THE EFFECTS OF MARINAS & BOATING ACTIVITY UPON MARYLAND TIDAL WATERWAYS

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INTRODUCTION

There are approximately 550 small, tidal waterways within the Maryland portion of the Chesapeake Bay system. Most of these waterways are named tidal creeks. These creeks are generally less than 365 meters (1,200 feet) in width and have a depth of 2.5 meters (8.0 feet) or less. Tidal creeks tend to harbor environmentally sensitive aquatic resources, such as wetlands (Spence 1967), submerged aquatic vegetation (Jupp and Spence 1977), and frequently serve as spawning and nursery grounds for important fish species (Funderburk et al. 1991). These waterways account for roughly 5% of the total surface area of tidal waters contained within the state.

The purpose of this paper is to review the scientific literature on the effects of boating activity and related facilities upon tidal creeks. The review focuses on boats fitted with engines. Smaller vessels, such as canoes and row-boats, are far less likely to cause significant impact upon the aquatic resources associated with tidal creeks. The review primarily addresses the effects of boating upon the following aquatic resources: wetlands, submerged aquatic vegetation, bottom dwelling communities, and fish.

This review was prompted by evaluations I have conducted of a number of proposed boating facilities in Maryland. I have found that the environmental impact is substantially greater when a facility is proposed for a site located in a tidal creek. It is my hope that this review will serve to guide future boating facilities to larger waterways where the benefits of recreational boating can be attained while preserving sensitive aquatic resources.

The potential aquatic resource impacts associated with the operation of boats include:

- the disturbance and resuspension of bottom sediments through the turbulence produced by boat propellers,
- damage to shorelines, wetlands, and submerged aquatic vegetation (SAV) beds as a result of the wake produced by boats, and
- the release of sewage and toxics.

Potential aquatic resource impacts associated with facilities supporting boating include:

- the release of eroded soils into the waterway and the destruction of wetlands and other important habitat features during facility construction,
- dredging-related impacts,
- the inhibition of tidal exchange due to piers and other obstructions as well as the creation of poorly flushed areas such as lagoons excavated from uplands,
- the release of stormwater pollutants from parking lots, rooftops and other impervious surfaces associated with marinas, and
- the release of toxic substances from boat hulls, piers and bulkheads.

SENSITIVE AQUATIC RESOURCES ASSOCIATED WITH TIDAL WATERWAYS

Rozas and Odum (1987) found that the productivity of a tidal system tended to increase as one journeyed into progressively smaller waterways. The authors attributed increased productivity to the greater abundance of emergent wetlands and submerged aquatic vegetation (SAV) in small tidal creek systems. Several factors tend to combine in small tidal waterways to create conditions which are conducive to sensitive aquatic resources.

Tidal creeks tend to be low-energy areas. The narrow width of these waterways provide little opportunity for the creation of wind-driven waves. Such a uniquely stable environment allows for the proliferation of fringe marsh, pocket wetlands, and SAV beds (Boesch and Turner 1984; Jacobson et al. 1987). These plant communities provide the habitat and food material required by a number of key components of the estuarine ecosystem (Moy and Levin 1991).

Creeks associated with salt marshes and other wetlands export large quantities of fish and invertebrate biomass (Boesch and Turner 1984). In fact estuarine fish productivity increases as the relative abundance of salt marsh within an estuary increases (Boesch and Turner 1984). Boesch and Turner stated that "juveniles of a number of economically important fishes and invertebrates heavily utilize the shallow habitats associated with the edges of salt marshes." Mock (1967) noted higher shrimp catches adjacent to a salt marsh when compared to collections made 50 to 100 feet from the wetland. The abundance of the Carolina marsh clam *(Polymesoda caroliniana)* was directly related to the density of plants within a salt marsh (Capehart and Hackney 1989).

Wetlands also account for a substantial portion of the pollutant attenuation occurring in small tidal waterways. Spurrier and Kjerfve (1988) found that salt marshes can absorb large quantities of nitrogen from adjacent tidal creeks. Chrzanowski and Spurrier (1987) documented a 20% to 70% reduction in microbial biomass after water passed through a stand of cordgrass *(Spartina alterniflora)*. Seneca et al. (1976) cited salt marshes as an important site for the storage and exchange of mineral nutrients. Simpson et al. (1983) studied nutrient and heavy metal retention in freshwater tidal wetland located in the Delaware River system. They found that the above ground portions of the plants stored nutrients and metals during the growing season, but a significant portion of these materials were released back into the aquatic environment when the plants decayed.

Small wetlands can be of greater ecological value than larger wetlands. Gucinski (1978) studied the relationship between ecological values and size of wetlands on the Mayo peninsula, Maryland. He found that wetlands less than 5 acres in size accounted for 54% of the total acreage and 72% of the seaward edge of wetlands. He also found that acre for acre, a small wetland has greater habitat value and plant growth than larger wetlands. Gucinski (1978) felt that wetlands located on small, tidal creeks were particularly important. He found that these wetlands tend to be situated at points that allowed an unusually high sediment and nutrient trapping rate. Wetland value may continue to increase down to areas as small as 0.1 acres (Gucinski 1978).

SAV is just as important as marshes to the overall health of an estuarine ecosystem. SAV beds provide food, shelter and nursery areas for invertebrates, fish, waterfowl, and marine mammals (Orth et al. 1984; Thayer et al. 1984). SAV also serves as a nutrient buffer (Kemp et al. 1984). Orth et al. (1984) stated that "When compared with nearby unvegetated areas, seagrass meadows contain a dense and strikingly rich assemblage of vertebrates and invertebrates." Grass beds support 1.1 to 29 times more invertebrates and fish when compared to unvegetated sites (Orth et al. 1984).

