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DISPOSAL OF VESSEL WASTES:

Shipboard and Shoreside Facilities

PHASE TWO: GRAYWATER

July 1979

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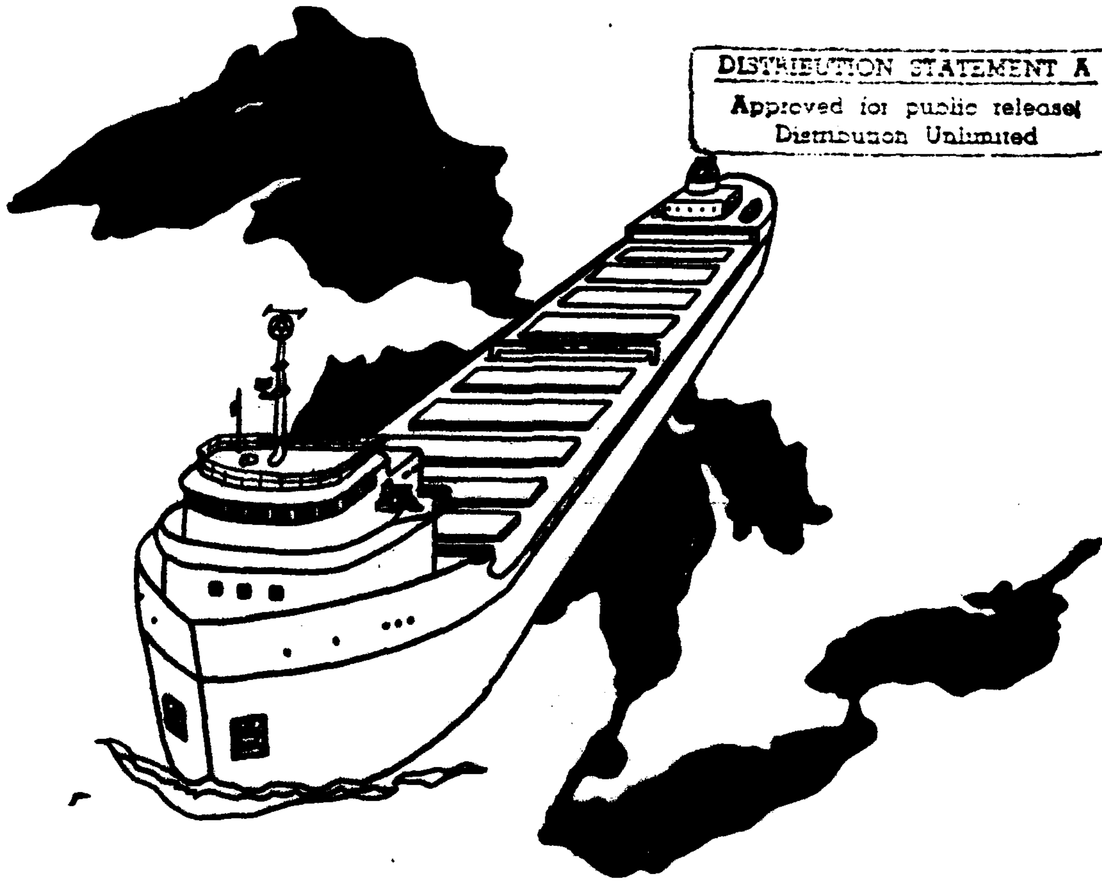

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This report deals specifically with liquid wastes known as graywater which is also generated aboard vessels. The term "graywater" refers to the domestic wastewaters collected from galley, laundry and shower sinks, and other miscellaneous shipboard sources.

This report has two main objectives: First, to define and document present graywater treatment and disposal methods and, second, to define and assess the effects of an extended navigation season information as baseline data. In order to meet these objectives, the study was organized into five major topics: 1) characterization of graywater waste, 2) evaluation of shipboard waste treatment units, 3) environmental assessment of graywater treatment on the Great Lakes, 4) evaluation of shoreside waste disposal ficilities, and 5) technical and economic assessment of graywater treatment and retention. Keywords;)

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22b. TELEPHONE *(Include Area Code)*
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The study documents present graywater treatment and disposal practices, and evaluates the effects of an extended shipping season on treatment methods, disposal practices and the Great Lakes. "Graywater" refers to wastewater collected from galley, laundry, shower and sinks. The study: (1) characterizes graywater wastes, (2) evaluates shipboard wastewater treatment devices (MSDs), (3) assesses environmental effects of graywater treatment on the Great Lakes, (4) evaluates shoreside disposal facilities and (5) assesses the economic and technical impacts of graywater treatment and retention. The findings of the study are: (1) the composition and generation of graywater exhibit extreme hourly variations, (2) MSDs will not be affected by winter, (3) MSDs can treat graywater to reasonable levels and to secondary treatment standards under optimum operating conditions, (4) the retention of combined black and graywater is not feasible because the amount of space required for a holding tank affects a vessel's trim and draft, and the high cost of installation, (5) the eutrophication of the Great Lakes during a normal or winter navigation season will not be accelerated if graywater is treated prior to discharge, (6) the coasts, harbors, and ice-covered waters present the greatest concern for the discharge of vessel graywater.

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DISPOSAL OF VESSEL WASTES:

Shipboard and Shoreside Facilities

PHASE TWO: GRAYWATER

Prepared by:

A.N. Titcomb
C.B. Bartley

ENVIRONMENTAL RESEARCH GROUP, INC.
Ann Arbor, Michigan
May, 1979

U.S. DEPARTMENT OF COMMERCE
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PREFACE

This report is the product of a study concerned with the disposal of graywater wastes generated by commercial vessels during an extended navigation season. The study was part of an overall study of the feasibility of an extended navigation season for the Great Lakes. The authors would like to extend their gratitude to the clerical staff for the many hours they spent in typing this report. Special thanks are also extended to all of the marine sanitation device manufacturers and government personnel who cooperated with us on our survey.

EXECUTIVE SUMMARY

INTRODUCTION

Concern for the effects of winter navigation on the Great Lakes and on vessel graywater disposal prompted the study resulting in this report. The study was conducted by the Environmental Research Group, Inc. for the U.S. Army Corps of Engineers, Winter Navigation Board. Two main objectives have been addressed by this report: first, to define and document present graywater treatment methods and disposal practices; and second, to evaluate and assess the effects of an extended navigation season on the treatment methods, disposal practices and the environment. The term "graywater" refers to wastewaters collected from galley, laundry, shower, sinks and other miscellaneous drains.

In order to meet the objectives previously stated, the study was organized into five major areas: 1) characterization of graywater wastes, 2) evaluation of shipboard waste treatment devices, 3) environmental assessment of graywater treatment on the Great Lakes, 4) evaluation of shoreside waste disposal facilities, and 5) technical and economic assessment of graywater treatment and retention. The first topic deals with the characterization of graywater wastes by water production and quality for various sources, e.g., laundry, galley and shower wastewaters. Shipboard marine sanitation devices (MSDs) were evaluated for feasibility of graywater treatment and for the effects of winter weather on performance. The environmental assessment evaluated the impacts of treated and untreated graywater on the Great Lakes for a projected extended season. Shoreside facilities were evaluated for their limitations in respect to receiving graywater, especially during an extended navigation season. Retention and other no-discharge techniques were evaluated for economic and technical impacts on shipping.

METHODS

Data on graywater regulations, characterization, treatment, disposal and impact were gathered by two principal methods: (1) by surveying agencies, groups and individuals involved with graywater treatment and disposal issues, and (2) by researching newly published literature. The major groups contacted for the graywater survey were marine sanitation device (MSD) manufacturers and government agencies, e.g. U.S. Coast Guard, U.S. Corps of Engineers. Other groups, such as port authorities, dock operators, and shipyards, were contacted where data gaps on graywater issues became apparent.

The major groups contacted provided information necessary to determine: 1) graywater legislation and regulations, 2) graywater treatment processes and cold weather problems and 3) effluent quality and costs of specific MSD units. The researching of old and newly published literature involved a computer search by the Maritime Research Information Service. Also, abstracts from the National Technical Information Service were reviewed for newly published government technical reports. Other sources of literature came from the libraries of the University of Michigan and the Great Lakes Basin Commission.

CHARACTERIZATION AND REGULATIONS OF GRAYWATER

Graywater, the subject of this report, is one of several forms of liquid waste which are produced by vessels on the Great Lakes. The term graywater commonly refers to domestic wastewaters generated aboard ship. Domestic wastewaters are usually considered those from galleys, laundries, showers, sinks and lavatories and miscellaneous small sources such as drains and drinking fountains located throughout the ship.

The amount of graywater generated varies considerably from vessel to vessel. The flow rate of combined blackwater and graywater ranges from 80 to 185 gallons per capita per day for Great Lakes vessels. This flow rate includes the 30 gpcd of blackwater because in the event of graywater regulations both black and graywater will probably be combined for the purpose of treatment of retention. The average daily flow rate figure most accepted by shipboard sources and manufacturers of marine sanitation devices is 100 gpcd. Flow rates also vary markedly from hour to hour with surges of flow two to four times the normal flow. These surges last for as long as an hour, and occur regularly.

The pollution potential of combined blackwater and graywater is indicated by several wastewater parameters, biochemical oxygen demand (BOD), coliform bacteria, and suspended solids (SS) being the major ones. On the basis of several testing programs it appears that combined blackwater and graywater contains average concentrations of 550 mg/l BOD_5, 450 mg/l suspended solids, and 10 to 20 mg/l total phosphorus. Wastewater parameters can vary widely when graywater is included because its content can change considerably. At one hour of the day, shower and sanitary waste may be the predominant contributors while at another hour the flow could largely consist of galley wastewaters. In general, the most significant pollution potential of graywater results from galley and laundry waste. Wash and rinse waters usually contain only minor amounts of contaminants.

Although blackwater regulation has established standards and a compliance timetable, there are currently no regulations pertaining to graywater unless it is included in the same wastestream as blackwater. In this case, effluent must meet the present blackwater standards. The Clean Water Act of 1977 (P.L. 95-217) has, however, given public notice that at some time in the future the term "sewage" will be redefined, for Great Lakes vessels only, to include graywater. Graywater is defined by this act to mean "galley, bath and shower water." The notable exclusion allowed by this definition is laundry waste. Also, due to the forthcoming redefinition of the term "sewage" with respect to the Great Lakes, any "no-discharge" status granted by the U.S. EPA would prohibit graywater disposal.

In addition to the inclusion of graywater in the regulations, P.L. 95-217 also stated the intention that:

> "the administrator [of the EPA] shall, with respect to commercial vessels on the Great Lakes, establish standards that will require at a minimum the equivalent of secondary treatment...."

This means that all current minimum effluent standards for the disposal of sewage would be made equivalent to at least that of shoreside secondary treatment, a stricter effluent standard.

EVALUATION OF SHIPBOARD TREATMENT DEVICES

This section is concerned with the shipboard treatment of combined black/graywater wastes by marine sanitation devices (MSDs). These devices include any equipment designed to collect and adequately dispose of sewage generated aboard ship. Information was obtained primarily from surveys of ship operators and manufacturers of MSDs. The information on MSDs was then characterized according to its U.S. Coast Guard Type designation and the principal process involved in its operation.

At the time of the survey of ship operators (summer of 1978), a large percentage of the vessels operating on the Great Lakes discharged all graywater directly overboard without treatment or collection of any kind. It was noted that for most vessels in the planning or initial construction stages, some type of treatment was planned in anticipation of future graywater legislation.

All MSDs are designed to accept a certain hydraulic load, usually expressed in gallons per day. When this load is exceeded, unit operations are taxed and treatment levels suffer considerably. Therefore, MSDs which are designed to accept the load from blackwater alone cannot adequately process the excessive amount of wastes due to the addition of graywater to the waste stream.

However, larger capacity units which do possess the capacity to handle both blackwater and graywater hydraulic loadings are available. These MSDs utilize several different processes to accomplish their task and meet different levels of treatment (Type I, II, III) as defined by the U.S. EPA and certified by the U.S. Coast Guard (USCG).

Type I MSDs, which macerate and chlorinate vessel waste, can physically accept the increased hydraulic flow due to graywater; however, the level of treatment administered is extremely minimal. Treatment is accomplished by heavy chlorination only and does not have the potential to produce treatment equivalent to secondary treatment as stipulated by P.L. 95-217. New installation of a Type I MSD will be prohibited for all vessels after January 30, 1980.

Like Type I units, Type II units are also flow-through systems, meaning an overboard effluent would be discharged to the receiving waters. These units consist of two main varieties, physical/chemical and biological. Both of these types of MSDs, when of sufficient design capacity, can accept a combined blackwater and graywater influent. All units surveyed were also designed to take into account daily surges of at least twice normal flow. Surges are considerable increases in graywater generation lasting an hour or more and are typically characteristic of combined black and graywater.

Grease, oils, fats and the content of the influent waste may pose a problem to these marine sanitation devices. Quantities of grease, oils, and fats are found in galley and laundry waste and, once inside an MSD, they tend to coat surfaces with which they come in contact. This results in clogged filters, screens, nozzles, etc., as well as buildup in piping. Grease traps, commonly found in drainage lines from the galley, are designed to remove grease, but maintenance of these devices is often neglected. Grease and oil in laundry waste, although less prevalent than that associated with galley waste, can also cause problems.

Some biological MSDs may incur problems due to the content of waste. The microorganisms which decompose the organic matter in wastewaters are most productive when provided a constant flow of consistent composition. If either influent characteristics vary too abruptly or radically, or certain toxic chemicals find their way into the waste stream, the growth of microorganisms can be adversely affected. Efficiency of the unit may decrease until the microorganism populations can adjust. If the "shock" is strong enough to kill the entire culture, it may take several weeks for the MSD to reach full efficiency again.

Based on the data received from manufacturers of these MSDs, it appears that black/graywater influent can be treated fairly consistently to Type II standards. However, units which are presently available (either biological or physical/chemical) do not appear to be able to produce an effluent of a quality equivalent to shoreside secondary treatment, except under optimum and test conditions.

Type III MSDs must meet a no-discharge standard which requires that no overboard discharge is allowed regardless of its quality. The two main varieties of Type III systems are incineration units and retention systems. Incineration units include any MSD which uses heat to burn or evaporate waste. Most incineration units, as reported, are not of sufficient capacity to accept the daily hydraulic load of both blackwater and graywater generated aboard ship. And, in general, the energy consumption of these typically high energy users is proportional to the amount of waste accepted. Therefore, even if units were of sufficient capacity to accept the addition of graywater, the cost of energy use would be excessive.

Retention systems merely hold wastewater for later discharge at a shoreside waste disposal facility. Two main types, based on the type of flush used, are available to Great Lakes' ship operators. The first, a low volume flush retention system, is designed to use a minimum amount of flushwater and to reduce the amount of blackwater waste to be retained. Most such systems, however, offer no advantages in the collection of graywater. The only exception reported was a system which recycled graywater for reuse as flush water. Manufacturers of low-volume systems in general report that graywater can be accepted but that it is not recommended because the holding tank would have to be of larger capacity. The second type, a standard flush retention system, is fabricated by shipyards, and may be designed to hold any amount of water. Section 5.0 of this report specifically discusses the feasibility of such retention systems.

Public Law 95-217 specifically excludes laundry waste in its definition of graywater. Laundry waste is commonly considered one of the domestic wastewaters which makes up graywater and is reported to have, for graywater, relatively high levels of contaminants. All responses to the survey by manufacturers of MSDs indicate that MSDs are designed to treat laundry waste as well as other sources of graywater or blackwater. Most ship operators who treat graywater now report the inclusion of laundry waste to their MSD,

The cold weather experienced during a winter navigation season was not reported as a major problem. The MSDs are usually located in or near the machinery spaces, which are usually warm. In the case of exposure to cold temperatures, immersion heaters would be employed to prevent problems. Without these precautions, some biological units may experience slower reaction times and thus reduced treatment efficiency. In general, the effects of winter weather on MSDs may be considered minimal and avoidable by the use of immersion heaters or similar devices.

ENVIRONMENTAL ASSESSMENT

The objective of this assessment is to determine the effects of discharging treated combined black and graywater during an extended navigation season on the Great Lakes. The major sources of potential impact to the environment from the discharge of treated combined wastewaters are: phosphorus from laundry wastes, BOD_5 load from galley wastewaters, and solids from garbage disposals. Disinfection of wastewaters with chlorine effectively removes coliform bacteria from the effluent. With excessive dosing of chlorine, however, residual chlorine and chloro-organics may be formed in the treated effluent.

Total phosphorus increases may result in increased productivity of algal biomass and, thus, the eutrophication of lakes. An increase in suspended solids may result in increased turbidity, interference with filter feeding organisms and decreased phytoplankton productivity and aesthetics. An increase in biochemical oxygen demanding substances may result in reduced levels of dissolved oxygen, which is essential to most aquatic organisms (exceptions are the anaerobes and tolerant species).

The effects of residual chlorine and chloro-organics (COs) are not affected by levels of treatment. Rather, their formation, concentrations, and effects are determined by the amount of chlorine used to disinfect sewage and the time in contact with organics. The increase in hydraulic loading of graywater may then increase CO and residual chlorine loading by a factor of 2-3 (2,000 gallons per day for graywater vs. 900 gpd for blackwater). However, the loadings of these pollutants are considered minor in comparison to municipal waste treatment plant loadings (millions of gallons per day). Also, the long-term effects are nearly impossible to quantify until more studies by public health and environmental agencies are completed. For these two reasons, disinfectant by-products were not considered in detail for graywater treatment (also see the blackwater report for more detail).

In order to assess the impact of treated combined wastewaters on the Great Lakes by commercial vessels, it was necessary to summarize the treatment performance for all of the Type II flow-through MSDs. No-discharge (USCG Type III) MSDs were not considered because their discharge is not directly to the receiving waters but usually to shore-based facilities. At these facilities, the shipboard wastes would undergo secondary treatment. Type I MSDs, macerator-disinfectors, were not deemed adequate to meet secondary treatment standards and thus were also excluded from this study.

Different treatment cases, or scenarios, were depicted in order to evaluate impacts associated with graywater treatment. In the first case (case #1), all types of graywater are assumed to be combined with blackwater and treated. The second case (case #2) is the same as the first except laundry wastes will not be treated. This case represents a strict formulation per P.L. 95-217, Section 59. The final case (case #3) represents the present situation in which graywater is discharged untreated and blackwater is treated with USCG Type II MSDs.

The annual load of a given pollutant discharged by commercial vessels into each of the Great Lakes was estimated by using an equation which involves the number of vessels annually traversing the lake, the crew size, the portion of the year a vessel is traversing the lake and the per capita annual loading of the given pollutant.

The number of vessels annually trafficking the Great Lakes (N) was obtained by converting reported annual traffic tonnage transported on the Great Lakes to a number of vessels by using a conversion factor of 18,511 long tons per vessel (supplied by the Maritime Administration). A more accurate count of the annual number of vessels per lake would have been desirable; however, such data are currently unavailable. When conversion factors were applied to the data on tonnages per lake, the average number of vessels annually trafficking each of the Great Lakes was obtained. The additional traffic that would result from an extended season was calculated by using a 4.94% increase in normal traffic. For more detail and specific references, see section 3.0 of the main report.

For study purposes, the number of men per vessel (S) was estimated to be 32. This number is the most common value reported by ship operators in response to ERG's survey. The portion of time any given vessel is trafficking each of the Great Lakes was estimated at a maximum by considering the average speed of a vessel and the longest round trip distance a vessel would traverse while passing through each of the Great Lakes.

The approach used to analyze the effects of treated combined wastewaters (case #1), of treated combined wastewaters without treated laundry wastes (case #2), and of untreated graywater on the Great Lakes ecosystem was to examine short- and long-term impacts from loadings. Short-term effects were estimated from the impacts of daily loading per vessel on harbors, coasts and offshore waters during winter and ice-free seasons. Long-term effects were estimated from the impacts of annual loadings of vessels to harbors, coasts and offshore waters of the Great Lakes during extended and normal navigation seasons.

Short-term impacts were defined as the effects of a daily loading from a vessel on receiving waters. Offshore and coastal waters would be least affected by the daily loading of treated black/graywater from vessels, and harbors would be the most negatively affected. These results are based upon the relative differences in mixing and dispersion properties of the respective receiving waters (e.g., mixing is more intense offshore than in harbors) and upon the amount of time a vessel would discharge in the receiving waters (e.g., 1 day in the harbor while at port, and less than a few hours in coastal waters while steaming from port to the open lake and vice versa). The short-term impacts anticipated from daily loadings of vessels during an ice-free period include a reduction of the DO of the surface waters and an increase in turbidity within the area of discharge from a vessel. The mixing induced by the vessel's motion will reduce the impacts. This is especially important in coastal waters.

The short-term impacts associated with daily loadings during ice-cover periods are similar to those experienced during ice-free periods. Ice-cover effectively reduces the intensity of wind-induced mixing and thus allows accumulation of pollutants. Daily loadings from vessels during ice-cover periods may impact sensitive coastal environments and harbors due to the reduced rates of dilution. Pollutants would accumulate until ice thawing and mixing commences, approximately 2-4 months depending upon the severity of ice-cover and climate. However, the impacts will be lessened due to the cold temperatures of the receiving waters which tend to reduce rates of biological activity (e.g. degradation).

Long-term impacts are assessed from annual loadings information. On an annual basis, the loadings of pollutants to harbors from vessels are found to range from 0.1% to 0.8% of the total annual loadings to harbors. As the worst case, loadings of TP, SS and BOD_5 from vessels comprise a small fraction (<1%) of the total annual load from other sources. The long-term impacts are considered minor with respect to the impacts from other sources for both the existing (normal) navigation season and the projected extended season.

The long-term impacts of vessel loadings during normal and extended navigation seasons on coastal environments are evaluated to be minor because: (1) vessels generally spend only a small fraction of time in the coastal zone on their way to and from port; 2) it would take 10,000 vessels per year passing through the coastal zone to increase levels of nutrients to analytically detectable levels; and 3) the longshore and littoral currents increase the mixing and dispersal properties of the receiving waters.

Under worst case conditions, annual loadings of TP, SS and BOD from vessels during a normal navigation season ranged from: 7,900 kg to 2,700 kg of TP; from 105,900 kg to 36,500 kg of BOD_5 substances; and from 81,800 to 28,200 kg of SS into the Great Lakes. For example these loadings comprise a small fraction (0.1%-0.2% for TP; 0.03%-0.20% for BOD_5 ; 0.003%-0.6% for SS) of the total annual loadings of TP, BOD_5 and SS from other sources: 7,900 kg of TP from vessels vs. 3,711,900 kg of TP from other sources (the sum of loadings from atmospheric, industrial, and non-point sources) into Lake Huron.

The effects of annual vessel loadings during a normal navigational season are an increase in concentrations of TP, SS and BOD_5 in the receiving waters and an increase in the annual areal loading rates of TP which could accelerate eutrophication of the Great Lakes. Increases in concentrations range from 0.47 nanograms per liter (ng/l) to 15.18 ng/l of TP, from 6.26 ng/l to 266.81 ng/l of BOD_5, and from 4.84 ng/l to 206.20 ng/l of SS into the Great Lakes. These increases are undetectable by present analytical methods (0.01 mg/l) and result in minor impacts. The annual loading of TP from vessels also results in minor increases in the areal loading rate of TP. This increase to the Great Lakes would not accelerate the eutrophication of the lakes.

With an extended navigation season, annual loadings from vessels will increase by 23-24% in respect to the normal navigation season loadings. However, this increase in annual loading would: (1) still comprise a small fraction (0.1%-0.3% for TP, 0.003%-0.26% for BOD_5, 0.003%-0.08% for SS) of the total annual loadings of TP, BOD_5 and SS from other sources (e.g., 10,200 kg TP from vessels vs. 3,714,200 kg TP from other sources into Lake Huron); (2) increase the concentrations of TP, BOD_5 and SS to levels in the nanogram per liter range; and (3) not accelerate the eutrophication of the Great Lakes.

