

**POTENTIAL IMPACTS FROM
MARINAS AND BOATS
IN BALTIMORE HARBOR**

Prepared for the Baltimore Regional Council of Governments

by

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Introduction

The Baltimore City Planning Commission has undertaken the task of developing Baltimore Harbor's resources for recreational marinas. The development plan is outlined in the Marina Master Plan of 1989. Between 1983 and 1985 there was a substantial increase in the number of existing and proposed marina slips (from 450 in 1983 to 2925 in 1985), and in 1985 the first Marina Master Plan was adopted. Now, five years later, the increase in existing and proposed marina slips continues (5502 in 1990), as do concerns associated with rapid development. In 1989 the Marina Master Plan was reviewed and revised in order to meet current needs and concerns. One of the components of the Plan, as outlined in the Executive Summary, is to address a variety of environmental issues. An initiative was undertaken by the Baltimore Regional Council of Governments (BRCOG), and a study was proposed to assess the water quality impacts of marinas. The Chesapeake Research Consortium (CRC) accepted responsibility for organizing a literature-based review of available information. The study itself was conducted by staff from the Chesapeake Biological Laboratory and Horn Point Environmental Laboratory, both of which are units of the University of Maryland's Center of Environmental and Estuarine Studies (CEES).

The study assessed water quality in Baltimore Harbor from available water quality data and from the perspective of potential impacts from boats and marinas. The assessment was approached by first constructing a nutrient input budget for Baltimore Harbor, which included diffuse, point and marina sources, then characterized flushing rates throughout Baltimore Harbor and lastly, explored biological oxygen demand (BOD) loadings and possible reductions in site-specific dissolved oxygen (DO) levels due to marina loadings. Based on potential DO reductions in marina basins, the feasibility or need for re-aeration of oxygen poor waters was also assessed. In general, loading and water quality data for Baltimore Harbor was limited and in many cases, mathematical models were used to estimate loading and flushing rates and biological oxygen demand (BOD) loadings.

The study began with a literature review of potential impacts from boats and marinas and flushing dynamics of semi-enclosed systems in order to assist in identifying problems associated with marina development and increased boating activity. Section 1 of this report summarized the literature review, highlighting findings which were particularly relevant to Baltimore Harbor.

A nutrient input budget for Baltimore Harbor was constructed (Section 2) to help identify other sources impacting water quality in addition to nutrient inputs from boats and

marinas. The nutrient input budget included diffuse, point and marina sources, and loading rates were calculated with the use of various models or loading data when available. The nutrient input budget was then divided into nutrient input budgets for several sub-basins of Baltimore Harbor in order to achieve a better idea of site-specific water quality conditions.

Flushing potentials for each marina in Baltimore Harbor were estimated in Section 3, using a mathematical model described in *The Coastal Marina Assessment Handbook* (EPA, 1985). Circulation and flushing characteristics of marina basins play important roles in the distribution and dilution of potential contaminants introduced by boating and marina activities. Using marina loadings and flushing rates from Sections 2 and 3, potential reductions in dissolved oxygen concentrations were estimated for each marina.

Since various mathematical models were used to calculate marina loadings, flushing rates and BOD loadings in Sections 2, 3 and 4, and since many assumptions were made in order to use these models, the implications these assumptions involve are discussed at length in the respective sections. Although the models help characterize water quality in Baltimore Harbor and in the marina basins, the models can not say what the actual water quality is and what the actual impact is. Therefore, one conclusion the study found was a field program is needed to better assess and monitor water quality in Baltimore Harbor. A strawman monitoring program is provided in the addendum to this study, along with a summary of the final meeting between BRCOG and MDE representatives and the authors.

Section 1

Summary of the Annotated Bibliography

1.1 Overview

The annotated bibliography focused on water quality impacts of boating and marina operations and on oxygen dynamics of semi-enclosed systems as related to flushing and reaeration processes. Factors found to contribute impacts to marina areas were summarized, and management and mitigative considerations suggested. This summary focuses on findings from the annotated bibliography which are particularly relevant to Baltimore Harbor's marina development program.

1.2 Water Quality Impacts of Boating and Marina Operations

Baltimore Harbor's marina development plan could potentially result in at least 5500 boats using the harbor for moorage and recreation. Both boat and marina related impacts are therefore of concern. The literature review identified three major factors associated with boating and marina impacts: nutrient additions (via sewage, bilge and gray water discharges), toxics and marina structural features. Nutrient additions could come from boats and/or marinas which discharge or leak untreated or partially treated sewage into marine waters, possibly creating health problems, increasing biological oxygen demand (BOD) and eutrophication. The discharge of bilge water or gray water from sinks, showers or deck drains can be other sources of nutrient additions into marine waters. Toxic contaminants could come from boat bottom paints, motor exhausts, storm water run-off and boatyard run-off (from cleaning, sanding, scraping and painting), decreasing water quality and possibly affecting the health of fish and other fauna. Marina structural features such as bulkheads, breakwaters and piers and wharfs could inhibit flushing, promote abundant fouling communities and decrease light penetration. All three of these factors can cause potential problems wherever there is a concentration of boats and marinas. The following discussion addresses specific concerns and impacts associated with each one of these factors.

1.21 Nutrient Impacts

Many boat pollution impact studies have focused on boat sewage as a major concern. This concern arises from the many implications of sewage pollution, including the potential for disease transmission, eutrophication of receiving systems due to increased nutrient loads and higher

BOD's and possible introduction of harmful chemicals used in marine sanitation devices, MSD's (Clark, 1982, Chmura and Ross, 1978, Walker et al., 1989). However, the extent of impact from boat sewage is not well known due to difficulties of testing for boat sewage and linking positive tests directly to boating activities (Clark, 1982 and Chmura and Ross, 1978). A common complication in boat pollution impact studies is that background levels of coliform bacteria from land-based sewage pollution often mask impacts which were related to marina or boating activities (Nixon et al., 1973, Faust et al., 1978). Faust (1982) was successful in conducting a study in an area where background coliform levels were well documented and thus was able to detect the presence of boat sewage. The impact appeared negligible, however, due to very high coliform bacteria mortality rates and adequate flushing. In an earlier study, Faust (1975) made the observation that in summer, when boating activity was highest, water temperatures were high as well, which apparently caused high coliform bacteria mortality rates. This has not been commonly observed elsewhere, and it may be that there are other factors influencing mortality rates such as salinity and dissolved oxygen levels. Another potential problem associated with sewage are high BOD's caused by the metabolism of the raw sewage which in turn could cause low dissolved oxygen concentrations. Since boating activity is highest in summer, when oxygen concentrations are also naturally low, the addition of sewage could intensify low dissolved oxygen conditions or cause a system which is barely coping with BOD to go hypoxic or anoxic.

Direct discharge of bilge water and gray water from sinks, showers and deck drains contribute to both nutrient and toxic impacts. Bilge water can contain gasoline, oils or cleaning detergents, all of which have been found to be toxic to the marine environment (Chmura and Ross, 1978, Carstea et al., 1975 and Crecelius et al., 1989). Food residues and cleaning detergents are common ingredients in gray water, containing both nutrients and toxics. It should be noted that bilge and gray water are not often collected at pump-out stations and are almost always directly discharged into marine waters.

The Water Quality Act of 1987 required that all vessels with installed toilet systems have MSD's. The type of MSD determines whether the sewage is treated (types 1 and 2) or is contained in a holding tank (type 3) until transfer to a marina pump-out station. The chemicals used in type 1 and 2 MSD's for treatment and in type 3 MSD for odor control have been found to be harmful to the marine environment (Walker et al., 1989, Clark, 1982, Chmura and Ross, 1978, Recreational Boat Pollution Work Group, 1991). Because type 1 and 2 MSD's are designed to legally discharge the treated sewage into the marine environment, these chemicals are also discharged and could cause marine health problems. Legally, raw, untreated sewage can not be discharged in coastal waters, but this regulation is difficult to enforce. Type 3 MSD's have seacocks or valves which allow direct discharge of raw sewage, and these can be opened and used legally outside the 3 mile coastal zone. It is impossible, however, to know whether these valves are illegally open

inside the 3 mile zone, and impossible to know how much sewage is impacting water quality, unless field studies are conducted.

Baltimore Harbor could potentially experience water quality impacts from high levels of boat sewage pollution, if areas are densely populated with boats which are discharging wastewater directly into the harbor, and if the areas are not well flushed. However, there is not enough water quality data from the harbor to determine whether there is an impact from boat and/or marina sewage at the present time. Several assumptions however can be made in the absence of sufficient field data to calculate potential marina loadings. Section 2.5 of this report describes the assumptions that must be made and calculates potential marina loadings in terms of nutrients (total nitrogen and total phosphorus). It was found that nitrogen and phosphorus loading from recreational marinas in Baltimore Harbor was 53,094 g N/day and 2,765 g P/day, respectively or 4,840,000 g N/summer and 252,000 g P/summer, respectively, assuming that 25% of the boats in marinas were in use. Northwest Branch was the highest impacted area, receiving 60% of the total nutrient load from marinas. It should be noted that these calculations do not include nutrient additions from bilge or gray water discharges.

Marina facilities and pump-out stations have also been identified as potential nutrient contributors (Chmura and Ross, 1978 and Clark, 1982). In most cases, sewage and gray water contamination resulted from leaky septic systems or sewage lines.

The 1987 Chesapeake Bay Agreement includes the goal of reducing nutrient additions to Chesapeake Bay by 40% of 1985 nutrient addition levels and more specifically, calls for a total elimination of pollutant discharges from recreational boats. The Chesapeake Bay Implementation Committee created the Recreational Boat Pollution Work Group (May, 1990) to address the issue of recreational boat pollution. The Work Group presented a report, Recreational Boat Pollution and the Chesapeake Bay (1991), in which recommendations were made for the reduction of recreational boat pollution. The recommendations involve all parties associated with recreational boating, from those who make regulations to those who are affected by regulations. Several suggestions were made in particular for the mitigation of boat and marina sewage discharges, a few of which are listed below.

1. The Coast Guard should make more frequent inspections aboard recreational vessels to determine whether MSD's are properly maintained and used.
2. Sensitive areas vulnerable to boat pollution should be designated as "No Discharge Zones".
3. Marinas should be responsible for having adequate pump-out facilities and well-maintained plumbing lines.

1.22 Toxic Impacts

Many studies have shown that bottom paints contribute significant levels of toxic metals to the marine environment (Nixon et al., 1973, Young et al., 1979 and Crecelius et al., 1989). Tributyltins (TBT's), which were banned in 1988 by the United States Organotin Antifouling Paint Control Act, were still detected in significant quantities in two Puget Sound marinas in 1989 (Crecelius et al., 1989). Copper, the most common ingredient in antifouling paint today, has also been found in fouling and benthic organisms and in sediments (Nixon et al., 1973, Young et al., 1979 and Crecelius et al., 1989). Crecelius et al. (1989) found copper concentrations to be up to 13 times greater in marina sediments than in sediments outside the marinas, and there appeared to be a spatial contamination of sediments for about 150 meters from the mouth of the two marinas studied. Young et al. (1979) also found an 8 fold increase in copper concentrations in areas inside marinas adjacent to boat yards where cleaning, scraping, sanding and repainting were common activities. These areas experience intense local toxic loads, but boatyard run-off can be controlled by filter systems which catch boatyard run-off before it enters the marina. Boatyard run-off should not be a problem in Baltimore City, because filter systems which remove toxics from boat bottom wash waters are required by Baltimore City's Critical Area regulations. Young et al. (1979) also found a marina which did not exhibit significant concentrations of copper or other boat related contaminants and attributed it to the marina design which maximized flushing efficiency. The contaminated marinas in the study by Young et al. had just one entrance into a well enclosed harbor, whereas the uncontaminated marina had three entrances which allowed for greater water circulation. Crecelius et al. (1989) also found that although two marinas had high levels of contamination, concentrations were small compared to concentrations in point and diffuse sources for Puget Sound. When marina concentrations were transformed into discharge rates per boat and prorated for the entire Puget Sound area, the rate of annual copper emission was found to be 2,000 kg/yr. The annual load of copper from the municipal, industrial and diffuse sources in the Puget Sound area was previously determined to be 222,000 kg/yr. Therefore, Puget Sound marinas contributed less than 1 percent of the total annual copper load. That is not to say that mitigation of copper loads from marinas was not necessary, but that in addition to mitigating copper and other toxic loads from marinas, diffuse and point source loads needed mitigation as well.

Another contributor of contaminants is motor exhaust (polynuclear aromatic hydrocarbons - PAH's, lead, carbon dioxide and monoxide). Crecelius et al. (1989) found concentrations of PAH's and lead in sediments inside two marinas to be 2 to 20 times and 2 to 5 times the concentrations of PAH's and lead outside the two marinas. These concentrations did not exceed standards set by EPA water quality criteria or apparent effects thresholds as determined for Puget Sound. Laboratory tests, however, do show a definite toxicity associated with outboard motor exhaust contaminants, but the degree of toxicity is dependent on the condition of the outboard

motor and the targeted organism. It is therefore not possible to determine a probable concentration of toxicity for Baltimore Harbor marina areas.

Stormwater run-off can be another contributor of toxic contamination. Because marinas often develop the shoreline by covering most of the surface area with non-permeable coverings, surface run-off often increases in marina areas (Chmura and Ross, 1978). The effects of stormwater run-off into a semi-enclosed system were studied by Chen et al. (1972), and significant levels of heavy metals, pesticides and organic debris were measured in the sediments and waters near storm drains. The organic debris, which tended to collect in the marina where flushing was inadequate, caused anaerobic conditions. Recreational marinas, as well as other shoreline developments, could install filter systems, as near to the shoreline as structurally possible, to prevent contaminants from entering into marina waters and into the harbor area in general. If such a filter system is not possible to install in a marina area, other mitigative measures, such as permeable ground coverings and bulkheads (for example, replacing concrete and other non-permeable coverings with gravel, sand or grass coverings) and adequate flushing in marinas, will in the least better disperse and dilute contaminants. However, stormwater run-off may be more than localized, if it is impacting large areas. This situation is discussed in Section 1.24 of this report.

In order to decrease impacts from toxic contamination, sources of contamination should be removed or decreased. Several suggestions were made in earlier studies:

1. Boatyards should be required to install filter systems which remove toxics from boatyard run-off. (Baltimore City already has this requirement.)
2. Marine engine exhaust systems should be improved to eliminate motor exhaust contamination.
3. Marinas should have filter systems as near to the shoreline as possible to prevent contaminants in stormwater run-off from entering into marina waters and into the harbor area in general. (Baltimore City has this requirement as well.)
4. Where filter systems are not possible to install, ground coverings and bulkheads should be made of permeable materials and flushing of marina waters should be adequate in order to better disperse and dilute local contamination from boats, marinas and stormwater run-off.

1.23 Marina Structural Impacts

Structural designs of marinas can influence the degree of water quality impact by affecting flushing, the amount of surface area available on which fouling organisms may grow and the amount of surface structure inhibiting light penetration (Chmura and Ross, 1978 and Nixon et al.,

1973). Large, solid, subsurface structures such as solid breakwaters or any type of wall structure used for wharf or pier foundation should be avoided, because flushing efficiency is decreased. In a study already mentioned (Chen et al., 1972), organic debris from stormwater run-off tended to accumulate behind a solid breakwater and caused anaerobic conditions to develop. A breakwater made out of a permeable material would have prevented organic debris build-up and low dissolved oxygen conditions. The new marinas in Baltimore City are broad, floating platforms, with floating wave attenuators as well. Flushing efficiency should not be reduced with this type of marina design, but organic debris build-up around these platforms and wave attenuators could still be a problem.

In another study, Nixon et al.(1973) observed diurnal oxygen stresses in marinas which were caused by the respiration of abundant fouling communities which had colonized much of the subsurface areas. Thus, limiting the subsurface area in marinas could prevent high BOD's by decreasing the populations of fouling organisms. The underside of the floating platforms used in Baltimore City marinas present an abundant surface area on which fouling organism could colonize. Diurnal dissolved oxygen levels around these platforms should be monitored to determine whether these areas are being impacted by high BOD's. Chmura et al. (1978) also recommended that piers, wharfs and docks be built high enough to allow light penetration to waters below. Light is needed for healthy phytoplankton and seagrass growth, which is desirable since these plants and grasses furnish oxygen to the water. Although it is unlikely that submerged aquatic grasses could grow in marina areas, due to depths required for boat traffic and low light penetration, the photic zone could still support phytoplankton communities. Single width marina platforms should not present too much of an impact on water column phytoplankton, however rafting platforms together or covering large water surface areas should be avoided.

Earlier studies have made the following recommendations on marina structural designs, some of which Baltimore City already follows.

1. Large, solid subsurface, structures should be avoided or made of a permeable material to allow for maximum flushing efficiency. The floating marinas of Baltimore City comply with this.
2. Subsurface areas should be limited to minimize fouling community abundances and prevent high BOD's.
3. Piers, wharfs and docks should be built high enough off the water or cover the least amount of water surface area in order to allow for light penetration to waters below which is needed by phytoplankton communities.

Section 1.3 Flushing of Semi-enclosed Systems

Of the many factors that influence the eventual impact a marina will have on the water quality within the marina and the surrounding body of water, the selection of a marina site and design with favorable hydrographic characteristics can do a great deal to reduce potential water quality impacts. Flushing and circulation are two critical physical characteristics of a potential marina which must be considered in the planning of a marina. For marinas that are situated in semi-enclosed basins, either natural or man-made, the configuration of the basin becomes an important factor in considerations of water quality impacts. Marina size and shape are two significant features of marina basin configuration.