Eighteen species of SAV occur within the Chesapeake Bay system (Orth et al. 1984). Since

1965 SAV has declined dramatically throughout the Chesapeake Bay system (Orth and Moore 1983). In general the decline has been most severe in the upper reaches of the estuary (Orth and Moore 1983). The decline has been attributed to eutrophication (Orth and Moore 1983; Kemp et al. 1983) and turbidity or sediment (Orth and Moore 1983; Kemp et al. 1983).

Several species of anadromous fish spawn in freshwater tributaries and utilize small tidal creeks as nursery areas. These species include alewife herring *(Alosa pseudoharengus)*, blueback herring *(Alosa aestivalis)*, and yellow perch *(Perca flavescens)*. Roughly 40% of Maryland's small, tidal waterways are fed by perennial freshwater tributaries and may have the potential to support anadromous fish spawning activity.

Commercial landings of anadromous fish species have declined alarmingly over the past 40 years. For example the Maryland catch for alewives was 7 million pounds in 1950 but has been 100,000 pounds/year since 1976 (Jones et al. 1988). Maryland yellow perch landings last peaked in 1965 at 230,000 pounds but has been less than 50,000 pounds per year since 1972 (Jones et al. 1988).

In summary, the conditions found in small, tidal waterways favor the proliferation of aquatic resources that are both sensitive to environmental disturbances and vitally important to the overall health of Maryland's estuarine waters.

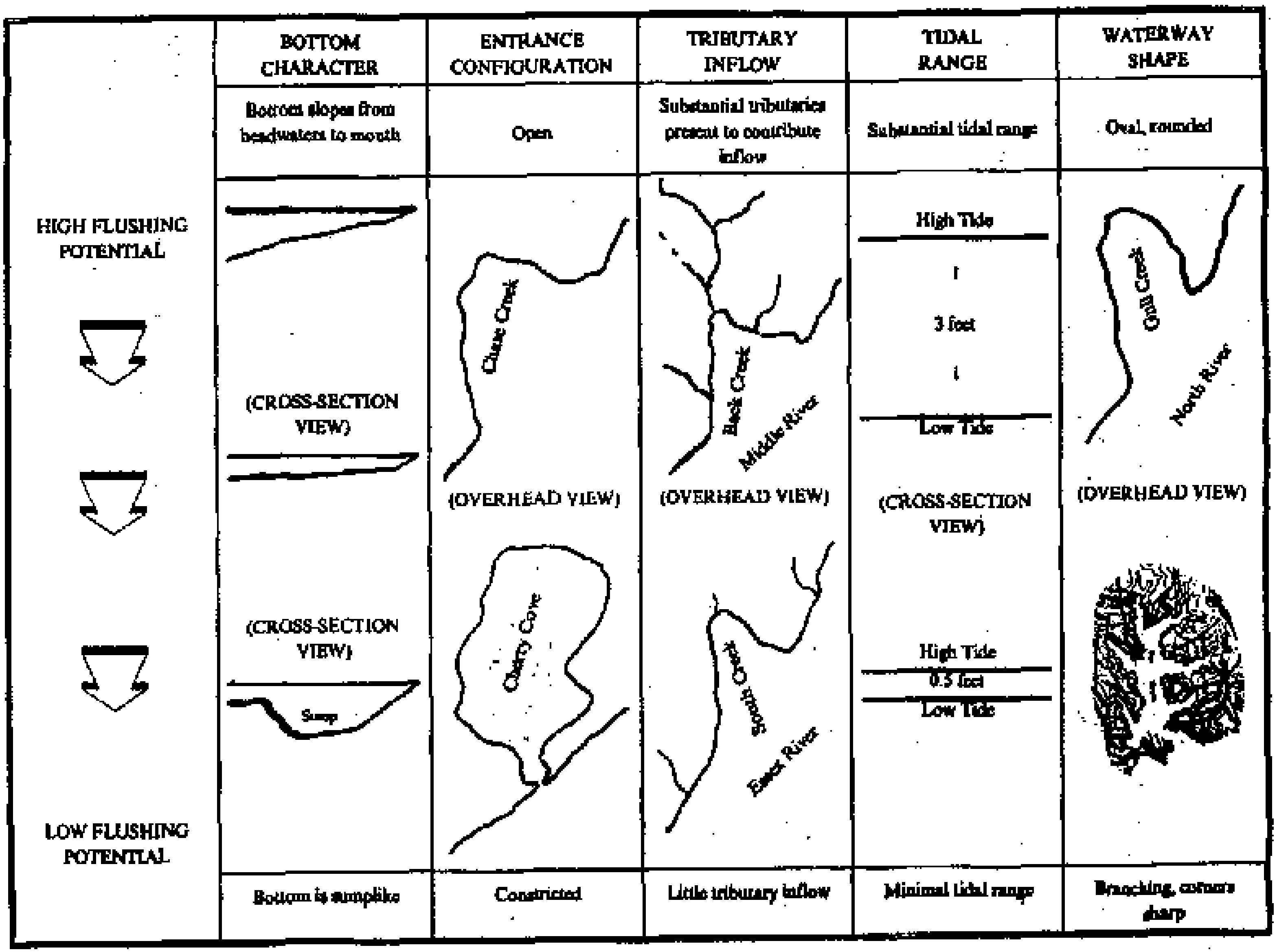
FLUSHING CHARACTERISTICS OF SMALL TIDAL WATERWAYS

Tidal exchange or flushing serves as a primary mechanism for transporting nutritional material from small, tidal waterways and for preventing an excessive accumulation of pollutants. With each tidal cycle the inflow and outflow of water dilutes pollutant concentrations (assuming the connecting water body is cleaner) and minute particles may become suspended and transported from the waterway. Wetland plants and submerged aquatic vegetation also reduce nutrient concentrations through uptake. Combined, tidal exchange and plant uptake are vital to maintaining the quality of a tidal creek.

In general, the upper reaches of estuaries and tidal creeks tend to be poorly flushed (EPA 1985b). But the actual degree of flushing is dependent upon: tidal range, tributary inflow, return flow, bottom and shoreline configuration, and the orientation to prevailing winds (EPA 1985b; NCDEHNR 1990; SCCC 1985; DNREC 1990). The relationships between these waterway characteristics and flushing potential are illustrated in Figure 1.