SHORESIDE FACILITIES EVALUATION

Any vessel which elects to hold black and graywater, instead of treating it onboard and discharging it to the lake, requires some type of shoreside wastewater receiving facility which will accept the retained waste. Also, should any state gain no-discharge status for its Great Lakes' waters, this type of facility will be required.

Three kinds of black and graywater disposal facilities are currently available at U.S. ports on the Great Lakes; however, not all kinds are available in each port. The three facilities are discharge risers, tank trucks and waste collection vessels.

Tank trucks, the most widely available of the three, do not appear to offer an adequate means of disposing of retained black and graywater due to their limited capacity: 1,500-2,000 gallons. The volume of combined black and graywater which would be retained aboard a ship ranges from 30,000-40,000 gallons. A number of trips by a single truck or many trucks would be required to pump out a 30,000 gallon holding tank. On the other hand, both discharge risers and waste collection vessels, e.g., barges, offer the capacity necessary to accept the retained black and graywater volume from a single vessel. Neither of these are widespread at Great Lakes ports and those that are available receive little or no use. The one notable exception to this lack of use is that of discharge risers owned and operated by fixed-base shipping operations. Company fleet vessels can discharge retained black and graywater each time they return to their regular home dock. No direct cost is incurred by the vessel.

Almost all waste from these sources receives ultimate treatment at a municipal wastewater treatment plant. Presently the volume of vessel waste going to these plants is barely discernible by plant operators. If this volume should increase, treatment plants would be able to accept any increases without complications. Though almost all the wastewater treatment plants have reached or are nearing their capacity, most are in the process of expansion or separating sanitary and storm drainage in order to increase capacity. Vessel waste does not play a major role in this problem and probably will not in the future, unless use of shoreside discharge by commercial vessels increases significantly.

Because the process of transferring black and graywater from a vessel's holding tank to a shoreside receiving facility is an outdoor operation, it is affected by the winter weather associated with an extended navigation season. Basically, these impacts involve locating facilities under cover of snow and the freezing of fittings, valves, lines, etc. These impacts are remedied by use of shovels, ice chisels and perhaps heating torches. Also, it should be noted that many vessels utilizing holding tanks for waste are already operating successfully under winter conditions. Vessel operators are contantly running later in the fall and earlier in the spring or even running year-round, thereby encountering winter conditions, and are experiencing no insurmountable problems.

ECONOMIC AND TECHNICAL EVALUATION OF GRAYWATER TREATMENT

The Clean Water Act of 1977 (P.L. 95-217) has given public notice that graywater in addition to blackwater will require treatment or retention in the future. Pursuant to this Act, the U.S. EPA will promulgate regulations defining the degree or kind of treatment required. A majority of ships on the Great Lakes today, however, possess only the capability to treat or retain blackwater wastes. Requiring treatment or retention of graywater will have an impact on both new and existing vessels.

Existing vessels will require repiping of graywater drains. Once this is accomplished, the owner of an older vessel will face one of three options to assure compliance. These are:

(1) Upgrade, if possible, the existing blackwater MSD to accept a larger hydraulic load.

(2) Replace the existing blackwater MSD with a larger unit able to handle both black and graywater.

(3) Purchase and install an additional MSD to handle the excess hydraulic flow of graywater.

Of these three options, the first is expected to prove most attractive to ship operators. This option involves the least amount of reinvestment and least affects the vessel. Both remaining options require more extensive expenditure; however, they should receive consideration if the existing blackwater unit cannot be upgraded. Determination of the best means of compliance should be based on the characteristics of the individual ship and the particular MSD currently installed.

Although the major impact of a graywater treatment requirement would fall on existing vessels able to handle blackwater flow only, vessels under new construction are also affected, but to a lesser degree. Integration of graywater drainage lines with those of blackwater during initial design and construction stages will prove less expensive than repiping drains aboard an older ship. The major economic impact will be the investment required to purchase and install a unit of large enough capacity to handle both black and graywater. In general, the larger units cost approximately twice the amount required for a blackwater only unit, or $14,000-$35,000 for biological units and $15,000-$50,000 for physical/chemical units.

Operational costs of some of the larger capacity units are greater than those of blackwater MSDs. Biological units reportedly experience increases of up to twice the $200-$800 annual costs for blackwater treatment. Physical/chemical cost increases would be slight due to the fact that many of these MSDs are designed to treat combined black/graywater or blackwater only waste streams. Most of the black/graywater units are physically larger than blackwater units. The amount of space required varies depending on the manufacturer.

Although not supported by cost data, it is reasonable to assume that the installation of the larger capacity MSD unit would result in greater expense than a smaller unit; however, the magnitude of this increase is not known. Since installation cost varies so widely depending on the individual vessel, comparison of cost data was not possible.

The other alternative in meeting graywater regulations, in addition to treatment, is retention. Retention systems, or holding tanks, are of two types, distinguished by their flush rate; these are low volume flush systems and standard flush systems.

Low-volume flush systems are capable of reducing, by various methods, e.g., vacuum collection or recycling, the amount of blackwater to be held but do not offer any such advantages in accepting graywater.

The principal characteristics for standard flush tanks capable of holding both blackwater and graywater generated onboard ship are developed for a typical vessel: Tank size based on 100 gpcd combined waste generation, 10 days retention time plus a 50% contingency margin is 48,000 gallons with a maximum weight (wet) of 202 long tons.

Maximum effect on trim results when the center of gravity of the holding tank is at its greatest distance from the longitudinal center of flotation, LCF, of the vessel. On a 580-ft bulk carrier, which typifies the older vessels operating today, adding a weight of 202 long tons at the aft perpendicular 293 ft from the LCF causes a change in draft forward and aft of approximately 3-1/2 ft. This represents a maximum or near maximum case. A holding tank may be located closer to the LCF, resulting in less effect.

The change in draft of a vessel due to added weight is determined by its tons per inch immersion factor, TPI. TPI is defined as the weight addition required, as the ship is floating at a certain waterline, to cause a parallel sinkage of one inch. A typical 580-ft bulk carrier may have a TPI factor of about 78.4. Using the value of TPI and assuming negligible heel and trim, this bulk carrier would experience an increase in draft of 2.58 inches due to the 202 long ton holding tank. If the center of gravity coincides with the LCF of the vessel, then this is the total extent of vessel impact. No increase in trim would result. In most instances this is not true and the change in draft and the change in trim would be additive.

A 3-1/2 ft change in trim and draft could have detrimental effects on the operating condition of vessels, especially older vessels, on the Great Lakes. In our example, the change in draft was less than 3 inches. The remainder is the maximum possible change in trim. By choosing a location as close to the vessel's LCF as possible, change in trim could be reduced considerably.

Whenever a tank containing a liquid substance is placed onboard a ship, its effect on stability should be assessed. Unless the tank is completely full or empty, the free movement of liquid within the tank can have an effect on the metacentric height of the vessel. This effect, termed free surface effect, results from a shift in the center of gravity which occurs when the tank is inclined. The metacentric height, or GM, is an indication of the initial stability of the ship.

Assuming holding tank size to be 30 ft x 18 ft x 12 ft and box-shaped, the maximum decrease in GM for a 650 ft-long ore carrier is 0.012 ft or a 0.078% decrease in initial stability. This is based on an initial GM of 15.25 ft. Should this tank be installed on a larger vessel such as the modern "1,000-footers," the decrease in GM is even less.

This calculation is for a standard, box-shaped holding tank with no special provisions. Measures are available to effectively reduce the free surface effect of a tank if necessitated. These include adding partial vertical partitioning plates and installing a holding tank with its longest dimension vertical. Both these measures would reduce the free surface area of the liquid within the tank and therefore its effect on initial vessel stability. In most cases, it appears safe to assume that the addition of a black/graywater holding tank will not significantly affect the initial stability of a Great Lakes vessel.

The installation of holding tanks would prove more difficult and have greater impact on older vessels than new ships. Finding usable space sufficient for a holding tank aboard an older vessel can be a major problem. Newer vessels generally have more space available.

A holding tank of 48,000 gallons capacity is very large and could tax the available usable space aboard Great Lakes vessels. While some vessels could retain black/graywater waste in a tank this large, it would not be reasonable to expect or require all Great Lakes' ships to comply with this type of wastewater disposal regulation for for the following reasons: (1) the difficulty of finding usable space aboard a vessel, (2) the effects of a tank on a vessel's trim and draft, (3) the lost revenue associated with space utilized for the holding tank ($27,000-$33,000) instead of cargo, and (4) the construction cost of a holding tank ($25,000).

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INTRODUCTION

This report is the second of two reports resulting from a concern for the effects of winter navigation in the Great Lakes on vessel waste disposal. This study was conducted for the U.S. Department of Commerce, Maritime Administration acting in concert with the U.S. Army Corps of Engineers, Winter Navigation Board. The first report focused on the shipboard and shoreside facilities and practices used for blackwater disposal and the effects of winter conditions on these facilities and practices. Blackwater refers to human body wastes collected in urinals and toilets onboard ships. This report, Phase II, is a supplement to the blackwater report and deals specifically with liquid wastes known as "graywater" which refers to the domestic wastewaters collected from galley, laundry, showers, and other miscellaneous shipboard sources.

This report has two main objectives: first, to define and document present graywater treatment and disposal methods and, second, to define and assess the effects of an extended navigation season on these methods using normal navigation season information as baseline data. In order to meet these objectives, the study was organized into five major topics: 1) characterization of graywater waste, 2) evaluation of shipboard waste treatment units, 3) environmental assessment of graywater treatment on the Great Lakes, 4) evaluation of shoreside waste disposal facilities, and 5) technical and economic assessment of graywater treatment and retention.

The first topic characterized graywater wastes by water production (hydraulic load) and water quality (chemistry) for the various sources, e.g. laundry, galley, and shower wastewaters. The evaluation of shipboard waste treatment units involves determining the feasibility of treating graywater with existing systems and the effects of cold weather on their overall performance. The environmental assessment involves the determination of loadings from treated and untreated graywater and the subsequent impacts on the Great Lakes ecosystem. The evaluation of shoreside facilities assessed existing facilities for the reception of graywater wastes and the limitations of these facilities, especially during an extended season. The economic and technical evaluation involved determining the economic and technical effects of treating or retaining graywater in order to meet pending secondary treatment requirements.

In this report blackwater and graywater will primarily be considered as a single combined waste stream. Some sections of this report draw heavily from the first phase report, which should be consulted for information dealing solely with blackwater. In the event of discrepancies between the two reports, the reader should bear in mind that more accurate and up-to-date information was obtainable in some instances for this report than for Phase I. The reader should also bear in mind that the information presented in these volumes is based on research and did not include any testing of marine sanitation devices or actual onsite environmental monitoring which was beyond the scope of this project. Finally, this report is based on the rules and regulations in effect at the time of this writing. Environmental control legislation is subject to rapid development and revision and, therefore, the regulations in force at the time of publication of this report may be superseded by new regulations in the future.

1.0 CHARACTERIZATION OF GRAYWATER WASTE

1.1 Introduction to Vessel Waste

The 400 or more commercial vessels on the Great Lakes today unavoidably produce several types of waste which must be disposed of in a manner that will afford the greatest protection to the environmental quality of the Great Lakes. These wastes include bilge waste, ballast water, solid waste, air pollutants and sanitary and domestic wastewaters.

Bilge waste consisting of oil and oil-contaminated water is discharged from the bilge of a vessel during normal operation. This waste, collected by drainage to the bilge area, is due to leakage from equipment, piping or tanks, repair or maintenance of equipment, or worn seals or parts in machinery. Rates of bilge water generation vary considerably with each vessel. In general, older ships generate approximately 2,600 gallons per hour while newer ships, less than 20 years old, generate half that amount (Gumtz, G.D., et al., 1974).

Ballast waste is water which has been placed in an unloaded or lightly loaded ship for the purpose of stability. Once in port, tremendous quantities are discharged. Although the amount varies with each type of vessel and its operation, an average volume discharged from Great Lakes ore and bulk carriers is 2,300,000 gallons per port visit (Gumtz, G.D. et al., 1974). This waste generally contains less than 100 parts per million (ppm) oil during initial pumping and is not considered a significant source of pollution.

As in residential households, solid waste consisting of paper, wood, glass, metals and plastics is also generated onboard ships. This refuse is regularly disposed of during port visits. Industrial liquid wastes containing acids, chemicals, cleaning agents and other fluids are also produced onboard vessels.

Emissions from ships' stacks also contribute to pollution of the Great Lakes environment. The amount of carbon monoxide, hydrocarbons, oxides of nitrogen and sulphur and particulates discharged to the atmosphere varies considerably with fuel and engine type and size used in a vessel.

In the past few years, sanitary wastes have become a major disposal concern. This type of waste, referred to as sewage or blackwater, is discussed in detail in Phase I of this report (Bartley, C.B., et al.). Blackwater consists of human body wastes collected from heads (toilets) and urinals onboard vessels and is generated at the rate of approximately 30 gallons per capita per day (gpcd). As of January 30, 1980, blackwater must be treated before discharge into the lake or held for shoreside discharge according to federal law. Blackwater is often separated from other shipboard waste for treatment by marine sanitation devices (MSDs) or retention in sewage holding tanks.

The last type of waste produced by vessels, termed "graywater," is the sole object of this report.

1.2 Physical Properties

Graywater commonly refers to domestic wastes generated onboard ships. These domestic wastes include wastewater from laundries, galleys (kitchens), showers, sinks, lavatories and miscellaneous drains. There is some discrepancy among different sources as to a standard definition of graywater. Most groups consider graywater to include all of the above domestic wastes. The federal government, however, currently defines graywater as "galley, bath, and shower water" only. In practice, it may prove more expensive to repipe certain sources of graywater than to plan for the treatment or disposal of graywater as a whole. Also, consideration of all graywater would protect the shipowner and manufacturers of MSDs from further impact should the definition and, therefore, requirements be revised in the future. For these reasons, all possible graywater components will be discussed and analyzed.

Unlike shoreside wastewater treatment systems, a ship is a closed system uncontaminated by storm water and industrial waste. Most of the components of vessel waste are, however, analagous to the average shoreside residence. Wastewaters from galleys (kitchens), laundries, heads (toilets), showers or bathtubs, and drainage from assorted sinks and lavatories all require disposal.

Laundry wastes consist mainly of the wastewater produced in washing machines. Some sink water may also be produced in laundries. Shipboard washing machines are usually of the standard shoreside household or institutional variety and, unlike most residential homes, may be found in more than one location on a ship.

Galley wastes result from normal food preparation, disposal equipment, and related activities. This includes dishwashers, garbage disposals and sinks. Wastes resulting from clean-up operations are also part of galley wastes.

Shower and lavatory wastewaters stem mostly from personnel accommodation spaces. A toilet, shower and lavatory is available to each member of the crew. Bathtubs are not common on commercial vessels. Public lavatories are also located in certain areas of the ship, such as the engine room, for use by the crew while on duty.

The remainder of graywater is composed of all additional domestic wastewater produced by the vessel. This includes any miscellaneous sinks, such as scrub sinks, located in different areas or departments onboard a ship, drinking fountains located throughout the ship and deck drains located below the waterline of the vessel. These smaller contributions to graywater may vary from vessel to vessel and some ships may have additional sources of graywater not mentioned here.

1.3 Graywater Flow Rate

The generation rate or hydraulic flow rate is of major importance in treating and disposing of vessel graywater. This rate, usually measured in gallons per capita per day (gpcd), is a measure of the amount of graywater produced by one person in one 24-hour period. The total hydraulic load for graywater is comprised of laundry, galley, shower and rinse and miscellaneous wastewaters.

Laundry wastewaters come from standard residential or institutional washing machines commonly used on vessels. A typical vessel with a complement of approximately 30 persons may have two such machines onboard. The size of the machine varies. A standard 60 lb washer will use 200 to 300 gallons of water in 40 to 55 minutes. Exact water usage depends on the cycles chosen. The hydraulic load from laundries is estimated to be 10 gpcd. On older vessels this may tend to be somewhat higher due to dirtier onboard conditions.

Rinse water from showers and lavatories amounts to another 35 gpcd. A common shower results in 24-30 gallons of wastewater. Normal consumption of water for each use of a lavatory or wash basin is about 1-1/2 gallons (Metcalf & Eddy, Inc., 1972).

Galley waste is another major contribution to graywater flow. This waste, comprised of dishwasher, garbage disposal, cooking and clean-up waste, amounts to approximately 10-20 gpcd. Rinse water from dishwashers is the greatest single contributor to galley wastewater.

The remainder of graywater is comprised of a number of miscellaneous sources including sinks not included in other sources, drinking fountains, deck drains and unexpected sources such as leakage from pipe connections and fittings. The total flow from these sources amounts to approximately 5 gpcd.

The flow rates shown in Table 1-1 are daily averages and are not constant throughout the day. The hydraulic flow rate of graywater fluctuates considerably during a typical 24-hour day. Surges, amounting to two to five times the average flow for as long as an hour or two, are common occurrences. Figure 1-1 is a hydrograph of water consumption over a 24-hour period for a dredge vessel with a crew of 50. While the exact usage may vary widely between different vessels, the general pattern of usage is typical aboard most vessels. Heaviest loads occur at breakfast, lunch and dinner time. Heavy galley loads occur after each meal. Shower and sanitary loads are most prominent before breakfast, in the early evening hours, and at shift changes. Laundry wastes are major contributions throughout the evening hours. Note the impact of this load at four hour intervals when the shift on duty changes.

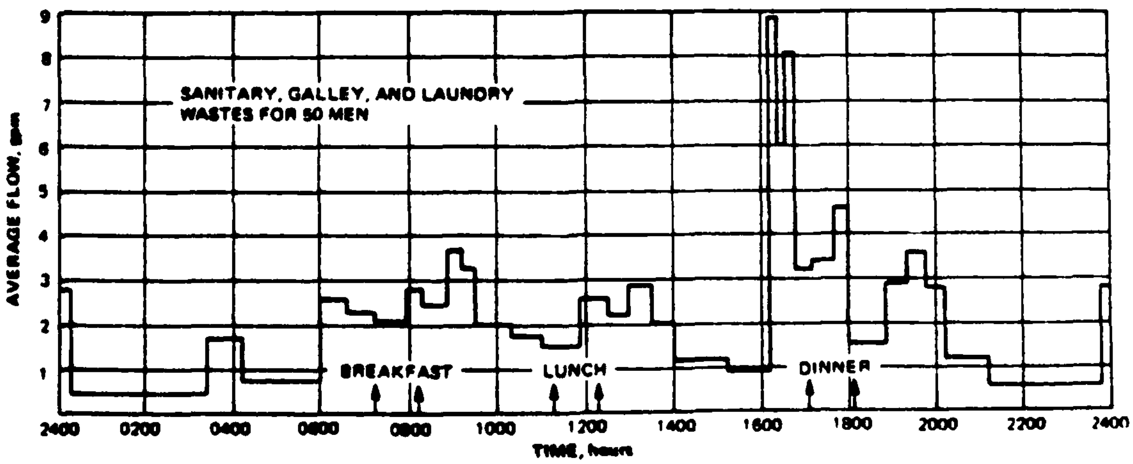


Figure 1-1
Wastewater Hydrograph for Dredge Gerig

(General Electric Co., 1971)

TABLE 1-1

Graywater Flow Rate Contributions by Source

Source	Flow Rate gpcd
Laundry	10
Galley	20
Shower/Lavatory	35
Miscellaneous	5
Total Graywater	70
Blackwater	30
Total Combined Black/Graywater	100

Several factors affect the hydraulic loads of wastewater produced. Total water usage on new vessels tends to be higher than that on older vessels due to a larger number of facilities. Other factors, such as crew diet, personal habits, and seasonal variations are usually of minor impact, but also help to explain the noticeable variability of shipboard waste loads.

In reviewing literature on graywater flow rates, it becomes apparent that considerable discrepancy exists. This wide range in data is due to the fact that the generation of graywater is variable on a single vessel, and the differences between vessels can be considerable. Hydraulic flow rates for graywater alone vary from 30 to over 100 gpcd. The value of 70 gpcd often used by MSD manufacturers and published sources will be used in this report. Blackwater, in comparison, has a more precise flow rate of 30 gpcd. In the event of graywater regulation it is expected that graywater and blackwater will be considered a single waste stream. Combined flow rates range from 80 to 185 gpcd for Great Lakes vessels (Mackey, T.P. and Nielson, R.A., 1974). The most generally accepted figure from shipboard sources and manufacturers of marine sanitation devices is 100 gpcd for combined black and graywater as shown in Table 1-1.

1.4 Chemical Properties

Before discussing the chemical composition of graywater, several definitions are in order. The following are the most common parameters used to measure the contaminants present in wastewater.

BOD- Biochemical oxygen demand is the most common parameter used to evaluate organic pollution. BOD, itself, is not a pollutant; it is a measure of the amount of dissolved oxygen (DO) consumed by organisms in wastewater. Existing biological life requires the dissolved oxygen in the water for metabolic processes. When high concentrations of DO are consumed by wastewater organisms, depletion of the amount of DO naturally available can occur. This depletion causes increased competition for the remaining DO by natural aquatic life. Those organisms which do not obtain the amount of DO required for their existence may die or suffer substantial effects. BOD is determined by incubating a sample of wastewater at a specific temperature, usually 20 degrees centigrade, for a specified time period, and taking DO measurements at the start and finish of this period. Most BODs are based on five days incubation; hereafter referred to as BOD_5. The most common units of BOD_5 are milligrams per liter (mg/l) or, the equivalent, parts per million (ppm).

SS- Suspended solids are solids that either float on the surface of, or are in suspension in, wastewater. They are removed for measurement by passing the wastewater through a filter. Suspended solids is normally expressed in units of parts solid per million parts water, ppm. According to the European Inland Fisheries Advisory Commission, 1965, there are at least four means by which suspended solids adversely affect fish and fish food populations:

(1) by acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, et cetera;

(2) by preventing the successful development of fish eggs and larvae;

(3) by modifying natural movements and migrations of fish;

(4) by reducing the abundance of food available to the fish....(U.S. Environmental Protection Agency, 1976).

TS - Total Solids are both the settleable and non-settleable fractions of suspended solids as well as dissolved solids.

Coliform -
The intestinal tract of man contains certain rod-shaped bacteria called coliform. A normal person excretes between 100 billion and 400 billion coliform bacteria per day, in addition to other bacteria. Coliform organisms are harmless to man and can, in fact, aid man by digesting organic matter in biological waste treatment systems. Coliforms are important in that they are used as an indication that pathogenic organisms may be present in waste. This is because the number of pathogenic organisms in waste is small in comparison and difficult to isolate. Pathogenic organisms, such as typhoid and dysentery, may originate in humans who are infected with disease or who are carriers of a particular disease. The absence of coliform organisms is considered an indication that the water is free from disease-producing organisms. *Escherichia coli* (*E. coli*) is a coliform entirely of fecal origin and is a common measure of water pollution potential. (Metcalf and Eddy, 1972)

pH - "pH" is a measure of the hydrogen activity in water and is an important factor in the chemical and biological systems of natural waters. Wastewater effluent discharged to natural waters must have a pH compatible with marine life present. A pH range of 6.5 to 9.0 appears to provide adequate protection for the life of both freshwater fish and bottom dwelling invertebrate fish food organisms. Outside this range, fish suffer adverse physiological effects increasing in severity as time and degree of deviation increases until lethal levels are reached. (U.S. Environmental Protection Agency, 1976)

COD- Chemical oxygen demand is a measure of the oxygen-consuming capacity of both organic and inorganic matter present in wastewater, natural waters and industrial and municipal wastes. COD is similar to BOD except that COD also measures the oxygen demand associated with inorganic matter.

