# Resuspension of Sediments by Watercraft Operated in Shallow Water Habitats of Anne Arundel County, Maryland

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ABSTRACT

Shallow water habitats rank among the most important components of the Chesapeake Bay ecosystem. The operation of watercraft in these sensitive environments increases the hydrodynamic energy of the site through the generation of surface wakes and propeller wash. When this energy exceeds the shear force of sediment material, sediment resuspension occurs. The degree and pattern of resuspension determine the impact to resident biota. In this study, a variety of common recreational watercraft were operated in the navigable headwaters of seven creeks in the mid-Chesapeake Bay area. The craft were operated according to existing regulations and the rules of good seamanship along an established course that ranged in depth from 0.3 to 1.8 m. Bottom sediments from the courses on each creek were analyzed for texture prior to testing. During testing, turbidity was measured in Nephelometer Turbidity Units (NTU) at the surface, middle, and bottom of the water column at each of the depths. No significant differences in turbidity were found among the 10 watercraft (ranging from a personal watercraft to a 235 hp displacement hull vessel) tested on the different creeks; however, when resuspension was intentionally induced, only turbidity at the lower portions of the water column was significantly increased. This suggests that studies of this type require sampling throughout the water column in order to fully evaluate potential adverse effects on sediment stability, regardless of the source.

INDEX WORDS: Sediment resuspension, turbidity, boat wake.

## INTRODUCTION

Shallow water habitats have been identified as one of the most important components of the Chesapeake Bay ecosystem. These areas, which are mostly located along the shorelines of the bay and its tributaries, are the habitat of rich and diverse plant communities. These communities, which include freshwater nontidal wetlands, tidal emergent wetlands and submergent wetlands, have been shown to be essential for maintaining water quality and biological productivity of aquatic ecosystems. Wetlands stabilize sediments, participate in aquatic nutrient cycling, serve as flood buffers and provide food and habitat for diverse animal populations including aquatic mammals, waterfowl, finfish, shellfish, mollusks and crustaceans. Unfortunately, despite their importance, shallow water habitats in general and wetlands in particular have experienced steady declines because of their close proximity to human activity. Historically, emergent wetlands have been altered or destroyed primarily by activities which convert these wetlands into fastland or open water. These activities are now heavily regulated by federal, state, and county statutes, thus the rate of wetland loss by direct conversion has been reduced significantly. Nevertheless, wetlands continue to decline, in part because of administrative exceptions to these protective statues but also because of the pressures placed on shallow water habitats by increased use of watercraft.

Watercraft can adversely affect the vegetation of shallow water habitats in several ways. These include:

1. Discharge of toxic compounds including antifouling paints, solvents and cleaners;
2. Discharge of nutrients from on-board septic facilities;
3. Discharge of phytotoxic petrochemicals used for fuels and lubricants;
4. Wake-induced shoreline and shallow bottom erosion;
5. Wake and propeller wash sediment resuspension.

The discharge of toxic materials has proven to be the easiest to document and reduce. The abundant scientific literature on the effects of hull paints containing the antifouling agent tributyltin resulted in legislation that sharply curtailed its manufacture and use. Septic discharges were addressed by passing laws requiring and subsidizing septic pumpout stations at marinas, although these facilities are not always used. Finally, petrochemical loading has been reduced by requiring additional safeguards on marina fuel pumps, changes in marine engine designs and more stringent standards for portable marine fuel tanks.