Flushing is promoted when the bottom of a tidal waterway slopes from the headwaters towards the mouth. Flushing is retarded when the entrance to a waterway is shallower than interior portions of the waterway. Of the 550 small, tidal creeks contained within Maryland, 22 are sumplike according to navigation charts published by the Department of Natural Resources (Maryland Department of Natural Resources 1990). Specifically, these 22 waterways have a depression or sump which is at least twice the depth of the entrance. A sump may allow sediments to accumulate. Pollutants may be associated with the accumulated sediments. As pollutants accumulate over time, the water quality impact can be magnified.

FIGURE 1: General Relationships Between Waterway Characteristics & Flushing Potential (After NCDEHNR 1990)



A broad, open waterway entrance allows a greater exchange of water during each tidal cycle. Forty of Maryland's tidal creeks have a constricted entrance where tidal flow must pass through a very narrow opening.

Freshwater inflow provides a force that pushes the mass of water within a creek towards the mouth. The greater the inflow, the greater the force and, therefore, the greater the flushing potential. According to topographic maps prepared by the Maryland Geological Survey, roughly 40% of all small tidal creeks receive inflow from a perennial tributary - streams which flow year-round. Of the remaining creeks half are fed by intermittent streams and half receive no tributary inflow.

As the configuration of a waterway becomes more convoluted and irregular, the degree to which resident water mixes with tidal inflow tends to decrease. The irregularities may create eddies and stagnant areas which do not fully mix with tidal inflow. In general, the more oval or rounded a waterway, the better mixing and flushing (NCDEHNR 1990).

Assessments of the potential impact of a proposed marina place considerable reliance upon equations to predict flushing time. The equations attempt to estimate how much time will be required to replace the water contained within the basin through tidal exchange. If the exchange time is no more than two to four days, then flushing is deemed adequate (EPA 1985b). With such a "quick" flushing rate it is assumed that pollutants will not build to undesirable levels.

Under some conditions the tidal exchange approach may adequately indicate the overall environmental quality of a proposed facility. The accuracy of the approach is generally best when the facility is located off of a large body of water and it is designed to enhance flushing by incorporating characteristics such as: a bottom sloping towards the inlet(s), rounded corners, two inlets set apart at the maximum possible distance, orientation to enhance wind-induced mixing, and so forth (Boicourt and Sanford; EPA 1985b). As one moves further away from these conditions the accuracy of the tidal exchange approach and flushing equations may decline.

Ideally the tools used to assess the potential impact of a proposed boating facility should relate directly to the most sensitive features which may be affected by the facility. The marina basin models employed by the states of Delaware and North Carolina are closer to this ideal tool when compared to a flushing equation (see DNREC 1990 and NCDEHNR 1990 for model description). Both models predict dissolved oxygen concentrations within a marina basin. But dissolved oxygen is only one of a number of factors that may be affected by a boating facility. Presently, tools that reliably predict the cumulative effects of a proposed facility upon sensitive aquatic resources do not exist. Furthermore, the models only assess the effects within the immediate vicinity of a facility and fail to provide a means for examining the regional effects (EA 1990).

In summary, the only statement that can be made with certainty is that the better the flushing characteristics of a marina basin or waterway, the lower the potential environmental impact. Small tidal creeks tend to possess characteristics which inhibit flushing. Thus these waterways are generally more vulnerable to water quality problems due to the higher potential for the accumulation of pollutants.

IMPACTS ASSOCIATED WITH BOATING & SUPPORT FACILITIES

Boating is an exceedingly important recreation activity in Maryland. It not only provides hundreds of thousands of people with an enjoyable pastime, but also drives a significant segment of the state economy. Boating facilities provide much of the public access to the Chesapeake Bay and its tributaries. The number of boats registered in Maryland has been increasing by an average of 5,240 per year over the past two decades.

As with most human activities, the positive benefits associated with boating come with an environmental cost. Boating and related activities may impact the aquatic environment through the disturbance of bottom sediments, wake-induced erosion of shorelines, wetlands, and SAV beds, the release of sewage and toxics, as well as habitat losses associated with the development of marinas and other support facilities.

Resuspension & Disturbance Of Bottom Sediments

A number of studies have shown a substantial negative impact upon SAV and bottom dwelling communities when boat traffic is concentrated in waters shallower than 2.5 meters (Gucinski 1981; Yousef 1974; FTU 1978; Pfitzenmeyer 1978; Williams and Skove 1981 and 1984). The impact results from the disturbance of sediments caused by boat propeller induced turbulence.

Yousef studied the effects of boating activity upon sediment resuspension in four freshwater lakes located in Florida. Significant boat propeller induced sediment resuspension occurred to a depth in excess of 1.6 meters. As depth and sediment particle size decreased, resuspension increased. And as logic would indicate, increasing outboard motor horsepower caused resuspension to increase. While Yousef found that boat activity initially increased dissolved oxygen levels, he also found that oxygen uptake by resuspended organic particle increased as well. An increase in nutrient levels also resulted from propeller induced sediment resuspension.

A viable benthic macroinvertebrate community is a crucial component of the estuarine food chain. Examples of these organisms include polychaetes, oligochaetes, isopods, amphipods, and clams. The overall productivity of fish and crab populations is directly related to the health of the benthos (Diaz and Schaffner 1990). Pfitzenmeyer (1978) found that propeller induced turbulence impairs benthic communities when the water depth is 1.8 meters or less.