The EPA (1985) lists the following marina basin design features that promote proper flushing:

1. Basin depths that are not deeper than the open water or channels to which the basin is connected and never deeper than the marina access channel.
2. Basin and channel depths that gradually increase toward open water.
3. Two openings at opposite ends of the marina to establish flow-through currents.
4. Single entrances (if it can't be helped) that are centered in rectangular basins rather than at one corner.
5. Basins with few vertical walls and gently rounded corners or circular or oval shaped.
6. Even bottom contours, gently sloping towards the entrance with no pockets or depressions.

The most common method for estimating potential flushing times for semi-enclosed marinas is to employ a various formulations of dilution equations based on tidal prism flushing as a transport model. Sanford et al (1991) and Van de Kreeke (1983) discuss the various assumptions that are involved in calculating flushing time for marina basins. As long as these assumptions are met, the application of a simple tidal prism flushing model can yield quite satisfactory results. The most important of these assumptions is that the tidal embayment is well mixed internally. Subsidiary assumptions are that there is insufficient vertical stratification to inhibit vertical mixing over the tidal cycle, and that the basin is small relative to a typical tidal excursion. Embayments that are not well mixed are likely to exhibit large internal gradients in concentration, with areas remote from the connection to the receiving water body flushing much more slowly than the rate predicted by the tidal prism model.

The single largest source of error in predicting tidal flushing was shown by both authors to be due to inappropriate specification of a return flow factor (i.e., the amount of water flushed from

the marina basin on ebb tide and subsequently returned into the marina on the following flood tide). The value of the return flow factor was shown by Sanford et al. (1991) to depend on both the relative momentum of the embayment channel and coastal currents and the amount of cross-plume diffusion that occurs outside the embayment. Jet-like channel currents on ebb tide push effluent waters away from the marina entrance, allowing the return flow on flood to be drawn from water relatively free from contaminants and thus decreasing the return flow factor. Rapid mixing of plume water and surrounding water also decreases the return flow factor in most cases. Excursion of plume waters into open water beyond the end of a point or sharp bend can greatly increase mixing. Any phase difference between the embayment channel currents and the water body currents should decrease the return flow factor.

In Section 3.2 site-specific flushing rates are calculated for existing and proposed marinas in the Harbor. In Section 3.3, the applicability of such equations is discussed for Baltimore Harbor.

1.4 Summary and Conclusions

Impacts from boats and marinas have the potential to decrease water quality to varying degrees. This potential for rapid decline in water quality caused by impacts from boats and marinas is increased in poorly flushed areas and in areas which are presently under stress from ambient BOD and toxic concentrations. Other sources impacting water quality are, on a local scale, storm water run-off into marina areas and, on a larger scale, diffuse and point source discharges into harbor areas. An important consideration, then, is the combined impact from marinas and boats along with impacts from local diffuse and point loads. However, local diffuse and point loads could be so heavy to be problems in and of themselves, which appears to be the case for Baltimore Harbor. It is therefore important to locate these diffuse and point source discharges in relation to the location of marinas in Baltimore Harbor. Site-specific loads for each marina, and a preliminary assessment of total nutrient impact is the focus of Section 2 of this report.

If diffuse and point source loads are great, off-site mitigations which decrease diffuse and point source impacts are highly recommended. Run-off contamination can be alleviated via intercepting ponds or wetlands as discussed by Chen et al. (1972) and Mitsch (1989). The intercepting ponds collect the contaminants in run-off, where they settle instead of discharging into marina waters. Mitsch (1989) in a study of wetlands as ecological tools for decreasing loads, found that wetlands, intercepting diffuse and point source loads from an upstream source, acted as sinks for nutrients and sediments. Baltimore Harbor may not have the luxury of space to achieve these types of mitigations in the marina areas, but this technique might be used elsewhere in the

watershed, where diffuse and point source loads begin to collect for transport downstream to Baltimore Harbor. This is to say that in addition to mitigating impacts from marinas and boats, mitigating diffuse and point source loads are critical as well.

These are the major impacts associated with marina and boating activities which have the potential to create water quality deterioration. The recommendations and mitigations suggested are to help guide managers in the development of Baltimore Harbor. For a more detailed explanation of the impacts discussed, the annotated bibliography can be consulted. As mentioned previously, a preliminary assessment of marina loading has been developed (Section 2.5) and diffuse and point source loading rates have been calculated for 4 sub-basins in Baltimore Harbor in order to determine site-specific nutrient loads to each marina area (Sections 2.3 and 2.4). Preliminary site-specific flushing rates and boat sewage BOD loadings are calculated in Sections 3.2 and 4.2

Section 2

Nutrient Inputs

2.1 Introduction

In the initial memorandum generated by this study, a preliminary nutrient input budget to Baltimore Harbor was determined. An examination of diffuse and point source loading revealed Baltimore Harbor to be heavily nutrient loaded, which created some concern as to the accuracy of the nutrient input budget. One of the goals of this final report is to improve the nutrient input budget and to make it more site-specific. Diffuse loading data do not exist for Baltimore Harbor; however, an intensive program has been initiated to monitor diffuse loading rates throughout Baltimore Harbor's drainage basin. Because these data are not yet available, two indirect methods were used to estimate diffuse nutrient loading rates to Baltimore Harbor. The first method involved extrapolating river flow and nutrient loading trends from a selected system where data exist and relating these trends to river flows in Baltimore Harbor. This method was compared to another method which estimated diffuse nutrient loading to Baltimore Harbor by calculating loading rates based on various land uses in Baltimore Harbor. Site-specific diffuse loading rates were obtained (via the first method) as well as site-specific point source loading rates. Point source loading rates were also updated and believed to be accurate. Another goal of this report was to calculate nutrient loading rates from each recreational marina in Baltimore Harbor.

2.2 The Four Sub-basins in Baltimore Harbor

Figure 2-1 depicts how Baltimore Harbor was divided into four sub-basins, showing for each sub-basin marina and point source locations. Marina locations are from Baltimore City Planning (Dolan and Gupta, pers comm) and point source locations are from MDE (Legg and Spath, pers comm). The upper portions of Northwest Branch and Middle Branch sub-basins are not shown in Figure 2-1; consequently, the point sources located in these upper sub-basins are also not shown. The nautical scale in Figure 2-1 applies only to the tidal portion in Baltimore Harbor. The drainage basins have been approximated for illustrative purposes and the actual land surface areas for each sub-basin are given in Table 2-2. The key to Figure 2-1 (Table 2-1) identifies the marinas and point sources according to number or letter.

Land surface area estimates are from Holway (BRCOG, pers comm) for the following drainages: Patapsco River (nontidal), Gwynns Falls, Jones Falls, Curtis Bay, Bear Creek, Old Road Bay and Cox, Stoney and Rock Creeks. Upper tributary land areas are from USGS (Water-

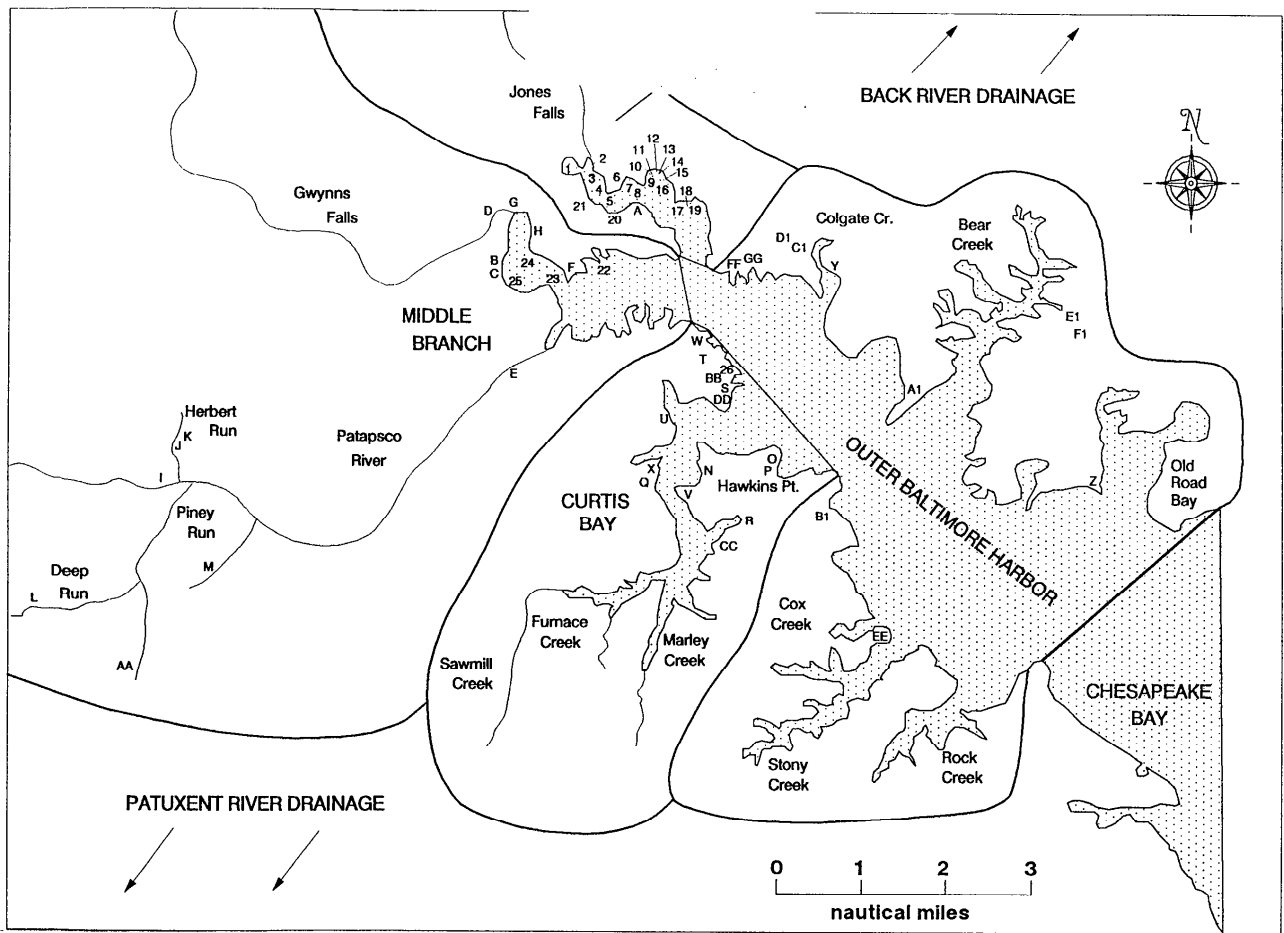


FIGURE 2-1. Map showing most of Baltimore Harbor drainage basin which has been divided up into four sub-basins: Northwest Branch, Middle Branch, Curtis Bay and Outer Baltimore Harbor (includes Colgate and Bear Creeks, Old Road Bay, Cox and Rock Creeks and the outer southeastern portion of tidal Patapsco River). The nautical mile scale applies only to the tidal portions of Baltimore Harbor. The drainage basins have been approximated for illustrative purposes; actual land surface areas for each sub-basin are given in Table 2-2. Marina and point source locations are shown and can be identified by the map key, Table 2-1.

Table 2-1. Baltimore Harbor map key identifies marinas and point sources are listed by key number or letter for each sub-basin in Baltimore Harbor. Point facilities, which are not shown in Figure 2-1 because the locations are off the map, are listed here with an NL designation.

KEY	NORTHWEST BRANCH	KEY	CURTIS BAY
	Marinas		Marinas
1	Inner Harbor	26	Port Liberty
2	Inner Harbor East		Municipal Facilities
3	Lady Maryland	BB	Patapsco STP
20	Tidewater	CC	Pitt - Des Moines Corp
21	Harborview	DD	U.S. Gypsum Co.
4	Constellation		Industrial Facilities
5	Brown's Wharf	N	WR Grace
6	Harbor's Edge	O	Balto Sewage Sludge
7	Belts Wharf Landing	P	B.F.I. Quarantine Road Landfill
8	Henderson's Wharf	Q	Amoco Oil Corp - Curtis Bay Terminal
9	Swann's Wharf	R	Chemetals
10	Thames Point	S	BG&E Wagner Station
11	Chester Cove	T	Amoco Oil Corp - Lube Div
12	Bayview	U	Curtis Bay Co
13	Anchorage Plaza	V	Union Carbide
14	Scarfield	W	Support Terminal Ser
15	Anchorage	X	Crown Central Petrol
16	Shipyard		
17	Baltimore International Yachting		
18	Tindeco Wharf		OUTER BALTIMORE HARBOR
19	Canton Cove		Marinas
	Municipal Facilities		None
	None		Municipal Facilities
	Industrial Facilities		Anne Arundel Co, Cox Ck
A	Proctor and Gamble	EE	Fort McHenry Tunnel
		FF	Lebanon Chem. Corp
		GG	Industrial Facilities
	MIDDLE BRANCH		SCM Glidco Organics
	Marinas	Y	Bethlehem Steel
22	Port Covington	Z	BG&E Riverside
23	Ferry Bar	A1	Cox Creek Refining
24	Baltimore Yacht Basin	B1	GM Corp - Assembly Div
25	Middle Branch Moorings	C1	Lever Bros
	Municipal Facilities	D1	Signode Supply
AA	Holiday Mobile Estates	E1	National Can Corp
NL	Woodstock Training Center	F1	
NL	Freedom District		
NL	Gaither Manor Apts		
NL	Mt Airy STP		
NL	Pheasant Ridge Estates		
NL	South Carol H.S.		
	Industrial Facilities		
B	BG&E Westport		
C	Carr-Lowrey Glass Co.		
D	Kaydon Ring and Seal		
E	Essex Ind. Chem		
F	Locke Insulators		
G	Valspar		
H	BG&E Spring Gardens		
I	JE Seagrams and Sons		
J	Halethorpe Extrusions, Inc.		
K	GM Corp - Electro/Motive Div		
L	Balto/Wash Auto Exchange		
M	Westinghouse Electric		
NL	Springfield Hos WTP		
NL	Arundel Corp - Delight Quarry		

TABLE 2-2. Diffuse and atmospheric loading rates to Baltimore Harbor sub-basins.

DIFFUSE LOADING BASED ON PATUXENT RIVER DIFFUSE LOADING

SUB-BASIN AREA (see map for delineations)	DRAINAGE AREA (mi ²)	ANNUAL AREAL RIVER FLOW (cubic feet/sec/mi ²)	ANNUAL TOTAL FLOW (cfs)	ANNUAL DIFFUSE LOADING		WATER SURFACE AREAS (m ² *10 ⁶)	BALT ANNUAL AVE RAINFALL (cm/yr)	ATMOSPHERIC DEPOSITION TO WATER SURFACES		TO LAND SURFACES			
				TN (kg N/yr)	TP (kg P/yr)			TN (kg N/yr)	TP (kg P/yr)	TN (kg N/yr)	TP (kg P/yr)		
NORTHWEST BRANCH													
Upper Jones Falls (Sorrento and above)	25.2	1.0	25.2	43939.3	5637.2	4.37	100						
Lower Jones Falls (below Sorrento)	33.8	1.0	33.8	58934.4	7561.0								
Northwest Branch adjacent areas	10.3	1.0	10.3	17959.3	2304.1								
Sub-total	69.3			120832.9	15502.2					6948.3	279.7	285384.3	11487.2
Areal sub-total (mg N or P/m ² /yr)				27651.0	3547.0								
MIDDLE BRANCH													
Upper Gwynns Falls (Villa Nova and above)	32.5	1.0	32.5	56667.7	7270.2	8.10	100						
Lower Gwynns Falls (below Villa Nova)	31.5	1.0	31.5	54924.1	7046.5								
Upper Patapsco (Hollofield and above)	285.0	0.4	114	198772.8	25501.5								
Lower Patapsco (below Hollofield)	80.3	1.0	80.3	140012.8	17962.9								
Middle Branch adjacent areas	9.5	1.0	9.5	16564.4	2125.1								
Sub-total	438.8			466941.8	59906.1			12879.0	518.4	1807022.3	72735.5		
Areal sub-total (mg N or P/m ² /yr)				57647.0	7396.0								
CURTIS BAY													
Upper Curtis Creek (at Crain Hwy and above)	5.0	0.2	1.2	2092.3	268.4	6.09	100						
Curtis Creek (below Crain Hwy) and Marley Ck	30.7	1.0	30.7	53529.2	6867.5								
Curtis Bay adjacent areas	1.1	1.0	1.1	1918.0	246.1								
Sub-total	36.8			57539.5	7382.0					9683.1	389.8	151546.1	6100.0
Areal sub-total (mg N or P/m ² /yr)				9448.0	1212.0								
OUTER BALTIMORE HARBOR													
OUTER SOUTHWESTERN TRIBUTARIES													
Stoney and Cox Creeks	7.5	1.0	7.5	13077.2	1677.7	80.34	100						
Rock Creek	3.9	1.0	3.9	6800.1	872.4								
Southwestern adjacent areas	3.9	1.0	3.9	6800.1	872.4								
OUTER NORTHEASTERN TRIBUTARIES													
Bear Creek	7.6	1.0	7.6	13251.5	1700.1								
Old Road Bay	2.5	1.0	2.5	4359.1	559.2								
Northeastern adjacent areas	10.6	1.0	10.6	18482.4	2371.2								
Sub-total	36.0			62770.4	8053.1			127740.6	5141.8	148251.6	5967.4		
Areal sub-total (mg N or P/m ² /yr)				781.0	100.0								
TOTAL	580.9		406.1	7.08E+05	9.08E+04	98.90		1.57E+05	6.33E+03	2.39E+06	9.63E+04		
AREAL TOTAL (mg N or P/m²/yr)				7160.0	919.0								

NOTES:

- 1) Diffuse loading is based on statistical regressions (see Fig. 2-2) relating diffuse loading in the Patuxent River (1983-1988) to river flow in Baltimore Harbor; lines used are: TN = ((4.458*cfs)+129.97) and TP = ((0.801*cfs)-76.40). These loading rates for Baltimore Harbor reflect normal rainfall conditions and do not take storm events into account.
- 2) Annual areal river flow was determined from the USGS (WATER-DATA REPORT MD-DE-84-89) record for Baltimore Harbor's drainage basin; all tributaries had normal riverflow during normal rainfall years, except for upper Patapsco River and upper Curtis Creek. These upper tributaries experience diversions further upstream, and this was reflected proportionally in lower than normal river flow rates. It has been noted that river flow in lower Jones Falls may also be affected by diversions, but this has not been taken into account here due to lack of data.
- 3) An average rainfall rate was used, and wet-fall nutrient concentrations are from Smullen et al (1982); TN = 1.59 mg/l and TP = 0.064 mg/l.
- 4) Water surface areas are from Cronin and Pritchard (1975) and were used to determine areal loading. Sub-basin drainage areas are from Jim Holway (pers comm) and from mapping grids; total drainage basin area is from USEPA (1982) and was used as a definitive total in determining sub-basin areas (see Fig. 2-1).

