Pollution Impacts from Recreational Boating:

A Bibliography and Summary Review

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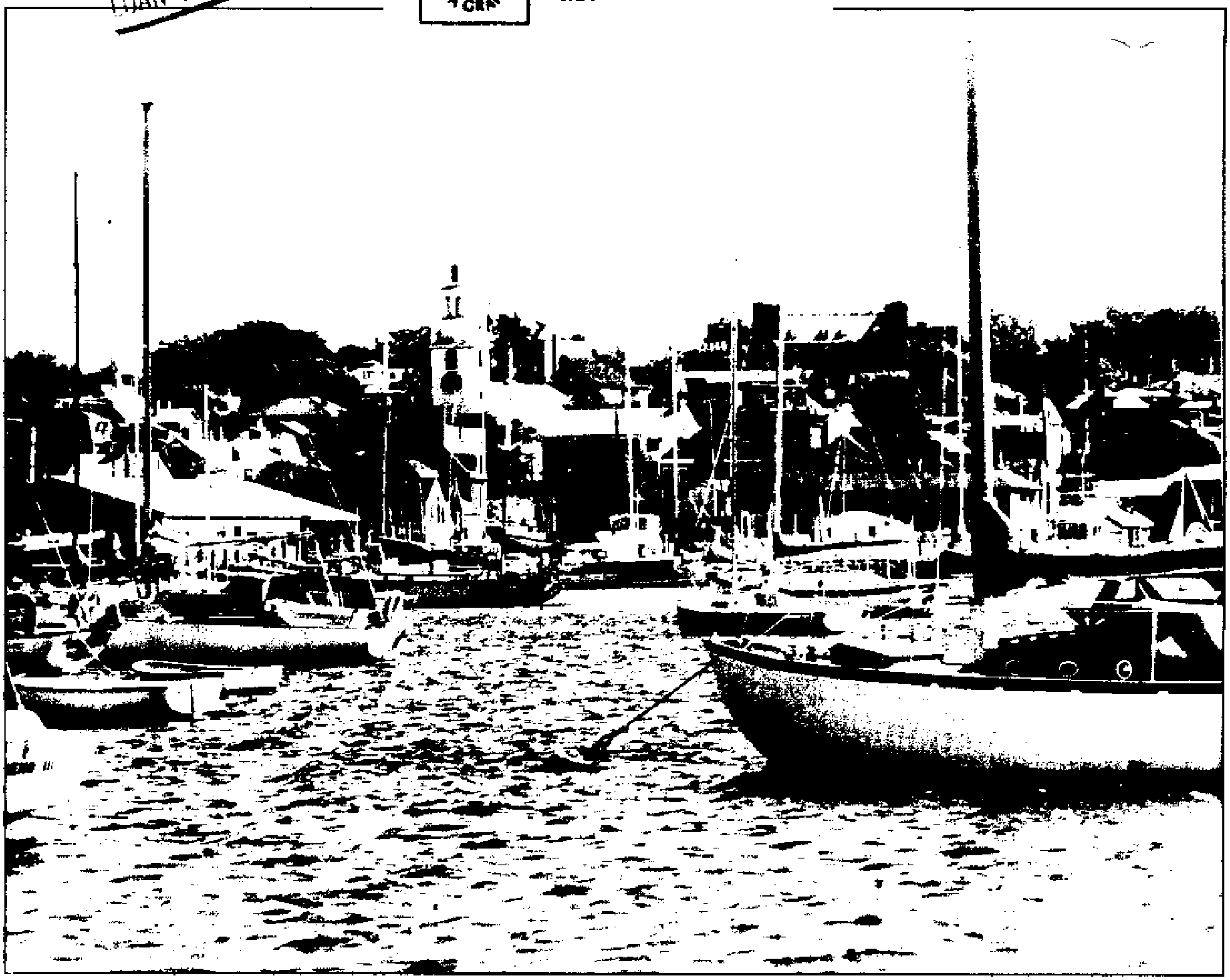

RHODE ISLAND SEA GRANT

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Rhode Island Sea Grant. January 1990.

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Preface

Recreational boating has increased tremendously in the last decade. Along with this growth has come the potential for an enormous increase in boating-associated pollutants. It has become essential to understand how pollution from recreational boats affects coastal-zone water quality so that responsible decisions can be made concerning the regulation of recreational boating.

The following brief literature review and selected bibliography focus on four of the major pollution problems associated with the use of recreational boats: (1) boat sewage, (2) boat engine pollution, (3) antifouling paints, and (4) plastic debris.

We hope that this synopsis and bibliography will prove useful for stimulating discussion and for developing policy regarding recreational boating on our coastal waters.

Acknowledgments

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LITERATURE REVIEW

BOAT SEWAGE

Although federal law (Federal Water Pollution Control Act, Section 312) requires recreational boats to be equipped with approved marine sanitation devices, boats still discharge treated waste legally and untreated waste illegally into coastal waters (see Table 1 for a description of marine sanitation device specifications). The discharge of these sanitary wastes from boats may impact water quality by (1) locally increasing biological oxygen demand and (2) introducing microbial pathogens into the environment (U.S. EPA, 1985).

Biological oxygen demand

Biological oxygen demand (BOD) is a measure of the dissolved oxygen required to decompose the organic matter in the water by aerobic processes. When the loading of organic matter increases, the BOD increases, and there is a consequent reduction in the dissolved oxygen available for respiration by aquatic organisms (U.S. EPA, 1985). Although the volume of wastewater discharged from recreational boats is small, the organics in this wastewater are concentrated, and therefore the BOD (1700 – 3500 milligrams/liter [mg/l]) is much higher than that of raw municipal sewage (110 – 400 mg/l) or treated municipal sewage (5 – 100 mg/l) (JRB Associates, 1981). Sewage discharged from recreational boats will thus increase the BOD in the vicinity of the boats. When this occurs in poorly flushed water bodies, the dissolved oxygen concentrations of the water may decrease. Cardwell (1981), for example, noted significant decreases in dissolved oxygen in several northwestern U.S. marinas in the late summer and early fall. Nixon et al. (1973) found lower dissolved oxygen levels in a developed marina area than in an adjacent undeveloped bay of similar size. They attributed these low dissolved oxygen levels, however, to the secondary effects of abundant fouling communities on marina pilings and docks and to sediment respiration rather than to boat discharges directly. In temperate regions, the effect of boat sewage on dissolved oxygen levels is exacerbated because the peak of the boating season coincides with the highest water temperatures and thus the lowest solubilities of oxygen in seawater and the highest rates of metabolism of marine organisms.