TOC- Total organic carbon is another means of measurement of organic matter present in water. A TOC determination is a faster and more direct method of estimating organic contamination of water undetected by either BOD or COD.

TP - Total phosphorus is a measure of both the dissolved and organic bound fractions of phosphorus. A measure of TP is useful in determining the potential for increased algal productivity.

These parameters are useful in describing the makeup of graywater. The chemical properties of galley, laundry, shower and sink, and miscellaneous sources are individually unique, but together make up the chemical characteristics of graywater.

As stated earlier, galley wastes consist of much the same basic wastes produced in a shoreside kitchen. Galley waste is a very important component of graywater in terms of chemical composition. This source contributes fats, oils and grease from butter, lard, margarine, vegetables and soaps. Fats are also commonly found in meats, in the germ of cereals, in nuts, and in certain fruits. Fats are amoung the most stable of organic compounds and, as such, are not easily decomposed by bacteria. Grease can cause problems in drainage lines and waste treatment systems, and if not removed before discharge to lake waters, grease can interfere with biological life in the surface waters and cause unsightly floating matter or films (Metcalf & Eddy, Inc., 1972). Limits for grease discharge to natural waters have been established for shoreside sources but shipboard discharges are unregulated.

Use of garbage disposals contributes suspended solids. The possible effects of suspended solids on marine life were discussed in the first part of this section.

Although the strength of galley waste varies considerably from vessel to vessel, it is estimated to contain an average of 0.042 lb BOD_5 per day per person. Suspended solids values average about 0.026 lb per day per person. Galley waste is a fairly high contributor of both BOD_5 and SS and comprises 21% and 12% per capita, respectively.

Laundry waste is another important contributor to pollution from ships. The washing process uses specifically selected chemicals to remove undesirable substances contaminating fabrics and textiles. These chemicals promote cleaning, bleaching, softening, removal and prevention of micro-flora and fauna, and the neutralization of alkalinity. The rinsewater produced by the machines contains varying amounts of these chemicals and the contaminants removed from clothes and other fabric. Wide variations can occur in soil, chemical and washwater loadings due to differences in wash cycles. Washwater from the total cycle of a typical load contains the following components:

425 ppm detergents
140 ppm TOC
430 ppm COD
180 ppm BOD
1200 ppm TS, Total Solids
150 ppm SS
100 ppm Oil and Grease
Source: Land, E.W. et al., 1976

Average laundry wastes contain approximately 0.007 lbs per capita per day BOD_5 and 0.009 lb per capita per day SS (Marland Environmental Systems). Estimates of average total phosphorus loadings from detergents range from 1.7-2.0 grams per capita per day (Vollenweider, 1968) to 2.9 gpcd (Gilbertson et al., 1972).

The detergents used in the laundry process are of concern regarding phosphate content. Although no specific standards currently govern phosphate discharge from ships in the Great Lakes, stringent regulations for shoreside discharge sources have been formulated.

There is presently much interest in controlling the amount of phosphorus compounds that enter the surface waters of the Great Lakes. Phosphorus is essential to the growth of algae and other biological organisms. Algae can be a considerable nuisance in surface water because under certain circumstances, rapid reproduction can occur, resulting in large floating colonies of algae, called blooms. This can limit the growth of certain kinds of fish and other aquatic life by depleting the dissolved oxygen supply. Algae blooms are usually characteristic of a eutrophic lake. Effluent from wastewater treatment, high in nutrients, causes enrichment and increases the eutrophication rate when discharged into natural surface waters.

Washwaters from showers and lavatories consist of approximately 40 mg/l BOD_5 (Storch, 1972) and minor amounts of soap, etc. These washwaters are not considered significant contributions to pollution. Likewise, the contributions from miscellaneous sources are not usually of great concern; however, they can, in some instances, contain detergents, cleaning agents, and dirty rinse waters. The volume and chemical composition of these wastes can vary widely.

In most cases, graywater would be combined with blackwater for treatment purposes. Blackwater has an average of 0.2 lb per day BOD_5 and .22 lbs per day SS (Foster, E.P., 1972). Blackwater also contains 0.5 to 2.31 lb per capita per year phosphorus. Nitrogen, a nutrient, is also present and, acting in combination with phosphorus, contributes to lake enrichment resulting in the growth of algae.

In Section 1.3 the variability of graywater flow was discussed. This variability also causes significant fluctuation in the chemical composition of graywater. For example, before breakfast the graywater composition could be 80% shower and sewage wastewater, while early evening flow could be nearly 100% laundry waste (Figure 1-1).

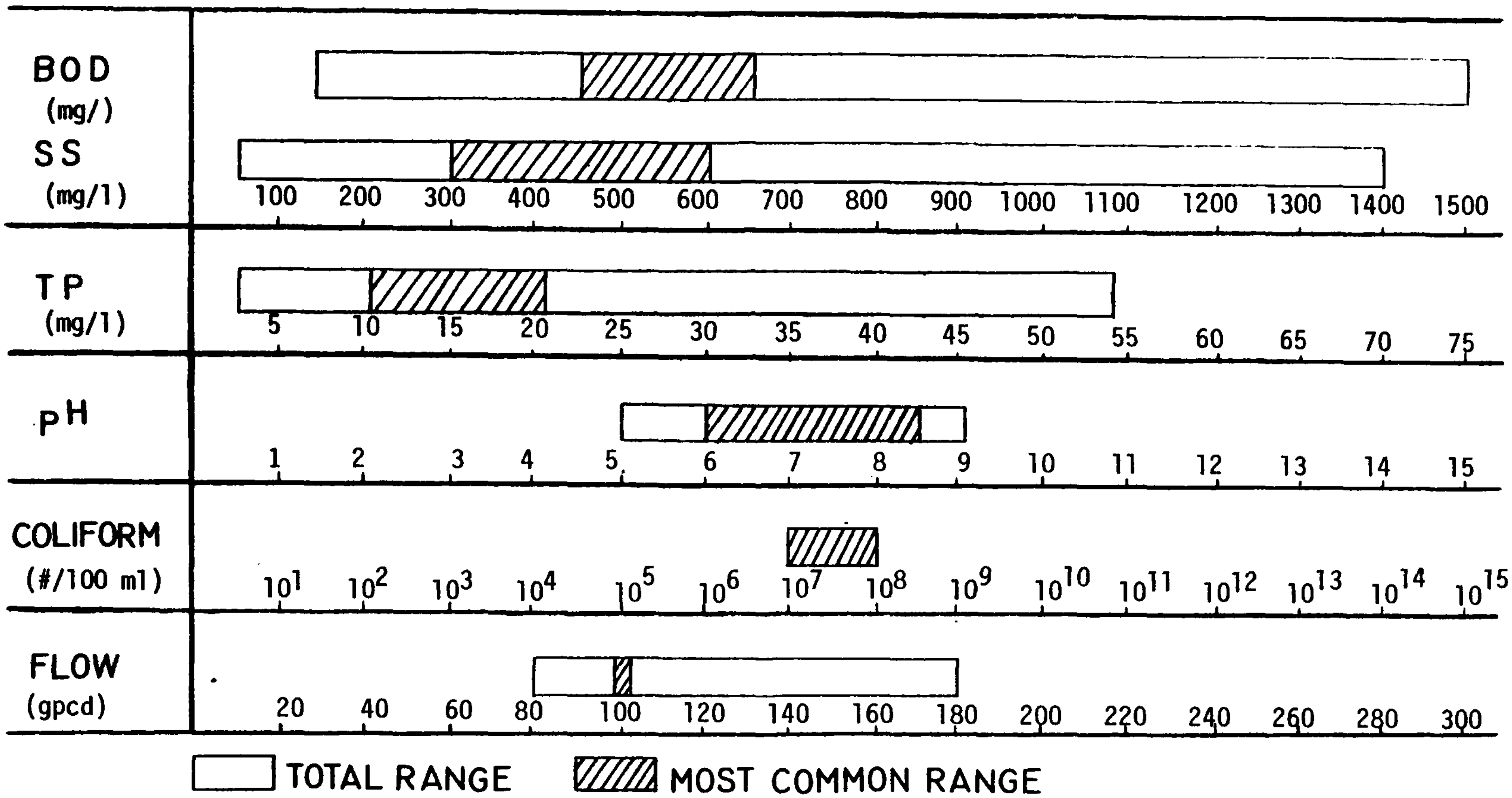
Pollutant characteristics also vary depending on the "strength" of the wastewater components. Wastewater primarily from showers and lavatories would be relatively "weak," while waste from galley and laundry combined would be considered "strong." Table 1-2 shows the relative range of pollutant parameters for influent black/graywater waste. While the average values of these parameters may vary considerably from ship to ship, the same wide range of property values occurs.

Although it is difficult to characterize wastewater by composition, a few generally accepted parameters are available to indicate average properties of blackwater and graywater combined. Black/graywater wastes contain an average concentration of 550 mg/l BOD_5, 450 mg/l SS and 225 mg/l TOC.

The concentration of total phosphorus (TP) in combined black/graywater wastes is variable depending on hourly/daily fluctuations in the composition of waste. Several sampling programs have provided data on U.S. and Canadian commercial vessels (General Electric Company, 1971; Mackey, T.P. and Nielsen, R.A., 1974). These studies monitored the daily influent parameters of raw black/graywater which entered MSDs and indicated that TP concentration ranged from a low of 3.4 ppm concentration to a high of 54.1 ppm. Based on the results of these two studies, an average concentration of TP of shipboard wastewater is between 10 and 20 mg. This is generally comparable to shoreside-

Table 1-2

PROPERTIES OF COMBINED BLACK & GRAYWATER WASTESTREAMS



generated wastewater: maximum concentrations of TP in shipboard-generated wastewater can at times exceed that of comparable maximum concentrations in shoreside-generated waste streams.

Although no test results are available, adding graywater to the waste stream may be expected to increase the temperature of wastewater. This is due to warm and hot wastewaters produced by showers, lavatories, galley and laundry sources. The temperature of the wastewater can have an effect on the chemical reaction time necessary in marine sanitation devices. The pH of black/graywater waste usually falls in the range of about 6 to 9 based on test results conducted on a 50-man-dredge (General Electric Company, 1971).

Table 1-3 summarizes both blackwater and black/graywater combined characteristics. Note the dilution effect of adding graywater volumes to blackwater. The result is a decrease in both BOD and SS.

1.5 Regulations of Vessel Waste Disposal

Until this decade vessel wastewaters have been discharged overboard without treatment. In 1972 the Federal Water Pollution Act Amendments (Public Law 92-500) were enacted by the U.S. Congress. These amendments identified vessels as pollution sources and required that marine sanitation devices (MSDs) be properly maintained and operated onboard vessels. MSDs are devices which collect blackwater (sanitary wastes) and either treat and dispose of the wastewaters or retain them for shoreside disposal.

Regulations, based on P.L. 92-500, were promulgated by the EPA in 1976. These existing regulations involve effluent standards of performance for MSDs and a time schedule of compliance (Figure 1-2). All MSDs manufactured for sale in the U.S. must receive U.S. Coast Guard certification of meeting Type I, II or III standards. These standards pertain to graywater if any graywater is piped to an MSD; however, the current effluent standards are not applicable to graywater if it is not piped to an MSD. A more complete discussion of the above may be found in Phase I of this study (Bartley, C.B., et al., 1979).

1.6 Graywater Legislation

In 1977 the Clean Water Act (P.L. 95-217) amended P.L. 92-500. These amendments, pertaining to commercial vessels on the Great Lakes, involved new definitions of the composition of wastewaters which must receive treatment and the level or extent of treatment. Specifically P.L. 92-500 defines sewage as "human body wastes and the wastes from toilets and other receptacles intended to receive or retain body wastes." P.L. 95-217 amends this definition by adding "except that, with respect to commercial vessels on the Great Lakes, such term shall include graywater." Graywater is then defined as "galley, bath and shower water." Laundry wastewaters were omitted in the definition although they are typically considered in characterizing graywater wastes.

P.L. 95-217 also give public notice that the level to which the effluent quality of the MSD is regulated will be revised. According to Section 312 of this act as amended by Section 59 of P.L. 95-217:

Table 1-3

Generally Accepted Characteristics of Blackwater
and Combined Black/Graywater

	Flowrate (gpcd)	BOD (mg/l)	SS (mg/l)	TP (mg/l)	TOC (mg/l)
Blackwater	30[b]	600[a]	800[a]	15[b]	N.A.
Combined Black/Graywater	100	550	450	20	225[c]

gpcd = gallons per capita per day
BOD = biochemical oxygen demand
mg/l = milligrams per liter
SS = suspended solids
TP = total phosphorus
TOC = total organic carbon

a) Kinney, E.T. and Constant, A.E., 1971
b) Bartley, C.B. *et al.*, 1979
c) Fisher, C.P. *et al.*, 1974

U.S. Coast Guard

MARINE SANITATION DEVICE COMPLIANCE SCHEDULE

30 Jan 76 | 30 Jan 77 | 30 Jan 78 | 30 Jan 79 | 30 Jan 80 | 30 Jan 81

New Vessel Schedule

Must install **Type I, II, III** MSD.

New installations must be **Type II** or **III** MSD.

Except

If **Type I** Device is installed by **30 Jan 1980**, then **Type I** Device may be used for the life of the device.

Existing Vessel Schedule

Must install **Type II** or **III** MSD.

Except

If **Type I** Device is installed by **30 Jan 1978**, then **Type I** Device may be used for the life of the device.

New Vessel	Keel laid on or after 30 January 1975.
Existing Vessel	Keel laid before 30 January 1975.
Type I Device	USCG certified to 1000 fecal coliform/100 ml, no "visible floating solids" standard.
Type II Device	USCG certified to 200 fecal coliform/100 ml, 150 mg/l total suspended solids standard.
Type III Device	USCG certified to no-discharge standard.
Existing Device	Those manufactured prior to 30 January 1976.

Figure 1-2

"The Administrator [of the EPA] shall, with respect to commercial vessels on the Great Lakes, establish standards which require at a minimum the equivalent of secondary treatment....Such standards and regulations shall take effect for existing vessels after such time as the Administrator determines to be reasonable for the upgrading of marine sanitation devices to attain such standard."

The secondary treatment referred to is the standard applied to shoreside discharge sources. This standard, as stated in 40 CFR Part 133, consists of the following limits for BOD_5, SS, fecal coliform bacteria and pH:

A. Biochemical oxygen demand (five-day)

(1) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams.

(2) The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 milligrams per liter.

(3) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for influent samples collected at approximately the same times during the same period (85 percent removal).

B. Suspended solids

(1) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter.

(2) The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 milligrams per liter.

(3) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for influent samples collected at approximately the same times during the same period (85 percent removal).

C. Fecal coliform bacteria

(1) The geometric mean of the value for effluent samples collected in a period of 30 consecutive days shall not exceed 200 per 100 milliliters.

(2) The geometric mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 400 per 100 milliliters.

D. pH

The effluent values for pH shall remain within the limits of 6.0 to 9.0.

New regulations incorporating the amendments of P.L. 95-217 have not yet been promulgated. There are several factors which will influence the formulation of the new regulations. It is likely that only the parameters of suspended solids and fecal coliform be considered for vessel waste as these were the only parameters considered for blackwater treatment. Another factor to be considered is that secondary treatment standards were designed for point sources of pollution and not for moving sources such as ships. This may call for revision of secondary treatment standards as they would apply to vessels. A reasonable goal that may be expected of shipboard waste treatment systems would be 90% reduction of contaminants. New regulations would also be expected to consider such factors as the time necessary for upgrading MSDs and the capital expense involved.

P.L. 95-217 also addressed the establishment by petition of local units of state government of a "drinking water intake zone" within a state's waters in which the discharge of treated or untreated sewage (including graywater) from vessels is prohibited. The petition process is similar to that followed for other no-discharge zone sections of the Act. Currently, no Great Lakes state has petitioned under this new section for a no-discharge status. States have successfully petitioned for no-discharge zones under other provisions of P.L. 92-500. The status of state legislation and no-discharge regulations is summarized in Phase I of this report concerning blackwater waste disposal from vessels (Bartley _et al._, 1979). No known changes in the status of any of the state's waters have occurred since the completion of that study.

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2.0 SHIPBOARD TREATMENT SYSTEMS

2.1 Introduction

Shipboard treatment or collection of black and graywater wastes generated aboard ship is accomplished by marine sanitation devices (MSDs). Phase I of this report (Bartley, C.B. et al., 1979) discusses the processes and problems associated with the treatment of blackwater by MSDs. This section deals with the treatment and collection of a combined waste stream of both black and graywater by MSDs.

2.2 Brief Review of Treatment Processes

Marine sanitation devices are certified by the U.S. Coast Guard as meeting one of three different types based on their effluent quality (Figure 1-2). Type I units, which comminute and chlorinate waste, are now legal only if they were installed prior to January 30, 1978 for existing vessels and January 30, 1980 for new vessels.

Type II MSDs are flow-through units, meaning a treated effluent is discharged to surrounding waters. These units consist of two main types, distinguished by the process employed. These are physical/chemical units and biological units. Physical/chemical units basically separate and store solids, in the form of sludge, and chemically treat the liquids for overboard discharge. Biological treatment units utilize microorganisms to decompose the organic content of waste. The liquid is then chlorinated and the effluent discharged overboard.

Type III MSDs are no-discharge systems. This is the most stringent performance standard in that no overboard discharge of effluent is allowed. Atmospheric emission is, however, permissible. The two main types of units which meet Type III certification standards are incineration units and retention systems. Incineration units burn wastes resulting in an atmospheric emission and a gray ash which is disposed of shoreside. Retention units and holding tanks store blackwater or combined black/graywater waste generated onboard ship until it can be discharged to a shoreside waste disposal facility.

For more detailed discussion of the process involved in MSDs the reader is referred to Phase I of this report, since the processes used in combined blackwater/graywater treatment are essentially the same as used for blackwater only.

2.3 Methods

Information for this section concerning marine sanitation devices (MSDs) was obtained by means of two surveys. The first survey consisted of contacting U.S. ship operators located in the Great Lakes area to determine their waste disposal practices. The survey was conducted during the summer of 1978 for Phase I of this report and resulted in data on 95 U.S. Great Lakes' vessels operating on the Great Lakes at the time of the survey. The results of that survey pertaining to graywater disposal will be presented in this section.

To gain further information on marine sanitation devices, the manufacturers of these units were contacted. The information sought included information on the graywater treatment process, specific unit information such as size, weight, cost, etc., effluent quality levels and any problems experienced due to treating graywater, winter weather, etc. This information was obtained by means of survey data sheets. The survey was conducted in two parts. First, a survey was conducted for Phase I of this report. Although this survey was aimed at obtaining information on blackwater treatment, much useful information pertaining to graywater treatment was also obtained. Second, another survey was conducted to obtain additional information on treating waste containing both black and graywater. This second survey generated responses from some manufacturers who had not been contacted during the first survey and also from several manufacturers contacted in the first survey. A total of 11 manufacturers responded. These manufacturers represented most major MSDs marketed in the United States and especially the Great Lakes region. The manufacturers were chosen to include producers of all the major processes and types of units available. The National Sanitation Foundation (NSF), which is involved in the testing and certification of MSDs, was also contacted.

The information received from these sources was then grouped according to the USCG Type and the basic process employed by the MSDs. The different groups were (1) Type I, Macerator-chlorinator (2) Type II, Physical-Chemical (3) Type II, Biological (4) Type III, Retention and (5) Type III, Incineration. The results and conclusion were then characterized by these groups. Although results are listed by group it must be noted that units produced by different manufacturers within a certain group may use many different variations and combinations of processes while still employing the same general operating principle. It should also be noted that a survey of this type may be subject to the individual qualifications and biases of the responding manufacturer. It is hoped that the effects of these factors have been minimized by contacting a number of different manufacturers.

2.4 Survey of Ship Operators

For Phase I of this report a survey of ship operators was conducted to determine the waste disposal practices of U.S. Great Lakes commercial vessels operating on the Great Lakes at that time (summer of 1978). The survey gathered information for a total of 95 vessels in operation. The results of this survey indicate that 83% of the vessels surveyed discharged all graywater directly overboard, 6% of the vessels (1 fleet) retained graywater and 11% included graywater in the waste stream to an MSD, resulting in the overboard discharge of treated effluent. Although not tabulated, it appeared that most vessels planned or currently under construction at the time were scheduled to treat graywater with an MSD. This indicated that the vessel operators were already aware of future graywater regulations, and were planning accordingly.

2.5 Survey of MSD Manufacturers

2.5.1 Type I Macerator-Chlorinator

Since installation of this type of MSD will soon be prohibited, the number of manufacturers marketing this type of unit for shipboard use is relatively few. The one manufacturer contacted in the survey indicated that the Type I unit could accept a waste of both black and graywater. The only treatment given in this case, however, is heavy chlorination to reduce coliform levels.

This type of treatment is minimum and could not meet secondary treatment standards as stipulated in P.L. 95-217. No problems due to cold weather operation were reported.

2.5.2 Type II Physical/Chemical

All the physical/chemical MSDs can accept and treat graywater without additional parts or other forms of upgrading. Physical/chemical MSDs use chemical flocculation, settling, and straining techniques for the removal of solids and reduction of BOD_5. The hourly peak hydraulic loadings posed little or no problem to the MSDs as the systems were designed for surges of 2 to 4 times the average daily loadings. Grease traps and degreasing chemicals are used in the process in order to avoid the clogging of filters.

The effects of winter weather on efficiency, treatment and the plumbing of the MSDs are considered minor. Physical/chemical systems are not as limited in treatment efficiency or performance by cold temperatures as biological systems. Some freezing of plumbing fixtures may occur unless immersion heaters are used or pipes are run alongside steam pipes.

The performance of most physical/chemical MSDs produces an average effluent of 155 mg/l BOD_5, 72 mg/l SS, 15/100 ml coliform, and 7 mg/l TP after treating gray/black wastewaters. The physical/chemical systems would, on the average, meet existing blackwater effluent standards (150 mg/l SS and 200/100 ml coliform); however, the systems would not meet secondary treatment standards for BOD_5 (30 mg/l) and SS (30 mg/l). The systems are capable of attaining secondary treatment levels under optimum operating conditions (Table 3, Appendix A).

Some of the manufacturers reported research and development in graywater treatment as well as systems which treat graywater solely.

2.5.3 Type II Biological

All the MSDs with biological processes can process graywater (Table 1 of Appendix A). Only one Type II biological MSD manufacturer contacted responded that its system did not reduce influent levels of pollutants (TP, SS, etc.) in graywater. In this case, graywater was piped to a chlorination tank and discharged. In all other cases, graywater was piped to the main surge tank and treated the same as blackwater. Biological systems use variations of land-based sewage treatment processes such as activated sludge, extended aeration and trickling filters (fixed substrates). All of these processes involve the growth of microorganisms which degrade solids, remove nutrients, and consume dissolved oxygen.

The obvious problems associated with biological systems are those which inhibit the growth of microorganisms such as small amounts of waste, i.e., available food stuffs (associated with overdilution of sewage or high surges in hydraulic load), toxic chemicals, fats and oils (which have slower degradation rates), and cold temperatures. All manufacturers of biological MSDs designed their systems for surges two to four times the average daily flow rate and thus experience no problems of overdilution. Grease traps or addition of enzymes are recommended for removal of fats and oils prior to treatment.

If biological MSDs are exposed to a winter climate, cold temperatures can greatly reduce efficiency and performance of treatment equipment. The use of immersion heaters and the location of MSDs in warm areas of a ship, e.g., near the engine room, are methods of resolving this potential problem. Freezing of pipes can be prevented by routing sewage pipes alongside steam pipes or by wrapping pipes with insulation.