Data Report, MD-DE-84-89) and were subtracted from Holway's estimates in order to give lower tributary land areas. An estimated adjacent land area for Baltimore Harbor was determined by subtracting the above drainage areas from the estimated total drainage basin area for Baltimore Harbor (USEPA, 1982). By using mapping gridlines, this adjacent land area was divided up among the four sub-basins, Northwest Branch, Middle Branch, Curtis Bay and Outer Baltimore Harbor. Outer Baltimore Harbor sub-basin includes Colgate and Bear Creeks, Old Road Bay and Cox and Rock Creeks, the outer, tidal portion of the Patapsco River and the adjacent land areas associated with the outer north-eastern creeks and bay and the outer south-western creeks. Table 2-2 shows the tributaries and adjacent land areas associated with each sub-basin.

2.3 Diffuse and Atmospheric Loading

One method used to determine diffuse nutrient loading rates to Baltimore Harbor involved statistical regressions of diffuse nutrient loading in the Patuxent River basin which were then related to river flow in Baltimore Harbor. The Patuxent River basin was chosen because the drainage basin was more similar to Baltimore Harbor's drainage basin than any of the others which are monitored as part of the Chesapeake Bay Water Quality Monitoring Program. Figure 2-2 shows the data used from the Patuxent River (Summers, pers comm) and the statistical regressions for river flow versus total nitrogen (TN) and total phosphorus (TP) loading rates. The diffuse TN and TP data used do not include any point source loading, and both river flow and diffuse TN and TP were measured at the fall-line. The above fall-line diffuse calculation used by Summers (pers comm) for estimating diffuse loading to the Patuxent River includes a term for nutrient loss to accommodate transport losses en route to the fall-line. Baltimore Harbor river flow was substituted into these linear equations to obtain estimates of TN and TP loading rates (Table 2-2). It should be noted that the loss term used by Summers (pers comm) would now be included in the estimates of diffuse loading rates for Baltimore Harbor via this extrapolation. River flow for the upper tributaries in Baltimore Harbor was determined from the USGS (Water-Data Report MD-DE-84-89) record. The record indicated normal river flow during normal rainfall years (about 1 cubic ft/sec/mi²) for all tributaries except for the non-tidal portion of the Patapsco above Hollofield and for Curtis Creek above Crain Highway. River flow for these upper tributaries was less than normal due to diversions upstream, and these diversions were reflected proportionally in river flow averages given in Table 2-2. Lower tributary river flow was assumed to be normal throughout Baltimore Harbor's drainage basin as well as river flow for land areas directly adjacent to the harbor. This is not the case for lower Jones Falls which experiences nutrient entrapment by Lake Roland. However, river flow data for the lower Jones Falls were not available for these

PATUXENT RIVER FLOW vs DIFFUSE TOTAL NITROGEN AND TOTAL PHOSPHORUS LOADING

YEAR	RIVER FLOW (cfs)	DIFFUSE TN (kg N/d)	DIFFUSE TP (kg P/d)
1983	506	2430	352
1984	438	2111	276
1985	216	1205	125
1986	216	1138	126
1987	292	1333	135
1988	305	1358	108

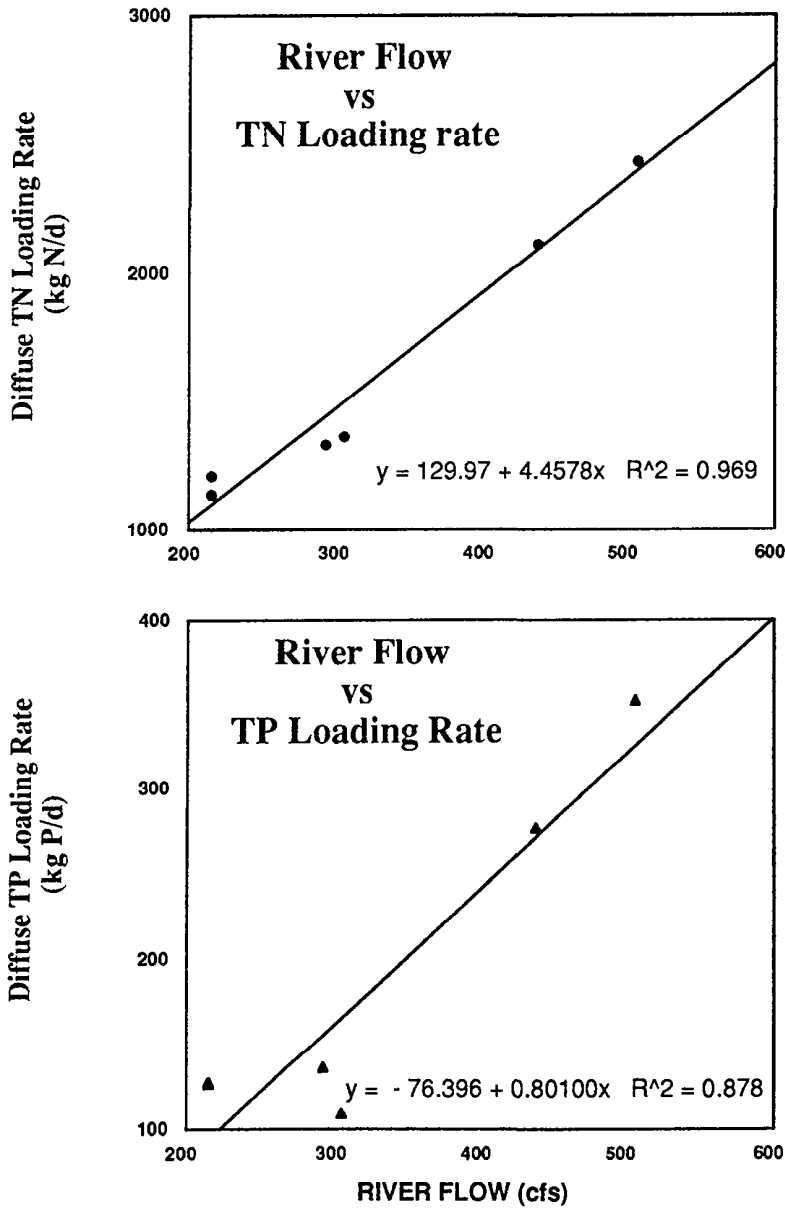


FIGURE 2-2. Data are from Summers (pers comm) and include river flow as measured at the fall-line and diffuse loading rates as determined for the area above the fall-line (not including point sources). The above fall-line diffuse calculation for the Patuxent River includes a term for nutrient loss which occurs during transportation downstream. Statistical regressions show a linear relationship between river flow and diffuse loading.

calculations. Annual total river flow was then calculated by multiplying drainage area by gauged river flow. Total river flow for the entire drainage basin was used in the linear regression to determine total diffuse TN and TP loading. Local diffuse loading according to tributary and sub-basin was calculated by taking a percentage of local river flow from total river flow and multiplying that percentage by total diffuse loading. This method yielded estimates of site-specific loading rates.

The uncertainty associated with this approach was in assuming that the Baltimore Harbor drainage basin was similar to the Patuxent River drainage basin. The similarity may be strongest in the upper reaches of the Baltimore Harbor drainage basin, but closer to Baltimore city, the similarity may be weaker due to the higher concentrations of both people, municipal and industrial facilities. This method most likely underestimated diffuse loading rates to Baltimore Harbor.

Another method employed to estimate diffuse loading involved calculating loading rates based on various land uses in the Baltimore Harbor drainage basin (Table 2-3). Loading rates of TN and TP for various land uses came from EPA (1983) and Beulac and Reckhow (1982). Site-specific loading rates could not be calculated using land uses, because land use data for each of the four sub-basins were not available. The land use model yielded higher estimates of total TN and TP diffuse loading by 40% and 86%, respectively. For comparison, the land use model was also used to calculate diffuse TN and TP loading rates to the Patuxent River (Table 2-3). Total loading rates for TN and TP based on data reported by Summers (pers comm) were then compared to loading rates from the land use model. Diffuse TN and TP loading rates predicted by the land use model were 13% lower than Summers' estimate for TN, and 23% greater than Summers' estimate for TP. The land use model for calculating diffuse loading, therefore, agrees reasonably well with Summers' diffuse loading rates for the Patuxent. It would seem then that the better estimates of diffuse loading to Baltimore Harbor are the loading rates predicted by the land use model.

Another approach to assess the differences between the land use model and the actual (Patuxent River) or extrapolated (Baltimore Harbor) method of calculating diffuse loading is by looking at historical loadings to the two drainage basins to see if the two have developed similarly (Table 2-3). Primitive loading to Baltimore Harbor, which assumes that the drainage basin was 100% forested, estimates TN loading to have doubled since primitive times and TP to have increased by a factor of 28. Primitive loading to the Patuxent River shows an increase in TN by a factor of 1.5 and an increase in TP by a factor of 21. This comparison indicates that the development in Baltimore Harbor has increased TN and TP 25% more than development has increased loads to the Patuxent River. This increase seems reasonable because of the intense development associated with Baltimore City. For the following analyses, the diffuse loading rate from the land use model will be used as the best approximation for diffuse loading to Baltimore Harbor.

TABLE 2-3. Diffuse loading to Baltimore Harbor and Patuxent River based on the land use model.

**BALTIMORE HARBOR DIFFUSE LOADING
BASED ON CURRENT AND PRIMITIVE LAND USE**

LAND USE	Nitrogen Loading Rate (kg N/acre/yr)	Phosphorus Loading Rate (kg P/acre/yr)	% of Baltimore Harbor's Drainage Basin	Land Area (acre)	Diffuse Loading TN (kg N/yr)	Diffuse Loading TP (kg P/yr)	
Residential: High density	7.3	1.0	5.7	21196.6	154735.1	21196.6	
Medium density	3.9	0.6	4.5	16734.2	65263.2	10040.5	
Low density	2.2	0.4	10.5	39046.4	85902.0	15618.5	
Commercial/Industrial	6.6	0.9	5.6	20824.7	137443.2	18742.2	
Cropland	3.6	0.9	20.5	76233.4	274440.1	68610.0	
Pasture	2.0	0.3	19.6	72886.5	145773.0	21866.0	
Forest	1.0	0.1	33.6	124948.3	124948.3	12494.8	
TOTAL DRAINAGE BASIN			100.0	371870.0	9.89E+05	1.69E+05	
					Diffuse loading based on Patuxent regression:	7.08E+05	9.08E+04
					Primitive diffuse loading:	4.65E+05	5.95E+03

**PATUXENT RIVER DIFFUSE LOADING
BASED ON CURRENT AND PRIMITIVE LAND USE**

LAND USE	Nitrogen Loading Rate (kg N/acre/yr)	Phosphorus Loading Rate (kg P/acre/yr)	% of Patuxent River's Drainage Basin	Land Area (acre)	Diffuse Loading TN (kg N/yr)	Diffuse Loading TP (kg P/yr)	
Residential: High density	7.3	1.0	0.6	3507.7	25606.2	3507.7	
Medium density	3.9	0.6	1.7	9730.9	37950.5	5838.5	
Low density	2.2	0.4	2.8	15841.0	34850.2	6336.4	
Commercial/Industrial	6.6	0.9	0.4	2489.3	16429.4	2240.4	
Cropland	3.6	0.9	20.6	116487.9	419356.4	104839.1	
Pasture	2.0	0.3	20.7	117280.0	234560.0	35184.0	
Forest	1.0	0.1	53.1	300413.3	300413.3	30041.3	
TOTAL DRAINAGE BASIN			100.0	565750.0	1.07E+06	1.88E+05	
					R. Summers' diffuse loading:	1.23E+06	1.45E+05
					Primitive diffuse loading:	7.07E+05	9.05E+03

NOTES:

- 1) Land use loading rates are from EPA (1983b) for developed land loading rates and from Beulac and Reckhow (1982) for agriculture and forest loading rates.
- 2) Percent land use of drainage basins is from EPA (1983a).
- 3) Assuming 100% forestation, primitive loading rates are 1.25 kg N/acre/yr and 0.016 kg P/acre/yr and are from Boynton et al. (1991).
- 4) Diffuse loading rates for the Patuxent River came from Summers (pers comm) and are 1983-1988 averaged rates.

Atmospheric loading to surface waters and to land areas for Baltimore Harbor was calculated using wet-fall nutrient concentrations from Smullen et al (1982) as shown in Table 2-2. Atmospheric TN and TP loading rates to surface waters were 16% and 4 % of TN and TP diffuse loading rates, respectively. This indicates that direct atmospheric deposition of TN to surface waters can be significant for Baltimore Harbor, especially in wet years. Wet-fall deposition of TN to land areas was 41 percent greater than diffuse TN discharges from the basin, indicating that there must be basin storages of TN. However, wet-fall deposition of TP was 57% less than diffuse TP discharges from the basin, suggesting that there must be basin losses of TP. This may mean that with consecutive wet years and super-saturated conditions, wet-fall deposition of TN to land areas could have a strong impact on TN diffuse loading.

Areal diffuse loading to four sub-basins of the harbor are shown at the bottom of Table 2-2. Values may be underestimated since these values are based on the diffuse loading rates from the Patuxent River regressions. Middle Branch sub-basin has the most intense areal diffuse loading, followed by Northwest Branch, Curtis Bay and Outer Baltimore Harbor sub-basins. This follows the trend in drainage basin sizes: Middle Branch has 76% of the total drainage basin, Northwest Branch has 12% and both Curtis Bay and Outer Baltimore Harbor have 6% of the total drainage basin. Areal diffuse loading in Outer Baltimore Harbor sub-basin is substantially smaller than areal diffuse loading in Curtis Bay (factor of 12), although the drainage basin sizes are similar. This is due to the large difference in the water surface areas of the two systems. Most of the water surface area is in Outer Baltimore Harbor sub-basin (81%) whereas Curtis Bay has only 6.2%, Middle Branch, 8.2% and Northwest Branch, 4.4% of the total water surface area. Diffuse loading will be more intense in a system which has less water area to absorb the nutrients.