SAV beds can be harmed by sediment resuspension. Gucinski (1981) found that boat propeller turbulence produced a statistically significant increase in light attenuation and suspended sediment when water depth was less than 2.2 meters. Gucinski (1981) also found that boats with a planing hull produced the maximum increase in the resuspension of bottom sediments when operating at high speed; low speed produced far less sediment resuspension. Gucinski (1981) concluded that the quantity of sediment resuspended by boat propeller turbulence was sufficient to reduce the productivity of SAV in shallow water. Gucinski (1981) also concluded that sediment resuspension becomes significant when a boat operates in a water depth of less than 2.2 meters. The author found indications that the relationship between sediment resuspension and depth may be exponential rather than linear. Thus it may be that depth only need be slightly greater than 2.2 meters to prevent significant resuspension. Unfortunately the data is not available to determine the depth at which the no-effect threshold occurs.

Williams and Skove (1981 and 1984) studied the effects of high-speed boat activity upon turbidity in the headwaters of South River, a tributary to the Chesapeake Bay. Water depth within the study area ranged from 1.0 to 2.0 meters. The authors felt that boating activity had the potential to produce a significant effect upon SAV in waterways where turbidity has been pushed near the critical threshold by other factors. It was recommended that high-speed boat activity be limited in waters that have a depth of 1.5 meters or less (Williams and Skove 1981).

If SAV is absent, then siting a boating facility in a small creek may preclude the return of these plants due to the reduction in light transmission attributable to the resuspension of bottom sediments. A study conducted by Community & Environmental Defense Services (Community & Environmental Defense Services 1991a) on Saint Leonard Creek, which is a tributary to Maryland's Patuxent River, determined that sediment resuspension due to boat propeller turbulence raised the turbidity level from an initial value of 7 NTUs to 385 NTUs (Nephelometer Turbidity Unit).

Community & Environmental Defense Services (1991b) conducted a similar study in Potomac Creek, located near Fredericksburg, Virginia. A 5.2 meter (17-foot) boat with a 40 hp outboard motor was operated approximately 15 meters offshore of a proposed launching ramp location. The boat was operated in a manner similar to the way in which vessels would leave the vicinity of the ramp. The background turbidity level was 43 NTUs. Operating the boat in 1.2 meters of water resuspended sufficient bottom sediment to cause a turbidity level of 350 NTUs. When operated in 0.9 meters of water the turbidity level reached 675 NTUs.

A report published by EPA's Chesapeake Bay Program indicated that four species of SAV require a turbidity level of less than 20 NTUs and eelgrass (*Zostera marina*) requires a turbidity of 15 NTUs or less (Chesapeake Bay Program 1989). Effler (1988) developed a very general relationship between turbidity, Secchi depth, and light transmittance. Effler found that turbidity greater than 15 NTUs will equate to a Secchi depth of less than 0.5 meters and a scattering coefficient (b) of less than 15 meters^{-1}. But Effler also reported that the relationship between turbidity and the other parameters varied from water body to water body.

The Chesapeake Bay Program (1989) report also stated that many anadromous fish species require a turbidity of less than 50 NTUs. Sediment suspended in the water column may coat the surface of a fish egg and interfere with oxygen exchange. Suspended sediment may also injure fragile gill filaments of larval fish (Klein 1983).

In summary, boating activity resuspends significant quantities of sediment when water depth is less than 2.2 meters (7.2 feet) and the effect is particularly acute when the bottom is composed of fine sediments. The degree of sediment resuspension is sufficient to impair: bottom dwelling communities through the phyical disturbance caused by boat propellers; submerged aquatic vegetation through the reduction in light transmission, and juvenile fish due to the effects of resuspended sediment upon gills. The turbidity generated by boats operating in shallow waters exceeds safe levels by up to 34-fold.

Boat Wake Effects

A report published by the Maryland Department of Natural Resources (Maryland Department of Natural Resources 1980) assessed the effects of boat wakes upon shore erosion rates. Four factors are necessary in order for a shoreline to have a high potential for erosion due to boat wakes:

1. Presence of exposed points of land in a narrow creek or cove,

2. fastland consisting of easily-erodible material,

3. steep nearshore gradient on the shoreline profile, and

4. location adjacent to a high rate of boating, with boats passing relatively close to the shoreline.

The first three conditions commonly occur in small, tidal creeks. And these waterways also tend to support an abundance of wetlands, SAV beds, and other environmentally sensitive aquatic resources. These plant communities developed in a low wave-energy environment and are, therefore, vulnerable to the erosive effects of wave action.

Several researchers have studied the effects of wave action upon SAV beds. Chambers (1987) examined SAV occurring along the shoreline of four lakes in southern Quebec. She found that wave action limited the minimum depth (0.12 to 1.1 meters) to which SAV beds will extend. The author stated that wave action may affect SAV directly through "biomass removal, seedling displacement, and propagule transport or indirectly through the erosion, sorting and deposition of sediment." Jupp and Spence (1977) found that wave action accounted for 80% of the SAV biomass loss in a scottish lake.

Wave action also damages emergent wetland vegetation. Coops et al. (1991) studied the effect of waves upon a freshwater wetland located in the Netherlands. The authors stated that much of the variation observed in wetlands occurring along lake shores can be attributed to the degree of wave exposure. Generally as the severity of exposure increases, wetlands decrease. They attributed the decrease to wave damage to plants, up-rooting of plants, and the transport of seeds and plant parts from the wetland.

Keddy (1984) found that exposure to waves along a Nova Scotia lake affected some wetland plants more severely than others. The abundance of the following species was negatively correlated with wave exposure: *Calamagrostis canadensis, Carex stricta, and Pontederia cordata.* But the abundance of two aster species and a bent grass species was positively correlated with exposure.

Raspopov et al. (1988) found that wave action limited wetland plants and benthic organisms inhabiting a lake located near St. Petersburg in the former USSR. Keddy (1985) and Wilson et al. (1985) found that several wetland species inhabiting freshwater lakes in Ontario preferred a shoreline with an intermediate degree of exposure to wave action. Stark and Dienst (1989) found that wave action was a significant factor in the decline of reed stands along the shore of Lake Constance in Germany.

