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(6) FEASIBILITY STUDY OF A BARGE MOUNTED SYSTEM FOR TREATMENT OF SEWAGE FROM ARMY WATERCRAFT HOLDING TANK.

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SUMMARY

The objective of this study was to determine the technical feasibility of using a barge mounted treatment system for handling blackwater wastes from U.S. Army watercraft. This would replace the current practice of pumping out the blackwater storage tanks on watercraft into tank trucks and transporting the materials to a sewage treatment plant.

In order to develop a barge mounted blackwater treatment system a body of information was gathered and analyzed. Initially an extensive literature search was conducted to determine the state-of-the-art in marine waste treatment. This included shipboard waste characterization (in terms of quantity and pollutant concentrations) and investigation of applicable legislation. Commercial and developmental marine sanitation devices (MSD's) were studied, as well as conventional wastewater treatment methodologies which appeared feasible for barge mounting. Specific design requirements involved in barge mounting of a treatment system were also identified. Based on this information, feasible barge locations and specific design wasteloads were determined.

Once the nature and quantity of the waste and basic design requirements were established, a preliminary screening of the spectrum of wastewater treatment unit processes was conducted to isolate a number of pertinent alternative systems. Suitability of these systems was based on capability to meet discharge requirements, adaptability to barge mounting and operational simplicity. These systems were then compared at each location from a cost and technical standpoint and the most feasible system(s) determined.

The literature search revealed very little regarding characterization of waste produced by reduced-flush and recirculating marine waste systems, which are the only types used aboard U.S. Army watercraft. A dearth of information also exists regarding treatability of these concentrated wastes.

Barge classification, which has a direct bearing on discharge limitations, is a disputed issue. No decision has been made by the EPA as to whether the barge will be classified as a "vessel" or point source. Selection of treatment alternatives was, therefore, based on the more stringent point source effluent requirements. Discharge limitations are also somewhat determined on the basis of location. For this reason and because of insufficient watercraft activity only 4 of the 13 initially considered sites were chosen for further evaluation.

At these four sites, six alternative treatment schemes were considered. Of these, four were physical/chemical systems, one was biological and one incorporated the use of a commercial marine sanitation device (MSD).

Physical/chemical treatment of blackwater appears most technically feasible with incorporation of a filter press, centrifuge or ultrafilter for coarse solids removal followed by a packed bed filter, activated carbon (for soluble organic removal) and effluent chlorination prior to discharge. Capital costs for this treatment were very high at three of the four sites due to limited blackwater volumes to be treated. At the fourth site, namely Ft. Eustis, costs for physical/chemical treatment of blackwater ranged from $150 to 172/1,000 gallons, excluding hauling of residues and barge retrofit.

Only if the barge is classified as a vessel will the MSD be considered further. Biological treatment of blackwater might not be able to provide adequate treatment because of intermittent loadings and variable waste characteristics.

PREFACE

This study into the feasibility of a barge mounted blackwater treatment system was part of a larger, ongoing U.S. Army watercraft pollution abatement program. The program was developed to ensure that existing requirements for marine pollution control, including both oily and non-oily wastes, can be met on Army watercraft by 1981. The study that follows was conducted to determine feasible means for treatment of a non-oily waste, i.e., blackwater.

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INTRODUCTION

PROBLEM STATEMENT

Although it is not generally recognized, the U.S. Army operates a rather large fleet of watercraft. These include small and large tugboats, landing craft, cranes, supply freighters, floating machine shops and beach discharge lighters, among others. In keeping with the mandates of the Federal Water Pollution Control Act Amendments of 1977 (Clean Water Act), the Army has undertaken an extensive watercraft pollution abatement program. The ongoing program entails installation of a collection, holding and transfer (CHT) system on each watercraft for retention and subsequent shore disposal of blackwater (human body wastes only). However, the existing means of blackwater disposal on shore; namely, contractor tank truck hauling; is fraught with difficulties.

A major problem with the use of contracted services to pump out holding tanks and dispose of blackwater has been the reliability of contractors. The tank trucks dispatched to the dock to service the watercraft are also used for a myriad of waste handling jobs such as the hauling of industrial wastes, cleaning of residential septic systems, etc. Thus, servicing the watercraft would have to be scheduled along with a series of other contracted hauling jobs. With this sort of arrangement, delays are likely.

A second limitation is the storage capacity of the tank truck. Because of roadway weight and size limitations, the cost of tractors to power the units and the need to drive into restricted spaces, the tank truck capacities are limited to unloading blackwater from one or, perhaps, two boats. This compounds the probabilities of delays.

Another uncertainty is the acceptability of blackwater at local sewage treatment plants. The prospect of continued use of tank truck haulers depends on this acceptability. The materials are fed into sewage treatment systems as a surge because the tank trucks cannot be tied up for long periods of time during which the blackwater can be metered into the system. Acceptability is based on the assurance that the blackwater will not create upset conditions for the sewage treatment plant. This will depend on the nature and size of the particular system and will, therefore, vary from locality to locality.

Another unacceptable problem with the use of tank trucks is the occurrence of avoidable spills into watercourses. There are no uniform and reliable hookup procedures and, as a result, makeshift hose connections are used which can and do fail. The tank truck operator has not been instructed in the deleterious environmental effects of spills and is not prepared to enforce countermeasures should spills occur. In short, the Army presently lacks control over the major concerns in disposing of watercraft blackwater.

One alternate means of blackwater handling which the Army has decided to explore incorporates the use of a central treatment facility mounted on a stationary barge. Such a system would facilitate blackwater transfer from each watercraft while also producing a treated effluent amenable to direct discharge into the watercourse.

STUDY OBJECTIVE

It was the objective of this study to evaluate the feasibility of such a treatment system on the basis of both technical and cost considerations. The study involved two basic components. A comprehensive literature review was first conducted to determine the state-of-the-art in watercraft waste characterization and treatability. The second major component of this study involved an evaluation designed to identify cost-effective treatment alternatives which would be suitable for barge mounting and satisfy local effluent discharge requirements.

SECTION 2

STATE-OF-THE-ART REVIEW

PURPOSE

The major function of this state-of-the-art review was to provide sufficient background information to enhance and reduce the work effort involved in the exploratory development program for a barge mounted blackwater treatment system. Specifically, the review was designed to determine the normal quantity and quality of blackwater wastes generated on watercraft as well as the variability in waste generation as a function of vessel type and flushing system. In addition, literature which described the treatability of these wastes by both physical/chemical and biological means was located.

The information obtained provided some of the background data necessary for evaluation and design of a barge mounted blackwater treatment system. The review was also utilized to identify subject areas where crucial information gaps exist.

INFORMATION SOURCES AND SUMMARY FORMAT

A number of information sources were utilized for this state-of-the-art review. Included in these information sources were computerized file search services, manual searches at local libraries, and bibliographical reference publications pertaining to the field of watercraft wastes and their treatment. The following list summarizes these sources:

1. Computerized File Searches:

   a. University of Wisconsin - Madison Information Services (IS) - This service contains over 60 data bases and has access to the collection of all 28 libraries in the University of Wisconsin system, as well as John Crerar Library in Chicago (a major research library for the Midwest and a translation center for the entire U.S. for International literature).

   b. Maritime Research Information Service -(MRIS) - This service functions under the auspices of the National Research Council and provides information pertaining to completed and maritime research. There is a special subject area in marine pollution abatement.

c. Smithsonian Science Information Exchange (SSIE) - This computerized file search provides information for ongoing research efforts only.

2. Manual Searches:

   a. Rexnord Technical Library.

   b. Marquette University - Memorial Library - Since Marquette has NROTC and AROTC programs, a number of military publications are in circulation.

   c. Milwaukee Public Library.

   d. Personal communications with researchers in the field of maritime pollution control.

   e. Review of reference lists contained in procured articles and publications.

3. Special Bibliographic Publications:

   a. "Characterization and Treatment of Sanitary Effluents from Watercraft - A Bibliography with Abstracts" (1).

   b. NTIS Search - "Shipboard Sewage Treatment: A Bibliography with Abstracts" (2).

   c. "Projects of the Agricultural and Marine Pollution Control Section" (3).

The computer file and manual searches yielded numerous pertinent abstracts, articles and publication sources. A number of publications and periodical articles were procured, reviewed and summarized. The vast majority of publications were ordered from NTIS. Figure 1 is a sample of the summary format used to facilitate categorization of the publications/articles.

INFORMATION REVIEW AND DISCUSSION

The literature review has been divided into five separate categories, each of which provides information pertinent to the project objectives. These categories are as follows:

1. Quality and quantity characteristics of human wastes (sewage or "blackwater") from watercraft.

2. Legislation pertinent to the discharge of these treated wastes into U.S. controlled waters.

3. Evaluation of cost and effectiveness of the many varieties of marine sanitation devices (MSD) which have been utilized for watercraft wastes.

LITERATURE REVIEW
BLACKWATER WASTES

Title: Development of On-Shore Treatment System for Sewage from Watercraft Waste Retention System

Authors: J. H. Robins and A. C. Green

Source: EPA-670/2-74-056

Date: July 1974

Topics Presented:

1. Waste Characteristics - 65 total samples from retention/recirculating CHT's from 6 categories of recreational vessels (waste age from 10 hours to 5 months) were analyzed for SS, VSS, TS, TVS, TOC, SOC, BOD_5, COD, T-N, NH_3-N, T-PO_4, zinc, conductivity, pH and coliforms.

2. Determined characteristics and toxic effects (on aerobic biological treatment processes) of the various commercially available chemical bacteriostats.

3. Tested physical/chemical treatment system consisting of: a) maceration/prechlorination, b) flocculation/clarification, c) activated carbon addition, d) DE precoat vacuum filtration, e) air separator and f) discharge of effluent. Achieved better than 90% BOD, SS, COD and T-PO_4 removal; effluent coliform densities < 10MPN/100 ml.

Additional Comments:

Figure 1. Representative bibliographical summary sheet.

4. Applicability of other more conventional wastewater treatment methodologies to the type of waste and barge(s).

5. Other specific design parameters for a barge mounted treatment system.

Waste Characterization

The quantity and quality of wastewater generated on watercraft is highly variable. Table 1 summarizes pollutant concentrations and Table 2 lists per capita mass pollutant loadings and flow rates. The high variability in concentrations and per capita flow rates can be attributed, in part, to the quantities of diluent, or carriage fluid, employed in various flushing systems (normal and reduced-flush and recirculating) as shown in Figure 2.

Mission profile induced variation is also very important. The duration of total mission, time of day and day of week of each mission, duration dockside and underway, type of vessel, weather conditions, etc., can all influence the waste characteristics. The ranges of per capita five day biochemical oxygen demand (BOD_5) and suspended solids (SS) mass loading rates (Table 2) attest to this variability. Diurnal fluctuations in shipboard wastewater flow rates have been reported to range from 2 to 5 times the daily average (13, 23). In most cases such fluctuations would not have a significant impact on the barge mounted system due to equalization provided by watercraft CHTs. Deterministic and stochastic predictive models have been developed by the U.S. Navy to estimate sewage generation rates and determine optimum holding tank capacities and treatment rates, although these models have not seen extensive application (24, 25).

Fecal coliform densities reported in the literature are also highly variable, ranging from 10^1 to 10^{10} organisms per 100 ml (4, 5, 6, 13, 16). This variation is attributable not only to the quantity of diluent used, but also to the use of chemical bacteriostats such as formaldehyde, zinc compounds and quaternary ammonium salts. Table 3 summarizes the use of some commercially available chemical additives.

In addition to parameters listed in Tables 1 and 2 limited information was found for a number of other pollutant parameters such as nutrients, metals, indicator organisms, etc.

Since the U.S. Army uses recirculating MSDs on a number of watercraft, it is important to characterize waste from these units. Although wastewater quality characteristics from a recirculation system on the LCU 1561 were reported by Voisinet (16), (Table 1) these wastes also contained a significant fraction of greywater (laundry, galley and shower wastewater).

Two reports were found which detail the quality of the recirculation fluids for blackwater alone (26, 27). Table 4 summarizes these data. Unfortunately, the objective of both of these studies was to evaluate the quality of carriage fluid as recycled back to the commode (Coast Guard MSD certification requirement) rather than as discharged from the holding tank in

TABLE 1. SUMMARY OF POLLUTANT CONCENTRATIONS IN SEWAGE GENERATED ON WATERCRAFT.

Waste Source	BOD_5, mg/l Avg.	BOD_5, mg/l Range	SS, mg/l Avg.	SS, mg/l Range	TS, % Avg.	TS, % Range	pH	Flushing System	Waste Type[c]	Reference
1. Recreational and commercial watercraft										
-General		100-1000		200-1100				Not specified	BW	4
		350-3500		475-4750			6.7	Not specified	BW	5
-Marinas	1960	30-9230	1540	72-9050	1.6	0.1-4.8	5.3-8.8	Not specified	MHT + BW	6
				400-17,200		0.2-4.4	6.0-8.6	Not specified	MHT	7
-Houseboat	187		150		0.04			Normal - freshwater	BW + GW	8
-Ferries	180[a]	78-960	396[a]	124-1150	4.5[a]			Normal - saltwater	BW + GW	9
	170	108-313	230	89-531			7.5-8.9	Normal - saltwater	BW + GW	10
2. Military watercraft										
- U.S. Navy:										
Submarine	1150				0.09			Not specified	BW	11
USS Dixon	550				0.5		6.5	Not specified	NS	12
USS Fulton	102	18-242	236	0-800	3.3	3.1-4.1	4.6-8.2	Normal - saltwater	BW	13,14
- U.S. Army:										
Dredge	650	175-880	600	125-1400			6.9-8.5	Not specified	BW + GW	15
LCU 1561	974	590-1830	1213	144-9480	0.3	0.2-1.0	7.5	Recirculating - freshwater	BW + GW	16
Craftor Mobile Toilet	22,500		12,700		2.9			Recirculating - freshwater	BW	17
- U.S. Coast Guard - Five Vessels[b]	1600	80-2180	885	65-4990	2.9	0.4-8.2	6.6-7.9	Not specified - salt and freshwater	BW	18
82' Patrol boat	1120	570-2340	3160	40-7500				Not specified	BW	19
110' Harbor tug	568	153-1830	1139	80-4920				Not specified	BW	19
180' Buoy tender	712	400-975	540	220-1050				Not specified	BW	19

[a] This value represents one grab sample rather than an average.

[b] Composite of five Coast Guard vessels of various sizes; all data obtained while vessels were underway, except the BOD_5 data which was obtained dockside.

[c] MHT - marina holding tank
NS - not specified
BW - blackwater
GW - greywater

TABLE 2. SUMMARY OF PER CAPITA POLLUTANT LOADINGS AND WASTEWATER FLOWS FOR SEWAGE GENERATED ON WATERCRAFT.

Waste Source	Average blackwater quantity, gpcd[g]				Avg. BOD_5, gram/cap-day	Avg. suspended solids, gram/cap-day	Waste type[f]	Reference
	Normal flush	Low flush	Recirculating	Unspecified				
1. Non-passenger ships	30	3	0.5				BW	20
2. Passenger ships:								
-Large: Crew	30	3	0.5				BW	20
Passengers	10	1	0.15				BW	20
-Water Bus: Crew	15	1.5	0.25				BW	20
Passengers	7.5	0.75	0.12				BW	20
3. Recreational and commercial watercraft								
-General				20-50	91		BW	4
				5-50	68	90	BW	5
-Houseboats				62	43	34	BW + GW	8
4. Military watercraft								
-U.S. Navy:								
General	35						BW	21
Submarine				5			BW	11
USS Fulton	20						BW	13
Three vessels[a]	11-17						BW	14
-Coast Guard[b]				30[c]	92[d]	84[e]	BW	18
5. Unspecified	30-45	3-9					BW	22

[a] USS Essex, USS Mullinnix, USS Northhampton

[b] Composite of 5 Coast Guard vessels; all data obtained while vessels were underway, except BOD data which were obtained while dockside.

[c] Wastewater flow range = 3-65 gpcd.

[d] BOD load range = 54 - 217 gram/cap-day.

[e] Suspended solids load range = 19-101 gram/cap-day

[f] BW - blackwater
GW - greywater

[g] gpcd = gallons/capita-day = 3.785 liters/cap.-day.

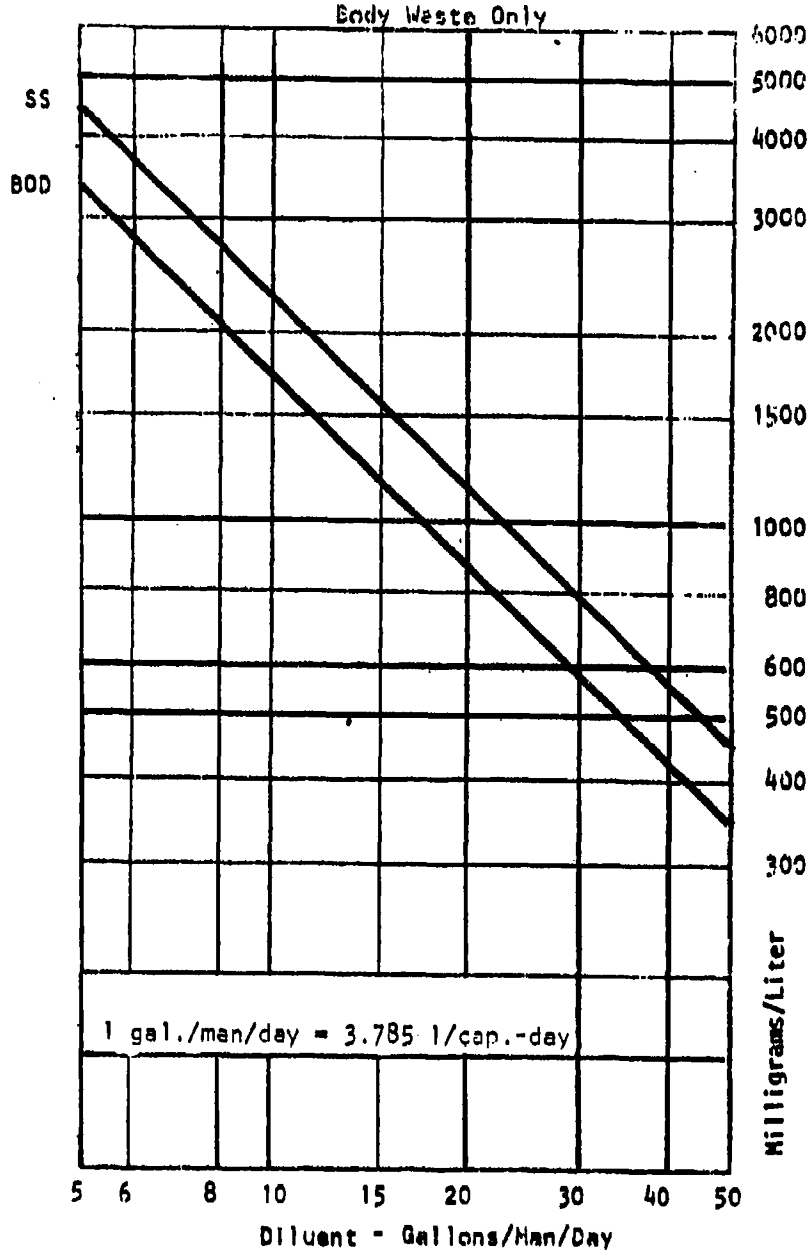

Figure 2. Effect of dilution on daily per capita waste pollution indices (5).

TABLE 3. CHARACTERISTICS OF CHEMICAL TOILET ADDITIVES (6).

Chemical Code	Dosage (gm/l)[a]	Form	Color	pH Range	Active Ingredient[b,c]	Other Ingredients	Heavy Metals
40	4.5-1.5	Liquid	Blue	6-8	35% Formaldehyde	Alcohol, perfume, surfactant, dye	None
20	3.9	Powder	Green	6-8	Paraformaldehyde	Perfume, dye	Pb, Cu, Ni, Fe
83	3.8	Liquid	Blue	6-8	Formaldehyde	Alcohol, perfume, surfactant, dye	No data
96	4.5-1.5	Liquid	Blue	6-8	28.5% Formaldehyde	Alcohol, perfume, surfactant, dye	None
26	4.4-2.0	Powder	Blue	6-7	87% Zinc Sulfate Monohydrate	Perfume, surfactant, dye	Zn
33	1.5	Powder	Blue	6-7	87% Zinc Sulfate Monohydrate	Perfume, surfactant, dye	Zn
38	1.7	Granule	Blue-Green	6-8	Quaternary Ammonium Salt	Perfume, surfactant, dye	None
57	1.5	Powder	Blue	6-8	Paraformaldehyde	Perfume, surfactant, dye	No data
71	1.5	Powder	Blue	6-8	Paraformaldehyde	Perfume, surfactant, dye	No data
15	1.2	Liquid	Blue	6-8	10% Quaternary Ammonium Salts	Dye	None

[a] Recommended dosage levels vary according to the application and size of recirculating/retention sanitary systems.

[b] Liquid formaldehyde-type additives employ formalin, which is 37% formaldehyde and 10% methanol.

[c] Paraformaldehyde is a formaldehyde polymer prepared by concentrating formalin at reduced pressure.

TABLE 4. QUALITY OF FLUSH-FLUID IN RECIRCULATING MARINE SANITATION DEVICES.

Type of flush-fluid	Parameter	No. of samples	Range	Mean	Standard deviation	Reference
Mineral-oil[a]	Turbidity, JTU	43	0-140			26
	Color, PCU	43	0-455			26
	Water-in-oil, ppm	43	8-660			26
	Bacteria, counts/100 ml	43	0-TNTC			26
Mineral-oil[b]	Color, PCU	26	10-40	16	10	27
	Water-in-oil, ppm	24	44-278	91	57	27
	Total plate count, no./ml	30	<1-10	2.23	2.96	27
Water[c]	Suspended solids, mg/l	19	170-1,950	900	517	27
	pH	20	6.6-8.9			27
	Standard plate count, no./ml	18	$8x10^4-1x10^{10}$	$1.7x10^9$	$3.7x10^9$	27
	Coliforms, no./100 ml					
	Fecal	18	$<10-7x10^6$	$7.6x10^5$	$2.1x10^6$	27
	Total	18	$2x10^4-2x10^9$	$2.5x10^8$	$6.7x10^8$	27
Water[d]	Suspended solids, mg/l	20	50-1,230	442	339	27
	pH	21	6.1-8.6			27
	Standard plate count, no./ml	17	$4x10^4-6x10^9$	$6.0x10^8$	$1.5x10^9$	27
	Coliforms, no./100 ml					
	Fecal	17	$<10-3x10^6$	$1.8x10^5$	$7.3x10^5$	27
	Total	17	$1x10^4-2x10^8$	$4.2x10^7$	$8.6x10^7$	27

[a] Oil-Transport-Medium Sewage Disposal System; prior to recirculation the oil is separated from the sewage solids by gravity and then filtered and disinfected; solids are macerated and incinerated.

[b] Chrysler Corp. - "Aqua-Sans" MSD; oil treatment prior to recirculation similar to system described in Footnote a.

[c] Monogram Industries, Inc. - "Jet-o-matic" MSD; water screened prior to recirculation and paraformaldehyde used as chemical additive.

[d] Koehler-Dayton, Inc. - "Commidore" MSD; operation similar to system described in Footnote c.

combination with the retained sewage solids. Wullschleger, et.al., (17) determined the characteristics of wastes from an experimental Craftor Mobile Toilet set up at Fort Belvoir, Virginia. This was a freshwater recirculation system using formaldehyde as a bacteriostat. These data are contained in Table 1.

It is important to note that those waste characteristics present in Tables 1 and 2 pertain to blackwater "as generated". The effects of storage on these wastes has not been established. Since only a small number of the CHTs on U.S. Army watercraft are continuously aerated, it is apparent that the proposed barge treatment system must be capable of handling both aerobic and anaerobic wastes.

Obviously, the effects of storage on waste characteristics will differ for aerobic and anaerobic conditions. Only two reports were found in the literature which describe these effects specific to watercraft wastes. Lardis and Geyer (28) reported the effects of anaerobic storage of an analagous synthetic waste under laboratory conditions. Under all test conditions, total DO depletion occurred within 100 hours of anaerobic storage. They also observed significant concurrent reductions in pH, oxidation reduction potential (ORP) and sulfate concentrations and increases in total volatile acids concentrations. They developed a predictive model capable of estimating the concentrations of potentially hazardous gases in CHTs. They concluded that anaerobic conditions should be avoided in CHTs.

Ferguson, et.al., (10) evaluated various methods of inhibiting anaerobic activity in CHTs on Washington State ferries. Since one of these methods was CHT aeration, they documented the oxygen uptake rates and BOD_5 reductions with time. However, the Washington State ferries employed full-flush collection systems and as such, initial BOD_5 concentrations were more dilute than would be expected from reduced - flush systems used on Army watercraft.

Legislation

The application of a barge mounted treatment system presents a rather unique situation from the standpoint of water pollution control legislation. If one views this barge as a "vessel", i.e., "capable of being used as a means of transportation on waters of the United States" (29), the effluent requirements are based on marine sanitation device (MSD) regulations promulgated by the U.S. Environmental Protection Agency and enforced by the U.S. Coast Guard. If the barge is legally classified as a point source, more stringent secondary treatment guidelines defined by U.S. EPA, would pertain. The classification of a barge system has not been finalized, so both categories are discussed.

Barge Classification-Vessel--

Legislation pertinent to treatment and discharge of vessel sanitary wastes has been developed over a numbers of years into present form. This development can be seen in Table 5.

TABLE 5. NATIONAL STATUTES AND INTERNATIONAL AGREEMENTS PERTINENT TO MARINE POLLUTION FROM SHIPPING (91).

Refuse Act of 1889.
Federal Water Pollution Control Act of 1948 (as amended in 1972 and 1977).
National Environmental Policy Act of 1969.
Water Quality Improvement Act of 1970 (PL 91-224).
Clean Air Act (1971).
Port and Waterways Safety Act of 1972.
United States and Canada Agreement on Great Lakes Water Quality 1972.
1973 International Convention for Prevention of Pollution from Ships.

It should be noted that foreign port authorities have imposed discharge standards for a number of years. In the 1960's, Canadian authorities required that for vessels with crews less than 40 members SS and fecal coliform concentrations for any discharge be less than 150 mg/l and 1,000 MPN/100 ml, respectively; for vessels with crews greater than 40 members, effluent BOD must be less than 50 mg/l, SS less than 150 mg/l and fecal coliform levels less than 1,000 MPN/100 ml (30). Also, Port of London Authorities have allowed no discharge in waters under its control for many years (30). International agreements have also been established under the auspices of the Intergovernmental Maritime Consultative Organization (IMCO) (31).

In the U.S., requirements which first established control of sewage from vessels were found in Section 13 of the Water Quality Improvement Act of 1970 (PL 91-224) (32). Responsibility for establishing performance standards for marine sanitation equipment was assigned to the EPA. Initial discharge requirements limited fecal coliform levels to 1,000 MPN/100 ml with "no visible floating solids", while final standards prohibited all sewage discharges from vessels with marine toilet facilities.

Section 312 of the Federal Water Pollution Control Act (FWPCA) (as amended in 1972 and 1977) (33), further defined sewage discharge requirements for vessels. The FWPCA empowered the U.S. EPA to issue standards of performance for MSD's. The U.S. Coast Guard was entrusted with implementation of those standards issued by EPA. The most current standards issued pursuant to the FWPCA governing MSDs, namely EPA 40 CFR 140 (January 1976) (29) and USCG 33 CFR 159 (April 1976) (34) lifted the blanket zero discharge requirement. These regulations allow the continued use of certified flow-through devices for vessel waste treatment. No prohibitions concerning sink and shower wastes emptying into U.S. waters are included. U.S. vessels as well as foreign flag vessels must comply while in territorial waters and estuaries, the Great Lakes, interconnected waterways and intermediate navigable rivers (31).

In the above regulations, marine sanitation devices are defined as, ". . . any equipment for installation on board a vessel which is designed to receive, retain, treat or discharge sewage and any process which treats such sewage" (29). MSD categories can be described as follows:

Type I - Provides minimal pollutant removal, fecal coliform levels must be less than 1,000 MPN/100 ml with no visible floating solids; mainly for small craft and interim compliance; most are physical/chemical (P/C) devices.

Type II - Effluents from these devices are acceptable in all navigable waters of the U.S. with some exceptions, must provide less than 150 mg/l suspended solids, 200 MPN/100 ml fecal coliform. May be P/C or biological system.

Type III - Originally designed to comply with "no-discharge" standard superceded in 1976. Typically employs recirculation, incineration or holding tank method of operation.

Use of these devices is dependent on certification by the U.S. Coast Guard (USCG) that effluent requirements can be met.

The new standards issued in 1976 separate all vessels into two classes: new and existing vessels. New vessels are those whose keel was laid after January 30, 1978 while existing vessels had their keels laid prior to that date. A recent Coast Guard waiver (43 FR29637) of July 5, 1978 (35) further classifies vessels into those over and under 65 ft (19.8 m) in length.

Owners of new vessels were required to install Type I, II or III MSDs by January 30, 1977. Subsequent to January 31, 1980 only Type II or III MSDs may be installed on large vessels. Existing large vessels must be equipped with Type II or III MSDs prior to January 31, 1980 although Type I devices installed before January 30, 1978 may remain in use for the life of the device. These regulations are summarized in Table 6, including vessel classification by size.

Federal regulations also allow more stringent local control if reasonable cause exists. States can petition the EPA for zero discharge regulation for environmentally sensitive receiving waters provided adequate facilities are available for safe and sanitary removal of sewage (29). Also, Section 312 (d) of the FWPCA further exempts vessels owned and operated by the Department of Defense if the Secretary of Defense "finds that compliance would not be in the interest of National Secutity".

Barge Classification-Point Source--

Barge classification as a point source would result in more stringent discharge limitations. Secondary treatment guidelines, as mandated by the Federal Water Pollution Control Act Amendments, would have to be met. Moreover, additional or even more stringent standards may be set by the State or locality in which the barge would be used. As outlined in Section 402 of the Act, the permit issuance program for each state must be approved by the EPA in conformance with the National Pollutant Discharge Elimination System (NPDES).