For any given water body, it is possible to predict the impact of BOD loading by boats by estimating the amount of BOD discharged from recreational boats into the water, the volume of the water body, the flushing rate, and the ambient dissolved oxygen. The estimated boat BOD loading can then be combined with sediment oxygen demand to provide an estimate of the total oxygen depletion in the water body. An example of an equation used to determine an oxygen mass balance over one tidal cycle is provided in the EPA's *Coastal Marinas Assessment Handbook* (U.S. EPA, 1985).

Pathogens

A potentially serious problem resulting from the discharge of sewage from recreational boats is the introduction of disease-carrying microorganisms from fecal matter into the coastal environment. A review of the public health impacts of coastal pollution is provided by Cabelli et al. (1983) and summarized in Appendix I. Humans are put at risk either by swimming in polluted waters or by eating shellfish (raw or partially cooked) taken from polluted waters. The major disease-carrying agents are bacteria and viruses, and the most common serious ailment is acute gastroenteritis. Other waterborne diseases that can be attributed to sewage pollution include hepatitis, typhoid, and cholera.

The indicators used to detect sewage pollution are not the pathogens themselves but, rather, coliform bacteria. These bacteria are always present in the human intestinal tract and are thus considered reliable indicators of the presence of human waste (U.S. EPA, 1985). However, there is quite a bit of uncertainty as to how well coliform bacteria predict the presence of pathogens and how safe the standards for shellfishing and swimming areas are (Cabelli et al., 1983; U.S. Congress, OTA, 1987).

Table 1. ***Water Quality Specifications for Marine Sanitation Device Discharges***[a]

MSD type	Coliform count[b]	Solids	Description
I[c]	<1000/100 ml	No visible floating solids (<10% of total suspended solids discharged)	Flow-through device meeting stated standards
II	<200/100 ml	<150 mg total suspended solids per liter of discharge	Flow-through device meeting stated standards
III	None	None	Holding tank

[a]Coast Guard Regulations on Marine Sanitation Devices, as amended through 3 February 1983.

[b]Represents the arithmetic mean of the fecal coliform bacteria in 38 of 40 samples when tested in accordance with 40 CFR, Part 136.

[c]Must have been installed prior to January 30, 1980.

Adapted from: U.S. Environmental Protection Agency. 1985. Coastal Marinas Assessment Handbook. Region IV EPA, Atlanta, Georgia.

The coliform indicators were originally developed for use with large treated sewage discharges and may not accurately predict pathogenic pollution from the small quantities of fresh fecal matter discharged from recreational boats. For measuring sewage pollution from boats, fecal coliform is thought to be a more accurate indicator than total coliform (U.S. Dept. H.E.W., 1972).

While there have been no studies directly linking the discharge of boat sewage to disease incidence, numerous studies have found elevated levels of fecal coliform bacteria where there are concentrations of recreational boats (U.S. Dept. of Interior, 1967). Cassin et al. (1971) found that coliform levels increased in the water column and in shellfish in direct relation to the number of boats in three of four recreational areas they sampled on Long Island, New York. Furfari and Verber (1969) found elevated levels of fecal coliform bacteria during and just after weekends when boats were anchored in Potter Cove, Rhode Island. Faust (1982) found a positive correlation between the number of boats and the level of fecal coliform bacteria in an arm of Chesapeake Bay. Other studies that found elevated indicator bacteria levels in boating areas include Ingram (1953), Udell (1960), Lear and Schminke (1967), Smith (1972), and Fisher et al. (1987). Some studies, on the other hand, found no correlation between boat densities and coliform levels (Seabloom, 1969), or found that background fecal coliform levels, especially from overland stormwater runoff, exceeded that caused by the boats (Mack, unpubl.; Nixon et al., 1973; Faust, 1978).

There have been several attempts to predict the amount of fecal coliform bacteria produced by a given number of boats or, conversely, the volume of water needed to accommodate a given number of boats without exceeding safe bacteria levels. Furfari (1968) estimated that about 1.4×10^5 cubic meters (37 million gallons) of water was needed per boat in order to keep fecal coliform concentrations below the recommended level for shellfishing areas of 14 fecal coliforms/100 milliliters (ml). Faust (1982) took into account bacterial survival times (see below) and estimated that between 1.0×10^5 and 2.2×10^5 cubic meters (26 to 58 million gallons) of water was required per boat. The U.S. Food and Drug Administration (FDA) used a value of 1.4×10^5 cubic meters of water per boat and constructed a table predicting total coliform counts from surface area, depth, and number of boats (U.S. Dept. H.E.W., 1972).

Once enteric (intestinal tract) microorganisms enter the water, the primary means by which they are removed are dilution, die-off, and sedimentation. The amount of dilution of microorganisms in a marina or harbor depends upon the volume of water (surface area and depth of the water body), the amount of flushing of the water body, and the background concentrations of bacteria or viruses. Tidal exchange, freshwater inflow, and wind influence the pattern and rate of flushing. In the absence of freshwater inflow, tidal flushing is not consistent throughout a water body but is generally greatest near the tidal connection and weakest at the head of the water body (Collias, 1976; Kator et al., 1982). Tidal flushing depends on tidal stage as well, with greatest flushing generally at the flood stage (Brandsma et al., 1973). The greater the flushing rate, the greater the dilution and the lower the concentration of bacteria. An example of a dilution equation is provided in the EPA's *Coastal Marinas Assessment Handbook* (U.S. EPA, 1985).