The Virginia Marine Resources Commission published a report entitled Wetlands Guidelines.[1] This undated report describes the 17 wetland types recognized within the state. The report lists the following wetland types as being resistent to wave induced erosion: saltmarsh cordgrass community, saltmeadow community, black needlerush community, big cordgrass community, reed grass community, brackish water mixed community, intertidal beach community, sand flat community, and sand/mud mixed flat community. Wetland types susceptible to erosion include: cattail community, arrow arum-pickerelweed community, and freshwater mixed community.

The impact of boat wakes upon a shoreline can increase sediment inputs to a waterway. Increased sediment entry may diminish channel depth and impair the productivity of fish, shellfish, and benthic macroinvertebrate communities (Gucinski 1981; Klein 1983). In the Maryland Department of Natural Resources study a trial run showed that the wake produced by a boat operating within 60 meters (200 feet) of a shoreline caused the suspended sediment concentration to rise from a background level of 5 mg/l to a maximum of 330 mg/l. Oysters and anadromous fish require habitat with a suspended sediment concentration of less than 35 and 50 mg/l, respectively (Chesapeake Bay Program 1989).

The Maryland Department of Natural Resources study found that boat wakes typically continue to reach the shoreline when a vessel passes even as far away as 150 meters. There is some reduction in wave energy as the distance between passing vessels and the shoreline increases. In the Maryland Department of Natural Resources study the wave energy impacting the shore from a vessel operating at a distance of 150 meters is 20% of that caused by a boat operating 60 meters off shore. The Maryland Department of Natural Resources study stated (on page 9-6) that "the greatest relative impact is likely to occur in narrow creeks where the channel width forces passage within two or three hundred feet (60 to 90 meters) from the shore."

Given the susceptibility of sensitive aquatic resources to boat wake effects, one should not strive to merely avoid the "greatest relative impact" but to reduce the impact below the threshold of impact. At this point in time it appears that this threshold is reached when boat wakes are generated less than 150 meters from shore. But several factors can affect the actual effect of a specific boat operating along a particular shoreline. In addition to the four factors cited at the top of page 8, characteristics such as water depth, hull design, and boat operating speed can also affect the size of wake produced by a vessel.

Boats operating on a number of small, tidal creeks in Maryland are restricted to a maximum speed of six-knots during weekends and holidays. But a six-knot limit does not necessarily eliminate impacts associated with boat wakes. In fact, the Maryland Department of Natural Resources study found that maximum wake impacts occur at a speed of seven to ten knots when a boat operates in depths less than 4 meters (13 feet). Thus a small error in judging speed could cause a boat operator to generate maximum wake effects while attempting to abide by the six-knot speed.

[1] The Virginia Marine Resources Commission can be reached by calling (804) 247-2200 or by writing to VMRC, Post Office Box 756, Newport News, Virginia 23607.

In summary, the wake produced by boats passing within 150 meters of a shoreline can exert significant force upon the shore. The closer the boat pass, the greater the force exerted. Wave action is a primary factor regulating the distribution and productivity of SAV and emergent wetlands. The erosion associated with boat wakes can also bring about high suspended sediment concentrations, which would exacerbate the impact upon SAV and benthic animals. Strict adherence to a six-knot speed limit will not necessarily eliminate the impact and could maximize the damages associated with boat wakes.

Boat Waste Discharges

A survey conducted among boaters in Anne Arundel County, Maryland in the late 1970's indicated that 52% of all registered boats have toilets on-board (OPZ 1980). Of these vessels, roughly two-thirds discharged toilet wastes through the hull and into the water. A more recent survey among 227 Maryland boaters indicated that a third of the vessels discharged partially treated wastes into the aquatic environment and the remainder use a holding tank or Port-A-Potty which should prevent direct waste release to waterways (Strand and Gibson 1990). A study conducted by the University of Maryland determined that one out of every ten to one out of every two boaters would use a boat-waste pump-out system (Strand and Gibson 1990).

Boat waste discharges may impact a waterway through the release of disease causing organisms, oxygen demand, and toxic substances. The U.S. Environmental Protection Agency estimates that a typical boat may release 130 million coliform bacteria during each hour of operation (EPA 1985b). But EPA's estimates are based upon a paper published in 1975 and may not reflect current boat waste disposal practices. Unfortunately this does not necessarily mean improved conditions. In fact, waterborne disease outbreaks are increasing in the United States. The number of outbreaks reported for the period of 1976-1980 was more than three times greater than the outbreaks occurring between 1961-1965 (Gerba and Goyal). The number of shellfish associated gastroenteritis cases reported for the period of 1980-1984 was three times higher than the total number of cases reported for the preceding 50 years (Richards 1987). While boat waste disposal probably plays a very small role in the overall incidence of waterborne disease, there are some situations in which the discharge of sewage from vessels could be a very significant factor. For example, the release of boat wastes into a small, poorly flushed tidal creek could create a significant public health threat.

EPA's *Coastal Marinas Assessment Handbook* (EPA 1985b) presents figures which indicate that a boat releases 5 grams (0.01 pounds) of oxygen demanding material during each hour of operation. For each part of oxygen demand released into a waterway, an equal quantity of dissolved oxygen will be removed. In a confined, poorly flushed waterway oxygen demand releases from boats could cause a significant decline in oxygen levels.

A Type II marine sanitation device (MSD) uses chlorine to disinfect sewage prior to discharge. A number of vessels operating in Maryland waters use a Type II MSD (Strand and Gibson 1990). Chlorine can be extremely toxic to the egg and larval stages of Maryland's most important aquatic organisms (Jones et al. 1988).

In summary, boat waste discharges can exert a significant negative impact upon the aquatic environment. The impact is likely to be most substantial in a small, poorly flushed waterway where pollutant concentrations may reach unusually high levels.