TABLE 6. SUMMARY OF MARINE SANITATION DEVICE REGULATIONS (35).

	Vessel length	
	Over 65 ft (19.8 m)	65 ft (19.8 m) or less
Vessel type	New	New
Timetable	Up to Jan. 30, 1980 -Install Type I,II,III MSD After Jan. 30, 1980 -Install Type II,III MSD	Up to Jan. 30, 1980 -Install Type I, II, III MSD After Jan. 30, 1980 -Install Type II, III MSD
Vessel type	Existing	Existing
Timetable	Up to Jan. 30, 1980 -No mandatory requirements After Jan. 30, 1980 Install Type II,III MSD Except if Type I MSD installed by Jan. 30, 1979, it may be used for the life of the device.	Up to Jan. 30, 1980 -No mandatory requirements After Jan. 30, 1980 Install Type II, III MSD

Definition of minimum secondary treatment standards, stated in terms of three pollutant parameters - five-day biochemical oxygen demand (BOD_5), suspended solids (SS) and pH is provided below (36):

1. Biochemical Oxygen Demand (BOD_5).

   a. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 mg/l.

   b. The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 mg/l.

   c. The average BOD removal over a period of 30 consecutive days shall not be less than 85 percent.

2. Suspended Solids (SS).

   a. The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 mg/l.

   b. The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 mg/l.

3. pH.

   a. The effluent values for pH shall be maintained within the limits of 6.0 and 9.0.

It should be noted that the above discussion of point source limitations pertains specifically to "publicly owned treatment works" (POTW). Section 212 of the Act defines a treatment work as "any devices and systems used in the storage, treatment, recycling and reclamation of municipal sewage or industrial wastes of a liquid nature". A POTW is further defined in 40 CFR 122.3 (37) as a treatment work "which is owned by a State or municipality". In Section 313 of the Act, it is stated that, in general, federal facilities are subject to the same requirements as any nonfederal entity. However, the President "may exempt any effluent source of any department, agency or instrumentality in the executive branch from compliance with any such a requirement if he determines it to be in the paramount interest of the United States to do so".

Marine Sanitation Device Evaluation

General Consideration--

It is important to review the state-of-the-art of marine sanitation device (MSD) technology for two reasons. First, these devices have been specifically designed to treat watercraft wastes, which can be significantly different from normal domestic wastewaters in municipal plants. The effectiveness of these devices will provide valuable insights into the selection of the optimum barge mounted system for similar wastes. Secondly, direct integration of one or more of these devices into the barge mounted system may be appropriate (depending on legal barge classification). If a particular device has proven to be reliable, cost-effective and amenable to the special constraints imposed by the barge, it should be given due consideration. Although abundant research has been done regarding treatment of watercraft wastes, cost-effectiveness evaluations and comparisons are difficult. Variable raw waste characteristics, environmental conditions, treatment objectives, and developmental stage are all factors which complicate the MSD evaluation.

Marine sanitation devices and developmental systems may be evaluated on the basis of a single objective: to provide efficient and economical treatment that will meet discharge guidelines in the unique hydraulic, biological, chemical and physical conditions of the shipboard environment. Special consideration must be given to physical characteristics of the treatment system and vessel. Bulk and weight are important in a shipboard system especially for retrofitting. Space must be made available and additional weight supported without affecting metacentric stability of the vessel (38). MSD systems must provide a high degree of reliability allowing continuous operation during extended periods without failure.

Treatment efficiency must also be maintained during roll, pitch and heave accelerations, and during periods of hydraulic loading variation (38). Mechanically, a shipboard MSD must be able to withstand shock, vibration and corrosive effects associated with the marine environment. Crew members must have a treatment system that is limited in its complexity, both to operate and maintain, that will provide a large degree of safety, and is aesthetically agreeable (38).

The cost of the treatment system is of obvious importance, but difficult to evaluate on the basis of information published in the general literature.

The costs of commercially available devices were generally out of date (4, 5, 38, 39, 40). Furthermore, reliable cost information was not provided for most developmental systems.

Brief History of Shipboard Sewage Treatment--
Until the advent of larger passenger ships, all waste was discharged directly overboard. With the introduction of large passenger vessels, some form of central sewage system was necessary. The system initially devised was a receiving tank with float controlled pump to discharge sewage overboard (30). When legislation was proposed limiting discharge into coastal water and harbors, research into the design of a sewage treatment plant suitable for use on-board ship was stimulated. Early designs were based on decanting the liquid effluent in one or more stages and finally chlorinating it before overboard discharge. Solids were retained until the ship left port, to be discharged at sea (30). Later, more sophisticated plants used anaerobic digesters and treated effluent with a solution of calcium hypochlorite. This system worked well for small ships but could not meet effluent requirements for larger ships (greater than 40 member crews) (30).

Modern Marine Sewage Treatment--
Prompted by legislation outlined previously, research was done on a wide variety of MSD systems. These systems have primarily been adaptations of land based systems with occasional shipboard testing. Although many systems appear to function adequately onshore, problems are encountered aboard ship. These problems are caused by conditions which are unique to the shipboard environment such as excessive corrosiveness, motion, shock and vibration (5).

MSD systems can be classified into three general categories: holding, flow-through and closed systems. Holding and closed systems are termed "no-discharge systems" and include holding tanks, incinerator/evaporators, and recirculation systems. Holding tanks collect all waste for pumpout at a shoreside facility or discharge beyond territorial waters. Incineration/evaporation systems can be used to boil off most of the water in sewage, leaving solids suitable for incineration. Recirculation systems separate solids from liquids; solids are placed in a holding tank for later pumpout while liquids are treated with a chemical disinfectant and recirculated as flush water. "No-discharge" or closed systems will not be discussed at length since, to date, the most stringent vessel requirement that would have to be met by the barge treatment system is the Type II classification as defined in the previous section. Type II devices are flow-through systems.

Marine Sanitation Devices and Treatment Systems for Shipboard Wastes--
Certified marine sanitation devices and developmental treatment systems may be categorized into biological, physical/chemical and electrochemical or electromechanical. Table 7 summarizes the evaluation of MSDs and developmental systems reported in the literature. Where available, information is included on influent (raw) waste concentrations, pollution control effectiveness, equipment scale, and whether the data represents onshore or shipboard testing. Information on the commercial availability of Type II

TABLE 7. SUMMARY OF EFFECTIVENESS OF EXPERIMENTAL AND COMMERCIALLY AVAILABLE MARINE SANITATION DEVICES INTENDED FOR SHIPBOARD USE.

MSD description	Influent type and/or characteristics	Pollution control effectiveness	Equipment scale or size	Study location	Devel. stage[a]	Manuf.	Reference
Biological							
Conventional Activated Sludge	Portable toilet waste BOD = 1100-2600 mg/l TSS = 2100-3600 mg/l Bacteriostats added	BOD and TSS removal = 90-98%	55 gal. drum	Onshore	E		6
Activated Sludge - Filtration - disinfection	Raw domestic sewage BOD = 167 mg/l avg. TSS = 157 mg/l avg.	BOD removal = 96% avg. TSS removal = 90% avg.	3000 GPD	Onshore	E		44
Activated Sludge - Ultrafiltration	Full flush toilet waste COD = 47-680 mg/l TSS = 83-1424 mg/l	Effluent BOD = 8.8 mg/l avg. Effluent TSS = 0 Coliform <240 MPN/100 ml 98.5% of the time	40 GPD	Onshore	E		45
Extended Aeration	Greywater (toilet, galley, shower, sink, laundry waste) BOD = 120-1820 mg/l TSS = 150-1510 mg/l	Effluent BOD = 30-2560 mg/l Effluent TSS = 90-9100 mg/l	580-3300 GPD	Shipboard	E		23
Extended Aeration	Greywater (as above) BOD = 82-1670 mg/l TSS = 75-5000 mg/l	BOD = 35-470 mg/l TSS = 52-660 mg/l	280-9360 GPD	Shipboard	E		23
Extended Aeration	BOD = 216 mg/l avg. TSS = 662 mg/l avg.	BOD = 10 mg/l TSS = 34 mg/l	10-100 crew members	Offshore oil rigs	CA	Levington	46
Extended Aeration	Full flush toilet wastes BOD = 140-160 mg/l fresh and saline	Effluent BOD = 25 mg/l	Not given	On and off-shore	CA		47
Activated Sludge-Disinfection	Not given	Type II	100-9000 GPD		CA	Red Fox	Manuf. Lit.
Modified Extended Aeration - Disinfection	Black and grey water	Type II	325-10000 GPD		CA	Demco	Manuf. Lit.
Aerobic Fixed Media - Disinfection	Black and grey water	Type II	9-1700 crew members		CA	St. Louis Ship	Manuf. Lit.
Biological Filter	Blackwater-toilet wastes	Type II	25-2500 GPD		CA	Microphor	Manuf. Lit.
Physical/Chemical							
Primary Sedimentation - Chlorination - Sludge Incineration	Blackwater TSS = 243 mg/l avg. BOD_5 = 206 mg/l avg. Fecal coliforms = 5.6×10^5 col/100 ml avg.	Effluent TSS = 63 mg/l avg. Effluent BOD_5 = 56 mg/l avg. 85% of effluent fecal coliforms ≤200 col/100 ml	1100 GPD	Shipboard	E		45
Primary Sedimentation - Ozonation - Residual Chlorination - Sludge Incineration	Blackwater TSS = 832 mg/l avg. COD = 1476 mg/l avg. Fecal coliforms = 5.6×10^6 col/100 ml avg. (primary effluent)	Effluent TSS = 35 mg/l Effluent COD = 191 mg/l Fecal coliforms = 10 col/100 ml avg.	400 GPD	Shipboard	E		48
Electrocoagulation - Solids Sep. - Chlorination - Sludge Incineration	Greywater (sanitary, galley, shower, laundry) BOD = 1000 mg/l avg. TSS = 1000 mg/l avg. Coliform = 10^8 MPN/100 ml	"Good" BOD & TSS reduct. Coliform <240 MPN/100 ml	45 crew members	Offshore	CA	General Elec.	46

[a]E = Experimental, CA = Commercially available. Note: gallons = 3.785 liters.

(continued)

TABLE 7 (continued).

MSD description	Influent type and/or characteristics	Pollution control effectiveness	Equipment scale or size	Study location	Devel. stage[a]	Manuf.	Reference
Physical/Chemical (continued)							
Electrocoagulation - Clarification - Activated Carbon - Chlorination	Grey water (galley, sanitary, laundry) BOD = 650 mg/l avg. TSS = 600 mg/l avg.	Effluent BOD = 94 mg/l avg. Effluent TSS = 49 mg/l avg.	5 GPM 97 man crew	Shipboard	E		15
Chemical Treatment - Carbon Adsorption - Chlorination	Recirculating toilet wastes TSS = 10000-13000 mg/l TOC = 10000-13000 mg/l	TSS removal = 99.9+% TOC removal = 97%	50 gal. batch	Onshore	E		17
Disinfection - Flocculation - Vacuum Filtration	Synthesized chemical toilet wastes TSS = 360-7420 mg/l BOD = 220-4000 mg/l	BOD & TSS removal = 97%	2.5 GPM	Onshore	E		6
Chemical Treatment - Filtration Carbon Adsorption - Chlorination	Full flush toilet waste BOD = 825 mg/l COD = 2399 mg/l	BOD & COD removal >90%	Small batch	Onshore	E		49
Centrifugation - Chloronation - Carbon Adsorption - Post-Chlorination	Greywater (sanitary, sink, showers, galley waste) TSS = 396 mg/l BOD = 180 mg/l	BOD & TSS <50 mg/l Coliform <240 MPN/100 ml	5 GPM	Shipboard	CA		9
Chemical Treatment - Filtration	Black and grey water	Type II	6000 GPD		CA	Hyde Prod.	Manuf. Lit.
Moving screen Filtration-Pressure Filtration - Carbon Adsorption - Chlorination	Synthesized - food and toilet wastes BOD & TSS = 500-1000 mg/l	BOD removal = 88-92% TSS removal = 86-95%	12-20 crew members 2650 l/day	Onshore	E		50
Wet oxidation	BOD = 500 mg/l avg.	BOD removal <90%	20 crew members	Onshore	E		51
Wet oxidation	BOD & TSS = 500 mg/l avg.	COD removal = 60-90%	20 crew members	Shipboard	E		52
Ultrafiltration-Incineration	Full flush toilet wastes BOD = 190 mg/l avg. TSS = 110 mg/l avg.	BOD removal = 72-100% TSS removal = 50-99%	50 crew members 5000 GPD	Onshore	E		53
Maceration-Ultrafiltration	Full flush toilet wastes TS = 2000-3650 mg/l Fecal coli. = 1×10^4 - 5.4×10^8 MPN/100 ml	TS = 12-15 mg/l Fecal coli. <10 MPN/100 ml	5-15 GPM	Onshore	E		54
Ultrafiltration	Full flush toilet wastes; TSS = 220-5170 mg/l	TSS = 2-47 mg/l Fecal coli. most was <160 MPN/100 ml	7-300 GPM	Onshore	E		55

[a]E = Experimental, CA = Commercially available. Note: gallons = 3.785 liters.

MSDs was provided by the U.S. Coast Guard (41) and equipment manufacturers. Specific characteristics of each system are described in more detail below.

Biological Processes - General Considerations--Biological MSD systems have traditionally employed aerobic processes. Anaerobic processes have been tried aboard vessels but production of noxious gases and corrosive by-products have deemed most of these processes unsatisfactory (5, 42). The most common systems are modeled after one of two biological unit processes: conventional activated sludge and extended aeration. A number of advantages and disadvantages have been cited for biological MSDs (4, 22, 43).

Advantages:

1. Simple to operate.
2. Inexpensive.
3. Moderate in size.
4. Minimum chemical requirements.
5. Larger systems can produce a high quality effluent.

Disadvantages:

1. Almost continuous operation is required (12 - 18 hour downtime is the maximum that can be tolerated, although startup can be achieved within 2 - 3 days by the addition of an operating medium).

2. The microorganisms responsible for decomposition of the waste can be sensitive to certain chemical additives, detergents, and abrupt changes in salinity.

3. The phenomenon of free surface transfer (i.e., disturbance of quiescent conditions normally required for sedimentation) caused by pitch and roll of the craft can upset the gravity separation of solids in clarifiers.

As stated previously, potential toxic effects caused by abrupt salinity changes or the addition of chemical additives (formaldehyde, zinc, quaternary ammonium salts) and detergents can be a significant problem for biological type MSDs. It is important that these potential toxicity levels be delineated. The evaluation of applicability of biological treatment methods (both aerobic and anaerobic) to the barge system will obviously have to take such toxicity effects into consideration. Since only blackwater wastes are to be treated by the barge, the toxicity effects of detergents will not be discussed here.

Apparently, the major effect of salinity on biological systems involves the rapid changeover from a freshwater to saltwater environment. Since different bacteria live in each environment, rapid interchange from fresh to salt water systems, and vice-versa, induces shock on biota which have been adapted to one or the other environment (22). Ferguson, et.al., (10) summarized maximum tolerable shock loads and steady-state concentrations for various biological treatment processes (Table 8). Note that the maximum tolerable shock loads for suspended growth aerobic and anaerobic systems are identical, but that aerobic systems can tolerate higher steady-state concentrations. Also note that fixed growth systems are less suscepcible to shock loads and can function at higher steady-state concentrations than suspended growth systems.

TABLE 8. CRITERIA FOR TOLERABLE SALINITY DOSAGES (10).

	Maximum tolerable shock load, as % seawater[a]	Maxiumum tolerable steady-state concentration, as % seawater[a]
Anaerobic digestion (suspended growth)	29%	43%
Activated sludge (suspended growth)	29%	100%
Trickling filters (fixed growth)	36%	100+%

[a]100 percent seawater = 28,000 mg/l NaCl.

Arkisón, et.al., (47) found that for a shipboard extended aeration process "neither the initial seawater-to-freshwater conversion nor the freshwater-to-seawater conversion appeared to have an adverse effect on the operation of the system as indicated by the normal BOD_5 levels". The conversions were effected within 24 hours. In another study, it was found that at normal organic and hydraulic loading rates, the effluent quality from an extended aeration process was unaffected by severe variations in salinity (56). However, when high organic and hydraulic loadings were coupled with severe salinity changes, significant reductions in process performance were observed. The time to recover from such upset was dependent upon the severity of the loads. They also found that high saltwater usage caused encrustation and clogging of the 0.125 inch (0.32 cm) orifices in the air diffuser mechanisms. They recommended that design clarifier overflow rates be one-half those of conventional plants due to density turnover caused by varying salinity levels.

The toxicity effects of chemical bacteriostats used in watercraft systems were studied by Robins and Green (6). They employed both respirometer and pilot activated sludge plant studies using actual commercially available MSD bacteriostats. Table 9 summarizes the results of the respirometer studies. They concluded that zinc additives at all concentrations greater than 15 to 20 mg/l exhibited deleterious or toxic effects. Formaldehyde and quaternary ammonium additives caused toxic effects at high concentrations but appeared to be biodegradable at low concentrations. They calculated the required dilutions to eliminate adverse toxic effects. In addition to the respirometer study, bacteriostat addition to a pilot activated sludge plant and subsequent microscopic examinations of mixed liquor were performed and cell yields were calculated. The overall conclusion, based on both a literature review and respirometer and pilot studies was that formaldehyde concentrations greater than 120 mg/l and zinc concentrations greater than 15 to 20 mg/l would cause upset and loss of removal efficiency for the activated sludge process. No upper limits were provided for quaternary ammonium salts beyond the data given in Table 9.

TABLE 9. TOXICITY DATA AND DILUTION REQUIREMENTS FOR CHEMICAL TOILET ADDITIVES (6).

Chemical code	Active ingredient	Recommended dosage, mg/l	Maximum non-toxic concentration[a], mg/l	Dilution factor[b]
26	Zinc sulfate	4420	20	220
33	Zinc sulfate	1500	15	100
20	Formaldehyde	3920	5900	1.0
40	Formaldehyde	4500	55	80
83	Formaldehyde	3750	2350	1.6
96	Formaldehyde	4500	400	11
38	Quaternary ammonium salt	1700	110	15

[a]Maximum chemical additive concentration that does not adversely affect the respiration rate of activated sludge.

[b]Volume dilution required of chemical additive at its recommended dosage to eliminate any adverse effect on respiration rate of activated sludge.

Robins and Green also found that the strength of the waste can play an important role in the toxic effects exerted by chemical bacteriostats. For example, formaldehyde is very reactive and will combine readily with various nitrogenous compounds in the waste. Thus, the extent of formaldehyde reaction with other sewage constituents will determine the amount of free formaldehyde available to affect the biota. Sewage constituents have similar effects on zinc and quaternary ammonium toxicities.

<u>Activated Sludge Treatment</u>--Conventional activated sludge treatment has been used to treat shipboard waste with varied results. Activated sludge processes entail feeding wastewater continuously into an aerated tank where micro-organisms metabolize and biologically flocculate the organics found in waste. Microorganisms (activated sludge) are generally settled from the aerated mixed liquor under quiescent conditions in a clarifier and returned to the aeration tank. Clear supernatant from the settling tank constitutes the plant effluent.

Activated sludge treatment of human waste from a full-flush toilet system demonstrated steady state BOD removals of 95 percent, with average influent BOD concentrations of 825 mg/l (49). This land based study demonstrated the treatment feasibility of conventional activated sludge treatment followed by dual-media filtration, carbon adsorption and chlorination. A good system response to shock loads was also shown. Biological treatment was also demonstrated aboard ship using conventional activated sludge followed by dual-media filtration and ozonation (44). Greywater (toilet, shower and sink wastes) with average BOD and SS concentrations of 1,160 mg/l and 827 mg/l, respectively, was treated. BOD and SS removals were 97.8 and 98.4 percent, respectively, through the entire treatment process. During this study the aeration tank was charged with activated carbon to aid microorganism growth. Simplified flow sheets of these two systems are shown in Figures 3 and 4.

More concentrated waste was treated using conventional activated sludge treatment in order to determine feasibility and any effects on treatment due to high concentrations of common bacteriocides (6). Samples were obtained from portable toilets at local construction sites. Influent waste had BOD concentrations of 1,100 to 2,560 mg/l and SS concentrations of 2,100 to 3,800 mg/l. Eight tests were done using fresh and eight using saline flushwater. Formaldehyde and zinc compounds were added as bacteriocides. Results were promising with SS and BOD removals between 90 and 98 percent. Significant system disruption with corresponding efficiency loss was noted, however, when formaldehyde and zinc levels reached 120 mg/l and 20 mg/l, respectively, as previously noted.

When conventional activated sludge treatment was supplemented by a physical membrane separation process, namely ultrafiltration, effluent quality was extremely good (45). Waste from full-flush toilets, containing average BOD and SS concentrations of 243 and 637 mg/l, respectively, was treated. Effluent concentrations of BOD and SS were less than 10 mg/l. In addition, fecal coliform levels were generally zero and less than 240 MPN/100 ml 98.5 percent of the time. Ultrafiltration is a pressure driven membrane process. When combined with activated sludge treatment the process is reliable, presents no safety hazards, is not affected by ship motion, is easily retrofitted and produces a superior effluent (45). It was also found that wide variations in temperature (39 to 113°F) and salinity (rapid changes from fresh to salt water) did not affect system performance. Four toxins were added to the system at various times to simulate cleaning operations and accidental spills. These included pine oil, Chlordane, Clorox (household bleach) and acetone. Only a small reduction in overall efficiency was noted during these tests. It was also found that flow surges similar to those found onboard ship did not impair membrane performance.

<u>Extended Aeration Treatment</u>--Extended aeration is a second biological method available for a barge mounted treatment system. Similar to conventional activated sludge treatment, solids are returned to the aeration tank for an extended length of time to resume further biological action on pollutional materials. A typical shipboard extended aeration sewage treatment plant is shown in Figure 5 (30).

Although extended aeration appears to be viable onshore, ship-mounted systems have encountered difficulty. Research has shown that systems

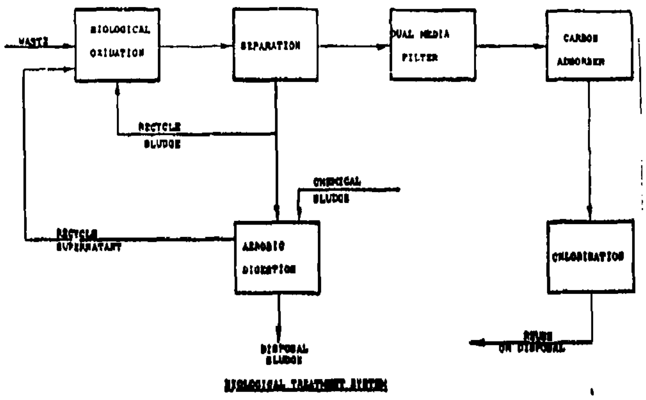

Figure 3. Conventional activated sludge system (49).

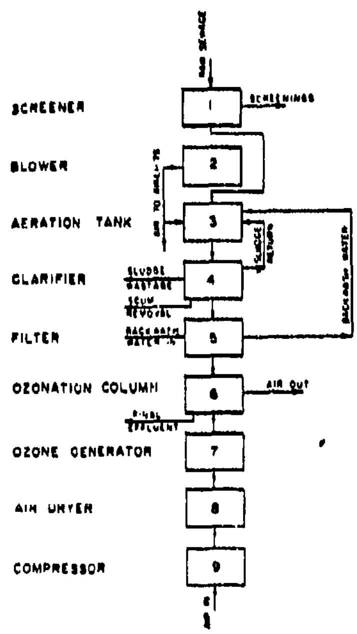

Figure 4. Conventional activated sludge with downstream modifications (44).

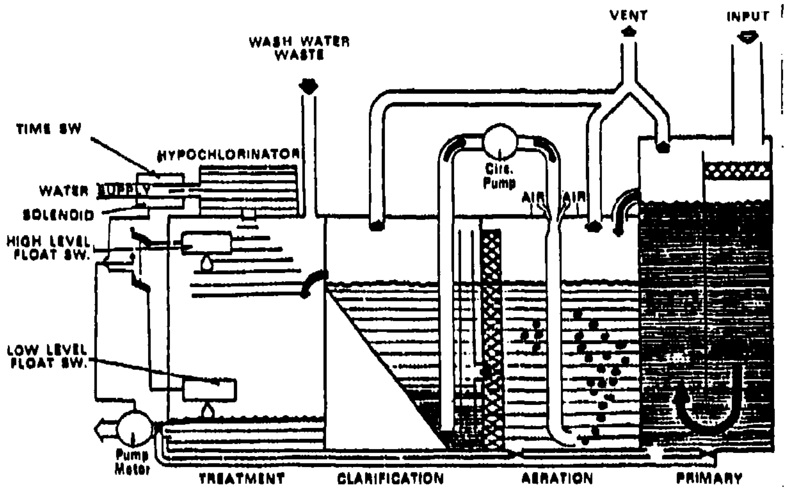

Figure 5. Extended aeration sewage treatment system (30).

installed on U.S. Army Corps of Engineers' dredges demonstrated erratic performance, although this was primarily attributed to design problems (5, 23). When greywater (full-flush toilets, shower and laundry waste) was treated, problems included inadequate sizing to handle peak flows, poor chlorinator design and other design problems such as plugged valves and pipelines. While influent BOD concentrations ranged from 37 to 780 mg/l and SS concentrations from 140 to 700 mg/l, effluent concentrations were highly variable. At times BOD and SS removal ranged between 90 to 95 percent, while at other times effluent concentrations were higher than influent levels (due mainly to solids carryover in clarifiers).

A number of other biological systems have been evaluated in the literature, mainly on a small scale. Vacuum aeration followed by chlorination was deemed ineffective since suspended solids could not be reduced sufficiently (57). When the system was modified by adding a filter to remove SS, the filter plugged easily and quickly. The applicability of the Rotating Disc Bio-Surf Process was also reviewed. It was concluded that although the process itself was feasible, significant system modifications would be required and further research was needed before any conclusions could be drawn (11). The Klock Submerged Filter Process was also studied for shipboard feasibility. It appeared to have good space and weight characteristics and probably a good cost/benefit ratio, but it was not commercially available at the time of the study (11).

It can be seen that a biological system is only as effective as the associated method of solids separation. Constant pitch and roll aboard ship may hinder settling to such a degree thay any promising results obtained from land based research are completely negated (19). Salinity changes in waste may cause a density turnover phenomenon which also disrupts sedimentation (43). Possible solutions to this problem include use of a fixed media bed (much like a trickling filter) or a pressurized clarifier. Sullivan (44) stated that pressurized clarifiers can tolerate 300 percent overload for three full months before volatile suspended solids reach the point of carryover.

Physical/Chemical (P/C) Processes-General Considerations--Although physical/chemical treatment systems consist of various non-biological processes; they have several advantages and disadvantages in common (4, 22, 40, 43).

Advantages:

1. Most P/C systems are compact in weight and bulk.
2. Flexibility in operation and control is available.
3. P/C systems are less sensitive than biological systems to flow variation, unusual loading conditions and the addition of chemical bacteriostats or saltwater.

Disadvantages:

1. Storage and handling of corrosive chemicals is often required.
2. Initial and operation/maintenance costs are often high.
3. Noxious odors can be a problem with some types of systems.
4. System control is often complex, requiring operator training and attention.
5. Removal and cleaning of filters (especially activated carbon columns) can be a problem.

The simplest and least expensive physical/chemical MSD is the Type I macerator/chlorinator. As the name implies, waste is macerated into small particles and disinfected for discharge overboard. This MSD requires little space and is capable of handling wastes from any type of flush system. However, its ability to meet required Type I effluent quality standards is marginal (22, 58). Specialized macerators are required to reduce particle sizes to levels low enough for effective disinfection. This equipment, in the highly corrosive marine environment, has a very high failure rate.

Modified maceration/disinfection systems were tested aboard Great Lakes iron carriers (48). Both chlorination and ozonation were evaluated for disinfection. The key feature of these systems was the incorporation of a primary settling tank for the removal of settleable solids. These solids were incinerated and only the clarified overflow from the settling basin was disinfected. Ozonation followed by small additions of hypochlorite consistently provided an effluent quality in conformance with EPA Type II MSD standards. Influent SS mean concentrations ranged from 243 to 882 mg/l.

Several other, more complex types of physical/chemical treatment systems have been investigated for treatment of shipboard wastes. These include electromechanical (or electrochemical), mechanical-chemical, wet air oxidation and ultrafiltration. Other treatment processes which may provide adequate treatment include moving screen filtration and rotary vacuum precoat filtration.

Electromechanical (or electrochemical) Treatment Systems--Electromechanical systems separate solids and liquids, convert or burn the solids and disinfect liquids for discharge overboard (15, 46). Solids separation may entail straining, centrifugation or other mechanical techniques. Solids flow to a sludge tank while liquids undergo electro-coagulation. A direct current is passed between pairs of iron plates immersed in the liquid. Ferrous hydroxide is formed which combines with negatively charged sewage to form a floc which is skimmed or strained and transferred to the sludge tank. The liquid is then disinfected and discharged while sludge is held for later discharge or incineration. These systems are smaller and lighter than biological systems but are quite complex and more expensive. They are also less susceptible to roll, pitch and heave onboard ship (40).

A shipboard study was conducted on an ocean going dredge with a 97 man crew (15). Greywater (sanitary, shower, galley and laundry) was treated using electrocoagulation at a rate of 5 gpm (18.9 l/min). Influent BOD and suspended solids concentrations averaged 658 and 600 mg/l, respectively, although they were highly variable. After the waste was comminuted, sodium aluminate was added to aid electrocoagulation. Solids were settled, while effluent was passed through activated carbon to reduce soluble BOD. Disinfection and incineration of solids followed. This treatment proved fairly successful as coliform levels were reduced to essentially zero while average effluent BOD and SS concentrations were 94 and 49 mg/l, respectively.

Mechanical-Chemical Treatment Systems--These types of systems are the most common form of physical/chemical treatment. They are very similar to electromechanical systems with solids separation being provided by physical or chemical means. Common chemical additives include alum and ferric chloride. This type of treatment can take many forms depending on the technology selected for each process, but, typically, wastes undergo chemical flocculation, solids separation, a polishing step and disinfection. Research has shown this type of treatment to be very promising even on a wide range of waste types (6, 9, 17, 49).