The survival time of enteric microorganisms in seawater has been studied extensively. Reviews of the early literature are provided by Greenberg (1956) and Mitchell (1968). Microorganisms, including fecal coliform bacteria, have a shorter survival time in seawater than can be explained by dilution and sedimentation alone (Ketchum et al., 1952). Both biological and physical factors affect the survival rate. Important factors include temperature, salinity, sunlight, microbial toxins, inorganic toxins (including salts), nutrient limitation, and predation (Carlucci and Pramer, 1959). Several authors also found that the survival rate of bacteria in the water column is extended by the addition of sewage (Metcalf and Stiles, 1965; Won and Ross, 1973) and by the addition of fine-grained sediment (Faust et al., 1975). The die-off of bacteria increases proportionally with increasing temperature (Faust et al., 1975). Consequently, bacterial survival rate is shortest in warm summer temperatures.

The final means by which microorganisms are removed from the water is sedimentation. Several authors have shown that bacteria (Gerba and McLeod, 1976) and viruses (Gerba and Schaiberger, 1975; Smith et al., 1978) that sink directly into the sediments, or attach to particles and then settle, exhibit longer survival times than those that are found in the overlying water. This is significant when considering the resuspension of sediment, either by natural causes such as rainfall or bottom currents or by manmade causes such as dredging or propeller wash. It is also significant when considering the filtering of sediment by shellfish.

Criteria for shellfishing areas. An issue that has received a great deal of attention is the potential pollution of shellfishing areas by recreational boats. Each coastal state regulates its own shellfish sanitation program under the voluntary National Shellfish Sanitation Program (NSSP). States use various approaches to achieve compliance with the NSSP standard of 14 fecal coliforms/100 ml of water for the taking of shellfish. Some states close all marinas to shellfishing and set standard buffer zones around marinas, while others use formulas based on surveys and local environmental information to determine closure areas (U.S. Dept. H.E.W., 1972; South Carolina Dept. of Health and Environmental Control, 1985; Maryland Dept. of the Environment, 1987).

The basic formula used for determining the number of allowable boats in a shellfishing area as developed by the FDA for the NSSP (U.S. Dept. H.E.W., 1988b) is:

$$\text{fecal coliforms (MPN*)/100 ml} = (N \times F \times E)/V,$$

where:

N = number of boats
F = fecal coliforms/person
E = population equivalent/boat
V = volume of dilution water available

The underlying assumptions of this formula and its parameters are: a 100% boat-occupancy rate, 100% overboard discharge of sewage, a population of 2 persons per boat, complete mixing in and around the marina, no bacterial die-off or growth, and no other sources of fecal coliforms. An analysis of these assumptions is provided in Table 2. The

**Note: MPN, or most probable number, is a simple statistical test for estimating bacterial densities.*

Table 2. ***Analysis of Assumptions in the NSSP Formula***

100% occupancy rate: Occupancy rate, which can be defined either as the percentage of total boats occupied on a particular day or as the percent of the boating season a boat is occupied, seldom approaches 50% (Eldredge, unpubl.; Maryland Dept. of Environment, 1987). Eldredge (1988) found occupancy rates (defined as percentage of occupied boats on a given day) ranging from 27% to 51% and averaging 38% in Narragansett Bay harbors on two high-use weekends. The occupancy rate for a particular area can be determined by direct survey. In the absence of any survey data, a conservative estimate of 50% is more realistic than 100%.

100% overboard discharge: This is a very difficult variable to determine or estimate. It depends on the percentage of boats that have heads on board and what type of heads they have, the degree of compliance with marine sanitation device regulations, the availability of pumpout facilities (Tanski, 1988), and the amount of use of onshore restrooms (Chmura and Ross, 1978). Surveys should be conducted to determine more accurately the percentage of overboard discharge. Alternatively, this percentage may be estimated by looking at the adequacy of onshore facilities and the types of boats in the marina or harbor. In the absence of survey data, an estimate of 50% for the failure rate of marine sanitation devices appears to be reasonable (South Carolina, 1985).

Persons per boat: This variable depends upon the length and type of boat. If no specific information is available, the FDA value of 2 appears to be a reasonable estimate.

Fecal coliforms per person: The generally accepted figure is 2 billion fecal coliforms per capita per day (Geldreich, 1966).

Complete mixing in and around the marina: Mixing depends upon variables such as tides, river input, the shape of the basin, and the location of the marina within the basin. Hydrographic studies are needed to determine these parameters. Tidal and river flushing rate should be included in the determination of dilution capacity of a marina.

No bacterial die-off or growth: As indicated above, fecal coliform survival in the water column depends on many features but appears to be strongly correlated with temperature and salinity. If possible, a decay rate of bacteria under the local conditions should be determined. If not, one could measure the average temperature and salinity in a marina or harbor area during the boating season and predict the die-off of fecal coliform bacteria using the relationship developed by Faust et al. (1975) or by using the decay coefficient cited by the U.S. EPA (1978). The role of sediments as a source of surviving bacteria needs further consideration. In the absence of local data or estimates, one should assume no die-off or growth.

No other sources of fecal coliform: There are likely to be background levels of fecal coliform from overland runoff and point sources in most marina and harbor areas. If this background level is greater than the standard (14 FC/100 ml), then the area would be closed to shellfishing regardless of boating use. If the background level is greater than zero but less than the standard then the background level should be incorporated into the equation.

marina policy adopted by the Interstate Shellfish Sanitation Conference in 1986 (Interstate Shellfish Sanitation Conference, 1986) and the revised NSSP manual of operations (U.S. Dept. H.E.W., 1988) both use this formula but recommend the use of all available information to account for regional differences. The ISSC marina policy and the methods used by some states for determining boat concentrations and buffer zones are described in Appendix II.

BOAT ENGINE POLLUTION

Though there have been numerous studies on the fate and effect of oil spills in the marine environment (see, for example, National Academy of Sciences, 1975), there have been relatively few reports on the impact of boat engine pollution.

Sources

Reports on boat engine pollution have focused on the effect of two-cycle outboard engines. Because two-cycle engines accomplish fuel intake and exhaust in the same cycle, they tend to release unburned fuel along with the exhaust gases. Older engines (manufactured prior to about 1972) drain excess fuel from the crankcase directly into the water while newer engines have scavenger devices to recycle this lost fuel. Two-cycle engines also have lubricant oil mixed in with the fuel, and this oil is released into the water along with the unburned fuel. There are over 100 hydrocarbon compounds in gasoline, as well as additives such as lead, while lubricant oils contain elements such as zinc, sulfur, and phosphorus (Jackivicz and Kuzminski, 1973b). Another important source of petroleum from recreational boats is the discharge of oily bilge water.

