate flow rate is the rate at which the system processes the greywater into clean water. As stated in section 4.2.1, the data was collected in two separate ways, by direct measurement of the flow and by measuring the volume recovered over time.

Incremental and cumulative volume was calculated from the measured instantaneous flow rates and time data. The average flow rate was calculated by plotting the cumulative volume vs. time. The slope of the line (volume per unit time) was used as the average flow rate.

An example of this method can be seen in Figure 17. Here the flow rate and cumulative volume are plotted together. The fit line for the volume was created using Microsoft Excel's "Add Trendline" function. The slope of the line can be seen in the upper right corner along with the R^2 value. In this case, even though the flow rate drops from 16.8 GPH to 14.0 GPH over the 2.6 hour test period, we are able to arrive at an average flow rate of 17.3 GPH.

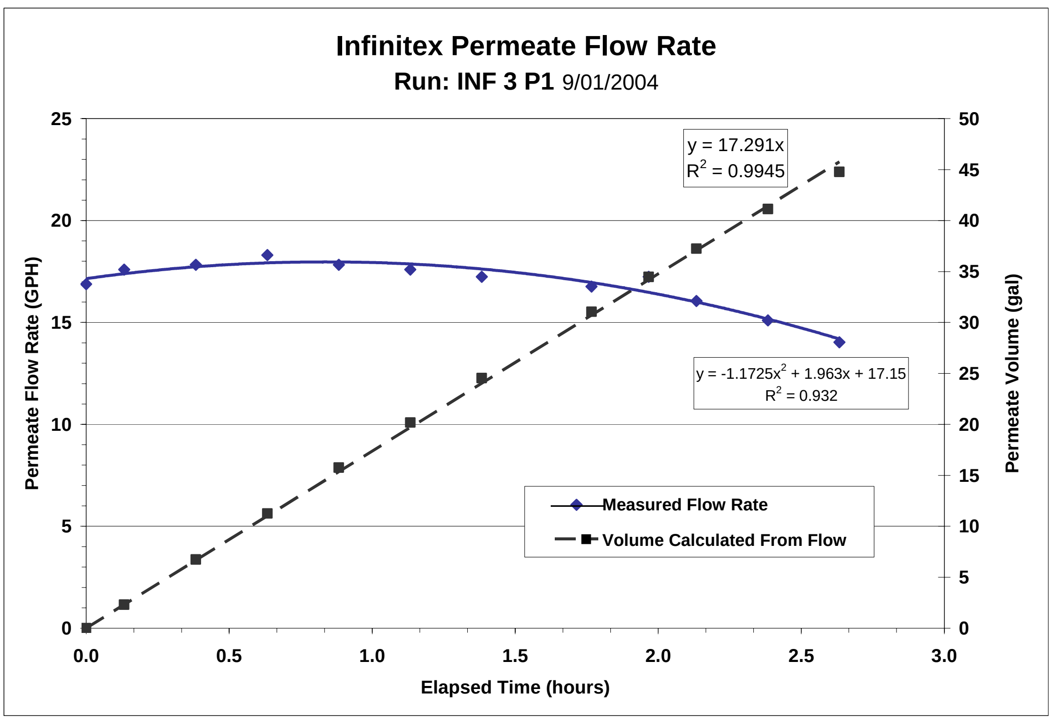

Figure 17: Average Flow Rate Determination

Permeate flow rate was also calculated by marking the 55-gallon permeate collection tank with a magic marker after each test. The mark was accompanied by the date, run #, and ending time. The starting time for permeate generation was recorded in a log book.

The results for each run are given in Table 4-3. Discrepancies between the values cannot be explained and it is unclear which method to trust in each situation. Fortunately, there is a great deal of permeate flow rate data for each of these systems that was accumulated before this demonstration. Furthermore, none of the systems had any problem filtering all the water before the next meal.

Table 4-3: Permeate Flow Rates

	Method 1	Method 2
	Graphing	Flow Rate from Weight of Water
Bristol 2 P1	n/a	13.19
Bristol 3 P2 *	11.65	19.02
Inf 1 P1 (MTR Filters)	8.66	7.09
Inf1 P4 (MTR Filters)	7.58	7.36
Inf 2 P1 Infinitex Filters	21.78	16.86
Inf 3 P1 Infinitex Filters	17.29	16.53
Ovation 2 P1	n/a	5.95
Ovation 2	n/a	28.50
Total Ovation 2 day 1	n/a	9.11
Ovation 2 P2 *	n/a	17.78

* Water in tank left overnight and sampled the following morning.

4.3.2. Waste Water Volume Reduction

Each system was required to reduce the overall volume of waste by 85%. This was supposed to be calculated very simply from the initial and final volumes of water. Unfortunately, initial volumes of greywater were not always recorded. This posed a challenge in calculating the initial volume from the flow rate and the known waste. Furthermore, the graduated marks on the holding tanks have a large margin of error.

Table 4-4 shows data that is accurate as possible, and a very reasonable scenario.

Table 4-4: Volume Reductions

	Start (gal)	Permeate (gal)	End (gal)	% Reduction	Notes
Bristol 1	45	30	15	66.7%	These runs always end with 15 gallons due to the configuration of the system
Bristol 2	61	46	15	75.4%	
Bristol 3	90	75	15	83.3%	
Bristol Total	**196**	**151**	**45**	**77.0%**	
Infinitex 1	68.5	63.5	5	92.7%	
Infinitex 2	45	44	1	97.8%	
Infinitex 3	59	49	10	83.1%	
Infinitex Total	**172.5**	**156.5**	**16**	**90.7%**	
Ovation 1	50	44	6	88.0%	The numbers for Ovation 2 have been calculated several different ways from the data and field log. This is the most accurate scenario.
Ovation 2	86	76	10	88.4%	
Ovation Total	**136**	**120**	**16**	**88.2%**	

The data shows the Infinitex reducing the waste by 90.7%, the greatest amount. The Ovation reduced the volume by 88.2% and the Bristol by 77.0%. The Bristol could have reduced the waste by more, but the configuration of the tank was such that 15 gallons was always left in the tank after processing. As Figure 18 shows, the output of the conical bottom tank was on the side, not the bottom. So after the level reached the level of the output, no more greywater could be delivered to the Bristol for processing.

Figure 18: Bristol Holding Tank - Detail

This problem was easily fixed by inserting a 3-way valve in the bottom drain line so that the Bristol can process from the bottom, or it can be used as a drain.

The ratio of the distillate and concentrate volume can be adjusted on the Ovation system. It was set for 90% but missed the mark slightly. This can be more finely tuned in later tests.

4.3.3. Overall Filtration Performance

Filtration performance is based upon both the average parameter level in the permeate stream and the average percent reduction or change of parameters. The average and lowest levels for each system were recorded and the percent reduction of each parameter from the feed was calculated. Percent reduction was calculated for each run using the following equation:

Equation 1: Percent Reduction

$$\frac{\text{Raw Greywater Level} - \text{Permeate Level}}{\text{Raw Greywater Level}} * 100$$

Percent reduction characterizes how well the system changed each parameter and predict permeate levels given any level in the feed. It can be thought of as the system's filtration efficiency. The overall percent reduction for each system over all runs is shown in Table 4-5 and graphically in Figure 19.

Table 4-5: System Performance: Percent Reduction

Parameter	Bristol	Infinitex	Ovation
Total Suspended Solids	94.5%	98.1%	99.8%
Total Dissolved Solids	43.5%	59.7%	83.5%
Oil and Grease	45.1%	90.3%	96.3%
BOD	66.1%	78.7%	98.5%
COD	70.5%	71.2%	98.2%
Carbonaceous BOD	64.0%	75.3%	98.7%
Turbidity	88.0%	91.1%	99.4%
Color	35.4%	68.3%	78.5%
Phosphorus	30.5%	66.1%	99.6%
Nitrate-Nitrite	-14.6%	-0.4%	58.8%

Some parameters such as pH are not included in this table because percent reduction values do not apply.

Figures 17 through 20 clearly show that the Ovation system removed a higher percentage of each one of the offending parameters. The Infinitex system was the second most effective while the Bristol system was the least effective in filtration.