In contrast, energetic impacts to shallow water habitats caused by watercraft are difficult to measure and, therefore, even more difficult to manage. Whether sediments are resuspended from shallow water habitats or eroded from shorelines, they often interfere with biotic communities. Resuspended sediments not only may act as carriers for organic and inorganic pollutants, but they also may reduce the concentration of dissolved oxygen and light availability in the water column (MÜLLER and PULS, 1996). Fine silts and clays may interfere with zooplankton and benthos respiration as well. Most of the studies examining the energetic effects of watercraft in shallow water habitats have focused on wake-induced shoreline erosion and sediment resuspension because the wake parameter is largely a surface phenomenon and therefore easily viewed. The physical parameters of the craft which determine wake size such as hull type, size, displacement and speed are easily measured. Experiments can employ ambient boat traffic to reduce cost and extend sample size for statistical analysis, and the habitat features of concern such as shoreline contours (recorded over time), fetch, soil types and vegetation can be readily determined, (for a review see KLEIN, 1992). In brief, this literature demonstrates that under some conditions watercraft-generated wakes can accelerate erosion and therefore presumably adversely affect the vitality of shallow water habitats. Interestingly, in contrast to discharge effects, which have been the target of protective legislation designed to minimize environmental damage, reduction of wake effects in the most sensitive areas of shallow water habitat has proven to be much more difficult. This difficulty has arisen from the irony that as boats reduce their speeds to conform to posted speed limits, they pass through a speed range in which the hull generates a maximum wake. After passage, when craft acquire hull displacement velocities, the proximity of boat propeller with bottom sediments is increased and the potential for bottom sediment resuspension is enhanced. Thus, attempts to reduce energetic impacts of watercraft in the headwaters of tributaries are often in direct opposition to human safety issues, or they rely on discretionary responsibility on the part of craft operators.

The effect of boating activity on wave generation and shoreline erosion has been documented (ZABAWA and OSTROM, 1980). This study addresses the remaining and arguably the most complex impact to shallow water habitats, the significance of wake and propeller wash on sediment resuspension. For any water body, there are three mechanisms which determine the effect of watercraft motion on the resuspension of bottom sediments (HOCHSTEIN, 1967). These mechanisms, which produce three different velocity components beneath the water surface, are backwater flow, surface waves and propeller wash.

Backwater flow is attributed to the volume of water displaced by the watercraft and is always in the direction opposite to the direction of watercraft movement. This force is defined by the blocking ratio $n$, which is equal to the cross sectional area of the channel divided by the cross sectional area of the submersed portion of the watercraft. For example, a small blocking ratio, which would be capable of inducing maximum sediment resuspension, could result from a large vessel with a large draft navigating a shallow restricted channel. However, because such events in the shallow water habitats of the state are rare and not in keeping with common sense seamanship, backwater flow should not normally be a significant cause of bottom sediment resuspension.

There are two different types of surface waves generated by ship movement, diverging waves and transverse waves. The pattern of these waves determines the orbital motion of water; hence bottom disturbance

varies with respect to parameters such as depth of water, hull size, displacement and velocity. Qualitatively, the surface waves produced by small craft of the type frequenting shallow water habitats normally have a relatively small orbital motion, and thus are capable of causing only minimal disturbance of bottom sediments.
Propeller wash is a combination of the vortex and turbulence generated by the propeller jet. The jet is in the shape of a cone where the local flow velocity decreases rapidly away from the propeller. According to HOCHSTEIN and ADAMS (1989), the velocity distribution is Gaussian, and the maximum propeller jet velocity in meters per second is a function of radial distance from the propeller axis.

The propeller jet velocity, as well as other available velocities caused by the different mechanisms detailed above, yields a shear force acting tangentially upon the bottom sediment. Once this shear force exceeds the shear force of the particular sediment material, sediment transport or resuspension occurs (MILLER et al., 1977 and HWANG, 1991). When this occurs, other forces such as tidal flow and current can then act on the "sediment plume" for subsequent distribution. This relationship may need major correction to suit small boat cases; however, this is the best model available at this time. As will be discussed, this phenomenon greatly complicated the collection of comparative data at different times and different locations.

Characteristics of sediments are also important factors in determining their resuspension by propeller wash. The primary factors influencing the potential for sediment resuspension are propeller jet velocity and sediment grain size. In general sediments with small grain sizes, especially clay and humus colloids, are more easily suspended than larger sediments, most commonly marine sands, in Maryland mid-bay shallow water habitats.