The average effluent reported from a survey of biological MSD manufacturers consists of 30 mg/l BOD_5, 48 mg/l SS and 138/100 ml coliform (Table 3, Appendix A). This effluent would meet existing shipboard Type II blackwater standards (150 mg/l SS and 200/100 ml coliform), but would not meet existing shoreside secondary treatment standards (30 mg/l BOD_5, 30 mg/l SS, 200/000 ml coliform). Under optimum operating conditions, biological systems like physical/chemical systems could meet secondary treatment standards (minimum levels in Table 3, Appendix A). One manufacturer reported that another treatment component could be added to its existing Type II system to provide tertiary treatment (Table 3, Appendix A). Both physical/chemical and biological processes produce approximately the same range of effluent quality.

None of the manufacturers contacted responded that they were involved in research and development of biological treatment of graywater. Also, no manufacturer produces a system which solely treats graywater; however, most responded that existing blackwater systems could be upgraded to accept graywater.

2.5.4 Type III Retention

Retention is a common practice in meeting Type III no-discharge standards. Type III MSDs which feature retention and are certified by the USCG are of two types: low-volume flush and standard flush systems. Standard collection systems collect and retain all black and gray wastewaters regardless of hydraulic load. Low-volume collection systems reduce the influent hydraulic load by using low flush volume and vacuum collection, recycling wastewaters (such as graywater), or reducing the volume of flush waters. The only low-volume system which reduces graywater flow is the recycling of graywater as flushing water. Low-volume systems are generally connected to holding tanks, incinerators, evaporators or other Type III MSDs and are not, themselves, treatment devices.

Standard or low-volume collection systems can generally be connected to approved Type III holding tanks. Most holding tanks are fabricated by shipyards and shipbuilders instead of MSD manufacturers. The design, limitations, constraints, and costs of constructing holding tanks are discussed in Section 5.0. Since holding tanks produce no overboard effluent, they can meet secondary treatment standards for combined wastewaters.

Winter weather poses freezing problems to the plumbing if immersion heaters, thermal taping and other antifreezing installations are not used for either standard or low-volume collection systems.

2.5.5 Type III Incineration/Evaporation

Other Type III MSDs use heat energy to incinerate and/or evaporate wastewaters. These systems are capable of treating gray/black wastewaters to no-discharge standards. Their use on ships is limited by certain constraints: The units require greater amounts of energy in order to treat both black and gray wastewaters. As cost of energy is proportional to energy consumption, the cost of treating combined wastewaters would be approximately two to three times the cost of treating only blackwater (30 gpcd for blackwater vs. 100 gpcd for combined). In the previous study, the operating cost of incineration and/or evaporation of blackwater was considered prohibitive for commercial vessels (Bartley, et al., 1979), and the same can be concluded for graywater treatment. Also, existing systems would be taxed by the increase in hydraulic load from graywater. This problem can be resolved by purchasing more units until sufficient capacity is available to process peak hydraulic loads. Enlarging the existing surge tanks would not resolve the problem if the existing devices could not process at least 3,200 gallons per day (32 persons x 100 gpcd). Section 5.0 discusses the option of installing additional units in more detail.

Existing devices can process gray/black wastewaters and meet the secondary treatment requirements of P.L. 95-217. Cold weather poses the same problems to these systems as to others and can just as easily be prevented.

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3.0 ENVIRONMENTAL ASSESSMENT

3.1 Introduction

Concern about the pollution of the Great Lakes has resulted in environmental legislation and has generated many studies. The impact on the Great Lakes due to the disposal of graywater wastes from vessels during an extended season is the subject of this assessment.

3.1.1 Objectives

The major objective of this study is to ascertain the environmental effects of discharging treated graywater wastes during winter with the advent of the winter navigation season. This is to be accomplished by first establishing a baseline of existing environmental data. Then the existing data will be used to derive a set of calculations concerning a projected winter navigation season. Finally, the impacts during winter and non-winter seasons will be assessed with the projected information.

3.1.2 Parameters of Study

The major constituents of graywater wastes which could impact the environment are: contributions of phosphorus from detergents, BOD_5 load from galley wastewaters, and solids from garbage disposals.

Phosphorus is a limiting nutrient in the Great Lakes such that elevations in concentrations of total phosphorus (TP) within the lakes can stimulate phytoplankton growth and increase the rate of eutrophication. These increases may lead to undesirable environmental conditions, e.g., algae blooms. Thus total phosphorus was a major parameter selected for this assessment.

Biochemical oxygen demand (BOD_5) is a measure of substances and organisms, e.g., bacteria, which compete with other aquatic organisms for dissolved oxygen (DO). A minimum concentration of DO to maintain good fish populations is 5.0 mg/l (U.S. Environmental Protection Agency, 1976), which generally occur in all but extremely eutrophic waters polluted with organic substances. As DO levels can be restored by the mixing action of currents, wind and waves, the hydrology of the receiving water is an important factor in assessing the impact on aquatic organisms.

Suspended solids may affect the water quality of receiving waters by increasing turbidity and to some degree decreasing light penetration. Waters which are turbid generally screen out light and this can result in lower productivity by algae. Very high concentrations of suspended solids can also result in the clogging of fish gills and other apparatus used for filter feeding by aquatic organisms. Suspended solids, if allowed to settle, can smother bottom dwelling organisms and decompose. Mineralization of organic matter (measured by SS) can result in nutrient release. The impacts to aquatic life from SS loading may be lessened with quick and thorough dispersion in receiving waters.

Disinfection of wastewaters with chlorine may have some short term deleterious effects. Depending upon the level of residual chlorine in the effluent, disinfection of sewage may result in fish mortality. This effect has been found at levels of 2.0 mg/l (Bellanca and Bailey, 1977). Levels of residual chlorine as low as 0.01 mg/l are not considered sufficient to protect salmonid fish species (Brungs, 1973). Some chloro-organics, which are formed by contact between free chlorine and organic chemicals, have been deemed carcinogenic by various federal health agencies (40 CFR Part 141). Growth inhibition has been observed to occur to some algae species when exposed to chloro-organics in chlorinated sewage (Sivaborvorn, 1978). As so many different compounds are formed by disinfection there has not been sufficient time to determine health and toxic hazards (Jolley, 1975; Glaze and Henderson, 1975).

The effects of residual chlorine and chloro-organics (COs) are not dependent upon levels of treatment. Rather, their formation, concentrations, and effects are determined by the amount of chlorine used to disinfect sewage and the time in contact with organics (Jolley, 1975; Brungs, 1973; Bellanca and Bailey, 1977). In terms of this study, the increase in hydraulic loading of graywater may then increase CO and residual chlorine loading by a factor of 2-3 (70 gpcd for graywater vs. 30 gpcd for blackwater). However, as mentioned in the blackwater study (Bartley et al., 1979) the loadings of these pollutants are minor in comparison to municipal waste treatment plant loadings. Second, the long-term effects are nearly impossible to quantify until more studies by public health and environmental agencies are completed. For these two reasons, disinfectant by-products will not be discussed for graywater treatment.

3.2 Methods

In order to assess the impact of treated combined (gray and black) wastewaters on the Great Lakes by commercial vessels, it was necessary to summarize the treatment performance for all of the Type II flow-through MSDs. No-discharge (USCG type III) MSDs were not considered because their discharge is not directly to the receiving waters but usually to shore-based facilities. At these facilities, the shipboard wastes would undergo secondary treatment. Also, Type I MSDs, macerator-disinfectors, were not deemed adequate to meet secondary treatment standards.

3.2.1 Scenarios

Different treatment cases, or scenarios, were depicted in order to evaluate impacts associated with graywater treatment. The first case (case #1) is one in which all types of graywater will be combined with blackwater and treated. The second case (case #2) is the same as the first except laundry wastes will not be treated. This case represents a strict formulation per P.L. 95-217, Section 59. The final case (case #3) is the present situation in which graywater is discharged untreated and blackwater treated with USCG Type II MSDs.

3.2.2 Literature and Data Search

Literature and data searches were conducted by the Maritime Research Information Services, which produced a good deal of information on various treatment systems and characterization of graywater wastes. Data about treatment performance and effluent concentrations of pollutants were derived from a survey of MSD manufacturers (see section 2.0), manufacturers' brochures and technical reports, and government studies. Information on other sources of loading were primarily obtained from International Joint Commission reports.

3.3 Loading Calculations

Loadings for each parameter of study and for each scenario were calculated using two basic equations (Table 3-1). The values for variables in each of these equations were obtained from the literature search or from survey data on MSDs.

3.3.1. Annual Loadings

The annual load of a given pollutant discharged by commercial vessels into each of the Great Lakes was estimated by using equation (1), which involves the number of vessels annually traversing the lake, the crew size, the portion of the year a vessel is traversing the lake and the per capita annual loading of the given pollutant (Upper Lakes Reference Group, 1977). The sources of the values used in equation (1) of Table 3-1 are listed briefly in Table 3-2.

The number of vessels annually trafficking the Great Lakes (N) was obtained by converting reported annual traffic tonnage transported on the Great Lakes (Department of the Army, 1976) to a number of vessels by using a conversion factor of 18,511 long tons per vessel (supplied by the Maritime Administration). A more accurate count of the annual number of vessels per lake would have been desirable; however, such data are currently unavailable. For the above stated reason, the data on the number of vessels are uncertain and probably inflated above the actual number, as most vessels carry more than 18,511 long tons of cargo. When conversion factors were applied to the data on tonnages per lake, the average number of vessels annually trafficking each of the Great Lakes was obtained. The additional traffic that would result from an extended season was calculated by using a 4.94% increase in normal traffic as estimated in a study conducted by the Commercial Navigation Task Group of the Navigation Work Group (1976). The actual figures are listed in Appendix B for both a normal season and an extended season of navigation.

For the purpose of this study, the number of men per vessel (S) was estimated to be 32. This value is the most commonly reported value by ship operators in response to ERG's survey (see blackwater study or Appendix B for more detail).

The portion of time any given vessel is trafficking each of the Great Lakes was estimated at a maximum by considering the average speed of a vessel and the longest round-trip distance a vessel would traverse if passing through each of the Great Lakes. The average speed of a cargo-carrying vessel was reported as 15 miles per hour during ice-free periods from discussions with ship operators. The longest distance a vessel could travel in a single trip was taken as the distance between the furthest two ports on opposite ends of a lake, e.g., number of miles from Duluth, MN to Sault Ste. Marie, MI on Lake Superior. The distance data for the longest trip on each lake as defined in the study can be found in Table 3-4 of the blackwater study (Bartley, et al., 1979). The longest trip data were then divided by the average speed and multiplied by two in order to determine the time a vessel would be on a lake traveling round trip. Next, the time in port (1 day as estimated in previous studies) (Upper Lakes Reference Group, 1977a, 1976) was added to the round-trip time estimate. The results of these calculations are found in Appendix B.

These longest trip estimates were adjusted for winter ice conditions by using 5 miles per hour as the average speed of commercial vessels during the winter months. This speed estimate was developed from discussions with ship operators. These adjustments were used when calculating the number of days a vessel is on the Great Lakes during the winter (Appendix B).

The annual per capita load (L_a) of a pollutant was obtained for each parameter either from the information reported by MSD manufacturers (see Section 2.0) or from the literature. The values used in the calculations are summarized in Table 3-3. In estimating per capita loadings, the maximum hydraulic loads and effluent concentrations were used to calculate maximum values.

As an example, the annual loading of TP to Lake Erie from commercial vessels treating combined gray/black wastewaters during a normal navigaton season was calculated to be 1,100 kg as the mean and 7,400 kg at a maximum. From Appendix B the variables are:

N = 6,263 vessels
Cf = 2.4 days/vessel
S = 32 persons
L_a - TP maximum = 5.6 kg/capita/year
L_a - TP mean = 0.8 kg/capita/year

Inserting these variables into equation (1) of Table 3-1 results in:

$N \times Cf \times S \times L_a$ - TP maximum
(vessels) x (2.4 days/365 days yr^{-1}) x (persons) (kg/capita $year^{-1}$)
6,263 x (2.4/365) x 32 x 5.6 = 7,400 kg
6,263 x (2.4/365) x 32 x 0.8 = 1,100 kg

The parameters in equation (1) can be varied to calculate an extended season annual load. First the load during winter was calculated as an example for Lake Erie (from the data in Appendix B):

N = 6,572 vessels (extended seasons) - 6,263 (normal season)
Cf = 4.8/120 days in winter
S = 32 persons
L_a - TP maximum = 5.6 kg/capita/yr
L_a - TP mean = 0.8 kg/capita/yr

Thus the winter maximum and mean loading are:

(6,572-6,263) x (4.8/120) x 32 x 5.6 = 2,200 kg
(6,572-6,263) x (4.8/120) x 32 x 0.8 = 300 kg

Then adding the winter loadings to the normal season TP loading for Lake Erie yields:

$L_n + L_w = L_e$
7,400 kg + 2,200 kg = 9,600 kg as a maximum
1,100 kg + 300 kg = 1,400 kg as a mean

The previous examples illustrated how case #1 loadings were calculated. By varying the annual per capita loading parameters, (L_a), for each of the different cases (case #1 = treated combined wastewaters, case #2 = treated combined wastewaters without laundry water, and case #3 = treated blackwater without treated graywater), annual loadings during normal and extended seasons can be calculated.

Case #2 Example

In this case, the parameter L_a is altered to reflect no treatment of laundry wastes. The best and most accurate way to change the parameter (L_a), is to subtract from it the fraction of the annual load which is treated laundry wastes (L_ℓ) and then add the annual load of untreated laundry wastes (L_u) to the difference: $L_a - L_\ell + L_u$. The fraction, (L_ℓ), can be estimated from the relationship between the loading of untreated laundry wastes (L_u), to influent loading of combined wastes, L_i: $\% = L_u/L_i \times 100$. Thus $L_\ell = (L_u/L_i) \times L_a$. Substitution yields:

$$L_a = (L_u/L_i) \quad L_a + L_u$$

As an example, using data from Tables 3-3 and 3-4 for total phosphorus loading:

L_a = 5.6 kg/capita/yr (maximum)
0.8 kg/capita/yr (mean)

L_u = 1.1 kg/capita/yr (maximum)
0.6 kg/capita/yr (mean)

L_i = 12.0 kg/capita/yr (maximum)
2.7 kg/capita/yr (mean)

The annual loading, to reflect the case of treatment of graywater excluding laundry waste, equals:

$$5.6 \text{ kg capita}^{-1} \text{ yr}^{-1} - (1.1 \text{ kg capita}^{-1} \text{ yr}^{-1}/12.0 \text{ kg capita}^{-1} \text{ yr}^{-1}) \times$$

$$5.6 \text{ kg capita}^{-1} \text{ yr}^{-1} + 1.1 \text{ kg capita}^{-1} \text{ yr}^{-1} = 6.2 \text{ kg capita}^{-1} \text{ yr}^{-1}$$

If the annual loading is estimated instead by a simpler but less precise method of adding the annual load of untreated laundry wastes (L_u) to that from the annual load from treated combined wastes (L_a), the result is: 5.6 + 1.1 = 6.7 kg/capita/yr or a 7% error. The second less precise method was used to calculate annual loading for each lake and parameter because the error is small, the method is simpler, and the result is biased towards the upper extreme. The values of loading for laundry are listed in Appendix C, as are the annual loadings per parameter per lake and seasons. To determine, for example, the annual loading of TP to Lake Erie from commercial vessels treating combined gray/black wastewater without treating laundry wastes, the annual loading to Lake Erie under case #1 conditions was added to the annual loadings of TP to Lake Erie from untreated laundry.

Normal Season

	Case #1	Case #2
maximum	7,400 kg	7,400 kg + 4.0 kg = 7,404 kg
mean	1,100 kg	1,100 kg + 2.6 kg = 1,103 kg

The same mean procedure was followed for calculating the extended season loadings and for the other lakes and parameters.

Case #3 Example

The annual loading to each lake with the treatment of blackwater was calculated in the previous study (Bartley, et al., 1979). The annual loading to each lake from untreated graywater was calculated (Appendix C) by using equation (1) in Table 3-1. The annual per capita load (L_a) for untreated graywater was calculated by multiplying the daily per capita load listed in Table 3-4 by 365 days in a year. Finally, to estimate the annual load to each lake for the case of treated blackwater and untreated graywater, the annual load for treated blackwater was added to that for untreated graywater, e.g., normal season on Lake Erie for TP = 677 kg (from treated blackwater) + 2,800 kg (from untreated graywater) = 3,477 kg.

3.3.2 Daily Loading

Daily loadings of parameters from commercial vessels were calculated in the same manner as annual loadings. In order to determine the daily per capita load, equation (2) in Table 3-1 was used. An example of this can be found in Table 3-4. Annual per capita loads already calculated were easily converted to daily per capita loads. A daily loading from a single commercial vessel was simply calculated as the product of the number of crew members and the daily per capita load (L_d x S).

3.3.3 Analysis

The approach used to analyze the effects of treated combined wastewaters (case #1), of treated combined wastewaters without treated laundry wastes (case #2), and of untreated graywater on the Great Lakes ecosystem was to examine short- and long-term impacts from loadings. Short-term effects were estimated from the impacts of daily loading per vessel on harbors, coasts and offshore waters during winter and ice-free seasons. Long-term effects were estimated from the impacts of annual loadings of vessels to harbors, coasts and offshore waters of the Great Lakes during extended and normal navigation seasons.

3.4 Short-Term Effects

The effluent from the wastewaters of commercial vessels is composed of various pollutants, e.g., total phosphorus, biochemical oxygen demand (BOD_5), fecal coliform bacteria, and suspended solids. Fecal coliform bacteria and SS levels are currently regulated for blackwater treatment (see Section 1.0), and the other pollutants may soon be regulated as a result of P.L. 95-217. Each of these pollutants' parameters has an impact on the receiving waters if untreated. The daily loading of these parameters were calculated for each case of treatment:

case #1 where all graywater and blackwater are treated, case #2, which is the same as case #1 except laundry wastewaters are untreated, and case #3, in which graywater is untreated. These three cases were then examined for their effects on harbor, coastal environments, and offshore waters.

3.4.1 Harbors

A vessel generally spends one day in port for loading and/or unloading of cargo. During this day, it may discharge on the average from 1.34 to 4.63 kg of BOD_5, 0.87 to 2.82 kg of suspended solids, and 0.07 to 0.23 kg of TP, depending upon the treatment practice (Table 3-5). In case #1 where all black/gray wastewaters are treated with existing Type II MSDs, the loadings might range from 1.34 to 6.62 kg BOD_5, 0.87 to 5.11 kg SS, and 0.07 to 0.49 TP, depending upon the hydraulic load. These pollutants would tend to accumulate in harbors that have reduced flow or exchange rates with the open offshore waters.

The short-term effects would be to increase phytoplankton productivity, increase the concentration of oxygen consuming substances, and increase turbidity as a result of TP, BOD_5, and SS loadings. The duration of these effects would depend upon the mixing and dispersal mechanisms operating in the harbor. In general, harbors possess poor mixing and dispersal properties when compared to offshore currents and fast flowing rivers.

Based on the average loadings in Table 3-5, case #1, in which all wastewaters are treated by existing Type II MSDs, would produce a load equivalent to one-third of that resulting from discharging untreated graywater (case #3). Discharging untreated laundry wastes (case #2) would produce only a 30% increase in the loadings in comparison to case #1 loadings (Table 3-5).

3.4.2 Coasts and Embayments

Coasts, which include connecting channels and embayments, generally have greater circulation and exchange rates with offshore waters than do harbors. Littoral and wind-driven currents strongly influence mixing and dispersion in the coastal environments. Commercial vessels traverse coastal waters when entering and departing port but spend most of their time in the offshore waters enroute to and from port. Because of the small amount of time spent in coastal waters and the strong mixing and dispersion properties, the effects of daily loadings from vessels would likely result in minor impacts to coastal environments.

3.4.3 Offshore Waters

When treated wastewater is discharged into offshore waters of the Great Lakes, it may have some immediate environmental effects, such as those described for harbors. The immediate effects would dissipate as the pollutants are dispersed and diffused. The diffusion and dispersal of treated wastewaters from vessels would be influenced by the propeller(s) and motion of a ship plowing through the water and by the natural mixing processes of the Great Lakes.

In a hypothetical case of an ore carrier with a design draft of 28 feet, beam of 70 feet, and traveling at a rate of 360 miles per day, a conservative estimate of the volume of water mixed by the passage of the ship in a day is: 28 x 70 x (360 x 5,280) = 3.72 x 10^{-9}cubic feet or 105.34 x 10 liters. When the daily load of pollutants (Table 3-5) is mixed throughout this volume (105.34 x 10^{-9} liters), an estimation of the resulting increase in concentration of pollutants above ambient levels can be obtained (Table 3-6). The estimated daily increases in concentration by one vessel do not appear to be sufficiently large to induce any short-term effects, either detrimental or beneficial. Currents would also further disperse and dilute the pollutants throughout the lake.

The mixing processes of the Great Lakes are affected by velocity and direction of winds, degree of thermal stratification and the temperature difference between the air and water surface. The velocity and direction of wind places a stress on the water column resulting in currents which transport mass and materials (Liu, et al., 1976). During the summer and late winter, when winds are more moderate than spring or autumn and the lakes have become thermally stratified, the wind-driven currents are known to extend 20-30 meters in depth, which corresponds to the depth of thermoclines in the deep waters of the Great Lakes.

Aiding the mixing of water masses are thermally driven internal currents. As the surface waters cool in late fall, the colder, more dense water sinks and warmer waters rise.

The net effect of wind-driven currents and thermal currents is that the loads from treated wastewaters of vessels are thoroughly dispersed, mixed, and diluted within a short time of the discharge even under moderate wind conditions and thermal stratification to depths of 20-30 meters. The rates of mixing and dilution will depend upon the seasonal and daily variations in winds and temperature and the degree of lake stratification.

3.4.4 Ice Conditions

The primary effect of ice-cover on lakes is the reduction of mixing processes. Other effects include reduction of light penetration, gas exchange, e.g., DO, and metabolic rates which can contribute to oxygen shortages and persistence of pollutants under the ice. When a pollutant is discharged under ice, it disperses and dilutes at a slower rate than if wind-driven or thermal currents were influencing the water mass transport (Stanislov and Mohtadi, 1971). As a vessel moves through an ice-covered lake, its discharge of treated wastewaters would be initially mixed by the ship's propeller(s) and motion as previously discussed. The pollutants would then mix and dilute at a slow rate once the water over the discharge becomes ice-covered.

Also, if the treated wastewater is at a warmer temperature than the water, e.g., at 60° F, then it is highly probable that the wastewaters would remain near the surface due to their lower density. This might result in immediate, localized impacts, especially in heavily ice-covered and sheltered areas. Examples of these areas are harbors or very sensitive coastal environments, but not the offshore waters of the Great Lakes. Thus some local effects of the discharge of treated gray and blackwater might persist until ice melts and currents are formed in the offshore waters.

In summary, the short-term impacts of daily loadings of pollutants from vessels are as follows:

(1) Daily loads of pollutants would accumulate in harbors because of the generally poor mixing properties of harbors.

(2) The effects of daily loadings from vessels would likely result in minor impacts to coastal environments during a normal navigation season because: (1) vessels spend a small amount of time in coastal waters, and (2) intense circulation and currents in coastal waters rapidly disperse and dilute pollutants.

(3) The daily loadings from vessels during winter, under ice-cover, will result in a slower rate of dispersion and dilution of pollutants, possibly impacting sensitive coastal environments and harbors.

(4) No short-term effects from the daily loadings of vessels are expected to impact offshore waters for the following reason: the movement of a vessel through the water and wind-driven currents tends to mix and dilute pollutants such that increases above ambient levels are of an amount insufficient to induce adverse effects.