2.4 Point Source Loading

Point source loading from municipal and industrial sources is depicted in Table 2-4. Municipal loading data are from MDE (Legg, pers comm) and are 1989 annual averages. The loadings from the municipal facilities listed in Table 3 comprise of about 99% of the total loading from municipal facilities. Industrial loading data came, in part, from Shanks (1989) and are 1987 and 1988 annual averages. However, the loading from the three major industrial facilities (WR Grace, Chemetals and Bethlehem Steel) have been updated by MDE (Legg, pers comm) and are 1989 annual averages. This is significant, because the loading from these three facilities make up 99% of the total TN and 86% of the total TP loading from industries. The loading from Bethlehem Steel includes only the diversion from Back River Sewage Treatment Plant and does not include

TABLE 2-4. Point loading rates to Baltimore Harbor sub-basins

POINT SOURCE	TN (kg N/yr)	TP (kg P/yr)	RECEIVING SYSTEM
NORTHWEST BRANCH			
Municipals			
None			
Industrials			
Proctor and Gamble	6953.7	2317.9	Northwest Branch
Sub-total	6953.7	2317.9	
Areal sub-total (mg N or P/m ² /yr)	1591.0	530.0	
MIDDLE BRANCH			
Municipals			
Holiday Mobile Estates	474.2	123.7	Lower Piney Run - low Pat - Middle Br
Woodstock Training Center	731.8	122.0	Upper Pat - Middle Br
Freedom District	18589.5	10771.6	
Gaither Manor Apts	51.7	67.7	South Branch - low Pat - Middle Br
Mt Airy STP	11850.4	1797.5	into South Branch - low Pat - Middle Br
Pheasant Ridge Estates	445.9	91.1	Meadow Branch - South Branch - low Pat - Middle Br
South Carol H.S.	221.9	32.8	Piney Run - South Branch - low Pat - Middle Br
Industrials			
BG&E Westport	82.8	0.0	Middle Branch
Carr-Lowrey Glass Co.	115.9	0.0	Middle Branch
Kaydon Ring and Seal	860.9	0.0	Gwynns Falls - Middle Branch
Essex Ind. Chem	49.7	0.0	Lower Patapsco R. - Middle Branch
Locke Insulators	314.6	0.0	Middle Branch
Valspar	16.6	0.0	Gwynns Falls into Middle Branch
BG&E Spring Gardens	0.0	0.0	Middle Branch
JE Seagrams and Sons	49.7	0.0	Lower Patapsco - Middle Br
Arundel Corp - Delight Quarry	2814.6	0.0	Upper Patapsco - lower Pat - Middle Br
Halethorpe Extrusions, Inc.	182.1	0.0	Herbert Run - low Pat - Middle Br
GM Corp - Electro/Motive Div	33.1	0.0	Herbert Run - low Pat - Middle Br
Balto/Wash Auto Exchange	16.6	0.0	Deep Ck - Piney Run - low Pat - Middle Br
Westinghouse Electric	413.9	993.4	into lower Patapsco - Middle Br
Springfield Hos WTP	1457.0	794.7	upper Piney Run - South Br - low Pat - Middle Br
Sub-total	38772.6	14794.5	
Areal sub-total (mg N or P/m ² /yr)	4787.0	1826.0	
CURTIS BAY			
Municipals			
Patapsco STP	1071695.8	81187.6	near Wagner's Pt - Curtis Bay
Pitt - Des Moines Corp	42.7	51.3	Curtis Ck - Curtis Bay
U.S. Gypsum Co.	157.6	26.3	Fishing Pt - Curtis Bay
Industrials			
WR Grace	435367.1	839.4	Curtis Ck - Curtis Bay
Balto Sewage Sludge	1407.3	546.4	Thoms Cove - mouth of Curtis Bay
B.F.I. Quarantine Road Landfill	132.5	0.0	Thoms Cove - mouth of Curtis Bay
Amoco Oil Corp - Curtis Bay Terminal	844.4	33.1	Curtis Ck - Curtis Bay
Chemetals	180233.0	23.2	Arundel Cove - Curtis Ck - Curtis Bay
BG&E Wagner Station	2980.2	0.0	Wagner's Pt - Curtis Bay
Amoco Oil Corp - Lube Div	16.6	0.0	north of Curtis Bay - Patapsco R
Curtis Bay Co	49.7	0.0	Curtis Bay
Union Carbide	82.8	0.0	Curtis Ck - Curtis Bay
Support Terminal Ser	1572.9	0.0	north of Curtis Bay - Patapsco R
Crown Central Petrol	33.1	0.0	Curtis Ck - Curtis Bay
Sub-total	1694615.4	82707.3	
Areal sub-total (mg N or P/m ² /yr)	278262.0	13581.0	
OUTER BALTIMORE HARBOR			
Municipals			
Anne Arundel Co, Cox Ck	227369.0	18447.1	Cox Ck - Patapsco R.
Fort McHenry Tunnel	74.5	12.4	Patapsco R - near Balt Harb Tunnel
Lebanon Chem. Corp	24.8	4.1	Patapsco R - near Balt Harb Tunnel
Industrials			
SCM Glidco Organics	7963.6	1788.1	Colgate Ck - Patapsco R
Bethlehem Steel	1763654.0	44783.4	Old Road Bay
BG&E Riverside	49.7	0.0	Sollers Pt near Bear Ck - Patapsco R
Cox Creek Refining	463.6	413.9	north of Cox Ck - Patapsco R
GM Corp - Assembly Div	298.0	49.7	Colgate Ck - Patapsco R
Lever Bros	33.1	447.0	into Colgate Ck - Patapsco R
Signode Supply	49.7	0.0	Bear Ck
National Can Corp	0.0	149.0	Humphrey Ck - Bear Ck
Sub-total	1999980.0	66094.8	
Areal sub-total (mg N or P/m ² /yr)	24894.0	823.0	
TOTAL	3.74E+06	1.66E+05	
AREAL TOTAL (mg N or P/m²/yr)	37819.0	1678.0	

NOTES:

Municipal loading data are from MDE (Legg, pers comm.) and are 1989 annual averages; industrial loading data are from Shanks (1989) and are 1987/88 averages, except for the loading rates for Bethlehem Steel (includes only the diversion from Back River), Chemetals and WR Grace which are 1989 averages from Legg; locations are from MDE (Legg and Spath, pers comm) and were obtained from Maryland coordinates.

the amount taken from the Patapsco River for cooling. Locations of municipal and industrial facilities came from MDE (Legg and Spath, pers comm) and are depicted on the map in Figure 2-1.

Areal loading rates to the four sub-basins are also shown in Table 2-4 and were highest in the Curtis Bay sub-basin, followed by Outer Baltimore Harbor sub-basin, then Middle Branch and Northwest Branch sub-basins. Point sources above the fall-line were included as well, where normally they might be included with diffuse loading as measured at the fall-line. This approach assumes that there were no losses during transport downstream or from diversions. This may not have been the case for some of the municipal loadings in the non-tidal portion of the Patapsco River in Middle Branch drainage basin. These municipal facilities are located in the far reaches of the Middle Branch drainage basin (that portion not depicted in Figure 2-1), and transport losses could be significant. The loadings from these facilities were 88% of the total point source load to the Middle Branch sub-basin. Therefore, the point source loading to Middle Branch may be over-estimated.

2.5 Marina Loading

There are or will be 26 recreational marinas in Baltimore Harbor, having a total of 5,502 slips (Table 2-5). The majority of the marinas (21) are located in Northwest Branch (Figure 2-1) and include 60% of the slips. Middle Branch has 4 marinas and 24% of the slips, and Curtis Bay has one large marina, with 16% of the slips. Boat densities (boats per acre of marina water) were also calculated. Total slip number (not including dry slips) was used as total boat number. Boat density for the Fells Point sector in Northwest Branch sub-basin did not include the slip number from Constellation marina, because there were no plans for Constellation, and consequently, surface area could not be determined. The highest boat density was seen in the Fells Point sector (41 boats per acre of marina water), and boat density in Northwest Branch overall was 1.6 boats per acre. For comparison, boat density was determined for Solomons Harbor (Jasinski, 1990) and found to be 4 boats per acre. Water quality has been monitored in Solomons Harbor from 1987 to the present, and no significant impact from marinas or boats has thus far been detected (Jasinski, 1990). From the standpoint of marina area to basin area, in Northwest Branch marina surface area was 11% of the total water surface area, and 3% in Middle Branch and 1% in Curtis Bay. This information, including water surface areas, was obtained from marina plans made available by Baltimore City Planning.

In order to calculate marina loadings in terms of TN and TP, rates of human fecal and urine discharges were obtained from Roche Biomedical Laboratory (Burlington, North Carolina, pers comm). Several assumptions had to be made concerning the number of people per boat and the

TABLE 2-5. Existing slips, permitted slips and planned slips as of February, 1991 in Baltimore Harbor.

SUB-BASIN (Sector) Marina	Slips Existing Feb 91	Additional Slips Permitted	Slips in Planning	Slips Total	Water Surface Area (square feet)	Boat Density (boats per acre)
NORHTWEST BRANCH						
(Canton)						
Anchorage	576			576	1,072,500	23
Anchorage Plaza		61		61	78,000	34
Baltimore International Yachting	170	408		578	1,370,000	18
Bayview	52			52	47,400	48
Canton Cove	30			30	41,600	31
Scarfield		70		70	65,450	47
Shipyard	20			20	15,000	58
Tindeco Wharf	20			20	31,000	28
Sub-total	868	539		1,407	2,720,950	23
(Fells Point)						
Belts Wharf Landing		49		49	25,219	85
Brown's Wharf	34			34	39,000	38
Chester Cove	40			40	64,600	27
Constellation			150	150	NO PLAN TO DATE	
Harbor's Edge	11			11	15,600	31
Henderson's Wharf	248		186	434	441,600	43
Swann's Wharf	64			64	91,200	31
Thames Point	53			53	46,800	49
Sub-total	450	49	336	835	724,019	41
(Inner Harbor)						
Harborview	234		240 dry 126 wet	600	900,000	17 (for 360 boats)
Inner Harbor	152			152	187,500	35
Inner Harbor East		199		199	370,990	23
Tidewater	44			44	46,090	42
Lady Maryland		48		48	45,500	46
Sub-total	430	247	240 dry 126 wet	1,043	1,550,080	23
MIDDLE BRANCH						
Baltimore Yacht Basin	197			197	304,700	28
Ferry Bar	58			58	124,180	20
Middle Branch Moorings	262			262	371,200	31
Port Covington			250 dry 550 wet	800	1,779,050	14 (for 550 boats)
Sub-total	517		250 dry 550 wet	1,317	2,579,130	18
CURTIS BAY						
(Fairfield)						
Port Liberty			800 dry 100 wet	900	787,620	6 (for 100 boats)
OUTER BALTIMORE HARBOR						
No recreational marinas were included from this area.						
TOTAL	2,265	835	2,402	5,502	8,361,799	21

NOTES:

Slips and water surface area of marinas were determined from marina plans made available by Baltimore City Planning. These are the most recent estimates, but it was noted that Henderson's Wharf may change their plans in the near future.

number of people discharging fecal and urine wastes. Carstea et al (1975) did a similar analysis, but their study considered boats underway instead of boats at dock. The assumption they made, which was based on previous surveys taken, was that there was an average of three people per boat and that half (1.5 people) contributed fecal matter. This assumption was one of several used to estimate marina loadings, whereby a total number of people to occupy a boat at dock was three. Consequently, all three people contribute urine at the normal discharge rate given and 1.5 people contribute fecal matter at the normal discharge rate given. The additional assumption made was that the slip number per marina was analogous to the boat number, and it was assumed that 25% of the boats at dock were occupied by the maximum number of three people. These assumptions yielded average rates per boat of TN at 38.6 g N/24 hr and TP at 2.01 g P/24 hr. Marina loading rates are given in Table 2-6.

Summer loads were also calculated for each sub-basin in Table 2-6 by multiplying the sub-total daily rate by the number of days in summer (91.25 days/summer). Northwest Branch had the highest summer loading rate as would be expected since the greater number of marinas are located in Northwest Branch. Marina areal loads, shown in Table 2-6, reflect better the potential for localized impact. Northwest Branch has the highest summer areal loading rate, followed by Middle Branch and Curtis Creek. The highest daily marina loading rates are also found in the Northwest Branch sub-basin. A low marina areal loading rate does not necessarily mean that the water quality in that marina is fine. There are other factors which could be affecting water quality and would need consideration, such as other sources of nutrient loading to that marina and the existing ambient water quality and flushing in that marina. Although water quality data for Baltimore Harbor is lacking, Sections 3 and 4 explore potential BOD's and flushing rates for each marina to better assess site-specific water quality conditions and potential marina impacts.

2.6 Conclusions

Table 2-7 shows annual and areal loading rates to Baltimore Harbor sub-basins, and figure 2-3 show areal loads for various systems, including systems inside Baltimore Harbor, Baltimore Harbor and other systems outside Baltimore Harbor. For comparative purposes, it is known from water quality monitoring programs that the Potomac and Patuxent Rivers experience moderately to severely reduced water quality conditions during summer. The Choptank River is one of the healthier systems in the Chesapeake Bay. All of the sub-basins of Baltimore Harbor, except the Patapsco River, experience loadings similar to or magnitudes greater than the loading in the Potomac River. High areal loads are indicative of systems potentially under stress from eutrophication, and it is very possible that the sub-basins in Baltimore Harbor are under eutrophication stress. Mitigating boat and marina loading at the site will have little effect on total

TABLE 2-6. Loadings from Baltimore Harbor marinas to Baltimore Harbor's sub-basins.

SUB-BASIN (Sector) Marina	WET SLIPS TOTAL	TOTAL NITROGEN (g N/day)	TOTAL PHOSPHORUS (g P/day)	MARINA AREAL TOTAL NITROGEN (mg N/m ² of marina/day)	MARINA AREAL TOTAL PHOSPHORUS (mg P/m ² of marina/day)
NORTHWEST BRANCH					
(Canton)					
Anchorage	576	5558.4	289.44	56	3
Anchorage Plaza	61	588.7	30.65	81	4
Baltimore International Yachting	578	5577.7	290.45	44	2
Bayview	52	501.8	26.13	114	6
Canton Cove	30	289.5	15.08	75	4
Scarfield	70	675.5	35.18	111	6
Shipyard	20	193.0	10.05	139	7
Tindeco Wharf	20	193.0	10.05	67	3
(Fells Point)					
Belts Wharf Landing	49	472.9	24.62	202	11
Brown's Wharf	34	328.1	17.09	91	5
Chester Cove	40	386.0	20.10	64	3
Constellation	150	1447.5	75.38		
Harbor's Edge	11	106.2	5.53	73	4
Henderson's Wharf	434	4188.1	218.09	102	5
Swann's Wharf	64	617.6	32.16	73	4
Thames Point	53	511.5	26.63	118	6
(Inner Harbor)					
Harborview	360	3474.0	180.90	42	2
Inner Harbor	152	1466.8	76.38	84	4
Inner Harbor East	199	1920.4	100.00	56	3
Tidewater	44	424.6	22.11	99	5
Lady Maryland	48	463.2	24.12	110	6
Sub-total (on a per day basis)	3,045	29384.3	1530.11	63	3
Sub-total (on a per summer basis)		2.68E+06 (g N/summer)	1.40E+05 (g P/summer)	5778 (mg N/m ² marina/summer)	301 (mg P/m ² marina/summer)
MIDDLE BRANCH					
Baltimore Yacht Basin	197	1901.1	98.99	67	3
Ferry Bar	58	559.7	29.14	49	3
Middle Branch Moorings	262	2528.3	131.66	73	4
Port Covington	550	5307.5	276.38	32	2
Sub-total (on a per day basis)	1067	10296.6	536.17	43	2
Sub-total (on a per summer basis)		9.40E+05 (g N/summer)	4.89E+04 (g P/summer)	3921 (mg N/m ² marina/summer)	204 (mg P/m ² marina/summer)
CURTIS BAY					
Port Liberty	100	965.0	50.25	13	1
Sub-total (on a per day basis)	100	965.0	50.25	13	1
Sub-total (on a per summer basis)		8.81E+04 (g N/summer)	4.59E+03 (g P/summer)	1203 (mg N/m ² marina/summer)	63 (mg P/m ² marina/summer)
TOTAL (on a per day basis)	5,502	40645.8	2116.53	52	3
TOTAL (on a per summer basis)		3.71E+06 (g N/summer)	1.93E+05 (g P/summer)	4775 (mg N/m ² marina/summer)	249 (mg P/m ² marina/summer)

NOTES:

- 1) Assumptions used to calculate waste discharge per boat: the average number of persons per boat is three and approximately 1.5 people contribute fecal material in a given 24-hour period (Carstee et. al., 1975); all three people contribute urine; and the number of slips was considered equivalent to the number of boats and 25% of the boats were assumed to be occupied.
- 2) The following loading rates for TN and TP excretions in stool and urine are from Roche Biomedical Laboratory (Burlington, North Carolina): for stool, TN <= 2g/24 hr and TP on the ave was negligible; for urine, TN on the ave = 11.85 g/24 hr and TP on the ave = 0.670 g/24 hr. Therefore, discharge rates per boat are 38.6 g TN/24 hr and 2.01 g TP/24 hr.
- 3) To calculate summer total loads, daily rates were multiplied by the total days in one season (i.e., 91.25 days).
- 4) Marina areal loadings are calculated using water surface areas of each marina.

TABLE 2-7. Annual loading rates and areal loads to Baltimore Harbor sub-basins.