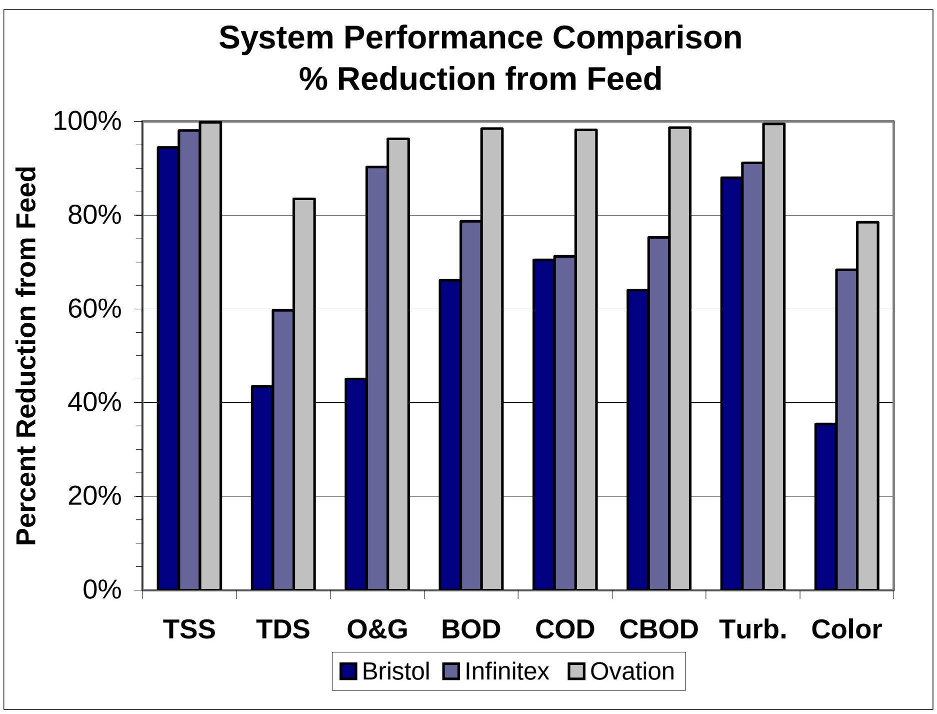

Figure 19: System Performance Comparison

A similar pattern is revealed when observing the final concentrations for each contaminant in the permeate stream. Table 4-6 shows the high, low, and average concentrations in the permeate for each contaminant and each system. Consistently producing the highest contaminant levels, the Bristol system performed the worst in each while the Ovation system did the best. The Infinitex system was always somewhere in-between.

Table 4-6: High, Low & Average Permeate Concentrations

		Bristol			Infinitex			Ovation		
		HIGH	LOW	MEAN	HIGH	LOW	MEAN	HIGH	LOW	MEAN
BOD	mg/L	582.0	339.0	447.3	502.00	100.00	291.20	30.00	6.00	17.33
CBOD	mg/L	518.0	276.0	390.7	471.00	100.00	277.00	23.00	4.00	13.33
COD	mg/L	1593.0	890.0	1136.5	1660.00	260.00	927.20	97.90	20.00	45.97
TSS	mg/L	70.0	2.0	28.4	19.10	1.00	4.62	2.00	1.00	1.37
TDS	mg/L	690.0	160.0	477.8	548.00	208.00	399.20	245.00	1.00	84.67
O&G	mg/L	237.7	6.4	62.2	15.00	5.00	7.86	6.90	5.00	5.63
pH	SU	7.1	4.8	5.8	6.90	5.09	6.10	8.34	4.70	7.03
TPhos	mg/L	8.2	2.5	5.0	3.32	0.13	1.74	0.06	0.02	0.03
NO_2/NO_3	mg/L	0.3	0.1	0.2	1.11	0.10	0.54	0.10	0.10	0.10
Turbidity	NTU	23.0	1.0	12.9	22.60	1.00	5.32	2.80	1.73	2.13
Color	CU	50.0	5.0	25.0	10.00	5.00	8.00	10.00	5.00	6.67