The hydrodynamic interactions between boat traffic and bottom sediments complicate the experimental design of field studies devoted to quantifying potential environmental impacts. Simply stated, watercraft can be operated in a manner that virtually guarantees sediment resuspension in most estuarine shallow water tributaries. This study was designed to quantify the impacts that small watercraft may impose on water clarity when they are operated in shallow, yet navigable waters according to existing regulations and the rules of good seamanship. Volunteers were asked to navigate their craft along a predetermined course on seven tributaries of the mid-Chesapeake Bay. Prior to operation, sediments at various depths along these courses were analyzed for texture. Water clarity was measured before and after the watercraft's operation at the bottom, middle, and surface of the water column using a Nephelometer to provide an integrated view of impacts on the ecological balance between benthic invertebrates and submersed photoautotrophs.

# METHODS

The seven subtributaries of the Magothy and Severn Rivers, Anne Arundel County, Maryland (Figure 1) selected for this study are representative of the types of creeks found throughout the mid-Atlantic population centers. Adjacent lands have historically experienced significant development and the shorelines, often structurally protected, are now occupied by private residences. Depths at the entrances to these subtributaries are greater than 1.8 m, and thus invite use by a variety of watercraft. The state of Maryland has imposed speed restrictions on these waterways that restrict speeds to 6 knots (11 kmph) with no wake. None of the creeks selected had been dredged within the five-year period preceding this study.

Test courses were established in each of the creeks in mid-channel at 0.3 m intervals at depths from 0.3-1.8 m using floating markers anchored to the bottom. Sediment samples from the upper 10 cm of the substratum were collected with a 5 cm diameter Wildco corer fitted with an eggshell core catcher. Individual samples were kept on ice in polyethylene bags for subsequent analysis. In the laboratory, sediments were spread in a thin layer in a shallow pan and allowed to air dry at room temperature for 4 to 7 days. Once dry, samples were macerated and then filtered though a no. 12 mesh sieve to remove wood fragments, gravel and other large debris. Screenings were then placed in foil pans, dried to a constant weight at 105 C and stored desiccated at 25 C pending analysis.

Fractional composition of the sediment samples followed standard methodologies (DAY 1956, 1965 and ASTM 1981) which utilize settling rates in liquid to determine grain size and density. Sediment composition is determined from these values. These data were then used to construct a standard curve for each sample from which composition was derived. .

Natural variability of water clarity from depths of 0.3-1.8 m at the surface, mid depth, and bottom of the water column was measured by accessing the pre-established navigation course using a 4.9 m (16 foot) flat bottom boat powered by an electric motor set 15 cm beneath the water surface. For each experiment three 100 ml water samples were then collected at the surface, mid-depth and within 5 cm of the bottom at each depth using a subsurface grab sampler. Turbidity of these samples in NTU, (Nephelometer Turbidity Units), was then determined with a Jackson Turbidometer. Water clarity also was determined by Secchi Disk. This technique is limited to single measurements of total water clarity and to water quality conditions where the depth of the water column is greater than the depth at which the Secchi disk reading is recorded.

Two experiments were performed to evaluate turbidity in selected creeks in the absence of boat traffic. To evaluate short-term sampling variability, five consecutive samples were taken from the surface, middle and bottom of the water column at each 0.3 m contour from 0.3-1.8 m, in Cattail, Dividing and Mill Creeks. The elapsed time for collecting all samples at a particular level in the water column at each depth was 15 minutes. A second experiment was performed to assess variation in turbidity over a period of 90 minutes, the time necessary to collect samples after test trials of different watercraft. In this experiment, samples were taken at the surface, middle and bottom of the water column at the 1.8 m contour and then consecutively at each depth contour. The sampling circuit was completed five times and the total elapsed time for obtaining all samples was 90 minutes.