(5) Dissolved oxygen of the surface waters will be reduced within the immediate vicinity of the discharge. Turbidity and phytoplankton productivity will have increased especially in areas or under conditions of reduced mixing, e.g., harbors and ice-cover.

The impacts of treated black/gray wastewaters from vessels in the open waters of the Great Lakes are minor and of short duration, except during winter when lakes are ice-covered. This conclusion is based upon the effects of daily loadings from a single vessel. The effects of the fleet of vessels is evaluated in the next section on long-term impacts. The short-term impacts include the slight reduction of DO and increase of phytoplankton productivity. The physical processes in the lake due to winter weather conditions are more fully discussed in the previous report on blackwater.

3.5 Long-Term Impacts

Long-term impacts to the Great Lakes ecosystem were assessed by examining the effects of annual loadings to harbors, coastal environments, and offshore waters during both normal and extended navigation previously mentioned in analyzing short-term impacts.

3.5.1 Harbors

The discharge of treated combined wastewaters into harbors may occur during the time a vessel is in port for 24 hours (Upper Lakes Reference Group, 1977a). Two harbors were considered for case studies. The first harbor, Presque Isle-Marquette, represented an area of low-volume vessel traffic (Department of the Army, 1976) and relatively unpolluted waters (Upchurch, 1976). The second harbor, Duluth-Superior, represents a higher volume of vessel traffic (Department of the Army, 1976) and relatively polluted waters (Upchurch, 1976;

Upper Lakes Reference Group, 1977a). The differences in water quality of the two harbors may be the result of differences in land use within the watershed, e.g., industrialization and commercialization. Vessel traffic volumes were used in calculating annual loadings [equation (1) of Table 3-1] for each harbor.

Presque Isle-Marquette

The existing conditions of the harbor are considered to be of high quality with respect to coastal waters, the open waters and other harbors of Lake Superior (Upper Lakes Reference Group, 1977a). The annual TP, BOD_5 and SS loads from the discharge of treated wastewaters during a normal and extended season were calculated (Table 3-7).

The BOD_5 loadings into the harbor from vessels ranged from 530 kg to 2,600 kg during a normal season with the treatment of combined wastewaters (Table 3-7). The range during an extended season was 731 kg to 3,600 kg. With the treatment of combined wastewaters, BOD_5 loadings are reduced more during both a normal and an extended season than if laundry or graywater were untreated (Table 3-7).

The trends of SS loadings are similar in two ways to those of BOD_5 loadings: The range of loadings is higher during the extended season than during the normal season for all cases of treatment, and loadings are greatly reduced with case #1 treatment. Total phosphorus loadings into the harbor from vessels ranged from 28 kg to 190 kg during a normal season and from 38 kg to 270 kg (case #1) during an extended season (Table 3-7). Calculations of loadings indicated that reductions in total phosphorus loadings would occur with Type II treatment of graywater [90 kg (case #3) vs 28 kg (case #1), Table 3-7].

To put these values into some perspective, a comparison was made to other sources of loadings. A study conducted by the International Reference Group on Great Lakes Pollution from Land Use Activities (1978) calculated the annual loadings of total phosphorus and suspended solids for the harbor from combined municipal, industrial and tributary sources to be 51,100 kg and 1,823,500 kg, respectively. The maximum annual loadings of TP and SS from vessels to the harbor with graywater treatment (case #1) were estimated at 190 kg and 2,000 kg, respectively.

During both a normal and an extended season, the TP and SS loadings from vessels would comprise less than 1% of the combined (tributary, municipal, industrial) load into Presque Isle Harbor (0.3% for TP; 0.1% for SS). The BOD_5 load from vessels could not be compared to other sources as data from other sources were not available. It appears that the BOD_5, total phosphorus and suspended solids loadings from vessels are a minor component of the total annual loads into the Presque Isle Harbor.

Duluth-Superior

The existing condition of the harbor is considered of poor quality with respect to open-lake waters, coastal waters and other harbors of Lake Superior (Upchurch, 1976). Total phosphorus was observed to range from 0.02-0.76 mg/l during 1973 (Upper Lakes Reference Group, 1977a), which is typical of eutrophic waters (Vollenweider, 1968). The annual TP, BOD_5, and SS loads from treated combined wastes during a normal and an extended season were calculated. In general, the BOD_5 loadings were greater during an extended season than during a normal season, e.g., 6,600 kg vs. 400 kg with combined wastewater treatment, and were less with treatment than without treatment of graywater (Table 3-8). These trends were also found for total phosphorus and suspended solids loadings.

To place the annual loadings to the Duluth-Superior Harbor into some perspective, a comparison was made to other loading sources (Table 3-9). From Table 3-9, contributions of TP were 199,000 kilograms from municipal sources, 32,000 kilograms from industrial sources and 2,000 kilograms estimated from vessels which treated black and graywater during an extended season. The contribution from vessels was 2,000 out of a total of 234,000 kilograms of TP or approximately 0.8% of the total annual TP load. Similar trends were observed for SS and BOD_5 loadings, e.g. vessels contributed annually 32,700 kg BOD_5 out of a total annual BOD_5 load of 23,683,000 kg or approximately 0.1% of the total. It appears that annual loadings of BOD_5, total phosphorus and suspended solids from treated graywater wastes of vessels would be a minor component of the total annual loads into the Duluth-Superior Harbor during either a normal or extended season.

3.5.2 Coasts and Embayments

As mentioned previously, coasts and embayments are uniquely influenced by littoral and wind-driven currents which effect the mixing and dispersion of pollutants. Moreover, it is generally known that nearshore waters of the Great Lakes have a higher concentration of nutrients and organisms. Most of the nutrients are contributed from terrestrial sources, e.g., surface runoff, erosion, and bedload from rivers and streams. For the most part, vessels spend a small portion of time in the coastal zone and the greatest portion of time in the offshore waters. The amount of time is proportional to the distance a vessel must travel to and from port. The greatest distance traveled is generally the length of the lake itself.

The annual loadings of pollutants from commercial vessels to coastal environments are considered small because of the small portion of time a vessel is in this zone. Also, the estimated increase in concentration resulting from daily loadings from vessels (Table 3-6) is so low (in nanogram range) that 10,000 vessels would have to discharge in the same area to raise levels to the milligram range. No port on the Great Lakes has this volume of annual traffic.

3.5.3 Offshore Waters - Normal Season

The long-term impacts to offshore waters were assessed from the effects of annual loadings during a normal navigation season. As in the blackwater report (Bartley, *et al*., 1979), the lakes were assumed to be thoroughly mixed due to the strong wind and wave energies which occur during spring and autumn. This results in the lakes mixing twice yearly.

Total Phosphorus

The annual load of TP from vessel traffic during a normal navigation season was calculated for each of the Great Lakes (Table 3-10). The loadings from vessels with graywater treatment (cases #1 and #2) are on the average three times less than those without graywater treatment. Again, treatment of graywater reduces loadings substantially.

Other sources of TP loading into the Great Lakes are municipalities, industries, agriculture, urban runoff, natural levels in tributaries and the atmosphere. The reported loadings from each of these sources were compared to loadings calculated for vessels (Table 3-11). The TP load from vessels (5,700 kg for Lake Superior), when compared to other loadings, is less than 10% of any other single source which ranges from 59,000 kg to 1,708,000 kg. Also, the TP load (5,700 kg) is less than 1% of the total annual loading (e.g., 2,963,700 kg for Lake Superior) to each lake. The contribution of TP from vessels is minimal compared to other sources of phosphorus. These results are in agreement with other studies which found that vessel wastes were a minor component in the TP loading to the Great Lakes (Upper Lakes Reference Group, 1977a,b). The TP loads from vessels calculated for Lakes Michigan, Erie and Ontario are not available from the International Joint Commission or any other group.

The increase in levels of TP within the Great Lakes as a result of vessel loadings was calculated (Table 3-12). The net increase in TP concentration in each lake would range from 0.47 nanograms per liter in Lake Superior to 19.69 ng/l in Lake Erie. These values are beyond limits of analytical detection (1.0 microgram/liter). Thus any increase in primary productivity in the ecosystem as a result of increased TP levels from the loading of treated combined wastewaters would likely be undetectable, as would be the subsequent effects on the Great Lakes ecosystem.

The areal loading rates to the Great Lakes were also calculated (Table 3-12) and plotted against the average depth of each lake (Figure 3-1). From Figure 3-1 it can be seen that only Lake Erie has a high loading rate typical of eutrophic lakes. Lake Ontario has a loading rate which if increased by 0.4 grams per m^2 per year, would result in eutrophication (Figure 3-1). When the annual areal loading rates from vessels (Table 3-12) are added to the total loading rate from other sources, a slight increase in the rates takes place; however, this results in virtually no change in the position of the lakes in respect to eutrophication (Figure 3-1).

BOD_5 and Suspended Solids

The annual load of BOD_5 and suspended solids from vessels during a normal season was calculated for the Great Lakes (Tables 3-13 and 3-14). As with TP loadings, the loadings of BOD_5 and SS from vessels which would treat graywater (case #1) were less than those which would not treat graywater. The BOD_5 load from vessels comprises less than 0.1% of the total BOD_5 load to the Great Lakes (Tables 3-15 and 3-16), e.g., 0.05% for Lakes Superior and Erie during a normal season. Similarly, the suspended solids load from vessels comprises less than 0.1% of the total suspended solids load to the Great Lakes (Table 3-16), e.g., 0.0001% for Lake Michigan during a normal season. The annual BOD_5 and SS loads from vessels during a normal season are minor components (0.1%) of the total annual load to the lakes. This is in agreement with the results of other studies which concluded that vessels contributed insignificant amounts of BOD_5 and suspended solids to the total annual load (Upper Lakes Reference Group, 1977a,b).

The increase in BOD_5 levels within the Great Lakes as a result of the annual load from vessels was calculated along with the increase in suspended solids (Table 3-17) and was found to be less than the lower limits of analytical detectability (0.10 mg/l for BOD_5 and the in situ lower limit of 0.10 mg/l for SS). The decrease in DO from the BOD_5 load and the increase in suspended solids from the SS load would be undetectable by normal analytical methods. In addition, the effects of BOD_5 dissipate in approximately 30 days with adequate mixing of the receiving waters. Thus any long-term impact of annual BOD_5 and suspended solids loading from the treated combined wastewaters of vessels on the open lake ecosystem would also be undetectable.

3.5.4 Offshore Waters - Extended Season

The long-term impacts on offshore waters were assessed from the effects of annual loading for a projected extended season. The lakes were assumed to be thoroughly mixed for the same reasons as given in the previous section.

Total Phosphorus

The annual load of TP from vessels alone during an extended season was calculated for each of the Great Lakes (Table 3-10). As a result of an extended season, the TP load would increase by 24% in Lakes Superior and Michigan, and 23% in Lakes Huron, Erie, and Ontario under worst case conditions (maximums from Table 3-10).

In comparing the annual TP load from vessels under extended season conditions to other sources, the findings are similar to those found for the normal navigational season. The calculated annual load from vessels comprises less than 1% of the total annual load (Table 3-11) and is minimal when compared to other sources of TP which enter each of the Great Lakes.

The increase in phosphorus levels as a result of treated combined wastes from vessels during an extended season is just as negligible as that during a normal navigational season (Table 3-12). These results are similar to the findings of other studies (Upper Lakes Reference Group, 1977a,b). With such a minimal increase in the concentration of TP, the net increase in annual primary and secondary production would also be minimal.

If the anticipated maximum annual load from vessels during an extended season were added to the total areal loading from other sources, the trophic position of the lakes, as shown in Figure 3-1, would change very little. The potential of commercial vessels to accelerate the eutrophication process of the Great Lakes during an extended season is low because the additional load generated is negligible in proportion to other sources.

BOD_5 and Suspended Solids

The annual load of BOD_5 and suspended solids during an extended season was calculated for the Great Lakes (Tables 3-13 and 3-14). Due to an extended season, the BOD_5 and suspended solids load averages increase, ranging from 24% in Lake Superior to 23% in Lake Michigan.

Comparison of the BOD_5 and suspended solids loads to loads from other sources indicates that BOD_5 and suspended solids from vessels during an extended season would comprise less than 0.1% of the total BOD_5 and SS load, respectively

(Tables 3-15 and 3-16). The load of BOD_5 and suspended solids from treated combined wastewaters during the extended season also appears to be a minor component of the total annual BOD_5 and suspended solids loads.

The increase in SS and BOD_5 levels within the lakes from treated combined wastewaters was calculated for an extended season (Table 3-17). The results of these calculations indicate that the increase in SS and BOD_5 levels during an extended season would be less than the lower detection limit for each of the parameters (0.10 mg/l for BOD_5 and 0.10 mg/l for SS). There would appear to be an undetectable impact on the open-water ecosystem of the Great Lakes from annual BOD_5 and SS loads during an extended season. Also, the additional BOD_5 loadings from vessel traffic during an extended season would appear to be too small to impair DO levels of the Great Lakes, as existing DO levels are considered sufficient to assimilate existing annual loadings (Upchurch, 1976a).

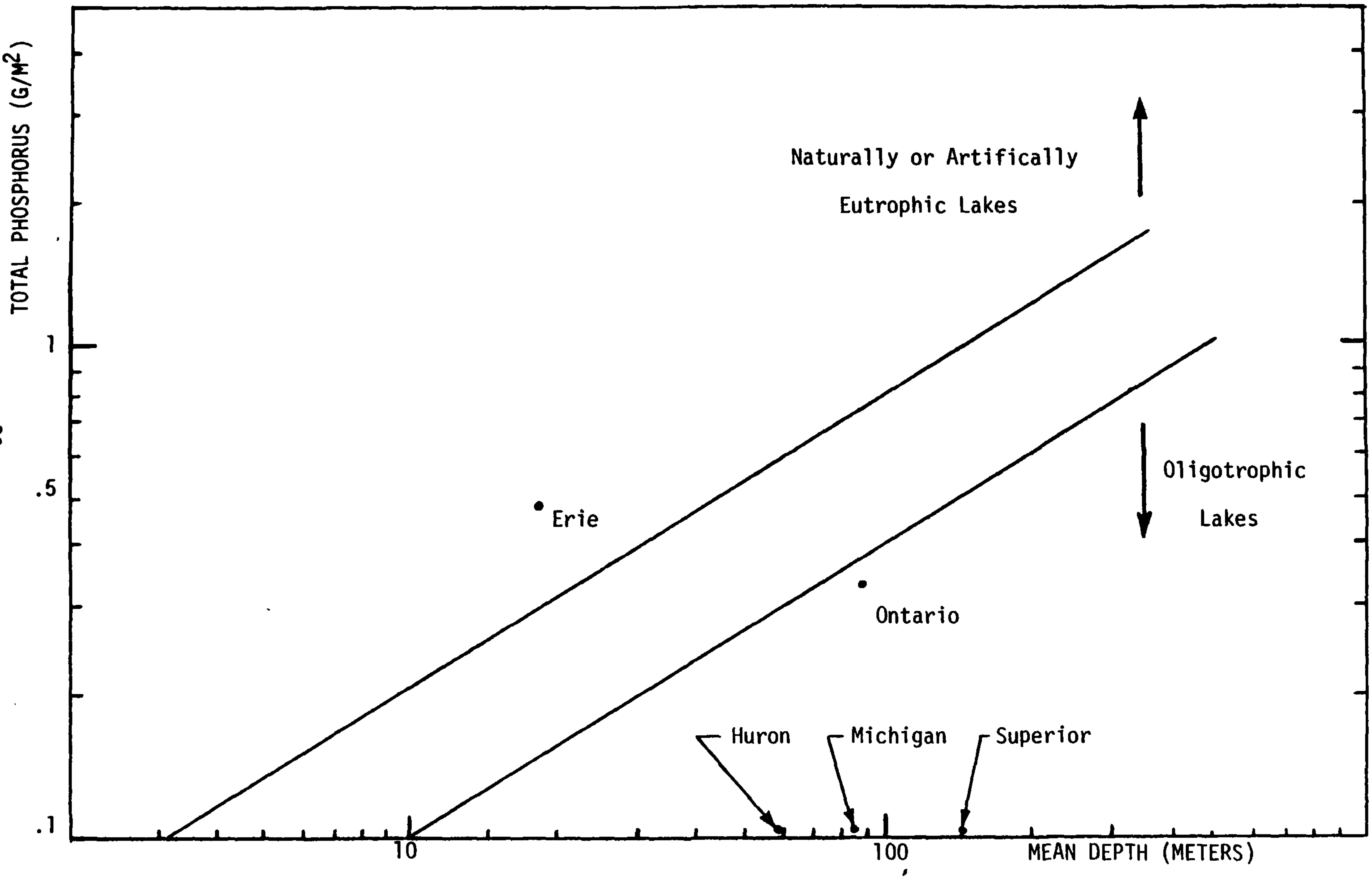

FIGURE 3-1 ANNUAL LOADING OF TOTAL PHOSPHORUS

SOURCE: According to Vollenweider, 1968

Table 3-1

Summary of Loading Equations

Equation	Definitions
(1) $L = N \times C_f \times S \times L_a$	N - Number of vessels trafficking the lake annually
	C_f - Portion of the year a vessel is on the lake
	S - Number of men per vessel
	L_a - Annual load of pollutant per man (tons or kg/person/year)
(2) $L_d = V \times C$	L_d - Daily loading (tons or kg/per capita per day)
	V - Volume (gallons converted to liters per capita per day)
	C - Concentration of pollutant (milligrams per liter)

TABLE 3-2

Summary of Parameters and Sources

Parameter	Sources of Values
N	Obtained for each lake from Department of the Army (1976) and converted from tons to vessels using 18,511 long tons per vessel conversion factor supplied by the Maritime Administration. Values listed in Appendix B.
S	Used 32 men per vessel average obtained from a survey of ship operators.
Cf	Based on a most common time a vessel takes to traverse the longest trip (maximum) in a lake and adding the time in port as obtained from reports (Upper Lakes Reference Group, 1977). Actual values listed in Appendix B.
L_a (TP and BOD_5 and SS)	Per capita load obtained from the literature and survey of MSD manufacturers. Values listed in both Appendices B and C for annual loadings under different cases of treatment.

Table 3-3

Estimated Pollution Parameters
As Reported by Marine Sanitation Devices
for Treatment of Black/Gray Wastewaters

Averages[a] of	Biochemical Oxygen Demand (5-day)	Suspended Solids	Total Phosphorus
Hydraulic Load (gallons/person/day)			
Maximum	185	185	185
Mean	119	119	119
Effluent Concentration (milligrams/liter)			
Maximum	295	228	22
Mean	93	60	5
Annual Per Capita Load[b] (kilograms/person/year)			
Maximum	75.5	58.3	5.6
Mean	15.3	9.9	0.8

[a] the values which were averaged were taken from Table 2-3

[b] Annual Per Capita load calculated by C (effluent concentrations) x H_1 (hydraulic load)

Table 3-4

Influent Characteristics and Loadings of
Blackwater, Graywater, and Laundry Wastes

Parameter	Blackwater[a]	Graywater[b]	Combined[c]	Laundry[d]
Hydraulic Load, in gallons/capita/day				
Maximum	35	155	185	20
Average	30	70	100	10
Biochemical O_2 Demand in milligrams/liter				
Maximum	N.A.	N.A.[g]	1500	N.A.
Average	600	N.A.	550	180
in grams/capita/day				
Maximum	N.A.	N.A.	1040	N.A.
Average	68	138	206	6.8
Suspended Solids in milligram/liter				
Maximum	N.A.	N.A.	1400	N.A.
Average	800	N.A.	450	150
in grams/capita/day				
Maximum	N.A.	N.A.	971	N.A.
Average	90	79	169	5.6
Total Phosphorus in milligrams/liter				
Maximum	N.A.	N.A.	48	N.A.
Average	15	N.A.	20	(43)[e]
in grams/capita/day				
Maximum	N.A.	N.A.	33	(2.9)[f]
Average	1.7	5.8	7.5	1.6

a data from blackwater study (Bartley, Leininger, and Titcomb, 1979)
b The difference between combined and blackwater (columns 1 and 3)
c from Table 1-2
d from Section 1.4
e from 425 mg/l detergents (section 1.4) x 10% by weight TP (Vollenweider, 1968)
f from Gilbertson *et al.* 1972
g N.A. = Data unavailable

Table 3-5

Daily Loadings From a Typical Commercial Vessel

Parameter	Cases of Graywater Treatment		
	Case 1	Case 2	Case 3
Biochemical O_2 Demand (5-day), in kg/day/vessel			
Maximum	6.62	N.A.	N.A.
Mean	1.34	1.6	4.63
Suspended Solids, in kg/day/vessel			
Maximum	5.11	N.A.	N.A.
Mean	0.87	1.05	2.82
Total Phosphorus, in kg/day/vessel			
Maximum	0.49	0.58	N.A.
Mean	0.07	0.12	0.23

Case 1: Black and gray wastewaters are treated by USCG type II MSDs

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Where blackwater is treated with type II MSDs and graywater is untreated

N.A.: data unavailable

Table 3-6

Increase in Concentration Resulting from
Daily Loadings and Vessel-Induced Mixing

Parameter	Cases of Graywater Treatment		
	Case 1	Case 2	Case 3
Biochemical O_2 Demand (5-day), in micrograms/liter			
Maximum	0.0628	N.A.	N.A.
Mean	0.0127	0.0152	0.0440
Suspended Solids, in micrograms/liter			
Maximum	0.0485	N.A.	N.A.
Mean	0.0083	0.0100	0.0268
Total Phosphorus in micrograms/liter			
Maximum	0.0047	0.0055	N.A.
Mean	0.0007	0.0011	0.0022

Case 1: Black and gray wastewaters are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3 Where blackwater is treated and graywater is untreated

N.A.: Data unavailable

Table 3-7

Annual Loadings to Preque Isle - Marquette Harbor
from Commercial Vessels Treating and Not Treating Graywater

Parameter	Case 1		Case 2		Case 2	
	normal	extended	normal	extended	normal	extended
Biochemical O_2 Demand (5-day), in kg/year						
Maximum	2,600	3,600	N.A.	N.A.	N.A.	N.A.
Mean	530	731	610	850	1,800	2,500
Suspended Solids, in kg/year						
Maximum	2,000	2,800	N.A.	N.A.	N.A.	N.A.
Mean	340	470	420	570	1,100	1,500
Total Phosphorus, in kg/year						
Maximum	190	270	190	270	N.A.	N.A.
Mean	28	38	28	38	90	120

Case 1: Black and gray wastewaters are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Graywater is untreated and blackwater is treated

N.A.: Data unavailable

Normal: Existing navigation season

Extended: Projected extended navigation season

Table 3-8

Annual Loadings to Duluth - Superior Harbor
from Commercial Vessels Treating and Not Treating Graywater

Parameter	Case 1		Case 2		Case 3	
	normal	extended	normal	extended	normal	extended
Biochemical O_2 Demand (5-day), in kg/year						
Maximum	23,800	32,700	N.A.	N.A.	N.A.	N.A.
Mean	4,800	6,000	5,600	7,700	16,600	22,900
Suspended Solids, in kg/year						
Maximum	18,400	25,300	N.A.	N.A.	N.A.	N.A.
Mean	3,100	4,300	3,800	5,200	10,100	13,900
Total Phosphorus, in kg/year						
Maximum	1,800	2,400	1,800	2,400	N.A.	N.A.
Mean	300	350	300	350	820	1,100

Case 1: Black and gray wastewaters are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Graywater is untreated and blackwater is treated

N.A.: Data unavailable

Normal: Existing navigation season

Extended: Projected extended navigation season

Table 3-9

Sources of Annual Loadings of Pollutants
to Duluth-Superior Harbor

Source	Loadings in Thousand Kilograms per Year		
	Total Phosphorus	Biochemical Oxygen Demand (5-day)	Suspended Solids
Municipal[a]	199.25	7,112.39	4,834.42
Industrial[a]	32.85	16,538.15	9,329.40
Vessels (Normal Season	1.80	23.80	18.40
Vessels[b] (Extended Season)	2.40	32.70	25.30
TOTAL (Normal Season)	233.90	23,674.34	14,182.22
TOTAL (Extended Season)	234.5	23,683.24	14,189.12

[a] Data includes tributary loadings and are obtained from the Upper Lakes Reference Group (1977a) report to the International Joint Commission

[b] Maximum values from Table 3-8 for case 1 treatment.