ANNUAL LOADING RATES

SUB-BASIN AREA	ANNUAL DIFFUSE LOADING		ANNUAL POINT LOADING		ANNUAL ATM LOADING		SUMMER MARINA LOADING		ANNUAL TOTAL LOADING	
	TN (kg N/yr)	TP (kg P/yr)	TN (kg N/yr)	TP (kg P/yr)	TN (kg N/yr)	TP (kg P/yr)	TN (kg N/yr)	TP (kg P/yr)	TN (kg N/yr)	TP (kg P/yr)
Northwest Branch	120833	15502	6954	2318	6948	280	2681	140	1.37E+05	1.82E+04
Middle Branch	466942	59906	38773	14795	12879	518	940	49	5.20E+05	7.53E+04
Curtis Bay	57540	7382	1694615	82707	9683	390	88	5	1.76E+06	9.05E+04
Outer Baltimore Harbor	62770	8053	1999980	66095	127741	5142	0	0	2.19E+06	7.93E+04
Total 1 (for entire drainage basin)	7.08E+05	9.08E+04	3.74E+06	1.66E+05	1.57E+05	6.33E+03	3.71E+03	1.94E+02	4.61E+06	2.63E+05
Total 2 (for entire drainage basin)	9.89E+05	1.69E+05							4.89E+06	3.41E+05

ANNUAL AREAL LOADS

SUB-BASIN AREA	SURFACE AREA (m ² *10 ⁶)	ANNUAL AREAL DIFFUSE LOADING		ANNUAL AREAL POINT LOADING		ANNUAL AREAL ATM LOADING		SUMMER AREAL MARINA LOADING		ANNUAL AREAL TOTAL LOADING	
		TN (mg N/m ² /yr)	TP (mg P/m ² /yr)	TN (mg N/m ² /yr)	TP (mg P/m ² /yr)	TN (mg N/m ² /yr)	TP (mg P/m ² /yr)	TN (mg N/m ² /yr)	TP (mg P/m ² /yr)	TN (mg N/m ² /yr)	TP (mg P/m ² /yr)
Northwest Branch	4.37	27651	3547	1591	530	1590	64	614	32	31445	4174
Middle Branch	8.10	57647	7396	4787	1826	1590	64	116	6	64140	9292
Curtis Bay	6.09	9448	1212	278262	13581	1590	64	14	1	289315	14858
Outer Baltimore Harbor	80.34	781	100	24894	823	1590	64	0	0	27265	987
Total 1 (for entire drainage basin)	98.90	7160	919	37819	1678	1590	64	38	2	46606	2662
Total 2 (for entire drainage basin)		9995	1704							49442	3448

NOTES:

- 1) Total 1 was calculated using diffuse loading based on statistical regressions relating diffuse loading in the Patuxent River to river flow in Baltimore Harbor. Total 2 was calculated using diffuse loading based on land use loading rates from EPA (1983b) and Beulac and Reckhow (1982).
- 2) Marina loadings are loadings from recreational marinas only and given in Table 2-6. Summer areal marina loads were calculated in the usual way, using water surface areas for each sub-basin.

TOTAL AREAL LOADING RATES

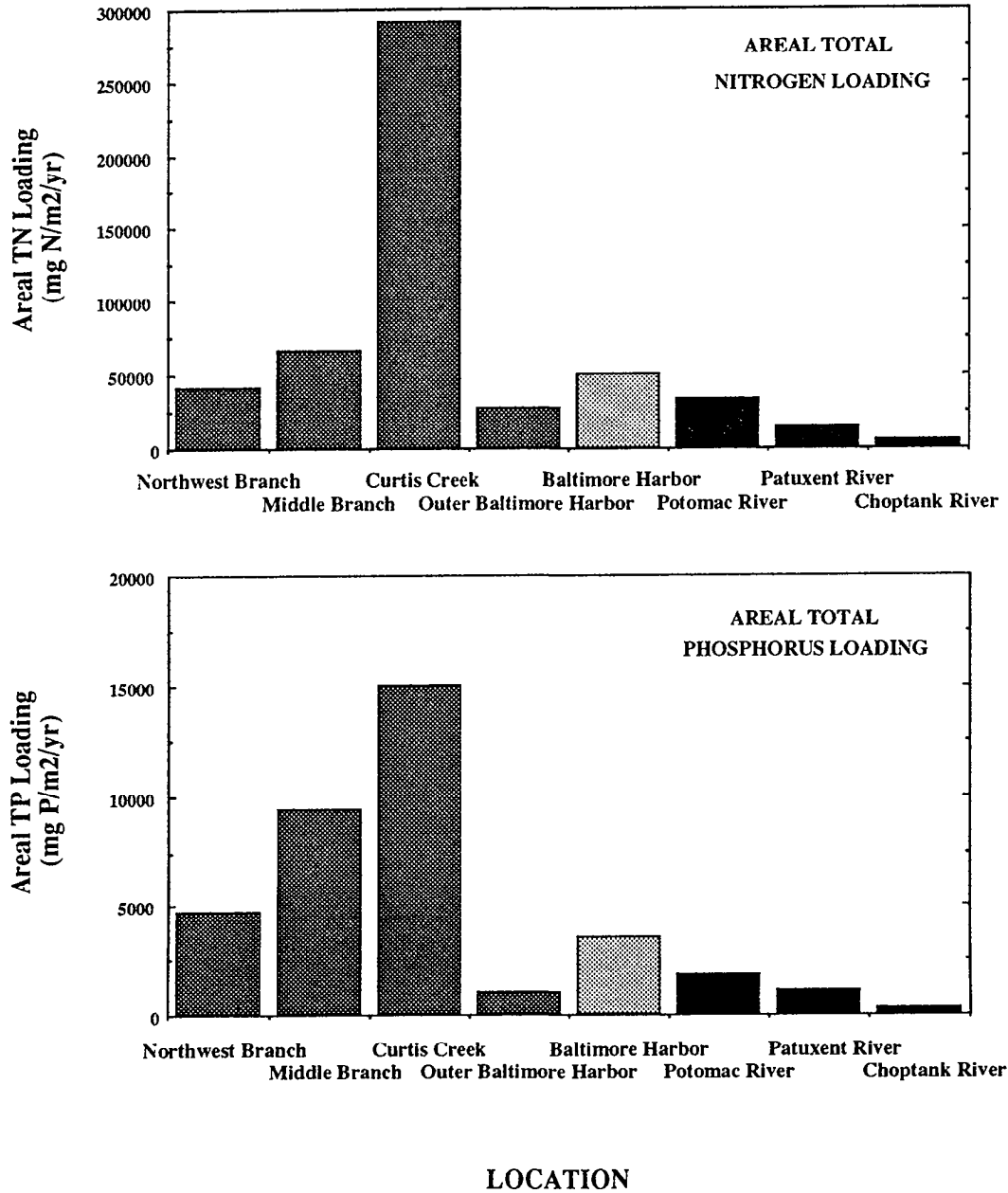


FIGURE 2-3 Bargraphs showing areal loading comparisons between systems within Baltimore Harbor, Baltimore Harbor and systems outside Baltimore Harbor in the Maryland portion of the Chesapeake Bay. Areal loads to the Potomac, Patuxent and Choptank Rivers are based on 1987 annual loads (Summers, pers comm) and on water surface areas from Cronin and Pritchard (1975).

loading to Northwest Branch and probably no effect on total loadings to Middle Branch and Curtis Bay due to the magnitudes of diffuse and point loading. This emphasizes the need to mitigate on two levels:

1. Mitigate boat and marina loading to improve water quality in marina areas.
2. Mitigate diffuse and point loading to improve water quality in both marina areas and in the harbor in general.

Section 3 Marina Flushing

3.1 Introduction

As discussed in Section 1, the circulation and flushing characteristics of marina basins play an important role in the distribution and dilution of potential contaminants introduced by marina- and boating-related activities. Since flushing rate is one of the critical physical characteristics controlling the dynamics of dissolved oxygen, the first step in determining the potential reduction in dissolved oxygen concentrations due to boating activity, and the subsequent possible need for, and feasibility of, mechanical aeration is to characterize the flushing ability of individual marinas. Thus, it was stated in the original memorandum of this study that site-specific estimates would be made of the flushing potential for the marinas existing or proposed in Baltimore Harbor.

The common flushing calculation method, cited by all state marina siting guides reviewed, is based on simplified dilution calculations derived on the basis of mass flow for a tidal prism flushing model, and is described in the EPA's (1985) *Coastal Marinas Assessment Handbook*. This method provides preliminary estimates of expected flushing capability and is intended for use in the planning stages of a project. The handbook notes that after a marina site has been selected flushing should be assessed via *site-specific* data collection and mathematical modeling techniques. The specific calculations employed to estimate expected flushing from a marina site depend on marina design and location (the theory of the tidal prism flushing model and its applicability to Baltimore Harbor will be discussed in Sec. 3.3). In this regard, the EPA distinguishes between semi-enclosed and open marinas. Marinas located within a confined area, either a natural basin or a man-made, bulk-headed enclosure, with only one or two openings to the surrounding water body, will have flushing characteristics considerably different than open marinas, located directly on a large bay or estuary without confinement.

3.2 Flushing Calculations

Since the EPA handbook states that open marinas not entirely enclosed by protective barriers have flushing characteristics "generally similar" to those of the water body itself, it was decided, for the sake of a conservative estimate of flushing potential for this report, that all marinas would be considered to be of the semi-enclosed variety. The

two exceptions to this decision are: the Constellation Marina, for which there was no marina plan to date and therefore the needed surface area variable could not be obtained to calculate a flushing estimate, and the Lady Maryland Pier, which definitely fits the description of an open marina, and can thus be assumed to flush with the Inner Harbor water.

The parameters required for estimating flushing time of a semi-enclosed marina are:

1. Average marina depth at high and low tide, based upon the representative tidal range for the area (Determined from official NOAA marina navigational charts, with marina locations determined from siting maps obtained from the Marina Master Plan 1989).
2. Surface area of the marina (Determined from marina blue-print plans made available from the Baltimore City Planning Department).
3. The percentage of discharged water returning to the basin on the following tidal cycle, i.e., the Return Flow Factor (Assumed to be 0.50 or 0.25, as discussed later in the text).
4. The volume of non-tidal freshwater flowing directly into the marina (Assumed to be zero for all marinas in Baltimore Harbor).

The expected flushing time can then be approximated by the following equation:

$$T_f = (T_c \times \text{LOG}(D)) / \text{LOG} \left(\frac{(A \times L) + (b \times A \times R)}{A \times H} \right)$$

where;

- T_f = Time of flushing (hours)
- T_c = Tidal cycle = 12.42 (hours)
- D = Dilution factor (0.05 for 95% dilution)
- A = Surface area of marina (m^2)
- L = Avg. depth of marina at low tide (m)
- b = Return flow factor = 0.50
- R = Range of tide = 0.335 (m), obtained from NOAA, NOS tide table for Baltimore Harbor
- H = Avg. depth of marina at high tide (m)

Since this approach is based on the dilution of an input of any given pollutant, a value for the desired amount of flushing of that pollutant must be entered into the equation as D . Since complete flushing will be approached asymptotically, a reasonable cutoff value for dilution must be chosen. If complete flushing is desired a reasonable value for D is reported to be 0.05, i.e., 95 % dilution of a given input. The most difficult parameter to determine is the appropriate value of "b", the return flow factor. This is the amount of water flushed from the marina on ebb tide and subsequently returned to the marina on the

following flood tide. It may have a value from 0.0 to 1.0 (for complete return), the exact value of which depends on the physical characteristics of the marina effluent plume and the circulation patterns in the body of water that flushes the marina, or in other words, what happens to the water outside the marina. Determining a site-specific value for b requires in situ empirical dye studies, in the absence of which subjective estimations must be made. For situations where no data are available, the EPA suggests a conservative estimate of 0.50, for 50 % back flushing. However, other studies (see, for example, Sanford et al., 1991) have suggested that this value may be too high, particularly if the outflowing current is stronger than the inflowing flood tide, and that a value of $b=0.25$ may be more appropriate. Thus, the calculations for the Baltimore Harbor marinas were run with both values for comparison.

The results of this calculation, applied to each marina, are given in Table 3-1. It can be seen that this equation produces flushing times for the marinas from approximately 19 days (for the Ferry Bar Marina) to 65 days (for Port Covington) with a value of $b=0.50$, and 12 to 44 days (for the same marinas, respectively) with a value of $b=0.25$. The EPA (1985), citing an unreferenced article by Boozer (1979), states that "for most cases, a 2 to 4 day flushing time is satisfactory while longer flushing times may not be acceptable." However, the discrepancy between the values produced by the above equation and the recommended flushing times given by the EPA is most likely be the result of the explicit assumptions of the EPA model. The following section will describe these assumptions and discuss the possibility that the tidal prism model of flushing exchange is inappropriate in calculating flushing times for Baltimore Harbor.

Section 3.3 Assumptions of Flushing Calculations

The flushing equation used above is based on a flushing mechanism known as the tidal prism flushing model. This model assumes that the exchange of water between the embayment and the surrounding water body is a result of the regular rise and fall of water due to the astronomical tide. Water entering the embayment on flood tide fills the intertidal volume (intertidal volume is equivalent to tidal prism) until high tide is reached. This new water mixes with the existing water in the embayment. As the tide falls to low tide, the intertidal volume of water flows out of the embayment as an ebb tidal current. Some fraction of this water is lost by advection or mixing into the receiving water body, and the remainder returns to the embayment on the following flood tide. The major assumptions of this model of flushing are therefore:

TABLE 3-1. Application of EPA (1985) marina flushing equation

MARINA	SURFACE AREA (m ²)	Low Water DEPTH (m)	High Water DEPTH (m)	FLUSHING TIME (w/b=-.5) (hours)	FLUSHING TIME (w/b=-.5) (days)	FLUSHING TIME (w/b=-.25) (hours)	FLUSHING TIME (w/b=-.25) (days)
Anchorage	99,635	4.27	4.61	975.62	40.7	650.58	27.1
Anchorage Plaza	7,246	4.88	5.22	1,107.21	46.1	739.17	30.8
Balt. Int. Yachting	127,273	4.57	4.91	1,040.34	43.3	694.15	28.9
Bayview	4,403	4.88	5.22	1,107.21	46.1	739.17	30.8
Canton Cove	3,865	3.05	3.39	712.43	29.7	473.37	19.7
Scarfield	6,080	3.96	4.30	908.75	37.9	605.56	25.2
Shipyards	1,394	3.05	3.39	712.43	29.7	473.37	19.7
Tindeco Warf	2,880	4.57	4.91	1,040.34	43.3	694.15	28.9
Belt's Warf	2,343	6.10	6.44	1,370.37	57.1	916.35	38.2
Brown's Warf	3,623	4.88	5.22	1,107.21	46.1	739.17	30.8
Chester Cove	6,001	4.88	5.22	1,107.21	46.1	739.17	30.8
Constellation							
Harbor's Edge	1,449	6.10	6.44	1,370.37	57.1	916.35	38.2
Henderson's	41,025	4.27	4.61	975.62	40.7	650.58	27.1
Swann's Warf	8,472	3.66	4.00	844.03	35.2	561.98	23.4
Thames Point	4,348	3.05	3.39	712.43	29.7	473.37	19.7
Harborview	83,610	6.40	6.74	1,435.09	59.8	959.91	40.0
Inner Harbor	17,419	4.27	4.61	975.62	40.7	650.58	27.1
Inner Harbor East	34,465	3.35	3.69	777.15	32.4	516.95	21.5
Tidewater	4,282	4.88	5.22	1,107.21	46.1	739.17	30.8
Balt. Yacht Basin	28,307	2.13	2.47	513.93	21.4	339.70	14.2
Ferry Bar	11,536	1.83	2.17	449.19	18.7	296.09	12.3
Mid. Br. Moorings	34,484	2.13	2.47	513.93	21.4	339.70	14.2
Port Covington	165,274	7.01	7.35	1,566.66	65.3	1,048.49	43.7
Port Liberty	73,170	6.40	6.74	1,435.09	59.8	959.91	40.0

1. The majority of the mixing is due to tidal flushing
2. The tidal prism volume completely mixes with the marina water volume.
3. The pollutant concentration decreases with each tidal dilution but will never completely flush

The most important assumption of this model, when considering its applicability to Baltimore Harbor, is that the majority of the mixing is due to tidal flushing. This assumption is certainly valid for most coastal estuarine environments which exhibit classical two-layer estuarine circulation. However, as discussed in the initial memorandum, Baltimore Harbor exhibits an atypical three-layer circulation pattern that produces circulation and flushing patterns unique to the harbor itself. The observations of Boicourt and Olson (1982), in addition to describing the three-layer circulation in general, made the following pertinent observations:

The three-layer circulation often dominates the flow to the point where semidiurnal tidal-current reversals are eliminated. Measurements show that the inflowing, surface layer is only 2 meters thick.

The wind-driven circulation often dominates other circulation components over short time intervals (up to 10 days). The wind-driven component is particularly prominent near the Harbor head (Middle Branch) and in the three principal tributaries (including Northwest Branch).

Typical observed residence times [read as flushing times] for the Baltimore Harbor are 3 days during the strongest wind events, 8-10 days when the flow is dominantly the three-layer component, and up to 20 days when density and wind forcing are weak [presumably times of classical two-layer circulation].

Most importantly for this discussion, is their conclusion that flushing times calculated on the basis of tidal and wind forcing were "an order of magnitude greater than those resulting from the three-layer circulation" (Boicourt and Olson 1982, p. 1). *If* this is true as well for the determination of flushing of *marinas* in Baltimore Harbor, which were calculated solely on the basis of tidal flushing, then the flushing times for the marinas calculated above could be from 2 to 6 days with 50% back-flushing and 1 to 4 days with 25% back flushing.

Another assumption of the tidal flushing model employed that is questionable in the Baltimore Harbor system is that there is complete mixing within the semi-enclosed marina. From data available for the Anchorage Marina (the only marina where such data is available), it is evident that stratified conditions exist (data discussed in Section 4) such that the assumption of complete vertical mixing appears not to hold. If the water volume in a

marina does not completely mix, the possibility exists for the trapping of deep water within the marina, resulting in potential water quality impacts.

Section 3.4 Conclusions

This section has put to use the only available equation for calculating preliminary potential flushing times, the output of which gives flushing times that are approximately an order of magnitude higher than those generally assumed to be non-detrimental to water quality impacts, and which are clearly unrealistic. However, as discussed, there are characteristics of Baltimore Harbor that may make it unsuitable for the application of such an approach. Since Boicourt and Olson (as discussed in the above section) find that flushing times for the Harbor basin are an order of magnitude higher when the effect of three-layer circulation is not accounted, it is tempting to conclude that no major flushing problems exists with the current and proposed marinas. However, given the lack of data for the site-specific areas of the harbor, it is impossible to reconcile the calculated flushing times with reality. Clearly, as is strongly recommended in the EPA's (1985) *Coastal Marinas Assessment Handbook* , the only way to resolve the flushing times of the marinas in Baltimore Harbor with any confidence is to develop numerical models based on field-collected data for the marinas in question. This is particularly important given the critical role flushing plays in determining the water quality impacts of all marina- and boating-related activities and inputs.