In the third pretest experiment, boat traffic was simulated by replacing the 12 volt trolling motor with a 9.9 hp gasoline engine. Starting at the 1.8 m depth, three circuits were made around the marked course as close as possible to the flags. The site was revisited for measurements using the low rpm electric motor to collect four sequential samples at each depth contour at the surface, middle and bottom of the water column. In subsequent tests employing a variety of watercraft, the electric powered boat was again used to access the test circuits to take the necessary measurements of turbidity immediately after the test watercraft navigated the course six times. All samples were collected and analyzed within 30 minutes of course navigation by watercraft. Captains of the test watercraft were instructed to obey the mandatory 6 knot (11 kmph), no wake, speed limits and to exercise their own judgement as to the minimum depth at which they would navigate the course prior to turning. All elected to turn their craft between the 0.6 and 0.9 m contours.

Standards errors for turbidity data were calculated by SigmaStat Statistical Software (SigmaStat for Windows Version 2.03, SPSS, Inc.

## RESULTS

The pattern of sediment composition in the seven subtributaries evaluated in this study shows sand dominating in the shallowest depths, but decreasing with increasing water depth (Figure 2). This pattern is characteristic of creeks, where the sediment load is derived primarily from runoff originating from uplands adjacent to the headwaters. In contrast, silt comprises 50-60% of the total sediment in Mill Creek (Figure 3), even in the shallowest water. Flushing is minimal in Mill Creek and deposition occurs from the mouth to the headwaters. The clay fraction remains at less than or equal to 10% for all depths in the seven creeks with the exception of two areas of Forked Creek (Figure 4). Since the heavier sand particles predominate in the shallows for six of the seven creeks, sediment resuspension by propeller is less likely than in Mill Creek, where the smaller silt particles can be more easily resuspended.

Cattail, Dividing and Mill Creeks were selected to evaluate the natural uniformity of turbidity throughout the water column. Significant differences in turbidity were found in each creek between the upper layers of the water column and the lower layer (Table 1). On Cattail Creek, only the 1.2 m depth showed consistent clarity throughout the water column. Turbidity values that are significantly different are shaded. For example, in Cattail Creek, turbidity values at all depths except 1.2 m are significantly different when comparing the surface readings with the bottom values. No significant differences were seen between the surface and middle of the water column or between the middle and the bottom. In contrast, Dividing Creek showed consistent clarity at the 0.3, 0.6, and 1.2 m depths while Mill Creek exhibited constant clarity at 0.6, 1.5, and 1.8 m depths. However, when the average NTUs are compared for all depths for each creek, turbidity at the surface was significantly less than that of the bottom layers (Table 1). Such changes in turbidity with depth pose significant consequences for the resident biota. For example, benthic organisms such as oysters could be adversely affected by excess sediment suspension near the bottom, while organisms such as submerged aquatic plants that extend toward the surface may be unaffected. Moreover, since water clarity is known to vary throughout the water column, assessment of sediment resuspension by watercraft requires analysis at the various layers rather than through a single composite measure, such as Secchi depth.

A second test was performed to evaluate the natural variability of water clarity among the different layers of the water column over the length of time necessary to conduct tests involving boats of varying size. In this experiment on Cattail Creek, clarity at each depth was determined in sequence so that the total elapsed time between the first and last measurements exceeded one hour. The results summarized in Table 2 demonstrate significant differences in water clarity between the surface and the bottom samples, yet remarkable consistency exists within each of the layers over the time required to complete each trial.

In order to assess the potential of small motorized watercraft to resuspend sediments, a series of tests were performed on each of the creeks. A 4.9 m flat-bottomed boat powered by a 9.9 hp motor was used to navigate the test circuits. Turbidity at each depth contour at each layer of the water column was measured four times before and after the course was navigated by the motorized test craft. Significant differences in turbidity were noted only five times in the 126 tests (Tables 3, 4 and 5). The shaded boxes in these tables designate turbidity values that are significantly different between the control and the test boat. Two were found in the surface layer at the 1.8 m depths of Mill and Dividing Creeks and once in the surface layer at the 0.3 m depth of Maynadier Creek. At the middle and bottom layers, significant differences were noted in the middle layer of the 0.9 m depth of Dividing Creek and in the bottom layer at the 0.6 m depth of Cool Spring Cove. The only significant increases in turbidity when all of the creeks are combined was in the water just overlying the bottom in the 0.6 m depths (Table 5). In subsequent tests with boat trials, neither Mill Creek nor Maynadier Creek were used as test sites.