Table 3-10

Annual Loading of Total Phosphorus to the Great Lakes From Commercial Vessels Treating Graywater

Lake	Maximum Loadings in Thousand Kilograms Cases of Graywater Treatment					
	Case 1		Case 2		Case 3	
	normal	extended	normal	extended	normal	extended
Superior						
Maximum	5.7	7.5	5.703	7.504	N.A.	N.A.
Mean	0.8	1.1	0.802	1.103	2.6	3.5
Michigan						
Maximum	5.4	7.1	5.403	7.104	N.A.	N.A.
Mean	0.8	1.0	0.802	1.003	2.5	3.2
Huron						
Maximum	7.9	10.2	7.904	10.205	N.A.	N.A.
Mean	1.1	1.5	1.103	1.504	3.5	4.6
Erie						
Maximum	7.4	9.6	7.404	9.605	N.A.	N.A.
Mean	1.1	1.4	1.103	1.403	3.5	4.5
Ontario						
Maximum	2.7	3.5	2.701	3.502	N.A.	N.A.
Mean	0.4	0.5	0.401	0.501	1.2	1.6

Case 1: Graywater and blackwater are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Where graywater is untreated and blackwater treated

N.A.: Data unavailable

Normal: Existing navigation season

Extended: Projected extended navigation season

Table 3-11

Sources of Annual Total Phosphorus Loadings to the Great Lakes

Source	Loadings by Lake and Source in Thousand Kilograms				
	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Atmospheric[a]	1,089	1,689	1,061	1,119	473
Industrial[a]	102	32	31	27	80
Municipal[a]	59	1,040	122	5,731	2,038
Tributary[a]	1,708	3,179	2,490	5,553	3,254
Vessels[b] (Normal Season)	5.7	5.4	7.9	7.4	2.7
Vessels[b] (Extended Season	7.5	7.1	10.2	9.6	3.5
Total (Normal Season)	2,963.7	5,945.4	3,711.9	12,437.4	5,847.7
Total (Extended Season)	2,965.5	5,947.1	3,714.2	12,439.6	5,848.5

[a] Reported values of total phosphorus loadings obtained from Great Lakes Water Quality Board (1978) report to International Joint Commission

[b] Maximum values from Table 3-10

Table 3-12

Increase in Total Phosphorus and Annual Areal Loadings to the Great Lakes from Annual Loadings of Lake Carriers Treating Graywater

Lake	Mean Depth (meters)	Lake Volume ($x10^{15}$ liters)	Increase[a] In Concentration (nanograms/liter) normal season	extended season	Surface Area (km^2)	Annual Areal Load (milligrams/meters from normal season	from other sources	from extended season
Superior	149	12.200	0.47	1.07	82,100	0.069	36.0	.091
Michigan	85	4.920	1.10	1.45	57,750	0.094	102.9	.123
Huron	59	3.537	2.25	2.91	59,500	0.133	62.2	.171
Erie	19	0.483	15.18	19.69	25,657	0.288	484.5	.374
Ontario	86	1.637	1.65	2.14	19,000	0.142	307.6	.184

[a] from case 1 levels (maximums) in Table 3-10

Table 3-13

Annual Loadings of Biochemical Oxygen Demand to the Great Lakes from Vessels Treating Graywater

	Maximum Loadings in Thousand Kilograms Cases of Graywater Treatment					
	Case 1		Case 2		Case 3	
Lake	normal	extended	normal	extended	normal	extended
Superior						
Maximum	76.4	101.1	N.A.	N.A.	N.A.	N.A.
Mean	15.5	20.5	18.0	23.3	53.5	60.3
Michigan						
Maximum	72.8	95.2	N.A.	N.A.	N.A.	N.A.
Mean	14.7	19.2	17.1	22.4	51.0	66.7
Huron						
Maximum	105.9	136.3	N.A.	N.A.	N.A.	N.A.
Mean	21.5	27.6	25.0	32.2	74.2	96.6
Erie						
Maximum	99.5	128.9	N.A.	N.A.	N.A.	N.A.
Mean	20.2	26.1	23.5	30.4	69.7	90.3
Ontario						
Maximum	36.5	47.5	N.A.	N.A.	N.A.	N.A.
Mean	7.4	9.6	8.6	11.2	25.6	33.3

Case 1: Graywater and blackwater are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Where graywater is untreated and blackwater treated

N.A.: Data unavailable

Normal: Existing navigation season

Extended: Projected extended navigation season

Table 3-14

Annual Loadings of Suspended Solids
to the Great Lakes from Commercial Vessels Treating Graywater

Lake	Maximum Loadings in Thousand Kilograms — Cases of Graywater Treatment: Case 1 normal	Case 1 extended	Case 2 normal	Case 2 extended	Case 3 normal	Case 3 extended
Superior						
Maximum	59.0	78.1	N.A.	N.A.	N.A.	N.A.
Mean	10.0	13.2	12.1	16.0	32.5	43.0
Michigan						
Maximum	56.2	73.5	N.A.	N.A.	N.A.	N.A.
Mean	9.5	12.5	11.5	15.1	31.0	40.8
Huron						
Maximum	81.8	106.5	N.A.	N.A.	N.A.	N.A.
Mean	13.9	18.1	16.8	21.9	45.0	58.7
Erie						
Maximum	76.8	99.6	N.A.	N.A.	N.A.	N.A.
Mean	13.0	16.9	15.8	20.5	42.4	55.0
Ontario						
Maximum	28.2	36.7	N.A.	N.A.	N.A.	N.A.
Mean	4.8	6.2	5.8	7.5	15.5	20.2

Case 1: Graywater and blackwater are treated

Case 2: Same as case 1 except laundry wastes are untreated

Case 3: Graywater is untreated and blackwater treated

N.A.: Data unavailable

Normal: Existing navigation

Extended: Projected extended navigation season

Table 3-15

Sources of Annual Biochemical Oxygen Demand
(5-Day) Substance Loadings to the Great Lakes

Source	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
	Loadings by Lake and Source in Thousand Kilograms Per Year				
Industrial[a]	53,071	N.A.[c]	4,891	14,162	17,045
Municipal[a]	1,643	19,710	1,460	125,377	28,908
Tributary[a]	98,367	17,415	88,366	64,860	62,305
Vessels[d] (Normal Season)	76.4	72.8	105.9	99.5	36.5
Vessels[b] (Extended Season)	101.1	95.2	136.3	128.9	47.5
TOTAL (Normal Season)	153,157.4	37,197.8	94,822.9	204498.5	108,294.5
TOTAL (Extended Season)	153,182.1	37,220.2	94,853.3	204527.9	108,305.5

a Loading values and sources obtained from Great Lakes Water Quality Board, 1975

b Loadings are maximum values obtained from Table 3-13

c Data unavailable

Table 3-16

Sources of Annual Suspended Solids
Loadings to the Great Lakes

Source	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
	Loadings by Lake and Source in Thousand Kilograms Per Year				
Industrial[a]	2,217,159	9,072	13,880	184,703	34,654
Municipal[a]	1,089	20,775	1,451	236,866	27,397
Tributary[a]	113,489	784,715	110,586	1,681,830	566,809
Vessels[b] (Normal Season)	59.0	56.2	81.8	76.8	28.2
Vessels[b] (Extended Season)	78.1	73.5	106.5	99.6	36.7
TOTAL (Normal Season)	2,331,796.0	814,618.2	125,998.8	2,103,475.8	628,888.2
TOTAL (Extended Season)	2,331,815.1	814,635.5	126,023.5	2,103,498.6	628,896.7

[a] Loadings and sources obtained from Great Lakes Water Quality Board, 1975.

[b] Loadings are maximum values obtained from Table 3-14.

Table 3-17

Increase in Suspended Solids and Biochemical Oxygen Demand Levels in the Great Lakes Resulting from Annual Loadings of Commercial Vessels

	Lake[a] Volume (x 10^{15} liters)	Increase in[b] Concentration BOD_5 (nanograms/liter)		Increase in[b] Concentration of SS (nanograms/liter)	
		Normal	Extended	Normal	Extended
Superior	12.200	6.26	8.28	4.84	6.40
Michigan	4.920	14.80	19.35	11.42	14.94
Huron	3.537	29.94	38.54	23.13	30.11
Erie	0.483	206.00	266.87	159.00	206.2
Ontario	1.637	22.30	29.02	17.23	22.42

[a] Obtained from Upchurch (1977b)

[b] Based on maximum annual loads (case #1 treatment in Tables 3-13 and 3-14) divided by lake volume.

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4.0 SHORESIDE DISPOSAL FACILITIES

4.1 Introduction

Any commercial vessel on the Great Lakes which elects to hold its blackwater and graywater, instead of treating it onboard and discharging it to the lake, requires some type of shoreside wastewater receiving facility to accept the retained waste. A survey of shoreside disposal facilities at selected U.S. Great Lakes ports found three major types of services available. These are discharge risers, tank trucks and waste collection vessels. The results of this survey, including a port-by-port description of facilities and an in-depth discussion of shoreside facilities, are found in Phase I of this report (Bartley, et al. 1979).

4.2 Discharge Risers

A discharge riser is a sewer line opening which is located dockside for the sole purpose of accepting wastewater pumped from ships via a long flexible hose. After entering a discharge riser, waste is transported through regular sewer lines to a wastewater treatment plant where it receives treatment and is ultimately disposed to nearby lakes or rivers.

Discharge risers are found at a number of ports; however, they are usually located at public docking facilities which primarily receive foreign flag vessels. At these docks the risers are usually only accessible from one or two berths. This means that for many vessels extra in-port maneuvering would be required, causing delay and added expense to shipowners who lose thousands of dollars per hour of delay. The one exception to this is the port of Burns Waterway Harbor-Port of Indiana. This port provides discharge riser service for seven of its eight available berths.

Waste disposal by discharge risers has several advantages. Assuming service is available at the berth used, wastewater can be pumped out of ship holding tanks into discharge risers during loading or unloading operations so no time is wasted due to sewage disposal. No prior arrangements must be made for service and if the ship experiences delays en route, the discharge risers will be waiting. The discharge risers are not directly limited by the capacity of waste they can accept, which means that they can handle black and graywater in any volume likely to be retained onboard ship.

As stated previously, most discharge risers at Great Lakes ports are found at public docks, but there are exceptions. Several private fixed-base shipping operations use discharge risers to dispose of wastes held by their fleet of vessels. Their ships, which return with regularity to their home dock, discharge upon each return. Because the discharge risers are owned by the same company which owns the docks and ships, no direct cost is incurred by each ship operator. This is the most successful and regular use of risers found on the Great Lakes.

Discharge risers at public terminals receive little or no use. Some have never been used and many others have not had enough use to justify the determination of a regular rate to charge for the service.

No problems with the compatibility of shipboard and shoreside fittings were noted during the survey. Adapters, supplied by the port or carried onboard ships, could solve any mismatching problems. Also, no spills or the likelihood of such were reported during the survey.

No major winter-related problems with discharge risers have been reported. Sewer lines should be located below frost level and, therefore should not experience freezing problems. The only winter problems noted were those of locating the risers under cover of snow and the freezing of fittings and possibly the riser opening. These are remedied by use of shovel, ice chisel or perhaps a heating torch, and are inevitable winter-related inconveniences commonly found throughout cold weather regions.

4.3 Tank Trucks

The most widely available form of waste disposal is provided by tank trucks. These tank trucks are of two main types, septic tank cleaning trucks and trucks available from industrial waste disposal or water pollution control companies. Septic tank cleaning trucks, used primarily to pump out residential septic tanks, are available in every port city on the Great Lakes. The capacity of these vehicles usually ranges from 1,500 to 3,000 gallons.

Tank trucks from industrial disposal or water pollution control companies are available in the larger American port cities on the Great Lakes such as Cleveland, Detroit, etc. These trucks have capacities of from 5,000 to 7,000 gallons.

In general, both types of tank trucks are equipped for vacuum suction although most ships use their own pumps. Once collected, waste from these trucks is usually transported to municipal wastewater treatment plants for treatment.

Although widely available, tank trucks are severely limited in pumping wastewater from ships due to their small capacities. To pump out holding tanks of 30,000 to 40,000 gallons of black and graywater, a number of trips would be necessary. This would prove expensive and very time-consuming.

At some docks on the Great Lakes, truck service is not possible. These docks have been designed such that vehicles cannot be accommodated. Some ore-loading docks, in particular, are constructed to allow railcar access only.

Many states use tank trucks as evidence of their ability to provide adequate shoreside waste receiving facilities for vessels that would not be allowed to discharge wastewater, treated or raw, in no-discharge waters. Tank trucks may be able to pump out limited quantities of waste, but their adequacy is strongly in question where large quantities of combined black and graywater are concerned.

Cold weather conditions during winter months do cause some problems and delays for tank trucks. Lines, valves and fittings often freeze during subfreezing weather. Problems of this type are solved by the use of ice chisels or heating torches. Tank trucks normally operate year-round whether they service vessels or not, so winter problems are not problems induced by an extended navigation season on the Great Lakes, but rather common occurrences in any winter environment.

4.4 Waste Collection Vessels

The last means of shoreside wastewater disposal found in ports is that of waste collection vessels. These craft include a boat utilizing an ondeck 3,000 gallon collection tank, a self-powered barge capable of accepting 5,000 gallons, and three large tankers capable of receiving 30,000, 48,000, or 77,000 gallons of wastewater, respectively. Waste collection service by vessels is presently available only at the ports of Cleveland and Duluth-Superior.

The smaller of these craft experience the same limitations of capacity as do tank trucks, but the larger of the vessels should be able to accept the blackwater and graywater held by any ship. The three large vessels have tremendous pumping capability such that time of pumpout should not be a restriction to any ship. The 30,000 gallon capacity tanker is able to pump out liquid waste and fuel a ship simultaneously. This provides advantages for both the ship being serviced and the service vessel. No additional manpower is required on the part of the service vessel to provide both services and, since the ship can discharge wastewater during normal fueling operation, no extra time is wasted in port.

Waste collection vessels can moor alongside any vessel at any dock in a harbor. This eliminates the problem of access encountered by tank trucks at some docks and the problem of extra in-port maneuvering common to many discharge risers.

For waste collection vessels there would be no special problems presented by a winter navigation season for Great Lakes shipping. Harbors and ports where collection vessels would be operating would be free of ice due to harbor bubblers and booms, etc. Freezing of valves, hoses, etc., may occur but again, these are normal occurrences in cold weather regions and do not present a major problem.

This type of wastewater disposal service has seen very little use to date. Commercial lakers have yet to be serviced on a regular basis.

4.5 Wastewater Treatment Plants

With the minor exception of occasional land disposal, waste from all of the aforementioned means of vessel waste disposal receive treatment at a wastewater treatment plant (WWTP). The present volume of vessel waste going to WWTPs is minor and considered negligible by plant operators. While the volume of vessel waste generated per ship increases when graywater is included, in general it should not present a problem for WWTPs based on the present usage of shoreside disposal facilities. However, the successful petition by Great Lakes States for no-discharge status of their waters would dictate the use of holding tanks, causing the vessel waste loading to WWTPs to increase significantly relative to the present vessel waste discharge.

Many WWTPs in port cities on the Great Lakes are currently at or nearing their capacity. As a result, many of these are in the process of expansion or taking steps to increase their capacity, e.g., reducing infiltration or excluding storm runoff from the waste stream. Vessel waste is not considered a factor in the need for increased capacity by WWTP authorities. Fast-growing city populations and increasing industrial loads are the major loads presently taxing WWTPs. Finally, a determination of the impact of increased hydraulic loadings from vessel wastes pumped ashore should best be conducted on a city-by-city basis, since local circumstances vary widely.

The contaminant loading of combined black/graywater is not expected to pose any major problems to WWTPs because it is similar in concentration to that from an average residential household.

There is an opinion voiced in the shipping industry that the effluent from some municipal WWTPs which accept sewage from ships, treat it and return it to the lake, is inferior in quality to that of MSDs which discharge treated effluent directly into the lakes. It is indeed true that WWTPs of major cities on the Great Lakes have consisted of older treatment works frequently operating above their design capacity, and that improvements have lagged far behind the development and advances of shoreside sanitary engineering. However, since the passage of P.L. 92-500 in 1972, shoreside WWTPs have been upgrading their facilities in order to meet established secondary treatment standards. These standards include the following limitations on WWTP effluent quality:

a) the arithmetic mean of effluent samples collected in 30 consecutive days shall not exceed 30 mg/l BOD

b) the arithmetic mean of effluent samples collected during 30 consecutive days shall not exceed 30 mg/l SS

c) the geometric mean of effluent samples collected during seven consecutive days shall not exceed 200 fecal coliform bacteria per 100 ml.

These standards are more stringent than the current Type II standards regulating treated blackwater effluent by vessels. As of 1979, many WWTPs have not completed their facilities improvements. Thus, shoreside WWTPs often experience difficulty in meeting their required standards, as do some shipboard MSDs. During periods of heavy rainfall, many WWTPs on the Great Lakes currently discharge raw or combined sewage directly into lakes and rivers due to large quantities of storm runoff or infiltration water in the waste stream. The plant is unable to adequately treat the tremendous volumes of wastewater and therefore diverts a large portion of the excess flow to natural water sources. However, as previously mentioned, these plants are currently in the process of expansion or modification to avoid this. It is possible, therefore, that the effluent quality from Type II MSDs may exceed that from shoreside WWTPs in some circumstances.

The Clean Water Act of 1977 (P.L. 95-217) includes a provision which, when acted upon, would require the discharge of vessel blackwater and graywater to meet, at a minimum, shoreside secondary treatment standards. Shipboard and shoreside discharge sources would then be scheduled to meet the same standards.

5.0 TECHNICAL AND ECONOMIC ASSESSMENT OF GRAYWATER TREATMENT AND RETENTION

5.1 Introduction

As discussed in Section 1.0, the Clean Water Act of 1977 (P.L 95-217) gave notice that, at some time in the future, the term "sewage" would be redefined to include graywater (i.e., galley, bath and shower waters). This would mean that graywater would be subject to regulation as is blackwater. The implementation of graywater treatment or retention requirements would have definite impacts on the Great Lakes shipping community in terms of both economic impacts to shipowners and shipboard impacts to both new and existing vessels. Section 2.0 discussed the technical considerations involving the MSDs. This section will evaluate the economic and shipboard impact due to treating or retaining graywater and will present a discussion of holding tank feasibility.

5.2 Impact of Graywater Treatment on Existing Vessels

As of January 30, 1980, all vessels must have installed a marine sanitation device which will treat sewage, or blackwater, generated onboard. In accordance with this federal regulation, most Great Lakes ship operators have installed or will install MSDs as required. Although many ship operators, anticipating future graywater regulation, have installed MSDs which are designed to treat or hold both black and graywater, the majority of Great Lakes vessels possess only the capability to treat or retain blackwater at this time. Graywater regulations would, therefore, have an impact on these vessels.

Existing vessels, most built before the announcement of possible legislation, usually discharge all graywater directly overboard. Graywater flows by gravity from its many sources to the nearest of several discharge points located around the perimeter of the hull. During installation, lines were kept short with no attempt made to combine domestic and sanitary drains. In order for graywater to be treated or retained, these drains must first be integrated with the blackwater lines leading to an MSD. This involves careful planning to maintain the slope necessary for gravity flow. Repiping, or rerouting, of drainage lines is an expensive, often complicated, and time-consuming operation. The cost of modifying graywater drains is extremely dependent on the complexities of existing shipboard piping and the characteristics of each individual vessel and is, therefore, difficult to assess.

Federal law gave notice that only wastewaters from galley, bath and showers would be considered candidates for possible regulation even though graywater is commonly considered as all domestic wastewaters. The notable exception to this, allowed by government, is laundry waste. However, to protect themselves from future repiping time and expense made necessary should laundry discharge be regulated in the future, many ship operators have included laundry wastewaters in the waste stream to their MSDs. It should prove more economically feasible to accomplish all repiping at one time. This seems a logical decision and may be widespread in the future should graywater be regulated.

Once the repiping of drains is considered, the owner of a ship with an MSD installed for blackwater has only three possible options:

1) Upgrade, if possible, the existing MSD to accept the additional hydraulic loading due to a waste stream consisting of both black and graywater.

2) Replace the existing MSD with another unit able to treat both black and graywater flows.

3) Install an additional MSD to handle the excessive hydraulic flow created by the addition of graywater to the waste stream.

The first option, upgrading a blackwater MSD, may prove the most viable alternative for ship operators to choose. This would mean adding to or modifying an existing MSD to accept a greater hydraulic flow than originally designed. The most important consideration involved is whether or not this operation is possible. Some MSDs are of modular construction so that their capacity may be increased by adding or replacing certain components of the system. Often MSDs may be upgraded by the installation of additional tanks which can accept larger quantities of wastewater. Other MSDs are designed for a certain hydraulic flow and cannot be upgraded.

The cost of upgrading an MSD is dependent on the characteristics of the individual MSD and the ship. One manufacturer of biological treatment units estimated that conversion from blackwater capability to combined black/graywater capability ranged from $10,000 to $20,000 for most ships.

Replacing the existing blackwater unit with one able to handle the additional flow of graywater is another option available to ship owners. This process involves removing an existing unit before its useful life has been expended and purchasing and installing a larger MSD. If the same space, interface fittings, etc. may be utilized by the larger unit, the operation becomes merely a replacement procedure. If this is not possible, the larger unit may require a new location which would involve repiping. In general, gaining black and graywater treatment capability by MSD replacement is an expensive proposition. Minimum cost, excluding the lost investment in the original MSD, would be $70,000 to $100,000 for the purchase and installation of a new MSD, plus whatever costs result from repiping of graywater drains.

The third option is adding an additional MSD to treat or retain the additional quantities of wastewater resulting from a combined black/graywater waste stream. Several manufacturers do offer an MSD which, they report, is able to treat graywater only. In addition to a minimum cost of from $70,000 to $100,000 for the purchase and installation of the additional MSD, there are many other considerations. Annual operational, maintenance and repair costs would be doubled and the additional unit would also require shipboard space and add additional weight to the vessel.

All three of these options represent an investment on the part of ship owners. Upgrading the present MSD is the most attractive option in most cases. This operation provides the best utilization of the existing MSD, requires the least capital investment and has the least effect on the vessel in terms of space, weight, maintenance and repair. The other two options require considerable investment. Of these two, replacing the blackwater MSD with one able to treat both black and graywater would likely be the most attractive to ship owners if their present unit cannot be upgraded. This would result in the lowest annual maintenance and repair problems for the crew to deal with and the lowest annual costs of energy usage and operation. Adding an additional unit would double the costs and problems to be encountered in treating shipboard waste. The option most feasible for a particular ship would best be chosen by considering the individual characteristics of the ship and MSD in question.

5.3 Impact of Graywater Regulation on New Vessels

Although the major impact of graywater regulation falls on existing vessels, new vessels are also affected. New vessels will be considered here as those built after official announcement of graywater regulation is made.

Piping of graywater drains on new vessels should not present as big a problem as on existing vessels. Integrated drainage systems for both black and graywater may be planned from the earliest design of piping layout. This is faster, more easily accomplished and less expensive than repiping at a later date. Even now, many ships are being built with these considerations in mind.