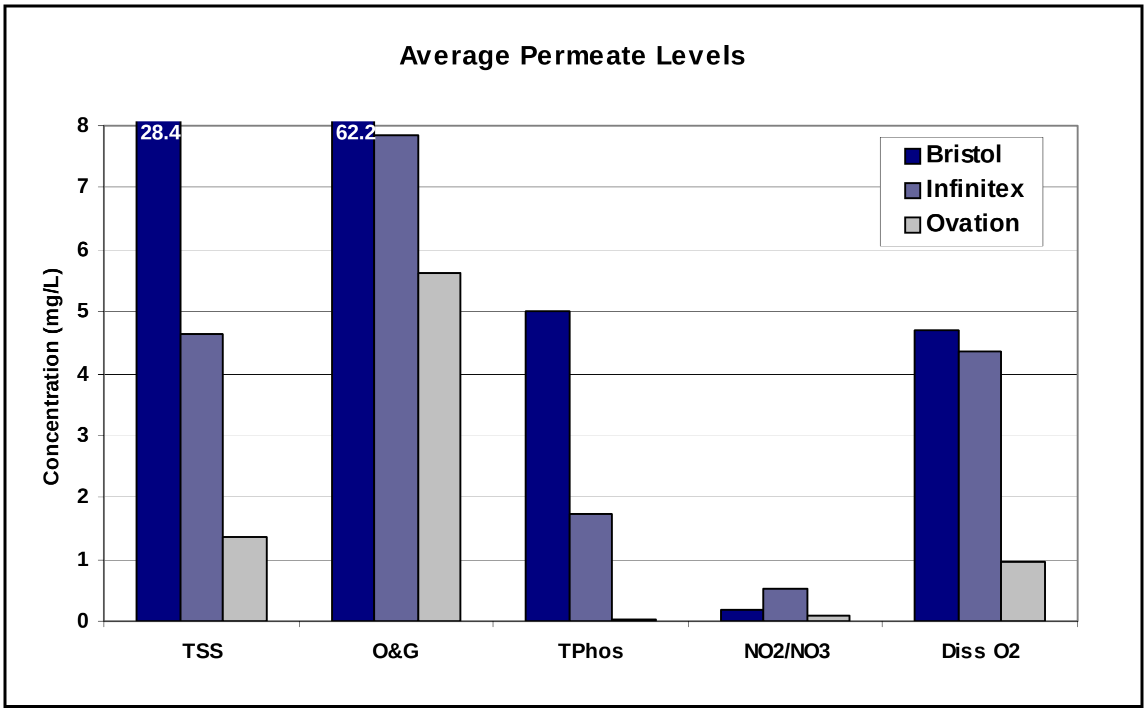

Figure 20: Permeate Levels: TSS, O&G, TPhos, NO2/NO3, Diss O2

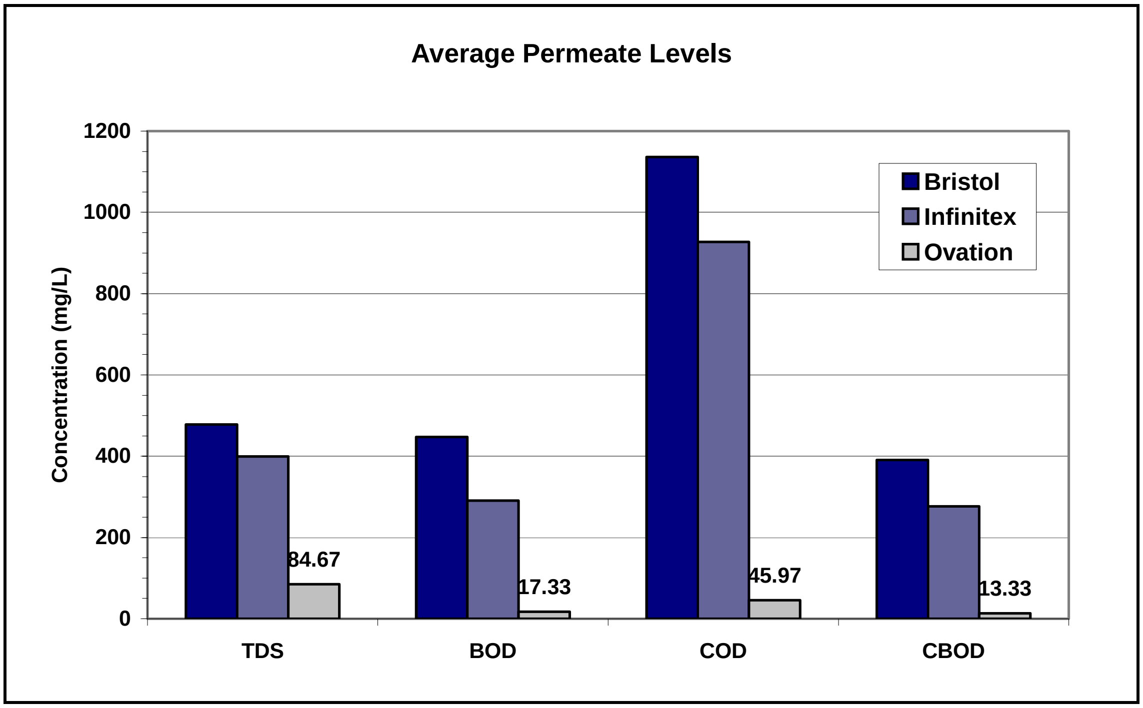

Figure 21: Permeate Levels: TDS, BOD, COD, CBOD

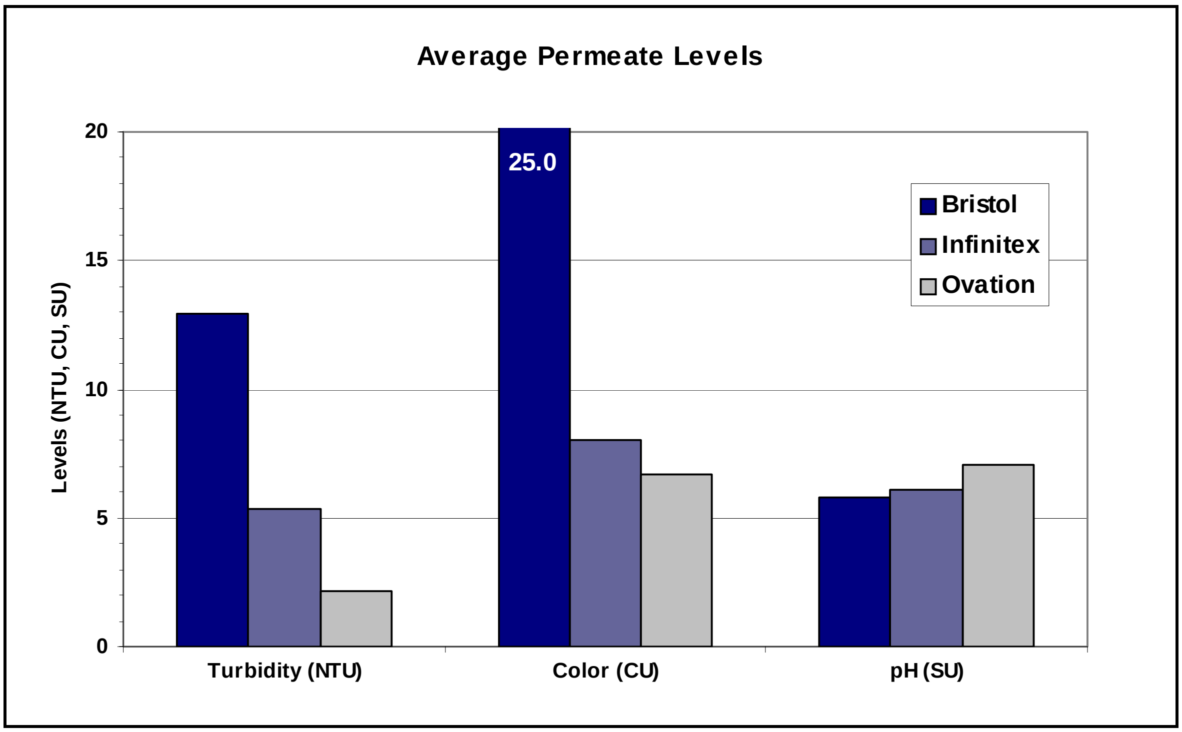

Figure 22: Permeate Levels: Turbidity, Color, and pH

4.3.4. Performance Variation Analysis

Variations in performance were evaluated by the fluctuation in percent reduction from run to run. To determine the extent of these fluctuations, the standard deviation between runs was calculated for each contaminant. shows the average percent deviation from the mean for each system and the standard deviation shown as a percentage.

For example, the Bristol system removed, on average, 94.5% of the total suspended solids (TSS) +/- 5.3%. The table shows that the Bristol system was significantly less consistent than the other two systems, but this is not necessarily the case. The values for O&G are thrown off by one data point indicating that that the O&G level actually *increased* by over 150%. If this outlier is thrown out, the mean become 84.3% and the standard deviation only 8.1%. This puts the system's consistency on par with the Infinitex system with an average standard deviation of only 11.5%. The outlier is incorporated in the data set because there was no way to explain the large inconsistency.

Table 4-7: Variations in Performance from Run-To-Run: Standard Deviation from the Mean as a Percentage of the Mean

	Bristol		Infinitex		Ovation	
	Mean Percent Reduction	Standard Deviation from Mean	Mean Percent Reduction	Standard Deviation from Mean	Mean Percent Reduction	Standard Deviation from Mean
TSS	94.5%	5.3%	98.1%	2.5%	99.8%	0.1%
TDS	43.5%	12.5%	59.7%	20.3%	83.5%	22.3%
Oil and Grease	45.1%	88.1%	90.3%	11.7%	96.3%	1.7%
BOD	66.1%	9.6%	78.7%	11.6%	98.5%	0.9%
COD	70.5%	7.4%	71.2%	14.7%	98.2%	1.6%
CBOD	64.0%	8.7%	75.3%	11.0%	98.7%	0.9%
Turbidity	88.0%	9.5%	91.1%	15.4%	99.4%	0.4%
Color	35.4%	27.8%	68.3%	16.2%	78.5%	20.2%
Average %dev		21.1%		12.9%		6.0%

Table 4-7 also shows that the Ovation system performed the most consistently, especially in reducing the BOD and TSS levels. While fluctuations below 10% are considered good, the average standard deviation for the Ovation system was only 6% and most of the levels fluctuated less than 2% between runs. It showed especially nice consistency removing TSS, BOD, and turbidity.

5. COST ASSESSMENT

5.1. COST REPORTING

This cost analysis compares three systems: 1) The AFSC without greywater recycling capability, 2) The AFSC using spiral-wound ultrafiltration as the greywater recycling technology, and 3) the AFSC using VCD to as the greywater recycling technology. The Infinitex system using the MTR filters was not assessed for costs because its permeate flow rate performance was considerably less than the Infinitex filters. The Bristol system was also not assessed because of inadequate system performance.

The basis for this cost analysis is the AFSC's Life Cycle Cost Estimate (LCCE), which is a detailed life cycle cost analysis that was performed in preparation for the procurement of 1,329 AFSC systems, and was approved by the Program Manager (PM) - Force Sustainment Systems. Used in the AFSC milestone B decision, this process identified direct and indirect costs associated with the production, fielding, and support of the AFSC, in constant FY04 dollars. Most notably, it identified costs associated with the use of potable water and greywater treatment and disposal.

In order to compare each system's operating costs, the entire system is taken into account. In other words, the operating cost of the spiral-wound system includes the costs of operating the AFSC as well. However, sunk costs such as AFSC design and procurement costs, are not taken into account because the AFSC will be purchased independent of the greywater recycling system, which will be added-on later as a P3I item.

The assessment shows a significant costs savings derived from the savings of potable water supply and greywater backhauling costs. Because the greywater is recycled for 3 days at a time, the analysis shows over a 50% savings in water. This cost savings is large enough to negate additional procurement, maintenance, and labor costs associated with either of the greywater treatment systems, so much so, in fact, that any additional costs, are almost negligible.

Because procurement is expected to span 5 years, the actual operating costs are not estimated to be the same every year. This will be shown in more detail in later sections. The operating costs reported in the tables below are for full deployment.

There are also several assumptions that were made to arrive at the reported costs. These are defined in section 5.2.1.

The following cost tables show the costs associated with the 1,329 AFSC systems that are to be procured.

The P-2 Finance software was used to determine the costs when accounting for the time value of money. The inputs and outputs can be found in Section 5.4.

Table 5-1: Baseline AFSC Technology Costs

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operation & Maintenance					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing and fielding	sunk	Labor to operate equipment	42,533,000	Dumping greywater on ground	Health risk		
Equipment Purchase	sunk	**Greywater backhauling**	**37,677,000**				
Installation	sunk	Fuel	4,254,000				
Training of operators	sunk	Equipment Maintenance	1,330,000				
		Potable Water	**25,118,000**				
TOTAL	sunk		110,912,000				

Table 5-2: Spiral-Wound Ultrafiltration Technology Costs

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operation & Maintenance					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing and fielding	350,000	Labor to operate System	43,998,000	Dumping greywater on ground	0		
Equipment Purchase	15,151,000	**Greywater backhauling**	**7,535,000**				
Installation	0	Fuel	4,847,000				
Training of operators	100,000	Equipment Maintenance	2,993,000				
Permitting Fees	50,000	**Potable Water**	**11,152,000**				
Delivery	333,000	Pre-Filters	670,000				
Spare Parts	1,515,000	Filters	665,000				
TOTAL	17,499,000		71,860,000				

Table 5-3: VCD Technology Costs

Direct Environmental Activity Process Costs – Ovation				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operation & Maintenance					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing and fielding	350,000	Labor to operate equipment	43,998,000	Dumping greywater on ground	0		
Equipment Purchase	15,151,000	**Greywater backhauling**	**7,535,000**				
Training of operators	100,000	Fuel	4,847,000				
Permitting Fees	50,000	Equipment Maintenance	3,824,000				
Delivery	348,000	**Potable Water**	**11,152,000**				
Spare Parts	2,273,000	Pre-Filters	670,000				
TOTAL	18,272,000		72,026,000				

5.2. COST ANALYSIS

The cost analysis was performed by combining the AFSC's LCCE using the Environmental Cost Analysis Methodology (ECAM). This begins by making reasonable assumptions, identifying all inputs and outputs of the system, developing process flow diagrams, and quantifying the resources to arrive at the direct costs. Indirect costs are then identified and quantified to reach an ECAM Level II analysis. The data is then imputed into a computer model that takes into account taxes, inflation, escalation of the cost of commodities, and depreciation among other factors.

The analysis is comparing the Ovation Products VCD system and the Infinitex Splitter XD spiral-wound ultrafiltration system to the FSC without any greywater treatment.

5.2.1. Assumptions

Table 5-4 through

Table 5-6 list the assumptions that were used during the cost analysis.