A shipboard study was completed using a physical/chemical system to treat greywater (sanitary, galley, shower and sink waste) aboard a ferry (9). Gross solids separation was accomplished using a vibrating screen followed by centrifugation. Chlorination was followed by carbon adsorption and post-chlorination. Due to the nature of this waste, chemical flocculation was not required; adequate solids separation was achieved by physical means namely a vibrating screen and centrifuge. Only fresh aerobic waste was treated and treatment objectives were met; BOD and SS concentrations were reduced to less than 50 mg/l and coliform counts limited to less than 240 MPN/100 ml. Shock loads to the system were also handled effectively.

Concentrated wastes were also treated quite effectively when solids separation was accomplished using chemical flocculation followed by clarification (6, 17, 49). Human waste from a standard water closet flushing system was treated in this type of system with favorable results (49). BOD and COD (chemical oxygen demand) were reduced from their average initial levels of 825 and 2,399 mg/l, respectively, by 90 percent or more. Ferric chloride was used as a chemical coagulant, followed by clarification, filtration, carbon adsorption and chlorination. A similar study had equally good results using prechlorination and alum (aluminum sulfate) as a coagulant followed by application of powdered activated carbon and diatomaceous earth prior to vacuum filtration (6). General results of this study are shown below (6).

Parameter	Influent concentration, mg/l	Removal, %
TSS	360 - 7420	97
BOD	220 - 4000	97
COD	1100 - 18600	97

In addition, coliform levels were reduced from 23 x 10^5 to 62 x 10^8 MPN/100 ml to less than 10 MPN/100 ml.

Mechanical-chemical treatment was also favorably demonstrated during another land based study in which very concentrated waste from a recirculating toilet was processed (17). Chemical coagulation was provided by ferric chloride and anionic polyelectrolytes and was followed by filtration to remove solids, carbon adsorption for color and organics removal and chlorination to further oxidize nitrogen and organics. Since the waste was taken from recirculating toilets, bactericides introduced during the flush cycle had previously reduced coliform counts to an acceptable level. Average influent concentrations and removals are listed below.

Parameter	Influent concentration, mg/l	Removal, %
SS	10000 - 13000	99+
TOC	10000 - 13000	97
TKN	1000 - 2300	99
Phosphates	200 - 300	99+
Color		97
TS	20000 - 30000	71

This waste was taken from recirculating aircraft toilets and from a Craftor Mobile Toilet set up for experimental purposes at Fort Belvoir, Virginia.

Other Physical/Chemical Treatment Systems--Several other treatment methods can be found in the literature. Although they may not be available commercially for shipboard use, laboratory studies have shown fairly good results. Included among these are: moving screen filtration, wet air oxidation, ultrafiltration and the use of a rotary vacuum precoat filter.

Moving screen filtration (MSF) was demonstrated using synthesized waste similar to that found on a marine vessel with full-flush toilets and a crew of 12 to 20 members (50). MSF was used alone to process only toilet wastes (200 to 700 mg/l SS and 200 to 400 mg/l BOD) resulting in SS removals of 50 to 70 percent and BOD removals of 30 to 60 percent. When MSF was combined with pressure filtration and coagulant filter aids to treat a mixture of food wastes and toilet wastes (500 to 1,000 mg/l each of SS and BOD) SS removals were 88 to 92 percent and BOD removals ranged from 86 to 95 percent. In this process the hydrophillic properties of cellulose sponge were used in conjunction with a fine pore plastic screen. Waste was delivered to a horizontal moving screen. Beneath the screen was a layer of cellulose sponge; both moved together. Liquids were drawn through the screen by the sponge leaving dewatered sludge on the screen. Both treatment schemes were followed by granular carbon adsorption and chlorination. This caused problems when food wastes were processed since MSF did not effectively remove grease that was capable of plugging the carbon columns.

Wet air oxidation is another process that has been investigated (mainly in the laboratory) to determine its applicability in treating watercraft waste. As the name implies, wet air oxidation entails oxidation of organic material in waste without a flame, in a wet state at elevated temperatures and pressures. Solids are then separated by settling, centrifugation or filtration and effluent is discharged. This process is capable of treating almost any waste, usually self sustaining, compact and flexible, but also requires high initial investment and power costs. Special training for operators is required and the process may cause an air pollution problem (42, 59). Corrosion may also be a problem. When concentrated sanitary waste was treated using wet oxidation, COD levels were reduced an average of 70 percent from an initial range of 1310 to 1980 mg/l (59). It was also found that oxidation of greywater (average BOD 500 mg/l) could result in a 90 percent or greater reduction in BOD and that seawater does not adversely affect system performance (52). In related studies, Willman (60) performed a mathematical analysis of oxygen diffusion during wet air oxidation and Koubek (61) studied the effectiveness of hydrogen peroxide "polishing" of wet air oxidation effluents.

Ultrafiltration has been shown, in the laboratory, to be effective in reducing SS, BOD and fecal coliform levels to acceptable limits without pretreatment (53,54,55, 97). As stated earlier, ultrafiltration is a pressure driven membrane process by which high molecular weight solids are removed for later treatment or storage. When full flush toilet waste, with SS concentrations of 2000 to 3650 mg/l and fecal coliform counts of 1×10^4 to 5.4×10^8 MPN/100 ml, was treated, effluent SS levels were less than 15 mg/l and fecal coliform counts were less than 10 MPN/100 ml (54). BOD removals ranged from 72 to 100 percent (53). The effectiveness of ultrafiltration in treating more concentrated blackwater has also been demonstrated (97). A UF system was operated in a "batch concentration" mode to treat 36 consecutive batches without cleaning or flushing. Wastes containing up to 85,200 mg/l SS were treated. Permeate SS remained less than 5 mg/l until feed SS reached 37,900 mg/l although fecal coliform levels were quite variable, ranging from 0 to 7.2×10^6 colonies/100 ml. Although UF is capable of producing a high quality effluent, shipboard feasibility has not been demonstrated.

Rotary vacuum precoat filtration, using a diatomaceous earth filter precoat, had resulted in 99.9 percent removal of suspended solids (26). Concentrated human waste with suspended solids concentrations ranging from 1540 to 13,294 mg/l were treated. Although this system appeared to effectively treat concentrated human waste, shipboard feasibility has not been investigated.

Many of the physical/chemical treatment systems described above are apparently capable of producing a high quality effluent when tested onshore. Problems similar to those found with biological systems may inhibit treatment efficiency aboard ship. If solids separation is accomplished by sedimentation, constant pitch, roll and heave while at sea may hinder settling. Shock loading should also be investigated, but effects of salinity and toxins are probably limited.

Conventional Wastewater Treatment Methodologies

There are a number of conventional unit processes which are legitimate candidates for integration into the barge mounted treatment system. These processes are as follows:

1. Suspended solids removal.

   a. Sedimentation.
   b. Filtration (vacuum, pressure, or media-bed).
   c. Centrifugation.
   d. Membrane separation (ultrafiltration).

2. Dissolved solids removal.

   a. Membrane separation (ultrafiltration).
   b. Powdered activated carbon adsorption.
   c. Granular activated carbon columns.
   d. Chemical precipitation.
   e. Chlorination.
   f. Anaerobic digestion.
   g. Anaerobic filtration.
   h. Aerobic treatment (fixed & suspended growth systems).
   i. Wet-oxidation.

Many of the above processes have been incorporated into existing MSDs or studied for potential shipboard use. These applications were extensively reviewed in the previous section. A comprehensive literature review for each of the above processes is not practical or warranted. Instead, only those which have not previously received attention as MSDs will be briefly reviewed here. These are centrifugation, pressure filtration, anaerobic digestion and filtration and sludge incineration.

Centrifugation--

Two basic types of centrifuges have been extensively used in wastewater treatment practice. These are imperforate bowl basket centrifuges and solid bowl decanter (scroll-type) centrifuges. The former requires batch operation while the latter is a continuous process. Centrifuges can be used for thickening wastewater suspensions or dewatering sludges.

Table 10 summarizes centrifuge performances for raw and digested primary sludges (62). These sludges would be most representative of blackwater wastes which must be concentrated on the barge. Scroll centrifuges, when used exclusively for thickening, have been limited to handling waste activated (biological) sludges. Grit removal and chemical conditioning is recommended prior to thickening or dewatering with a scroll centrifuge (62). Polymer is the most common chemical conditioner because of the corrosiveness and abrasiveness of other conditioners such as ferric chloride or lime. It should also be noted that solids recovery is inversely proportional to the feed total solids concentration (62). This is important because the solids concentrations in blackwater are anticipated to be somewhat lower than those given in Table 10.

Pressure Filtration--
The use of pressure filtration (recessed plate or diaphragm type) for solids separation provides several advantages (63, 64, 65). The cake produced is generally drier than that from most other sludge dewatering devices (30 to 60 percent total solids). This not only reduces the volume of sludge destined for ultimate disposal, but may also enhance the cost-effectiveness of incineration as a means of disposal. Cake drier than 30 percent total solids is capable of sustaining autogenous combustion, thus minimizing the use of supplementary fuel (66). Moreover, improved solids capture provides a high quality filtrate (usually less than 100 mg/l suspended solids) (67).

TABLE 10. TYPICAL CENTRIFUGE PERFORMANCES
FOR MUNICIPAL RAW AND ANAEROBICALLY DIGESTED PRIMARY SLUDGES (62).

Centrifuge type	Purpose	Sludge type[a]	Feed solids, % TS	Cake solids, % TS	Polymer required, lb/ton[b]	Solids recovery, %
Basket	Thickening	An.D.	2-3	8-10	0	95-97
		P(70%)+ TF(30%)		7- 9	1.5-3.0	94-97
Basket	Dewatering	Raw P	4-5	25-30	2-3	95-97
Scroll	Dewatering	Raw P	5-8	25-36	1-5	90-95
				28-36	0	70-90
Scroll	Dewatering	An. D.	2-5	28-35	6-10	98+
		P	9-12	30-35	0	65-80

[a] P = primary sludge, TF = trickling filter sludge, An.D. = anaerobic digestion.

[b] lb/ton = pounds of polymer per dry ton feed solids = 0.5 g/Kg.

Primary disadvantages of pressure filtration from the standpoint of municipal sludge dewatering include relatively high capital and labor costs and the fact that a batch operation is required.

Table 11 summarizes typical and specific fixed volume recessed plate pressure filtration performance for dewatering raw and digested primary sludge. Again, lower feed solids than those listed in Table 11 are anticipated for blackwater. The major effect of reduced feed solids concentration on filter performance is to extend the cycle time (72, 73, 74) of the batch operation. For example, it was found that reducing the feed solids concentration from 6 to 3 percent increased the press time by a factor of 3.2 (72).

TABLE 11. TYPICAL AND SPECIFIC PRESSURE FILTER PERFORMANCES FOR MUNICIPAL RAW AND ANAEROBICALLY DIGESTED PRIMARY SLUDGES.

Sludge type[a]	Feed solids, % TS	Type of chemical conditioner	Chemical dose, lb/ton[b]	Cake solids, % TS	Total cycle time, hrs.	Reference
Typical raw P	5-10	Ferric chloride	100			62
		Lime	200	45	2.0	
		Ash	2000	50	1.5	
Raw P	6-6.5	Ferrous sulfate	200	40	5.5	68
		Lime	400			
Raw P	4-5.5	Ferrous sulfate	300	35-40	6.0	68
		Lime	360			
Raw P		Lime	420-480	33-34	5-7	69, 70, 71
Raw P	4	Lime	200	40	4	67
Raw P	7.5	None		50	1.5	67
Raw P	4-7	Lime	100-500			
		Ferrous sulfate	100-300	40-50	3-7	65
		Aluminum Chlorohydrate	20-40			
Digest. P	8	Ferric chloride	120	40	2	67
		Lime	600			

[a]P = primary sludge.

[b]lb/ton = pounds of chemical conditioner per dry ton feed solids = 0.5 g/Kg.

Anaerobic Processes--

Anaerobic digestion has seen little MSD application mainly because of limited space and weight availability for onboard MSDs. Conventional digester design for high-rate processes calls for hydraulic retention times on the order of 15 to 20 days (75, 76, 77), necessitating large tank volumes. Some recent developments in anaerobic digestion technology, i.e., the anaerobic contact process (ACP) (78, 79, 80) and the anaerobic filter (81, 82, 83), can provide stable operation with much shorter hydraulic retention times (HRT). This is accomplished in both processes by increasing solids retention time and decreasing HRT. For the ACP, this is achieved by concentrating digester effluent and recycling concentrated sludge back to the reactor (analogous to activated sludge). The anaerobic filter is a fixed growth process analogous to the trickling filter.

Both processes have been utilized in the past exclusively for dilute, soluble and highly biodegradable industrial wastes. High suspended solids concentrations can be a source of problems for the anaerobic filter (81). In addition, it is desirable to have a relatively warm wastewater for both processes. Anaerobic digestion systems perform most efficiently at mesophillic or thermophillic temperatures (84). If the wastewater is inherently warm, the cost-effectiveness of these processes (as dictated by energy recovery through methane production) is greatly enhanced. Energy derived from the system is directly related to the temperature and concentration of biodegradable matter.

Anaerobic treatment of blackwater from Army watercraft would appear to be advantageous from several perspectives. First, and most obvious, is the energy recovery aspect. Another is the relatively low production of excess sludge (85). Relatively higher rates of pathogen destruction (sludge stabilization) and control of odors by having a totally closed system are other advantages (86, 87).

There are also several disadvantages which might preclude use of these processes for this application. Methane bacteria are extremely sensitive to even slight environmental changes such as pH, temperature and toxic material concentrations (84, 85). Microbial population imbalance caused by organic shock loadings can lead to process failure and a "sour" digester. Recovery is difficult once a digester has gone sour and the aforementioned odor control advantage is negated. Also, these processes (ACP and anaerobic filtration) have not been extensively tested with wastewaters of domestic (sanitary) origin nor has their ability to meet secondary treatment standards been adequately demonstrated. The only study to date was done by Schroepfer and Ziemke (78), who determined that BOD_5 removals are on the order of 70 to 75 percent for a domestic wastewater using a modified anaerobic contact process (the rapid adsorption process) designed specifically for the treatment of relatively cool wastes.

A final, and perhaps decisive disadvantage of anaerobic processes is the inability to treat wastes with high seawater concentrations (greater than 12,000 mg/l NaCl) as was shown in Table 8 (10).

Sludge Incineration--

Disposal of solids generated by barge treatment processes can be accomplished by onboard incineration or shore disposal in an approved sanitary landfill or on agricultural land. The method of choice depends partly on relative costs, but also on the operational simplicity.

Of the three basic types of sludge incinerators, (multiple hearth, fluidized bed and electric furnace) the electric furnace would probably be most suitable for barge application. Modular construction, suitability for intermittent operation, operational simplicity and no fossil fuel requirements make this process especially attractive for small treatment plants (62). Disadvantages include relatively high replacement costs for certain parts, potentially high electricity costs (if onboard electrical generators are not used) and the necessity for high voltage (240 to 480 V) equipment and safety precautions (62).

Barge-Specific Design Information

The technical literature was searched for information on the specific design problems which might be encountered in the barge mounting of a treatment system. Information was found describing guidelines for holding tank design and ship-to-barge (or shore) blackwater transfer hose and coupling configurations.

Holding Tank Design--

The Inter-Governmental Maritime Consultative Organization (IMCO) published guidelines for design of port reception facilities (88). To calculate peak seven-day period sewage volume received from vessels at a given port, the following formula was recommended:

$$S = \sum_{i=1}^{4} S_i$$

Where:

S = Volume of sewage received in peak seven-day period (l/week).

S_i = $N_i Q_i T_i P_i$ = Volume of sewage received in peak seven-day period from vessel type i (i = 1, harbor vessel; i = 2, inland and coastal waterway vessel; i = 3, seagoing cargo vessel; i = 4, seagoing passenger vessel) (l/week).

N_i = Number of ith vessel type in port during peak seven-day period (vessels/wk).

Q_i = Average daily sewage generation rate on ith vessel type (l/cap.-day).

T_i = Average vessel duration in port or in restricted waters during peak seven-day period (days).

P_i = Average number of persons on board typical ith vessel type.

The following estimates were provided for Q_I and T_I for each vessel type:

Vessel Type	Q_I l/cap.-day (gpcd)[a]	T_I days
Harbor	100 (26)	7
Inland and coastal waterway	100 (26)	7
Seagoing cargo:		
bulk cargo	140 (37)	2-3
combination carriers	140 (37)	2-6
general cargo	140 (37)	1-6
Seagoing passenger	140 (37)	1-2

[a]Reduced-flush systems generate 12 to 36 l/cap.-day (3 to 10 gpcd).

Detailed design criteria for shipboard sewage holding tanks were developed which covered most vessel types, crew sizes, vessel stability requirements and types of flushing system (20). Construction guidelines cover materials, configurations, capacities, location, structure, stability effects, protective coatings, shore connections and piping, pumping and electrical details. Operation and maintenance guidelines were included as well as an evaluation of the economic impact of CHT installations.

Vessel-to-Barge Connections--

Equipment and materials of construction for vessel-to-barge sewage transfer is an important design consideration. Optimum equipment selection is contingent upon durability, reliability, simplicity, safety and operational flexibility. A study at the Civil Engineering Laboratory (Port Hueneme, California) (89) investigated transfer materials including bronze quick disconnect connectors, two types of rubber hose, two types of plastic hose and three types of hose clamping materials. It was recommended that collapsible rubber hose is best suited where hose reel size or storage space is limited. Plastic hose was recommended for vacuum discharge systems since it will not collapse. The best clamp type and connector mounting procedures for each hose type were also specified.

A much more comprehensive report was published by the Civil Engineering Lab the following year (90). The entire ship-to-shore transfer procedure was optimized. Separate systems were recommended for ports with high and low ship turnovers. Loading, transporting, connecting, disconnecting, unloading, cleaning and storing procedures were evaluated. The equipment evaluated included various transport vehicles, hoses, hose caps and plugs, hose supports, powered reels, storage and loading racks, a hose cleaning rack and a hose cleaning apron.

SUMMARY AND IDENTIFICATION OF ADDITIONAL DATA REQUIREMENTS

Waste Characterization

There is a significant body of information in the literature documenting vessel wastewater characteristics. The data on daily per capita waste flows (quantity) for each type of flushing system are uniform and reliable. Therefore, once certain assumptions on watercraft mission profiles are made, it should not be difficult to estimate design total blackwater flow rates for each potential barge location.

However, the literature obtained thus far provides little quality data related specifically to the type of wastes which would be derived from U.S. Army watercraft, i.e., from reduced-flush or recirculating systems. Several reports documented per capita BOD_5 and SS loadings (gram/day) but these data are highly variable and do not provide insights into storage effects (either aerobic or anaerobic) on these pollutants. No quality information was found for oil recirculation sytems and only one report listed data for a water recirculation system.

Legislation

The history of vessel pollution control is well documented. The historical perspective is interesting, but current regulations are obviously of most importance. Current EPA regulations for discharges from "vessels" stipulate that treatment devices newly installed meet Type II MSD specifications. This requires effluent suspended solids concentrations of less than or equal to 150 mg/l and fecal coliform counts of less than or equal to 200/100 ml. There is no BOD_5 requirement. States can petition the EPA for zero-discharge regulations for environmentally sensitive receiving waters.

If the barge is to be legally classified as a point source, discharge requirements become more stringent and complex. Although most areas of the country have adopted EPA's "secondary treatment" criteria of 30 mg/l BOD_5 and suspended solids, many have additional requirements such as fecal coliforms, nutrients (nitrogen and phosphorus) and more stringent pH limitations. In addition, some areas employ more complex control techniques such as waste assimilative capacity allocations and/or mixing zone requirements and advanced (tertiary) waste treatment.

MSD Evaluation

The majority of the literature obtained describes the effectiveness of existing or developmental MSDs. Such information will be very useful in the selection of alternative schemes for treatment of blackwater wastes from U.S. Army watercraft. Unfortunately, most of the MSDs and developmental systems evaluated were applied to wastes much more dilute than those anticipated in this study. Furthermore, the ability of an MSD to meet vessel discharge standards provides little insight into its ability to meet point source discharge requirements.

Conventional Wastewater Treatment Methodologies

Again, conventional treatment plants handle a waste which is more dilute than blackwater from reduced-flush or recirculating commodes. The documented effectiveness of these treatment schemes is, therefore, of little value to this study. Another area of potential applicability is sludge treatment methodology. The effectiveness of conventional sludge treatment schemes such as vacuum and pressure filtration, centrifugation, gravity or dissolved air flotation thickening, wet oxidation, incineration and aerobic and anaerobic digestion all might provide valuable insights. Unfortunately, most municipal sludges are more concentrated than blackwater wastes from Army craft. Moreover, it is generally not the intent of sludge handling operations to produce a sidestream of high enough quality for surface water discharge. Treatment and disposal of Army blackwater wastes presents a fairly unique situation.

Barge-Specific Design Information

Information has been found describing adequate port reception facilities, guidelines for holding tank design, and ship-to-barge hose and coupling configurations.

SECTION 3

SYSTEM DESIGN EVALUATION

PURPOSE

The purpose of the system design evaluation was to determine the technical and economic feasibility of a barge mounted blackwater treatment system. The evaluation methodology consisted of five distinct phases:

1. Development of design requirements.
2. Preliminary screening to identify alternatives.
3. Technical evaluation of alternative systems.
4. Cost evaluation of alternative systems.
5. Selection of recommended systems.

The design requirements which had to be delineated included blackwater characterization in terms of average and peak blackwater quantities and pollutant concentrations, and regulatory effluent quality standards (vessel and point source). Based on this information, feasible barge locations and specific design wasteloads were determined.

Once the basic design requirements were established, a preliminary screening of the entire spectrum of wastewater treatment unit processes was conducted to isolate a number of pertinent alternative systems. Criteria used to determine suitability of alternatives included capability to meet discharge requirements, basic adaptability to barge mounting, and simplicity of operation.

The purpose of the technical evaluation was to determine which of the preliminary treatment schemes are most suitable from a technical standpoint. The estimated costs associated with major components of the barge mounted treatment alternatives provided another basis of comparison. Cost components included capital, operating and maintenance expenses on a unit cost basis. The final selection of recommended systems for each potential barge location was then made on the basis of both technical and cost considerations.

It should be noted that a good portion of this evaluation procedure was reliant upon a rather sparse data base. Limited information was available on waste characteristics and performance of treatment processes on concentrated wastewaters. Therefore, the assumptions which were made for this evaluation have been carefully documented, but still require additional field verification.

DEVELOPMENT OF DESIGN REQUIREMENTS

Waste Characterization

One of the first steps in any wastewater treatment design is determination of waste characteristics. This includes both waste flow volumes (average and peak) and the pollutant concentrations (mg/l) and loadings (kg/day). For treatment of watercraft blackwater, this determination was complicated by the use of different flushing systems, different holding tank designs (especially with regards to aeration) and the lack of specific data on vessel mission profiles.

Table 12 summarizes the number and types of watercraft used by the U.S. Army (256 total), their locations, and the characteristics of individual CHT (conveyance, holding and transfer) systems. There are four basic types of flushing systems used:

1. Low-flush gravity transport ("Duner" and "GATX" commodes).
2. Low-flush vacuum transport ("Jered").
3. Mineral oil recirculation ("Chrysler").
4. Water recirculation ("Monogram").

Seawater is used as the flushing diluent in all water transport CHTs with the exception of the LCU 1400's which use freshwater. Waste volumes and pollutant concentrations are a function of the type of CHT system and the crew size, as well as a number of other factors such as vessel mission profiles.

Determination of Waste Volumes

Information regarding per capita waste volumes which was found in the general literature indicated that reduced-flush systems generate about 3 gallons (11.4 liters) per person per day and that recirculating systems generate around 0.5 gallons (1.9 liters) per person per day. Independent evaluations of all three low-flush systems ("Duner", "GATX" and "Jered") were also found in other sources. The U.S. Forest Service (92) tested the "Duner" commode and found that the most likely average flush volume (excluding body wastes) was 0.21 to 0.37 gallons (0.8 to 1.4 liters). An evaluation of the "GATX" system by the U.S. Navy also determined that the average flush volume was from 0.26 to 0.37 gallons (1.0 to 1.4 liters) (93). Actual per capita daily contributions were not calculated for either study, however. Using a general rule of thumb of from 6 to 9 flushes per person per day, and a daily per capita body waste volume of 0.9 gallons (3.4 liters) (5), the total waste volume would be from 2.2 to 4.2 gpcd (8.3 to 15.9 l/cap.-day). Therefore, the design value of 3 gpcd (11.4 l/cap.-day) recommended by German and Milne (20) for reduced-flush gravity transport systems seems reasonable.

The U.S. Navy also performed an evaluation of the "Jered" vacuum transport, low-flush system aboard a destroyer (94). It was estimated that the daily per capita blackwater flow rate for this system ranged from 1 to 2 gpcd

TABLE 12. SUMMARY OF U.S. ARMY WATERCRAFT TYPES, LOCATIONS, AND BLACKWATER CHT CHARACTERISTICS.

Location	Quantity and type of vessel	Tank size (gal.) Ind.[d]	Tank size (gal.) Total	Crew size Ind.	Crew size Total	Flushing system[b]	Holding tank aeration	Discharge hose size Nominal diameters (in)	Discharge hose size Length (ft)
Ft. Eustis	3-100' Tugs	623	1,869	16	42	low (gravity)	at pump-out	1.5	25
	5-65' Tugs	514	2,570	6	30	low (gravity)	at pump-out	1.5	25
	1-Sutton	11,000	11,000	34	34	low (gravity)	continuous	4	50
	9-LCU 1400	505	4,500	14	126	low (gravity)	at pump-out	1.5	25
	5-LCU 1600 (CF-1)	627	3,343	14	126	low (vacuum)	at pump-out	4	25
	4-LCU 1600 (CF-2)	500	2,000	14	56	low (gravity)	at pump-out	2	-[a]
	1-100 ton crane	500	500	11	11	oil-recirc.	at pump-out	1.5	-[a]
	1-FMS	7,150	7,150	32	32	low (gravity)	continuous	4	50
	1-143' Tug	3,600	3,600	34	34	low (gravity)	continuous	4	50
	2-J-Boat	5	10	4	8	water-recirc.	none	-[a]	-[a]
	17-LCM 8	5	85	4	68	water-recirc.	none	-[a]	-[a]
	Totals (53 craft)	-	37,157	-	573				
Baltimore	3-100' Tugs	623	1,869	16	42	low (gravity)	at pump-out	1.5	25
	1-65' Tugs	514	514	6	6	low (gravity)	at pump-out	1.5	25
	1-100 ton crane	500	500	11	11	oil-recirc.	at pump-out	1.5	-[a]
	1-FS 790	9,000	9,000	32	32	low (gravity)	continuous	4	50
	Totals (6 craft)	-	11,883	-	97				
Marcus Hook	1-100' Tug	623	623	16	16	low (gravity)	at pump-out	1.5	25
	1-65' Tug	514	514	6	6	low (gravity)	at pump-out	1.5	25
	Totals	-	1,137	-	22				
Tacoma	1-100' Tug	623	623	16	16	low (gravity)	at pump-out	1.5	25
	1-65' Tug	514	514	6	6	low (gravity)	at pump-out	1.5	25
	1-FMS	7,150	7,150	32	32	low (gravity)	continuous	4	50
	17-LCM-3	5	85	4	68	water-recirc.	none	-[a]	-[a]
	Totals (20 craft)	-	8,424	-	122				
Sunny Point	1-100' Tug	623	623	16	16	low (gravity)	at pump-out	1.5	25
Azores	2-100' Tug	623	1,246	16	32	low (gravity)	at pump-out	1.5	25
Ft. Island	1-BDL Page	13,444	13,444	55	55	low (gravity)	continuous	4	50
	6-LCU 1400	500	3,000	14	84	low (gravity)	at pump-out	1.5	25
	Totals	-	16,444	-	139				
Morehead City	8-LCU 1400	500	4,000	14	112	low (gravity)	at pump-out	1.5	25
Kwajalein	4-LCU 1400	500	2,000	14	56	low (gravity)	at pump-out	1.5	25
Okinawa	1-100 ton crane	500	500	11	11	oil-recirc.	at pump-out	1.5	-[a]
Aberdeen	11-J-Boat	5	55	4	44	water-recirc.	none	-[a]	-[a]
	1-LCM-8	5	5	4	4	water-recirc.	none	-[a]	-[a]
	Totals	-	60	-	48				
Alexandria	15-LCM-8	5	75	4	60	water-recirc.	none	-[a]	-[a]
St. Petersburg	10-LCM-8	5	50	4	40	water-recirc.	none	-[a]	-[a]
Storage[c]	115 vessels								

[a] No hose onboard.

[b] All CHT's will use seawater as diluent except for LCU-1400's which will use freshwater.

[c] Not to be incorporated into barge design.

[d] Ind. = Individual vessel tank size.

Note: 1 in. = 2.54 cm
1 ft = 0.305 m
1 gal = 3.785 liters

(3.8 to 7.6 l/cap.-day). Therefore, using a value of 3 gpcd will provide conservative design rates.

Based on the above design per capita blackwater generation rates, and further assuming that the watercraft in question will have a full crew living onboard for 24 hours/day, average daily total blackwater generation rates can be calculated (Table 13). Based on these generation rates and vessel CHT sizes, average watercraft holding times can also be estimated (Table 13). Assumptions concerning watercraft mission profiles and frequency of barge operation will determine average daily watercraft blackwater discharge rates. This will be further discussed later in this report.

Determination of Pollutant Concentrations

As previously stated, little information was found in the general literature on concentrations of pollutants in wastes from reduced-flush and recirculating systems. Therefore, a preliminary, non-intensive sampling and analysis program was conducted at Fort Eustis, Virginia on February 21 to 22, 1980, where the heaviest Army watercraft activity is located. Of all the watercraft located at Fort Eustis, only six of those in port at the time of sampling had both an installed CHT and a crew. Of these six, three were sampled.