The major impact of graywater regulation concerns the MSD which must be purchased and installed onboard. The purchase cost of an MSD is typically a function of its daily hydraulic flow capacity. Since the addition of graywater to the waste stream increases the hydraulic flow, considerably larger MSDs will cost more than those which treat only blackwater. The amount of this increase varies from unit to unit; however, the price for a unit able to accept both black and graywater is usually approximately twice that of a blackwater model.

Cost of biological Type II treatment units designed to treat only blackwater ranged from approximately $7500 to about $20,000; units able to treat both black and graywater ranged from $14,000 to $35,000. The most widely used biological treatment units on the Great Lakes require $10,000 to $15,000 addition investment for a black and graywater MSD as opposed to a blackwater only MSD.

Physical/chemical units able to treat both black and graywater range from $11,400 to $50,000. Several of the more prominent of these units on the Great Lakes offer only one model sized to handle either blackwater alone or black/graywater combined. Prices of these units are in the $40,000 to $50,000 range.

Along with the increased capital cost of larger capacity MSDs, there are also increases in the operational costs. This is mainly due to increased chemical requirements of the larger units. Physical/chemical operational costs commonly range from $1,100 to $3,000 per nine-month season. Since many physical/ chemical units were designed for larger capacities, the increases in operational costs are slight. Biological counterparts, however, reportedly experience increases of up to twice their normal blackwater operational costs of $200 to $800 per year.

According to the survey of manufacturers presented in Section 2.0, the physical size of black/graywater MSDs is greater than that of blackwater MSDs. This means that more shipboard space will be required. On newer vessels this is no problem; however, the older vessels still operating on the Great Lakes today often are limited in their space availability. The amount of the increase varies considerably from unit to unit. One particular biological unit manufacturer, for example, reported a size of 8.5 ft x 5.25 ft x 6.5 ft for their unit capable of treating blackwater, while their unit capable of treating both black and graywater generated onboard Great Lakes ships is 12 ft x 7 ft x 8.25 ft, more than a twofold increase in size.

With most of the MSDs surveyed (Section 2.0) an increase in weight also accompanied the increase in size. Biological treatment units are subject to the greatest increase in weight. Most physical/chemical units surveyed were already able to treat both black and graywater so no increase in weight was noted. Though data on weight were limited, it appeared that biological units experience up to a 250% increase in dry weight and a 200% to 400% increase in operating weight. Of the units surveyed, the majority of biological units with black and graywater capacity were approximately 40,000 lb operating weight and 8,000 lb dry weight. In general, the space and weight attributed to Type II MSDs is not of major impact on Great Lakes vessels. The annual lost revenue for the heaviest of these units is less than $3,000 for a normal or extended season.

The last expense associated with an MSD is that due to installation. From the data available it was not possible to determine the increase in costs for an MSD sized to treat all blackwater and graywater waste over one with blackwater capability only. This was due to cost variation caused by characteristics of individual vessels and the particular MSD chosen. Installation costs for blackwater MSDs vary from one to three times the unit cost with two being the most common factor. Although not clear from the data gathered, it is reasonable to assume that installation of a larger unit would result in greater expense. The magnitude of this increase, however, is not known.

5.4 Technical and Economic Feasibility of Gray/Blackwater Retention

In addition to treatment, the other alternative which would meet any future graywater regulation is retention. This means holding all wastewaters in tanks onboard ship until they can be properly discharged to a shoreside waste receiving facility. These shoreside facilities are discussed in depth in Section 4.0 of this report.

There are two basic types of holding tank systems distinguished by the type of flush system which is used. The first is known as low-volume flush. This is based on the minimum use of water as a flushing medium which allows the smallest possible size holding tank. Although there are many types of low-volume flush systems, most use air or vacuum pressure rather than water to move waste through drainage lines to a central collection point. A small amount of water, about 2 pints, is used only to contain the waste and cleanse the bowl after use.

Manufacturers indicated that low-volume systems can accept graywater, although no known method is presently available to reduce the amount of graywater to be retained. One manufacturer contacted does, however, offer a system which collects graywater separately from blackwater, purifies it, and then reuses it as flush water. With the possible exception of this type unit, low-volume flush retention systems do not offer any advantage when graywater is received other than reducing the amount of blackwater held. No use of low-volume flush systems on the Great Lakes was found. They receive mention here for completeness.

The other type of retention system, most common on the Great Lakes, vessels which use holding tanks, involves use of a standard flush system. This system, similar to shoreside facilities, uses 4 to 6 gallons of water per flush, resulting in a blackwater flow rate of 30 gallons per capita per day. Since this is the most common type of retention and because this system would have the maximum effect on the vessel itself, all further discussion and analysis will refer to standard flush systems only.

Principal Characteristics

Combined black/graywater is typically generated at the rate of 100 gallons per capita per day (see Section 1.0). The average complement of a Great Lakes vessel will be considered 32 persons. Therefore, the average amount of wastewater to be retained per day is 3,200 gallons.

The capacity of this holding tank will be determined by the length of time between pumpout and the contingency margin included in the design. Due to the limited availability of shoreside pumpout facilities, it is advisable for ships to have holding tank capacity sufficient for a round-trip voyage on the Great Lakes. Eight days should be sufficient for a round-trip between any two points on the five lakes during the normal season. During winter navigation conditions this may be extended to ten days. Ten days will also allow a one way trip from any point on the lakes to Montreal or other ports on the St. Lawrence River.

A contingency margin should also be considered in the determination of holding tank capacity. A 50% margin, or another five days, should be sufficient. This margin, in excess of anticipated retention time, takes into account factors which may require additional holding capacity. These factors include additional passengers contributing to the daily load, unexpectedly excessive daily flow, and delays in transit due to rough weather, locking, excessive loading/unloading time, running in ice, awaiting icebreaker assistance, etc.

Total retention time (including contingency margin) for which the holding tank should be designed is 15 days or 480 man days. This means that based on the previous figures, a holding capacity of 48,000 gallons is required. This is calculated as follows:

32 man crew	x 100 gpcd	x 15 days retention time	=	48,000 gallons total tank capacity

Weight is an important consideration when the economic impact of a holding tank is assessed since each ton of holding tank weight represents a

revenue producing ton of cargo which cannot be carried. The weight of a holding tank includes the combined weight of contents and the tank itself.

Based on the above capacity requirements of 48,000 gallons the maximum content of the tank would weigh 178.32 long tons (LT). This is based on wastewater weight of 62.43 lb/ft^3, the weight of water. In this case, the usable volume of the tank is assumed to be completely used so the impact of holding tank weight is the maximum possible. In most cases, the weight of the tank contents would be considerably less.

As discussed in Phase I of this report, steel will be used in the fabrication of the holding tank. The material selection has an impact on the total weight but, while other materials may have less weight, steel is the most economical selection at this time. Steel used in tank construction will be considered 1/2 inch (20.4 lb/ft^2) plate. A 30 ft x 18 ft x 11 ft-10 inch tank which holds 48,000 gallons would have a weight of 24.3 LT. This includes an extra 20% to cover the weight of stiffeners, fittings, inside coating, etc. The weight of the tank itself may vary slightly with different shapes and will be less if existing bulkheads, decks, or the shell are used as boundaries.

Thus, the maximum total weight attributable to a holding tank for graywater is 202.6 LT. The principal characteristics for a black/graywater retention tank as developed in this Section are summarized in Table 5-1.

Effect on Vessel

Adding a holding tank for wastewater can affect the disposition and operation of a vessel in several ways. Major areas which require attention are trim and draft, stability, and the space available for such an installation.

Maintaining design trim and draft within limits are important considerations when weight such as a holding tank is added onboard a vessel. Vessels on the Great Lakes are extremely limited in the amount of water which they can draw due to common depth restrictions of harbors, rivers, locks, etc. and proper trim is essential to the safe and efficient operation of a vessel. Any appreciable weight added onboard a vessel causes its trim and draft to change. Trim is the difference between the draft forward and the draft aft. Trim and draft are interrelated and depend on the location of the holding tank installation.

Maximum effect on trim results when the center of gravity of the holding tank is at its greatest distance from the longitudinal center of flotation, LCF, of the vessel. The LCF is the longitudinal center of the area of the waterplane at which the vessel is floating. Upon additions or deletion of weight, a ship rotates or "trims" around this point. On a 580 ft bulk carrier, which typifies the older vessels operating today, adding a weight of 202 LT at the aft perpendicular 293 ft from the LCF causes a change in draft forward and aft of approximately 3-1/2 ft. This represents a maximum or near maximum case. A holding tank may be located closer to the LCF resulting in less effect.

The change in draft of a vessel due to added weight is determined by its tons per inch immersion factor, TPI. TPI is defined as the weight addition required, as the ship is floating at a certain waterline, to cause a parallel sinkage of one inch. A typical 580 ft bulk carrier may have a TPI factor of about 78.4 (Rawson & Tupper, 1976). Using the value of TPI and assuming negligible heel and trim, this bulk carrier would experience an increase in draft of 2.58 inches due to the 202 LT holding tank previously discussed. If the center of gravity coincides with the LCF of the vessel then this is the total extent of vessel impact. No increase in trim would result. In most instances this is not true and the change in draft and the change in trim would be additive.

A 3-1/2 ft. change in trim and draft could have detrimental effects on the operating condition of vessels, especially older vessels, on the Great Lakes. In our example, the change in draft was less than 3 inches. The remainder is the maximum possible change in trim. It is evident from this change in trim that the location selected for such a large tank onboard a ship is critical. By choosing a location as close to the vessel's LCF as possible, change in trim could be reduced considerably. The amount of this reduction depends on the particular ship and the holding tank location. In general, the effect of a 48,000 holding tank on trim and draft could considerably impact the operating disposition of some Great Lakes vessels.

Whenever a tank containing a liquid substance is placed onboard a ship, its effect on stability should be assessed. Unless the tank is completely full or empty, the free movement of liquid within the tank can have an effect on the metacentric height of the vessel. This effect, termed free surface effect, is due to a shift in the center of gravity which occurs when the tank is inclined. The metacentric height, or GM, is an indication of the initial stability of the ship and is defined as the vertical distance between the center of gravity of the ship and the metacenter of the particular vessel. The impact of free surface effect is independent of the position of the tank in the ship; the tank can be at any height in the ship at any position along its length and need not be on the centerline. The effect, unless the tank is full or empty, is also independent of the amount of liquid in the tank provided the surface area, when inclined, does not change appreciably.

Assuming holding tank size to be 30 ft x 18 ft x 12 ft and box-shaped, as previously mentioned, the maximum decrease in GM for a 650 ft ore carrier is 0.012 ft or a 0.078% decrease in initial stability. This is based on an initial GM of 15.25 ft. Should this tank be installed on a larger vessel, such as the modern "1,000-footers," the decrease in GM is even less.

This calculation is for a standard box-shaped holding tank with no special provisions. Measures are available to effectively reduce the free surface effect of a tank if necessitated. These include adding partial vertical partitioning plates and installing a holding tank with its longest dimension vertical. Both these measures would reduce the free surface area of the liquid within the tank and, therefore, its effect on initial vessel stability.

A holding tank designed to hold both blackwater and graywater generated onboard a Great Lakes vessel would have a maximum of 0.078% change in initial stability. If necessary, this negligible effect can be reduced by certain

TABLE 5-1

Principal Characteristics for Blackwater/Graywater Holding Tank for a Typical U. S. Great Lakes Bulk Carrier

Volume Capacity[a]	48,000 gallons
Design Retention Time[a]	10 days
Contingency Margin[a]	5 days
Max. Retention Time[a]	15 days/480 man days
Tank Weight - empty	24.3 LT
Tank Weight - full	202.6 LT
Space Required	6398.2 ft^3

a) based on normal vessel complement of 32 persons and a combined wastewater flow rate of 100 gallons per day.

measures. Therefore, in most cases, it appears safe to assume that the addition of a black/graywater holding tank will not significantly affect the initial stability of a Great Lakes vessel.

The last area of impact deserving attention is that of available shipboard space. Most holding tanks are located low in the engine room so that all waste lines can drain by gravity. This eliminates the need for pumps. The amount of usable shipboard space available low in the engine room is very limited in many vessels. Newer vessels tend to have more usable space available while many older vessels are extremely limited in this regard. One single tank of 48,000 gallons could easily tax the capacity of many ships on the Great Lakes. This, of course, should be determined on an individual vessel basis, taking into account the configuration and dimensions of the proposed holding tank.

Holding tanks should be designed to fit the space available on the particular vessel. Unlike treatment systems, holding tanks do not require much service area. Only one side need be accessible for inspection and maintenance so bulkheads, decks or the shell may be used as boundaries. If space is not available for a single large holding tank then, perhaps, multiple tanks of smaller capacity could be designed to fit the available space. The tanks could be cross-connected so only one discharge outlet is required. Also, several vessels operating on the Great Lakes today have successfully converted existing shipboard tank space to hold wastewater generated onboard. These tanks formerly held ballast water or fuel. If retention of wastewater is to be considered, then all possible options should be examined. In one instance, a 10,000 gallon holding tank was installed on the boat deck of a bulk carrier, exposed to the weather.

A holding tank of 48,000 gallons capacity is very large and could tax the available usable space aboard Great Lakes vessels. While some vessels could retain black/graywater waste in a tank this large (one fleet of ore carriers has installed and uses holding tanks of approximately this volume on each of their vessels), it would not be reasonable to expect or require all Great Lakes ships to comply with this type of wastewater disposal regulation for both blackwater and graywater.

5.5 Economics of Black/Graywater Retention Tanks

In order to determine the annual cost of using a holding tank to store black and graywater for shoreside discharge several costs must be considered. These are initial fabrication and installation cost, capitalization of these costs, lost revenue due to weight addition, operating and maintenance and finally the cost of pumpout.

Since tanks of a magnitude sufficient to hold both black and graywater are rare on the Great Lakes, data on the cost of fabrication and installation are extremely limited. One shipyard estimated such a tank would cost at least $50,000. More specific cost figures were obtained from the operator of a fleet of ore carriers who installed holding tanks of approximately 40,000 gallons in 1971. Cost at that time for retention and pumpout facilities and retro-fit installation came to $125,000 per ship. Assuming a 7% inflation rate per year in the cost of labor and materials, the cost to a shipowner today would be approximately $215,000 per vessel.

Again, due to the limited availability of cost data, it is not possible to break the cost of holding tanks down in terms of installation, new and retro-fit, and the cost of the tank itself. However, it is generally acknowledged that installation costs of retro-fit installations on existing ships are significantly greater than installation during initial vessel construction. This increase in cost is due largely to the repiping of drains required on many existing ships and the modifications to the vessel which are required. The amount of work necessary and, therefore, the cost, depends greatly on the characteristics of the individual vessel to be outfitted.

Capitalization costs to cover the construction and installation of a holding tank must also be considered in assessing the cost of black/graywater retention. Assuming an interest rate of 10% and that the loan will be repaid over an economic life period of 20 years, annual payment would amount to $25,254. This is an estimate only and does not take into consideration any allowances or subsidies granted by state or federal agencies for vessel construction or modification.

Another important area of concern to shipowners is the amount of revenue lost due to the weight of holding tanks. Shown in Table 5-2 is an estimate of lost revenue for a regular season consisting of 45 round-trip voyages of six days duration and an extended season including an additional ten-round trip voyages of nine days in length.

The next cost to be considered is that of operating and maintenance. These costs vary depending on the equipment used in conjunction with the holding tank. Equipment may range from nothing to a Type I treatment unit which provides both comminution and chlorination to retained sewage. Some vessels employ either comminution only or chlorination only. Operating and maintenance vary from zero for a bare holding tank to approximately $1,500 for an extended season ($1,200 for a normal season) for a holding tank provided with both comminution and and chlorination equipment. These costs are mainly for the chemicals used to disinfect and deodorize.

The last important expense to be considered is for shoreside discharge. Pumpout facilities and costs vary from port to port. Most are used for blackwater only and are expensive at this time. The high cost of disposal may be due to a general lack of use and demand of the available facilities by vessel operators. If demand on the part of ship operators should increase, then a more competitive and active environment may result in lower and more reasonable costs for these services.

Actual cost for the pumpout of both blackwater and graywater are difficult to assess. No ship operators were found who regularly had such large quantities of wastewater removed from their holding tanks by commercial means. Tank trucks with repeated trips could accomplish the task; however, the limited capacity and the time which would be required would, in most cases, be prohibitive.

Table 5-2

Annual Lost Revenue Due to Retention of Black and Graywater

Graywater Holding Tank Wt.	Voyages Per Year	Lost Revenue
202.6 LT[c]	45[a] (normal season)	$ 27,351[b]
202.6 LT[c]	55 (extended season)	$ 33,429[b]

a) Woodward, J.B., 1978

b) Based on freight rate of $3/LT

c) Previously developed in Section 5.4 of this report

Discharge risers, commonly located at public dock facilities which service mostly foreign flag vessels, are not usually accessible by domestic bulk carriers. The use of these facilities by any vessel, foreign or domestic, has in general been so rare that, in many cases, a rate structure for the service has never been developed. Therefore, it would not be fair to base an annual pumpout cost on this type of discharge riser.

In addition to public terminal locations, some discharge risers are also found at private facilities. Several fixed base shipping operations use this method of disposal for their fleet vessels which are fitted with sewage holding tanks. This appears to be a convenient cost-effective method of sewage discharge. Company vessels return to their home dock on a regular basis and, because the discharge risers are company-owned, no direct cost to the ship results.

Waste collection vessels (see Section 4.0), available in at least two ports, can accept the large quantities of black and graywater waste which would require disposal. Today, however, these vessels have not been utilized by ship operators for this purpose. The minor use they have seen has been accepting much smaller quantities of waste (10,000 gallons or less). Often this use has been on a regular contract basis which provides the lowest cost to shipowners. Because of the lack of cost data for these vessels, it is not possible to estimate the annual cost of pumpout by waste collection vessels.

Because of this lack of cost data for the disposal of large quantities of wastewater, it will be assumed in our estimate of annual cost that the shoreside disposal facilities used for discharge will be company-owned and, as such, no direct cost will result. If this is not the case, the cost of discharge will be of considerable impact to annual cost and must be considered.

Based on the above figures, the annual cost for holding tank use is approximately $54,000 for a normal nine-month season and $60,000 for a year-round extended season. These figures are shown in Table 5-3.

Table 5-3

Annual Cost of Black/Graywater Retention

	Normal Season	Extended Season
Pumpout	- 0 -*	- 0 -*
Operating and Maintenance Expenses (chlorine, etc.)	1,200	1,500
Lost Revenue (Maximum)	27,351	33,429
Annual Loan Payments (20 year economic life)	25,254	25,254
TOTAL ANNUAL COST TO SHIPOWNER	$ 53,805	$ 60,183

* See ref. in text

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CONCLUSIONS

1) The regulation of vessel graywater waste will have an impact on the shipping community of the Great Lakes but the advent of winter navigation is not expected to adversely affect the disposal of graywater waste by vessels.

2) The minor effects of winter conditions on MSDs exposed to cold temperatures are easily prevented by the use of immersion heaters and similar heating or insulating devices. The unavoidable freezing effects on winter shoreside disposal facilities are typically resolved by the use of ice chisels, heating torches, etc., and are considered commonplace in a winter environment.

3) The generation rate and composition of graywater waste is extremely variable and changes considerably from hour-to-hour and vessel-to-vessel.

4) Type II marine sanitation devices (MSDs) available at this time are capable of meeting current blackwater effluent standards but do not appear capable of consistently meeting shoreside secondary treatment standards except under optimum operating conditions.

5) MSDs which are designed to accept only blackwater flow are not capable of adequately treating or retaining the additional hydraulic loading of graywater. For an older ship with this type of MSD, upgrading the existing unit, if possible, should prove the most technically and economically feasible means of compliance for ship owners.

6) Retaining all blackwater and graywater onboard vessels does not appear to be feasible for all Great Lakes vessels due to the high cost of such an installation, the large amount of space required and the impact of such a tank on vessel trim and draft.

7) For ships which do retain all black/graywater onboard, the most feasible means of shoreside disposal is provided by discharge risers and waste collection tankers. Tank trucks, in most cases, could not adequately accept the tremendous volume of blackwater and graywater.

8) Based on information received from ship operators and manufacturers of MSDs, there does not appear to be justification for the exclusion of shipboard laundry waste from graywater regulation.

9) The long-term impacts associated with the treatment of graywater and subsequent loadings of pollutants, under worst case conditions of treatment, are minor and virtually undetectable. Annual total phosphorus loading from vessels during normal navigation season conditions would not accelerate the natural eutrophication process and jeopardize

the trophic status of the Great Lakes. Annual loadings of BOD_5, suspended solids and total phosphorus would not increase their respective in-lake levels to analytically detectable concentrations. Thus the Great Lakes ecosystem is capable of assimilating the annual loadings of pollutants.

The long-term impacts associated with graywater treatment and the extension of the normal navigation season under worst case conditions of treatment performance are the same as those for the existing or normal navigation season (as above) for the same reasons.

10) Ice-covered receiving waters will be impacted in the short term due to the reduced rates of dilution and dispersal associated with ice-cover. These impacts will be lessened by the cold temperatures of the receiving waters and by ice breaking and thawing. The greatest concern would be for harbors which generally have poor mixing properties anyway and for some sensitive coastal environments. The short-term impacts to ice-covered receiving waters endure until ice thaws, mixing commences and the pollutants disperse. No long-term effects on the ecosystem are anticipated.

11) Short-term impacts of daily loadings from vessels using existing MSDs for the treatment of graywater are moderate. Impacts would be most severe on receiving waters with poor mixing properties, e.g., harbors and under ice-cover.

RECOMMENDATIONS

It is recommended that:

1) The entire Great Lakes-St. Lawrence Seaway system have a single regulation governing the disposal of blackwater and graywater waste from vessels.

2) The "no-discharge" provision of P.L. 92-500 be re-examined with respect to graywater. Graywater and blackwater retention, which is the only practical means of meeting such a regulation, may not prove feasible for all ships.

APPENDIX A

SURVEY FORMS AND DATA FOR GRAYWATER STUDY

SURVEY FORM

1. Is each MSD capable of reducing the influent levels of pollutants from combined wastes? If not, can the MSD treat blackwater only? Or, how can it be upgraded?

2. What process is used by each MSD to treat combined wastewaters?

3. Based upon an average influent from combined wastes (please specify hydraulic flow rate, and levels of BOD_5, suspended solids, total phosphorus and coliform if possible) what is the average effluent (again specify levels of BOD_5, suspended solids, coliform and total phosphorus)? If your company manufactures more than one MSD using different processes, answer the above question for each type.

4. The relationship between increased flow rates of graywater and cold weather has been observed shoreside. Do seasonal changes in the hydraulic flow rate occur shipboard? How? Please give flow rates for winter, summer, autumn and spring.

5. Hydraulic flow rates for graywater peak during different times of day i.e. shift changes, meal times). Do the peak flow rates of graywater pose problems for your MSDs? Which units and processes? What are the problems?

6. What is the expected life time of the MSD?

7. What is the purchase cost of each of your MSDs designed to treat blackwater wastes at 30 gpcd for approximately 25-40 person crew?

8. What is the purchase cost of each of your MSDs designed to treat combined (black/graywater) wastes produced by a crew of 25-40?

9. What are the operational costs for each of the above units?

10. Do you manufacture any units which can treat only graywater? Is it feasible or possible with any of your existing MSDs?