Table 5-4: Assumptions Used Throughout the Entire Cost Analysis

This cost analysis assumes the following:	
1	The greywater treatment system is integrated with the new AFSC
2	1,329 units will be fielded as a P3I for the new AFSC. This equals the number of new AFSCs to be fielded.
3	When recycling water, the first meal of each deployment uses 100% potable water.
4	The sanitation sink ALWAYS uses potable water - therefore a maximum of 100 gal per AFSC per meal can be recycled.
5	Any remaining clean water not used will be dumped (safely) on the ground.
6	The current protocol is to either dump greywater directly on the ground or backhaul it, not both. The percent savings calculated reflects a decrease from each of these options independently.
7	Cost savings is based on recycling greywater for 3 days at a time. At the end of the 3 day deployment, all the water is dumped and the AFSC is filled with fresh water

Table 5-5: Assumptions for the AFSC cost calculation

The AFSC O&M support costs were calculated using these assumptions:	
1	Water is estimated at 300 gallons per day per unit @$0.50/gal. Units will be fielded for 21 days/ six time /year for 126 days/year. Cost per unit per year is $18,900.00.
2	Water disposal is estimated at 300 gallons per day per unit @$0.75/gal. Units will be operated same as above. Cost per unit per year is $28,350.00.
3	Fuel cost is calculated at 5 gals/per day for each of 3 MBUs for a total of 15 gals of JP8 fuel per day. The units will be fielded for 126 days/year. The fuel cost is $1.34/gal. 1890 gal per unit costs $2,533.00.
4	In addition to the AFSC's LCCE estimate of fuel cost, the AFSC uses a 2KW generator for 6 hours per day, 126 days/year @ 0.66 gal/h, or 498.96 gal/year. The fuel cost is $1.34/gal for $668.60/year/unit. The total AFSC fuel cost is $3201.60/unit/year
5	Military operators. There are two E-2 operators 6 hours/day times 126 days/year @ $17.49/hour. There is one E-4 supervisor two hours/day times 126 days @ $22.06/hour. Total unit operations labor cost per year is $32,004/year.
6	Annual maintenance is 45.36 hours for an E-4 @ $22.06/hour or $1001/unit/year.
7	Tents are replaced every 10 years at a cost of $4,750.00 per tent.

Table 5-6: Assumptions for the Greywater Recycling cost calculation

The greywater O&M support costs were calculated using these additional assumptions:	
1	Capital costs are estimated at $11,400/unit. See Table 5-13.
2	Prefilter costs are estimated at 2 filters per day @ $2/filter or $504/unit/year.
3	A set of ultrafilters (2) are replaced every 2 years. This is calculated as 1/year/unit @ $500/filter or $500/unit/year. This cost only applies to the spiral-wound ultrafilter, not the VCD system.
4	Potable water use is estimated at 104.7 gallons per day per unit @$0.50/gal. Units will be fielded for 21 days/ six time /year for 126 days/year. Cost is $6,596.10/unit/year
5	Water disposal is estimated at 60 gallons per day per unit @$0.75/gal. Units will be operated same as above. Cost per unit per year is $5,670.
6	Fuel Costs: The 2-KW generator is used for an extra 4 hours per day @ 0.66 gal/h, or 2.64 gal/day @ $1.34/gal for a cost of $3.54/day/unit, or $445.74/year/unit. This is added to the AFSC's total fuel cost for a total of $3647.34/unit/year
7	Labor Costs are military operators. There is one E-2 operator for an extra 0.5 hours/day times 126 days/year @ $17.49/hour. The subtotal unit labor cost per year is $1,101.87/year. This is added to the AFSC's labor cost for a total of $33,105.87/unit/year.
8	Estimate .03 hours of maintenance actions for each operational hour @ 15 operational hours per day, or 0.45 hours/system/day. For 126 days per year, that's 56.7 hours/system/year. At $22.06 per hour composite standard rate for E-4 soldier, that's $1250.80/system/year Maintenance operations include cleaning, performing PMCS, and replacing assembly components. The operator will be responsible for care and cleaning of the greywater system. Hourly composite rate obtained on-line from DTIC at www.dtic.mil/comptroller/rates/2005.

Table 5-7: Additional Assumptions for VCD cost calculation

The greywater O&M support cost were calculated using these additional assumptions:	
1	VCD system capital costs are estimated at $11,400 per unit. See Table 5-13.
2	The VCD system does not require filters or replacement filters.
3	Prefilter costs are estimated at 2 filters per day @ $2/filter or $504/unit/year.
4	Assume the annual maintenance required for each greywater treatment system is $1876.20 based on 85.05 hours at $22.06 per hour composite standard rate for E-4 soldier. Estimate .045 hours of maintenance actions for each operational hour @ 15 operational hours per day. The VCD system is expected to require more maintenance than the ultrafiltration system.

5.2.2. Flow Diagrams

The first step in the ECAM process is to identify the process and its waste streams using flow diagrams. The following diagrams depict the current sanitation system and the proposed system of recycling water back into the wash and rinse sinks of the AFSC. Figure 23 shows that currently, all three of the sinks drain to a grease separator which remove oil, grease and fat from the water. This doesn't reduce the overall volume of the water disposed, nor does it clean the water enough to be disposed of on the ground. The proposed concept is shown in Figure 24. Here, the water is pumped to a greywater treatment system and back into the sanitation sinks. The recycled water is only used in the 1st and 2nd sinks. Fresh, potable water is always used in the sanitizing sink for proper sanitation.

Figure 24 also shows the volumetric flow rates for each stream according to the AFSC's LCCE. 300 gal/day of potable water are added to the system and converted to greywater. 80% of this water is cleaned for reuse while 20% is unusable concentrate that requires backhauling. Not all of the clean water can be used, however. This could result in up to 40 gal of cleaned greywater to be discharged to the ground. This practice would not cause environmental harm or be unsanitary due to the quality of the water.

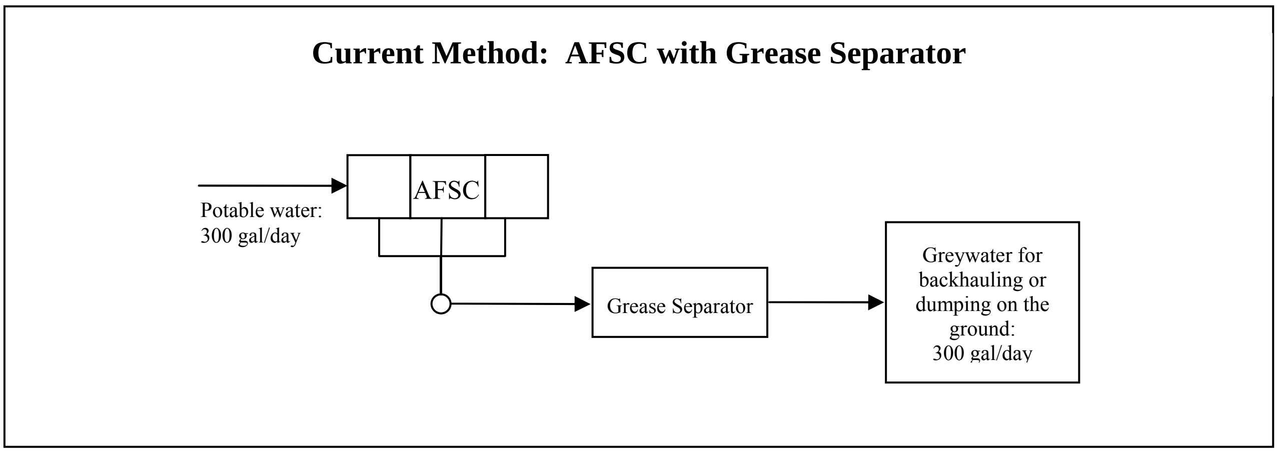

Figure 23: Flow Diagram of Current Sanitation

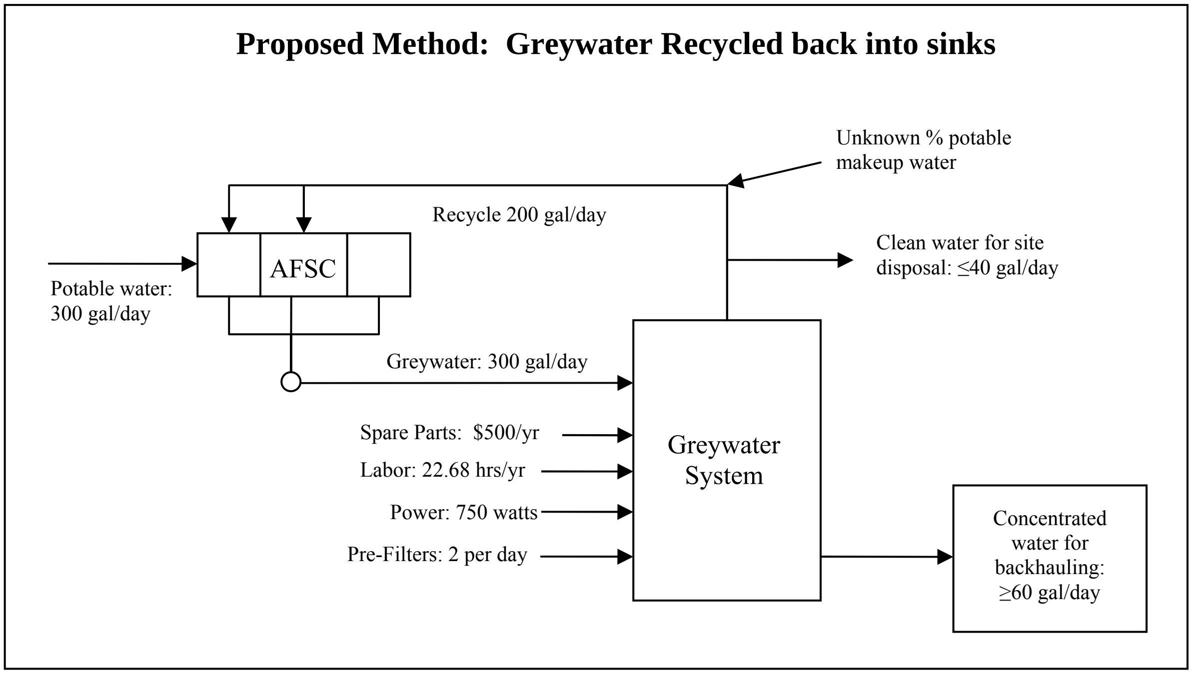

Figure 24: Inputs and Outputs to the Greywater Recycling System

5.2.3. Water Savings Analysis

The amount of water saved by recycling will be determined by the number of consecutive days of deployment. The first meal of the deployment will require the sinks to be initially filled with potable water, and the last meal of the deployment will require the disposal of all the water.