Fortunately, samples from three of the four types of general flushing systems used by the Army aboard watercraft were obtained. The following vessels were sampled:

1. LCU-1579 - reduced-flush, gravity transport system; holding tank had been pumped out four days prior to sampling.

2. LCU-1675 - reduced-flush, vacuum transport (Jered) system; the ship's crew was uncertain about the time span from the last CHT pump-out.

3. BD-6081 (60 ton crane) - mineral oil recirculating flush system; samples were taken immediately after a waste load was transferred from the oil/waste separator unit to the holding tank.

The holding tanks were all mixed prior to sampling to ensure that representative aliquots were obtained. For the mineral oil system, however, the mixing energy supplied did not seem adequate to completely homogenize the density layers. The sample obtained may, therefore, underestimate the water content of the total mixture.

Table 14 summarizes concentrations of pollutants for each of three wastes obtained from Fort Eustis, as well as the characteristics of a waste from a water recirculation system taken from a previous report (17). Water recirculation represents the fourth type of flushing system that the Army

TABLE 13. ESTIMATED WATERCRAFT BLACKWATER GENERATION RATES AND CHT HOLDING TIMES.

Location	Quantity and type of vessel	Daily blackwater generation rates, (gpd)[a]	Estimated CHT holding time, days
Ft. Eustis	3-100' Tugs	144	13
	5-65' Tugs	90	29
	1-Sutton	102	110
	9-LCU 1400	378	12
	9-LCU 1600 (CF-1)	378	10
	4-LCU 1600 (CF-2)	168	12
	1-100 ton crane	6	91
	1-FMS	96	75
	1-143' Tug	102	35
	2-J-Boat	4	2.5
	17-LCM 8	34	2.5
	Totals (53 craft)	1,502	25[b]
Baltimore	3-100' Tugs	144	13
	1-65' Tugs	18	29
	1-100 ton crane	6	91
	1-FS 790	96	94
	Totals (6 craft)	264	45[b]
Marcus Hook	1-100' Tug	48	13
	1-65' Tug	18	29
	Totals	66	17[b]
Tacoma	1-100' Tug	48	13
	1-65' Tug	18	29
	1-FMS	96	75
	17-LCM-8	34	2.5
	Totals (20 craft)	196	43[b]
Sunny Point	1-100' Tug	48	13
Azores	2-100' Tug	96	13
Ft. Island	1-BDL Page	165	81
	6-LCU 1400	252	12
	Totals	417	39[b]
Morehead City	8-LCU 1400	336	12
Kwajalein	4-LCU 1400	168	12
Okinawa	1-100 ton crane	6	91
Aberdeen	11-J-Boat	22	2.5
	1-LCM-8	2	2.5
	Totals	24	2.5
Alexandria	15-LCM-8	30	2.5
St. Petersburg	10-LCM-8	20	2.5
Storage[c]	115 vessels		

a. Assuming full crew 24 hours/day and blackwater generation rates of 3 gpcd for reduced-flush and 0.5 gpcd for recirculating systems.
b. Flow weighted average holding time for all watercraft at this location.
c. Not to be incorporated into barge design.

Note: 1 gallon = 3.785 liters

TABLE 14. ANALYTICAL CHARACTERIZATION OF BLACKWATER FROM THREE U.S. ARMY WATERCRAFT SAMPLED AT FORT EUSTIS, VIRGINA (FEBRUARY 21-22, 1980) AND A WATER RECIRCULATING TOILET AT FORT BELVOIR, VIRGINIA[a].

Pollutant parameter	Flushing system: Reduced-flush, gravity transport[b]	Reduced-flush, vacuum transport[c]	Mineral oil recirculation[d]	Freshwater recirculation[a]
Total solids, mg/l	26,630	9,620	4,130	28,800
Volatile total solids, mg/l	20,150	3,810	1,880	21,200
Total suspended solids, mg/l	26,550	3,050	165	12,700
Total volatile suspended solid, mg/l	19,450	2,320	110	12,100
Total dissolved solids, mg/l	1,740	6,070	3,860	15,100
BOD, mg/l: total	7,800	1,600	10,400	22,500
soluble	2,600	1,100	4,500	4,530
COD, mg/l: total	34,920	6,184	3,110	
soluble	2,920	2,000	230	
TOC, mg/l: total	11,200	1,960	6,480	13,200
soluble				3,700
Oil and grease, mg/l	754	548	1,851	
Total Kjeldahl nitrogen, mg/l	1,560	1,260	1,040	2,280
NH_3-N, mg/l	965	1,200	230	
Organic nitrogen[f], mg/l	595	60	810	
(NO_2+NO_3)-N, mg/l	1.8	0.25	0.80	
Total phosphorus, mg/l	580	102	82	334[e]

[a]See Reference 17.

[b]LCU - 1579.

[c]LCU - 1675.

[d]BD-6081 (60 ton crane).

[e]PO_4-P.

[f]Org.-N = TKN - NH_3-N.

proposed to install aboard certain types of watercraft. None of these systems were available for sampling at Fort Eustis. Chemical analyses were performed at the Rexnord Analytical Laboratory according to procedures outlined in Standard Methods (95) and by the U.S. EPA (96).

Table 15 summarizes the percent fractions of total pollutant concentrations. Again significant differences were observed between the four types of flushing systems. Higher volatile solids content and lower soluble BOD_5 and COD fractions for the gravity transport reduced-flush system compared to the vacuum system may be due to differences in waste age. That is, the waste from the gravity system was much "fresher" than the vacuum system and, therefore, subject to less solids solubilization.

The data from the mineral oil recirculating system are also interesting. In spite of the fact that the water content of the waste may have been underestimated (due to insufficient mixing turbulence in the holding tank), the total solids and total suspended solids were lower than anticipated, only 4,100 and 165 mg/l, respectively. Furthermore, about 45 percent of the total solids were oil and grease, a large portion of which might be attributable to mineral oil. The low COD concentrations relative to BOD_5 may be due to the fact that straight chain aliphatic compounds, of which this mineral oil might have been comprised, are not oxidized by the reagent used for the COD test, but are available for biological oxidation (95).

Although the major function of this preliminary sampling was to obtain data from which design wasteloads could be determined, there were several other benefits derived. The effort provided an opportunity for Rexnord personnel to witness the watercraft activity firsthand. The difficulties encountered in the tank truck transfer procedure were apparent. In some cases, the watercraft crew was not familiar with operating characteristics of the CHT system. Tank truck scheduling was also an obvious problem.

In addition to the data obtained from Fort Belvoir (17) and Fort Eustis, the U.S. Navy has conducted onboard technical evaluations of the "GATX" and "Jered" reduced-flush systems. The "GATX" system was evaluated aboard the YTB-790 (yard tugboat, barge) (93) and the "Jered" system was evaluated aboard a Naval destroyer (94). Table 16 summarizes the data from these evaluations.

The data from the two gravity transport flushing systems (U.S. Army LCU 1579 and U.S. Navy YTB-790) are difficult to compare because one used freshwater and the other saltwater as diluents. The two pollutant parameters unaffected by diluent type, namely BOD and TSS, indicated that the waste from the LCU-1579 was more concentrated. Comparison of the data from the two vacuum transport (Jered) systems was more encouraging. Total solids concentrations were comparable, although the volatile and COD fractions were significantly higher for the Navy destroyer. Since no information on waste age was available for either vessel, the reason for this discrepancy is not known.

TABLE 15. PERCENT POLLUTANT FRACTIONS FOR BLACKWATER WASTES FROM FORT EUSTIS WATERCRAFT[a] AND FORT BELVOIR CRAFTOR TOILET[b].

	Reduced-flush gravity transport[c]	Reduced-flush vacuum transport[d]	Mineral oil recirculation[e]	Water recirculation[b]
Percent of total solids				
Volatile solids	76	40	46	74
Dissolved solids	15	63	93	52
Suspended solids	99.7	32	4	44
Oil and grease	3	6	45	
Volatile suspended solids percent of TSS	73	76	67	95
Soluble BOD_5, percent of total BOD_5	33	69	43	20
Soluble COD, percent of total COD	8	32	7	
Soluble TOC, percent of total TOC				28

[a]February 21-22, 1980.
[b]See Reference 17.
[c]LCU-1579.
[d]LCU-1675.
[e]BD-6081 (60 ton crane).

TABLE 16. SUMMARY OF U.S. NAVY ONBOARD TECHNICAL EVALUATIONS OF REDUCED-FLUSH BLACKWATER COLLECTION SYSTEMS.

	GATX[a]	JERED[b]	JERED[c]
Per capita blackwater generation rate, gpcd		1 - 2	
Waste age, days	3 - 8		
Total solids, mg/l			
Mean	35,700	11,350	
Range	24,000 - 51,000	7,830 - 19,500	
Standard deviation	9,190	2,850	
Total volatile solids, mg/l			
Mean		6,880	
Range		3,930 - 10,270	
Standard deviation		2,300	
Total suspended solids, mg/l			
Mean	16,400		12,500
Range	5,350 - 33,400		2,750 - 22,370
Standard deviation	9,480		
BOD, mg/l			
Mean	3,000		16,800
Range	690 - 5,220		2,870 - 61,000
Standard deviation	1,322		
COD, mg/l			
Mean		12,630	
Range		2,630 - 20,560	
Standard deviation		6,050	

[a]Gravity transport system installed aboard YTB-790; Saltwater diluent; tested from October 6, 1975 to January 16, 1976; See reference 93.

[b]Vacuum transport system installed aboard unnamed destroyer; tested 1974; See reference 94.

[c]Vacuum transport systems on one westcoast vessel and manufacturer's office unit; See reference 98.

For the purpose of system design, the pollutant concentrations listed in Table 14 will be used. The only exception is that concentrations from the reduced-flush gravity transport system are assumed to be equal to the vacuum transport system. It is felt that extremely high concentrations in the sample from LCU 1579 (gravity transport) are uncharacteristic and that values from LCU-1675 (vacuum transport) would be more representative of average loadings.

Effluent Requirements

At the time of report preparation there existed an internal disagreement within the EPA over legal barge classification. As reviewed previously, if the barge is classified as a "vessel" the effluent quality need only be in conformance with Type II MSD limitations, i.e., ≤ 150 mg/l TSS, ≤ 200 fecal coliforms/100 ml. States may petition EPA for zero-discharge standards in environmentally sensitive waters, but to date none of the 13 potential barge locations are affected by such petitions.

If the barge treatment system is to be considered as a point source subject to NPDES (Clean Water Act) criteria, the effluent requirements become more stringent and complex. Most states have adopted EPA's definition of secondary treatment as the minimum standard and then also included limitations on fecal coliforms, chlorine residual, or nutrients, especially in environmentally sensitive (e.g., shellfish) waters.

Until a formal opinion on barge classification is obtained from the EPA, Rexnord Inc., has been instructed to proceed with this evaluation under the assumption that the barge would be a point source. Then, if the EPA determines that the barge is a vessel, the design can be more easily adapted to meet MSD Type II requirements.

Contacts were made with the regulatory agencies responsible for issuance of point source discharge permits at each potential barge location. Table 17 summarizes the effluent requirements for each of the 13 potential locations. Bioassay (continuous, flow-through type) tests are required for the lower James River (Ft. Eustis, VA) because of recent legislation prompted by the Kepone incident. Based on the results of these toxicity tests, more stringent effluent standards may be applied.

At Fort Island, HI (Pearl Harbor) all sanitary wastewater discharges (treated or untreated) will be prohibited after 1981. The advanced wastewater treatment requirements for St. Petersburg, FL (Tampa Bay) are necessary because these waters are part of the Wilson Grizzle Area and are rigidly protected under Florida law.

Selection of Feasible Barge Locations

Inspection of Tables 14 and 15 reveals that of the 13 potential barge locations, only four have sufficient flow rates and do not have unduly stringent effluent quality standards to warrant further in-depth consideration of a barge mounted treatment system. These are Fort Eustis,

TABLE 17. EFFLUENT STANDARDS FOR POINT SOURCE DISCHARGES FOR EACH POTENTIAL BARGE TREATMENT SYSTEM LOCATION.

Barge location	Receiving Water	Effluent standards (30 day averages)					Permit agency
		BOD_5 mg/l	TSS, mg/l	pH	Fecal coliforms, counts/100 ml	Other	
Ft. Eustis, VA	Lower James River	30	30	6–9	200	Bioassay tests 1.5 ≤ Cl_2 resid. ≤ 2.5 ppm	Commonwealth of Virginia State Water Control Board
Alexandria, VA	Potomac River	30	30	6–9	200	None	Same as Fort Eustis
Baltimore, MD	Patapsco River	30	30	6–8.5	200	<0.5 ppm total Cl_2 residual	State of Maryland Dept. of Natural Resources Water Resources Administration
Aberdeen, MD	Upper Chesapeake Bay	30	30	6–8.5	70[a]	<0.5 ppm total Cl_2 residual	Same as Baltimore
Marcus Hook, PA	Delaware River	30	30	6–9	200	90% BOD_5 removal, BOD_{20} ≤ 1.3 x BOD_5, TDS limit if saltwater used	Commonwealth of Pennsylvania Dept. of Envir. Resources Bureau of Water Quality Man.
Tacoma, WA	Puget Sound	30	30	6–9	200	None	State of Washington Dept. of Ecology
Morehead City, NC	Onslow Bay	30	30	6–9	200	None	North Carolina Department of Natural Resources and Community Development Division of Envir. Manag.
Sunny Point, NC[b]	-					No data	Same as Morehead City
Fort Island, HI	Pearl Harbor					Before 1981: water quality standards beyond mixing zone After 1981: zero-discharge of treated domestic wastewater	State of Hawaii Department of Health Pollution Technical Review Branch
St. Petersburg, FL	Tampa and Boca Ciega Bays	5	5		200 (recreation areas) 70 (shellfish areas)	1 mg/l total P 3 mg/l total N Free chlorine residual > 1.0 ppm 15 minute minimum Cl_2 contact	State of Florida Dept. of Environmental Regulation
Kwajalein Island[c] Micronesia	Pacific	30	30	6–9	200	None	U.S. EPA, Region IX Permits Branch
Okinawa, Ryukyu Island	Pacific					No data	Japan
Azores, Portugal	Atlantic					No data	Portugal

[a]Total coliforms.

[b]The location of this port was not known by MERADCOM personnel.

[c]Presently a U.S. territory, but will acquire independent status within two years. At that time the standards could change.

Baltimore, Tacoma and Morehead City. Although there are more than ten watercraft at Alexandria, Aberdeen, and St. Petersburg, the waste flow rates are quite small. At Fort Island, the flow rate is large (due mainly to the BDL Page) but the zero-discharge requirement for Pearl Harbor after 1981 precludes the operation of a barge there. The new domestic wastewater treatment plant being built by the U.S. Army at Kwajalein Island is the most logical means of blackwater disposal. The other sites simply do not have sufficient watercraft activity to make a barge mounted treatment system cost-effective. The 115 watercraft currently in storage were not included in this analysis.

Determination of Design Wasteloads

The following assumptions have been used for the determination of design wasteloads:

1. All watercraft at each location will have a full crew living onboard 24 hours/day, seven days/week. Although this assumption may overestimate the actual volume of blackwater generated, it provides anticipated peak loadings for design purposes. However, the maximum frequency of barge operation (including watercraft discharge reception) will only be eight hours/day, five days/week.

2. Raw blackwater generation rates are 3 gpcd (11.4 lpcd) for reduced flush (gravity and vacuum transport) and 0.5 gpcd (1.9 lpcd) for recirculating (water and mineral oil medium) systems.

3. Holding tanks will generally be discharged when filled to the 80 percent level, unless such level is attained over a weekend.

4. Pollutant concentrations in blackwater from each of the four types of flushing systems used aboard Army watercraft are as listed in Table 14, except that concentrations for the reduced-flush gravity transport system are assumed to be comparable to the vacuum transport systems, as previously discussed.

Based on these assumptions, a computer program was written to calculate, for a five year period, the number of watercraft discharging per day, amount of blackwater discharged daily and daily discharge frequency distribution. Figure 6 is a flow chart for this computer program. For this analysis it was further assumed that blackwater accumulations in individual watercraft holding tanks at time zero were randomly distributed. Analyses were also made with the assumption that all watercraft holding tanks were empty at time zero, but results were not appreciably different than with the random distribution.

The results of these analyses at all four potential sites are summarized in Tables 18 to 21. For Fort Eustis it can be seen that the predicted maximum daily blackwater discharge to the barge is 16,700 gal. (63.2 m^3) although 80 percent of the time the discharge volume will be less than

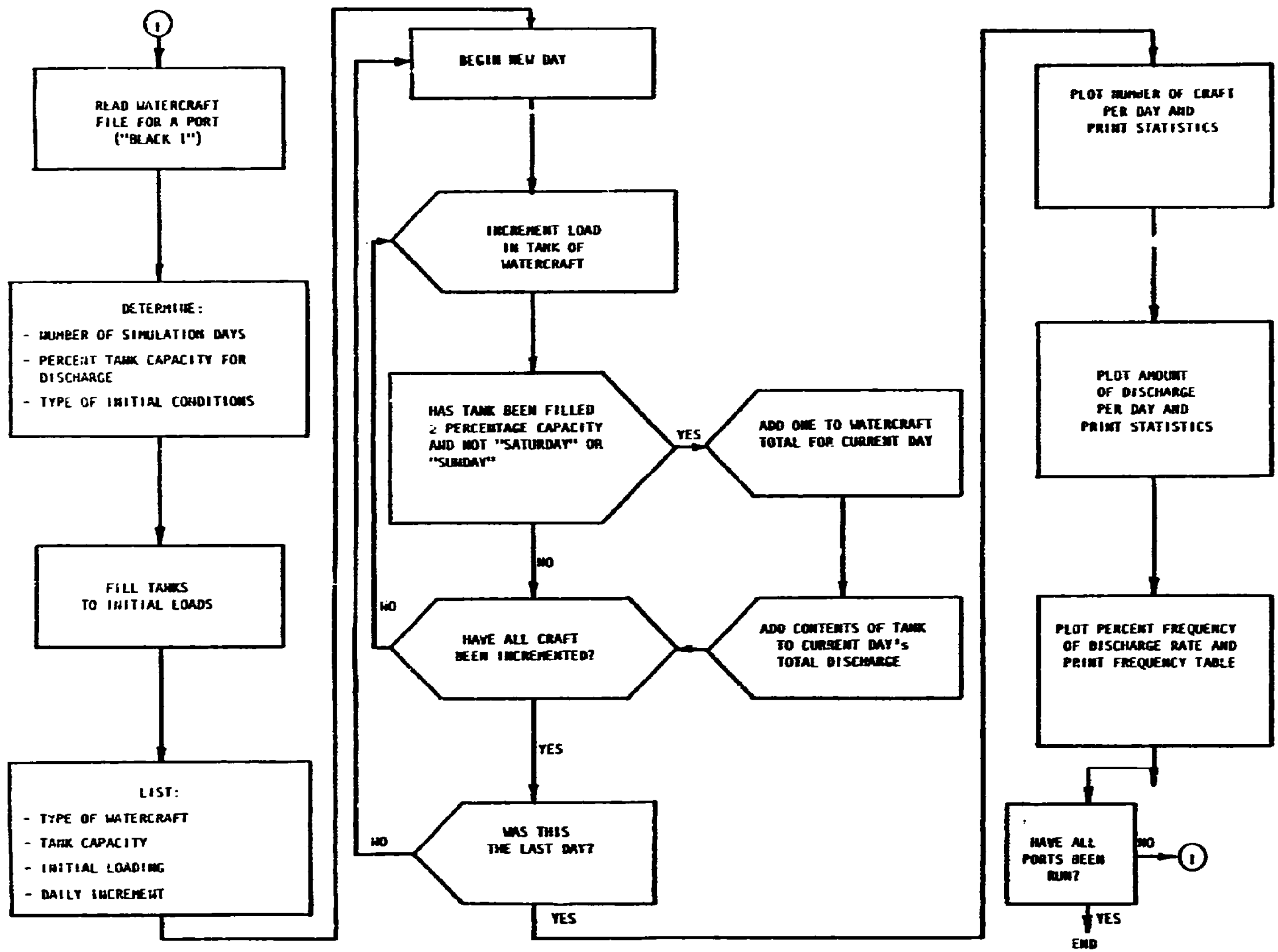

Figure 6. Flow diagram for simulation of watercraft discharging blackwater at home port (File "Black 2").

TABLE 18. RESULTS OF WATERCRAFT BLACKWATER DISCHARGE FREQUENCY ANALYSIS FOR FORT EUSTIS, VIRGINIA FOR FIVE YEAR TIME SPAN.

	Absolute maximum	Predicted 5-year values			
		Mean	Median	Maximum	Minimum
Number of watercraft discharges per day	53	16	6	33	0
Amount of total daily discharge, GPD	37,200	2,190	760	16,700	0

Daily discharge range, GPD[a]	Frequency, percent
0 - 500	45.04
500 - 1,000	11.34
1,000 - 1,500	8.66
1,500 - 2,000	8.66
2,000 - 2,500	6.24
2,500 - 3,000	2.68
3,000 - 3,500	3.55
3,500 - 4,000	0.82
4,000 - 4,500	1.47
4,500 - 5,000	1.92
5,000 - 5,500	1.19
5,500 - 6,000	2.74
6,000 - 6,500	0.87
6,500 - 7,000	1.31
7,000 - 7,500	0.81
7,500 - 8,000	0.70
8,000 - 8,500	0.65
9,000 - 9,500	0.32
9,500 - 10,000	0.26
10,000 - 10,500	0.10
10,500 - 11,000	0.26
11,000 - 11,500	0.11
11,500 - 12,000	0.05
12,000 - 12,500	0.05
13,500 - 14,000	0.05
14,500 - 15,000	0.05
15,000 - 15,500	0.05
16,500 - 17,000	0.05

[a]Ranges not listed had zero discharge frequency; GPD = 0.003785 m^3/day.

TABLE 19. RESULTS OF WATERCRAFT BLACKWATER DISCHARGE FREQUENCY ANALYSIS FOR BALTIMORE, MARYLAND FOR FIVE YEAR TIME SPAN.

	Absolute maximum	Predicted 5-year values			
		Mean	Median	Maximum	Minimum
Number of watercraft discharges per day	6	0.5	0	4	0
Amount of total daily discharge, GPD	11,900	380	0	9,250	0

Daily discharge range, GPD[a]	Frequency, percent
0 - 100	77.86
400 - 500	4.22
500 - 600	5.21
600 - 700	2.51
900 - 1,000	0.49
1,000 - 1,100	5.31
1,200 - 1,300	2.41
1,400 - 1,500	0.44
1,500 - 1,600	0.05
1,700 - 1,800	0.16
1,800 - 1,900	0.05
7,400 - 7,500	0.66
7,900 - 8,000	0.05
8,100 - 8,200	0.22
8,500 - 8,600	0.05
8,600 - 8,700	0.05
8,700 - 8,800	0.16
9,100 - 9,200	0.05
9,200 - 9,300	0.05

[a]Ranges not listed had zero discharge frequency; GPD = 0.003785 m^3/day.

TABLE 20. RESULTS OF WATERCRAFT BLACKWATER DISCHARGE FREQUENCY ANALYSIS FOR TACOMA, WASHINGTON FOR FIVE YEAR TIME SPAN.

	Absolute maximum	Predicted 5-year values			
		Mean	Median	Maximum	Minimum
Number of watercraft discharges per day	20	10	0	19	0
Amount of total daily discharge, GPD	8,400	300	0	6,800	0

Daily discharge range, GPD[a]	Frequency, percent
0 - 100	52.32
100 - 200	33.81
400 - 500	1.59
500 - 600	4.30
600 - 700	3.29
700 - 800	2.52
800 - 900	0.05
900 - 1,000	0.16
1,000 - 1,100	0.16
1,200 - 1,300	0.16
5,800 - 5,900	0.44
5,900 - 6,000	0.44
6,000 - 6,100	0.05
6,100 - 6,200	0.38
6,300 - 6,400	0.11
6,400 - 6,500	0.11
6,800 - 6,900	0.11

[a]Ranges not listed had zero discharge frequency; GPD = 0.003785 m^3/day.

2,500 (9.5 m^3) gallons. Similar discrepancies between the peak and mean daily discharges were observed for the other three sites. The intermittent nature of the loadings are also exemplified by the high frequency of low daily discharge volumes (or zero discharges) relative to the daily average.

TABLE 21. RESULTS OF WATERCRAFT BLACKWATER DISCHARGE FREQUENCY ANALYSIS FOR MOREHEAD CITY, NORTH CAROLINA FOR FIVE YEAR TIME SPAN.

	Absolute maximum	Predicted 5-year values			
		Mean	Median	Maximum	Minimum
Number of watercraft discharges per day	8	1	0	4	0
Amount of total daily discharge, GPD	4,000	480	0	1,990	0

Daily discharge range, GPD[a]	Frequency, percent
0 - 100	71.40
400 - 500	9.48
1,200 - 1,300	4.77
1,400 - 1,500	4.77
1,500 - 1,600	0.05
1,700 - 1,800	4.82
1,800 - 1,900	4.66
1,900 - 2,000	0.05

[a]Ranges not listed had zero discharge frequency; GPD = 0.003785 m^3/day.

Based on the above analyses, design barge storage volumes and treatment rates have been selected (Table 22). At Fort Eustis, the minimum holding tank volume would have to be 11,000 gallons (41.6 m^3) to receive wastes from the largest craft (Sutton). A value of 12,500 (47.3 m^3) gallons was selected for design to provide 5 days holding capacity under normal hydraulic loads (9.5 m^3/day). This provides time either for maintenance on the treatment system, or to keep up with normal discharge volume subsequent to extremely large discharges from the Sutton, FMS or 143 ft (43.6 m) tug. It is unlikely that all three craft would require discharge at about the same time. However, if the crews adhere to the rule of discharge at 80 percent tank volume, this will provide 7, 15 and 22 days of additional storage time aboard the individual craft for the 143 ft (43.6 m) tug, FMS and Sutton, respectively (see Table 13). This should provide adequate time for the treatment system to catch up.

At Baltimore, the minimum holding tank size would have to be 9,000 gallons (34.0 m^3) to accomodate the FS 790. The maximum predicted daily discharge rate was 9,250 gallons (35.0 m^3). Because average hydraulic loadings are only around 380 gpd (1.4 m^3/day), the stated design treatment rates in Table 22 have been increased according to the minimum size of available treatment equipment. This merely implies that the frequency of treatment unit operation will decrease.

The design storage volume at Tacoma is 7,200 gallons (27.3 m^3) because of the FMS. The maximum predicted daily discharge rate is only 6,800 gallons (25.7 m^3). Again actual treatment rates are contingent upon the size of available equipment.

At Morehead City, there are 8 LCM 1400's, all with 500 gallon (1.9 m^3) CHT's. The program predicted a maximum discharge of 1,990 gallons. Therefore, 2,000 gallons (7.6 m^3) was selected for barge holding tank volume. Again, actual treatment rates will be contingent upon available equipment.

TABLE 22. DESIGN BARGE STORAGE VOLUMES AND TREATMENT RATES.

Barge location	Design storage volume, gallons	Design treatment rate, gpd	Design treatment rate, gpm[a]
Fort Eustis, VA	12,500	2,500	5
Baltimore, MD	9,000	-[b]	5
Tacoma, WA	7,200	-[b]	5
Morehead City, NC	2,000	-[b]	5

[a]Assuming 8 hr/day operation.

[b]Treatment rate is equipment limited. Note: 1 gal. = 3.785 liters

Flow weighted pollutant concentrations for each barge location, based on data obtained from the preliminary sampling program at Fort Eustis, have been calculated and are presented in Tables 23 to 26. These data, when combined with the previously predicted hydraulic loadings, provide design and expected average pollutant loadings to the barge treatment systems (also provided in Tables 23 to 26). It is quite apparent that, except for Fort Eustis, the average daily loadings are significantly lower than the equipment limited design daily pollutant loadings. At Baltimore, for example, the treatment system will only have to be operated an average of about one out of seven working days to keep up with normal barge loadings.

PRELIMINARY SCREENING TO IDENTIFY ALTERNATIVES

The objective of this phase of the design evaluation was development of various flow schematics which meet certain basic technical criteria. Essentially, this consisted of an initial screening of processes to isolate those suitable for treatment of concentrated blackwater and adaptable to barge mounting.

Some of the criteria used for this initial screening of systems included:

TABLE 23. DESIGN BLACKWATER POLLUTANT LOADINGS AT FORT EUSTIS, VIRGINIA.

Pollutant parameter	Flow weighted concentration, mg/l	Average loading,[a] lb/8-hr day	Design loading,[b] lb/8-hr day	Design loading, lb/hr
TS[c]	10,000	180	210	26
TVS[c]	4,200	77	88	11
TSS	3,500	64	70	9
TVSS	2,600	47	54	7
TDS	6,500	119	140	18
$TBOD_5$	2,200	40	46	6
$SBOD_5$	1,200	22	25	3
TCOD	6,900	130	140	18
SCOD	2,000	37	42	5
TOC	2,300	42	48	6
Oil & Grease	560	10	12	2
TKN	1,300	24	27	3
NH_3-N	1,200	22	25	3
Org.-N	100	2	2	-
TP	114	2	2	-

[a]Based on mean daily (5-day/wk) discharge rate of 2,190 gpd.

[b]Based on treatment rate of 5 gpm (2,500 gpd).

[c]These data based on freshwater diluent. If seawater is used, 30,000 to 40,000 mg/l should be added to the TS and TDS concentrations.

Note: 1 gallon = 3.785 liters
1 lb = 0.454 kg

TABLE 24. DESIGN BLACKWATER POLLUTANT LOADINGS AT BALTIMORE, MARYLAND.

Pollutant parameter	Flow weighted concentration, mg/l	Average loading,[a] lb/8-hr day	Design loading,[b] lb/8-hr day	Design loading, lb/hr
TS[c]	9,500	30	200	25
TVS[c]	3,800	12	80	10
TSS	3,000	10	63	8
TVSS	2,300	7	48	6
TDS	6,500	21	140	18
$TBOD_5$	1,800	6	38	5
$SBOD_5$	1,200	4	25	3
TCOD	6,100	19	130	16
SCOD	2,000	6	42	5
TOC	2,100	7	44	6
Oil & Grease	580	2	12	2
TKN	1,300	4	27	3
NH_3-N	1,200	4	25	3
Org.-N	100	0.3	2	-
TP	100	0.3	2	-

[a]Based on mean daily (5 day/wk) discharge rate of 380 gpd.