Fate

Once discharged into the water, petroleum hydrocarbons may remain suspended in the water column, concentrate at the surface, or settle to the bottom. Many of these hydrocarbon compounds will not persist for very long because of their immiscibility, volatility, or biodegradability, or because of the effects of weathering (Jackivicz and Kuzminski, 1973a). While petroleum may disappear rapidly from the water column, the portion that reaches the sediment may persist for several years (Olsen et al., 1982). Lead compounds from gasoline additives tend to sink to the bottom sediments (Chmura and Ross, 1978).

Effects

The most obvious effects of pollutants from marine engines include odor, an off taste in fish, and toxic effects on marine organisms. Estimates vary as to the exact thresholds of these effects. English et al. (1963), using engines with no scavenger devices, found an odor threshold at 1 part per million (ppm) (1 gallon fuel burned per million gallons water) and noticeable fish tainting at 8 ppm. An Environmental Protection Agency/Boating Industry of America study (U.S. EPA, 1974) noted an odor threshold at 3 ppm and off taste at 110 ppm. Outboard motor exhaust water in high concentrations can exhibit toxic effects on various species of fish and wildlife (Jackivicz and Kuzminski, 1973b). The nature and degree of these effects varies by species (Nixon et al., 1973). For example, Clark et al. (1974) found that gill tissue damage in mussels occurred more quickly than in oysters because the oysters were able to close their shells and exclude hydrocarbons while the mussels were not.

Although normal levels of outboard motor usage have not been shown to have a toxic effect on aquatic communities, toxic effects have been demonstrated from sustained low concentrations of petroleum in estuaries. In experimental mesocosms, sustained concentrations of 0.1 ppm of No. 2 fuel oil in the water column caused reductions in zooplankton, while sustained concentrations of 500 ppm had severe, long-lasting effects on benthic organisms (Olsen et al., 1982). Table 3 indicates the concentrations of hydrocarbons considered toxic to marine organisms. Concentrations in excess of these toxic levels occur in the water column and sediment in many urbanized estuaries, and elevated hydrocarbon levels also occur in marina sediments (Voudrias, 1981). Petroleum hydrocarbon pollution from boats may thus contribute to already toxic concentrations of hydrocarbons in the water column and sediment and increase long-term effects.

Table 3. ***Estimated Toxic Concentrations of Soluble Aromatic Fractions of Petroleum Hydrocarbons for Marine Organisms***[a]

Class of organisms	Toxic concentration (ppm)
Larvae (all species)	0.1 – 1.0
Swimming crustaceans	1 – 10
Bottom-dwelling crustaceans	1 – 10
Other bottom-dwelling organisms (worms, etc.)	1 – 10
Snails	1 – 100
Finfish	5 – 50
Bivalves	5 – 50
Flora	10 – 100

[a]United Nations, 1982.

Source: U.S. Environmental Protection Agency. 1985. Coastal Marinas Assessment Handbook. Region IV EPA, Atlanta, Georgia.

ANTIFOULING PAINTS

Antifouling paints are used on ship hulls to prevent fouling by marine organisms. The problem is that active ingredients in these paints may also have toxic effects on nontarget organisms. Copper and organotin compounds are the most common active ingredients in antifouling paints. Other toxic compounds, such as mercury, arsenic, and polychlorinated biphenols (PCBs), are no longer used due to their toxicity (Bellinger and Benham, 1978).

Copper

Elevated copper concentrations have been found in the environment in the vicinity of shipyards where hull scraping and painting occur. Young et al. (1979) found high levels of copper in the water and in mussels in the vicinity of shipyards in southern California. Bellinger and Benham (1978) found elevated levels in the sediments in the vicinity of dry docks in England. They considered the risk from the metals to be minimal while vessels are at sea, due to the high dilution capacity of the ocean. Nixon et al. (1973) found higher concentrations of copper in macroalgae, fouling communities, and sediments in a marina than in an adjacent undeveloped bay.

Tributyltin

Tributyltins (TBTs) are a class of organic tins that have been used recently as the biocides in antifouling paints. There are two classes of TBT paints: conventional (also called free association), which leach continuously from the painted surface, and copolymer, which are released at a controlled, slower rate. Due to the rapid leaching of TBT from boat hulls into the water, elevated levels of TBT and its breakdown products have been found in the water, in sediment, and in organisms where there are concentrations of recreational boats. Recreational boats were the main users of TBT paints until recently. A 1987 survey found that 97% of TBT use was on boats of 65 feet or less and that 93% of this use was on recreational boats (Lucas and Williams, 1987). Recent regulations now limit TBT use (see below).

Fate. Unlike copper, TBT in seawater degrades quickly. Estimates of the half-life of TBT in seawater range from 3.5 to 15 days (Seligman et al., 1986; Hinga et al., 1987). TBT is removed from the water column by adsorption to lipids and particulate matter, metabolism by plants and animals, and photolysis (Cardwell and Sheldon, 1986). Within the water column, the primary means of degradation in the presence of light appears to be debutylation by planktonic algae, especially diatoms, while in the absence of light, degradation is primarily by bacteria (Champ and Bleil, 1988). Due to its lipophilic properties, TBT tends to concentrate in the surface microlayer, where it has been found at up to 27 times the subsurface concentrations (Cleary and Stebbing, 1987). Once TBT adsorbs to particulates and sinks into the sediment it tends to concentrate and degrade slowly (Stang and Seligman, 1987; Espourteille, 1988).

Effects. TBT has been reported to cause acute and chronic toxicity to marine organisms, especially bivalves and small crustaceans such as copepod zooplankton. Significant declines in oyster and clam populations occurred in areas where there were concentrations of boats using TBT paints, and these populations recovered quickly after TBTs were banned (Alzieu, 1986; Laughlin and Lindén, 1987). Bivalves are especially susceptible because of their limited ability to metabolize the compound and because they are found in nearly anoxic sediments that lack the bacterial species necessary to degrade TBT (Espourteille, 1988). Sublethal effects have been noted for a variety of fish species. A review of the laboratory and field studies on the toxicity of organotins is provided by Champ and Bleil (1988).