Equations were developed that describe the amount of potable water used, dirty water backhauled, and clean water dumped on the ground. The current practice was determined by the estimate published in the AFSC's LCCE which estimates each system uses 300 gpd of potable water and disposes of 300 gpd of greywater. Water usage is variable with a high end of 250 gal +/- 20%. These equations were entered into a spreadsheet that uses the length of deployment in days as the independent variable.

Equation 2 $$H_2O_{Used} = 200 + 100(x-1)$$

Equation 3 $$Backhauled = 60x$$

Equation 4 $$Dump = 140 + 40(x-1)$$

Where: x = number of consecutive days of use
H_2O_{Used} = gallons of potable water used
Backhauled = gallons of concentrate for backhauling
Dump = gallons of remediated water safe to dump on the ground

The application of these equations, as shown in Table 5-8, show that the water savings increases with the number of days the water is recycled; however, there are diminishing returns that approach 66% percent savings. There is a decrease of potable water consumption of 55.6% after a three day period, and 65.6% after 30 days.

Table 5-8: Savings of Water at Various Deployment Lengths

	Percent Reduction of Volume		
Days of deployment	Potable Water Saved	Greywater Backhauled	Greywater Dumped on Ground
3	55.6%	80%	75.6%
7	61.9%	80%	81.9%
14	64.3%	80%	84.3%
21	65.1%	80%	85.1%
30	65.6%	80%	85.6%

Even though the AFSC's LCCE estimates deployments of 21 days, percent savings values were calculated using the more conservative deployment duration of three days because the squad usually "jumps" to a new location every three days.

For the purposes of this estimation, water costs are represented per gallon and it is assumed that volumetric reductions translate directly into cost reductions. It is outside the scope of this study to perform a detailed logistical study that would take Mission, Enemy, Terrain, Troops & Time Available (METT-T) variables into account.

5.2.4. Resource Consumption and Costs

This section attempts to encompass all direct and capital costs of the proposed system including: water, disposal, fuel, labor, spare parts, and system components. The savings are realized in the drastic reduction of water used and water disposal costs. The values below, as in the previous section, are based upon the values published in the AFSC's LCCE.

The quantities of each of the resources used in each of the systems are listed in Table 5-9. The numbers of gallons of greywater treated and dumped on the ground are shown to be equal because in any given situation, greywater could be discharged to the ground, either by accident (collection tank full) or by standard operating procedure (SOP). All values shown are relative to a greywater treatment system.

Table 5-9: Resource Consumption Table (Based on 1,329 Units)

Resource	Estimated Annual Quantity		
	Current Method	Ultra-filtration	VCD
Potable water	50,236,200 gal	22,304,000 gal	22,304,000 gal
Greywater Treatment (Backhauling)	50,236,200 gal	10,047,240 gal	10,047,240 gal
Greywater Dumping (on ground)	50,236,200 gal	12,257,633 gal	12,257,633 gal
Fuel	3,174,822 gal	3,617,164 gal	3,617,164 gal
Labor for Operations	1764 man-hrs/unit	1890 man-hrs/unit	1890 man-hrs/unit
Labor for Maintenance	45.36 hr/unit	102.06 hr/unit	130.41 hr/unit
Pre-Filters	0	334908 filters	334908 filters
Filters	0	1329 filters	0 filters

Potable water and greywater treatment costs are variable, as explained in section 5.2.6. In Table 5-10, the highest values, also used in the AFSC's LCCE, are used. Costs could be associated with the health issues that are associated with dumping greywater to the ground; however, this is outside the scope of this cost analysis.

Take note that Table 5-10 shows the cost of two separate scenarios, *either* dumping the greywater on the ground *or* backhauling the greywater for proper disposal. In reality, both scenarios are taking place at the same time.

Table 5-10: Direct Process Costs (Current Process)

Resource	Annual Quantities Used and Cost Factors		Annual Cost Dumping	Annual Cost Backhauling
Potable water	50,236,000 gal	$0.50/gal	$25,118,000	$25,118,000
Greywater Treatment (Backhauling)	50,236,200 gal	$0.75/gal	N/A	$37,677,000
Greywater Dumping (on ground)	50,236,200 gal	N/A	Heath Issues	N/A
Fuel	3,174,822 gal	$1.34/gal	$4,254,000	$4,254,000
Labor for Operation	2,344,000 man-hrs	$18.14/man-hr	$42,533,000	$42,533,000
Labor for Maintenance	60,290 man-hrs	$22.06/hour	$1,330,000	$1,330,000
Total	**----**	**----**	**$73,235,000 + health issues**	**$110,912,000**

Table 5-11: Direct Process Costs (Sprial-Wound Ultrafiltration Process)

RESOURCE	ANNUAL QUANTITIES USED AND COST FACTORS		ANNUAL COST
Potable water	22,304,000 gal	$0.50/gal	$11,152,000
Greywater Treatment (Backhauling)	10,047,240 gal	$0.75/gal	$7,535,000
Greywater Dumping (on ground)	7,485,194 gal	N/A	No Heath Issues
Fuel	3,617,164 gal	$1.34/gal	$4,847,000
Labor for Operation	2,511,810 hours	$17.51/man-hr*	$43,998,000
Labor for Maintenance	135,637 man-hrs	$22.06/hour	$2,993,000
Pre-Filters	2 per unit/day	$2 /filter	$670,000
Ultra Filters	1 /unit/year	$500 /filter	$665,000
Total	----	----	**$71,860,000**

* see assumptions for actual labor unit cost breakdown

Table 5-12: Direct Process Costs (VCD Process)

RESOURCE	ANNUAL QUANTITIES USED AND COST FACTORS		ANNUAL COST
Potable water	22,304,000 gal	$0.50/gal	$11,152,000
Greywater Treatment (Backhauling)	10,047,240 gal	$0.75/gal	$7,535,000
Greywater Dumping (on ground)	7,485,194 gal	N/A	No Heath Issues
Fuel	3,617,164 gal	$1.34/gal	$4,847,000
Labor for Operation	2,425,413 hours	$18.14/man-hr*	$43,998,000
Labor for Maintenance	173,345 man-hrs	$22.06/hour	$3,824,000
Pre-Filters	2 per unit/day	$2 /filter	$670,000
Ultra Filters	N/A	N/A	$0
Total	----	----	**$72,026,000**

* see assumptions for actual labor unit cost breakdown

5.2.5. Capital Costs

The cost of the basic ultrafiltration system is estimated to be equal to that of the VCD system, approximately $10,000 each. There will be one system procured for each new AFSC procured, totaling 1329 units; however there is a possibility for a larger market because the AFSC will not replace all of the 3000+ FSCs currently in service and greywater recycling systems could be procured for those systems as well. The conservative quantity of 1329 is used for this study.

Table 5-13: Capital Costs

Item	Cost Per Unit	Number of Units	Total Cost
Greywater Treatment System	$10,000	1329	$13,290,000
Clean Water Bladder	$600	1329	$797,400
Greywater Bladder	$600	1329	$797,400
Hoses and connectors	$200	1329	$265,800
Total	**$11400**	**1329**	**$15,150,600**

5.2.6. Variable Costs

The extent of the monetary savings from a reduction in potable water and greywater treatment is dependant on several variable costs including potable water costs, greywater treatment costs, the amount of potable water required, fuel costs, and other METT-T factors. This particular study disregards complex logistical variables such as fuel and METT-T and uses a set price for fuel and water.

This cost model was designed to calculate costs based on three variables: the volume of water used, the cost per gallon of potable water, and the cost per gallon of disposal of greywater. Table 5-14 shows the cost boundaries of each of the three variable costs and the percent of uncertainty within each variable.