[b]Based on treatment rate of 5 gpm (2,500 gpd).

[c]These data based on freshwater diluent. If seawater is used, 30,000 to 40,000 mg/l should be added to the TS and TDS concentrations.

Note: 1 gallon = 3.785 liters
1 lb = 0.454 kg

TABLE 25. DESIGN BLACKWATER POLLUTANT LOADINGS AT TACOMA, WASHINGTON.

Pollutant parameter	Flow weighted concentration, mg/l	Average loading,[a] lb/8-hr day	Design loading,[b] lb/8-hr day	Design loading, lb/hr
TS[c]	8,700	22	180	23
TVS[c]	3,500	9	73	9
TSS	2,500	6	52	7
TVSS	1,900	5	40	5
TDS	6,200	16	130	16
$TBOD_5$	3,100	8	65	8
$SBOD_5$	1,700	4	35	4
TCOD	5,600	14	120	15
SCOD	1,700	4	35	4
TOC	2,700	7	56	7
Oil & Grease	780	2	16	2
TKN	1,200	3	25	3
NH_3-N	1,000	3	21	3
Org.N	200	0.5	4	-
TP	100	0.3	2	-

[a]Based on mean daily (5 day/wk) discharge rate of 300 gpd.

[b]Based on treatment rate of 5 gpm (2,500 gpd).

[c]These data based on freshwater diluent. If seawater is used, 30,000 to 40,000 mg/l should be added to the TS and TDS concentrations.

Note: 1 gallon = 3.785 liters
1 lb = 0.454 kg

TABLE 26. DESIGN BLACKWATER POLLUTANT LOADINGS AT MOREHEAD CITY, NORTH CAROLINA.

Pollutant parameter	Flow weighted concentration, mg/l	Average loading,[a] lb/8-hr day	Design loading,[b] lb/8-hr day	Design loading, lb/hr
TS[c]	9,600	38	200	25
TVS[c]	3,800	15	80	10
TSS	3,000	12	63	8
TVSS	2,300	9	48	6
TDS	6,600	26	140	18
$TBOD_5$	1,600	6	33	4
$SBOD_5$	1,100	4	23	3
TCOD	6,200	25	140	18
SCOD	2,000	8	42	5
TOC	1,960	8	41	5
Oil & Grease	550	2	11	1
TKN	1,300	5	27	3
NH_3-N	1,200	5	25	3
Org.-N	100	0.4	2	-
T.	100	0.4	2	-

[a]Based on mean daily (5 day/wk) discharge rate of 480 gpd.

[b]Based on treatment rate of 5 gpm (2,500 gpd).

[c]These data based on freshwater diluent. If seawater is used, 30,000 to 40,000 mg/l should be added to the TS and TDS concentrations.

Note: 1 gallon = 3.785 liters
1 lb = 0.454 kg

1. General capability to meet discharge requirements.
2. Basic adaptability to barge mounting.
3. Simplicity.
4. Reliability.
5. Versatility.
6. Amount of operating experience for domestic wastewater or watercraft blackwater.
7. Availability of small-scale equipment.

As was emphasized in the state-of-the-art review, there is a paucity of information available on the treatability of concentrated blackwater. Design criteria and anticipated levels of performance must be extrapolated from dissimilar operating conditions. With this limitation in mind, preliminary alternative process schematics were selected. Figures 7 to 12 illustrate these systems.

Unit processes denoted by dashed boxes were considered optional items. For some optional items, recommendation for incorporation into the barge system will be based on relative economics. For example, use of incineration in Alternatives 1, 2, 3 and 6 for reduction of sludge volume to ultimate disposal will depend on relative landfill and carbon purchase and regeneration costs. Other items will be incorporated if deemed necessary from laboratory treatability studies. Diatomaceous earth precoat use will be contingent upon filtrate quality and cake discharge characteristics which can only be determined by bench-scale tests. The need for centrifugation in Alternatives 4 and 5 can likewise only be determined by actual testing. Optional items will be considered separately in the ensuing cost evaluation section.

Alternatives 1 to 4 are quite similar in that each is a physical/chemical system with a coarse solids removal step (filter press, centrifuge, vacuum filter or ultrafilter) followed by dual media filtration, activated carbon adsorption of soluble organics and chlorine disinfection. The selection of coarse solids removal equipment was largely determined by the high raw blackwater solids concentrations and the fact that barge motion precludes the use of most gravity separation techniques. Another benefit from using these particular devices is that the residues generated usually do not require further concentration prior to ultimate disposal (with the possible exception of ultrafiltration).

For all of these treatment systems, the raw blackwater holding tank would be aerated. This aeration, in conjunction with an operational procedure of maintaining a certain amount of waste in the tank between treatment cycles as a source of biomass, might provide sufficient bio-oxidation of small molecular weight organics which are difficult to remove by carbon adsorption.

Alternative 5 incorporates an aerobic bio-oxidation process (extended aeration) with ultrafiltration separation in lieu of the traditional gravity secondary clarifier which may be subject to upset due to barge motion. The use of this system would only be feasible at the Fort Eustis location,

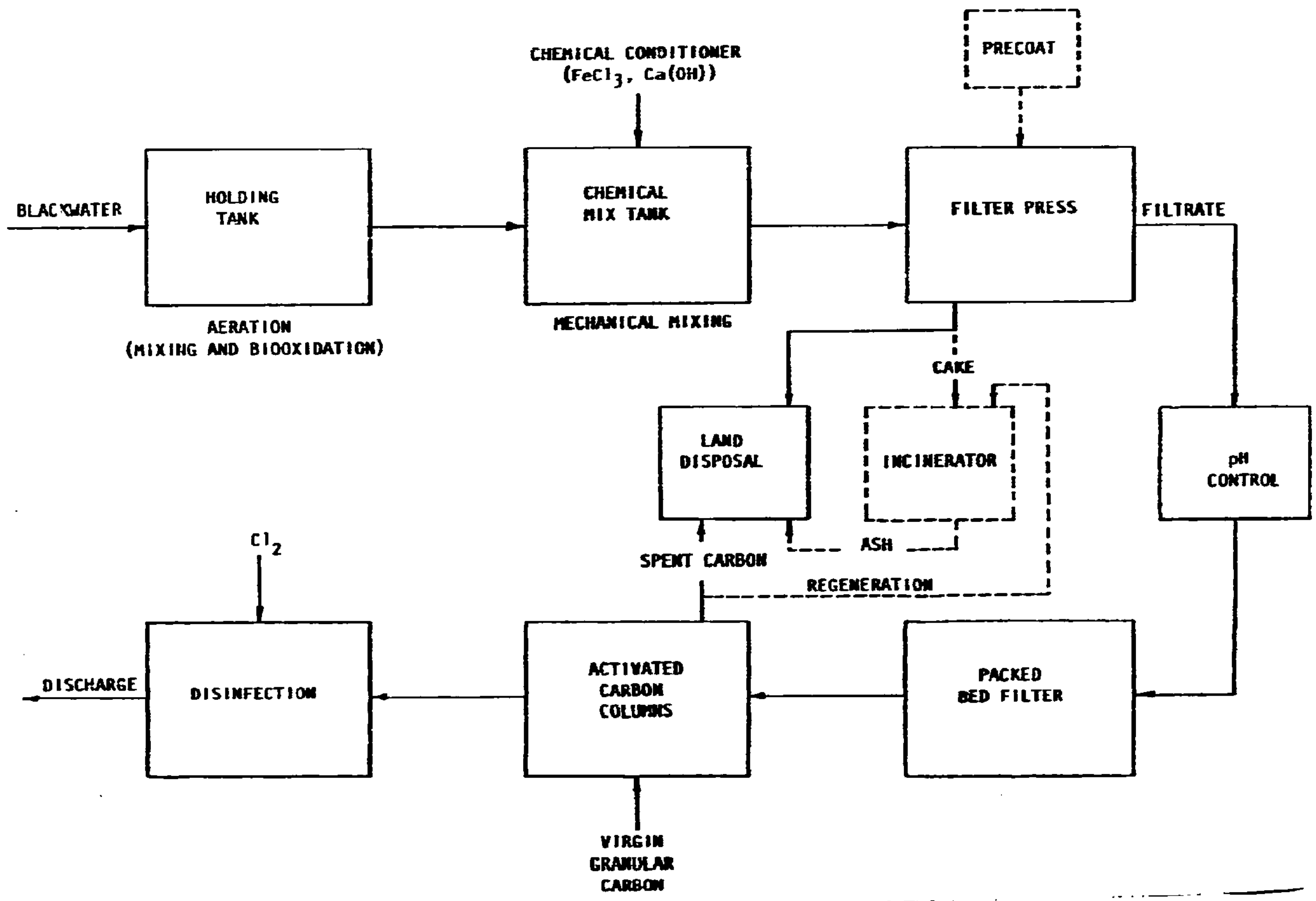

Figure 7. Schematic representation of potential barge mounted blackwater treatment system - Alternate 1.

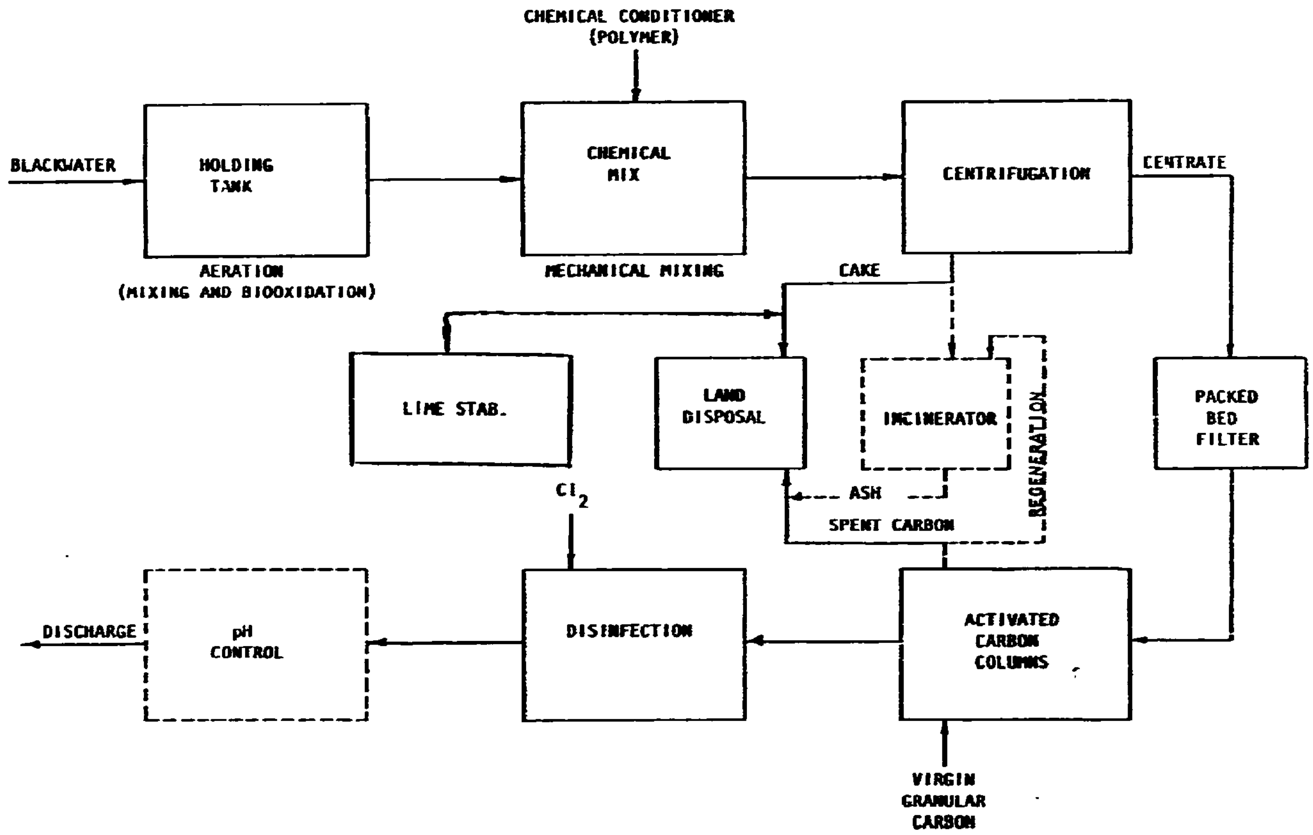

Figure 8. Schematic representation of potential barge mounted blackwater treatment system - Alternate 2.

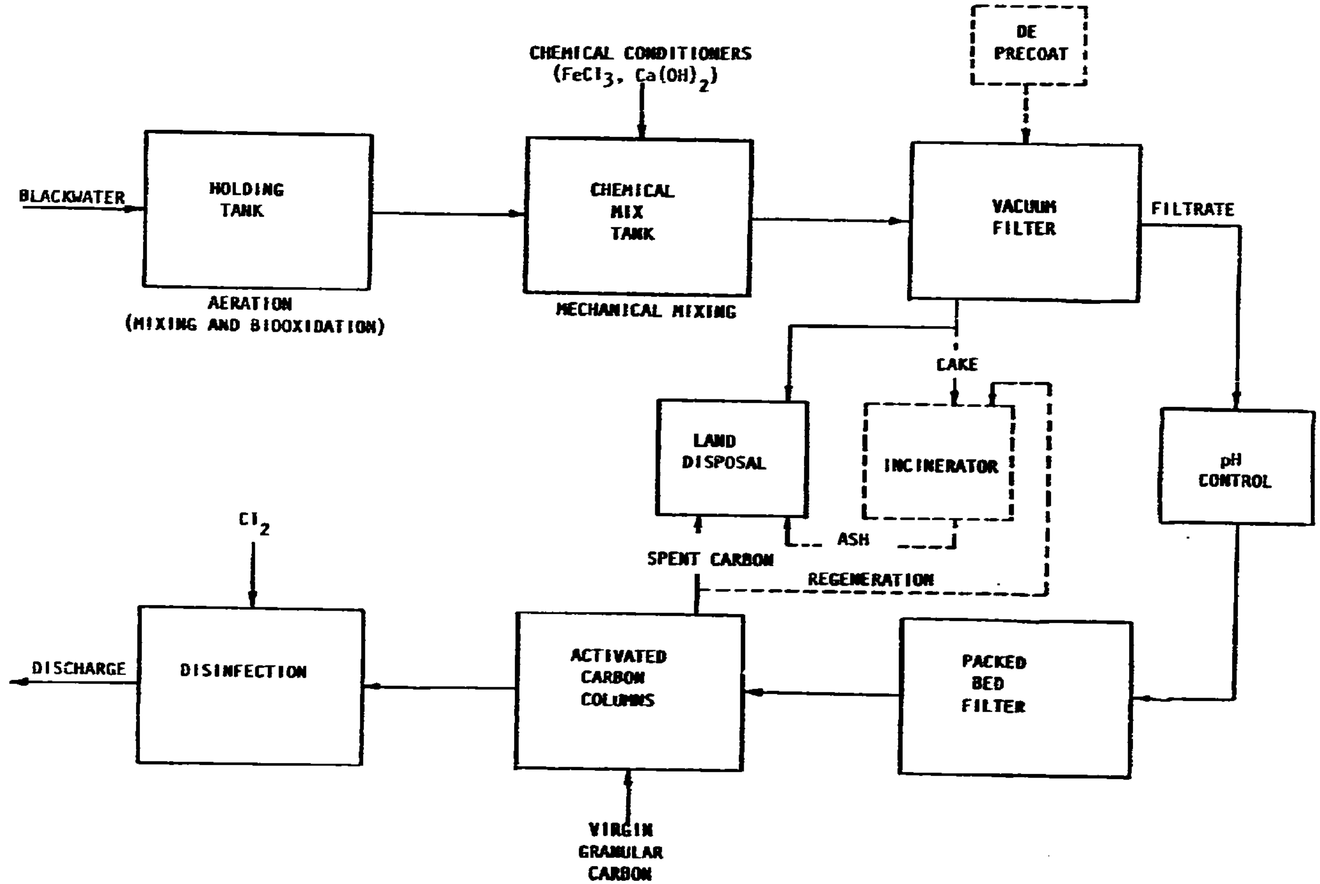

Figure 9. Schematic representation of potential barge mounted blackwater treatment system - Alternate 3.

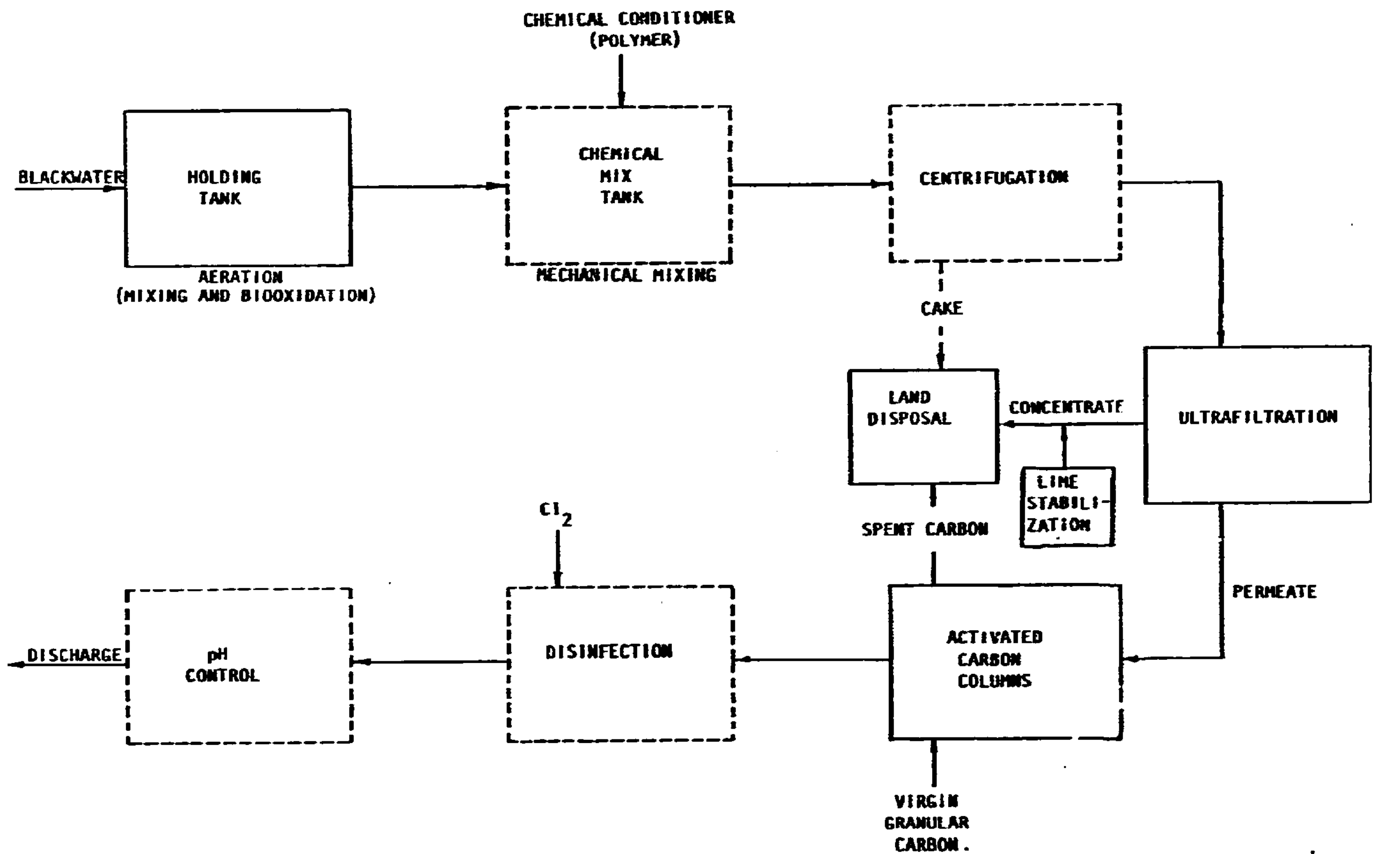

Figure 10. Schematic representation of potential barge mounted blackwater treatment system - Alternate 4.

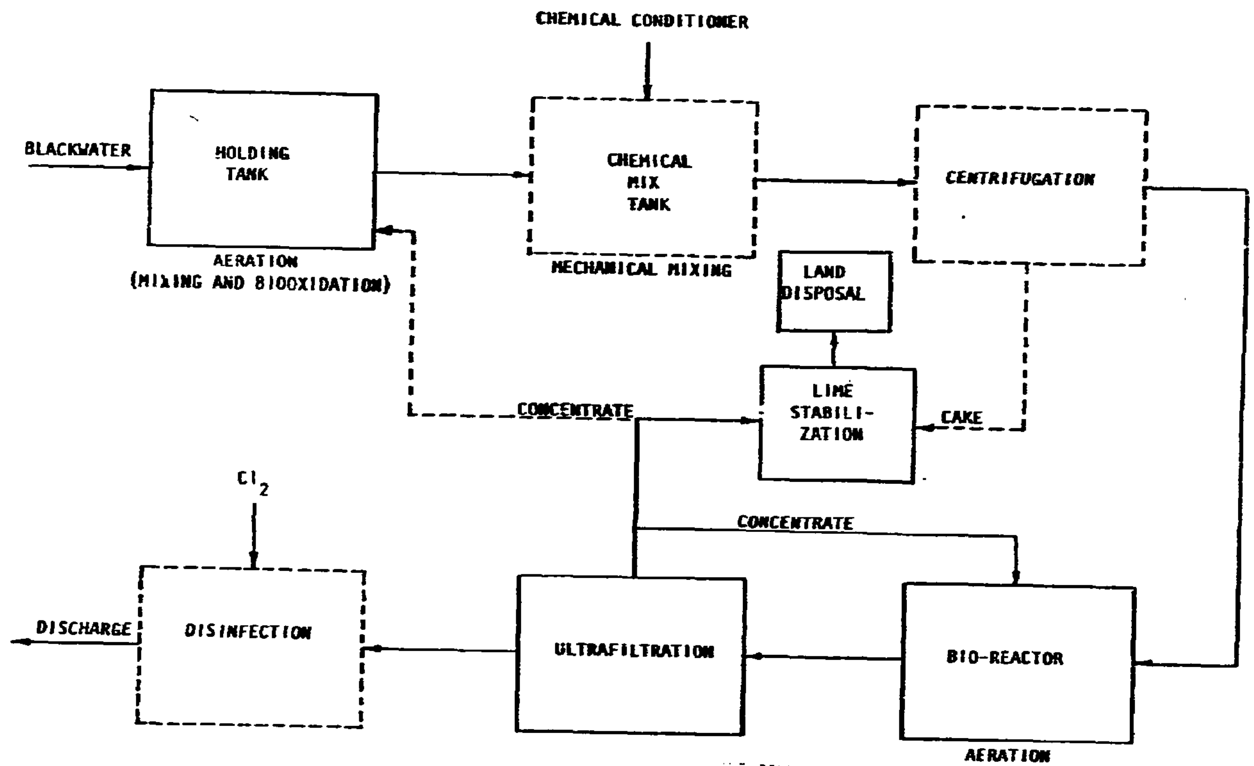

Figure 11. Schematic representation of potential barge mounted blackwater treatment system - Alternate 5.

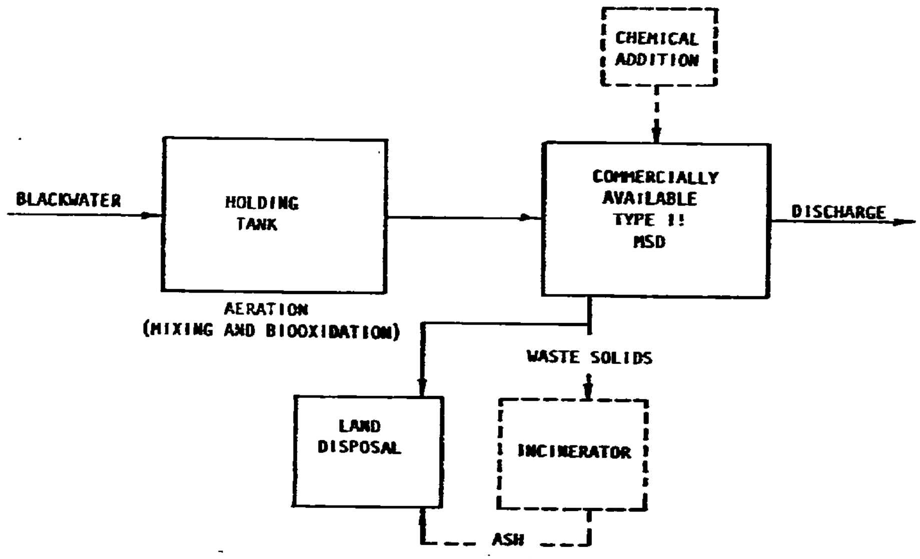

Figure 12. Schematic representation of potential barge mounted blackwater treatment system - Alternate 6.

however. The low waste flows and intermittent discharges at the other locations preclude this application because of anticipated start-up difficulties. At Fort Eustis, the large equilization storage volume and relatively high predicted watercraft activity might permit the use of a biological process although it is questionable.

Finally, Alternative 6 covers the possibility that the EPA will classify the barge as a vessel rather than a point source. Four Type II MSDs, which are presently Coast Guard certified and commercially available, were investigated. Three of these were biological systems and one was physical/chemical. There are two additional MSD considerations which should be noted here. First, the systems provided in Alternatives 1 to 4 can be quite readily downgraded to Type II MSD standards by simply omitting activated carbon adsorption and possibly dual media filtration. Secondly, one manufacturer of a commercially available Type II biological fixed growth MSD claimed that the system could readily meet point source discharge standards, if so specified. However, meager operating data were provided to support this contention.

It is apparent from inspection of these preliminary alternatives that treatment of blackwater to point source discharge levels necessitates a certain amount of operational complexity. Physical/chemical systems have the advantage of being amenable to intermittent operation and variable waste strength, but also require considerable chemical handling and operational complexity. Biological systems are simpler to operate but might not provide consistent performance under the variable loadings anticipated in this application.

These problems will be considered in more detail in the Technical Evaluation phase.

TECHNICAL EVALUATION

General

The purpose of the technical evaluation phase was to determine which of the preliminary flow schematics met certain specific mandatory and secondary performance/adaptability criteria. Also included in this phase of the evaluation was the development of general and specific design considerations and the selection of unit sizing assumptions. The end result of this analysis was the designation of one or more of the preliminary alternatives as most suitable for this application on the basis of technical considerations alone. The final selection of recommended systems for each location will also incorporate cost considerations.

General Design Considerations

There are a number of general design constraints which apply to every alternative. These constraints are mostly related to the physical operation of the barge and have minor impact on the evaluation of alternative treatment systems. These considerations are as follows:

1. That the barge mounted system provided sufficient storage and treatment capacity to accept and treat the blackwater from multiple watercraft at a predetermined capacity established on the basis of expected peak loadings to prevent delays in unloading blackwater from watercraft.

2. That access areas be provided so that several watercraft can come alongside and transfer blackwater at one time.

3. That barge mounted pumping systems, hose, and fittings be provided to safely accommodate the various pumping systems on watercraft, or in the absence of such systems on watercraft, to provide for blackwater transfer.

4. That trained personnel be in charge of the transfer process, knowledgeable in countermeasures to be taken to prevent spills to the watercourse in the event of pumping system failure.

5. That treatment of blackwater be designed to provide or produce an acceptable effluent quality for discharge into the watercourse and treatment residuals which can be either stored or incinerated on the barge.

6. That treatment residuals that will be transported off the barge be contained in such a way to facilitate the transport and ultimate disposal process.

7. That the treatment system not require inordinate amounts of supplies and fuel to operate.

8. That the barge mounted system not pose problems to safety and health for operating and maintenance personnel.

9. That air contaminants, odors, noise and other contaminants that are generated by the storage and treatment system not be a source of pollution for ambient surroundings.

10. That provisions be made for pumping out the blackwater storage tanks into tank trucks should a power outage, equipment failure, or other upset condition prevent treatment on the barge.

11. That materials handling aboard the barge and at supply and discharge points be simplified and automated to the extent that special provisions or equipment are not necessary for normal operation of the system.

12. That provisions be made for operation of the blackwater transfer and treatment systems during any time of the day, or season of the year.

13. That an entire system be self-contained and capable of generating its own power using a generator set and/or fuels which can be safely stored on board in quantities sufficient to allow extended operation of the system in case of a fuel supply problem.

14. That barge mounting of the treatment system provide for stability during operation and during towing and for proper access for operation and maintenance.

15. That treatment and storage designs assume that a full crew will be assigned to every watercraft and that these crews will be living on-board 24 hours/day.

16. That the barge treatment system is to be manned only 5 days/week, 8 hours/day.

Specific Design Considerations

The design of a barge mounted treatment system incorporated a large number of specific design considerations. Each piece of equipment was designed to be reliable and require as little maintenance as possible. Back up systems were provided where necessary and environmental factors were considered prior to equipment selection.

Feed Pumps and Comminutors (Alternatives 1, 2, 3, 4, 5, 6)--
A dual pump arrangement was estimated for the main feed pumping system. Since this is a critical operation, a malfunction during discharge could prevent the timely departure of a vessel. Therefore, a dual or parallel system would be provided to function as a back up system as necessary. With one pump in operation, the maximum discharge time for the largest vessel at any harbor would be two hours, or with both pumps operating one hour. Each pump would have a comminutor on the suction side of the pump to shred any fibrous material that might exist in the blackwater to 0.25 in. (0.64 cm) size. Valving was provided to permit operation of one, two or no pumps (for crafts with their own pumping system).

The purpose of the pumping system is to transfer blackwater from the holding tank of a particular craft to the holding tank of the treatment barge. For this operation, pumps with high suction lift and low discharge head capabilities would be needed. The pump also will have to handle relatively high solids in the flow stream. Therefore, an electric motor driven self priming diaphragm pump was chosen for this application.