Stormwater Runoff

Stormwater may wash a substantial amount of polluting materials from the rooftops and paved surfaces associated with a boating facility. In the early 1980's the U.S. Environmental Protection Agency conducted an intensive study of the quality of rainwater runoff from developed lands (EPA 1983). This study revealed that stormwater runoff from developed lands may contain 77 priority pollutants, a number of which are either toxic to aquatic organisms or carcinogenic. Runoff also contains nutrients, oxygen demand, fecal coliform bacteria, sediment, heat, and other conventional pollutants.

The pollutants associated with stormwater runoff stem from: fossil fuel combustion; automobile operation; lawn care practices; the corrosion, abrasion, and erosion of surfaces such as rain gutters and shingles. Much of the pollution associated with stormwater runoff washes from impervious surfaces, such as roads, parking lots, rooftops, and sidewalks associated with a marina.

Of the many toxic compounds detected in stormwater runoff copper, lead, zinc, and petroleum hydrocarbons are the most ubiquitous. Olsenholler (1991) states that the petroleum hydrocarbon concentration averages 3.7 mg/l in runoff from urban areas in the Chesapeake Bay watershed. Thomson and Webb (1984) found that chronic oil pollution can cause severe, long-term damage to salt marsh vegetation. When exposed to crude oil and a 40:1 gasoline:2-cycle engine oil mixture oyster spat densities were significantly lower and maximum spat size was smaller when compared to uncontaminated study sites (Smith and Hackney 1989). But Smith and Hackney (1989) also stated that "Conclusions on the possible effects of petroleum on growth, reproduction and edibility of *C. virginica* cannot be made based upon this study."

But of the many toxic substances associated with runoff, copper most frequently exceeds the safe levels establish by the U.S. EPA (EPA 1983). Copper can exert a deletrious effect upon a number of important components of an estuarine ecosystem. The copper entrained in stormwater stems in part from auto operation and other forms of fossil fuel combustion.

Waddell and Kraus (1990) found that copper inhibited the growth of *Spartina alterniflora* seedlings. At a concentration of 500 µg/l copper can cause oyster tissues to acquire a green color and bitter taste, both of which affect marketability (Roosenburg 1969).

In Jamica Bay, New York benthic macroinvertebrate species richness and diversity declined as the concentration of cadmium, copper, lead and mercury in sediments increased (Franz and Harris 1988). A New Zealand study correlated elevated levels of copper, lead, zinc, and hydrocarbons in sediments with a reduced benthic macroinvertebrate community (Roper et al. 1988).

Piles Creek, a tidal waterway in New Jersey, is contaminated with copper and several other metals. Weis and Khan (1991) noted that mummichogs (*Fundulus heteroclitus*) inhabiting Piles Creek exhibited reduced growth and reduced fin regeneration when compared to fish from unpolluted waterways. Wright (1988) found that copper concentrations were sufficiently high in some Maryland striped bass *(Morone saxatilis)* spawning waters to threaten larvae.

In a marine system the copper concentration should not exceed 3 micrograms per liter (µg/l) for more than one hour and this concentration should not be exceeded more frequently than once every three years (EPA 1985a). Maintenance of this standard is necessary for the protection of both plants and animals from the sub-lethal effects of copper. The most sensitive organisms begin to die when the copper concentration exceeds 20 µg/l (Schueler 1987).

Throughgout the U.S. the concentration of copper in stormwater runoff averages 47 µg/l and attains a maximum of 114 µg/l once every 2.5 to 3 years (Schueler 1987, Table 1.1 and Table 1.3). The most stressful storm event would be that which falls short of producing runoff from lawns and woodland, but produces large volumes of runoff from the rooftops and paved surfaces associated with a marina. Given the soil characteristics typical of coastal areas, that storm event would equal 2.5 cm of rainfall in a 24-hour period. In the Chesapeake Bay region such a storm event occurs typically two or three times per year (Schueler 1987, Figure A.3).

A 2.5 cm rainfall event would produce 250 cubic meters of runoff for each hectare of impervious surface associated with a boating facility. If the copper concentration is 114 µg/l, then the runoff must be diluted 38 fold to meet the 3 µg/l standard. Assuming an average depth of one meter in the receiving waters, then the runoff from each hectare of impervious surface must disperse throughout 1 hectare (2.5 acres) of the tidal creek before the copper concentration is reduced to the safe level. As runoff disperses the threshold of mortality - 20 µg/l - will be exceeded throughout 0.15 hectares (0.4 acres) of the waterway.

Copper is somewhat less toxic to freshwater organisms when compared to saltwater species (EPA 1985a). For example, acute copper concentrations set forth in the Maryland water quality standards call for a value of no more than 6.1 µg/l in estuarine waters and a maximum of 18 µg/l in freshwater (COMAR 26.08.02.03-2). Therefore if runoff from impervious surfaces enters an estuarine or tidal fresh system, then the impact would be reduced.

Several practices are available for controlling the movement of stormwater pollutants into aquatic systems. The most commonly applied practices can be described as either a pond or an infiltration device. An infiltration device is intended to hold stormwater until it can soak into the earth. The device may consist of a modified pond or a stone-filled trench. While a pond may remove a maximum of 40% of the copper entrained in stormwater, infiltration can keep 95% to 99% of this toxic metal out of the aquatic environment (Schueler 1987). Infiltration will also remove 90% of the oxygen demand and 70% of the nutrients entrained in runoff (Schueler 1987). A pond can remove up to 40% of the oxygen demand and 60% of the nutrient load (Schueler 1987). Although more effective than ponds, not all sites are suitable for infiltration. Following is a listing of the conditions needed to accommodate infiltration:

infiltration rate of 0.53 inches/hour or greater,
the water table cannot rise to within four feet of the bottom of the device,
and

the land slope must be 5% or less.

It would also be wise to avoid the use of infiltration on very sandy soils. Pollutants released into a coarse grained soil may pass through the sandy soil and cause contamination upon entering a nearby waterway.