Table 5-14: Variable Costs

Variable Cost	Low Value	High Value	% Uncertainty
Water Usage (gal)	200	300	20%
Cost of water (per gallon)	$0.03	$0.50	88.6%
Cost of disposal (per gallon)	$0.10	$0.75	76.4%

Table 5-15, shows the impact of the variable costs. Eight scenarios are calculated at the low and high cost boundaries of potable water and waste disposal. As the cost of water and disposal increases, so will the cost savings because recycling greywater reduces the amount of water and disposal at a flat rate. For example, the first box shows a scenario where the AFSC, without the benefit of recycling, uses 200 gallons per day, the cost of potable water is $0.03 per gallon, and the cost of disposal is $0.10 per gallon. In this scenario, the Infinitex Splitter XD ultrafiltration system is not cost effective, costing an average of $2.1 million per year for 25 years. The Ovation Products VCD system is also not cost effective, costing about $2.3 K per year for 25 years to operate. These numbers do *not* account for inflation, the time value of money, or depreciation; they are only to show the effect of changes in variable costs. See Section 5.4 for the costs associated with the time value of money.

However, when calculating the savings using the estimated costs and quantities found in the AFSC's LCCE, as seen in the lower right hand corner of the table, the greywater recycling system will **save an average of $32 million per year for 25 years**.

Table 5-15: Yearly Savings Depending on Cost Variable Extremes

		Potable/Disposal $0.03/$0.10	Potable/Disposal $0.50/$0.10	Potable/Disposal $0.03/$0.75	Potable/Disposal $0.50/$0.75
200 gpd	Infinitex	($2,131,054)	$5,220,471	$12,497,728	$19,849,253
	VCD	($2,375,889)	$4,975,637	$12,252,893	$19,604,418
300 gpd	Infinitex	($771,140)	$10,256,148	$21,172,032	$32,199,320
	VCD	($1,015,975)	$10,011,313	$20,927,197	$31,954,485

5.3. COST COMPARISON

5.3.1. Reduction of Logistics and Greywater Disposal

Both of the technologies presented will reduce the cost of water and offsite wastewater treatment significantly enough to offset the costs of development, procuring, fielding, operating and maintaining the technology in the field. The reduction in logistics is the result of the reduction in potable water consumption by more the 50%.

5.3.2. Cost Differences

According the cost analysis, the difference in cost savings between spiral-wound ultrafiltration and VCD will be minimal. Each unit costs the same and will require the same amount of capital equipment, such as water tanks, bladders, pumps, pre-filters and hoses.

Table 5-12 shows that the VCD system will be slightly cheaper due to the fact that it doesn't require the purchase or replacement of ultrafilters. This increases the apparent cost savings by $665,000 per year.

5.3.3. Replacement Parts

Spare parts for the spiral-wound ultrafiltration system were estimated as 10% of the capital costs. This mirrors the estimate in the AFSC's LCCE. The more complex VCD system is estimated to require spare parts totaling 15% of the system's capital costs.

5.4. P-2 FINANCE SOFTWARE ANALYSIS

The assumptions and figures reported in Sections 5.1 through 5.3 were inputted into the P-2 Finance spreadsheet using a discount rate of 7%, a study period of 15 years, and a straight-line depreciation method. The salvage value for the equipment was estimated to be 1% of the capital cost. Fuel costs were estimated to escalate 15% per year. Evidence of this was supported by historic costs of #2 diesel fuel in the U.S. as reported on the US Department of Energy website, http://tonto.eia.doe.gov/oog/info/wohdp/diesel.asp [8]. The inputs and outputs of the software are shown below. The internal rate of return was estimated to be 417% for the spiral-wound ultrafilter and 420% for the VCD.

P2/FINANCE
Version 3.0

09/26/2005

PROJECT TITLE:	Greywater Recycling
PREPARED BY:	Chad Haering
ORGANIZATION:	EET, CFD, NSC, RDECOM
COMMENTS:	Assumptions: 1. Discount Rate = 7% 2. Study Period = 15 years 3. Greywater Backhaul Stream Reduced by 85% 4. Equipment Purchase Cost = $10,000 per unit 5. Equipment Installation/Implementation Cost = $0

P2/FINANCE

Pollution Prevention Financial Analysis
and Cost Evaluation System

Version 3.0

09/26/2005

DEFAULT PARAMETERS

Analysis Name: Greywater Recycling 09/26/2005 Default-pg1

Global Parameters

P2/FINANCE uses the Inflation Rate, Discount Rate, and Income Tax Rate entered here for calculations on the Tax Deduction Schedule, Incremental Cash Flow Analysis, and Incremental Profitability Analysis sheets.

Inflation reflects the overall rate at which you expect prices to increase. For cases in which this Inflation Rate does not fully capture expected price changes, P2/FINANCE allows you to define an additional Escalation Rate for each Annual Operating Cost category.

Inflation Rate: 0.0%

The Discount Rate accounts for the fact that there is an opportunity cost to using money -- if you choose to invest in one project, you lose the opportunity to gain a return on another investment. Many companies use their weighted average cost of capital as a Discount Rate. For more information on Discount Rate and its relationship to inflation, see the on-line help.

Discount Rate: 7.0%

State and local income taxes are deductible from the taxable income used to calculate federal taxes. Enter your Local, State, and Federal Income Tax Rates below, and P2/FINANCE will calculate an Aggregate Income Tax Rate.

Local Income Tax Rate	
State Income Tax Rate	
Federal Income Tax Rate	
Aggregate Income Tax Rate	0.0%

The Default Parameters entered by the user in this section can be applied to the entire project file by pressing the button below. <u>Do not press this button</u> unless you are sure that you want these values to apply to the <u>entire project file</u>!

P2/FINANCE uses the Depreciation Method and Period entered here as defaults for all initial investment Costs. You can change the Depreciation Method and Period for individual categories on the Initial Investment Costs sheet.

Depreciation Method	sl
Depreciation Period	15.0

To specify Depreciation Method, use these abbreviations:

Straight Line	SL
150% Declining Balance switching to Straight Line	1.5DB
200% Declining Balance switching to Straight Line	DDB or 2DB
Expensed (tax deductible in the first year)	EXP
Working Capital (not tax deductible)	WC

The Default Parameters entered by the user in this section can be applied to the entire project file by pressing the button below. <u>Do not press this button</u> unless you are sure that you want these values to apply to the <u>entire project file</u>!

Scenario Parameters

P2/FINANCE allows you to create two alternative financial analysis scenarios, which represent different investment options you are considering. You can also create a baseline scenario, which contains data on your current "business-as-usual" operations. On the Incremental Cash Flow Analysis and the Incremental Profitability Analysis sheets, the Alternative Scenarios are compared to the Base Scenario, i.e., P2/FINANCE calculates incremental cash flows and profitability.

The Investment Year and Lifetime entered here are used as defaults for both Initial Investment Costs and Annual Operating Costs. P2/FINANCE assumes that investments occur AT THE END OF THE INVESTMENT YEAR, so the default Start Year for Annual Operating Costs is Investment Year + 1. The most common Investment Year will be Year 0, i.e., most initial Investment Costs are incurred at the very beginning of the project lifetime.

Alternative Scenario 1

Name: Using Ultrafiltration

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

Alternative Scenario 2

Name: Using VCD

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

Base Scenario

Name: Disposal of Greywater by Backhauling

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

INITIAL INVESTMENT COSTS - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration 09/26/2005 Inv-Alt1-pg1

Initial Investment Costs — $ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	0
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$1,927,000
Delivery Charges			$42,394
Spare Parts			$192,700
Fielding support (3% of unit cost)			$57,810
Salvage Value	$19,270	TOTAL	$2,219,904

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Electricity			
Steam			
Water			
Fuel			
Plant Air			
Inert Gas			
Refrigeration			
Sewerage			
General Plumbing			
Salvage Value		TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house Planning			$70,000
In-house Engineering/Design			
Procurement			$80,000
Vendor/Contractor Fees			$100,000
Field Testing			$100,000
Salvage Value		TOTAL	$350,000

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Demolition & Clearing			
Old Equipment/Rubbish Disposal			
Grading/Landscaping			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$10,000
Process/Equipment Training			$20,000
Vendor/Contractor Fees			$70,000
Salvage Value		TOTAL	$100,000

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$50,000
Permit Fees			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$50,000

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Working Capital			$6,478,416
Salvage Value		TOTAL	$6,478,416

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Inv-Alt1-pg2

Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	1
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	2
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	3
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	4
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

INITIAL INVESTMENT COSTS - Alternative Scenario 2

Alternative Scenario 2: Using VCD 09/26/2006 Inv-Alt2-pg1

Initial Investment Costs	$ Amount	Initial Investment Costs	$ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	0
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$1,927,000
Delivery Charges			$44,321
Spare Parts			$289,050
Salvage Value	$19,270	TOTAL	$2,260,371

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Electricity			
Steam			
Water			
Fuel			
Plant Air			
Inert Gas			
Refrigeration			
Sewerage			
General Plumbing			
Salvage Value		TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house Planning			$70,000
In-house Engineering/Design			
Procurement			$80,000
Vendor/Contractor Fees			$100,000
Field Testing			$100,000
Salvage Value		TOTAL	$350,000

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Demolition & Clearing			
Old Equipment/Rubbish Disposal			
Grading/Landscaping			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$10,000
Process/Equipment Training			$20,000
Vendor/Contractor Fees			$70,000
Salvage Value		TOTAL	$100,000