High levels of bioaccumulation of TBT have been reported. Bacteria and phytoplankton bioaccumulate TBT at concentrations of 600 to 30,000 times the exposure concentration, while bioaccumulation levels as high as 4,000 have been reported for bivalves (Cardwell and Sheldon, 1986). Despite the high bioaccumulation rate by shellfish, there are no indications that consumption of contaminated shellfish by humans is of concern.

Regulation. Tributyltin antifouling paints are now restricted in the United States by the Organotin Antifouling Paint Control Act of 1988. This act bans the use of organotin paints on all boats of less than 25 meters, except for those with aluminum hulls, and limits the use of antifouling paints on other vessels to those paints that are certified by the U.S. EPA as releasing less than 4 micrograms per square centimeter per day into the water (Champ and Bleil, 1988). At least 13 states in the United States have also enacted their own legislation (e.g., Rhode Island Tributlytin Antifoulant Paint Control Act of 1988).

PLASTIC DEBRIS

The production and use of plastics has increased dramatically over the past few decades. Two of the qualities that make plastic so popular — its light weight and its durability — also make it a marine pollution problem. Plastic that is discarded into the ocean tends to float, persist, and accumulate. Marine plastic debris can be found anywhere in the world oceans (Dahlberg and Day, 1985; Pruter, 1987; Wilbur, 1987) and in large quantities on the world's beaches (Merrell, 1980; Hays and Cormans, 1974; Pruter, 1987).

Sources

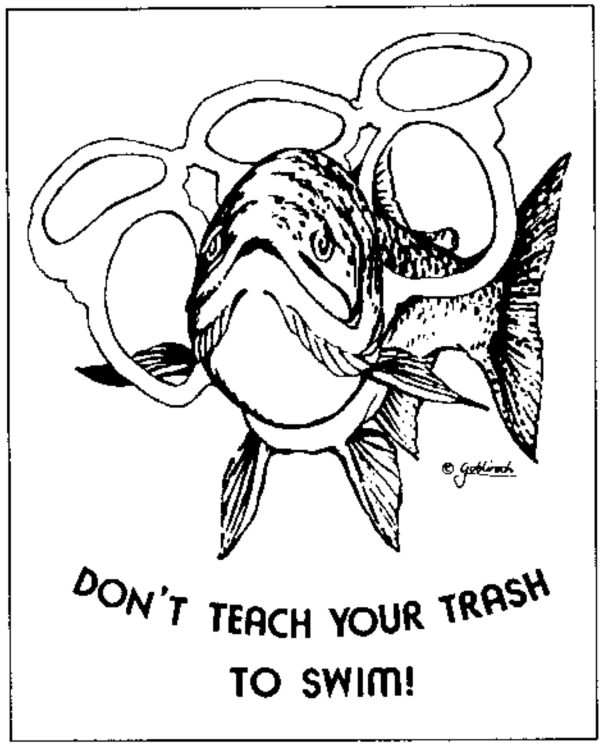
Although the majority of marine plastic debris is thought to come from commercial fishing, shipping, and industry, recreational boating also contributes to the problem. In some coastal areas and harbors, in fact, the majority of plastic debris appears to come from recreational boaters (Cundell, 1973; Steinhauer et al., in prep.). An estimated 16 million recreational boaters use the nation's coastal areas (Cottingham, 1988), and, according to a 1975 study (National Academy of Sciences, 1975), discard over 100,000 tons of garbage annually. A large part of this garbage is plastic, including plastic bags, six-pack holders, and monofilament fishing line.

Effects

Since plastics float and persist, they tend to be concentrated by ocean currents along coastal areas. This results in closure of beaches due to pollution (Swanson and Zimmer, in prep.), damage to boats (Takehama, in prep.) and great harm to marine life (Laist, 1987). Although difficult to quantify, entanglement in and ingestion of plastics by marine mammals, seabirds, marine turtles, and fish may be quite significant. Entanglement can cause drowning, starvation, strangulation, and increased vulnerability to predation. These effects may be responsible for significant declines in the populations of certain species, such as northern fur seals (Fowler, 1985). Ingestion of plastic items, such as pellets and bags, by animals that mistake the debris for prey can cause starvation due to blockage of the intestine, ulceration of the stomach, and toxic effects. Of special concern are effects on endangered species of sea turtles (Balazs, 1985). In addition to affecting marine life at sea, plastic debris washing up on beaches may have detrimental effects on nesting seabird colonies (Gochfeld, 1973).

Regulations

The Marine Plastic Pollution Research and Control Act (MPPRCA) of 1987 is a national law implementing Annex V of the International Convention for the Prevention of Pollution from Ships (known as MARPOL). The MPPRCA prohibits the dumping of plastics at sea and restricts dumping other ship-generated garbage in the navigable waters of the U.S. and the open ocean. The Annex V provisions of this law apply to all watercraft including the smallest recreational vessels. The law went into effect on December 31, 1988, and is enforced by the Coast Guard. In addition to limiting dumping, these regulations require all marinas to have adequate facilities for the disposal of garbage. With these regulations in force, the problem of plastic debris pollution from boats should be drastically reduced.



Drawing courtesy of the Marine Refuse Disposal Project, Port of Newport, Oregon.