Generally the soils associated with the lands adjacent to a tidal waterway are not suited to infiltration. Thus some stormwater related impact may be unavoidable when a boating facility is sited near a waterway. The degree of impact will be increased if the waterway is poorly flushed or harbors sensitive aquatic resources.

Other Sources of Toxics

Other boating related sources of toxins include leaching of biocides from hulls and treated wood, engine exhaust, and minor boat maintenance.

A study of eleven marina basins in North Carolina found that while metals were generally below detection limits, in some basins the concentration of copper and zinc attained a maximum of 30 µg/l and 80 µg/l, respectively (NCDEHNR 1990). The Maryland water quality standards for copper and zinc are set at 3 to 18 µg/l and 95 to 120 µg/l, respectively (COMAR 26.08.02.03-2).

Vernam and Connell (undated) found that the sediments associated with poorly flushed marinas contained high levels of metals. Generally, copper, lead, and zinc concentrations increased as marina flushing rate decreased. Chromium and copper exceeded EPA Region V criteria for contamination of sediments. They also found a significant trend between proximity to a poorly flushed marina and the copper concentration in hard clams (*Mercenaria mercenari*a).

Weis and Weis (1992) have studied the toxic effects of treated wood. The wood used for piers, pilings, and decking in marine situations may be treated with oxides of chromium, copper, and arsenic (CCA). Wood used for marine application has 1.5 pounds of CCA per cubic foot. Organisms placed in aquaria with pieces of CCA treated wood have exhibited adverse effects ranging from minor growth reductions to death. There is some evidence that copper accounts for a large portion of the toxicity associated with CCA. CCA treated wood has exerted a toxic effect upon snails, fiddler crabs, fish embryos, sea urchins, and green algae. The concentration of CCA in sediments decreases with distance from treated structures. The concentration of copper, chromium, and arsenic in sediments was higher in marinas and canals that are minimally flushed. The metals may accumulate in the tissues of algae and other organisms growing upon CCA treated wood. In one experiment mud snails died when they were fed algae that grew upon CCA treated wood. Weis and Weis offered two options for reducing the impact of CCA treated wood: 1) the wood should be soaked for two or three months before placing it in the aquatic environment or 2) use "wood" manufactured from recycled plastic.

EPA's *Coastal Marinas Assessment Handbook* contains several citations for elevated metals in marinas (EPA 1985b, page 4-71). One study revealed that copper levels were higher in benthic algae, fouling communities, and sediments within a marina when compared to a nearby marsh. Another study detected high copper levels in mussels collected from a boat harbor.

The release of toxics from boat hulls, pilings, and engine exhaust can add to stormwater inputs and increase the volume of water which exceeds water quality standards. The combined impact will be greatest in those waterways exhibiting the poorest flushing rates and supporting organisms sensitive to the contaminants associated with boating facilities.

Soil Erosion & Sediment Pollution

Soil erosion and subsequent sediment pollution from a construction site can easily reach 200 times the rate from rural lands (Klein 1983). Without control the sediment pollution derived from a typical construction site can damage two to three miles of waterway below the site and recovery may take as long as a century (Klein 1983). Fortunately measures such as mulching and grass establishment can retain much of the sediment on the construction site. Unfortunately these measures are seldom applied to the extent needed to fully protect aquatic resources.

In 1990 Community & Environmental Defense Services (Community & Environmental Defense Services 1990) surveyed erosion and sediment control quality on 90 construction sites located throughout the Chesapeake Bay watershed. The survey determined that only one out of every four sites had control measures which would keep roughly half of the eroded soil out of nearby waterways. Only 10% of the developing lands had measures which would reduce soil loss by 90% or more. And until a 90% reduction is achieved, substantial harm will be done to waters draining the developing site (Klein 1983).

Although the construction of a marina or launching ramp may disturb a smaller area when compared to other development activity, the close proximity of the facility to a waterway ensures that much of the sediment leaving the site will enter the aquatic environment. The impact will be particularly acute when the facility is constructed adjacent to a small tidal waterway, where a poor flushing rate combines with the presence of sensitive aquatic resources.

Dredging

A number of researchers have documented the negative effects of dredging upon estuarine communities in general, and benthic macroinvertebrates in particular (Allen and Hardy 1980; Daiber et al. 1975; Gilmore and Trent 1974; Kaplan et al. 1974; Pfitzenmyer 1975 and 1978; Van Dolah et al. 1984). Kaplan et al. found that dredging reduced the productivity of benthic macroinvertebrate communities by 67%, which can translate into a direct decline in the productivity of an estuary (Diaz and Schaffner 1990). Pfitzenmeyer (1975, 1978) found that dredging reduced benthic production by 87%. The impact is due to a change in current velocity, habitat disturbance, resuspension of sediments, increased water depth, and a reduction in numbers of macroinvertebrates remaining within the waterway which, in turn, reduces the rate of recolonization. Increased water depth and reduced current velocity can act in concert to lower the flushing rate within the dredged waterway, which can increase the impact of pollutants entering the system.

Recovery from the effects of dredging can take a few weeks to a number of years (Taylor and Saloman 1968; Kaplan et al. 1974; Pfitzenmyer 1975 and 1978; Van Dolah et al. 1984). Three studies have documented a general relationship between the impact of dredging and the size of the affected waterway.

Pfitzenmeyer (1975 and 1978) studied the effects of hydraulic dredging upon seven waterways within the Chesapeake Bay system. The bottom area dredged in three of the waterways accounted for less than 0.1% of the total bottom area (Cuckold Creek, Tred Avon River, and the Choptank River). Dredging had very little impact upon bottom dwelling organisms in these three waterways. In the four other waterways dredging affected 1% to 4% of the bottom area (Lewis Creek - 1%, Hungerford Creek - 1.7%, Little Kingston Creek - 2%, and Chapel Cove - 4%). The benthic community of Lewis Creek recovered within 10 months following dredging. Sampling conducted in Hungerford Creek yielded inconclusive results. The benthic fauna of Little Kingston Creek was equivalent to or more diverse than the community at control stations two to four years following dredging. The effects of dredging in Chapel Cove could not be detected one year later. The studies conducted by Pfitzenmeyer (1975 and 1978) indicate that the initial effects of dredging tend to be mild and of short duration when the area dredged accounts for less than 2% of the total surface area of the affected waterway.