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$50,000
Permit Fees			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$50,000

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	4
Working Capital			$6,588,309
Salvage Value		TOTAL	$6,588,309

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Inv-Alt2-pg2

Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	1
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$76,038
Spare Parts			$495,900
Salvage Value	$33,060	TOTAL	$3,877,938

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	2
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$76,038
Spare Parts			$495,900
Salvage Value	$33,060	TOTAL	$3,877,938

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	3
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$76,038
Spare Parts			$495,900
Salvage Value	$33,060	TOTAL	$3,877,938

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	4
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$76,038
Spare Parts			$495,900
Salvage Value	$33,060	TOTAL	$3,877,938

INITIAL INVESTMENT COSTS - Base Scenario

Base Scenario: Disposal of Greywater by Backhauling   09/26/2006   Inv-Base-pg1

Initial Investment Costs	$ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Process Equipment	
Storage and Materials Handling Equipment	
Safety/Protective Equipment	
Monitoring/Control Equipment	
Laboratory/Analytical Equipment	
Spare Parts	
Salvage Value	
TOTAL	$0

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Electricity	
Steam	
Water	
Fuel	
Plant Air	
Inert Gas	
Refrigeration	
Sewerage	
General Plumbing	
Salvage Value	
TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

In-house Planning	
In-house Engineering/Design	
Procurement	
Vendor/Contractor Fees	
Salvage Value	
TOTAL	$0

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

In-house	
Demolition & Clearing	
Old Equipment/Rubbish Disposal	
Grading/Landscaping	
Equipment Rental	
Vendor/Contractor Fees	
Salvage Value	
TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

In-house	
Equipment Rental	
Vendor/Contractor Fees	
Salvage Value	
TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

In-house	
Trials/Manufacturing Variances	
Process/Equipment Training	
Safety/Environmental Training	
Vendor/Contractor Fees	
Salvage Value	
TOTAL	$0

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

In-house	
Permit Fees	
Vendor/Contractor Fees	
Salvage Value	
TOTAL	$0

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Inv-Base-pg2

Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Salvage Value	
TOTAL	$0

ANNUAL OPERATING COSTS - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration — 09/26/2005 — Op-Alt1-pg1

Annual Operating Costs	$ Amount	Annual Operating Costs	$ Amount

Direct Materials (Purchase, Delivery, Storage)

Escalation Rate 0.0% — Start Year	1
End Year	15
Prefilters	$670,000
Replacement Filters	$665,000
TOTAL	$1,335,000

Utilities

Escalation Rate 15.0% — Start Year	1
End Year	15
Fuel Costs ($1.34/gal)	$4,847,000
Potable Water ($0.50/gal)	$11,152,000
TOTAL	$15,999,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate 6.0% — Start Year	1
End Year	15
Operating & Supervision (Base+ultrafiltration)	$43,998,000
Maintenance (base+ultrafiltration)	$2,993,000
TOTAL	$46,991,000

Waste Management (Labor, Materials)

Escalation Rate 5.0% — Start Year	1
End Year	15
Greywater Hauling / Treatment / Disposal ($0.75 / gal)	$7,535,000
TOTAL	$7,535,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate 0.0% — Start Year	1
End Year	15
Permitting (Item 13)	$0
Training	$0
Monitoring/Inspections/Audits (Item 1)	$0
Testing/Sampling Waste Streams (Items 7&8)	$0
Generator Fees/Taxes	
TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate 0.0% — Start Year	1
End Year	15
Labeling	
Manifesting	
Recordkeeping	
Reporting	
TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate 0.0% — Start Year	1
End Year	15
QA/QC	
Product Rejects (1 in 1000)	$2,012
Product Returns (1 in 1000)	$2,012
TOTAL	$4,024

Revenues - Product

Escalation Rate 0.0% — Start Year	1
End Year	15
TOTAL	$0

Revenues - By-product

Escalation Rate 0.0% — Start Year	1
End Year	15
Marketable By-products	
Marketable Pollution Permits	
TOTAL	$0

Insurance

Escalation Rate 0.0% — Start Year	1
End Year	15
TOTAL	$0

Op-Alt1-pg2

Future Liability

Escalation Rate 0.0% — Start Year	1
End Year	15
Fines/Penalties	
Legal Costs	
Personal Injury	
Property/Natural Resource Damage	
Remediation	
TOTAL	$0

Other

Escalation Rate 0.0% — Start Year	1
End Year	15
	$0
	$0
TOTAL	$0

Other

Escalation Rate 0.0% — Start Year	1
End Year	15
TOTAL	$0

Other

Escalation Rate 0.0% — Start Year	1
End Year	15
TOTAL	$0

ANNUAL OPERATING COSTS - Alternative Scenario 2

Alternative Scenario 2: Using VCD — 09/26/2006 — Op-Alt2-pg1

Annual Operating Costs	$ Amount

Direct Materials (Purchase, Delivery, Storage)

Escalation Rate	0.0%	Start Year	1
		End Year	15
Prefilters			$670,000
Replacement Filters			$0
		TOTAL	$670,000

Utilities

Escalation Rate	15.0%	Start Year	1
		End Year	15
Fuel Costs ($1.34/gal)			$4,847,000
Potable Water ($0.50/gal)			$11,152,000
		TOTAL	$15,999,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate	4.0%	Start Year	1
		End Year	15
Operating & Supervision (Base+VCD)			$43,998,000
Maintenance (Base+VCD)			$3,824,000
		TOTAL	$47,822,000

Waste Management (Labor, Materials)

Escalation Rate	5.0%	Start Year	1
		End Year	15
Greywater Hauling / Treatment / Disposal ($0.75 / gal)			$7,535,000
		TOTAL	$7,535,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate	0.0%	Start Year	1
		End Year	15
Permitting			
Training			
Monitoring/Inspections			
Testing			
Generator Fees/Taxes			
		TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate	0.0%	Start Year	1
		End Year	15
Labeling			
Manifesting			
Recordkeeping			
Reporting			
		TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate	0.0%	Start Year	1
		End Year	15
QA/QC			
Product Rejects (1 in 1000)			$2,012
Product Returns (1 in 1000)			$2,012
		TOTAL	$4,024

Revenues - Product

Escalation Rate	0.0%	Start Year	1
		End Year	15
Change in Product Throughput			
Change in Market Share			
		TOTAL	$0

Revenues - By-product

Escalation Rate	0.0%	Start Year	1
		End Year	15
Marketable By-products			
Marketable Pollution Permits			
		TOTAL	$0

Insurance

Escalation Rate	0.0%	Start Year	1
		End Year	15
Workers' Health Insurance			
Workers' Compensation			
Pollution Liability Insurance			
		TOTAL	$0

Op-Alt2-pg2

Future Liability

Escalation Rate	0.0%	Start Year	1
		End Year	15
Fines/Penalties			
Legal Costs			
Personal Injury			
Property/Natural Resource Damage			
Remediation			
		TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15
		TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15
		TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15
		TOTAL	$0

ANNUAL OPERATING COSTS - Base Scenario

Base Scenario: Disposal of Greywater by Backhauling | 09/26/2006 | Op-Base-pg1

Annual Operating Costs	$ Amount	Annual Operating Costs	$ Amount

Direct Materials (Purchase, Delivery, Storage)

Escalation Rate	0.0%	Start Year	1
		End Year	15

Raw Materials: HCl (M&E Item)	
Solvents	
Catalysts	
Other (Deionized Water)	
TOTAL	$0

Utilities

Escalation Rate	15.0%	Start Year	1
		End Year	15

Fuel ($1.34/gal)	$4,254,000
Potable Water ($0.50/gal)	$25,118,000
TOTAL	$29,372,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate	4.0%	Start Year	1
		End Year	15

Operating & Supervision	$42,533,000
Maintenance	$1,330,000
Other: HW Drums (M&E Item)	
TOTAL	$43,863,000

Waste Management (Labor, Materials)

Escalation Rate	5.0%	Start Year	1
		End Year	15

Greywater Hauling / Treatment / Disposal	$37,677,000
TOTAL	$37,677,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate	0.0%	Start Year	1
		End Year	15

Permitting (Item 13)	
Training/Instructing (Items 3&4)	
Monitoring/Inspections/Audits (Item 1)	
Testing/Sampling Waste Streams (Items 7&8)	
Generator Fees/Taxes	
TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate	0.0%	Start Year	1
		End Year	15

Labeling	
Manifesting	
Recordkeeping: MSDS/Emer Resp Plan Maint (Item 2)	
Reporting (Item 6)	
Other: HW Mgmt/P2 Plan Maint (Item 5)	
TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate	0.0%	Start Year	1
		End Year	15

QA/QC	
Product Rejects	
Product Returns	
TOTAL	$0

Revenues - Product

Escalation Rate	0.0%	Start Year	1
		End Year	15

Change in Product Throughput	
Change in Market Share	
TOTAL	$0

Revenues - By-product

Escalation Rate	0.0%	Start Year	1
		End Year	15

Marketable By-products	
Marketable Pollution Permits	
TOTAL	$0

Insurance

Escalation Rate	0.0%	Start Year	1
		End Year	15

Workers' Health Insurance	
Workers' Compensation	
Pollution Liability Insurance	
TOTAL	$0