Tables 6 – 9 show the results of testing the effects of five different boats on changes in water turbidity throughout the water column in four different creeks. Each "average" value is an average of the turbidity data for the top, middle and bottom of the water column for each depth contour. All data for all boats at that contour depth are averaged in the "average combined change" row. The same five boats were used on the two creeks of the Magothy River that were studied, Cattail Creek and Dividing Creek. In Cattail Creek, the only significant increase in turbidity was in the 0.9 m contour with the 4.9 m jon boat. The other significant changes were decreases in turbidity following use of the volunteers' boats. Similar results were seen for Dividing Creek (Table 7). The only two trials that resulted in an increase of turbidity were in the shallowest waters (0.3 and 0.6 m); once in the 0.3 m interval with the 5.5 m Lund and once in the 0.6 m interval with the 4.9 m jon boat. Two trials resulted in a significant increase in water clarity, once in the 0.3 m depth with the 5.5 m Lund and once in the 0.6 m depth with the sailboat.

Six different boats were compared in the two creeks of the Severn River that were studied, Maynadier Creek and Weems Creek. The change in turbidity throughout the water column for Maynadier Creek is shown in Table 8. Despite the fact that the boats in these creeks had much larger engines, only two significant increases in turbidity were noted. The 5.2 m Whaler with a 90 hp engine did cause an increase in turbidity at the 0.6 m and 0.9 m depths. When data for all of the boats are combined, there was a significant increase in turbidity at the 0.9 m depth. When these same boats were run in Weems Creek, there were no significant changes in turbidity at any depth.

Finally, all of the results from all of the trials in water 0.6 m deep or greater for all of the creeks are combined to produce Table 10. These data reveal that there were no significant changes in turbidity at any depth. This table represents the results of 66 trials. It also shows that the greater the depth of the water in the creek, the less the change in turbidity. At 0.6 m there is a change of 1.4 NTUs and at 0.9 m there is a change of 0.7 but at greater depths there is less than 0.5 NTU difference in the control and the boat trial.

## DISCUSSION

There seems to be a widespread assumption that operating boats in shallow waters of creeks will cause sediments to be resuspended and will increase turbidity. Sediment resuspension will scour the bottom and redistribute sediment particles. This redistribution of particle size may in turn be detrimental to benthic invertebrates and rooted vegetation. Increased turbidity in itself may harm benthic invertebrates by interfering with respiration and will limit light availability within the water column, thus reducing the potential for primary producers. This study was conducted to test the effects of boat traffic on sediment resuspension in shallow waters in controlled conditions. One significant aspect of this study was that boaters were instructed to use good judgement and to operate within the speed and wake restrictions that were posted. All the creeks we studied had an 11 kmph speed limit and were "no wake" zones.

A key aspect of a study such as this is to utilize methods that can clearly measure turbidity at varying depths within the water column. Thus, the use of a turbidometer was critical for comparing the effects of boats on water clarity at the surface, middle and bottom of the water column. Before the effect of boat activity could be determined, the background or natural turbidity of each creek was established. A preliminary study was performed to determine if there were significant differences in the water clarity of creeks when there was no boat traffic. This study revealed that there were significant increases in turbidity when comparing the surface water layer with the bottom water (Table 1). It was possible to distinguish between the turbidities of water layers when care was taken not to disturb the water column and not to resuspend the sediments. Thus, subsequent studies using volunteer boaters were evaluated by determining the changes in turbidity before and after a boat traveled the experimental circuit, rather than comparing absolute values of turbidity.

A second preliminary study established that there were no significant differences in water clarity at any given depth throughout the period of time required to run a trial of the control or "before" the completion of the measurements with an experimental boat (Table 2). In this experiment, the test circuit was run by the boat with the trawling motor five complete times, and water samples were collected for turbidity measurements at each depth contour after each time around the circuit. The total elapsed time for this experiment was approximately 90 minutes, well over the length of time required for subsequent experiments with volunteer boats. A potential change in turbidity over this time period was a concern because it was possible that tidal currents alone might alter turbidity within a one-hour period. However, this was demonstrated not to be the case. This experiment also demonstrated that, when care is taken to collect measurements without disturbing the water column, samples can be collected repeatedly without changing water column turbidity.