Holding Tank (Alternatives 1, 2, 3, 4, 5, 6)--
Holding tanks in general, were sized to have capacity slightly in excess of the largest craft to be served. They were rectangular in shape to minimize space requirements. External tank support was provided to prevent sludge hangup on inside ledges. One of the long sides of the tank will be sloped inward to localize sludge buildup. The tank would be constructed of mild steel with an interior coal tar epoxy coating.

A cover would be provided with an access manhole for interior inspection and repair. The tank will be vented through an activated carbon canister for odor control. Aerobic conditions will be maintained through aeration at a rate of 60 cfm/1,000 ft^3 (1.0 l/m^3-sec) to provide moderate agitation to keep particles in suspension and sufficient oxygen for biological activity. A high pressure water flush line located near the bottom of the tank will rinse any residual sludge from the tank sides and bottom after emptying. An air bubbler system was chosen to indicate tank level.

Ferric Feed System (Alternatives 1, 3)--
Due to the small quantity of ferric chloride required, a lined 55 gallon (208 liter) drum would be provided for dilution of the concentrated ferric chloride with water. Diluted, it can be more accurately metered into the appropriate preconditioning tank to reach the desired level.

Lime Feed System (Alternatives 1, 2, 3, 4, 5, 6)--
The use of hydrated lime is recommended for conditioning and sludge stabilization due to the small quantity of lime required. The hydrated lime can be dumped directly into the hopper of a volumetric feeder of stainless steel construction and then metered into a fiberglass tank filled with water to achieve a stock concentration. The stock lime slurry can be pumped to a conditioning or stabilization tank until the desired level is achieved.

Because the lime slurry is likely to settle out in a non-flowing line, the pump should be operated continuously during treatment operations. The lime slurry can be circulated in a closed loop and fed to the tank only when needed. Prior to system shutdown it will be necessary to flush the lines with high pressure water.

Polymer Feed System (Alternatives 2, 4, 5)--
The polymer system was estimated to include a fiberglass stock tank with one day holding capacity, since some treatment systems only operate occasionally. Sufficient liquid or dry polymer to reach a 0.1 percent stock solution is mixed daily by pouring the polymer into this tank after it has been prefilled with water. A mixer must be operated continuously during the dilution. A chemical pump will be included to simultaneously meter the polymer into the feed line from the main holding tank to the centrifuge.

Diatomaceous Earth Precoat (Alternatives 1, 3)--
The diatomaceous earth system would consist of a fiberglass stock tank with one day holding capacity. The diatomaceous earth can be mixed manually by pouring it into this tank which has been prefilled with water to form a slurry. The mixer must be operated continuously during this operation, and the solution is mixed to a maximum concentration of 1 lb of D.E./gal. of water (120 kg/m^3). A slurry pump would be included to feed the slurry to the filter press cavity or the vacuum filter hopper.

Preconditioning Tanks (Alternatives 1, 2)--
Two fiberglass parallel preconditioning tanks would be utilized for the filter press and vacuum filter system. One tank serves as a feed source

for the downstream process while the other tank is off-line for use as a chemical mix tank and to provide necessary contact time for stabilization. Each tank would be equipped with a variable speed mixer to permit initial rapid mixing and then flocculation in the same tank. Activated carbon odor control would also be provided.

Filter Press (Alternative 1)--
Many types of filter presses can be used for blackwater treatment. Available types include plate and frame, conventional recessed chamber plate, "tank type" recessed chamber plate and diaphragm recessed chamber press. Units are available in both horizontal and vertical stacking arrangements and with various materials of construction including cast iron, stainless steel and synthetic material (i.e., "plastics" and elastomers). In most cases the plate and frame press has been replaced by the recessed chamber plate press which has fewer leakage problems.

One difficulty that may exist with a conventional press is that the smallest standard frame depth is about one inch (2.54 cm). If a one inch (2.54 cm) frame is used and the sludge is pumped at a "normal" solids flux rate, the capacity of the unit may be greater than the amount of solids captured during a typical 8-hour barge treatment cycle. Storing a partially dewatered sludge in the filter press overnight could result in undesirable operating difficulties. One way to solve this problem would be use of a diaphragm filter press which provides more operational flexibility.

Both the diaphragm and recessed plate presses have an initial fill cycle characterized by relatively high flux rates. As cake accumulates on the filter media, the flux in the conventional press is reduced to maintain acceptable pressure levels. The press cycle must then continue at these low flux rates until the entire press volume is filled with cake. This results in lengthy cycle times. With the diaphragm press, conversely, the fill cycle is terminated when the flux rates decrease and diaphragms are inflated with water or air under high pressure, greater than 200 psig (1,379 kPa), to rapidly squeeze additional water from the cake. This results in higher throughput capacity (shorter cycle times), drier cake and more operational flexiblity. For example, if a run must be terminated with a partially filled cavity, the squeeze cycle can be activated to provide a cake dry enough for discharge. This feature is especially attractive for this barge application.

Because of these operating advantages, the diaphragm press was chosen for the design. Since the unit will be exposed to ferric chloride and salt water it must be resistant to corrosion. The two most standard materials for corrosion resistance are stainless steel and plastic (polypropylene or elastomer). The plastic plates are more subject to warpage and leakage but are lower in cost, more corrosion resistant, lighter in weight and easier to handle. Therefore, the plastic plates were chosen for this design.

A wide variety of filter media consisting of different materials of construction and pore size are available. These can be either permanent or disposable. Final choices will have to be determined by laboratory and field testing.

Because a filter press is a labor intensive operation, most large scale units are highly automated. This automation adds drastically to the costs as well as to the complexity of the unit. For this application, a minimum automated unit appears most feasible. This unit would be simple enough in construction to permit maintenance and repairs by local mechanics rather than factory representatives. With long anticipated cycle times, the manual discharge operations should only be required once or twice a day. Therefore, automated squeezing equipment, plate shifting and vibratory hardware, air purge for feed and filtrate lines and media washing equipment would add unnecessary complexity and cost.

It was determined that the cake from the unit will be conveyed to covered drums for storage until disposal or incineration.

Centrifuge (Alternatives 2, 4, 5)--
The liquid-solid separation in a centrifuge is similar to gravity sedimentation except the applied force is increased many fold. The three types of centrifuges that have found application in the wastewater field are disc-nozzle, perforate bowl basket, and solid bowl scroll. Of the three types, the disc-nozzle has seen the least application to date since it requires considerable upstream pretreatment of the wastewater to remove large solids and fibrous material. Because of this restriction on type of wastewater feed, the disc-nozzle was not considered a viable selection.

Basket and scroll centrifuges have been used more extensively and successfully for wastewater applications. The basket centrifuge is a batch operation while the scroll centrifuge is a continuous operation. The basket centrifuge is suitable for a wide variety of wastewater applications but the scroll centrifuge normally has better solids handling capacity and adaptability to various wastewaters. It is also anticipated that the rocking action of the barge may have a less detrimental affect on the scroll centrifuge operation. Therefore, the scroll centrifuge was selected as the type of unit to evaluate further.

A scroll centrifuge consists of a cylindrical-conical bowl with an internal scroll conveyor. Wastewater is introduced into the center of the revolving bowl where solids are acted upon by high centrifugal separating forces. Under this force, solids are thrown against the wall of the bowl. The liquid (centrate) is discharged by gravity over a weir. Solids are moved by the scroll conveyor along the wall of the bowl where they are "plowed" up the conical beach and discharged by gravity.

Operating variables that can be changed to improve separation are feed rate, polymer addition, bowl speed, pool depth and conveyor speed.

Centrifuges are available in both carbon steel and stainless steel construction. Considering the operating environment and the possibility of the wastewater having a high salt content, stainless steel construction was selected. However, for cost and weight savings, a fiberglass access cover was specified instead of stainless steel.

It is anticipated that centrate from the unit will be directed to a small sump and then pumped to a larger centrate holding tank for treatment. Cake from the centrifuge would be lime stabilized and conveyed to drums with removable covers until disposed of or incinerated.

Vacuum Filter (Alternative 3)--
Vacuum filtration is one of the oldest and most popular methods of wastewater dewatering. However, its inherent high energy consumption is making other alternatives appear more attractive.

The typical components of a vacuum filter are a horizontal cylindrical drum covered by a filter media, a slurry vat, a vacuum pump, and a chemical conditioning system as required. The most popular media are synthetic fiber cloth or stainless steel coils.

The unit works by rotating the partially submerged drum in the vat and creating a vacuum inside of the drum. The vacuum causes filtrate to be drawn through and cake solids to be deposited on the media. Cake discharge is normally accomplished with a stationary scraper or passing the media over small rollers.

Operating variables that can be changed to improve filter yield or cake solids concentration are feed solids concentration, filter drum speed, the ratio of form time to dry time and the level of conditioning. Besides traditional lime and ferric chloride conditioning, precoating the drum with a diatomaceous earth cake has proven helpful for difficult sludges. Because of the corrosive operating environment, all principal contact parts must be stainless steel.

The filtrate from the unit would be pumped to filtrate holding tank for downstream treatment. Cake from the unit would be conveyed to drums with removable covers until disposal or incineration.

Filtrate/Centrate Tank (Alternatives 1, 2, 3, 4, 5)--
The covered filtrate/centrate tank would be of fiberglass construction and would have a 2 hour holding capacity. This tank would provide holding time for upstream equipment effluent prior to bringing downstream equipment on line. It also would permit downstream equipment to continue running during short periods of upstream equipment shutdown.

pH Adjust System (Alternatives 1, 2, 3, 4)--
Adjustment of pH if needed, would be accomplished in the filtrate/centrate holding tank. The pH adjustment system would consist of a pH probe, pH controller, chemical feed pump and tank mixer.

Ultrafiltration (UF) (Alternatives 4, 5)--
Ultrafiltration is a pressure driven membrane process which is used to remove high molecular weight solids from a waste stream, producing a permeate (effluent) and a concentrate (retentate) which may be 2 to 50 fold more concentrated than the original wastewater. In a typical installation, the feed solution is filtered to remove gross solids, then pressurized and

sent to the membrane permeators. Filters, tanks, pumps and piping required for this system are conventional items.

Membrane permeators are available in several different configurations, namely plate and frame, spiral wound, hollow fiber and tubular. Plate and frame membranes consist of thin plastic discs covered with a porous substrate and a membrane. The discs are then stacked and sealed or placed in a pressure vessel. Permeate flow is forced into a central pipe and removed. Although plate and frame membrane configurations require a minimum of floor space, they are difficult to clean and very expensive.

Spiral wound membrane systems consist of planar membranes with a porous supporting material sandwiched between membranes. Edges are sealed and the entire sandwich structure is wrapped around a central tube and placed in a pressure vessel. Feed solution is fed into the vessel along the membrane surface with permeate flowing through the membrane and porous structure into the central tube. Spiral wound membranes are low in cost, compact and have a low pressure loss per unit membrane area, but are easily plugged, hard to clean and require some waste pretreatment.

In hollow fiber ultrafiltration, membranes are spun into very fine hollow tubes. These thin cylinders need no supporting structure to withstand pressures encountered. Bundles of fibers are placed in a pressure vessel and waste is fed through them. Permeate transfers through the fibers and is collected at the end of the pressure vessel. Advantages of hollow fiber UF include low cost, minimum floor space requirements and low pressure loss per unit membrane area. Disadvantages include easy plugging and difficult cleaning.

Tubular membrane systems consist of a tube inside a porous casing which gives support and serves as a pressure vessel. As flow goes through the tube, permeate goes through the membrane and seeps through the porous casing. Although a moderately large floor space is required, membranes are easily cleaned and individual tubes are replaceable. Due to easy cleaning, tube replacement and minimum pretreatment requirements, tubular membranes were chosen as most feasible for the treatment of raw blackwater and bio-reactor effluent, as found in treatment Alternatives 4 and 5, respectively. It is assumed that tubular membrane UF can yield a permeate with negligible SS and a concentrate with 8 to 10 percent solids.

Biological Oxidation (Alternative 5)--
Biological treatment or oxidation of organic wastes entails the use of microorganisms which use oxygen to convert wastes into more organisms and energy. The ultimate end products of this oxidation process are carbon dioxide and water.

A number of biological treatment methods are available for use in treating blackwater. These may be grouped into two categories, fixed and suspended growth. Fixed or attached growth systems include trickling filters and rotating biological contactors (RBC's) among others. Suspended growth biological systems include the various forms of activated sludge treatment and aerobic stabilization ponds. As can be seen, all treatment methods listed are aerobic. Anaerobic systems will not be considered for this application due to low microbial tolerance for saline wastes. Also, aerobic stabilization ponds will not be considered due to obvious space limitations.

Fixed growth systems include trickling filters, rotating biological contactors (RBC) and a rather unique submerged fixed media process developed specifically for shipboard use (certified Type II MSD). The large area requirements and questionable performance under vari le loadings precludes barge application of trickling filters. Barge motion and vibration may cause problems with RBC's in terms of biomass sloughing and feed through spillage. Little operating data was available to demonstrate that the special marine fixed growth process was capable of consistently achieving point source effluent standards. This does not imply that the process cannot provide such effluent quality, but that more supporting data are required.

Activated sludge treatment of shipboard waste was also considered. Of the many modes of activated sludge treatment, extended aeration appears to be most promising. Due to long aeration and detention times, intermittent loading should cause fewer problems than with other modes. Although the largest quantity of oxygen is consumed, more complete oxidation and BOD removal is realized. This almost complete oxidation produces the smallest quantity of excess biological solids of any activated sludge treatment s scheme.

The biological oxidation system would consist of a covered carbon steel tank with a coal tar epoxy lining. The tank would be vented through an activated carbon canister for odor control and aerated by a blower with a diffuser pipe across the tank bottom.

Packed Bed Filter (Alternatives 1, 2, 3)--
The packed filter would be composed of several layers of selected filter media and stratified such that the maximum filtering takes place in each layer and allows solids capture to occur through the full depth of the unit. The media would be selected such that, after backwashing, the media will be stratified in its original position.

The primary purpose of the packed bed filter is to protect the carbon columns from pluggage by the residual particulate matter remaining in the filtrate or centrate. The flow through the unit would be pressurized, downward, and carefully controlled to maintain a constant flow rate throughout the run.

The tank would be of carbon steel construction with a phenolic epoxy interior and rust-inhibited painted exterior.

The backwash cycle would be activated by an automated timer-controller. The system could also be modified for activation by a differential pressure switch. Manual activation gives the operator better control. The unit is expected to have a minimum run time of 8 hours. Experience will dictate the backwash frequency, but backwashing the unit at the end of each day may be the simplest approach.

In addition to the multimedia tank and control valves, the system would include a feed and backwash pump. The backwash water from the unit would be sent to the raw feed holding tank. The filtrate from the unit would be pumped to filtrate tank (described below).

Filtrate Tank 1 (Alternatives, 1, 2, 3, 4)--
The covered filtrate tank would be of fiberglass construction with a 2 hour holding capacity. This tank could serve as a source of backwash water for the packed bed filter with adequate holding capacity to allow backwashing while simultaneously feeding activated carbon columns.

Activated Carbon Columns (Alternatives 1, 2, 3, 4)--
The purpose of the activated carbon columns is to remove the soluble BOD remaining in the wastewater. Activated carbon columns will also remove suspended solids but this is more efficiently handled in a packed bed filter preceding the unit.

The system would consist of six carbon steel tanks with phenolic epoxy interiors and rust-inhibiting painted exteriors. The flow through the units was anticipated to be in a series, pressurized and operated in the downflow mode. Valving was included which allows selected tank(s) to be taken off line for carbon replacement or repairs. Each tank will be provided with appropriate automated backwash valves and an independent automated time-controller for backwashing.

The backwash water from the unit would be sent to the raw feed holding tank. The filtrate from the unit would be pumped to Filtrate Tank 2 (described below).

Filtrate Tank 2 (Alternatives 1, 2, 3, 4)--
The covered filtrate tank would be of fiberglass construction with a 2 hour holding capacity. This tank could serve as a source of backwash water for the activated carbon columns.

Disinfection (Alternatives 1, 2, 3, 4, 5)--
Because of the low flow rate and dosing requirement encountered on the barge most disinfection systems are impractical. The system recommended for this application is a tablet type chlorinator. The unit consists of a plastic flow housing with an adjustable operating level holding stabilized chlorine tablets. The tablets gradually dissolve, chlorinating the water as it flows by.

To provide the necessary contact time downstream from the chlorinator, a multichannel stainless steel contact tank will be provided.

Residue Disposal (Alternatives 1, 2, 3, 6)--
The two principal methods of disposal are sanitary landfill or on-barge incineration. For sanitary landfill disposal the sludge must be stabilized by aerobic or anerobic digestion, by air drying, composting or lime

treatment. At some locations, even the stabilized sludge is not acceptable for landfill disposal.

Another means of sludge disposal would be application on agricultural land. This method of disposal might be pertinent, but the site specific nature of this technique precluded further evaluation of this alternative during this stage of the feasibility study.

The other, more costly, alternative would be on-barge incineration. The three basic types of incineration processes commonly employed for sewage sludges are:

1. Multiple hearth.
2. Fluidized bed.
3. Electric (infrared) furnaces.

The relatively low solids production and the anticipated intermittent barge treatment operation make the first two types of incinerators impractical. Therefore electric furnaces were chosen as the only viable alternative. After extensive searching, only one manufacturer of electric furnaces was found. Their smallest standard unit would be too large for our application, however, they would be capable of modifying this unit with considerable redesign to fit our application. This system has the additional advantage of application for carbon regeneration, as well as sludge incineration.

The high capital cost of the unit is explained by the many components required. Some of these components are the electric (infrared) incinerator, incinerator belt conveying system, combustion air blower, combustion air preheater, wet scrubber, induced draft exhaust fan, control and instrumentation panel, motor control center, and electric afterburner.

Monitor Instrumentation (Alternatives 1, 2, 3, 4, 5)--
The amount of instrumentation to be utilized for the barge system is quite variable. If both monitoring and recording capabilities are included the price increases significantly. Since the operators will be present whenever principal equipment is running, only the monitoring capability should be needed in most locations. The type of instrumentation required would be flow, pressure, pH, temperature, turbidity, and residual chlorine content.

Compressor (Alternatives 1, 2, 3, 4, 5, 6)--
Each system would be furnished with an air compressor. The amount of air required for each system will vary depending upon its particular needs. Air will be needed to operate air driven pumps, valves and cylinders, and will also be used for flushing lines, backwashing the packed bed filter media, and instrumentation. The compressed air can also be used for aerating the main holding tanks or the bioreactor, however, using a low pressure blower is more energy efficient.

Generator (Alternatives 1, 2, 3, 4, 5, 6)--
Each system would be furnished with at least one generator. For most systems, two generators would be provided. One large generator is required for the

high power demand periods when the principal equipment is being operated, and a smaller more fuel efficient unit during periods when only the aeration equipment is being operated. The units would provide 440 volt power and with a transformer, 110 volt power. The units would be diesel powered to minimize fuel consumption and permit safer fuel storage.

Assumptions for Unit Sizing

To size various pieces of treatment equipment for each alternative, literature sources were reviewed and equipment vendors were consulted. The unique nature of waste to be treated by the barge system complicated this procedure considerably. Literature sources provided design guidelines for waste either much more dilute or much more concentrated than anticipated for U.S. Army blackwater. Equipment vendor recommendations were considered in conjunction with literature data and the engineering judgement of project personnel to derive best estimates of unit sizing parameters for each type of equipment described in the previous section. These estimates are preliminary and should be used only to compare alternatives. More accurate design values will require field verification (or laboratory treatability testing) because of the unique nature of the wastewater.

Table 27 summarizes the unit sizing parameters employed for each unit process for Alternatives 1 to 5. Each of these is further described below.

Chemical Conditioning (Alternatives 1, 2 and 3)--
The levels of chemical conditioning for pressure filtration, centrifugation, and vacuum filtration were derived from the literature. These are typical values for more concentrated wastes, but were in general agreement with vendor recommendations. It is conceivable, however, that actual conditioning of more dilute blackwater might require higher doses.

The levels of lime listed for conditioning do not incorporate the use of lime for simultaneous stabilization of the cake for land disposal. This level, for Alternatives 1 to 5, was assumed to be 600 lb/ton, 30 percent of dry solids (300 g/kg) as listed in Table 27.

The use of diatomaceous earth (DE) precoat for pressure and vacuum filtration was considered an optional item contingent upon further laboratory scale testing.

Filter Press (Alternative 1)--
Filter presses, especially smaller units, are used in many applications other than wastewater treatment. Therefore, many equipment vendors were not familiar with the particular operating requirements for wastewater dewatering and usually overestimated their equipment capacity. Several vendors were experienced with wastewater dewatering but typical influent total solids concentrations were much higher than Army blackwater.

Generally, it would be more economical to thicken the sludge upstream of the filter press to decrease the size of the press needed. However, in this application, a gravity thickening process would probably not be successful because of barge motion.

TABLE 27. SUMMARY OF UNIT SIZING PARAMETERS FOR BARGE MOUNTED BLACKWATER TREATMENT SYSTEMS.

Alternative	Unit process	Unit sizing parameters	Treatment effectiveness	Source or reference
1	Conditioning			
	$FeCl_3$	120 lb/ton dry solids		62
	$Ca(OH)_2$	530 lb/ton dry solids		62
	DE precoat	200 lb/ton dry solids		62
1	Filter press[b]		Effluent TSS <100 mg/l	EV
	Recessed plate	0.05 gpm/sf, 0.1 lb/hr-sf		67
	Diaphragm	0.12 gpm/sf, 0.2 lb/hr-sf		EV
1-3	Packed bed filter (downflow, pressurized)	4.6 gpm/sf	Effluent TSS <30 mg/l	EV
1-4	Activated carbon (downflow, pressurized)	4.6 gpm/sf 0.5 lb SCOD/lb carbon	Effluent BOD <30 mg/l	EV 102, 103
1-6	Chlorination	5 mg/l as Cl_2		104
2	Polymer conditioning	10 lb/ton dry solids		62
2	Scroll centrifuge	Hydraulic + solids loadings	Effluent TSS < 350 mg/l	EV 67
3	Conditioning			
	$FeCl_3$	100 lb/ton dry solids		62
	$Ca(OH)_2$	260 lb/ton dry solids		62
	DE precoat	200 lb/ton dry solids		62
3	Vacuum filter[b]	0.4 lb/hr-sf	Effluent TSS <300 mg/l	EV
4	Ultrafiltration	20 gpd/sf	Effluent TSS <30 mg/l	54, 55, EV
1-5	Lime stabilization ($Ca(OH)_2$)	600 lb/ton dry solids		62

TABLE 27. SUMMARY OF UNIT SIZING PARAMETERS FOR BARGE MOUNTED BLACKWATER TREATMENT SYSTEMS (continued).

Alter-native	Unit process	Unit sizing parameters	Treatment effectiveness	Source or reference
5	Bioreactor	F/M ratio - 0.05 36 - 48 hr. HRT 20,000 mg/l MLSS		45, 104 54, 55
5	Ultrafiltration	15 gpd/sf	Effluent TSS + BOD_5 <30 mg/l	EV

[a]EV = Equipment vendor.

[b]Without DE precoat.

Note: lb/ton = 0.5 g/Kg
gpm/sf = 0.68 l/m^2-sec
lb/hr-sf = 4.89 Kg/m^2-hr
gpd/sf = 0.041 m^3/m^2-day

It is expected that a higher initial flux rate can be used than normally employed because of the thinner wastewater feed. It is unknown if this higher initial flux rate will have a detrimental effect on filtrate quality.

A review of literature sources and discussion with vendors resulted in the sizing parameters of a flux rate of 0.05 gpm/sf (2.04 $l/min\text{-}m^2$) for the recessed plate press and a flux rate of 0.12 gpm/sf (4.89 $l/min\text{-}m^2$) for the diaphragm press. This flux rate represents an average flux rate over the duration of the cycle. This would also be equivalent to 0.1 lb of dry suspended solids/hr-sf (0.49 $Kg/m^2\text{-}hr$) for the recessed plate press and 0.2 lb/hr-sf (0.98 $Kg/m^2\text{-}hr$) for the diaphragm press.

For most municipal sludge dewatering applications total solids content is used to estimate chemical conditioning demands and design loading rates. This approach is satisfactory for municipal sludges where the dissolved solids fraction of the total solids is relatively small. However, for Army blackwater applications, with a large fraction of soluble constituents, the suspended solids portion had to be used in unit sizing parameters.

Packed Bed Filter (Alternatives 1 to 3)--
For a packed bed filter, the vendors standard unit selection resulted in a pressurized downflow rate of 4.6 gpm/sf (187 $l/min\text{-}m^2$). Sources indicated that this value is within the permissible flow range.

Activated Carbon (Alternatives 1 to 4)--
For an activated carbon system, standard unit selection also resulted in a pressurized downflow rate of 4.6 gpm/sf (187 $l/min\text{-}m^2$). A significant concern is whether the carbon column will become anaerobic during operation, resulting in gas formation and poor quality effluent. This can be circumvented by frequent backwashing with water treated with chlorine and caustic soda.

Most vendors were not familiar with the application of activated carbon at the high soluble BOD/COD loadings required for this application. Therefore, it is recommended that laboratory testing be done to determine the rate of carbon exhaustion. An estimated value of 0.5 kg SCOD removal/kg of carbon was used. This value results in considerable carbon consumption. Therefore, the design was developed so that when all carbon columns were connected in series and on line, they would provide twice the minimum contact time required. This arrangement should permit 2 to 3 filters to be off line for carbon replenishment and still provide adequate treatment.

Chlorination (Alternatives 1 to 6)--
The assumed chlorine dose (as Cl_2) for all alternatives was 5 mg/l. As shown in Table 17, chlorine residuals must be closely controlled at several barge locations for the sake of shellfish protection. The type of chlorine system selected for this application was tablet chlorination with calcium hypochlorite being the predominant ingredient. A more accurate determination of chlorine demand can only be determined by laboratory tests.

Scroll Centrifuge (Alternative 2)--
The size of the scroll centrifuge was based on empirically derived relationships supplied by equipment vendors. Primary variables in centrifuge equipment selection include hydraulic and solids loadings, and the nature of the solids. Efficient operation of the unit requires bench testing to determine optimum residence times, gravitational forces, and chemical dosages.

Vacuum Filter (Alternative 3)--
A general rule-of-thumb cited by one equipment vendor was that vacuum filter yield in pounds dry solids per square foot per hour (lb/sf-hr) can be directly related to the percent dry solids in the feed stream. For example, a feed sludge with 3 percent dry solids would result in a yield of roughly 3 lb/sf-hr (14.7 Kg/m^2-hr). The literature, in general, supported this relationship for typical (2 to 6 percent dry solids) sludges. Little information exists for more dilute sludges, but the extrapolated value of 0.4 lb/sf-hr (1.96 Kg/m^2-hr) for blackwater was selected since other data were unavailable.

Ultrafiltration (Alternatives 4 and 5)--
Design values for tubular membrane ultrafiltration flux rates for raw blackwater and activated sludge mixed liquor were selected both on the basis of reported literature values and contact with equipment vendors. Values of 15 gpd/sf and 20 gpd/sf (0.6 and 0.8 m^3/m^2-day) were selected for activated biomass and raw blackwater, respectively. They represent steady state (long duration) fluxes, rather than the initially high rates of 40 to 70 gpd/sf (1.6 to 2.9 m^3/m^2-day) often reported.

Extended Aeration--
The most common and acceptable means of designing extended aeration systems is to select a food/microorganism ratio (F/M) expressed as the daily BODs loading divided by the mass of suspended solids under aeration. This ratio is then combined with a design hydraulic retention time (HRT) and a selected mixed liquor suspended solids (MLSS) concentration to calculate the required aeration tank volume. The F/M ratio and HRT listed in Table 27 are common for extended aeration systems, but the MLSS concentration is substantially higher than common practice. This is attributable to the inordinately high influent BOD_5 concentrations. A similar system was utilized effectively for watercraft wastes as reported by Baily, <u>et.al.</u> (45).

Air requirements were based on a value of 1.6 Kg O_2 required/Kg BOD_5 removed, 10 percent oxygen transfer efficiency and an oxygen concentration in air of 23.3 percent. These are commonly accepted values in sanitary engineering practice.

Design of Full-Scale Barge Mounted Systems

Application of the unit sizing parameters described provided full-scale equipment sizes for each barge location. This includes major process equipment sizes, holding tank volumes, pump and motor capacities, chemical needs, etc. These equipment requirements are detailed in Appendix A.

In addition to these data, Table 28 summarizes chemical usage and the nature and quantities of treatment residues generated for each barge location and treatment alternative.

Evaluation Criteria

A list of mandatory and secondary performance/adaptability criteria was established to facilitate the comparison between the four physical/chemical systems and biological treatment system. Only a cost comparison will be made for Alternative 6 (MSD-Type II) since different technical objectives, i.e., level of treatment, preclude technical comparison.

The list of technical criteria are as follows:

1. Mandatory criteria:

   a. Ability to consistently meet point source discharge standards.
   b. Reliability (susceptibility to upset).
   c. Operational simplicity.
   d. Versatility (ability to treat variable strength blackwater with intermittent operation).
   e. Adaptability to barge mounting.
      Not affected by barge motion and vibration.
      Suitability from the standpoint of weight and stability.
      Space requirements.

2. Secondary criteria:

   a. Low chemical needs (usage and handling).
   b. Low energy requirements.
   c. Operational safety.
   d. Low maintenance requirements.
   e. Provides odor control.
   f. Generates low volume, dewatered residues for ultimate disposal.
   g. Performance not adversely affected by saltwater or mineral oil.
   h. Degree of operating experience with this type of waste.

The four physical/chemical systems are quite similar with the exception of coarse solids removal equipment. Therefore, only this equipment need be comparatively evaluated; then the biological system as a whole will be compared with physical/chemical systems.

Evaluation Results

Physical/Chemical Systems--

Coarse Solids Removal Equipment--The four devices which have been cited as potentially suitable for this application (filter press, vacuum filter, ultrafilter and centrifuge) can be compared on the basis of some of the mandatory and secondary criteria previously listed. Table 29 provides such an evaluation by ranking each device in sequential order of criteria satisfaction. For example, the degree of solids capture (i.e., quality

TABLE 28. TYPES AND QUANTITIES OF TREATMENT CHEMICALS USED AND RESIDUES GENERATED FOR BARGE MOUNTED BLACKWATER TREATMENT SYSTEMS.