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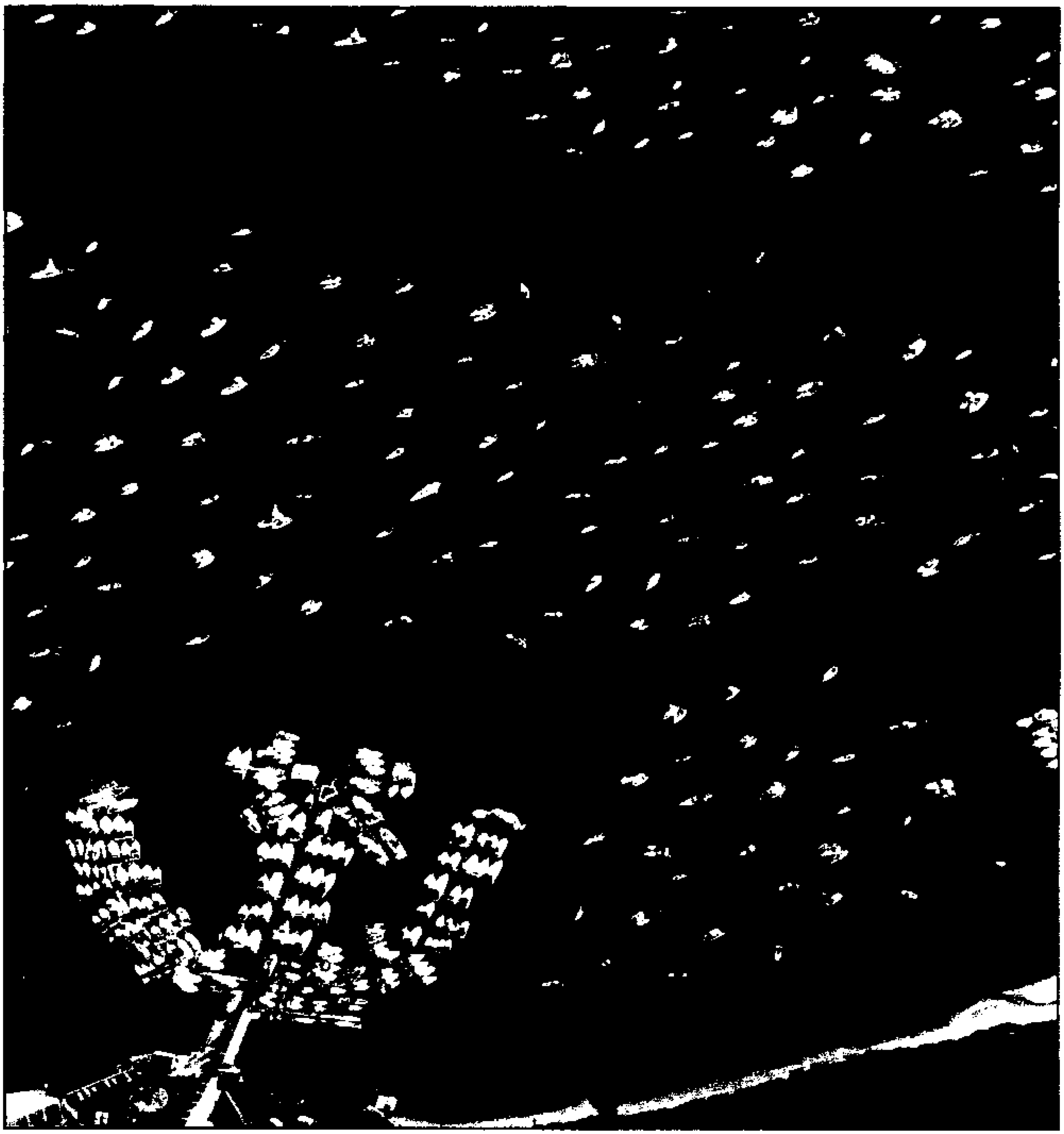

New Harbor, Block Island, Rhode Island, July 4th weekend, 1988. Photograph by Wilkins Studio, Wakefield, RI.

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APPENDIX I

Microbial, Infectious, and Biotoxigenic Diseases Transmitted by the Recreational and Shellfish-borne Routes

Agent	Disease	Route of transmission[a] Rec.	Route of transmission[a] Shell.	Source of the agent[a] Human feces	Source of the agent[a] Animal feces	Source of the agent[a] Sewage	Source of the agent[a] Water
<u>Bacteria</u>							
Salmonella sp.	Typhoid and paratyphoid[b] fevers, salmonellosis	+	+	+	+	+	–
Shigella sp.	Bacillary dysentery	+	-	+	-	+	-
Pseudomonas aeruginosa[c]	Otitis externa, skin infections[d]	+	-	+[m]	+[m]	+	+[n]
Aeromonas hydrophila[c]	Infected wounds	+	-	+[m]	+[m]	+	+[n]
Vibrio vulnificus	Infected wounds[e]	+	-	-	-	-	+
Vibrio parahaemolyticus	Gastroenteritis[f]	-	+	+[m]	-	+[o]	+[n]
Vibrio cholerae (01)	Cholera[g]	-	+	+[o]	–	+[o]	?
Non-01 *V. cholerae*	Cholera-like disease	-	+	+[m]	-	+[o]	+
Leptospira sp.[c]	Leptospirosis (Weil's disease)	+	-	+[m,p,o]	+[p]	-	-
Campylobacter sp.	Gastroenteritis	-	+[h]	+[m]	+	+[o]	-
Clostridium botulinum	Food poisoning (botulism)[i,j]	-	+	-	+	-	+
various species[k]	Gastroenteritis	?	+	+[q]	+[q]	+[q]	+[q]
Mycobacterium marinum	Infected wounds	+	-	-	-	-	+
<u>Viruses</u>							
Hepatitis A	Infectious hepatitis	+	+	+	-	+	-
Norwalk-like	Acute, infectious non-	+	+	+	-	+	-
Human rotavirus	bacterial gastroenteritis	+[l]	?	+	-	+	-
Adenovirus, types 3 and 4	Pharyngo-conjunctival fever[c]	+[r]	-	+	-	+	-
Coxsackievirus	Pleurodynia, others	+[s]	-	+	-	+	-
<u>Protozoa</u>							
Naegleria sp. (pathogenic)	Primary amoebic meningoencephalitis	+	-	-	?[t]	+	+
Bird shistosomes	Swimmer's and clam digger's itch	+	-	-	+	-	-
<u>Algae</u>							
Gonyaulax sp.	Paralytic shellfish poisoning[i]	u	+[v]	-	-	-	+

Notes:

[a]Water = multiplies in environmental waters; Rec. = recreational (swimming); Shell. = shellfish consumption; Animal = lower animals. All agents in human feces also assumed to be present in sewage.

[b]Rare for recreational route; none for shellfish route since 1959.

[c]Primarily in fresh water.

[d]Primarily from hot tubs and whirlpool baths.

[e]Less frequently by *V. parahaemolyticus* and *V. alginolyticus* strains.

[f]Specific toxigenic strains.