Table 1

Results of Survey[1] of Marine Sanitation Device Manufacturers

on Blackwater Treatment

USCG Certified Type	Process	Capable of Processing Graywater yes/no	Cold Weather Problems In			Res. & Dev. in Graywater Treatment yes/no	Other Comments
			Efficiency none/some	Treatment none/some	Freezing none/some		
I	maceration & sterilization	1/0	1/0	1/0	1/0	0/1	-
II	Physical / chemical or biological	4/0	1/2	1/2	1/3	1/3	1. need heaters for cold weather 2. need research grants for graywater treatment
III	Retention	2/0	2/0	2/0	1/1	0/2	1. volume of graywater is a problem
	Other, e.g., incineration, evaporation	2/1	3/0	3/0	1/2	1/2	1. volume of graywater flow is a problem 2. more energy required for graywater
	SUMMARY	9/1	7/2	7/2	4/6	2/8	1. cold weather freezing of lines requires heaters 2. Volume of graywater flow could be a problem

[1] Survey results from a study by Bartley, et al. 1979

Table 2

Responses to Survey of Marine Sanitation

Device Manufacturers on Graywater Treatment

Question No.	Physical/Chemical Type II MSDs					Biological Type II MSDs				
	Yes	No	Does Not Apply	Don't Know	No Response	Yes	No	Does Not Apply	Don't Know	No Response
1a	2	0	0	0	0	2	1	0	0	0
1b	0	0	2	0	0	1	1	1	0	0
1c	0	0	2	0	0	1	1	1	0	0
4	0	0	0	1	1	0	3	0	0	0
5	0	2	0	0	0	0	2	0	0	0
10	1	1	0	0	0	0	3	0	0	0
6a: 0-10 years			0					0		
10-20 years			0					1		
> 21 years			2					1		

Question # pertains to those on survey form

Table 3

Reported Results of Survey of Marine Sanitation Device Manufacturers on Graywater Treatment Performance

Average and Range ( ) of Values per Parameter

	Parameters	USCG Type II MSDs: Physical Chemical Treatment	USCG Type II MSDs: Biological[1] Treatment
Influent	Hydraulic load in gallons per capita per day	110 (185 - 80)	128 (185 - 100)
	Biochemical O_2 Demand (5 Day) mg/l	465 (1,500 - 150)	500 (500)
	Coliform, #/100 ml	- (10^7 - 10^6)	- (10^5)
	Total Phosphorus mg/l	15.7 (54.0 - 5.0)	12.0 (12.0)
Effluent	Biochemical O_2 Demand (5 Day) mg/l	155 (550 - 8)	30 (40 - 6)
	Suspended Solids mg/l	72 (400 - 4)	48 (55 - 4)
	Coliform, #/100 ml	15 (90 - 0)	138 (200 - 14)
	Total Phosphorus mg/l	7 (22 - 1)	2 (2)
% Reduction	Biochemical O_2 Demand (5 Day)	68	92.5
	Suspended Solids	86	92.5
	Coliform	99	N.A.
	Total Phosphorus	58	80

[1]Also available from one manufacturer is tertiary treatment unit with an average effluent of 10 mg/l BOD_5 and 10 mg/l SS.

Table 4

Feasibility of Graywater Disposal By Use of No-Discharge

Types of Marine Sanitary Devices[1]

Process	Cold Weather Effects			Capable of Graywater Waste		Limitation to Graywater Treatment
	Efficiency some/none	Treatment some/none	Freezing some/none	a) treatment yes/no	b) processing yes/no	
Incineration, Evaporation	0/2	0/2	1/1	2/0	2/0	1. increase in flow may tax capacity of system 2. increase in flow would require more energy for processing
Low-volume flush system , e.g., retention, recycle	0/3	0/3	2/1	0/3	2/1	1. requires larger holding tank for increase in flow 2. increased flow may tax capacity of system 3. vacuum collection system not applicable to graywater
SUMMARY	0/5	0/5	3/2	2/3	4/1	

[1] Data obtained from previous survey (Bartley, et al., 1979) and from manufacturers brochures and technical reports.

MARINE SANITATION DEVICE MANUFACTURERS RESPONDING TO SURVEY

Chrysler Corp. - Space Division
New Orleans, LA

Clearwater, Inc.
Walworth, WI

Colt Industries
Beloit, WI

Demco, Inc.
Oklahoma City, OK

GARD, Inc. / GATX Corp.
Niles, IL

Hamworthy USA, Inc.
Buffalo, NY

Hyde Products, Inc.
Westlake, OH

Jered Industries, Inc.
Birmingham, MI

Koehler - Dayton
New Britain, CT

Red Fox Industries
New Iberia, LA

Saint Louis Ship / FAST Systems
Saint Louis, MO

Sigma Treatment Systems
Brooklyn, NY

Walton Wilson International
Hoboken, NJ

Summary of Ship Operator Survey

Number of vessels which discharge graywater directly overboard with no treatment	79	(83%)
Number of vessels which treat graywater	10	(11%)
Number of vessels which retain graywater	6	(6%)
Total Number of Vessels Surveyed	95	(100%)

Great Lakes Ship Operators Providing Information for Survey

American Steamship Company
Buffalo, New York

AMOCO Oil Company
Whiting, Indiana

Bethlehem Steel Corporation, Great Lakes Steamship Division
Cleveland, Ohio

Columbia Transportation Division, Oglebay Norton Company
Cleveland, Ohio

Erie Sand Steamship Company
Erie Navigation Company
Erie, Pennsylvania

Ford Motor Company, Marine Division
Dearborn, Michigan

Hanna Mining Company
Cleveland, Ohio

Inland Steel Company
Chicago, Illinois

Marine Fueling
Cleveland, Ohio

S & E Shipping Corporation
Cleveland, Ohio

United States Steel Corporation, Great Lakes Fleet
Duluth, Minnesota

APPENDIX B

DATA ON ANNUAL LOADINGS OF COMMERCIAL VESSELS FROM TREATED WASTEWATERS

Table 1

Annual Loadings, Data and Parameters for the Great Lakes During a Normal and a Extended Navigation Season From Combined Wastewaters

Parameter[1]	Superior	Michigan	Huron	Erie	Ontario
N_{ij} - Normal	3607	4229	6401	6263	2205
Extended	3785	4438	6717	6572	2314
Cf_{ij} - Normal	3.2	2.6	2.5	2.4	2.5
Winter	7.0	5.4	5.1	4.8	5.1
S(crew #)	32	32	32	32	32
L_a - BOD Maximum	75.5	75.5	75.5	75.5	75.5
(kg/capita/yr) Mean	15.3	15.3	15.3	15.3	15.3
L_a - SS Maximum	58.3	58.3	58.3	58.3	58.3
(kg/capita/yr) Mean	9.9	9.9	9.9	9.9	9.9
L_a - TP Maximum	5.6	5.6	5.6	5.6	5.6
(kg/capita/yr) Mean	0.8	0.8	0.8	0.8	0.8
	x10^{3}kg tons	x10^{3}kg tons	x10^{3}kg tons	10x^{3}kg tons	10x^{3}kg tons
L-BOD (Normal/Max)	76.4(84.2)	72.8(80.2)	105.9(116.7)	99.5(109.6)	36.5(40.2)
(Normal/Mean)	15.5(17.1)	14.7(16.3)	21.5(23.7)	20.2(22.2)	7.4(8.1)
(Extended/Max.)	101.1(111.5)	95.2(104.9)	136.3.(150.2)	128.9(141.9)	47.5(52.3)
(Extended/Mean)	20.5(22.6)	19.2(21.2)	27.6(30.4)	26.1(28.7)	9.6(10.6)
L - SS (Normal/Max)	59.0(65.0)	56.2(61.9)	81.8(90.1)	76.8(84.7)	28.2(31.0)
(Normal/Mean)	10.0(11.0)	9.5(10.5)	13.9(15.3)	13.0(14.4)	4.8(5.3)
(Extended/Max)	78.1(86.1)	73.5(81.0)	106.5(117.7)	99.6(109.5)	36.7(40.4)
(Extended/Mean)	13.2(14.6)	12.5(13.8)	18.1(19.9)	16.9(18.6)	6.2(6.8)
L - TP (Normal/Max)	5.7(6.2)	5.4(5.9)	7.9(8.7)	7.4(8.1)	2.7(3.0)
(Normal/Mean)	0.8(0.9)	0.8(0.8)	1.1(1.2)	1.1(1.2)	0.4(0.4)
(Extended/Max)	7.5(8.3)	7.1(7.8)	10.2(11.3)	9.6(10.5)	3.5(3.8)
(Extended/Mean)	1.1(1.2)	1.0(1.1)	1.5(1.6)	1.4(1.5)	0.5(0.6)

[1] $L\text{-}k = N_{ij} x CF_{ij}/365 \times S \times L_a\text{-}k$ where N_{ij} = # of vessel trafficking lake "i" annually for "j" season

Cf_{ij} = days a vessel is on lake "i" for "j" season

S = 32 persons/vessel

L_a-k = annual per capital load for "k" pollutant (TP, SS, BOD)

L-k = annual load for "k" pollutant

APPENDIX C

DATA ON ANNUAL LOADINGS OF COMMERCIAL VESSELS FROM UNTREATED WASTEWATERS

Table 1

Annual Loadings, Data, and Parameters for the Great Lakes During Normal and Extended Seasons from Untreated Laundry Wastewaters (Case #2)

Parameters (Note: N, Cf, and S are the same as in Appendix B for each lake and season)		Great Lakes: Superior		Michigan		Huron		Erie		Ontario	
L_a - BOD_5 (kg/capita/yr)	Maximum	NA		NA		NA		NA		NA	
	Mean	2.5		2.5		2.5		2.5		2.5	
L_a - SS (kg/capita/yr)	Maximum	NA		NA		NA		NA		NA	
	Mean	2.1		2.1		2.1		2.1		2.1	
L_a - TP (kg/capita/yr)	Maximum	.003		.003		.003		.003		.003	
	Mean	.002		.002		.002		.002		.002	
		$x10^3$kg	tons	$x10^3$kg	tons	$x10^3$kg	tons	$x10^3$kg	tons	x103kg	tons
L-BOD_5	(Normal/Maximum)		NA		NA		NA		NA		NA
	(Normal/Mean)	2.5	2.8	2.4	2.7	3.5	3.9	3.3	3.6	1.2	1.3
	(Extended/Max)		NA		NA		NA		NA		NA
	(Extended/Mean)	3.3	3.7	3.2	3.4	4.6	5.0	4.3	4.7	1.6	1.7
L-SS	(Normal/Maximum)		NA		NA		NA		NA		NA
	(Normal/Mean)	2.1	2.3	2.0	2.2	2.9	3.2	2.8	3.0	1.0	1.1
	(Extended/Max)		NA		NA		NA		NA		NA
	(Extended/Mean)	2.8	3.1	2.6	2.9	3.8	4.2	3.6	3.9	1.3	1.5
		kg	tons	kg	tons	kg	tons	kg	tons	kg	tons
L-TP	(Normal/Maximum)	3.0	.003	2.9	.003	4.2	.005	4.0	.004	1.4	.002
	(Normal/Mean)	2.0	.002	1.9	.002	2.8	.003	2.6	.003	1.0	.001
	(Extended Max)	4.0	.004	3.8	.004	5.5	.006	5.1	.006	1.9	.002
	(Extended Mean)	2.7	.003	2.5	.003	3.7	.004	3.4	.004	1.3	.001

NA = data unavailable

Table 2

Annual Loadings, Data, and Parameters for the Great Lakes During Normal and Extended Seasons from Untreated Graywater Wastes (Case #3)

Parameters (Note: N, CF, and S are the same as in Appendix B for each lake and season)		Superior		Michigan		Huron		Erie		Ontario	
L_a - BOD_5 (kg/capita/yr)	Maximum	NA		NA		NA		NA		NA	
	Mean	50.4		50.4		50.4		50.4		50.4	
L_a - SS (kg/capita/yr)	Maximum	NA		NA		NA		NA		NA	
	Mean	28.8		28.8		28.8		28.8		28.8	
L_a - TP (kg/capita/yr)	Maximum	NA		NA		NA		NA		NA	
	Mean	2.1		2.1		2.1		2.1		2.1	
		$x10^3$kg	tons	$x10^3$kg	tons	$x10^3$kg	tons	$x10^3$kg	tons	$x10^3$kg	tons
L-BOD_5	(Normal/Maximum)	NA		NA		NA		NA		NA	
	(Normal/Mean)	51.0	56.2	48.6	53.5	70.7	77.9	66.4	73.2	24.4	26.8
	(Extended/Maximum)	NA		NA		NA		NA		NA	
	(Extended/Mean)	57.0	62.8	63.6	69.9	92.0	101.3	86.0	94.7	31.7	34.9
L-SS	(Normal/Maximum)	NA		NA		NA		NA		NA	
	(Normal/Mean)	29.1	32.1	27.8	30.6	40.4	44.5	38.0	41.8	13.9	15.3
	(Extended/Maximum)	NA		NA		NA		NA		NA	
	(Extended/Mean)	38.6	42.4	36.3	39.9	52.6	57.9	49.2	54.1	18.1	19.9
L-TP	(Normal/Maximum)	NA		NA		NA		NA		NA	
	(Normal/Mean)	2.1	2.3	2.0	2.2	2.9	3.2	2.8	3.0	1.0	1.1
	(Extended/Maximum)	NA		NA		NA		NA		NA	
	(Extended/Mean)	2.8	3.1	2.6	2.9	3.8	4.2	3.6	3.9	1.3	1.5

NA = data unavailable

APPENDIX D

PER CAPITA VALUES FOR THE TREATMENT OF BLACKWATER

Table 1

Source of Values for Per Capita Load

by Type of Blackwater Treatment and by Parameter

Parameter	Definition	Type I[a] Treatment Value	Source	Type II[a] Treatment Value	Source
L_a-TP	Total phosphorus per capita load	0.639 Kg/yr (1.41 lbs/yr)	McCarty et al., 1967	0.512 Kg/yr (1.128 lb/yr)	Metcalf & Eddy, 1972; Chapra, 1977
L_a-BOD_5	BOD_5 per capita load	24.869 Kg per man per yr[b] (54.83 lbs/yr)	Federal Standards and Survey data (see section 2.1)	90% removal of Type I load or 24.869 Kg/man/yr	Minimum from survey data (see Section 2.1) for Type II MSD's
L_a-SS	Suspended solids per capita load	33.16 Kg per man per yr[c] (73.10 lbs/yr)	Federal Standards and Survey data (see section 2.1)	90% removal of type I load or 33.16 Kg/man/yr	Minimum from survey data (see section 2.1) for type II MSD's
L_a-CO	Chlorinated Organics per capita load	0.166 Kg per man per year[d]	Glaze and Henderson, 1975	0.166 Kg per man per year	No reduction based upon study by Julley, 1975

a U.S. Coast Guard Certified Type I and II Levels of Treatment (33CFR Part 159)
b .60 g/l x 113.56 l/day/man x 365 days/year
c .80 g/l x 113.56 l/day/man x 365 days/year
d .004 g/l x 113.56 l/day/man x 365 days/year

APPENDIX E

DRAFT,TRIM AND STABILITY CALCULATIONS

The following assumptions and calculations formed the basis for discussion on Page 113 :

Explanation of Terms:

GM = distance from the center of gravity to the metacenter

KB = distance from keel to the center of bouyancy

BM = distance from the center of bouyancy to the metacenter

γtank liquid = density of sewage

γwater = density of water

B, beam = 75 ft.

∇ = displacement volume = length x beam x draft = 650 x75 x 25= 1218,750 ft.^{3}

i tank for std. flush = moment of inertia of tank = 14,580 ft.^{4}

T, draft = 25 ft.

H, depth of vessel = 32 ft.

For the purpose of approximation the vessel is assumed to be a rectangular block 650 ft. long x 75 ft. beam x 25 ft. draft. This is a close approximation due to the box-like design of Great Lakes bulk carriers.

$GM = \overline{KB} + \overline{BM} - \overline{KG}$

Based on the approximation stated previously:

$$\overline{KB} = \frac{T}{2} = \frac{25}{2} = 12.5 \text{ ft.}$$

$$\overline{BM} = \frac{B^2}{12T} = \frac{(75)^2}{12(25)} = 18.75 \text{ ft.}$$

$$\overline{KG} = \frac{H}{2} = \frac{32}{2} = 16 \text{ ft.}$$

$$GM = 15.25 \text{ ft.}$$

The loss of GM due to free surface effect of a holding tank - std. flush =

$\frac{\gamma tank}{\gamma water}\left(\frac{i_T}{\nabla}\right)$ but γtank = γwater $\therefore$ Loss of GM= $\frac{i_T}{\nabla}$ = .012 ft.

Reduction of GM = .012 ft. =.078 %

The following calculations and information formed the basis of discussion on Page 112 :

Explanation of Terms (all tons = 2240 lbs.)

$W_{std. flush}$ = 202 LT as developed in this report

TPI = 78.4 (Rawson and Tupper, 1976)

LCF = 3.8 ft fwd. of midship (Rawson and Tupper, 1976)

MTI, moment to change trim one inch = 775 ft. tons (Rawson and Tupper, 1976)

L_{bp}, length between perpendicular = 580 ft (Rawson and Tupper, 1976)

ΔT = parallel sinkage

FP = fore perpendicular

AP = aft perpendicular

X = distance from centroid of holding tank to the ships LCF. This is equal to 293.8 ft. to represent a near maximum case.

Parallel Sinkage and Change in Trim Due to the Addition of Sewage Holding Tank

$$-\Delta T = \frac{W_{std\ flush}}{TPI} = \frac{202}{78.4} = 2.58 \text{ in.}$$

$$\text{Trimming moment} = W_{std.\ flush}\ X = 202 \times 293.8 = 59347.6 \text{ ft tons}$$

$$\text{Trim BP} = \frac{\text{Trimming Moment}}{MTI\ (12)} = \frac{59347.6}{775(12)} = 6.38$$

$$\text{- Draft Change at FP due to trim} = \frac{\text{distance from FP to LCF}}{L_{BP}} \times \text{trim BP} = \frac{286.2}{580} \times 6.38 = 3.15 \text{ ft.}$$

$$\text{- Draft Change at AP due to trim} = \frac{\text{distance from AP to LCF}}{L_{BP}} \times \text{trim BP} = \frac{293.3}{580} \times 6.38 = 3.23 \text{ ft.}$$

APPENDIX F

GLOSSARY

GLOSSARY

Activated carbon	A process in which dissolved matter is removed by adsorption onto carbon granules.
Aerobic process	A treatment or disposal process requiring free dissolved oxygen for biodegredation
Anaerobic process	A treatment or disposal process which does not require free dissolved oxygen for biodegredation.
Benthos	Macro-invertebrates which live on, in or near the bottom of lakes, rivers and/or streams and important to fisheries.
Biomass	A measurement of the mass of an individual organism at a given point in time.
Blackwater	Human body wastes collected in heads (toilets) and urinals.
BOD_5	Five day biochemical oxygen demand, a measurement of oxygen consuming potential of a substance due to biological respiration.
Bulk freighter	Commercial vessel involved in transportation of bulk commodities such as iron, ore, coal, grain, sand, limestone, oil, etc.
Bulkhead	Vertical partition walls which subdivide a ship into compartments or rooms.
Captive Port	Port whose commercial shipping is totally dominated by the shipping of one private company.
Chlorinated hydrocarbons or chloro-organics	Organic matter or hydrocarbons which contain the chlorine element bonded to the organic matter; may be toxic, carcinogenic and bioaccumulated.

Coliform	The type of bacteria found in the intestines of warm blooded mammals, usually measured by the indicator organism, *E. coli*.
Commercial vessels	Vessels engaged in Great Lake industrial shipping trade excluding tugs, barges, dredges car ferries.
Diatom	An aquatic plant whose exo-skeleton is composed of silica.
Discharge riser	Permanent sewer fixture into which vessel may pump retained sewage. This fixture transports waste into the municipal sewer system.
Draft	The depth to which a vessel is submerged in water.
Ecosystem	The interaction of the ecological community with the environment resulting in a functioning whole.
Effluent	The wastewaters discharged from a waste treatment unit.
Electro-coagulation	A process in which suspended organic matter is aggregated by electrical charge.
Epilimnion	The upper layer of water mass in stratified lakes.
Eutrophication	The process of enrichment of a lake with nutrients that stimulate the growth of organisms.
Extended season	A 12-month shipping season on the Great Lakes.
Fixed-base operator	A shipping operation in which vessels return with regular frequency to a single company dock.
Flocculated cells	Small microorganisms which have aggregated into a loose and fluffy mass.

Graywater	Wastewater from sink, showers, galley and laundry generated onboard a ship.
Gpcd	Gallons per capita per day, the rate of flow of liquids.
Head	Term for a toilet on a ship or boat.
Hypolimnion	The lower layer of water mass in a stratified lake.
LCF	Longitudinal center of floatation- the location of the center of the area of the waterplane at which a vessel floats. LCF is usually expressed in terms of its proximity to midship.
Load	The mass of a substance which is discharged into a body of water usually expressed in terms of mass per unit of time.
Low-volume flush system	Type of flush system for heads based on minimal use of water as a flushing medium.
LT	Long ton; LT - 2240 pounds
Metacenter	The point of intersection of a vertical line drawn through the center of buoyancy of a vessel heeled to a small angle of inclination and the center-line plane of the vessel.
Metacentric height or GM	The vertical distance between the center of gravity of a vessel and the metacenter. A measure of the stability of a vessel.
MGD	Million gallons per day - commonly used a measure of flow rate with respect to wastewater treatment plants.
Mixed port	Port comprised of both public and privately owned shipping facilities.

MSD	Any equipment for installation onboard a vessel and which is designed to receive, retain, treat, discharge or process sewage.
Oligotrophic	The state of limited enrichment of a lake with nutrients that stimulate the growth of organisms.
Perpendicular, foward and aft	The forward perpendicular abreviated FP, is the vertical line through the intersection of the design waterline of the vessel and the fore side of the stem. The aft perpendicular (AP) is usually the vertical line through the intersection of the design waterline and the aft side of the straight portion of the rudder post.
Photosynthesis	The process by which plants assimilate CO_2 and H_2O to form sugars.
Phytoplankton	Aquatic plants suspended in the water column.
Potable water	Fresh water carried onboard a ship for drinking, cooking, and sanitary purposes.
Primary productivity	The rate of organic material produced by plants through photosynthesis in a given unit of time.
Private dock	Ship receiving facilities owned and operated by a private company.
Public dock	Ship receiving facilities owned and operated by federal, state or local authorities.
Runoff	The water and materials which flow over the surface of the soil.

Saltie	Term for foreign flag vessel
Secondary consumer	Organisms which directly consume primary producers (aquatic plants) as food.
Secondary productivity	The rate of organic material produced by organisms through the consumption of other organisms in a given unit of time.
Sewage	Considered to be human body wastes collected from urinals and toilets or termed black-water.
Shipping lane	The waters traversed by commercial vessels along a commonly travelled route.
Soil lines	Run of piping which carries waste from heads to a collection or treatment point.
Standard flush system	Type of flush system for heads based on water as the sole flushing medium.
Suspended solids	The solid organic matter suspended in water.
Tank truck	Vehicle used for liquid waste disposal.
Thermocline	A narrow layer of water in a stratified lake which separates warmer upper mass of water from a colder deeper mass of water.
Total phosphorus	The amount of phosphorous from dissolved fractions, inorganic forms, and organic forms of phosphorous.

TPI	Tons per inch immersion factor-the weight required to change the draft of a vessel at a given waterline by one inch.
Tramp operation	Operation of vessels with varying points of origins and destinations of voyages.
Transparency	The measurement of the amount of light transmitted through water.
Treated sewage	Sewage which has been passed through marine sanitation devices whose effluent contains reduced levels of pollutants.
Tributary	A small creek or stream which feeds into a larger river or lake.
Trim	The difference between the draft of a vessel forward and the draft aft.
Vessel sewage	Sewage generated onboard vessels.
Zooplankton	Small microorganisms suspended in water which are animals and not plants.