Section 4 Oxygen Depletion in Marinas

Section 4.1 Introduction

The following section describes several calculations used to estimate the potential reduction in the concentration of dissolved oxygen as a result of boating activities in the existing and proposed marinas in Baltimore Harbor. Marina structures themselves do not *directly* contribute Biochemical Oxygen Demand (BOD) to marina waters, and therefore do not directly result in the reduction of dissolved oxygen in marina water (except for the possibility of providing large surface areas for the colonization of oxygen-consuming microorganism fouling communities, as discussed in Section 1). The Baltimore City Planning Department has, however, expressed the concern that many boat owners used their boats solely at dock and thus contribute BOD through their activity within the marina. Although it is known that boat discharges, both direct waste discharge and discharges from boat Marine Sanitation Devices (both MSD type 1 and 2) release suspended organic matter into the water column, there have been few empirical studies relating boat discharges to increases in water-column BOD, as discussed in Section 1. However, for a worst-case scenario, the EPA has published an estimate of BOD loading from pleasure boats, intended for calculating the potential decrease in DO possible from excessive boating activities within a marina. Therefore, in order to assess the potential impacts of in-marina boat use on dissolved oxygen (DO), and thus the possible need for mechanical aeration on the marina water, equations developed by the EPA (1985, 1991) were used to estimate site-specific potential reductions in DO for each marina, existing and proposed, listed in the Marina Master Plan.

Section 4.2 BOD Loadings and Reductions in DO

To assess the decrease in DO, loading rates of BOD must first be determined for each marina. The EPA estimated BOD loading rate per boat is given to be 4.54 g/hr. This value is based on the assumption that there are an average of three persons per boat, the average per capita discharge of BOD is 75.6 g, and that half the people on board contribute fecal material per 24 hours. To derive an estimate of total BOD loading per marina, the EPA recommends assuming 25% of the boats are in use. For the purposes of this assessment, it was assumed that the total number of wet slips for each marina is equal to

the number of boats, and calculations were done assuming both 25% and 50% of boats were in use for sake of comparison. It was further assumed, to derive a maximum estimate of impact that each boat was in use for 24 hours a day. The resulting loading rates are surely overestimated. The purpose of this analysis is, however, to determine the maximum, "worst case" scenario for potential reductions in marina DO concentrations. This estimated loading rate is then converted into a BOD concentration for the marina water by the following equation:

$$B_C = BOD_r \times T_C \times F_{12} / (1-b) \times V_p .$$

where; B_C = BOD concentration due to boat loading (mg/l)
 BOD_r = BOD Flow Rate from boats in use (mg/day)
 T_C = Tidal Cycle = 12.42 (hours)
 F_{12} = 1.17×10^{-5} (converts units to mg/l)
 b = Return Flow Factor = 0.50
 V_p = Tidal Prism Volume (m^3)

As discussed in the previous section, b , the return flow factor, must be subjectively estimated when lacking in situ empirical data. For these calculations the very conservative value of 0.50 was used, again, to give a maximal estimate of the effect of boat use of BOD concentrations. The volume of the specific marinas' tidal prism was determined as the marina surface area times the tidal range (0.34 m). The results of these calculations are given in the third column of Table 4-1 for 25% of boats in use, and Table 4-2 for 50% of boat in use.

It is significant to compare these BOD concentrations from boat loading to the values in Table 4-3, which is a tabulation of ambient BOD concentrations for the surface waters of Northwest Branch and Middle Branch, which were measured by the Baltimore City Department of Water Quality (obtained from B. Stack, Dept. Water Quality). The average BOD concentration for all marinas in the Northwest Branch, which has 81% of the total number of marinas, at 50% boat use is 1.01 mg/l, while the average BOD concentration for the year in the Northwest Branch is 10.34 mg/l. The lowest value reported (1.43, for December 1986) is still higher than the basin average, and in July, when boat use will be the highest and thus potential BOD loading from boats may in fact begin to approach the calculated BOD load, the basin average is less than 4% of the ambient measured BOD concentration.

To determine the resulting reductions in ambient DO concentrations, the calculated BOD concentrations due to loadings from boat use is combined with an estimate of Sediment Oxygen Demand (assumed to be 1.5 $g/m^2/day$, a value typical of the range

**TABLE 4-1: POTENTIAL OXYGEN DEPLETION FOR BALTIMORE HARBOR MARINAS
ASSUMING 25% OF BOATS IN USE IN THE MARINA**

MARINA	NO. OF SLIPS	BOD CONC. (mg/l)	Ambient DO (mg/l)	After EPA 1991		% Reduct. in DO	After EPA 1985		% Reduct. in DO
				DO high tide (mg/l)	DO low tide (mg/l)		DO remain. 1 tidal cycle (mg/l)	DO remain. 2 tidal cycles (mg/l)	
Anchorage	576	0.480	12.8	12.68	11.50	-10.01	12.26	11.78	-7.84
Anchorage Plaza	61	0.699	12.8	12.75	11.59	-9.33	12.19	11.63	-9.00
Balt. Int. Yachting	578	0.377	12.8	12.68	11.51	-9.97	12.33	11.90	-6.86
Bayview	52	0.980	12.8	12.80	11.64	-8.92	12.05	11.37	-11.06
Canton Cove	30	0.644	12.8	12.63	11.38	-10.97	12.09	11.46	-10.33
Scarfield	70	0.955	12.8	12.75	11.56	-9.56	12.01	11.31	-11.52
Shipyard	20	1.191	12.8	12.73	11.48	-10.21	11.83	10.98	-14.11
Tindeco Warf	20	0.576	12.8	12.71	11.54	-9.68	12.23	11.72	-8.31
Belt's Warf	49	1.736	12.8	12.98	11.85	-7.28	11.72	10.72	-16.13
Brown's Warf	34	0.779	12.8	12.76	11.60	-9.21	12.15	11.55	-9.59
Chester Cove	40	0.553	12.8	12.72	11.56	-9.54	12.26	11.77	-7.93
Constellation	150								
Harbor's Edge	11	0.630	12.8	12.77	11.64	-8.91	12.26	11.77	-7.87
Henderson's	434	0.878	12.8	12.76	11.57	-9.44	12.07	11.41	-10.72
Swann's Warf	64	0.627	12.8	12.68	11.46	-10.30	12.15	11.57	-9.46
Thames Point	53	1.012	12.8	12.70	11.44	-10.46	11.91	11.14	-12.87
Harborview	600	0.596	12.6	12.59	11.47	-8.98	12.12	11.67	-7.41
Inner Harbor	152	0.724	12.6	12.55	11.37	-9.79	11.98	11.41	-9.47
Inner Harbor East	199	0.479	12.6	12.45	11.22	-10.97	12.03	11.52	-8.56
Tidewater	44	0.853	12.6	12.60	11.44	-9.23	11.95	11.34	-10.03
Balt. Yacht Basin	197	0.578	14.2	13.90	12.53	-11.73	13.23	12.39	-12.74
Ferry Bar	58	0.417	14.2	13.80	12.38	-12.85	13.21	12.37	-12.91
Mid. Br. Moorings	262	0.631	14.0	13.71	12.35	-11.80	13.04	12.21	-12.75
Port Covington	550	0.276	14.2	14.14	13.03	-8.26	13.82	13.47	-5.17
Port Liberty	100	0.113	14.8	14.69	13.57	-8.29	14.46	14.13	-4.53

**TABLE 4-2: POTENTIAL OXYGEN DEPLETION FOR BALTIMORE HARBOR MARINAS
ASSUMING 50% OF BOATS IN USE IN THE MARINA**

MARINA	NO. OF SLIPS	BOD CONC. (mg/l)	Ambient DO (mg/l)	After EPA 1991		% Reduct. in DO	After EPA 1985		% Reduct. in DO
				DO high tide (mg/l)	DO low tide (mg/l)		DO remain. 1 tidal cycle (mg/l)	DO remain. 2 tidal cycles (mg/l)	
Anchorage	576	0.960	12.8	12.45	11.26	-11.86	12.03	11.33	-11.31
Anchorage Plaza	61	1.397	12.8	12.40	11.24	-12.03	11.85	10.98	-14.12
Balt. Int. Yachting	578	0.754	12.8	12.49	11.32	-11.42	12.14	11.55	-9.60
Bayview	52	1.960	12.8	12.31	11.15	-12.72	11.58	10.45	-18.24
Canton Cove	30	1.288	12.8	12.33	11.07	-13.37	11.79	10.89	-14.78
Scarfield	70	1.911	12.8	12.29	11.09	-13.21	11.56	10.43	-18.37
Shipyards	20	2.381	12.8	12.16	10.91	-14.65	11.28	9.92	-22.35
Tindeco Warf	20	1.153	12.8	12.43	11.26	-11.90	11.95	11.18	-12.51
Belt's Warf	49	3.471	12.8	12.11	10.98	-14.10	10.87	9.06	-29.09
Brown's Warf	34	1.558	12.8	12.38	11.22	-12.23	11.77	10.83	-15.29
Chester Cove	40	1.106	12.8	12.45	11.29	-11.68	11.99	11.25	-11.98
Constellation	150								
Harbor's Edge	11	1.260	12.8	12.45	11.33	-11.38	11.95	11.17	-12.58
Henderson's	434	1.756	12.8	12.32	11.14	-12.81	11.65	10.60	-17.06
Swann's Warf	64	1.254	12.8	12.37	11.16	-12.68	11.85	11.00	-13.91
Thames Point	53	2.023	12.8	12.22	10.96	-14.23	11.44	10.24	-19.87
Harborview	600	1.191	12.6	12.29	11.17	-11.36	11.83	11.10	-11.94
Inner Harbor	152	1.448	12.6	12.19	11.01	-12.61	11.63	10.74	-14.77
Inner Harbor East	199	0.958	12.6	12.22	10.99	-12.80	11.81	11.09	-11.97
Tidewater	44	1.706	12.6	12.17	11.02	-12.58	11.53	10.54	-16.36
Balt. Yacht Basin	197	1.155	14.2	13.64	12.27	-13.59	12.97	11.91	-16.12
Ferry Bar	58	0.834	14.2	13.61	12.19	-14.16	13.02	12.03	-15.27
Mid. Br. Moorings	262	1.261	14.0	13.42	12.06	-13.86	12.76	11.69	-16.50
Port Covington	550	0.552	14.2	14.00	12.89	-9.24	13.69	13.20	-7.05
Port Liberty	100	0.227	14.8	14.64	13.52	-8.68	14.40	14.02	-5.26

**Table 4-3: Ambient BOD Concentrations for Surface Waters
of Northwest and Middle Branches**

Ambient BOD measured in the Northwest Branch		Ambient BOD measured in the Middle Branch	
Date	BOD, mg/l	Date	BOD, mg/l
2/25/86	4.29	2/25/86	2.86
3/18/86	2.86	3/18/86	2.86
4/29/86	5.72	4/29/86	5.72
7/27/86	12.86	7/27/86	17.15
7/29/86	35.73	7/29/86	4.29
8/26/86	4.29	8/26/86	4.29
9/23/86	N/A	9/23/86	10.00
11/18/86	24.29	11/18/86	4.29
12/16/86	1.43	12/16/86	1.43
2/22/87	11.43	2/22/87	8.57
2/24/87	7.15	2/24/87	2.86
4/28/87	5.72	4/28/87	2.86
6/30/87	4.29	6/30/87	15.72
7/30/87	21.44	7/30/87	7.15
8/25/87	4.29	8/25/87	5.72
9/29/87	5.72	9/29/87	4.29
10/27/87	5.72	10/27/87	4.29
12/1/87	18.58	12/1/87	12.86
Annual Avg.	10.34		6.30

Note: Values calculated from 5 day incubations of SURFACE water.
Data from Baltimore City Dept. of Water Quality

encountered for benthic estuarine mud, for lack of any site-specific data in Baltimore Harbor) in the following EPA equations:

$$DO_R = ((DO_a \times V_p \times 1000 + (DO_s - DO_a) \times V_p \times 1000 \times (e^{-k_1 \times T_c/24}) - B_c \times V_p \times 1000 \times (T_c/24) - (B \times A \times T_c/24) + DO_a \times V_l \times 1000)) / (V_h \times 1000). \quad \text{eq. 1}$$

$$DO_H = ((1000 \times DO_a \times V_p + 1000 \times V_p \times (DO_s - DO_a) \times (1 - e^{-k_a \times T_c/24}) - 1000 \times V_l \times B_c \times (1 - e^{-k_1 \times T_c/24}) - B \times A \times T_c/24 + 1000 \times V_l \times DO_a)) / (1000 \times V_h). \quad \text{eq. 2}$$

$$DO_L = ((1000 \times DO_H \times V_l - 1000 \times V_l \times B_c \times (1 - e^{-k_1 \times T_c/24}) - (B \times A \times T_c/24)) / (1000 \times V_l). \quad \text{eq. 3}$$

$$k_a = K_L / H. \quad \text{eq. 4}$$

where;

- DO_H = DO concentration at high tide (mg/l)
- DO_L = DO concentration at low tide (mg/l)
- DO_R = DO concentration remaining after one tidal cycle (mg/l)
- DO_a = Ambient DO of water flushing into marina (mg/l)
- DO_s = Saturated DO concentration (mg/l)
- B_c = Biochemical Oxygen Demand due to boat loadings (mg/l)
- K_L = DO transfer coefficient (ft/day), based on tidal currents of 0.5 ft/day.
- H = marina depth (ft)
- k_a = Reaeration coefficient (day^{-1})
- k_1 = BOD Oxidation coefficient = 0.25 (day^{-1})
- T_c = Tidal cycle = 12.42 (hours)
- V_l = Volume of marina at low tide (m^3)
- V_h = Volume of marina at high tide (m^3)
- A = Surface area of marina (m^2)
- B = Sediment oxygen demand = 1500 ($\text{mg}/\text{m}^2/\text{day}$)

Equation 1 comes from the 1985 EPA Coastal Marinas Assessment Handbook. Equations 2 through 4 are revised versions from the 1991 Handbook which is still in revision but were made available in draft form for this project by the EPA (Robert Lord, pers. communication). The 1985 version gives the amount of DO remaining after one tidal cycle, and by substituting the calculated DO_R back into the equation in place of DO_a , the amount of DO remaining after two tidal cycles. The 1991 version includes a term for the reaeration

coefficient (determined from eq. 4) for air-water oxygen exchange, and gives the concentration of DO at high tide (eq. 2), which is then entered into eq.3, to give the concentration during the following low tide.

Ambient DO values were obtained from approximately monthly, basin-specific, surface DO concentration data for the years 1986 and 1987, provided by the Baltimore City Department of Water Quality and represent the only oxygen data available for much of Baltimore Harbor. Since peak boating season occurs during the summer months, when oxygen levels are generally lower, the DO_a values used were averages of the data for the month of July of both years. As will be discussed in section 4.3, it is important to note that these are surface values only, no basin-specific bottom water oxygen data was available. As with sediment oxygen demand, B, values for K_L and K_I were also obtained from EPA estimates in lieu of real data for the harbor. K_L , the DO transfer coefficient was determined from table 4-12a of the 1991 draft revision of the EPA handbook. It is determined from tidal velocities and mean tidal depth. Since the lowest reported tidal velocity in table 4-12a was 1 ft/sec, and average tidal velocities for Northwest and Middle Branches are on the order of 0.5 ft/sec, the values given in the table were extrapolated downward to the appropriate values of 2 ft/day for tidal depths of <10 ft, and 1.5 ft/day for tidal depths of 10 to 20 ft. These values were then divided by the mean depths of the marinas to obtain k_a , as per eq. 4.

The results of these DO calculations are given in Tables 4-1 and 4-2, for 25% and 50% boat use, respectively. The complete worksheet (with 50% boat use) is given in the appendix for reference. It can be seen from the tables that, with 50% of all boats in use 24 hours a day, the percent reduction in DO solely attributable to boat use ranges from 8.68% (for Port Liberty) to 14.65% (for the Shipyard Marina) based on the 1991 revision of the model. By comparison, when 25% of the boats are assumed to be in use in the marina, the range in percent reductions of DO is from 7.28% (for Belt's Wharf Marina) to 12.85% (for the Middle Branch Moorings).

Section 4.3 Assumptions and Implications of Model Calculations

There are several implicit and explicit assumptions in the model equations that merit discussion. As in the flushing time equations discussed in the previous section, the mechanism of water exchange between marina and surrounding water-body, responsible for bringing oxygen into the marina, is implicitly assumed to be primarily due to tidal flushing. As discussed in the previous section, the assumption of tidal prism volume as the

primary exchange mechanism appears to substantially underestimate actual exchange rates (exchange rate being the inverse of flushing time as defined previously, i.e., $1/T_f$) due to the complex, three-layer circulation patterns experienced in Baltimore Harbor. If this is in fact the case, then the result would be an overestimation of the amount of oxygen reduction due to BOD loading.