Alternative(s)	Parameter	Barge location: Fort Eustis	Baltimore	Tacoma	Morehead City
1	Chemical conditioners[a]:				
	$FeCl_3$, lb/day	4	1	0.3	0.7
	$Ca(OH)_2$, lb/day[b]	19	3	2	4
1, 3	Diatomaceous earth precoat[c], lb/day	7	1	0.6	1
1-4	Activated carbon use, lb/day	75	12	8	16
1-5	Tablet chlorination[d], lb/wk	0.75	0.11	0.09	0.14
1	Filter cake generated[e]:				
	% Total solids	35	35	35	35
	lb/day Total solids	87	14	8	17
	lb/day Ash[f]	39	7	3	7
2	Chemical conditioner[a], polymer - lb/day	0.3	0.05	0.03	0.06
2	Centrifuge cake generated[d]:				
	% Total solids	18	18	18	18
		13	13	15	14
	lb/day Total solids	65	10	6	12
	lb/day Ash	18	3	1	3
	lb/day $Ca(OH)_2$ for stabilization	19	3	2	4
3	Chemical conditioner[a]:				
	$FeCl_3$, lb/day	3	0.5	0.3	0.6
	$Ca(OH)_2$, lb/day[b]	19	3	2	4
3	Filter cake generated[e]:				
	% Total solids	22	22	22	22
	lb/day Total solids	86	14	8	17
	lb/day Ash[f]	27	5	2	5

TABLE 28. TYPES AND QUANTITIES OF TREATMENT CHEMICALS USED AND RESIDUES GENERATED FOR BARGE MOUNTED BLACKWATER TREATMENT SYSTEMS (continued).

Alternative(s)	Parameter	Barge location			
		Fort Eustis	Baltimore	Tacoma	Morehead City
4	Concentrate generated:				
	% Total solids	10	10	10	10
	lb/day Total solids	64	10	6	13
	lb/day $Ca(OH)_2$ for stabilization	19	3	2	4
5	Concentrate generated:				
	% Total solids	8	8	8	8
	lb/day Total solids	66	9	6	12
	lb/day $Ca(OH)_2$ for stabilization	20	3	2	4

[a] Expressed as 100 percent $FeCl_3$, $Ca(OH)_2$ or polymer; corrections for commercial quality not made here.

[b] Lime dose elevated for disposal stabilization.

[c] The use of DE precoat is optional at this point.

[d] Main ingredient of tablets is calcium hypochlorite.

[e] These values include the chemical conditioners, but not the DE precoat.

[f] Does not include additional lime for stabilization.

Note: lb/day = 0.454 Kg/day

TABLE 29. COMPARISON OF FOUR TYPES OF COARSE SOLIDS REMOVAL METHODS FOR BARGE MOUNTED PHYSICAL/CHEMICAL SYSTEMS.

Criteria	Ranking sequence[a]
Suspended solids capture	UF > FP > VF > CE
Reliability (lowest maintenance frequency)	CE > FP > VF > UF
Operational simplicity (least complex)	CE > UF > VF > FP
Versatility (most adaptable to variable feed characteristics)	FP > UF > CE > VF
Adaptability to barge mounting	
Least affected by motion	FP ≈ UF ≈ CE > VF
Least affected by vibration	FP ≈ UF > VF ≈ CE
Least weight	UF > CE > FP > VF
Least space required	UF > CE > FP > VF
Lowest conditioning chemical needs	UF > CE > VF > FP
Lowest energy requirements	UF > FP > CE > VF
Highest operational safety	CE ≈ UF > VF > FP
Least subject to odor problems	
During operation	UF ≈ CE > FP > VF
After discharge	FP ≈ VF > UF > CE
Ease of residue disposal	FP > VF > CE > UF
Least adversely affected by	
Salt water	FP ≈ CE ≈ UF ≈ UF
Mineral oil	CE > FP > VF > UF
Operating experience with "thin" sludges (less than 1% suspended solids)	CE > VF UF > FP

[a]UF - Ultrafiltration (without upstream centrifugation).
FP - Diaphragm filter press (not precoat).
VF - Vacuum filter (no precoat).
CE - Centrifugation (scroll type).

of filtrate, permeate or centrate) is highest with ultrafiltration and lowest with centrifugation. The basis for many of the ranking sequences is self-explanatory, while others will be further described below.

Operational simplicity was one of the more important constraints in this evaluation. In this instance, simplicity refers not to degree of complexity in the physical principles behind each device but rather to the amount of operator attention which is required for effective performance. With this in mind, the filter press operation was ranked lowest because the small equipment scale necessitated manual discharge of the cake in a batch process, whereas other equipment can be operated continuously. The vacuum filter requires monitoring of the vacuum and filtrate systems as well as drum submergence and cake discharge. The centrifuge and ultrafiltration units are simple input/output devices, although the ultrafiltration process involves considerable recirculation to maintain flow velocity.

Adaptability to barge mounting is another critical design constraint. The vacuum filter was ranked low in terms of barge motion because of uncertain effects on filter performance from turbulence in the feed trough. Barge vibrations may cause excessive wear on critical bearings for both the vacuum filter and centrifuge. The filter press and ultrafilter should be relatively unaffected by barge motion and vibration.

Although none of the four devices impart serious safety problems, the filter press poses the highest probability of operator injury during the manual discharge operation.

The ultrafilter and centrifuge present the fewest odor problems during operation because they are closed systems. The use of lime for conditioning and stabilization should minimize odors from the other processes both during, and especially after, cake discharge. The cake discharged from the centrifuge and ultrafilter might be foul smelling until lime stabilized.

As previously discussed, the means of ultimate disposal of treatment residues can be either on-barge incineration or land disposal. In either case, it is advantageous to have as dry a cake as possible. For incineration, this reduces energy requirements (less water to evaporate) and, for land disposal, it reduces the volume of residue to be transported. The filter press provides the highest cake solids while ultrafiltration provides the lowest.

None of the four alternatives would be adversely affected by saltwater since corrosion-resistant materials of construction were specified. Mineral oil in high concentrations could be a problem for the filtration processes due to media or membrane fouling. However, anticipated mineral oil concentrations should not preclude application of these processes (see Table 29).

Unfortunately there is limited operating experience for all four processes in treating this particular type of waste. Although a ranking sequence was provided for this criterion, there was not adequate information available to confidently determine which alternative would be most suitable.

It is apparent from inspection of Table 29 that no single device clearly dominates in terms of suitability for this application. However, if one places subjective emphasis on certain criteria, recommendations on highest degree of suitability can be made. The diaphragm filter press has many performance advantages relative to the other devices, most crucial of which are generation of a dry, stabilized cake, a high quality filtrate, good versatility and relatively little impact from barge motion and vibration. The major disadvantages appear to be the amount of operator attention required during press discharge (consuming roughly one hour per eight hour day) and the high level of chemical conditioning.

Ultrafiltration offers several noteworthy advantages such as high permeate quality, good adaptability to barge mounting, and operational simplicity. Major disadvantages include possible need for pretreatment to prevent membrane fouling and the further treatment (stabilization and possibly dewatering) of the concentrate prior to land disposal or incineration.

The use of centrifugation also has advantages such as operational simplicity, low conditioning chemical requirements, and reliability. Disadvantages include poorer quality effluent (centrate), high energy demand, and the need to further treat the cake prior to land disposal.

Inspection of Table 29 reveals that vacuum filtration generally ranked lower than other devices for most critiria. It should also be noted that each device was ranked exclusive of optional features such as DE precoat for vacuum and pressure filtration and upstream centrifugation for ultrafiltration. Use of this optional equipment could alter several of the ranking sequences. For example, using DE precoat vacuum filtration could provide a filtrate quality comparable to pressure filtration. Also the use of centrifugation upstream of the ultrafiltration could reduce potential fouling problems and associated maintenance frequency.

Comparison of Biological and Physical/Chemical Systems--
The major advantages and disadvantages of biological systems relative to physical/chemical systems were covered quite extensively in the state-of-the-art review for marine sanitation devices. These considerations are also valid for a barge mounted system designed to meet point source discharge standards. A more detailed analysis predicated on the mandatory and secondary criteria previously listed will be undertaken here.

Mandatory Criteria--For the biological system, the ability to consistently meet point source discharge standards is related to several other mandatory criteria. The ability of the system to perform reliably with variable strength feed and intermittent operation is questionable. At Fort Eustis, where watercraft activity will be greatest, the large amount of equalization (storage) volume on the barge might provide a consistent enough feed source. At the other sites, low and infrequent blackwater discharge volumes preclude application of a biological system. The use of ultrafiltration to concentrate mixed liquor for the biological system eliminates barge motion problems which may have been encountered with gravity clarification.

In summary, when considering mandatory criteria, the use of a physical/chemical treatment system has the decisive advantage of being able to handle variable waste strength and intermittent loadings. However, laboratory verification will be required to confirm the ability of carbon adsorption to reduce the high soluble BOD concentrations to less than 30 mg/l. Finally, although the biological system is simpler to operate than most of the physical/chemical systems, its inability to operate intermittently significantly reduces its applicability to barge mounting in most areas.

Secondary Criteria--It is clear that one of the primary disadvantages of physical/chemical systems is the necessity for extensive chemical handling facilities. Although quantities of most treatment chemicals required for this application are quite small, the necessary handling equipment required additional capital cost and increased operational and maintenance complexity.

Energy consumption for the biological system is higher than the filter press and ultrafiltration physical/chemical systems, but lower than vacuum filtration and centrifugation options. The residue generated by the biological system (ultrafiltration concentrate) requires further treatment (lime stabilization and/or dewatering) prior to ultimate disposal. Such treatment is also required for the physical/chemical systems except Alternatives 1 and 3 where lime stabilization is performed in conjunction with chemical conditioning.

If the Army watercraft primarily use saltwater as commode diluent, as anticipated, there should be no toxicity problems for the biological process. However, if saltwater and freshwater are used interchangeably, there could be toxicity problems due to shock.

None of the alternatives pose a significant threat to the health and safety of operating personnel. Odors can also be effectively minimized for all alternatives. Operating experience with biological systems for concentrated wastes is as limited as for physical/chemical processes.

COST EVALUATION

In order to more objectively evaluate the barge mounted treatment alternatives an effective cost analysis was undertaken. Total costs were based on both capital and operation and maintenance (O&M) costs expressed as a total yearly cost and cost per unit volume of blackwater treated. This generalized approach was selected rather than more complex feasibility criteria since the purpose of the cost evaluation was to provide ballpark comparable costs.

Capital costs were obtained from various sources including manufacturing representatives and literature. Amortization of these costs required certain assumptions. Major equipment was assumed to have a service life of 15 years with no salvage value. All other equipment was estimated to have a service life of 7.5 years, again with no salvage value. These service life periods are on the low end of the ranges stipulated by the EPA (99), but the corrosiveness and vibrational shock induced on the equipment in the marine environment justifies the selection of conservative values. A yearly cost was then determined using an amortization rate of 7.125 percent assuming no inflation on equipment requiring replacement after 7.5 years. For each treatment alternate, capital costs were determined for each site and for treatment trains consisting of mandatory equipment and both mandatory and optional equipment.

Certain economic factors which may be considered in a more complete analysis have been omitted here. These factors fall beyond the scope of this project but should be noted. Included are: depreciation (although no salvage value is assumed), equipment delivery, engineering services and contingencies. Installation, piping and valving was considered assuming a factor of 10 to 20 percent of cost, dependent on the piece of equipment. This estimate may prove to be conservative if extensive retrofitting is required during installation. Specific barge retrofit considerations were excluded from this analysis since the actual barge class which would be used has not been determined.

Operations and maintenance costs were determined taking labor, energy, material, chemical, replaceable equipment and solids disposal into consideration. Labor requirements were determined by estimating work loads based on volume of wastewater, frequency of pump-out operation and treatment equipment complexity. One or two man teams with eight hours per day, 5 days per week blackwater treatment were assumed. A base pay rate of $10/hr was deemed appropriate for comparative purposes, although overhead and fees are not included. Regular and breakdown maintenance are included in labor costs, while supervisory costs are not. Start-up costs, although often significant, were not determined.

Energy costs, with the exception of optional incineration, were derived from total equipment energy consumption, assuming a cost of $0.10/KWh. These costs varied widely due to intermittent treatment at some locations. Incinerator energy costs were assumed to be one or two percent of capital costs, dependent on frequency of use.

Chemical and material costs were based on current market prices and estimated usage. Costs were calculated for virgin activated carbon, ferric chloride ($FeCl_3$), lime [$Ca(OH)_2$], polymer and chlorine. Acid (for pH control), filter media and ultrafiltration cleaning solutions costs were deemed negligible and not included.

Replacement equipment, including filter cloths and ultrafiltration tubes were determined on the basis of past experience and equipment use. Economic consideration was not given to the acquisition of parts.

Solids disposal on shore and incineration were also considered. Land disposal of solids was assumed to have a cost of $14.00/dry ton ($15.40/metric ton) which is representative cost for landfilling at a private site (100). These costs could be reduced substantially if a suitable agricultural site was found. Hauling costs are not included since haul distances were not known. Incineration for the purpose of solids disposal and carbon regeneration was included as an option in a number of treatment schemes. Although this requires a large capital investment, substantial savings in carbon costs and solids disposal are gained. This savings, in some cases, made the optional treatment schemes more economical in terms of operation and maintenance.

Costs for each treatment alternative at each site are shown in Tables 30 to 35. Mandatory and optional schemes are included, showing amortization, operation and maintenance, total yearly cost and cost per 1,000 gal. (3,785 liters) of blackwater treated. These costs are also graphically represented in Figure 13. A complete breakdown of these costs can be found in Appendix B.

As can be seen from Tables 30 to 35, wide variation in costs exists between various sites. In all cases, the Ft. Eustis site requires the highest yearly expenditure but cost per 1,000 gal. (3,785 liters) is the lowest. This is due to larger blackwater volumes encountered. Higher costs per volume are encountered at other sites since smaller flows must be handled while capital costs remain relatively constant. This consistency in capital costs can be attributed to the fact that design treatment rates at locations of lower watercraft activity are limited by the minimum size of commercially available equipment. This produces a low utilization of invested capital costs.

On the basis of cost alone, Alternate 6 (MSD-Type II) is most feasible although this option is only applicable if the barge is classified as a vessel rather than a point source. Alternative 5 (biological treatment) ranks next in terms of relative treatment cost, although as discussed earlier, biological treatment is only technically feasible at Ft. Eustis. Of the remaining alternatives, costs are comparable at each site for both mandatory and optional treatment schemes.

It is quite obvious that centralized barge treatment is relatively expensive. For comparison, it has been estimated that the existing cost for blackwater disposal by tank truck hauling was roughly $80/1,000 gallons (3,785 liters) based on a flat rate of $50 per watercraft pumpout (10.). However, elimination of the problems associated with the tank truck operation (including any hidden costs) might justify this expenditure. Moreover, EPA classification of the barge as a vessel will allow blackwater treatment aboard the barge at Fort Eustis at a total cost roughly comparable to the existing means of disposal (excluding barge retrofit costs).

SELECTION OF RECOMMENDED SYSTEMS

In order to identify the treatment system(s) most feasible for barge mounting, comparisons were made on the basis of technical and cost

TABLE 30. TOTAL TREATMENT COSTS ANTICIPATED AT EACH BARGE LOCATION
ALTERNATE 1
PHYSICAL/CHEMICAL TREATMENT WITH FILTER PRESS SOLIDS REMOVAL.

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Mandatory treatment processes				
15 yr. amortization, ($/yr)	22,730	21,980	21,610	19,260
Operation and maintenance, ($/yr)	68,800	33,280	32,150	31,210
Total yearly cost, ($)	91,530	55,260	53,760	50,470
$/1000 gal. (3785 l)	160.74	559.30	689.20	404.40
Mandatory and optional treatment processes				
15 yr. amortization, ($/yr)	40,220	39,380	39,100	36,750
Operation and maintenance, ($/yr)	54,620	32,030	31,820	29,020
Total yearly cost, ($)	94,840	71,410	70,920	65,770
$/1000 gal. (3785 l)	166.40	722.80	909.20	527.00

TABLE 31. TOTAL TREATMENT COSTS ANTICIPATED AT EACH BARGE LOCATION
ALTERNATE 2
PHYSICAL/CHEMICAL TREATMENT WITH CENTRIFUGE SOLIDS REMOVAL.

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Mandatory treatment processes				
15 yr. amortization, ($/yr)	22,900	21,010	20,630	18,290
Operation and maintenance, ($/yr)	69,000	33,220	32,140	31,180
Total yearly cost, ($)	91,900	54,230	52,770	50,100
$/1000 gal. (3785 l)	161.40	548.90	676.50	401.40
Mandatory and optional treatment processes				
15 yr amortization, ($/yr)	40,400	38,510	38,140	35,800
Operation and maintenance, ($/yr)	54,370	31,900	31,760	28,920
Total yearly cost, ($)	74,770	70,410	69,900	64,720
$/1000 gal. (3785 l)	166.30	712.70	896.15	518.60

TABLE 32. TOTAL TREATMENT COSTS ANTICIPATED AT EACH BARGE LOCATION
ALTERNATE 3
PHYSICAL/CHEMICAL TREATMENT WITH VACUUM FILTER SOLIDS REMOVAL.

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Mandatory treatment processes				
15 yr. amortization, ($/yr)	23,680	22,930	22,560	20,210
Operation and maintenance, ($/yr)	71,080	33,720	32,590	31,590
Total yearly cost, ($)	94,760	56,650	55,150	51,800
$/1000 gal. (3785 l)	166.40	573.40	707.00	415.10
Mandatory and optional treatment processes				
15 yr. amortization, ($/yr)	41,170	40,420	40,060	37,700
Operation and maintenance, ($/yr)	56,880	32,460	32,250	29,460
Total yearly cost, ($)	98,050	72,880	72,310	67,160
$/1000 gal. (3785 l)	172.00	737.60	927.00	538.10

TABLE 33. TOTAL TREATMENT COSTS ANTICIPATED AT EACH BARGE LOCATION
ALTERNATE 4
PHYSICAL/CHEMICAL TREATMENT WITH ULTRAFILTER SOLIDS REMOVAL.

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Mandatory treatment processes				
15 yr. amortization, ($/yr)	18,690	16,240	16,130	13,520
Operation and maintenance, ($/yr)	68,075	33,270	32,200	30,890
Total yearly cost, ($)	87,035	49,510	48,330	44,410
$/1000 gal. (3785 l)	152.80	501.10	619.60	355.80
Mandatory and optional treatment processes				
15 yr. amortization, ($/yr)	25,350	22,920	22,810	20,210
Operation and maintenance, ($/yr)	70,120	33,660	32,570	31,300
Total yearly cost, ($)	95,470	56,580	55,380	51,510
$/1000 gal. (3785 l)	167.70	572.70	710.00	412.70

TABLE 34. TOTAL TREATMENT COSTS ANTICIPATED AT FT. EUSTIS LOCATION ALTERNATE 5 BIOLOGICAL TREATMENT.

	Ft. Eustis
Mandatory treatment processes	
15 yr. amortization, ($/yr)	16,470
Operation and maintenance, ($/yr)	49,300
Total yearly cost, ($)	65,770
$/1000 gal. (3785 1)	115.50
Mandatory and optional treatment processes	
15 yr. amortization, ($/yr)	22,200
Operation and maintenance, ($/yr)	51,030
Total yearly cost, ($)	73,230
$/1000 gal. (3785 1)	128.60

TABLE 35. TOTAL TREATMENT COSTS ANTICIPATED AT EACH BARGE LOCATION
ALTERNATE 6
CERTIFIED TYPE II MARINE SANITATION DEVICE.

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Mandatory treatment processes				
15 yr. amortization, ($/yr)	12,470	10,600	10,220	7,880
Operation and maintenance, ($/yr)	31,070	30,540	30,530	27,230
Total yearly cost, ($)	43,540	41,140	40,750	35,110
$/1000 gal. (3785 1)	76.50	416.40	522.40	281.30
Mandatory and optional treatment processes				
15 yr. amortization, ($/yr)	29,390	27,520	27,140	24,800
Operation and maintenance, ($/yr) ($/yr)	33,890	33,500	33,500	30,200
Total yearly cost, ($)	63,280	61,020	60,640	55,000
$/1000 gal. (3785 1)	111.00	617.60	777.40	440.70

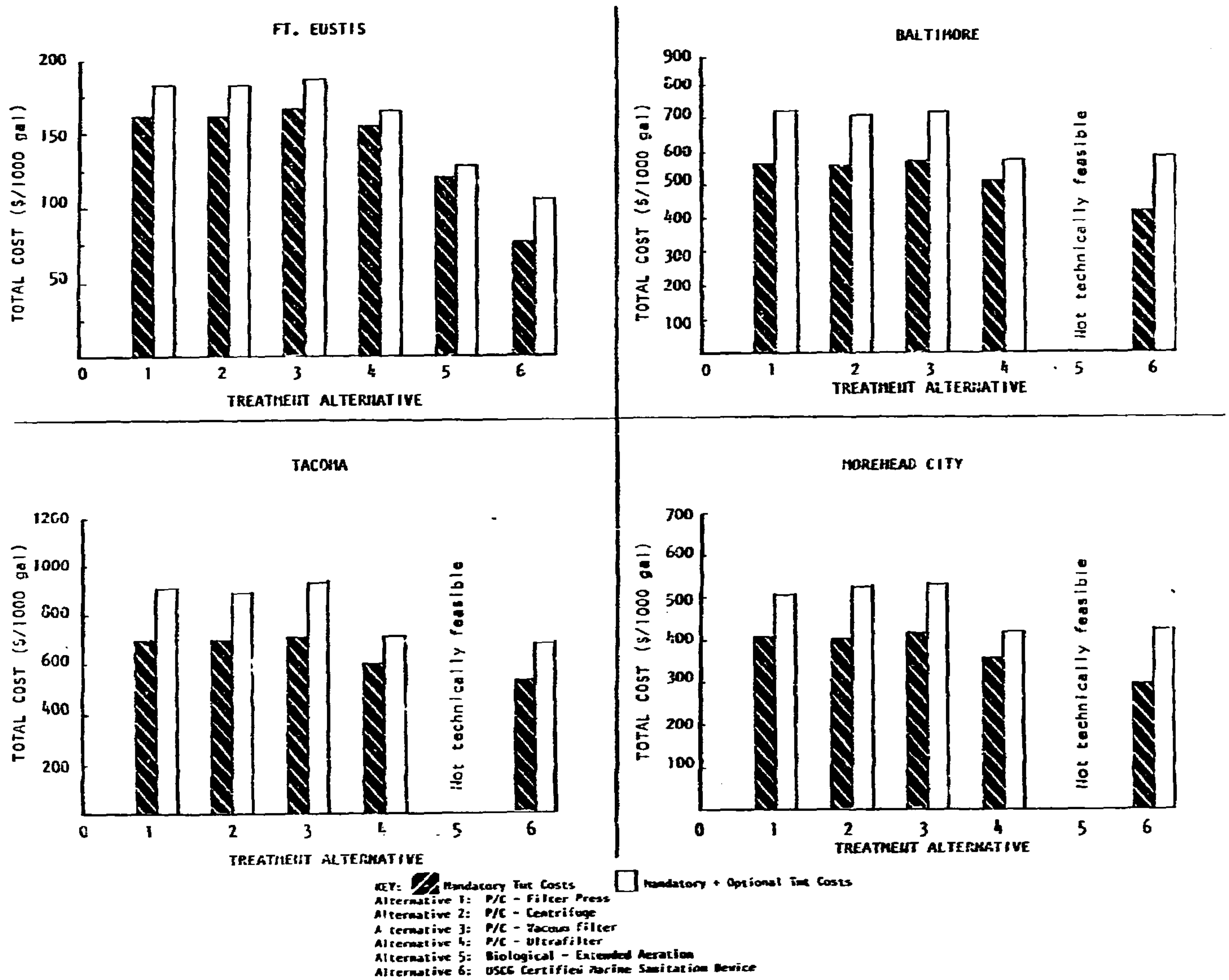

Figure 13. Graphic representation of comparative costs.

considerations. A cursory examination of costs determined for each alternative demonstrates that barge treatment facilities at Baltimore, Tacoma and Morehead City are probably far too costly to be acceptable. Costs are more reasonable at Fort Eustis. Also, only Fort Eustis has blackwater discharge rates high enough to provide fairly continuous use of treatment equipment. The ensuing summary of the selection process will therefore, be concentrated only on Fort Eustis facilities.

Alternative 6 was the least costly treatment scheme. Technically this system incorporates a Coast Guard certified Type II marine sanitation device which can meet vessel discharge requirements. If the barge mounted treatment system is classified as a vessel, this alternative should be given further consideration. However, if point source requirements must be met there is no assurance that these more stringent standards can be met with a Type II device. In terms of cost, substantial savings can be realized through utilization of biological treatment (Alternative 5). As stated previously though, infrequent blackwater discharges might preclude use of biological treatment even at Ft. Eustis. Although simpler to operate with minimal chemical requirements, the ability of a biological system to meet point source discharge requirements under highly variable loadings is questionable. This system should not be considered further unless additional treatability tests demonstrate the inadequacy of physical/chemical systems.

The treatment systems most feasible at Ft. Eustis are physical/chemical in nature. This includes Alternatives 1 (filter press), 2 (centrifuge), 3 (vacuum filter) and 4 (ultrafiltration). Among these, optional treatment processes (with the exception of incineration) will no longer be considered although later laboratory treatability studies may indicate these are necessary.

Of the listed alternatives, ultrafiltration (Alternative 4) has proven slightly less expensive, while other alternatives are very similar in cost; so similar in fact, that the subsequent comparisons will be carried out primarily on the basis of technical feasibility.

Although vacuum filtration (Alternative 3) has seen extensive use and produces a relatively dry cake, it is rather complex, requires frequent maintenance, large amounts of energy, might be adversely affected by barge motion and appears to be least adaptable to variable feed characteristics. Therefore, this alternative will, no longer be considered.

Each of the remaining alternatives have technical advantages and disadvantages which very closely balance. Use of a filter press (Alternative 1) will result in the highest cake solids and appears to be most adaptable to varying feed characteristics when compared to the other dewatering technologies. Although more operator attention is required, the filter press will probably be least affected by motion and vibration and high salinity. It should also be noted that a filter press is not energy intensive but chemical requirements may be quite high.

Centrifugation of blackwater may also be feasible for this application. It is the least complex unit to operate although it may be adversely affected by barge vibration. Chemical requirements are also quite low but energy requirements may offset this savings. A disadvantage of centrifugation is the lower efficiency of suspended solids capture.

Finally, ultrafiltration must be considered feasible for this application dependent on further testing. Although this process is very effective in removing suspended solids and requires the least energy and chemicals, it may be adversely affected by mineral oil and produces a high volume, low solids content sludge. Maintenance may be the biggest problem associated with ultrafiltration. Membrane pluggage and replacement may be encountered due to unique blackwater characteristics.

Although preliminary cost data exclude use of incineration for solids disposal and carbon regeneration, hauling costs (not included in land disposal costs) may be high due to larger quantities of solids and carbon to be disposed of and long hauling distances. In this case, incineration may be a cost effective disposal means and further consideration should be given to it.

From a cost and technical standpoint Alternatives 1 (filter press), 2 (centrifuge) and 4 (ultrafiltration) appear feasible. It should be noted however, that this is a unique situation in terms of environment and waste characteristics and further investigations, including treatability studies, should be undertaken to ensure operational efficiency and allow a more complete evaluation of economic feasibility.

SECTION 4

CONCLUSIONS

Based on a review of the current marine sewage treatment state-of-the-art and a more specific technical and cost evaluation, the following conclusions can be drawn regarding the breadth of information available in the technical literature and the feasibility of a barge mounted blackwater treatment system.

1. Very little data are available regarding characterization of waste produced by reduced-flush and recirculating marine waste systems.

2. Although numerous studies have been conducted on treatability of vessel wastewaters and although there is a broad data base on domestic sewage treatment and residue handling in municipal plants, little of this information is directly relevant to evaluating treatment of blackwater from U.S. Army watercraft. In general, most watercraft and all municipal wastewaters are an order of magnitude more dilute than anticipated U.S. Army blackwater while most residues (sludges) from municipal plants are an order of magnitude more concentrated. Blackwater from reduced-flush and recirculating marine sanitation systems presents a unique situation from the standpoint of treatability.

3. Technical evaluation of the centralized barge treatment concept was warranted at four of thirteen potential locations (Fort Eustis, VA; Baltimore, MD; Tacoma, WA; and Morehead City, NC). These sites were selected on the basis of degree of watercraft activity, blackwater volume, and stringency of effluent standards.

4. Smaller blackwater volumes encountered at Baltimore, Tacoma and Morehead City result in very high capital costs per unit volume treated. Blackwater treatment using a barge system is most economically feasible at Ft. Eustis. Total treatment costs to meet point source effluent quality were estimated to range from $116 to 172 per 1,000 gallons (3,785 liters) of treated blackwater at Fort Eustis excluding hauling of residues and barge retrofit.

5. The barge classification decision to be made by the U.S. EPA will have a profound effect on cost of centralized blackwater treatment. If the barge is classified as a vessel, total treatment costs could be reduced to around $77/1,000 gallons (3,785 liters) treated at Fort Eustis (again excluding barge retrofit and residue hauling).

This would compare more favorably with the estimated existing cost of approximately $80/1,000 gallons (3,785) for tank truck hauling.

6. Biological treatment of blackwater might not be able to provide adequate treatment to obtain point source effluent quality due to intermittent loadings and variable waste characteristics.

7. Use of physical/chemical blackwater treatment to obtain point source effluent quality (incorporating filter press, centrifuge or ultrafilter for coarse solids removal) appears feasible from a technical standpoint. Further suspended solids removal should be accomplished using a packed bed filter with soluble organics removal by activated carbon. The effluent would then be chlorinated prior to discharge.

8. The use of on-barge incineration for solids disposal and carbon regeneration does not dramatically increase total treatment of costs at Fort Eustis, but does add a significant amount of operational complexity.