[g]Only since 1973 by 0-1 strains.

[h]Only two shellfish-borne outbreaks.

[i]Toxin in food.

[j]Problem in food processing.

[k]Possibly caused by enteropathogenic *E. coli* and *A. hydrophila, Yersinia enterocolitica*, and the protozoan *Giardia lamblia*; much less frequent than viral gastroenteritis.

[l]Inferred from prospective epidemiological bathing beach study.

[m]Other source more important.

[n]Density probably influenced by nutrient loading.

[o]Not a significant source in U.S.

[p]Urine not feces.

[q]Varies with potential agent.

[r]Characteristically associated with use of swimming pools, not natural water bodies.

[s]Two questionable outbreaks in fresh water.

[t]Seed from birds suggested.

[u]Upper respiratory symptoms from other less toxigenic dinoflagellates, *Prorocentrum* sp.

[v]Shellfish poisoning is also due to other dinoflagellates with different toxins.

In addition, there are a number of other pollution-associated agents that could cause swimming or shellfish-associated disease, although there is **no evidence** that they have done so. They include the bacteria *Staphylococcus aureus, Klebsiella*, and *Clostridium perfringens*; most of the enteroviruses; amoebae such as *Entamoeba histolytica;* and a number of exotic multicellular parasites.

Source: Cabelli, V.J., Levin, M.A., and Dufour, A.P. 1983. Public health consequences of coastal and estuarine pollutions: Infectious diseases. In: Myers, E.P., and Harding, E.T., eds. Ocean disposal of municipal wastewater: Impacts on the coastal environment. MIT Sea Grant (MITSG 83-33), Cambridge, MA.

APPENDIX II

Policies and Formulas for Determining Allowable Numbers of Boats

Part 1. Interstate Shellfish Sanitation Conference Marina Policy

In accordance with the recommendation of the National Shellfish Sanitation Program that marinas be considered as potential sources of pollution in shellfish growing waters, the Interstate Shellfish Sanitation Conference adopts the following policy with respect to marina facilities, docking facilities, and other mooring areas.

Definition: A marina is any structure (docks, ramps, floating docks, etc.) which is utilized for docking, storing or otherwise mooring vessels and usually but not necessarily providing services to vessels such as repairing, fueling, security, etc.

1. The Interstate Shellfish Sanitation Conference recognizes that biological and chemical contamination associated with marine facilities may be of public health significance and may result in loss of safe shellfish growing areas.
2. The potential for contamination in the immediate vicinity of a marina will require a prohibited, restricted or conditionally approved classification of that area within the marina proper for the harvesting of shellfish.
3. If waters adjacent to the marina are impacted, additional closed areas (Prohibited, Restricted, or Conditionally Approved) beyond the marina proper will be required. The Interstate Shellfish Sanitation Conference obligates itself to the development of scientific practices for:
   - A. Determining the need for additional closed areas beyond the marina proper;
   - B. Developing uniform techniques for establishment of closed areas based on any or all of the following factors: Dilution, dispersion, die-off or residence time, hydrography, marina design, and marina usage.
4. The ISSC recommends the use of dilution analysis for marina closure determinations. The dilution analysis should incorporate the following assumptions:
   - A. An occupancy rate of the marina.
   - B. An assumed rate of boats which will discharge untreated waste.
   - C. The rates assumed in A and B, due to significant regional differences, will be determined by the State Shellfish Control Agency in each state. The basis of the assumptions will be documented and should reflect a reliable worse case condition.
   - D. 2×10^9 fecal coliforms per person per day.
   - E. 2 persons per boat.
   - F. Wastes are completely mixed in and around the marina.
   - G. The area to be closed is based on a theoretical calculated value of 14 fecal coliforms per 100 ml water.
   - H. The area to be closed is based on the volume of water in the vicinity of the marina.

Comments

- Other places where boats are moored or docked will be considered by the State Shellfish Authority or on a case-by-case basis with respect to sanitary significance relative to actual or potential contamination.
- There are significant regional differences in all factors that affect marina pollution loading. Sufficient flexibility must be allowed to account for those differences.

- Research is needed to improve the predicted pollution loading under different hydrographic conditions and to quantify the public health risks (from microbial and chemical contaminants) of consuming shellfish harvested in and around marinas.
- Best Professional Judgement of qualified shellfish sanitarians must be applied to determining adequate restrictions on harvesting in and around marinas.
- It is recommended that following marina or docking facility construction, buffer zone sizing be established using the best technology available to the State Shellfish Control Agency. Implied is that the State Shellfish Control Agency strive to develop the best available technology.

Reprinted from: Interstate Shellfish Sanitation Conference. 1986. Marina Policy. Adopted at fourth Interstate Shellfish Sanitation Conference, 1986.

Part 2. State of Maryland Marina Assessment Model

Methodology

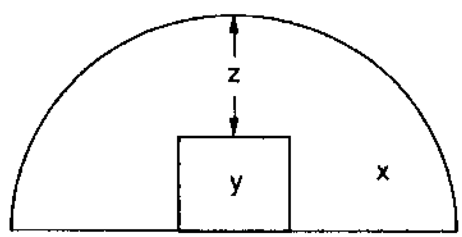
Using the ISSC's dilution analysis, a 13% occupancy rate and a volume of dilution water based on 900 square feet of surface area per boat slip, the fecal coliform concentration within a marina proper can be calculated. Once the concentration within the marina proper is known, the distance beyond the marina necessary to provide a sufficient volume of dilution water to meet a theoretical calculated value of 14 fecal coliforms per 100 ml water can be determined.

Calculations predicting fecal coliform concentrations beyond the marina are predicated on:

1. An average depth of 8.5 feet in the area outside the marina.
2. The volume of available dilution water outside the marina is equivalent to $(x - y) \times 8.5$ feet, where:

   x = surface area within the region formed by a semicircle extending "z" distance beyond the marina's outer perimeter,

   y = surface area of the marina proper as shown below.



3. During the ebbing tide, the total number of fecal coliform bacteria contained in a volume of water equivalent to the top one foot (tidal prism) of the marina proper is evenly dispersed in the water beyond the marina proper.