In addition, it is assumed that the water within the marina is vertically mixed and that the BOD is exerted evenly in the vertical dimension. An examination of vertical profiles of temperature, salinity (as measured by conductivity) and dissolved oxygen data, taken within the Anchorage Marina (see fig. 4-1), the only location where such data are available, clearly shows that the marina water is *not* vertically mixed. The resulting internal gradients would tend to impede flushing of oxygen to deeper water or areas more remote from the openings of the marina. Given a density-stratified water-column, the majority of the BOD is going to be exerted in the lower layer, uncoupled to reaeration from air-water exchange of oxygen. This raises the possibility of a lower layer of low-DO water being trapped under stratified conditions and subject to higher BOD exertion than is calculated from the above equations, which would have serious water quality impacts not addressed by the model as it is formulated here.

Although the data used for ambient DO concentrations were from surface waters only, Versar Inc. provided data from a central Middle Branch station that included both surface and bottom water oxygen concentrations (see fig. 4-2) that, not surprisingly, showed lower concentrations of DO in the bottom waters during the warmer months of the year, when Biochemical Oxygen Demand is generally highest. The calculated percent reductions in DO due to BOD will not vary greatly depending on the value used for DO_a (there will be some change in the values calculated from eqs. 2 and 3 due to the effect of the reaeration term). However, if a substantial portion of the flushing water is bottom water containing low levels of oxygen to begin with, the same amount of oxygen depletion will have a more serious effect. At this point, without more site-specific bottom water oxygen data, as well as, specific circulation/flushing data, it is not possible to assess how much the bottom water contributes to oxygen delivery to the marina or what the vertically integrated DO concentrations are for the water flushing each of the specific marinas.

In the mass balance approach used here for calculating decrease in DO, it is explicitly assumed that there is no increase in oxygen levels within the marina due to biological activity, such as photosynthesis and respiration, or the loss of DO due to microbial nitrification of ammonium (NH_4) to nitrate (NO_3). In a system such as Baltimore Harbor, which is heavily loaded with nutrients (as discussed in section 2), the contribution of biological activity can be, and almost surely is, a major component in the dynamics of

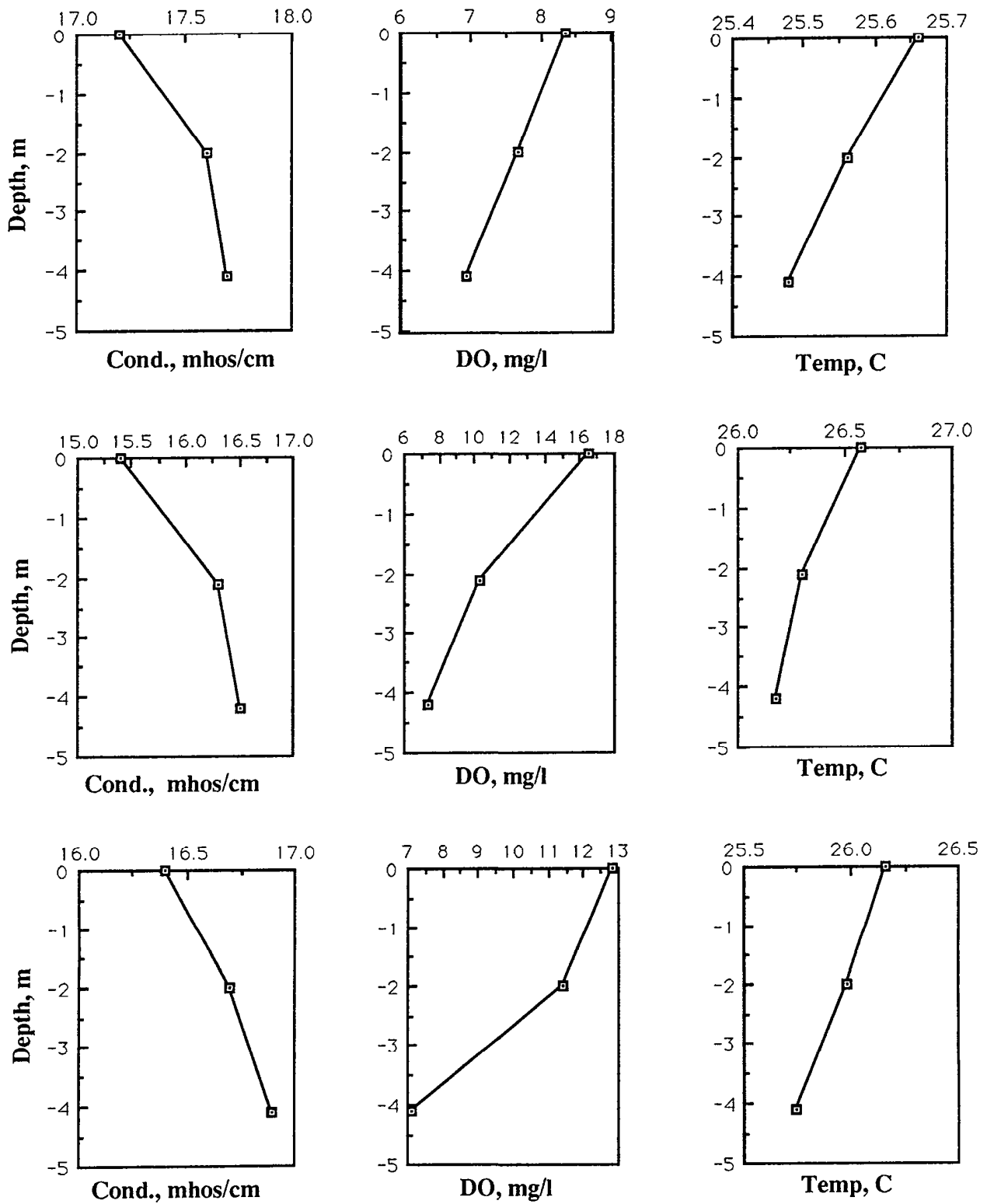


Fig 4-1. Conductivity, dissolved oxygen, and temperature profiles for Anchorage Marina. Top panel, 9/13/90. Middle panel, 9/7/90. Lower panel, 9/6/90. Data from Baltimore City Department of Water Quality.

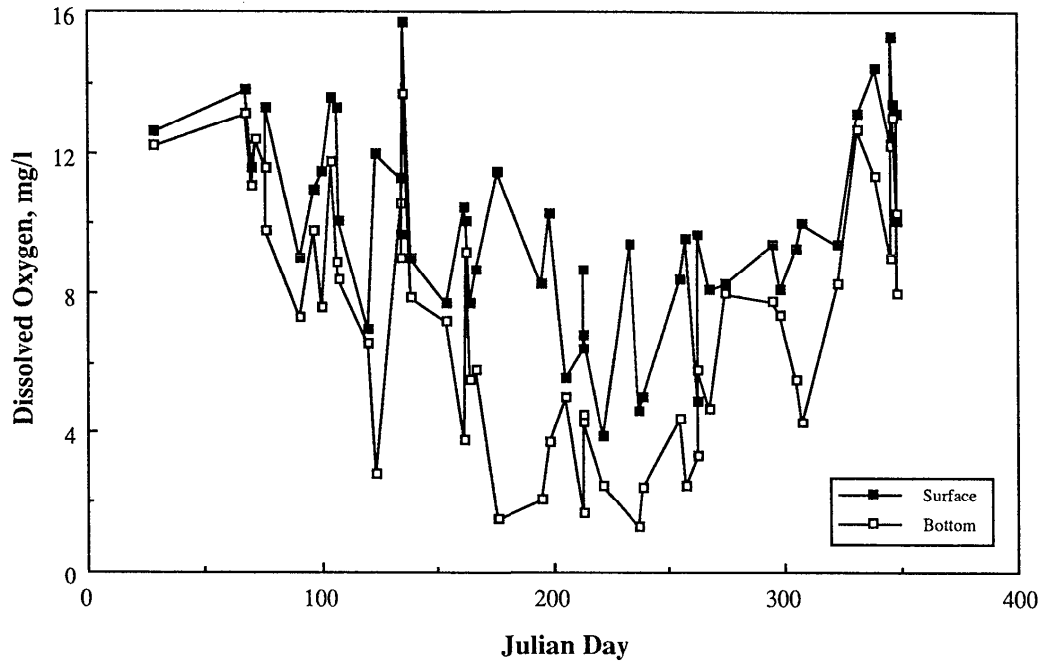


Fig 4-2. Annual dissolved oxygen concentrations for Middle Branch, Baltimore Harbor. Composite of 1984 to 1990. Data from Versar Inc.

dissolved oxygen. Given sufficient light, inputs of nutrients (i.e., nitrogen and phosphorus) will promote increased photosynthesis, thus producing oxygen as well as fixed organic matter, which provides metabolic substrates for heterotrophic consumption (i.e., respiration), potentially resulting in the net loss of oxygen from the water-column.

Under steady-state conditions, the balance of photosynthesis and community respiration should be the same, thereby resulting in no net effect on DO. However, there are many situations which result in the imbalance of the two processes, particularly in the vertical direction. This is especially the case in a turbid, stratified water-column (such as in Baltimore Harbor), where photosynthesis is confined to the upper layer, the organic matter produced as a result tends to sink to the lower layer, which is dominated by the consumption of organic matter (and therefore oxygen). The density barrier imposed by the stratified water-column subsequently prevents the vertical exchange of oxygen-rich surface water with oxygen-depleted bottom waters, setting up a situation resulting in depletion of oxygen in the bottom waters.

If the vertical separation between production and respiration is complete, that is, if all the organic carbon that is produced via photosynthesis sinks to the lower, non-photosynthetic, layer before being respired, then the nutrients entering the water body can be considered to be directly converted to BOD. This scenario would exert its greatest effect in large, deep, and slow-flushing marinas (such as Port Covington or Harborview Marina, for example) during periods of vertical stratification. An estimate of the resulting BOD effects on marina DO concentrations in the extreme case of complete conversion of nutrient loading by boating activity in the marinas, as calculated in section 2.4, could be determined by the stoichiometric conversion between nitrogen and carbon in the process of producing organic matter from photosynthesis. Since organic plant matter is composed of carbon and nitrogen in the constant ratio of 106:16::C:N, multiplying the nitrogen by 6.625 converts nitrogen to organic carbon, the break-down of which by heterotrophic respiration consumes oxygen in a one-to-one ratio.

Table 4-4 reports the calculated BOD and subsequent oxygen reduction from the break-down of the BOD produced. It can be seen from comparing Tables 4-1 and 4-2 with Table 4-4, that the average percent reduction in DO concentration for all marinas, when using the 1991 version of the EPA model, increases only slightly upon inclusion of marina nitrogen loading. The 1985 EPA model results in a stronger reduction in DO concentration, with the average percent reduction increasing from 14.85 % to 17.23 %. Since the 1991 model calculations have a term for air-water exchange (k_a , the reaeration coefficient), the model assumes that the water volume in the marina is in contact with the air surface, and therefore vertically mixed. Large drops in DO levels, represented as large departures from

TABLE 4-4. Conversion of total Nitrogen input from marinas to BOD and oxygen depletion

Marina	Total N g N/day	BOD Flow Rate (mg/day)	BOD Conc. (mg/l)	DO ambient (mg/l)	After EPA 1991		% Reduc. in DO	After EPA 1985		% Reduc. in DO
					DO high tide (mg/l)	DO low tide (mg/l)		DO remain. 1 tidal cycle (mg/l)	DO remain. 2 tidal cycles (mg/l)	
Anchorage	22,233.6	147,297,600	4.504	12.8	11.90	10.72	-16.11	10.33	8.06	-36.92
Anchorage Plaza	2,354.6	15,599,225	6.559	12.8	11.60	10.44	-18.29	9.35	6.14	-51.92
Balt. Int. Yachting	22,310.8	147,809,050	3.538	12.8	12.06	10.89	-14.78	10.80	8.96	-29.86
Bayview	2,007.2	13,297,700	9.201	12.8	11.19	10.03	-21.49	8.07	3.67	-71.27
Canton Cove	1,158.0	7,671,750	6.047	12.8	11.62	10.36	-18.92	9.57	6.68	-47.72
Scarfield	2,702.0	17,900,750	8.970	12.8	11.21	10.01	-21.64	8.19	3.97	-68.93
Shipyards	772.0	5,114,500	11.178	12.8	10.85	9.60	-24.91	7.18	2.14	-83.23
Tindeco Warf	772.0	5,114,500	5.410	12.8	11.77	10.60	-17.04	9.90	7.22	-43.49
Belt's Warf	1,891.4	12,530,525	16.293	12.8	10.09	8.97	-29.84	4.59	-3.18	-124.85
Brown's Warf	1,312.4	8,694,650	7.311	12.8	11.49	10.33	-19.20	8.99	5.44	-57.43
Chester Cove	1,544.0	10,229,000	5.193	12.8	11.81	10.65	-16.63	10.01	7.42	-41.92
Constellation	5,790.0	38,358,750								
Harbor's Edge	424.6	2,812,975	5.914	12.8	11.72	10.60	-17.10	9.67	6.73	-47.34
Henderson's	16,752.4	110,984,650	8.242	12.8	11.33	10.15	-20.60	8.54	4.61	-63.92
Swann's Warf	2,470.4	16,366,400	5.885	12.8	11.67	10.46	-18.17	9.66	6.80	-46.77
Thames Point	2,045.8	13,553,425	9.497	12.8	11.10	9.85	-22.95	7.96	3.63	-71.59
Harborview	23,160.0	153,435,000	5.591	12.6	11.60	10.48	-16.85	9.67	6.88	-45.39
Inner Harbor	5,867.2	38,870,200	6.798	12.6	11.37	10.19	-19.13	9.07	5.80	-53.98
Inner Harbor East	7,681.4	50,889,275	4.498	12.6	11.69	10.45	-17.02	10.15	7.92	-37.15
Tidewater	1,698.4	11,251,900	8.005	12.6	11.20	10.04	-20.32	8.49	4.64	-63.17
Balt. Yacht Basin	7,604.2	50,377,825	5.422	14.2	13.00	11.63	-18.06	11.07	8.36	-41.09
Ferry Bar	2,238.8	14,832,050	3.917	14.2	13.15	11.72	-17.43	11.68	9.55	-32.73
Mid. Br. Moorings	10,113.2	66,999,950	5.919	14.0	12.73	11.37	-18.79	10.68	7.82	-44.15
Port Covington	30,880.0	204,580,000	3.771	14.2	13.49	12.38	-12.83	12.10	10.10	-28.91
Port Liberty	34,740.0	230,152,500	9.583	14.8	13.17	12.04	-18.62	9.80	5.06	-65.82

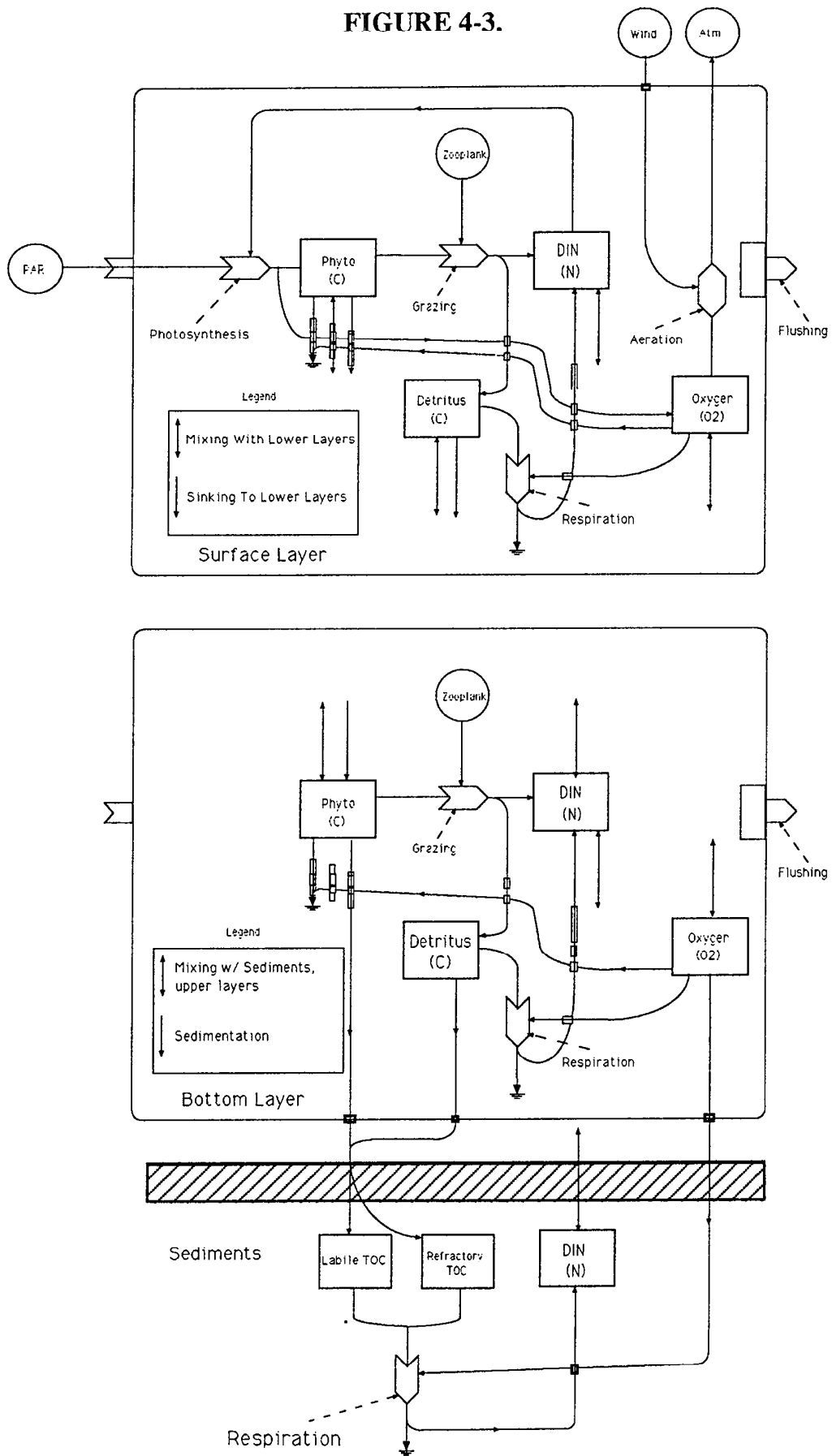
saturation in eq. 2, act to increase the magnitude of the gas exchange into the water, and as a result, this term acts to dampen oxygen fluctuations. However, under stratified conditions, where vertical mixing is inhibited by vertical density gradients, the bottom water tends to remain isolated from the surface and thus from regeneration via air-water gas exchange. Since, in this case, the BOD is being exerted primarily in the bottom waters, the 1985 version of the model may in fact be more representative of the actual percent reduction in DO concentrations that could result if nutrient inputs from boating activities in the marina were exerted as BOD.