The boat trials themselves were carried out on four different creeks within two subtributaries of the Chesapeake Bay. All four creeks had similar sediment characteristics; sand predominated in the shallower water, while silt became increasingly important in deeper water. Clay was a minor fraction at all depths in the four creeks used in the boat trials. Boats ranged in size from personal watercraft to larger ski boats with 295 hp motors. Since speeds were limited by the 11 kmph limit in all creeks, no boats were able to plane, and thus the planing hulls acted as displacement hulls in this study. Despite this range in boat size and the shallow depths of the creeks, only a few significant increases in turbidity of the water column could be determined. There were no significant increases in the surface water and none in the middle layer of water at any of the depth contours. Only in the bottom water at the 0.6 m depth contour was there a significant increase in turbidity in this part of the study.

We found that boats of varying size do not significantly increase the turbidity of water at any depth within the water column if boaters obey the 11 kmph, no wake, restrictions. Although there were a few instances out of the 66 trials conducted in this study where turbidity did increase after boat activity, the overall effect was not significant (Table 10). Additionally, we found that sand predominates in the shallow depths of the creeks we studied and this may account for the lack of resuspended sediments in these creeks. Although the percentage of sand decreased with increasing depth and the percentage of silt increased proportionately, bottom water at the deeper contours did not reflect increased turbidity with boat activity. Since six of the seven creeks we investigated in this study follow this pattern of sand predominating in the shallow water, we feel that these results are applicable to most creeks within the study area.

In preliminary studies, we found that water clarity varies with depth of the water column in the absence of boating activity and that the methods used to measure the effect of boats on water clarity must take this into account. We were able to show the effect of boat activity by determining the change in turbidity clarity before and after a given boat trial.

# CONCLUSIONS

The evaluation of sediment resuspension in shallow water creeks is a difficult task. The physics dictating energy transfer from watercraft propellers to the water column is exceedingly complex especially when coupled with extant environmental conditions including water depth, current, tidal flow, bottom contour, creek width and volume, sediment characteristics, time of year, and potential activity by resident bottom dwelling biota such as carp (*Cyprinus carpio*) and cownose rays (*Rhinoptera bonasus*). Experimental design can be easily manipulated to produce preconceived results since it is always physically possible to suspend sediments when their shear force is exceeded. How watercraft are operated becomes a key variable that can be difficult to objectively quantify. Finally, there are the cumulative effects of multiple boat passages where all physical variables may interact to produce site energetics completely different from those resulting from the passage of a single craft.

This study was designed to assess the impacts of watercraft on shallow water creeks in Anne Arundel County, Maryland. We focused on the effects of recreational watercraft that are operated according to existing regulations and under the rules of good seamanship. The conclusion of this study was that there was no significant increase in turbidity due to resuspension under these restricted operating conditions. The combination of an 11 kmph no wake limit and its effect on reducing navigational errors is significant since every craft tested could produce forces capable of resuspending the natural sediment of the tributaries. Three issues of concern remain to be examined; the first is the effect of watercraft on creeks whose sediment composition is dominated by silts and clays. Such environments require substantially less disturbance for inducing sediment resuspension. The results of a study designed to determine the impact of watercraft in silty creeks may be useful in prioritizing creeks for dredging. The second issue is the determination of the cumulative effects of multiple watercraft since the scenario of operating multiple craft simultaneously is best reflective of actual creek use, especially on weekends during the boating season. The extent of such traffic on Anne Arundel County creeks is significant and imposes great difficulty for designing experimental replicates. Finally, the extent to which watercraft operators adhere to navigational regulations and exercise good seamanship is subject to question. Enforcement of no wake zones may provide a viable mechanism to reduce boating impacts on sensitive shallow water environments.

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