SECTION 5

RECOMMENDATIONS

In order to more accurately assess the feasibility of a barge mounted blackwater treatment facility certain areas need further investigation. Therefore, the following recommendations are made.

1. Further, more complete, blackwater characterization should be investigated to ensure proper facility design and effective treatment. Waste variability should also be studied since this could have a major impact on treatability.

2. Any dispute regarding barge classification should be settled. The resulting effluent guidelines could drastically affect the type and degree of treatment required and the cost associated with that treatment.

3. At sites where a barge mounted treatment system is not feasible, optimization of blackwater disposal should be studied. This would help reduce problems inherent in current tank truck disposal methods.

4. Effects of salinity and chemical additives on the coarse solids removal technologies and carbon adsorption should be determined in order to maximize treatment efficiencies and minimize operational problems.

5. On-barge incineration of treatment residues and carbon regeneration should not be removed from consideration if solids hauling costs exceed capital and O&M costs associated with the incinerator.

6. Treatability studies should be undertaken, using lab or pilot scale equipment to determine the most efficient means of treating blackwater to achieve effluent requirements. In order to further refine equipment design and more accurately determine scale-up costs, studies should incorporate the use of a centrifuge, filter press and ultrafilter for coarse solids removal. Pretreatment requirements prior to these processes should also be investigated as well as chemical dose optimization and soluble organic removal with activated carbon.

7. If treatability studies indicate that physical/chemical blackwater treatment is ineffective, biological treatment should be investigated on a lab or pilot scale basis.

SECTION 6

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APPENDIX A

TABLE A1. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE I

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Self Priming Diaphragm Pump (2)	3 HP - 100 GPM	3 HP - 100 GPM	3 HP - 100 GPM	1/2 HP - 20 GPM
1/4" slots comminutor	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.
Coal Tar Epoxy Lined Holding Tank	12,500 gal.	9,000 gal.	7,500 gal.	2,000 gal.
Aeration Blower	5 HP - 100 CFM	5 HP - 100 CFM	5 HP - 100 CFM	1 1/2 HP - 25 CFM
$FeCl_3$ Pump	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.
$Ca(OH)_2$ System				
316 SS Volumetric Feeder	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr
Fiberglass Mix Tank	65 gal.	65 gal.	65 gal.	65 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Centrifugal Slurry Pump	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM
Preconditioning System				
Fiberglass Tanks (2)	500 gal.	500 gal.	500 gal.	500 gal.
Variable Speed Mixer	1/3 HP	1/3 HP	1/3 HP	1/3 HP
Filter Press System				
Feed Pump	1 HP-10 GPM @ 100 PSI	1 HP-10 GPM @ 100 PSI	1 HP-10 GPM @ 100 PSI	1 HP-10 GPM @ 100 PSI
Polypropylene Diaphragm Filter Press	5 chambers 50.2 ft^2-2.1 ft^3	5 chambers 50.2 ft^2-2.1 ft^3	5 chambers 50.2 ft^2-2.1 ft^3	5 chambers 50.2 ft^2-2.1 ft^3
Sludge Conveyor	1 HP	1 HP	1 HP	1 HP
Filtrate Tank (3)	750 gal. - fiberglass	750 gal. - fiberglass	750 gal. - fiberglass	750 gal. - fiberglass
pH Adjust Mixer	1/3 HP	1/3 HP	1/3 HP	1/3 HP
Packed Bed Filter	1 @ 20" dia.	1 @ 20" dia.	1 @ 20" dia.	1 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI
Activated Carbon Columns	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.	6 @ 20 dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI
Air Compressor	10 HP	10 HP	10 HP	10 HP
Large Generator	60 KW	60 KW	60 KW	60 KW
Small Generator	10 KW	10 KW	10 KW	10 KW
Optional				
Diatomaceous Earth System				
Fiberglass Mix Tank	200 gal.	200 gal.	200 gal.	200 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Slurry Pump	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Incinerator (Infrared furnace) throughput capacity	dry solids - 87 lb/day carbon - 75 lb/day	14 lb/day 12 lb/day	8 lb/day 8 lb/day	17 lb/day 16 lb/day

TABLE A2. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE 2

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Self Priming Diaphragm Pump (2)	3 HP - 100 GPM	3 HP - 100 GPM	3 HP - 100 GPM	1/2 HP - 20 GPM
1/4" slots comminutor	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.
Coal Tar Epoxy Lined Holding Tank	12,500 gal.	9,000 gal.	7,500 gal.	2,000 gal.
Aeration Blower	5 HP - 100 CFM	5 HP - 100 CFM	5 HP - 100 CFM	1 1/2 HP - 25 CFM
Polymer System				
Fiberglass Mix Tank	100 gal.	100 gal.	100 gal.	100 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Polymer Feed Pump	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.
Centrifuge	3,000 G's	3,000 G's	3,000 G's	3,000 G's
Feed Pump	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM
Main Drive	5 HP	5 HP	5 HP	5 HP
Back Drive	1 HP	1 HP	1 HP	1 HP
Sludge Conveyor	1 HP	1 HP	1 HP	1 HP
$Ca(OH)_2$ System				
316 SS Volumetric Feeder	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr
Fiberglass Mix Tank	65 gal.	65 gal.	65 gal.	65 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Centrifugal Slurry Pump	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM
Centrate/Filtrate Tank (3)	750 gal. fiberglass	750 gal. fiberglass	750 gal. fiberglass	750 gal. fiberglass
Packed Bed Filter	1 @ 20' dia.	1 @ 20" dia.	1 @ 20" dia.	1 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI
Activated Carbon				
Columns	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI
Air Compressor	10 HP	10 HP	10 HP	10 HP
Large Generator	50 KW	50 KW	50 KW	50 KW
Small Generator	10 KW	10 KW	10 KW	10 KW
Optional				
Incinerator (infrared furnace) throughput capacity	dry solids - 65 lbs/day carbon - 75 lbs/day	10 lbs/day 12 lbs/day	6 lbs/day 8 lbs/day	12 lbs/day 16 lbs/day

TABLE A3. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE 3

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Self Priming Diaphragm Pump (2)	3 HP - 100 GPM	3 HP - 100 GPM	3 HP - 100 GPM	1/2 HP - 20 GPM
1/4" slots comminutor	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.
Coal Tar Epoxy Lined				
Holding Tank	12,500 gal.	9,000 gal.	7,500 gal.	2,000 gal.
Aeration Blower	5 HP - 100 CFM	5 HP - 100 CFM	5 HP - 100 CFM	1 1/2 HP - 25 CFM
$FeCl_3$ Pump	1/4 HP - 20 GPM max.	1/4 HP - 20 GPM max.	1/4 HP - 20 GPM max.	1/4 HP - 20 GPM max.
$Ca(OH)_2$ System				
316 SS Volumetric Feeder	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr
Fiberglass Mix Tank	65 gal.	65 gal.	65 gal.	65 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Centrifugal Slurry Pump	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM
Preconditioning System				
Fiberglass Tank (2)	500 gal.	500 gal.	500 gal.	500 gal.
Variable Speed Mixer	1/3 HP	1/3 HP	1/3 HP	1/3 HP
Vacuum Filter	3'φ x 3' lg	3'φ x 3' lg	3'φ x 3' lg	3'φ x 3' lg
Feed Pump	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM
Vacuum Pump	10 HP	10 HP	10 HP	10 HP
Filtrate Pump	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Drum Drive	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Agitator Drive	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Sludge Conveyor	1 HP	1 HP	1 HP	1 HP
Filtrate Tanks (3)	750 gal.-fiberglass	750 gal.-fiberglass	750 gal.-fiberglass	750 gal.-fiberglass
Packed Bed Filter	1 @ 20" dia.	1 @ 20" dia.	1 @ 20" dia.	1 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI	1 HP 30 GPM @ 20 PSI
Activated Carbon Columns	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI
Air Compressor	10 HP	10 HP	10 HP	10 HP
Large Generator	60 KW	60 KW	60 KW	60 KW
Small Generator	10 KW	10 KW	10 KW	10 KW
<u>Optional</u>				
Diatomaceous Earth System				
Fiberglass Mix Tank	200 gal.	200 gal.	200 gal.	200 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Slurry Pump	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Incinerator	dry solids - 86 lbs/day	14 lbs/day	8 lbs/day	17 lbs/day
	carbon - 75 lbs/day	12 lbs/day	8 lbs/day	16 lbs/day

TABLE A4. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE 4

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Self Priming Diaphragm Pump (2)	3 HP - 100 GPM	3 HP - 100 GPM	3 HP - 100 GPM	1/2 HP - 20 GPM
1/4" slots comminutor	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.	1/3 HP - 140 GPM max.
Coal Tar Epoxy Lined Holding Tank	12,500 gal.	9,000 gal.	7,500 gal.	2,000 gal.
Aeration Blower	5 HP - 100 CFM	5 HP - 100 CFM	5 HP - 100 CFM	1 1/2 HP - 25 CFM
$Ca(OH)_2$ System				
316 SS Volumetric Feeder	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr
Fiberglass Mix Tank	65 gal.	65 gal.	65 gal.	65 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Centrifugal Slurry Pump	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM	1/2 HP - 2 GPM
Ultrafilter	100 ft^2 membrane area - 3 HP	30 ft^2 membrane area - 1 1/2 HP	30 ft^2 membrane area - 1 1/2 HP	30 ft^2 membrane area - 1 1/2 HP
Filtrate Tanks (2)	750 gal.-fiberglass	750 gal.-fiberglass	750 gal.-fiberglass	750 gal.-fiberglass
Activated Carbon Columns	6 @ 20" dia.	6 @ 20" dia.	6 @ 20" dia.	5 @ 20" dia.
Feed Pump	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI	1 HP 10 GPM @ 40 PSI
Backwash Pump	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI	1 HP 20 GPM @ 20 PSI
Air Compressor	10 HP	10 HP	10 HP	10 HP
Large Generator	50 KW	50 KW	50 KW	50 KW
Small Generator	10 KW	10 KW	10 KW	10 KW
Optional				
Polymer System				
Fiberglass Mix Tank	100 gal.	100 gal.	100 gal.	100 gal.
420 RPM Mixer	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Polymer Feed Pump	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.	1/4 HP - 20 GPH max.
Centrifuge	3,000 G's	3,000 G's	3,000 G's	3,000 G's
Feed Pump	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM	1/2 HP - 5 GPM
Main Drive	5 HP	5 HP	5 HP	5 HP
Back Drive	1 HP	1 HP	1 HP	1 HP
Sludge Conveyor	1 HP	1 HP	1 HP	1 HP
Centrate Tank	750 gal.-fiberglass	750 gal.-fiberglass	750 gal.-fiberglass	750 gal./fiberglass
pH Adjust Mixer	1/3 HP	1/3 HP	1/3 HP	1/3 HP

TABLE A5. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE 5

	Ft. Eustis
Self Priming Diaphragm Pump (2)	3 HP - 100 GPM
1/4" slots comminutor	1/3 HP - 140 GPM max.
Coal Tar Epoxy Lined	
Holding Tank	12,500 gal.
Aeration Blower	5 HP - 100 CFM
Bioreactor Tank	3,300 gal.
(Lined Mild Steel)	
Feed Pump	1/2 HP - 5 GPM
Aeration Blower	1 1/2 HP - 24 CFM
Ultrafilter	100 ft^2 membrane area 3 HP
$Ca(OH)_2$ System	
316 SS Volumetric Feeder	1/2 HP - 2.4 ft^3/hr
Fiberglass Mix Tank	65 gal.
420 RPM Mixer	1/2 HP
Centrifugal Slurry Pump	1/2 HP - 2 GPM
Compressor	10 HP
Large Generator	50 KW
Small Generator	10 KW
Optional	
Polymer System	
Fiberglass Mix Tank	100 gal.
420 RPM Mixer	1/2 HP
Polymer Feed Pump	1/4 HP - 20 GPH max.
Centrifuge	3,000 G's
Feed Pump	1/2 HP - 5 GPM
Main Drive	5 HP
Back Drive	1 HP
Sludge Conveyor	1 HP
Centrate Tank	750 gal.-fiberglass

TABLE A6. MANDATORY AND OPTIONAL EQUIPMENT REQUIREMENTS - ALTERNATE 6

	Ft. Eustis	Baltimore	Tacoma	Morehead City
Self Priming Diaphragm Pumps (2)	3 HP - 100 GPM	3 HP - 100 GPM	3 HP - 100 GPM	1/2 HP - 20 GPM
1/4" slot comminutor	1/3 HP - 140 GPM	1/3 HP - 140 GPM	1/3 HP - 140 GPM	1/3 HP - 140 GPM
Coal Tar Epoxy Lined Holding Tank	12,500 gal.	9,000 gal.	7,500 gal.	2,000 gal.
Aeration Blower	5 HP - 100 CFM	5 HP - 100 CFM	5 HP - 100 CFM	1 1/2 HP - 25 CFM
MSD	3 HP 2500 GPD	3 HP 500 GPD	3 HP 500 GPD	3 HP 500 GPD
$Ca(OH)_2$ System				
Volumetric Feeder	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr	1/2 HP - 2.4 ft^3/hr
Mix Tank	65 gal.	65 gal.	65 gal.	65 gal.
Mixer (420 rpm)	1/2 HP	1/2 HP	1/2 HP	1/2 HP
Slurry Pump	1/2 HP 2 GPM	1/2 HP 2 GPM	1/2 HP 2 GPM	1/2 HP 2 GPM
Sludge Conveyor	1 HP	1 HP	1 HP	1 HP
Air Compressor	10 HP	10 HP	10 HP	10 HP
Generator	30 KW	30 KW	30 KW	30 KW
<u>Optional</u>				
Incinerator	dry solids - 85 lbs/day	13 lbs/day	7 lbs/day	15 lbs/day

APPENDIX B

TABLE B1. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATE 1

		Fort Eustis	Balti- more	Tacoma	Morehead City
MANDATORY					
Long durables (15 yr)					
Holding tank		19,700	14,200	11,800	4,800
Filter press		36,000	36,000	36,000	36,000
	Total	55,700	50,200	47,800	40,800
Short durables (7½ yr)					
Feed pumps		12,200	12,200	12,200	4,600
Aeration equipment		4,700	4,000	3,400	2,300
$FeCl_3$ system		1,100	1,100	1,100	1,100
$Ca(OH)_2$ system		6,400	6,400	6,400	6,400
Sludge conveyor		2,500	2,500	2,500	2,500
Filtrate tanks (3)		6,000	6,000	6,000	6,000
pH control		3,300	3,300	3,300	3,300
Packed bed filter		10,500	10,500	10,500	10,500
Activated carbon col.		20,500	20,500	20,500	20,500
Disinfection equipment		1,500	1,500	1,500	1,500
Instrumentation		10,000	10,000	10,000	10,000
Compressor		3,500	3,500	3,500	3,500
Large generator		8,000	8,000	8,000	8,000
Small generator		2,000	2,000	2,000	2,000
	Total	92,200	91,500	90,900	82,200
OPTIONAL					
DE precoat (7½ yr)		3,200	3,200	3,200	3,200
Incinerator (15 yr)		150,000	150,000	150,000	150,000
15 yr amortization ($/yr)					
Mandatory		22,730	21,980	21,610	19,260
Mandatory + optional		40,220	39,380	39,100	36,750
$/1000 gal. (3785 liters)					
Mandatory		39.90	222.50	277.00	154.10
Mandatory + optional		70.60	398.60	501.30	294.50

TABLE B2. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 1.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY ($/yr)				
Labor (O&M)	41,600	25,000	25,000	25,000
Energy	6,550	4,840	4,840	1,740
Materials				
Virgin carbon	19,500	3,120	2,080	4,160
Chemicals				
$FeCl_3$	360	90	30	60
$Ca(OH)_2$	100	20	10	20
Cl_2	90	10	10	20
Equipment				
Filter cloths	300	150	150	150
Land disposal	300	50	30	60
Total yearly costs	68,800	33,280	32,150	32,210
$/1000 gal. (3785 liters)	120.80	336.84	412.20	250.10
OPTIONAL ($/yr)				
Labor (O&M)	41,600	25,000	25,000	25,000
Energy	6,650	4,860	4,860	1,760
Materials				
Virgin carbon	1,950	310	210	420
Chemicals				
$FeCl_3$	360	90	30	60
$Ca(OH)_2$	100	20	10	20
Cl_2	90	10	10	20
DE precoat	480	70	40	70
Equipment				
Filter cloths	300	150	150	150
Disposal				
Incinerator	3,000	1,500	1,500	1,500
Landfill	90	20	10	20
Total yearly costs	54,620	32,030	31,820	29,020
$/1000 gal. (3785 liters)	95.90	324.20	407.90	232.50

TABLE B3. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATE 2.

		Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY					
Long durables (15 yr)					
Holding tank		19,700	14,200	11,800	4,800
Centrifuge		37,000	37,000	37,000	37,000
	Total	56,700	51,200	48,800	41,800
Short durables (7½ yr)					
$Ca(OH)_2$ system		6,400	6,400	6,400	6,400
Feed pumps		12,200	12,200	12,200	4,600
Aeration		4,700	4,000	3,400	2,300
Polymer system		3,200	3,200	3,200	3,200
Sludge conveyor		2,000	2,000	2,000	2,000
Centrate tanks (3)		6,000	6,000	6,000	6,000
Packed bed fil.		10,500	10,500	10,500	10,500
Act. carbon system		20,500	20,500	20,500	20,500
Disinfection		1,500	1,500	1,500	1,500
Instrumentation		10,000	10,000	10,000	10,000
Compressor		3,500	3,500	3,500	3,500
Large generator		10,000	10,000	10,000	10,000
Small generator		2,000	2,000	2,000	2,000
	Total	92,500	85,400	84,800	76,100
OPTIONAL					
pH control (7½ yr)		3,300	3,300	3,300	3,300
Incinerator (15 yr)		150,000	150,000	150,000	150,000
15 yr. amortization ($/yr)					
Mandatory		22,900	21,010	20,630	18,290
Mandatory + optional		40,400	38,510	38,140	35,800
$/1000 gal. (3785 liters)					
Mandatory		40.20	212.70	264.50	146.60
Mandatory + optional		70.90	389.80	489.00	286.80

TABLE B4. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 2.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY ($/yr)				
Labor (O&M)	41,600	25,000	25,000	25,000
Energy	7,280	5,000	5,000	1,890
Materials				
Carbon	19,500	3,120	2,080	4,160
Chemicals				
Polymer	240	40	20	50
Cl_2	90	10	10	20
Land disposal	290	50	30	60
Total yearly costs	69,000	33,220	32,140	31,180
$/1000 gal. (3785 liters)	121.20	336.20	412.00	249.80
OPTIONAL				
Labor	41,600	25,000	25,000	25,000
Energy	7,340	5,010	5,010	1,900
Materials				
Carbon	1,950	310	210	420
Chemicals				
$Ca(OH)_2$	100	20	10	20
Polymer	240	40	20	50
Cl_2	90	10	10	20
Disposal				
Incinerator	3,000	1,500	1,500	1,500
Landfill	50	10	Neg.	10
Total yearly costs	54,370	31,900	31,760	28,920
$/1000 gal. (3785 liters)	95.50	322.90	407.20	231.70

TABLE B5. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATE 3.

		Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY					
Long durables (15 yr)					
Holding tank		19,700	14,200	11,800	4,800
Vacuum filter		30,500	30,500	30,500	30,500
	Total	50,200	44,700	42,300	35,300
Short durables (7½ yr)					
Feed pumps		12,200	12,200	12,200	6,400
Aeration		4,700	4,000	3,400	2,300
$FeCl_3$ system		1,100	1,100	1,100	1,100
$Ca(OH)_2$ system		6,400	6,400	6,400	6,400
Chem. tanks		7,300	7,300	7,300	7,300
Filtrate tanks (3)		6,000	6,000	6,000	6,000
Sludge conveyor		2,000	2,000	2,000	2,000
pH control		3,300	3,300	3,300	3,300
Packed bed filter		10,500	10,500	10,500	10,500
Act. carbon system		20,500	20,500	20,500	20,500
Disinfection		1,500	1,500	1,500	1,500
Instrumentation		10,000	10,000	10,000	10,000
Compressor		3,500	3,500	3,500	3,500
Large generator		10,000	10,000	10,000	10,000
Small generator		2,000	2,000	2,000	2,000
	Total	101,000	100,300	99,700	91,000
OPTIONAL					
DE precoat (7½ yr)		3,200	3,200	3,200	3,200
Incinerator (15 yr)		150,000	150,000	150,000	150,000
15 yr amortization ($/yr)					
Mandatory		23,680	22,930	22,560	20,210
Mandatory + optional		41,170	40,420	40,060	37,700
$/1000 gal. (3785 liters)					
Mandatory		41.60	232.10	289.20	161.90
Mandatory + optional		72.20	409.10	513.60	302.10

TABLE B6. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 3.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY				
Labor	41,600	25,000	25,000	25,000
Energy	8,840	5,280	5,280	2,200
Materials				
Carbon	19,500	3,120	2,080	4,080
Chemicals				
$FeCl_3$	360	90	30	60
$Ca(OH)_2$	100	20	10	20
Cl_2	90	10	10	20
Equipment				
Filter cloth	300	150	150	150
Land disposal	290	50	30	60
Total yearly costs	71,080	33,720	32,590	31,590
$/1000 gal. (3785 liters)	124.80	341.30	417.80	253.10
OPTIONAL				
Labor	41,600	25,000	25,000	25,000
Energy	8,940	5,300	5,300	2,220
Materials				
Carbon	1,950	310	210	410
DE precoat	480	70	40	70
Chemicals				
$FeCl_3$	360	90	30	60
$Ca(OH)_2$	100	20	10	20
Cl_2	90	10	10	20
Equipment				
Filter cloth	300	150	150	150
Disposal				
Incinerator	3,000	1,500	1,500	1,500
Landfill	60	10	Neg.	10
Total yearly costs	56,880	32,460	32,250	29,460
$/1000 gal. (3785 liters)	99.90	328.50	413.50	236.00

TABLE B7. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATE 4.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY				
Long durables (15 yr)				
Holding tank	19,700	14,200	14,200	4,800
Ultrafilter	30,000	15,000	15,000	15,000
Total	49,700	29,200	29,200	19,800
Short durables (7½ yr)				
Feed pumps	12,200	12,200	12,200	4,600
$Ca(OH)_2$ system	6,400	6,400	6,400	6,400
Act. carbon system	20,500	20,500	20,500	20,500
Filtrate tank (2)	4,000	4,000	4,000	4,000
Aeration	4,700	4,000	3,400	2,300
Compressor	3,500	3,500	3,500	3,500
Instrumentation	10,000	10,000	10,000	10,000
Sludge conveyor	2,000	2,000	2,000	2,000
Small generator	2,000	2,000	2,000	2,000
Generator	8,000	8,000	8,000	8,000
OPTIONAL				
Polymer system (7½ yr)	3,200	3,200	3,200	3,200
Sludge conveyor (7½ yr)	2,000	2,000	2,000	2,000
Disinfection (7½ yr)	1,500	1,500	1,500	1,500
Filtrate tank (7½ yr)	2,000	2,000	2,000	2,000
pH control (7½ yr)	3,300	3,300	3,300	3,300
Generator (7½ yr)	2,000	2,000	2,000	2,000
Centrifuge (15 yr)	37,000	37,000	37,000	37,000
15 yr amortization ($/yr)				
Mandatory	18,690	16,240	16,130	13,520
Mandatory + optional	25,350	22,920	22,810	20,210
$/1000 gal. (3785 liters)				
Mandatory	32.80	164.40	206.80	108.30
Mandatory + optional	44.50	232.00	292.40	161.90

TABLE B8. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 4.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY				
Labor	41,600	25,000	25,000	25,000
Energy	6,085	4,930	4,930	1,500
Materials				
Carbon	19,500	3,120	2,080	4,160
Chemicals				
Lime	100	20	10	20
Equipment				
UF tubes	500	150	150	150
Land disposal	290	50	30	60
Total yearly costs	68,075	33,270	32,200	30,890
$/1000 gal. (3785 gal.)	119.60	336.70	412.80	247.50
OPTIONAL				
Labor	41,600	25,000	25,000	25,000
Energy	7,800	5,270	5,270	1,840
Materials				
Carbon	19,500	3,120	2,080	4,160
Chemicals				
Polymer	240	40	20	50
Lime	100	20	10	20
Cl_2	90	10	10	20
Equipment				
UF tubes	500	150	150	150
Land disposal	290	50	30	60
Total yearly costs	70,120	33,660	32,570	31,300
$/1000 gal. (3785 liters)	123.10	340.70	417.60	250.80

TABLE B9. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATE 5.

		Fort Eustis
MANDATORY		
Long durables (15 yr)		
Holding tank		19,700
Ultrafilter		30,000
	Total	49,700
Short durables		
Feed pumps		12,200
Aeration		4,700
Bioreactor		9,600
Sludge conveyor		2,000
Sump		2,500
$Ca(OH)_2$ system		6,400
Compressor		3,500
Instrumentation		10,000
Small generator		2,000
Large generator		8,000
	Total	60,900
OPTIONAL		
Sludge conveyor (7½ yr)		2,000
Disinfection (7½ yr)		1,500
Polymer system (7½ yr)		3,200
Filtrate tank (7½ yr)		2,000
Centrifuge (15 yr)		37,000
15 yr amortization ($/yr)		
Mandatory		16,470
Mandatory + optional		22,200
$/1000 gal. (3785 liters)		
Mandatory		28.90
Mandatory + optional		39.00

TABLE B10. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 5.

	Fort Eustis
MANDATORY	
Labor	41,600
Energy	6,940
Chemicals	
Lime	100
Equipment	
UF tubes	500
Land disposal	160
Total yearly costs	49,300
$/1000 gal. (3785 liters)	86.58
OPTIONAL	
Labor	41,600
Energy	8,340
Chemicals	
Lime	100
Polymer	240
Cl_2	90
Equipment	
UF tubes	500
Land disposal	160
Total yearly costs	51,030
$/1000 gal. (3785 liters)	89.60

TABLE B11. MANDATORY AND OPTIONAL CAPITAL COSTS - ALTERNATIVE 6.

		Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY					
Long durables (15 yr)					
Holding tank		19,700	14,200	11,800	4,800
MSD		20,000	10,000	10,000	10,000
	Total	39,700	24,200	21,800	14,800
Short durables (7½ yr)					
$Ca(OH)_2$ system		6,400	6,400	6,400	6,400
Aeration		4,700	4,000	3,400	2,300
Feed pumps		12,200	12,200	12,200	4,600
Pumps		3,500	3,500	3,500	3,500
Sludge conveyor		2,000	2,000	2,000	2,000
Chemical system		1,500	1,500	1,500	1,500
Instrumentation		5,000	5,000	5,000	5,000
Compressor		3,500	3,500	3,500	3,500
Generator		6,000	6,000	6,000	6,000
	Total	44,800	44,100	43,500	34,800
OPTIONAL					
Incinerator (15 yr)		150,000	150,000	150,000	150,000
15 yr amortization ($/yr)					
Mandatory		12,470	10,600	10,220	7,880
Mandatory + optional		29,390	27,520	27,140	24,800
$/1000 gal. (3785 liters)					
Mandatory		21.90	107.30	131.00	63.10
Mandatory + optional		51.60	278.50	347.90	198.70

TABLE B12. MANDATORY AND OPTIONAL O&M COSTS - ALTERNATE 6.

	Fort Eustis	Balti-more	Tacoma	Morehead City
MANDATORY				
Labor	25,000	25,000	25,000	25,000
Energy	5,860	5,500	5,500	2,200
Chemicals				
Lime	100	20	20	10
Land disposal	110	20	10	20
Total yearly cost	31,070	30,540	30,530	27,230
$/1000 gal. (3785 liters)	54.60	309.10	391.40	218.20
OPTIONAL				
Labor	25,000	25,000	25,000	25,000
Energy	5,860	5,500	5,500	2,200
Disposal				
Land	30	Neg.	Neg.	Neg.
Incinerator	3,000	3,000	3,000	3,000
Total yearly cost	33,890	33,500	33,500	30,200
$/1000 gal. (3785 liters)	59.50	339.10	429.50	242.00

GLOSSARY

ACP - Anaerobic contact process.

Aerobic - In the presence of oxygen.

Anaerobic - In an oxygen free environment.

BOD - Biochemical oxygen demand.

Bioassay - Determination of pollutant load and toxicity through the use of living organisms.

Bio-oxidation - Oxidation of organic material through biological means.

Blackwater - Watercraft waste consisting strictly of human wastes (feces and urine).

C - Centrifugation

CHT - Conveyance, holding and transfer system.

COD - Chemical oxygen demand.

Carriage fluid - also Diluent - Fluid used to transport waste in sanitary system.

Centrate - Centrifuge effluent.

Comminutor - Device used to chop waste into small particles.

DE - Diatomaceous earth.

Diluent - See carriage fluid.

EPA - Environmental Protection Agency.

F/M - Food to microorganism ratio in biological system.

FP - Filter press.

FWPCA - Federal Water Pollution Control Act

Fecal coliforms - Non-pathogenic indicator bacteria used to measure microbial pollution of animal or human origin.

Filtrate - Effluent from filtering process.

Flux - Flow per unit area in filter or membrane process.

Greywater - Watercraft waste consisting of two or more of the following; galley, shower, or laundry waste.

HRT - Hydraulic retention time.

IMCO - Inter-Governmental Maritime Consultative Organization.

MLSS - Mixed liquor suspended solids.

MSD - Marine sanitation device.

MSF - Moving screen filtration.

Macerator - Device used to chop waste into small particles.

Mixed liquor - Living substrate present in suspended growth biological system.

NPDES - National Pollutant Discharge Elimination System.

O&M - Operation and maintenance.

POTW - Publicly owned treatment works.

Permeate - Effluent from a membrane process.

Point source - Term used to define discharge limitations as set by the EPA.

RBC - Rotating biological contactor.

Residues - Solids generated by treatment processes.

SS - Suspended solids.

TSS - Total suspended solids.

USCG - U.S. Coast Guard

VF - Vacuum filter.

Vessel - Term used to define discharge limitations as set by the USCG.