Op-Base-pg2

Future Liability

Escalation Rate	0.0%	Start Year	1
		End Year	15

Fines/Penalties	
Legal Costs	
Personal Injury	
Property/Natural Resource Damage	
Remediation	
TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

Medical Exams - Medical Labor (Item 10)	
Medical Exams - Lost Labor (Item 11)	
TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

SCENARIO SUMMARY - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration 09/26/2005 Summ-Alt1-pg1

INITIAL INVESTMENT COSTS	Cost	Salvage Value	Inv. Year	Lifetime	Depreciation Period	Depreciation Method
Purchased Equipment (Purchase, Tax, Delivery)	$2,219,904	$19,270	0	15	15	SL
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	350,000	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	100,000	0	0	15	15	WC
Permitting	50,000	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	6,478,416	0	0	15	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Delivei	3,808,512	33,060	1	15	15	SL
Purchased Equipment Year 2 (Purchase, Tax, Delivei	3,808,512	33,060	2	15	15	SL
Purchased Equipment Year 3 (Purchase, Tax, Delivei	3,808,512	33,060	3	15	15	SL
Purchased Equipment Year 4 (Purchase, Tax, Delivei	3,808,512	33,060	4	15	15	SL

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$1,335,000	1	15	0.0%
Utilities	15,999,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	46,991,000	1	15	6.0%
Waste Management (Labor, Materials)	7,535,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	4,024	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

SCENARIO SUMMARY - Alternative Scenario 2

Alternative Scenario 2: Using VCD 09/26/2005 Summ-Alt2-pg1

INITIAL INVESTMENT COSTS	Cost	Salvage Value	Inv. Year	Lifetime	Depreciation Period	Depreciation Method
Purchased Equipment (Purchase, Tax, Delivery)	$2,260,371	$19,270	0	15	15	SL
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	350,000	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	100,000	0	0	15	15	WC
Permitting	50,000	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	6,588,309	0	0	4	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Delivei	3,877,938	33,060	1	15	15	SL
Purchased Equipment Year 2 (Purchase, Tax, Delivei	3,877,938	33,060	2	15	15	SL
Purchased Equipment Year 3 (Purchase, Tax, Delivei	3,877,938	33,060	3	15	15	SL
Purchased Equipment Year 4 (Purchase, Tax, Delivei	3,877,938	33,060	4	15	15	SL

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$670,000	1	15	0.0%
Utilities	15,999,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	47,822,000	1	15	4.0%
Waste Management (Labor, Materials)	7,535,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	4,024	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

SCENARIO SUMMARY - Base Scenario

Base Scenario: Disposal of Greywater by Backhaulin 09/26/2005 Summ-Base-pg1

INITIAL INVESTMENT COSTS	Cost	Salvage Value	Inv. Year	Lifetime	Depreciation Period	Depreciation Method
Purchased Equipment (Purchase, Tax, Delivery)	$0	$0	0	15	15	WC
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	0	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	0	0	0	15	15	WC
Permitting	0	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	0	0	0	15	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 2 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 3 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 4 (Purchase, Tax, Deliver	0	0	0	15	15	WC

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$0	1	15	0.0%
Utilities	29,372,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	43,863,000	1	15	4.0%
Waste Management (Labor, Materials)	37,677,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	0	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

INCREMENTAL PROFITABILITY ANALYSIS

Analysis Name: Greywater Recycling 09/26/2005 Profit-pg1

P2/FINANCE calculates three indicators of profitability. (See on-line help for more detailed descriptions.)

Net Present Value (NPV), the most reliable indicator, is the value in today's dollars of the discounted future savings of a project. A positive NPV indicates a profitable project. When considering multiple projects, the most profitable project has the highest NPV.

Internal Rate of Return (IRR) is the Discount Rate for which the NPV of a project would equal zero. An IRR greater than the Discount Rate indicates a profitable project. When considering multiple projects, the most profitable project usually, but not always, has the highest IRR. IRR cannot be calculated for some projects with irregular cash flows.

Discounted Payback is the time period within which the discounted future savings of a project repay the Initial Investment Costs. A shorter payback period often, but not always, indicates a more profitable project because Discounted Payback does not account for cash flows that occur after the payback period. Discounted Payback cannot be calculated for some projects.

P2/FINANCE provides four time horizons for calculating Net Present Value and Internal Rate of Return. P2/FINANCE automatically calculates the profitability over 5, 10, and 15 years. You may choose an optional fourth time horizon between 1 and 15 years.

Optional Time Horizon 3

This analysis calculates the incremental profitability of each Alternative Scenario relative to the Base Scenario.
Base Scenario: Disposal of Greywater by Backhauling

Net Present Value ($)

Scenario	Name	Years 0-5	Years 0-10	Years 0-15	Years 0- 3
Alternative Scenario 1	Using Ultrafiltration	171,416,301	373,665,758	606,670,953	96,795,910
Alternative Scenario 2	Using VCD	182,472,240	414,027,359	691,087,168	100,992,400

Internal Rate of Return (%)

Scenario	Name	Years 0-5	Years 0-10	Years 0-15	Years 0- 3
Alternative Scenario 1	Using Ultrafiltration	416.9%	417.1%	417.1%	413.3%
Alternative Scenario 2	Using VCD	419.9%	420.1%	420.1%	416.1%

Discounted Payback (years)

Scenario	Name	Payback
Alternative Scenario 1	Using Ultrafiltration	0.26
Alternative Scenario 2	Using VCD	0.00

6. CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION

6.1. CONCLUSIONS

The data showed that the Bristol International system did not perform as well as the other two systems. At 145 lbs, it was the lightest system, and the nature of the tubular membranes added flexibility to the configuration, but the filtration performance was lacking, showing high average permeate concentrations and low overall percent reductions.

The Infinitex Splitter XD ultrafilter and the Ovation Products VCD did well enough to consider them for use in a military application, but each had their problems. The VCD system displayed exceptional water quality but had a physical configuration that was too heavy and complicated, while the ultrafilter's physical configuration was rugged and lightweight but displayed a sub-par water quality. Table 6-1 outlines the strengths and weaknesses of these two systems based on both performance and cost effectiveness..

Table 6-1: Strengths and Weaknesses

Technology	Strengths	Weaknesses	Proposed Action
Spiral-wound Ultrafiltration (Infinitex XD)	• Simple, rugged design • Lightweight (150 lbs) • Portable • Long-lasting filters • Adequate flow rate (17 GPH) • Exceptional % reduction of waste volume (91 %)	• Water quality did not meet EPA "secondary water" goal (see Table 1)	Work with CHPPM to set a new set of standards specifically for recycling greywater in sink systems
VCD	• Water quality exceeds "secondary water" standard • Adequate flow rate • Adequate % reduction of waste volume (82%)	• Heavy (300 lbs) • Fragile • Complex design	Contractor is independently pursuing a smaller, lighter, less complicated prototype that will need to be tested.

6.2. RECOMENDATIONS

The Ovation Products Corporation's VCD system distills water efficiently but is very heavy, complex, and fragile. OPC has indicated a new alpha prototype will be completed by April 2005. It will weigh less than 150 lbs and be 4-man lift capable, consistent with our requirements. The electronic controls, currently bulky and complex, will be simplified and replaced by a single microprocessor. NSC will characterize the new prototype's performance, including flow rates, water quality as well as its size, weight, portability and ruggedness. Testing will be accomplished in a manner similar to that described in the Demonstration Plans for the current tests.

The second effort will be to continue to work with the U.S. Army Center of Health Promotion and Preventative Medicine (USACHPPM) to develop new standards and guidance to specifically address field kitchen greywater treatment and recycling. Preliminary talks with CHPPM have been positive and they agree that remediating and recycling water back into the sink system is a good idea. It is NSC's goal to develop a set of water standards that are appropriate for the mission of field sanitation, and allow the use of the greywater system. This will also include testing of the greywater system integrated with the sinks. Longevity studies will determine number of cycles the water can be reused as well as the amount of makeup water that will be required.

A one year follow-on project will allow us the resources to accomplish these goals and finish the job of transitioning one of these technologies to the soldier.

6.3 ENVIRONMENTAL CHECKLIST

State or local permits for dumping greywater might apply; however, the USACHPPM is the Army's governing body for water quality and recycling.

No water was dumped on the ground during the test. All water was collected and backhauled by a wastewater treatment contractor.

6.5 END-USER ISSUES

The U.S. Army and U.S. Marine Corps are the only two end-users identified so far. Other possible users include FEMA, Red Cross, National Guard, Air Force and the Navy. The Army and Marine Corps have to this point both expressed interest in a (COTS) item that is lightweight, portable and could, at the very least make their field kitchen areas cleaner by removing solids, oil and grease from the waste stream and at best recycle the waste water back into the wash and rinse sinks.

All systems being demonstrated were COTS items and it is anticipated that only a few minor modifications will need to be made to the systems to customize them for the Armed Forces. In this way there will be little or no negative impact on the commercialization of these items.

7. REFERENCES

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