Discussion

While simplistic in its assumptions, the methodology used in this assessment model represents a realistic approach in that the coliform bacteria in a body of water at the marina are diluted first within the marina confines and then the total number of fecal coliform organisms contained within the volume of water equivalent to the tidal prism (one foot) is dispersed in the area outside the marina on the subsequent tide.

Not considered in this assessment are other influencing factors which individually or collectively may result in an increase or decrease of fecal coliform loading in and around a marina. These factors include:

1. bacteria die-off rates
2. flushing rates/time of travel

3. freshwater inflow
4. wind conditions
5. turbidity
6. salinity
7. water temperature
8. background levels of bacteria
9. time of year
10. shoreline contour/bottom contour

Most of these factors would contribute to additional decreases in fecal coliform concentration and survival. Therefore, the model is conservative.

Conclusion

The presence of a marina may increase the fecal coliform concentration in water. However, increased fecal coliform levels appear significant only within the marina proper. Impact on the bacteriological quality of water immediately surrounding a marina is marginal and rapidly becomes non-detectable as the distance from the marina increases.

Based on the information and the dilution calculation presented in this paper, Maryland has determined that to adequately protect the public from consumption of potentially contaminated shellfish in the vicinity of a marina, the following buffer zone sizes be established:

Marina Size (# slips)	Buffer Zone Size (feet beyond marina)
1-50	100
51-100	150
>100	200

Reprinted from: Maryland Department of the Environment. 1987. Marina assessment model for predicting bacterial loading. Annapolis, MD.

Part 3. State of South Carolina
Procedures for Buffer Zone Determinations
Marina Boat Docking Facility

The following factors affect water quality impacts of boat docking/marina facilities and the potential for contamination of shellfish from such facilities.

1. Site characteristics (size, shape, topography, geography, and hydrography).
2. Number and size of boats.
3. Usage of boats.
4. Types of docking (resident, community, lease, transit, etc.).
5. Facilities and services available at each docking area (gas, oil, repairs, food, water, supplies, pumpouts, etc.).
6. Types of waste disposal equipment on boats.
7. The existing background water quality conditions.

These factors will be given consideration in determining the necessity of a buffer zone around marinas and/or docking facilities in open Class SA waters. It is extremely difficult to establish specific criteria for these;

therefore, professional judgement must often be applied in reaching a determination as to the necessity of a buffer zone. If, after a careful review of the above factors, the Shellfish Section deems that a buffer zone is necessary, the following procedures will be applied in determining the size of the buffer zone:

1. In the absence of a site specific hydrographic study, a 1000-foot buffer zone will be required around the facility. The point of measurement will be a 1000-foot radius in all directions from all points of the boat docking facility.

2. An applicant may request a reduced buffer zone if a site specific hydrographic study, which is acceptable to the agency, is presented by the applicant and this study indicates that such action is warranted. The hydrographic study must include worse case conditions for dynamic diluting flow and worse case conditions for static volumes for any and all tide cycles including low slack tide and high slack tide. The evaluation will include all inter-relationships of hydrographic factors and coliform bacteria.

   The applicant must consult with the Shellfish Section on his study plans before initiation of a study.

3. When hydrographic studies are used to calculate dilutions and dispersions of fecal coliform, the following assumptions and/or criteria will be used:

   A. There will be 50% boat occupancy assumed at the facility.

   B. Two (2) people will occupy each boat.

   C. Marine Sanitation Device (MSD) malfunction rate:

      1. If the boat docking facility allows only boats with MSD Type III heads (no discharge), the malfunction rate = 10%.

      2. If the boat docking facility allows any other boats with MSD types I, II, and III, the malfunction rate = 50%.

   D. Fecal bacterial loading rate per person/day = 2.0×10^9 (Geldreich, 1966) using a 12-hour tidal cycle day.

   E. All discharges are instantaneous and evenly dispersed.

   F. Background water quality data will be used in determining actual buffer zone lines.

4. In determining the size of the buffer zones, the Shellfish Section will calculate expected fecal coliform concentrations at given distances from the docking facility. These predicted concentrations will be compared to the standard of 14/100 ml and an actual buffer zone line will then be drawn.

5. It will be necessary to protect the shoreline adjacent to the boat docking facilities to prevent contamination from floating and settleable solid matter associated with human waste. This floating matter is easily influenced by tidal currents and wind direction. To ensure this protection, buffer zones may be extended beyond the calculated distance necessary for diluting the waste. This extension will extend to the immediate shoreline unless an acceptable alternative means of shoreline protection is provided to ensure that the potentially contaminating solid fecal matter **does not** reach the shellfish beds located near the shoreline in the vicinity of the docking site.

   This provides protection at low slack tide and high slack tide with prevailing wind conditions that might push waste to shore. After low and high slack tide conditions, the dynamic tidal current diluting flow then removes this waste and dilutes it according to measured flows and concentrations as established by the hydrographic study.

If a complete evaluation indicates that a buffer zone smaller than 1000 feet provides adequate public health protection, the Shellfish Section will reduce the buffer zone appropriately. Similarly, if the hydrographic survey indicates that a 1000-foot buffer zone is not adequate to protect public health, the size of the buffer zone will be expanded beyond the 1000-foot radius. It will be mandatory that the following conditions are accepted, incorporated and enforced as a part of all certifications or permits.

1. Pumpout facilities for boat sanitary waste are provided.

2. Enforcement procedures are required for those berthing facilities that allow MSD Type III only.
3. A monitoring program will be designed by the agency and implemented to measure conditions in and around the docking facility for parameters affecting the classification of shellfish areas. The applicant must bear sampling and laboratory costs. These include:
   - A. Fecal and total coliform in the water.
   - B. Fecal and total coliform in shellfish meats.
   - C. Temperature.
   - D. Salinity.
   - E. Heavy metals.

The sample stations shall include but not necessarily be limited to inside the zone, outside the zone, and along the zone line.

The time of sampling, the placement of sampling stations and the frequency of sampling will be established by the Department.

If monitoring results reveal that the established buffer zone is inadequate, the Shellfish Section will increase the size as necessary to protect the public health.

Reprinted from: South Carolina Department of Health and Environmental Control, Shellfish Division. 1985. Technical procedures for buffer zone determinations around boat docking facilities. Columbia, SC.