Section 4.4 Summary and Conclusions

The comparison of BOD concentrations produced as a result of boat loadings in the marinas, Tables 4-1 and 4-2, and the measured BOD concentrations in the ambient water in Baltimore Harbor, Table 4-4 (and discussed in Section 4.2), seem to suggest that even with 50% of the boats in use 24 hours a day, the resulting loading of BOD to the harbor water body is insignificant relative to what is already present during the warmer boating months of the year (from Table 4-3). The question remains, however, as to the effect marina boating activities have on the water quality of the marina water volume itself. At this point it is clear that any specific assessment of the feasibility of mechanical reaeration within the individual marinas is unrealistic due to the complete lack of actual BOD and flushing characteristics for the marinas, and the large uncertainty in the calculated theoretical values obtained from the EPA models employed, due to the assumptions required of these models. As discussed in Section 4.3, the various assumptions implicit in the application of the model equations have opposite implications for the amount of DO reduction in the marina water. Specifically, the assumption of the tidal prism as the primary exchange mechanism for Baltimore Harbor marinas appears to overestimate the amount of DO reduction experienced in the marina, while the assumption of complete vertical mixing within the marina water body appears to underestimate the amount of DO reduction.

In addition to the above uncertainties, the model calculations applied in this report completely disregard the effect of biological activity on the dynamics of dissolved oxygen in the marinas. Clearly, an empirical understanding of the biological processes acting in the interaction between dissolved nutrients and the production and consumption of organic matter is necessary in any attempt to estimate the effects of marina related activity in a system such as Baltimore Harbor which is so heavily loaded with nutrients. Figure 4-3 is a simple conceptual diagram depicting both the biological variables and biogeochemical and physical processes that interact in determining the oxygen dynamics of the system. Given

FIGURE 4-3.



some real measurements of the biological rates and stocks represented in Fig. 4-3, such as, for example, water column production and respiration rates, phytoplankton standing stocks, sedimentation rates, etc., coupled with physical circulation measurements, as discussed in sect. 3, a realistic understanding of BOD production and oxygen depletion could then be obtained. It would be a straight forward field project to obtain such information and would serve as a basis for developing a numerical simulation model from the conceptual diagram depicted in Fig. 4-3, for tracking BOD and oxygen depletion. An outline of a such a monitoring program is proposed in the addendum to this report.

Conclusion

It was the intent of this study to assess the potential water quality impacts of marina development in Baltimore Harbor, based on findings from a literature review and analyses of existing water quality and nutrient loading data. The assessment focused on nutrient inputs and oxygen depletion that results from BOD loading from marina and boating activities. Marina and boating activities can impact water quality on two levels, the harbor system as a whole, and more specifically, the marina basin itself. Whether the marina acts as a point source of nutrients to the entire harbor basin, or whether impacts affect water quality just within the marina basin, depends largely on the flushing ability of Baltimore Harbor and of the specific marina in question.

As discussed in Sections 2 and 4, the effects of nutrient and BOD increases due to marina and boating activities to the harbor system as a whole are small relative to total nutrient loads and ambient BOD concentrations. Therefore, mitigation of total loads and high ambient concentrations with respect to water quality for the entire harbor system becomes important, as well as mitigating marina and boat related impacts with respect to water quality in marina basins. However, with respect to marina basins, the impacts are more difficult to assess. As the estimation of impacts gets more site-specific (i.e. from system-wide to individual marinas), several assumptions are required in order to calculate the assessment. Thus, the estimations become more uncertain, overwhelming the ability to estimate impacts to the marina basins. Most of these assumptions and uncertainties are involved in the flushing calculation. Therefore, better estimates of site-specific marina flushing rates are needed, since flushing rates determine the extent to which water quality is impacted in marina basins. Site-specific data for the variables and processes as depicted in Figure 4-3 are also needed to better understand and estimate nutrient loading, BOD production and oxygen depletion in marina basins. Therefore, the need to reaerate oxygen poor waters can not be adequately determined at this time due to the uncertainties associated with the DO calculations.

The assessments of impacts from marina and boating activities made in this study are preliminary, but reveal two important points: 1) point and diffuse loads to Baltimore Harbor are large, and 2) field data are needed to determine more site-specific impacts to individual marina basins. Therefore, the recommendations based on the results of this study are to mitigate, where possible, diffuse, point, marina and boat loads to Baltimore Harbor, and to initiate field programs to measure the necessary parameters involved in the site-specific assessments (the parameters described in detail in Sections 2, 3 and 4). As soon as a field program is underway in Baltimore Harbor, a better assessment of the need for reaeration will also be forthcoming.

Addendum

The first draft of the final report was discussed on July 15, 1991 by BRCOG and MDE representatives and the authors. Baltimore City was represented by Jim Holway, Program Manager from Baltimore Regional Council of Governments, Mary Dolan, Chief of Coastal Resources and Environmental Planning Section, Bob Hewitt, also from Coastal Resources and Environmental Planning Section and Bill Stack, from Water Quality Management Office. Maryland Department of the Environment was represented by Richard Eskin and Betsy Dobler. The authors of the report received suggestions for revision, and the committee discussed the conclusions of the report and strategies for future action.

A major concern identified by both the BRCOG and MDE representatives was that although potential nutrient loads from marinas and boats may be small as compared to total loads, mitigations must nevertheless include marina and boat impacts, as well as mitigating diffuse and point source loads. Baltimore City Critical Area Commission is asking all development in critical areas, which includes marina development, to reduce pollution loadings by 10% or pay an offset fee. This action by the City is in response to the 1987 Chesapeake Bay Agreement. It was also mentioned that the Clean Water Act will soon require local jurisdictions to reduce pollutant loadings from stormwater sources. Therefore, it is irrelevant that marina loadings are a small portion of total loadings to Baltimore Harbor, since everyone is required to reduce pollutant loadings to the Chesapeake Bay.

The committee focused next on two conclusions drawn from the report, the need to better understand site-specific flushing characteristics and the overall need for water quality data on Baltimore Harbor. Permits for marina development in Baltimore Harbor are presently being reviewed by the City, and therefore, a certain amount of urgency is associated with any collection of data on flushing and water quality. Flushing characteristics seem to be most critical for adequate marina site assessment, and the suggestion was made that a contract agency perform the required tests (dye studies) to determine flushing characteristics for both Northwest and Middle Branches. Water quality data are also critical, both for determining adequate marina sites and for better assessing impacts from marinas and boats. However, data collection may be best achieved with a long-term monitoring program, which focuses on both specific marina sites and pre-selected areas throughout the harbor. The suggestion was made that perhaps marina operators could become involved with site-specific collection of water quality data inside marinas, and given a strawman monitoring program (to follow), the state/city could be responsible for monitoring locales outside marinas in Baltimore Harbor. Two important characteristics for a monitoring program were emphasized: that the monitoring was done

by an experienced monitoring group, and that for the long-term, techniques and procedures must have continuity in order to withstand scrutiny and reveal trends.

Monitoring Program for Baltimore Harbor Marinas

To properly assess the potential impact of marina development on water quality of Baltimore Harbor and its contiguous waters, it is essential that additional data be collected. Toward that end, we provided here a brief sketch of a multicomponent data collection program for Baltimore Harbor and its associated marinas. This description is organized into three sections; although we judge that all of these would be required to fully estimate the impact of marina development, our understanding of the Harbor ecosystem would be improved measurably if any of these studies were accomplished. The program outlined here is based on our experience in conducting such studies and on our analysis of data needs for assessing the potential pollution problem associated with marinas. Obviously, it should be modified according to statistical analyses of existing data and within the constraints of available funding.

Physical circulation and flushing. We recommend that a short term study using continuous dye releases at key sites in the interior of each of the three major coves in the Harbor in which marinas exist or for which they are planned (Northwest Branch, Middle Branch, Curtis Bay). These experiments should be conducted at each site twice during the summer months. Each study would involve continuous release and tracking of dye (e.g. rhodamine) over a period of 2-5 days. In conjunction with these observations on dye dispersal, measurements of physical structure (CTD profiles) and currents should be made also at key points in each cove and in the Harbor proper. We believe that these regional dye release studies would be of far greater value than would smaller scale studies of flushing in individual marinas.

Monitoring of Harbor water quality. A long-term monitoring program of water quality and related variables should be established in Baltimore Harbor and in its major marinas. We recommend establishing one permanent station in each of four major arms of the Harbor (Northwest Branch, Middle Branch, Curtis Bay, Bear Cr.) and three stations along the main axis of the Harbor (one of these would be the current MDE station at Key Bridge). Additional stations should be established in the mixing zones between the Harbor and several major representative marinas (e.g. Anchorage, Port Covington, Port Liberty).

Each station should be sampled at 1-4 week intervals and at 2-5 water depths, depending on initial observations of variabilities and analyses for statistical power of interpretation. As a minimum, we recommend the following variables be measured at each sampling: temperature, salinity, depth, oxygen, chlorophyll a. Nutrient concentrations (totals and major species of N, P and Si) should be measured monthly in surface and bottom waters at each site. Once per year replicate samples of surficial sediments should be collected for analyses of toxic contaminants, including metals, PAHs, PCBs.

Synoptic description of water quality and related processes. Ultimately, analysis of water quality problems in Baltimore Harbor should involve numerical modeling of ecological and physical processes. Therefore, in addition to the data collected in the monitoring program described above, we recommend that the following measurements be made for purposes of calibrating rates in a conventional ecological model (e.g. Fig. 6):

- 1) plankton production
- 2) plankton respiration (surface and bottom)
- 3) benthic oxygen consumption
- 4) benthic nutrient regeneration.

We recommend that these rates be measured at approximately monthly intervals for one summer season (May - Aug). These data, in conjunction with a modeling effort, would greatly facilitate interpretation of monitoring data described above.

APPENDIX.
 POTENTIAL OXYGEN DEPLETION FOR BALTIMORE HARBOR MARINAS: COMPLETE WORKSHEET

Marina	No. of Slips	Surface Area (m ²)	Depth (m)	Marina Vol.	Marina Vol.	Tidal Prism	BOD Flow Rate (mg/day)	BOD Conc. (mg/l)	DOambient (mg/l)
				Low Tide (sq. meters)	High Tide (sq. meters)	Volume (sq. meters)			
Anchorage	576	99,635	4.27	425,441	459,317	33,876	31,380,480	0.960	12.8
Anchorage Plaza	61	7,246	4.88	35,360	37,824	2,464	3,323,280	1.397	12.8
Balt. Int. Yachting	578	127,273	4.57	581,638	624,910	43,273	31,489,440	0.754	12.8
Bayview	52	4,403	4.88	21,487	22,984	1,497	2,832,960	1.960	12.8
Canton Cove	30	3,865	3.05	11,788	13,102	1,314	1,634,400	1.288	12.8
Scarfield	70	6,080	3.96	24,077	26,144	2,067	3,813,600	1.911	12.8
Shipyard	20	1,394	3.05	4,252	4,726	474	1,089,600	2.381	12.8
Tindecos Warf	20	2,880	4.57	13,162	14,141	979	1,089,600	1.153	12.8
Belt's Warf	49	2,343	6.10	14,292	15,089	797	2,669,520	3.471	12.8
Brown's Warf	34	3,623	4.88	17,680	18,912	1,232	1,852,320	1.558	12.8
Chester Cove	40	6,001	4.88	29,285	31,325	2,040	2,179,200	1.106	12.8
Constellation	150						8,172,000		
Harbor's Edge	11	1,449	6.10	8,839	9,332	493	599,280	1.260	12.8
Henderson's	434	41,025	4.27	175,177	189,125	13,949	23,644,320	1.756	12.8
Swann's Warf	64	8,472	3.66	31,008	33,888	2,880	3,486,720	1.254	12.8
Thames Point	53	4,348	3.05	13,261	14,740	1,478	2,887,440	2.023	12.8
Harborview	600	83,610	6.4	535,104	563,531	28,427	32,688,000	1.191	12.6
Inner Harbor	152	17,419	4.27	74,379	80,302	5,922	8,280,960	1.448	12.6
Inner Harbor East	199	34,465	3.35	115,458	127,176	11,718	10,841,520	0.958	12.6
Tidewater	44	4,282	4.88	20,896	22,352	1,456	2,397,120	1.706	12.6
Balt. Yacht Basin	197	28,307	2.13	60,294	69,918	9,624	10,732,560	1.155	14.2
Ferry Bar	58	11,536	1.83	21,111	25,033	3,922	3,159,840	0.834	14.2
Mid. Br. Moorings	262	34,484	2.13	73,451	85,175	11,725	14,273,760	1.261	14.0
Port Covington	550	165,274	7.01	1,158,571	1,214,764	56,193	29,964,000	0.552	14.2
Port Liberty	100	73,170	6.4	468,288	493,166	24,878	5,448,000	0.227	14.8

APPENDIX CONTINUED.

POTENTIAL OXYGEN DEPLETION FOR BALTIMORE HARBOR MARINAS: COMPLETE WORKSHEET

Marina	DOsaturation (mg/l)	KsubL	KsubA	After EPA 1991			After EPA 1985		
				DO high tide (mg/l)	DO low tide (mg/l)	% Reduction in DO after low tide	DO remaining 1 tidal cycle (mg/l)	DO remaining 2 tidal cycles (mg/l)	% Reduction in DO after 2 tidal cycles
Anchorage	8.3	1.5	0.11	12.45	11.26	-11.86	12.03	11.33	-11.31
Anchorage Plaza	8.3	1.5	0.09	12.40	11.24	-12.03	11.85	10.98	-14.12
Balt. Int. Yachting	8.3	1.5	0.10	12.49	11.32	-11.42	12.14	11.55	-9.60
Bayview	8.3	1.5	0.09	12.31	11.15	-12.72	11.58	10.45	-18.24
Canton Cove	8.3	1.5	0.15	12.33	11.07	-13.37	11.79	10.89	-14.78
Scarfield	8.3	1.5	0.12	12.29	11.09	-13.21	11.56	10.43	-18.37
Shipyards	8.3	1.5	0.15	12.16	10.91	-14.65	11.28	9.92	-22.35
Tindeco Warf	8.3	1.5	0.10	12.43	11.26	-11.90	11.95	11.18	-12.51
Belt's Warf	8.3	1.5	0.07	12.11	10.98	-14.10	10.87	9.06	-29.09
Brown's Warf	8.3	1.5	0.09	12.38	11.22	-12.23	11.77	10.83	-15.29
Chester Cove	8.3	1.5	0.09	12.45	11.29	-11.68	11.99	11.25	-11.98
Constellation									
Harbor's Edge	8.3	1.5	0.07	12.45	11.33	-11.38	11.95	11.17	-12.58
Henderson's	8.3	1.5	0.11	12.32	11.14	-12.81	11.65	10.60	-17.06
Swann's Warf	8.3	1.5	0.12	12.37	11.16	-12.68	11.85	11.00	-13.91
Thames Point	8.3	1.5	0.15	12.22	10.96	-14.23	11.44	10.24	-19.87
Harborview	8.4	1.5	0.07	12.29	11.17	-11.36	11.83	11.10	-11.94
Inner Harbor	8.4	1.5	0.11	12.19	11.01	-12.61	11.63	10.74	-14.77
Inner Harbor East	8.4	1.5	0.14	12.22	10.99	-12.80	11.81	11.09	-11.97
Tidewater	8.4	1.5	0.09	12.17	11.02	-12.58	11.53	10.54	-16.36
Balt. Yacht Basin	8.3	2.0	0.29	13.61	12.24	-13.77	12.97	11.91	-16.12
Ferry Bar	8.3	2.0	0.33	13.58	12.16	-14.40	13.02	12.03	-15.27
Mid. Br. Mooring:	8.4	2.0	0.29	13.40	12.03	-14.04	12.76	11.69	-16.50
Port Covington	8.3	1.5	0.07	14.00	12.89	-9.24	13.69	13.20	-7.05
Port Liberty	8.3	1.5	0.07	14.64	13.52	-8.68	14.40	14.02	-5.26

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