Kaplan et al. (1974) studied the effect of dredging upon the benthic community of Goose Creek, which is a small, shallow lagoon located on Long Island, New York. Approximately 7% of the bottom of Goose Creek was dredged. Significant recovery had not occurred by the end of the study period, which was 11 months after dredging took place. The authors found that dredging had altered the bottom configuration of Goose Creek sufficiently to reduce current velocity by 50%. They theorized that the reduction in velocity accounted for a substantial portion of the lack of recovery in the benthos.

Taylor and Saloman (1968) investigated the effects of dredging upon Boca Ciega Bay, in Florida. Hydraulic dredging had been used in the 1950's to fill in 20% of the Bay. The authors found little evidence of recovery ten years after dredging. Canals created through dredging exhibited the most stressed benthic community. The authors related the poor benthos of the canals to the change in bottom composition and current velocity. The dredging process removed the veneer of sand and shell which formerly blanketed the bottom of the Bay exposing a clayey substratum. The clay provided a much poorer habitat for bottom dwelling organisms. The diminished current velocity was not sufficient to restore the sand veneer over the clay.

The impact of dredging may be compounded if shallow water habitat is converted into deeper water, particularly if submerged aquatic vegetation beds are eliminated (Taylor and Saloman 1968; Morton 1977; Allen and Hardy 1980). Current policy in Maryland discourages dredging in waters shallower than -3.0 feet (mean low water).

In summary, the effect of dredging upon the benthic community of tidal waterways tends to be mild and of short duration when less than 2% of the bottom area is disturbed. The impact becomes more severe and recovery can take more than one year when 2% to 7% of the bottom is affected. Reduction in benthic organisms can be severe and long lasting when dredging causes a shift in bottom composition from sand to clay and a reduction in current velocity sufficient to impede the return of coarse sediments. The loss of shallow water habitat, particularly vegetated areas, also results in an unusually high degree of impact.

Loss Of Wetlands & Other Habitat
Wetlands are crucial to the well-being of a tidal waterway. They provide habitat and a source of food for a vast assemblage of organisms. The uplands bordering a tidal creek are also important. Each hectare of wooded land adjoining a tidal creek may contribute 2,300 cubic meters (150,000 gallons) of high quality groundwater inflow to the waterway each year. Adjoining woodlands also contribute food material, habitat (fallen trees, etc.), and other benefits.

It can be difficult to develop the lands adjacent to a small waterway without impacting either wetlands or woodlands. Presently marsh creation is viewed as a method of compensating for "unavoidable" wetland losses. Unfortunately, created wetlands may fail to provide the same benefits associated with natural wetlands. Moy and Levin (1991) found that after three years a created *Spartina* marsh supported far fewer organisms and sparser stands of vegetation when compared to an adjacent natural marsh. An upland forest habitat was also destroyed in constructing the project.

Moy and Levin (1991) also reviewed the findings of other researchers who examined attempts to create wetlands. One study examined seven pairs of created and natural marshes and determined that even after the passage of 19 years the artificial wetlands supported infaunal densities about half those of the natural systems. An unpublished study conducted by the Annapolis office of the U.S. Fish & Wildlife Service documented a 70% failure rate among wetland creation projects (Bernstein and Zepp 1990).

Is it possible to create a wetland which provides most of the benefits of a natural system? Perhaps. But the likelihood of achieving full replication is not very good. The Chesapeake Executive Council established a policy of "no net loss" of wetlands and a long-term goal of a "net resource gain" with respect to wetland functions. Unless marsh creation technology improves dramatically in the near future, the Council will not achieve its policy or goal while wetlands are destroyed in small pieces.

CONCLUSIONS
Small tidal waterways tend to support an abundance of sensitive aquatic resources. These resources serve as a crucial component of the collective estuarine ecosystem. Boating and support facilities may impact these resources through the resuspension of bottom sediments, wake-induced damages, boat waste discharges, stormwater pollution, the release of toxics from treated surfaces and engine exhaust, the pollutional effects of soil erosion, and habitat losses associated with dredging and marina construction.

The many benefits associated with boating and support facilities can be attained with less resource impact by siting marinas, launching ramps, and other facilities adjacent to waters that are greater than 2.2 meters (7.2 feet) in depth and where the majority of the vessels associated with the facility will pass at least 150 meters (500 feet) from shore. If a slight margin for safety were added, then the resource protection buffers would become 2.5 meters (8.0 feet) for depth and 365 meters (1,200 feet) for width.

RECOMMENDATIONS
New boating facilities should avoid the 5% of Maryland's tidal waterways which are less than 365 meters (1,200 feet) in width or less than 2.5 meters (8.0 feet) in depth, and any other waterways which

may be uniquely susceptible to environmental impacts, such as creeks which have a constricted entrance, a sump, little tributary inflow, or an irregular shoreline configuration.

Even if a waterway lacks emergent wetlands, SAV beds, and anadromous fish spawning or nursery areas, one should not assume that the creek is suitable for a boating facility. Instead the waterway should be viewed as it may appear when current water quality enhancement programs begin yielding healthier tidal creeks. The waterway should be managed as though that higher level of quality has been attained. Otherwise, the effort to restore the Chesapeake Bay system will be inhibited.

Boaters should be encouraged to "make no wake" when operating within 150 meters of a shoreline or in waters less than 2.5 meters in depth. Increased installation of boat waste pump-out facilities at marinas would reduce sewage releases, but an intensive education program must also be mounted to increase boater use of pump-out facilities. Marinas owners should consider the installation of stormwater pollution control measures.

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